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Logistic Efficiencies and Naval Architecture for Wind Installations with Novel Developments

Project acronym: **LEANWIND**
Grant agreement no 614020
Collaborative project
Start date: 1st December 2013
Duration: 4 years

Deliverable 8.6 – Viability and Implementation Roadmap and Strategy Document

Lead Beneficiary: The University of Edinburgh
Due date: 31st May 2017
Delivery date: 1st June 2017
Dissemination level: PU (Public)

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 614020.

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Document Information

Version	Date	Description			
			Prepared by	Reviewed by	Approved by
1.0	01/05/2017	Initial draft – compilation of contributions from D8.6 partners	University of Edinburgh	University College Cork, University of Hull, Fraunhofer	University of Edinburgh
2.0	12/05/2017	Draft - 2nd round review	University of Edinburgh	EDF, 1-Tech, Dissemination Committee	University of Edinburgh
3.0	26/05/2017	Final	University of Edinburgh	University College Cork, MARINTEK	University College Cork, MARINTEK

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Definitions

ABP	Associated British Ports
ACOP	Approved Code of Practice
AHP	Analytical Hierarchy Process
AIL	Abnormal Indivisible Load
BST	Basic Safety Training
CM	Condition Monitoring
DfE	Design for Environment
DSS	Decision Support System
EA	UK Environmental Agency
EU-OSHA	The European Agency for Safety and Health at Work
FID	Final Investment Decision
FIT	Feed in Tariffs
GBF	Gravity Base Foundations
GIS	Geographical Information System
GWO	Global Wind Organisation
H&S	Health and Safety
HETA	Humberside Engineering Training Association
HLV	Heavy Lift Vessel

HOTA	Humberside Offshore Training Association
HSE	UK Health and Safety Executive
HSWA	UK Health and Safety at Work Act
IMO	International Maritime Organization
ISPS	The International Ship and Port Facility Security Code
LCOE	Levelised Cost of Energy
MCA	Marine Coastguard Agency
MET	Meteorological Station
NELC	North East Lincolnshire Council
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OSPAR	“Oslo and Paris” Convention for the protection of the marine environment of the north-east Atlantic
OSW	Offshore Wind
OWT	Offshore Wind Turbine
PPE	Personal Protective Equipment
SEA	The UK Offshore Energy Strategic Environmental Assessment
SHEQ	Safety Health Environment and Quality
SME	Small and Medium Size Enterprise
SOLAS	Safety of Life at Sea
SOV	Offshore Service Vessel
STEM	Science Technology Engineering Mathematics
UVDB	UK Vendor Database system
WDT	Weather Down Time

Executive Summary

This deliverable presents the findings and results from Task 8.5 "Viability, Implementation Roadmap and Strategy" from Work Package 8 "Economic and market assessment" of the LEANWIND project. It gives a comprehensive analysis of the current challenges in the offshore wind sector. These challenges cover the fields of Regulation and Legislation, Health and Safety, Training, Environment, and Finance. Moreover, the deliverable analyses these challenges and offers a set of non-technical solutions.

The document is organised as follows: there are four sections, covering "Installation", "Operation & Maintenance", "On-land and port Infrastructures" and "Vessels". Each chapter is subdivided in to two parts, covering specific challenges and solutions. Within each of the subchapters there are sections including each of the categories mentioned in the previous paragraph. Finally, there is a summary of the proposed recommendations in this deliverable.

This deliverable identifies key industry challenges related to offshore wind and the potential solutions identified within the LEANWIND project. These challenges have been divided into non-technical categories to determine the business and policy landscape required for the successful implementation of solutions. Considering the non-technical issues as well as finding technical solutions to challenges in various sectors can greatly increase the viability and potential industry up-take of project innovations. The recommendations proposed in this deliverable have been summarised in the following table.

SUMMARY OF RECOMMENDATIONS

Regulation & Legislation	- Standardization of operations and maintenance activities and knowledge sharing to improve efficiency and lead to common European Union best practices, which ultimately reduces wasteful processes. - Collaboration among offshore wind developers of all European Union member states and national authorities, as well as relevant stakeholders, is needed to achieve efficiencies in on-land and port infrastructure activities, such as on-land transportation, component handling and in developing proposed Abnormal Indivisible Load transportation corridors. - Government incentives are required to encourage collaboration among offshore wind developers, port operators, and so forth, which are in fierce competition, to minimise the offshore wind industry's environmental and financial impacts due to on-land activities required for grid connection (i.e., cable laying and dredging in ports and inland waterways). - Further studies are needed not only to assess the merits of the United Kingdom's zone appraisal and planning for offshore wind development, but also to evaluate options and benefits from having similar approaches in other European countries. - Consideration should be given to the applicability of current emissions regulations to offshore wind installation vessels operating in Emissions Control Areas as such vessels follow very different routines to normal shipping. - The wide variety of (often competing) regulations relating to vessel operations at a regional, national and European Union level needs to be rationalised and standardised to provide greater certainty of compliance.
Health & Safety	- To minimise health & safety hazards, a 'prevention through design' concept should be implemented. Offshore wind developers need to consider existing health & safety risk assessment criteria at the early stages of wind farm design.

	- Establish a common online information platform for existing and potential suppliers to the offshore wind industry, detailing all the necessary offshore wind requirements in terms of required standards and licences to provide visibility of the offshore wind industry expected working standards. - Cross-sector and cross-border learning are suggested to compile offshore wind industry specific health & safety regulations. Offshore wind industry players, at different levels and sub-industries, need to be encouraged to share their information with relevant health & safety authorities across European Union countries about any hazards, controls, regulations, monitoring activities, among other industry-specific health & safety aspects. - There is a need to develop offshore wind specific health & safety guidelines considering current and future technologies as well as training programmes that include both health & safety and technical training. - A guideline to safe and acceptable working hours for offshore wind crews should be created at a European Union level to ensure that the requirements of round-the-clock operations are met with no increase in risk to crew safety.
Training	- Some degree of standardisation and a common European framework are required for escort drivers' and traffic directors' competence training. Further information is required to assess the viability of introducing elements of offshore wind component transportation in such training courses. - Implement virtual reality training facilities as an alternative to training facilities with real equipment, and encourage original equipment manufacturers to loan their equipment to training providers for specific training purposes. - Cooperation is needed among schools, employers, universities, institutions and government agencies to ensure more suitably qualified graduates, as well as to address the 'mechatronics' skills gap. In addition, further assessment of skills transferability from military, shipbuilding, submarine and aircraft industries to offshore wind industry is needed. - Further information is required about the possibility of cross-border offshore wind health & safety training standards.

	- Training programmes should be implemented to develop diving skills specific to the requirements of offshore wind installation techniques.
Environmental	- Understanding and minimizing negative impacts of operations and maintenance activities on the environment is a necessary part of a wider goal to reduce greenhouse gas emissions. There is also currently a lack of understanding of the environmental effects of operations and maintenance activities. - Waste management plans for the waste generated during on-land operations are required. - Flood risk assessment and prevention measures in any new port development should be promoted. - Common online information sharing platforms to help on-land transportation process would be of great value. - Produce decommissioning programme or plan outlining available recycling options for all offshore wind components. Consider knowledge sharing with oil and gas industry in decommissioning of oilrigs. - Further study into the impact of altered sedimentation during installation operations is required to ensure a minimal impact on marine life.
Financial	- The sector needs to invest further in decision-making tools and technical solutions that can help reduce costs considering current and future wind farms. - Consider further study of wind turbine size and weight optimisation. - More supplier development programmes are needed to increase the capacity of suitable suppliers and achieve economies of scale. This can be achieved through collaborative action among governments and offshore wind industry players.

	- It is anticipated that significant cost reductions could be achieved through the development of innovative moorings and foundations solutions. Innovation programmes in this area should be instigated and actively supported.
Other	- Encourage industry players to have standardised ways of recording information related to cost of offshore wind farm development as well as methods of sharing such information for research and development, to work on cost optimisation strategies and related financial analysis. - Active collaboration in standardisation groups (e.g. IEC61400-series) and discussions with certification bodies (e.g. DNV-GL) will help progress standardisation across the sector. - Forming and establishing new research priorities, particularly regarding accident scenarios, public accident data bases and electrical powering of SOVs in offshore wind farms during maintenance/accommodation phase.

Table of Contents

1. INTRODUCTION

This deliverable presents the findings and results from Task 8.5 "Viability, Implementation Roadmap and Strategy" from Work Package 8 "Economic and market assessment" of the LEANWIND project. It gives a comprehensive analysis of the current challenges in the offshore wind sector. These challenges cover the fields of Regulation and Legislation, Health and Safety, Training, Environment, and Finance. The deliverable analyses these challenges and gives a set of non-technical solutions.

The document is organised as follows: there are four sections, covering "Installation", "Operation & Maintenance", "On-land and port Infrastructures" and "Vessels". Each chapter is subdivided in two parts, covering specific challenges and solutions. Within each of the subchapters there are sections including each of the categories mentioned in the previous paragraph. Finally, there is a summary of the proposed recommendations in this deliverable. This deliverable considered information provided by diverse LEANWIND Work Packages, particularly WP2, WP3, WP5 and WP8, as well as external information sources.

The first chapter, "INSTALLATION", focuses on the challenges faced during the installation phase of the offshore wind plant. The second chapter, "OPERATION & MAINTENANCE", concentrates on solutions to issues for Operation & Maintenance purposes. The third chapter, "ON-LAND AND PORT INFRASTRUCTURE", pays attention to activities developed in the harbour and onshore environment related to offshore wind installation and management. The last chapter, "VESSELS AND ACCESS SYSTEMS", analyses the role of vessels during installation and operation & maintenance tasks during the offshore wind plant lifecycle.

Finally, the recommendations explained within the previous chapters are summarised in the last section: "CONCLUSIONS: SUMMARY OF RECOMMENDATIONS". These recommendations take the form of non-technical methods to improve industry solutions in the offshore wind sector.

This deliverable identifies key industry challenges related to offshore wind and the potential solutions identified within the LEANWIND project. These have been divided into non-technical categories to determine the business policy landscape required for the successful implementation of solutions. Considering the non-technical issues as well as finding solutions to challenges in various sectors can greatly increase the viability and potential industry up-take of project innovations.

2. INSTALLATION

2.1. Installation industry challenges

2.1.1. Introduction to challenges

The primary LEANWIND objective is to provide cost reductions across the offshore wind farm lifecycle and supply chain through the application of lean principles and the development of state of the art tools and technologies. LEANWIND specifically focuses on finding solutions to key challenges and research priorities identified by the industry.

This section details the challenges associated with installation in the offshore wind sector as part of the LEANWIND project. The information has been extracted from Deliverables 2.1, 2.3, 3.1 and 3.2.

2.1.2. Summary of challenges

There are several key challenges associated with offshore wind installation, namely:

- **The introduction of new regulations** to fit new installation industry requirements.
- **Promoting knowledge sharing** between different actors in the installation sector.
- **High risk diving.**
- **Safety in different types of personnel transfer systems.**
- **Specific cutting-edge knowledge sharing** for technicians and engineers.
- **Specific health and safety courses.**
- Adjustment of tasks to fit **weather windows.**
- **Noise generation** due to assembly tasks offshore.
- **Financial challenges** related to the type of foundations used.
- **Current state of technology** in the installation industry.

2.1.3. Challenges associated with research priorities

2.1.3.1. Regulation & Legislation challenges

The main challenges associated with Regulation & Legislation are:

- The introduction of new regulations.
- Promoting knowledge sharing.

The insertion of new regulations. There are some regulations out of the scope of the International Maritime Organisation that could strongly affect the design of vessels for offshore wind farm installation. Those regulations mainly relate to the environmental impact variables, such as[1]:

- Noise radiated from the harbour.
- Underwater noise from piling and marine operations.
- Presence of Sulphur Oxides (SOx). Emissions limited by the Annex VI of the International Convention for the Prevention of Pollution from ships (MARPOL).
- Presence of Nitrogen Oxides (NOx). Emissions limited by the Annex VI of the International Convention for the Prevention of Pollution from ships (MARPOL).
- Other emissions that may extend beyond the Marine Pollution (MARPOL) via national legislation.
- Increased turbidity because of disturbed sediment from construction activities.

Promoting knowledge sharing. Collaboration between various stakeholders in the sector (e.g. universities, research centres, companies) will help in improving common knowledge through the creation of a database or a set of codes of good practice.

This is also important in terms of lessons learnt. If stakeholders can be encouraged to share details of failures, accidents and non-conformance, that would help others not to make the same mistakes.

2.1.3.2. Health & Safety challenges

The challenges associated with installation activity Health & Safety are:

- High risk diving.
- Safety in different types of personnel transfer systems.
- Heavy lifting.
- Safe weather conditions.
- Crane operations.
- Crew rotation and maximum working hours.

High risk diving. Diving can be a high-risk activity that requires careful planning, monitoring and safety considerations. Moreover, additional complications can occur in the presence of rough sea states and unpredictable weather, such as are common in OSW sites[2].

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[1] Deliverable 3.1, WP Framework/Industry challenges report – novel vessels and equipment. LEANWIND, 2014.

[2] Stuart, P.D. What are the challenges of installing, operating and maintaining wind turbines offshore? MSc dissertation. Loughborough University.

Safety in different types of personnel transfer systems. There is a safety challenge in different types of transfer system. This is more noticeable when rough sea states are present and leads to downtime when safe transfer cannot be achieved. An improvement in this section would lead to decreasing downtime and increasing cost saving.

Safe weather conditions. Maritime weather conditions commonly have a greater impact on safe working conditions than those onshore[3]. Operations are typically required to halt when safe conditions are exceeded, resulting in operational downtime and increased costs.

Heavy lifting and crane operations. To ensure operator safety, vessels with crane facilities are subject to operational limiting conditions over and above standard limits when cranes are in use. The shutdown of crane operations due to weather conditions in excess of safe levels can lead to significant operational downtime and increased costs.

Crew rotation and maximum working hours. Offshore operations typically take place on 24-hour basis. The number of staff required to be offshore at any one time is dictated by a combination of operational requirements and the maximum length of shift that can be safely allocated.

2.1.3.3. Training challenges

The main challenges associated with training for OSW installation are:

- Specific cutting-edge knowledge of technicians and engineers.
- Health and safety.
- Standardised training.

Specific cutting-edge knowledge of technicians and engineers. Novel installation techniques and process improvements to reduce cost may be expected during a project. Specific training should be given to technicians and engineers in these topics.

Health and safety. In addition to the basics in this matter, specific health and safety courses focused on the installation process should include the factors examined in section 2.1.3.2.

Standardised training to allow mobility of workers between organisations and countries.

2.1.3.4. Environmental challenges

Challenges related to environment issues during installation phase are:

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[3] *Renewable UK. Vessels Safety Guide, Guidance for Offshore Renewable Energy Developers, https://www.thecrownestate.co.uk/media/451017/ei-km-in-hs-safety-042012-vessel-safety-guide-guidance-for-offshore-renewable-energy-developers.pdf, 2012, accessed April 2017.*

- Weather windows.
- Noise generation.
- Vessel-related pollution.
- Generation of sediment.

Weather windows. The season during which the installation takes place determines the weather downtime for the different phases[4]. The suitable conditions required for installation offshore create the weather windows[5]. Waiting for optimal weather windows results in operational downtime. In addition, the significant wave height presents challenges for the installation of floating foundations, while the installation of heavy components at the hub height is the most sensitive task to wind speed and weather conditions.

Noise generation. Noise generated during installation operations can produce a significant risk to marine life[6]. This is particularly derived from impact driven piling. The use of larger diameter piles implies the use of bigger hammers, which in turn are likely to produce more noise and harm marine life.

Vessel-related pollution. Local, national and European regulations affect vessels use during offshore operations.

Generation of sediment. A noticeable change in the sediment patterns is expected from offshore installation activities.

2.1.3.5. Financial challenges

The main financial challenges faced during the installation phase are related to the need for cost reduction. This is affected by the high cost of foundations and types of platforms used, weather issues affecting installation timing and problems related to the current state of technology development.

Foundations. Typically, the cheapest foundations to purchase are not the cheapest to install[5], due to sensitivity to precision in the installation because of the weight and volume of the structure. For example, the large self-weight of Gravity Based Foundations (GBFs) is required to resist sliding shears or overturning moments, but in turn, there is an increased

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[4] Deliverable 3.2, Key design parameters and criteria related to installation and maintenance, LEANWIND, 2015.

[5] Deliverable 3.1, WP Framework/Industry challenges report – novel vessels and equipment. LEANWIND, 2014.

[6] Deliverable 2.1. WP Framework/Industry Challenges report – Construction, deployment and installation. LEANWIND, 2014.

installation cost. On the other hand, the implementation of floating foundations must have minimal installation and maintenance costs whilst also allowing for efficient mooring, maintain stability and acceptable range of displacements[7]. Moreover, during the decommissioning stage, deep foundations may be costly to remove[8].

Weather windows. There are potential cost reductions closely linked to extending the weather windows in which offshore operations are feasible[9]. Allowing more time for operations to take place directly relates to reduced operational downtime and associated costs.

Current state of technology. Nearly 30% of the capital costs in an offshore wind farm come from costs associated with design, manufacture and installation of array components[10]. Researching new practical and innovative foundation designs may decrease those costs in future wind farms.

Rates for installation vessels and equipment. The difference between charter vessel day-rates and outright purchase prices requires careful financial analyses to choose the optimal solution. Influencing factors include the size and number of projects to be undertaken, the capabilities of the vessels in question, and the vessel costs themselves.

Impact of H&S regulation. Linked to the set of challenges summarised in the Health and Safety section, an increase in the required number of staff may be needed.

2.2. Installation industry solutions

2.2.1. Introduction to solutions

This section outlines the innovations developed by LEANWIND to address the installation challenges identified in previous sections. Moreover, it specifies how these innovations may be implemented to help solve the non-technical issues and build the policy landscape needed for the successful up-take of solutions.

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[7] Skaare, B., Hanson, T.D., Nielsen, F.G., Yttervik, R., Hansen, A.M., Thomsen, K. and Larsen, T.J., Integrated dynamic analysis of floating offshore wind turbines, European Wind Energy Conference and Exhibition, 2007.

[8] Deliverable 2.1. WP Framework/Industry Challenges report – Construction, deployment and installation. LEANWIND, 2014.

[9] Deliverable 3.1, WP Framework/Industry challenges report – novel vessels and equipment. LEANWIND, 2014.

[10] Carbon Trust, Offshore wind accelerator – Foundation innovators, 2012.

2.2.2.Summary of solutions

As outlined in section 2.1.2, the key challenges and research priorities identified by the offshore wind industry are:

- **The insertion of new regulations.**
- **Promoting knowledge sharing.**
- **High risk diving.**
- **Safety in different types of transfer systems.**
- **Specific cutting-edge knowledge sharing for technicians and engineers.**
- **Specific health and safety courses.**
- **Better use of weather windows.**
- **Noise generation.**
- **Financial challenges related to the type of foundations used.**
- **Current state of technology in the installation industry.**

In the next section, the proposed LEANWIND innovations for the installation industry are presented.

2.2.3.Solutions associated with research priorities

2.2.3.1. Regulation & Legislation solutions

The main challenges in regulation and legislation sector for the installation industry were:

- The development of regulations to better fit the new needs of the sector.
- Promoting knowledge sharing.

Although the development of regulations is not considered in LEANWIND, an attention call should be given to the qualified authority to inform them about the need for new guidelines.

For example, SOx and NOx emissions are controlled under MARPOL Annex VI through global standards applicable to all ships operating around the world and through Emission Control Areas (ECAs) where limitations that are more stringent are applicable.

ECAs may be established under the revised Annex to give effect to more stringent standards applicable to SOx and NOx. ECAs limiting SOx emissions have been established in: the Baltic Sea; the North-East Atlantic, including the North Sea and waters to the Northwest adjacent to Southern Norway; in a 200-mile zone, adjacent to North America for specific waters in the Pacific, Atlantic and Gulf coasts of the United States and Canada; and for selected waters in the Caribbean adjacent to Puerto Rico and the U.S. Virgin Islands. The North American and U.S. Caribbean ECAs also restrict NOx emissions.

MARPOL Annex VI provides a structure for governments to apply more stringent control technologies in emission control areas (ECAs) that have been designated to apply advanced engine technology for new ships operating in these areas. This should be revised considering the specific conditions developed during the installation of offshore turbines.

A knowledge distribution platform could be created to better connect stakeholders in the installation industry. Regular meetings could be set to promote experience sharing and methods that could improve future projects.

Moreover, related to the lessons learnt, anonymous databases can be created to allow stakeholders to feel confident to share their experiences avoiding any damage to their product marketing or reputation. An example of a common platform for knowledge sharing is the European Technology & Innovation Platform on Wind, ETIP Wind. Key stakeholders in the platform are the wind energy industry, political stakeholders and research institutions[11].

2.2.3.2. Health & Safety solutions

The challenges in health and safety were high risk diving and safety in various transfer systems.

During the installation process, divers are needed for key processes. Typical diving risks are contamination of breathing gas by hydrocarbon, carbon dioxide or carbon monoxide, displacement of demand valve, caustic cocktail, and many other issues linked to pressure changes during descent, such as sudden chilling of inner ear, helmet squeeze or suit compression[12]. On top of the classical diving risks, dangerous situations may appear during the installation process of offshore wind farms. Training focused on this specific approach to these risks could be useful for divers. Also, the use of Remote Operated Vehicles (ROVs) can reduce unnecessary risks associated with the installation process.

Safety in different transfer systems can be enhanced by extending security measurements during the installation process. For example, promoting the use of marine carriers offers extensive protection from falling, collision, heavy landings and immersion during transfer. Moreover, reducing the need for personnel transfer for non-essential tasks would reduce risks.

The traditional approach for the planning of floating crane operations is commonly based on sequential 2D-drawings, load charts and empirical formulas for the determination of dynamic amplification factors. These factors can be used to determine by what level the allowable load of the crane should be reduced for offshore operations when compared to harbour operations. The aspect of time for the execution of the crane lifting operation is

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[11] *ETIP Wind: https://etipwind.eu/, accessed on April 2017.*

[12] *Ikeda, T.; Ashida, H. (2000). "Is recreational diving safe?". Undersea and Hyperbaric Medical Society. Retrieved 2009-08-08.*

based on experience. This approach is not as effective when coping with new operating conditions or equipment, or if the task is the optimisation of the overall process. In such a case, direct simulation of a lifting operation provides a better approach[13]. In this regard, the use of simulators would reduce risks considerably.

Related to safe weather conditions, there are stricter weather limitations when people are involved in at-sea operations. These limits should be revised specifically for offshore wind operations, considering duration of operations, type of vessels and limitations, specific site and environmental conditions, among others[14].

Maximum working hours during offshore operations should be revised, depending on the weather conditions and type of operation. Crew rotation is a feasible approach to ensure the correct development of procedures. This issue is controlled by the Health & Safety Executive in the UK[15], although that document is from early 2009. Due to the advances in the offshore sector in the recent years, a thorough revision should be made. Moreover, a European common offshore working hours framework should be applied, as described in LEANWIND D6.3[16].

2.2.3.3. Training solutions

It is clear there is a need to develop training programmes, both for health & safety and technical training as well as for installation optimisation. When developing training programmes it is important to identify the competences required for carrying out installation. Competencies are a person's knowledge of a subject, combined with his/her skills and ability to carry out the task. Following this definition, it is clear that a person can be i.e. technical competent, but lack competencies in H&S issues which could be important onboard.

Developing a simulator based tools to facilitate the development of operational procedures and training of crews for the installation phase will assist in developing the overall competencies of the crew and add to the safety and efficiency of the installation phase. This will involve simulating the LEANWIND Installation vessel

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[13] http://www.offshorewind.biz/2013/10/04/heavy-lift-direct-simulation-of-offshore-lifting-operations/. *Accessed on April 2017.*

[14] *Renewable UK. Vessels Safety Guide, Guidance for Offshore Renewable Energy Developers, https://www.thecrownestate.co.uk/media/451017/ei-km-in-hs-safety-042012-vessel-safety-guide-guidance-for-offshore-renewable-energy-developers.pdf, 2012, accessed April 2017.*

[15] *Health and Safety Executive, UK Government. Policy on working hours offshore. Offshore information sheet No 8/2008 (revised March 2009).*

[16] LEANWIND report D6.3, full report at www.leanwind.eu.

Above approach is well established in the oil and gas sector and have to some extend also been used by some operators and ship-owners in the wind installation industry.

Standardised training across Europe would allow mobility of workers across organisations and countries. A common programme agreed between different countries would ensure high quality basic training of workers. In addition, by having the same programmes across different countries would allow for international exchange of workers, providing a useful experience sharing, and improving the quality of work. It is important to recognise that a standard training programme will not cover wind farm specific tasks and these should be developed for each individual wind farm / installation method.

2.2.3.4. Environmental solutions

The key challenges identified in the environmental field were related to weather windows, noise generation, vessel pollution and generation of sediment.

To address challenges related to weather windows, offshore operations should be carried out in summer where possible, as this provides the most favourable weather conditions[17]. This task should be linked to onshore assembly of turbine components, reducing the number of challenging offshore lifts[18].

Moreover, improving the access to cutting-edge weather forecasting would reduce significantly the extra costs associated to unfitting weather windows[19].

To reduce noise generation, some assembly procedures can be completed onshore. This would lead to higher risk during the transfer process. Then, this should work together with the improvement in the forecasting tools to ensure an appropriate window for each task and the use of advanced transfer methods.

Local, national and European regulations affect vessel use during offshore operations. This superposition on environmental legislation makes it sometimes difficult to apply it easily. A revision on those regulations and a pooling are proposed to make the process more effective.

Changes in sediment patterns are expected from offshore installation activities. This change could affect several industries and activities: from fishing, by changing fish habitats, to changing beach dynamics, affecting tourism activities. Moreover, other

[17] Deliverable 2.1. WP Framework/Industry Challenges report – Construction, deployment and installation. LEANWIND, 2014.

[18] Deliverable 3.1, WP Framework/Industry challenges report – novel vessels and equipment. LEANWIND, 2014.

[19] Deliverable 2.3., Novel turbine deployment and installation challenges, LEANWIND, 2014.

established wave and tidal farms near the offshore location could be affected by these sediment pattern changes. This issue should be studied through numerical and experimental modelling to analyse all facts that could have a very important effect on environment and economy, as deliverable D8.5[20] will address.

2.2.3.5. Financial solutions

To reduce installation costs, the main points to focus on have been summarised as foundations, weather windows, current state of technology, rates for equipment and effects of H&S solutions.

Although floating substructures may not be cost competitive yet and installation issues still exist[21], further research will make it a viable solution, reducing installation costs for future farms. Investing in this field is an alternative to classical heavy foundations. This solution is linked to another financial problem: the current state of technology in foundations. Research focused on innovative foundations in installation methods could be worthwhile for future developments.

Weather windows can be extended by improving the available forecasting software. Investing in software development could mean a big difference in efficiency and cost reduction. In addition, linked to this topic, equipment and personnel availability and flexibility would be needed to fit the weather windows better.

The difference between charter vessels and outright purchase may involve some financial issues related to the possibility of investment in vessels for longer projects. A common international legislation in the use of vessels for installation purposes would help in this type of decisions, improving the financial flexibility. More information in this subject can be found in sections OPERATION & MAINTENANCE and VESSELS AND ACCESS SYSTEMS. Several wind farm transport and installation vessels have been purpose-built in recent years. Most of these vessels are equipped with jack-up systems that increase the building costs and reduce the transported load capacity. An alternative approach is the use of specialised conventional heavy lift carriers. These vessels provide the necessary crane and transport capacity. Typically, they are equipped with a dynamic positioning system. These vessels are not dependent on time consuming mooring or jacking operations that saves operational time and eventually money[22].

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[20] LEANWIND report D8.5, full report at www.leanwind.eu.

[21] Deliverable 3.2, Key design parameters and criteria related to installation and maintenance, LEANWIND, 2015.

[22] Word shipping council, http://www.worldshipping.org, 2017.

Similarly, the set of challenges summarised in the Health and Safety section, might increase the required number of staff. In addition, the use of ROVs would suppose an expensive solution. These facts must be considered during project expenses planning.

Installation strategy

The installation strategy for turbines affects the whole installation operation. A different strategy depending on site characteristics should be adopted by comparing conventional and innovative methods[23]. This fact is also linked to the specific turbine used and the substructure design[24], determining the lifting requirements for installation. Moreover, the number of joints present in offshore wind turbines make installation difficult[25]. This issue can be solved by devising support structure solutions with a reduced number of joints, reducing the number of offshore operations required.

Cable installation is also a subject to analyses. This can be achieved by combining the cable deployment with other installation operations, such as the foundation deployment and J-Tube installation[23]. A more complete installation strategy has been developed by work package 5 and 8[26].

The following table outlines the solutions proposed by LEANWIND for the installation phase. Although most of those are technical, only the non-technical innovations have been considered in this deliverable. Most of the innovations proposed for the installation industry are directly applicable to the installation strategy described above. Moreover, these innovations need to be considered in new regulations.

Table 1 LEANWIND innovations in Installation.

LEANWIND deliverable	Innovation	Description
D2.3	Identify and assess novel turbine transport methodologies	Novel systems will be considered and analysed in order to identify their benefits and potential cost savings.

[23] Logistic efficiencies and naval architecture for wind installation with novel development (LEEANWIND). Annex I – Description of work, 2013.

[24] Deliverable 3.1, WP Framework/Industry challenges report – novel vessels and equipment. LEANWIND, 2014.

[25] Deliverable 2.1. WP Framework/Industry Challenges report – Construction, deployment and installation. LEANWIND, 2014.

[26] LEANWIND work packages 5 and 8, full reports at www.leanwind.eu.

D2.3	Identify and assess novel turbine assembly strategies	Evaluate traditional assembly practices and compare with novel systems including pre-assembly and pre-commissioning.
D2.4	Foundations deployment strategies	Identifying and planning the deployment strategies for the innovative foundation concepts developed in T2.2 and T2.3.
D2.2	Cable laying, burial and trenching	Examining the common issues and requirements related to the trenching path and burial depths of cables.
D2.3	Challenges and installation strategies for scour protection	Various methods and systems will be compared and recommendations will be made regarding the capabilities of each method.
D3.3	Novel Lifting Concepts	A set of recommended lifting concepts will be shortlisted in the framework of improved vessel operability and optimisation for design and cost of a vessel
D3.3	Deck Layout Optimisation	Specific vessels will be analysed and an optimised vessel layout will be proposed. The methodology used to optimise the vessel layout may be considered an innovation in the project depending on how work progresses in that area.
D5.5	Specialist software	This would include computational algorithms and specialist inputs derived from simulator software and/or trials data.
D5.5	Port layout optimisation model	A mathematical programming based model for the optimal layout of offshore wind support ports, principally in the construction life cycle phase. .Capable of handling irregular land areas and multiple turbine components that need to be stored and moved within the port area.
D5.3	Installation Optimisation Model	Installation Optimisation Model Vessel resource management for the installation phase.
D5.7	Holistic Supply Chain Model	A prior-to-port optimisation model that optimises the total cost of transport and storage of wind turbine parts prior to arrival at port. The model will be constructed as a mathematical programme and contain variants for the construction and O&M life cycle phases.

3. OPERATION & MAINTENANCE

3.1. O&M industry challenges

3.1.1. Introduction to O&M industry challenges

This section details the challenges associated with O&M in the offshore wind sector as part of the LEANWIND project. The information has been extracted from Deliverable 4.1

WP Framework / Industry challenges Report – O&M as well as additional research and discussions with relevant partners.

3.1.2.Summary of challenges

There are a number of challenges associated with the O&M sector including operational efficiency and costs, accessing sites near and far offshore, health and safety and training.

The following summarises key research priorities for O&M identified by the offshore wind industry[27, 28] and highlighted in LEANWIND deliverable D4.1:

- **Standardization of O&M activities and knowledge sharing** to increase efficiency and reduce costs.
- **Optimise O&M logistics and strategies** for a given site from a long-term planning perspective and on a short term/day-to-day basis to maximise energy production at the lowest cost.
- **Improve accessibility** by overcoming the lack of suitable, purpose-built **vessels** and develop new **access systems** to increase safe personnel transfers beyond 1.5m significant wave height (Hs).
- Adopt strategies and develop technologies to **reduce the need for manned interventions and corrective maintenance.**
- **Consider the implications of far offshore sites**
- **Consider the challenges associated with new technologies such as maintenance of floating turbines and the increasing size of turbines**

3.1.3.Challenges associated with research priorities

The key industry challenges mentioned in section 2.1.2 are considered below under the following categories: Regulation & Legislation; Health & Safety; Training; Environmental; and Financial. This identifies the non-technical actions required by the private and public sectors to address these challenges and facilitate the up-take and implementation of solutions.

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[27] Strategic Research Agenda / Market Deployment Strategy (SRA/MDS), European Wind Energy Technology Platform, 2014, available online at http://www.windplatform.eu/fileadmin/ewetp_docs/Documents/reports/TPWind_SRA.pdf

[28] ECOWindS - Newsletter for The European Clusters for Offshore Wind Servicing, 1, 2014; and Mike Newman, ORE Catapult, 'Operations and maintenance in offshore wind: key issues for 2015/2016,' September 2015.

3.1.3.1. Regulation & Legalisation challenges

The main challenges associated with Regulation & Legislation are:

- The harmonization of international standards and rules
- Promoting knowledge sharing

The harmonization of international standards and rules. Effective Operation & Maintenance requires free flow of labour, services and capital equipment such as vessels and wind turbine parts. The absence of barriers to free flow will result in higher efficiency for cross-border logistics, a larger available pool of labour and skill sets, and ultimately, cost reduction for O&M activities in the offshore wind industry. As of 2016, almost 90% of the world's offshore wind power was concentrated in European waters [29] and fortunately, the internal single market of the European Union largely accommodates this free flow. The looming exit of the United Kingdom from the EU and the single market is likely to complicate matters. If, for example, an O&M vessel carrying technicians and turbine spare-parts departs from a Belgian port is bound for an Offshore Wind Farm (OWF) in the UK, its departure could be delayed because of differences in Rules & Regulations between the respective countries and future trade barriers could mean import tariffs may have to be paid for the spare parts, resulting in extra costs. Another possible scenario is that O&M technicians from certain nationalities will not be allowed to work on wind farms located in UK waters.

A further impediment to the free flow is the fact that each EU member state is free to apply additional rules to EU directives in their national legislation. Take for example commercial diving, which is regularly required for O&M activities. EU Directive 2005/36/EC regulates the recognition of all professional qualifications, which means that, among others, professional diving qualifications from each member state should be recognised across the EU, assuring free flow of diving labour. However, in 2013 there was a question in the European Parliament [30] about the requirement in the Netherlands for non-Dutch professional divers to have a Dutch certificate for commercial diving activities in Dutch waters, which is in fact a violation of the EU Directive. Currently the certificate is no longer required by non-Dutch nationals, however, before any diving work commences, non-Dutch nationals must contact the authorities in the Netherlands to have their qualifications assessed and subsequently must be interviewed to have their actual knowledge

[29] http://www.gwec.net/global-figures/global-offshore/

[30] http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+WQ+E-2013-000047+0+DOC+XML+V0//EN&language=en

assessed[31]. Clearly this is a time-consuming procedure and a hindrance to the free flow of labour.

Commercial diving in the Netherlands is just one example that would benefit from European wide standardization. Similarly, the Health & Safety challenges described in the next section would benefit from standardization. However, perhaps an even bigger challenge in terms of cost reductions for O&M in the offshore wind industry, as in any industry, is to minimise the number of Rules & Regulations. Additional Rules & Regulations will usually generate additional administration and very often forces operators to invest in extra equipment and personnel, thus generating extra costs.

Promoting knowledge sharing. As asserted in D4.1, savings may be found through increased collaboration or knowledge sharing, both within individual companies as well as between suppliers and operators.[32] This would facilitate optimising O&M strategies during the project lifetime. However, knowledge sharing is a key challenge for offshore wind O&M as data is generally commercially sensitive. This is particularly the case for reliability data. The sharing of knowledge regarding technical failures that occurred in the past will be particularly valuable. However, it will be challenging to encourage companies to participate in knowledge sharing of past failures as this is seen as damaging to their reputation, therefore the greatest challenge will be to make knowledge sharing appealing and acceptable. Most O&M costs are determined by unexpected failures and corrective maintenance, so sharing reliability data could help determine the cause of failures as well as standardize the terminology used. This common learning could impact turbine designs, improving component reliability; impact which elements would most benefit from condition monitoring; and a better understanding of the reliability and risks could lead to increased scheduled and less unplanned maintenance. However, while a wind farm is under warranty, the turbine manufacturer generally undertakes O&M activities and does not share reliability data with the asset owner. As warranty periods expire, farm operators may take over O&M in-house and will be able to gather this data or future farm contracts will seek further access from manufacturers.

3.1.3.2. Health & Safety challenges

Besides the usual offshore Health & Safety issues such as risk of fire or Man Over Board (MOB) situations, the challenges associated with Health & Safety (see also D6.3) specifically for O&M in the offshore wind industry relate to:

- Personnel Transfer from vessels to wind turbines
- Working at heights

[31] Email conversation with Ms Carin Bot, spokeswoman for NADO, the Dutch commercial diving association.

[32] LEANWIND D4.1.

- Working with High Voltage equipment
- Health & Safety challenges associated with new technologies

On a global level health & safety of people at sea is regulated by the International Maritime Organisation in the Convention of Safety of Lives at Sea [33], or SOLAS, and by the International Labour Organisation which has issued general safe working standards.

Personnel Transfer

Current technology allows the safe transfer of personnel from Crew Transfer Vessels to offshore wind turbines in sea states of approximately 1.5 m significant wave height. To increase the weather window for O&M, and decrease down time for the wind turbines, new technology to ensure safe transfer at higher sea states will need to be developed (see also section 3.1.2).

Considering existing regulations and legislation, there is currently no EU or national legislation specifically for personnel transfer at sea. SOLAS has a short chapter on the transfer of pilots to cargo ships but nothing specifically for the transfer of personnel to offshore wind installations or for any offshore installations. However, several organizations have issued guidelines and recommendations for the safe transfer of personnel to offshore wind installations, such as:

- Classification bureaus like Lloyd's Register[34] and DNV-GL[35]
- The International Maritime Contractors Association (IMCA)[36]
- The Health and Safety Executive (HSE) in the UK[37]
- The Global Offshore Wind Health and Safety Organization (G+)[38]

The above guidelines are all similar. However, there currently is no single standard set of guidelines specific for personnel transfer to offshore wind structures. The development of a standard set of guidelines and industry standard training could provide a best practice to improve efficiency as well as safety.

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33 SOLAS consolidated edition 2004.

34 www.lr.org/en/_images/229-78787_Model_STS_Plan.docx

35 http://rules.dnvgl.com/docs/pdf/gl/maritimerules/gl_iv-6-9_e.pdf

36 http://offshore-industry.net/info/imcam202.pdf

37 http://www.hse.gov.uk/offshore/infosheets/is1-2007.pdf

38 http://publishing.energyinst.org/__data/assets/pdf_file/0009/123867/WEB-VERSION-Guidelines-for-the-management-of-service-vessels-22.01.15.pdf

Working at heights

The dangers associated with working at heights offshore will generally be similar to those onshore. The EU Directive 2009/104/EC regulates Health & Safety requirements on the work floor in Europe and has a chapter on working at heights. The same rules in the directive on working at heights apply both onshore and offshore. Generally, safety considerations for working at height will be the same onshore and offshore, however, when working at height offshore, additional measures may be required such as the use of fall-arrester compatible lifejackets [39], for example. Of course, these additional measures should not impair the effectiveness of safety equipment for work at height.

IMCA[40] and G+[41] have both issued guidelines and recommendations specifically for work at heights in the offshore wind industry.

High Voltage

The dangers associated with high voltage onshore are similar to the dangers associated with high voltage on offshore installations, as are the safety requirements regarding high voltage for both onshore and offshore installations.

Serious concerns regarding offshore high voltage installations are the exposure of personnel to electromagnetic radiation in enclosed spaces constructed of steel, and fire hazards resulting from short circuits or exploding electrical equipment on offshore high voltage substations.

DNV-GL[42, 43] and the International Electrical Commission[44] have issued safety guidelines for working with offshore high voltage installations, which are considered the industry standard.

Health & Safety challenges associated with new technologies

[39] http://media.capitalsafety.com/Assets/AUS/Brochure/ExoFit%20XP%20Flotation%20Harness%20Brochure.pdf

[40] http://www.imca-int.com/safety-environment-and-legislation/safety-environment-and-legislation-videos/sel-009.aspx

[41] http://publishing.energyinst.org/__data/assets/pdf_file/0020/123842/WEB-VERSION-G9-Work-at-Height-Guidelines-02.12.14.pdf

[42] http://rules.dnvgl.com/docs/pdf/dnvgl/OS/2015-07/DNVGL-OS-D201.pdf

[43] https://rules.dnvgl.com/docs/pdf/DNV/codes/docs/2013-11/OS-J201.pdf

[44] IEC 60533, Electrical and electronic installations in ships – Electromagnetic compatibility

Turbine ratings continue to grow, with 6 to 8 MW becoming the norm, and wind farms continue to be built farther offshore. Consequently, hub heights and rotor diameters will increase compared to existing turbines and met-ocean conditions at new offshore wind farm sites will likely be harsher, resulting in new health & safety challenges, particularly for working at heights. Another consequence of wind farms being built farther offshore is that in the event of an accident the transfer time of any casualties to emergency medical facilities onshore, either by boat or helicopter, will be longer.

Floating wind turbines bring additional challenges, mainly regarding safe transfer of O&M technicians. The natural periods in heave, roll and pitch of the Crew Transfer Vessel will differ considerably with the natural periods of the floating wind turbine, meaning the relative motions potentially will increase compared to personnel transfer on a fixed offshore wind turbine under comparable sea-states [45].

3.1.3.3. Training challenges

The main challenges associated with training are:

- Offshore specific training courses covering the technical and H&S aspects
- Standardization of training for technicians

The two main areas relating to training required for O&M in the offshore wind industry are:

- **Technical knowledge of technicians and engineers**: across Europe there are many institutes offering industry specific training, ranging from 1-day courses up to higher certificates, aimed at operation & maintenance of wind turbine technology.
- **Health & safety**: besides the basic safety & sea survival training, which is compulsory for any person working at sea [46], health & safety training for offshore wind turbine technicians should also involve the challenges mentioned in section 1.3.2

Ideally, a course comprising both the technical and health & safety subjects, aimed specifically at offshore wind O&M technicians, offering a qualification which is internationally recognised and complies with the standards set by the industry [47] should be created, as this will improve the free flow of labour. Presently no such course exists.

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[45] M. Shanley et al, 2017. *"Access to a floating wind turbine"*. Design & Construction of Wind Farm Support Vessels, 29 - 30 March 2017, London, UK. pp 89 - 97

[46] http://www.imo.org/en/OurWork/HumanElement/TrainingCertification/Documents/34.pdf

[47] http://www.globalwindsafety.org/download/2701/gwo_basic_maintenance_training_standard_version_0.pdf

3.1.3.4. Environmental challenges

As part of the policies to reduce greenhouse gas emissions the EU has set ambitious targets[48] for renewable energy; 20% of final energy consumption will have to be generated from renewable sources by 2020 and 27% of final energy consumption by 2030, most of which will be supplied by wind energy. Currently 12.6 [49] GW of offshore wind energy capacity is connected to the grid in European waters and Offshore Wind Farms totalling 4 GW of capacity are under construction, 5 GW are at the pre-construction stage and 20 GW are consented[50]. This constitutes an enormous increase in the amount of Offshore Wind Turbines, which is good news with regards to the efforts of reducing Green House Gas (GHG) emissions. However, it is also important to understand and minimize the impacts that OWFs may have on their local environment.

The environmental impacts during the construction phase of OWFs are well understood, but the impacts during the operational phase are less well known. The offshore wind industry is relatively young and, as such, an insufficient amount of research data has been gathered to fully understand the environmental impacts of OWFs that have been in operation so far.

The main Environmental challenges during the O&M stage are:

- **Obstructions to birds.** The main concerns are bird collisions with rotors and towers of the wind turbines, and the possible obstruction of OWFs to migration routes[51]. OWFs may cause local and migratory birds to avoid the area essentially leading to habitat loss. This is one of the areas requiring more research to determine the extent of the problem, and to devise mitigation measures.
- **Noise.** It is not yet clear what impact related noise levels have on marine mammals and fish species[52]. More research is required.
- **Electromagnetic fields.** There are some concerns about electromagnetic fields emitted by high-voltage cables and their impact on species that use electromagnetism for orientation or the detection of prey[52]. This is another area requiring more research.
- **O&M vessels.** Minimizing O&M vessel movements makes sense from a cost reduction perspective but it also minimizes disturbance of marine fauna

[48] https://ec.europa.eu/energy/en/topics/renewable-energy

[49] https://windeurope.org/about-wind/statistics/offshore/european-offshore-wind-industry-key-trends-and-statistics-2016/

[50] http://www.4coffshore.com/windfarms/

[51] "Assessing the impacts of wind farms on birds", Alan Drewitt et al

[52] "Effects of offshore wind farms on marine wildlife—a generalized impact assessment" Lena Bergstrom et al.

(underwater noise and collision risk) and reduces the risk of vessel-based pollution. Another benefit is the reduction of fuel consumption and associated GHG emissions. Minimizing O&M vessel movements can be achieved by improving turbine reliability, effective O&M planning and technologies reducing the need for manned inspection/intervention (e.g. remote inspection/presence, improved condition monitoring).

- **Material and parts management.** Any waste materials, hazardous materials resulting from O&M activities (paint chippings, batteries, solvents, lubrication oils etc.) must be disposed of properly and preferably recycled. The treatment of waste generated on offshore installations is regulated by the International Convention for the Prevention of Pollution from Ships, (MARPOL 73/78), Annex V [53]. The re-manufacturing of spare parts rather than replacing parts, particularly gearboxes, could have beneficial environmental effects, as this would reduce depletion of raw materials[54]. However, more research is required to determine whether this is a reliable and cost-effective method.

Besides the environmental concerns, there are also indications that OWFs might actually be beneficial for the marine environment. The structures and scour protection in OWFs form artificial reefs that attract benthic species and fish. The abundance of fish attracts their predators (seals, porpoises) and exclusion zones around the wind turbines provide protection from commercial fishing, effectively resulting in habitat gain[55,56]. It could also be argued, however, that this “reef forming” attracts unwanted or invasive species at the expense of native populations. As with the challenges mentioned above, artificial reef forming around OWFs will require further research. In fact, quantifying the environmental impacts, both negative and positive, can be regarded as an additional challenge.

3.1.3.5. Financial challenges

The prevailing challenge identified by the industry is reducing the costs of O&M. On the 3rd of June 2016, eleven of the top energy companies in Europe[57] signed a declaration saying offshore wind can reduce costs to €80/MWh by 2025 with a strong pipeline of projects. The document declared that, with the right build out and regulatory framework, the industry

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[53] http://www.comitemaritime.org/Uploads/Young%20CMI/Paper_2_Violeta_Radovich.pdf

[54] “Impact of spare parts remanufacturing on the operation and maintenance performance of offshore wind turbines: a multi-agent approach” Mohammed Dahane et al

[55] “Effects of offshore wind farms on marine wildlife—a generalized impact assessment” Lena Bergstrom et al

[56] WWF-Norway, Environmental Impacts of Offshore Wind Power Production in the North Sea

[57] Signatories included Adwen, EDPR, Eneco, E.ON, GE, Iberdrola, MHI Vestas, RWE, Siemens, Statoil and Vattenfall

is confident that it can achieve cost levels below 80 €/MWh for projects reaching Final Investment Decision (FID) in 2025, including the costs of connecting to the grid. More recently, OSW developers in Germany have promised to have completely subsidy free farms in operation by 2025[58]. The intention is to "make offshore wind fully competitive with conventional power generation."[59] Operations and maintenance (O&M) costs are an important factor when considering ways to reduce costs. Typical estimates for O&M expenditure from 14-30% of the cost of energy,[60] contributing 2 to 4 €c/kWh to the lifecycle costs.[61] BVG Associates estimate that the proportion of LCOE for a wind farm (500 MW, 4MW turbines, a water depth of 35m and 40km from shore) constructed in 2013 is up to 33%.[62]

O&M requirements are extremely variably depending on the site, and O&M can contribute to substantial cost overruns, sometimes costing up to three times more than was originally projected.[63] The variable nature of O&M costs impacts the business risk. In addition to O&M costs, unexpected failures and difficulties accessing a site due to weather conditions impact wind farm availability (the percentage of time a turbine is able to produce electricity), with downtime leading to loss of revenue.

With the significant economic impact of O&M on OWFs, it is clear that O&M strategies need to be improved and new technologies developed to reduce costs and increase availability. However, the marine environment makes it difficult to access and maintain wind farms, demanding expensive equipment including vessels and cranes. The expected increase of wind turbine capacities up to 6-8 MW could reduce the numbers in future farms, and thereby the numbers requiring maintenance. However, there is a higher penalty for downtime and potentially more expensive components to repair and replace as well as additional logistical time and cost to transport larger components. Offshore wind farms are also expected to move further from shore into deeper waters and harsher conditions. While

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[58] https://www.bloomberg.com/news/articles/2017-04-13/germany-gets-bids-for-first-subsidy-free-offshore-wind-farms

[59] http://www.offshorewindindustry.com/news/major-energy-companies-sign-offshore-wind

[60] Rebecca Martin, Iraklis Lazakis, Sami Barbouchi and Lars Johanning, 'Sensitivity Analysis of Offshore wind farm operation and maintenance cost and availability,' Renewable Energy, Vol. 85, January 2016, pp. 1226-1236.

[61] Van de Pieterman, R.P., H. Braam, T.S. Obdam, L.W.M.M. Rademakers and T.J.J. van der Zee, *Optimisation of maintenance strategies for offshore wind farms – A case study performed with the OMCE-Calculator*, presented at the Offshore 2011 conference, Amsterdam, The Netherlands, ECN Wind Energy, 14 December 2011, www.ecn.nl/docs/library/report/2011/m11103.pdf

[62] BVG Associates, 'Offshore wind: Industry's journey to £100/MWh, Cost breakdown and technology transition from 2013 to 2020,' May 2013.

[63] Stancich, R., 'Turbine O&M costs to spiral in coming years,' May 2010, http://social.windenergyupdate.com/om/turbine-om-costs-spiral-coming-years

taking advantage of greater wind resources, this will also exacerbate existing O&M challenges e.g. accessibility and increase costs. Alternative O&M strategies may have to be developed for new sites as well as new technologies such as towing in floating turbines for major maintenance to reduce on-site visits.

3.2. O&M industry solutions

3.2.1. Introduction to O&M solutions

This section outlines the potential solutions to the challenges outlined above and indicates the innovations developed in LEANWIND that could contribute.

3.2.2. Summary of solutions

As outlined in section 3.1.1, the key challenges and research priorities identified by the offshore wind industry include:

1. **Standardization of O&M activities and knowledge sharing** to increase efficiency.
2. **Optimise O&M logistics and strategies** for a given site from a long-term planning perspective and on a short term/day-to-day basis to maximise energy production at the lowest cost.
3. **Improve accessibility** by overcoming the lack of suitable, purpose-built **vessels** and develop new **access systems** to increase safe personnel transfers beyond 1.5m significant wave height (Hs).
4. Adopt strategies and develop technologies to **reduce the need for manned interventions and corrective maintenance.**
5. **Consider the implications of far-shore sites**
6. **Consider the challenges associated with new technologies such as maintenance of floating turbines and increasing size of turbines**

Several LEANWIND innovations are being developed to help address some of these challenges as indicated in Table 2. The first column in the table indicates the LEANWIND reports that describe the innovations developed within the scope of LEANWIND, which are mentioned in the second column. The numbered columns in the table refer to the challenges mentioned above.

Table 2 LEANWIND innovations relating to outlined challenges.

LEANWIND Deliverable[64]	Innovation	Description
D3.4, D3.5	O&M vessel design	Development of a service operations vessel concept design and access equipment specifically for offshore wind O&M considering current and future sites.
D6.5, D7.3	Ship simulator based tools	Development of ship simulator based tools to facilitate assessment of innovative technological design solutions and the development of operational procedures and training of crews and operators for the in-service phase.
D4.2, 4.5, 4.6, 4.7	i) O&M Strategy Model	A strategic decision support tool designed for aiding stakeholders in selecting the optimal maintenance and logistics strategy for offshore wind farms.
	ii) Dynamic Scheduling Model	A tool for optimising scheduling of preventative and corrective O&M for offshore wind farms. The focus is on short term optimisation and mainly on the use of CTV (Crew Transport Vessels). The main objective is to minimise the total maintenance cost.
	iii) Risk Based O&M Model	This is a framework for applying a risk based approach to planning O&M. The approach is based on pre-posterior Bayesian decision making that allows in a rational way and on a theoretical basis to plan future actions/decisions taking into account prior knowledge and knowledge from measurements/condition monitoring/structural health monitoring/ inspection. Further influence of

[64] See executive summaries of deliverables on www.leanwind.eu

		future actions is accounted for though decision rules. The approach takes into account life cycle costs.
D4.2, 4.4, 4.7	i) RAMS methodologies will be developed for critical components' identification and characterisation	These are risk-based methodologies on the reliability, availability, maintainability, safety and security of the various WT components. The outcome will be a group of critical components which have high impact on the operation and maintenance providing excessive combination of failure rates, maintenance and repair times, maintenance and repair costs.
	ii) Develop Reliability based design tools	This is a methodology for developing reliability based design tools using existing software tools & advanced modelling methodologies taking into account the critical components, those components that evolve on the improvement of technology and experts' opinion.
	iii) Software tools based on existing software for simulation and optimisation of the degradation models	Adapt/improve degradation models simulating and optimising using existing software and, if necessary, developing some software.
D4.4	i) Condition monitoring software - Development of protocols and structure to make diagnosis of failures in wind turbines. It will be implemented in an online service where you can obtain diagnosis "on demand".	The overall scope is to develop an on-line framework for Diagnosis and Prognosis of Off shore Wind Turbines. The approach is based on the use of Artificial Intelligence (AI), the latest advances in Communications Technologies (CT) and modern features of software programming. An internet-based on line service will be the main result. The users will have tools to configure the inputs (data and models), processes and outputs in an autonomous way without the need of human assistance. Test cases for Diagnosis and Prognosis of Wind Turbines equipments are going to be included in the service in order to show the characteristics and potential of the approach.

D4.3	i) Development of a prototype for remote presence.	The remote presence prototype that consists of a sensor platform with normal cameras, an IR camera for thermographic imaging and microphone for capturing audio. Future versions of the system can be equipped with more sensors and manipulators. The platform moves on a rail inside the turbine nacelle to get access to different parts of interest in the turbine. Operators on land can get a sense of presence inside the turbine in order to do maintenance and inspections can use the system. It can also collect information autonomously for later use. The purpose of remote presence is to reduce the need to travel offshore for operation and maintenance of offshore wind turbines. These visits are expensive, time consuming, dangerous and dependent on favourable weather condition. Examples of uses of remote presence are investigation of diagnoses from condition monitoring and SCADA systems and as a tool for preparation of larger maintenance operations.
D4.7	Identification of O&M Access Solutions	Identifying O&M access, safety assessment and risk analysis.
D5.6	A strategic logistic decision support tool (DST) for the O&M phase. O&M Vessel Fleet Optimisation Model	The optimization based DST determines optimal resources (e.g. vessels, ports, technicians) and underlying schedules and activities. Vessel resource management for the O&M phase

The following section specifically identifies potential solutions to the non-technical issues identified under the categories; Regulation & Legislation; Health & Safety; Training; Environmental; and Financial.

3.2.3. Solutions associated with research priorities

3.2.3.1. Regulation & Legislation solutions

BVG Associates' report contends that as offshore wind projects have been relatively small and close to shore, O&M strategies have not been very different to those for onshore wind farms.[65] However, given the variety of additional challenges e.g. access, the need for expensive vessels, H&S issues etc., specific OWF strategies need to be developed and standardized in order to increase efficiency and reduce costs. An ORE Catapult report outlining key O&M issues for 2015/2016 highlights the need for standardisation and sharing of knowledge such as standardised boat landing connectors and standardisation of operational key performance indicators.[66] The standardization of O&M activities and knowledge sharing would lead to best practices, which ultimately reduce wasteful processes. It could also develop better training programmes as well as offshore wind specific regulations to improve personnel safety.

The standardization process of Rules & Regulations is a matter for the industry associations to address and falls outside the scope of the LEANWIND project; however, several LEANWIND innovations such as O&M Strategy models[67] can potentially help to determine best practices to streamline the O&M process.

A possible solution for the knowledge sharing related to O&M issues could be the establishment of an online platform or database where O&M related data is available for operators and contractors. The condition monitoring[68] and remote presence tools[69] could be integrated with such a platform, therefore making the data available in real-time. Encouraging companies, particularly turbine manufacturers, to share valuable data gathered over the years is very challenging. Perhaps a system could be established whereby confidential disclosure agreements could protect the information from reaching

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[65] BVG Associates, Offshore Wind Cost Reduction Pathways: Technology Workstream, June 2012.

[66] Mike Newman, ORE Catapult, 'Operations and maintenance in offshore wind: key issues for 2015/2016,' September 2015.

[67] LEANWIND reports D4.2, 4.5, 4.6 and 4.7, executive summaries will be made at www.leanwind.eu.

[68] LEANWIND reports D4.4, executive summaries will be made at www.leanwind.eu.

[69] LEANWIND reports D4.3, executive summaries will be made at www.leanwind.eu.

parties other than the companies involved, possibly even accommodated by an EU Directive to enhance its legal basis.

Realistically, a knowledge-sharing platform will be very hard to establish and this would be another task best suited to the industry associations. No studies for a knowledge-sharing platform have been conducted within LEANWIND.

3.2.3.2. Health & Safety solutions

The key challenges identified for Health and Safety include:

- Personnel Transfer from vessels to wind turbines
- Working at heights
- Working with High Voltage equipment
- Health & Safety challenges associated with new technologies
- Longer transfer time of casualties from the OWF to medical facilities onshore in case of accidents

Considering potential solutions to these issues, LEANWIND has conducted studies to assess transfer technology and methods as well as developing a novel O&M vessel concept and access equipment to facilitate safe transfers up to 2.5m using a motion compensated gangway.[70]

Improving designs of offshore wind turbines to allow easier access to areas where work at height is required, could significantly increase safety of personnel and reduce the time required for O&M. The requirement to work at heights could be reduced for example by inspecting the turbine blades with a drone rather than manually. Besides their potential use for a knowledge-sharing database, the development of the LEANWIND internet based failure diagnosis system, and prototype for remote presence in offshore wind turbines are designed to reduce manned intervention and corrective maintenance. Another potential benefit of the LEANWIND remote presence prototype is the inclusion of an infrared thermal camera that could provide early warning of imminent failure of high voltage equipment thus reducing the risk of fire.[71]

Standardization could also help improve H&S, particularly developing standards for new technologies. In LEANWIND, an assessment of existing issues and regulations across different countries has been conducted. In addition, the report includes a risk assessment of selected new technologies/innovation categories within the framework of LEANWIND dealing with innovations for worker access systems, lifting arrangements, and novel vessel

[70] LEANWIND reports D3.4, 3.5, 4.7, executive summaries at www.leanwind.eu.

[71] LEANWIND reports D4.3 and 4.4, executive summaries at www.leanwind.eu.

concepts. The aim of this assessment is to define possible control options and risk mitigation measures, and recommend training requirements for offshore personnel.[72]

Longer transfer times from far-offshore wind farms to onshore facilities in case of accidents can be mitigated by providing excellent medical facilities on board of the Service Operations Vessel, which will serve as an onsite base the OWF.

3.2.3.3. Training solutions

It is clear there is a need to develop training programmes, both for health & safety and technical training as mentioned in section 5.1.2.3. LEANWIND considers training requirements from both perspectives including:

- Assessing H&S issues and identifying training gaps that need to be filled in order to cover the actual competencies required in the wind industry. D6.3 proposes training requirement guidelines that will help in improving the overall level of safety for workers in Offshore Wind Farms.[72]
- Developing simulator based tools to facilitate the development of operational procedures and training of crews for the in-service phase.[73] This will involve simulating the LEANWIND O&M vessel[74]

As mentioned in section 5.1.2.3, there are already some institutes that provide O&M training for wind energy. However, much of it is fragmented with many courses paying only limited attention to the situation for offshore wind. Ideally, all components required for offshore wind O&M training are combined into a single course. Particularly for health & safety there is potential for a programme of knowledge transfer from well-established H&S training in the oil and gas sector.

3.2.3.4. Environmental solutions

The key environmental challenge identified in section 5.1.2.5 is to understand and minimize the impacts that OWFs may have on their local environment. In LEANWIND, D8.5 assesses the positive and negative impacts of project innovations e.g. new foundation systems, installation activities etc. as well as collating the current experience of the environmental life cycle of offshore wind farms. LEANWIND report D8.5 will highlight the best practices of industry and examples of collaborative research initiatives for environmental monitoring, compiling mitigation techniques for negative environmental

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[72] LEANWIND report D6.3, full report at www.leanwind.eu.

[73] LEANWIND reports D7.3 and D6.5, executive summaries will be made available at www.leanwind.eu.

[74] LEANWIND report D3.4, executive summary at www.leanwind.eu.

effects.[75] In addition, the following innovations may contribute in minimize environmental impacts:

- *Reducing the need for manned interventions.* The Condition Monitoring Software and remote presence prototype[76] are all designed to reduce the need for manned interventions, which in turn will reduce vessel movements and downtime for offshore wind turbines. Beside economic benefits this will also reduce environmental impacts.
- *Optimising operational capabilities and efficiency of O&M vessels.* The innovations described in LEANWIND reports D4.2 (O&M strategy model), D4.2 (RAMS methodology), D4.5 (Risk-based strategy framework), D4.6 (Dynamic scheduling model) and D5.6 (A strategic logistic decision support tool (DST) for the O&M phase) are all designed to optimise O&M strategies and operations, which in turn should result in further reductions of manned interventions and vessel movements.

3.2.3.5. Financial solutions

The main challenge for O&M is reducing costs. Potential solutions include; optimising O&M strategies, reducing the amount of manned interventions, overcome the lack of suitable, purpose built vessels and improve accessibility to offshore wind turbines.

Table 3 indicates the LEANWIND innovations that could potentially provide cost reductions for O&M in the offshore wind industry linked to these required solutions.

Table 3 LEANWIND innovations which provide cost reduction for O&M.

Solution	LEANWIND innovation
Optimising O&M logistics and strategies	• O&M strategy model, D4.2 • Dynamic scheduling model, D4.6 • Risk based O&M model, D4.5 • A strategic logistic decision support tool (DST) for the O&M phase, D5.6
Reducing the amount of manned interventions	• RAMS methodologies, risk-based maintenance, optimised O&M strategies and dynamic scheduling, D4.2, D4.5 & D4.6 • Condition monitoring software, D4.4 • Remote presence prototype, D4.3
Overcome the lack of suitable, purpose built vessels	• Service Operations Vessel and access equipment, D3.4 & D3.5

[75] LEANWIND report D8.5, full report will be made available at www.leanwind.eu.

[76] Please see LEANWIND reports D4.2 and D4.3, executive summaries at www.leanwind.eu.

Improving accessibilty to offshore wind turbines	• Service Operations Vessel and access equipment, D3.4 & D3.5

Further explanation is given below.

Optimise O&M logistics and strategies

Considering current strategies, a typical farm would undertake planned maintenance on a 6-monthly or primarily an annual basis, with corrective unplanned maintenance where a fault occurs. The European Wind Energy Technology Platform's (*TPWind*) 2014 strategic research agenda summarises the overall target for the O&M sector to minimise unplanned maintenance due to failures and to standardize planned maintenance activities so as to maximise the energy yield while reducing the costs of O&M.[77] To achieve this, the document identifies three key research priorities including developing versatile service fleets and safe access methods; improving reliability and availability; and improving asset management.[78] Considering the latter (asset management) the report asserts the need for the development of lifecycle cost models that can determine the cost-benefits of a strategy for a specific site and technologies.

There is a need for a variety of decision support tools to provide cost optimal planning of logistics and strategies as well as tools that can optimise the scheduling on a short term/day-to-day basis to maximise energy production at the lowest cost. Industry have a growing interest in these tools as OWF warranty periods (usually 5 years during which the turbine manufacturers lead O&M activities) are coming to an end, and owners/operators are considering taking over operations in-house. Until that point, they may not have had access to information in order to develop a strategy. While manufacturers may have had a target availability to achieve, operators could use these tools to optimise activities.

O&M cost modelling is often used in due diligence to aid investment decisions by OWF developers. Potentially, improved O&M cost modelling may reduce the risk and financing costs, including contingencies, insurance etc., prior to development, by improving accuracy and credibility in modelling and input assumptions.

There are a number of key elements of an O&M strategy where savings may be highest:

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[77] Strategic Research Agenda / Market Deployment Strategy (SRA/MDS), European Wind Energy Technology Platform, 2014, available online at http://www.windplatform.eu/fileadmin/ewetp_docs/Documents/reports/TPWind_SRA.pdf.

[78] Strategic Research Agenda / Market Deployment Strategy (SRA/MDS), European Wind Energy Technology Platform, 2014, available online at http://www.windplatform.eu/fileadmin/ewetp_docs/Documents/reports/TPWind_SRA.pdf.

- According to the literature, unplanned maintenance comprises the majority of the day-to-day operational costs, and about half of these relate to using large vessels e.g. jack-ups.[79] Due to the significant cost of vessels, decision support tools could be used to develop optimal vessel fleet solutions as well as improved scheduling, grouping and routing to optimise usage and reduce costs. With the particularly large cost associated with Heavy-Lift Vessels (HLVs), there is a need to develop the best strategies for chartering or to develop strategies that reduce the need for HLVs.
- Poor supply chains ultimately lead to delays, costs and downtime. Decision support tools could be used to determine the optimal port base for O&M activities for a given offshore wind farm. According to the BVG Associates 2012 report, there is scope for significant improvements in inventory management to more accurately track of turbine parts, spares, consumables and tooling to ensure that the correct spares and equipment are on hand when required[79].

As well as planning a strategy, decision support tools could also allow industry to undertake cost-benefit analysis of new technologies to inform their investment decisions e.g. using condition-monitoring or a remote presence device, or the use of a mothership vessel in a far-shore wind farm scenario.

Adopt strategies and develop technologies to reduce the need for manned interventions and corrective maintenance.

While improving offshore access for technicians is required, innovation should focus on reducing the number of interventions required and minimising the vessel transfers necessary to operate a site. A key challenge for the industry, particularly as farms move further from shore, is to adopt strategies that reduce the need for manned interventions and corrective maintenance e.g. reliability-centred, condition-based, risk-based maintenance etc. In addition, industry needs to improve or develop the technologies required e.g. Condition Monitoring (CM) systems, automation, instrumentation and robotics.

The EWEA project *Wind Energy – The Facts* (2009) asserts that a general view is emerging that it is better to invest in reliability to avoid maintenance than in trying to overcome the challenges of offshore O&M by creating systems and equipment to facilitate it.[80] The report assesses the impact of various maintenance strategies on the design of wind turbine systems. For example, should they be designed for long life and reliability with less access for maintenance or designed in a less cost-effective way for easy access to components. Other issues include whether or not to have a heavy-duty internal crane or a lighter internal

[79] BVG Associates, Offshore Wind Cost Reduction Pathways: Technology Workstream, June 2012.

[80] Garrad Hassan and Partners (An EWEA project, WindFacts), *Wind Energy – The Facts,* Part 3: Economics, EWEA, March 2009, pp. 108-110.

winch to raise a heavy-duty crane brought by a maintenance vessel. Decisions remain about which components should be maintained offshore in the nacelle, which can be accessed, handled and removed to shore for refurbishment or replacement, and when to draw a line under component maintenance capability and accept that certain levels of fault will require replacement of a whole nacelle.[81]

While reliability-centred maintenance focuses on improving the reliability of components to minimise on-site maintenance, condition-based or risk-based maintenance seeks to predict component failures based on reliability data and condition-monitoring to allow more efficient O&M scheduling. Condition monitoring assesses the health of a component, allowing the maintenance team to detect failures early and avoid emergency failure or further damage, and provides them with time to plan maintenance economically around equipment, spare-parts, and technician availability.[82, 83] Anders Soe-Jensen, head of offshore wind at Vestas, states the importance of having predictive maintenance and "surveillance that lets you know exactly [what is happening at the site], when you go out to a turbine, you don't go out to find out what is wrong."[84] Condition-monitoring can also inform the planned maintenance strategy, potentially reducing scheduled visits to site where they are not required.

The main "components" of a condition monitoring system are sensors; a communication network between the various turbines and operators; and a data collection system.[85] While monitoring equipment is becoming quite widely used and developed to collect data and register minor and major faults, there is a need for significant improvements in CM systems as a whole. They need to be offshore specific and better integrated using a greater number of sensors, improved data communication and analysis software with better prognosis and diagnosis capabilities. They should also adopt international standards for data capture, storage, communication and presentation. Key challenges include:

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[81] Garrad Hassan and Partners (An EWEA project, WindFacts), *Wind Energy – The Facts,* Part 3: Economics, EWEA, March 2009, p. 110.

[82] Rademakers, L.W.M.M., H. Braam, and T.W. Verbruggen, *R&D Needs for O&M of Wind Turbines,* ECN Wind Energy, 2003, www.kernenergie.nl/pub/www/library/report/2003/rx03045.pdf

[83] Maples, B., G. Saur, M. Hand, R. van de Pierterman, and T. Obdam, *Installation, Operation, and Maintenance Strategies to Reduce the Cost of Offshore Wind Energy*, National Renewable Energy Lab Technical Report, July 2013.

[84] Cameron, 'Offshore Wind Targets Cheaper O&M,' 26 September 2011, www.renewableenergyworld.com/rea/news/article/2011/09/offshore-wind-targets-cheaper-o-m

[85] Rademakers et al, *R&D Needs for O&M of Wind Turbines,* ECN Wind Energy, 2003, www.kernenergie.nl/pub/www/library/report/2003/rx03045.pdf

- Determining the most cost-effective measurement or monitoring strategy.
- Improving the use of SCADA system data to provide a more reliable, flexible, and efficient tool for automatic WT monitoring and control.
- Meeting requirements for remote and e-monitoring.
- Developing protocols for integration of several data sources.[86]

BVG associates 2012 report predicts that the implementation of holistic condition monitoring systems could lead to a 1.5% reduction in operational and planned maintenance OPEX and a 5% reduction in unplanned service OPEX. This innovation is expected to result in a 0.25% increase in wind farm availability as the balance of unplanned service activity moves from reactive to proactive.[87] However, the success of CM systems development would benefit from the ability to share data between manufacturers and owners or operators. This is a key issue as wind turbine manufacturers only share data where contractually obligated. Industry also need to be able to assess the cost benefits and identify the critical subsystems to monitor, in order to justify investment in CM and remote diagnostic systems. Current decision support models do not generally consider CM or remote presence technologies. Therefore, is a need to examine how CM can be coupled to models to support the planning and continuous improvement of maintenance strategies.

Improve accessibility and overcome lack of purpose-built vessels

Good accessibility is vitally important to reaching desired industry targets for availability (c. 95%), minimizing downtime and revenue losses incurred while waiting for weather windows to undertake maintenance. Access is often impeded by harsh sea state conditions making transport and personnel transfer impossible. This challenge will be exacerbated as farms move further offshore into deeper waters. Jan Mathiesen of the Carbon Trust explains that “There is a technology gap in three areas — for transfer systems, for vessels and for launch and recovery systems.”[88] A solution to improve accessibility is overcoming the lack of suitable, purpose-built vessels that can operate in harsher wind and wave conditions and are fitted with access systems that allow safe personnel transfers in conditions exceeding the current typical 1.5m Hs restriction. This would increase the windows available to access wind farms.

BVG Associates’ 2012 report asserts that using larger vessels with access systems allowing technician transfers up to 2.5m Hs would have a significant impact in reducing O&M expenditure as well as increasing energy production. A number of access systems

[86] Please see LEANWIND report D4.4

[87] BVG Associates, Offshore Wind Cost Reduction Pathways: Technology Workstream, June 2012.

[88] Cameron, ‘Offshore Wind Targets Cheaper O&M,’ 26 September 2011, www.renewableenergyworld.com/rea/news/article/2011/09/offshore-wind-targets-cheaper-o-m

are available or being developed e.g. the Ampelmann, MaXccess or the Turbine Access System designed by Houlder and BMT Nigel Gee. It is expected that increasing transfers to 2.5m could reduce planned maintenance by 0.8%; unplanned service OPEX of 2.5%; and increase availability by 0.5%. It is anticipated that, by FID 2020, 80 per cent of this potential will have been achieved and this will have been adopted on 90 per cent of wind farms.[89]

Where sites may prove inaccessible to vessels due to rough water conditions, helicopters provide a more costly but speedy alternative to ensure turbines are up and running as soon as possible. To reduce the costs and complexity of flying a great distance while carrying parts, AWS Truewind (2009) suggest helicopter access from an oversized substation rather than from onshore.[90] However, *The Wind Energy – The Facts* report (2009) asserts that helicopter access is very expensive to be used as a routine method of transport.[91] ORECCA (2010-2011) agree that helicopters are not economical or practical for regular use.[92] For sites further from shore, motherships and floaters could provide solutions to increase accessibility and ultimately reduce downtime.

The use of accommodation vessels permanently stationed at offshore wind farms is only a recent development and is considered economically viable for wind farms located 50 km or more from the port of operations. The Belgian Bligh Bank offshore wind farm, for example, has a special O&M hotel service vessel. According to Kristof Verlinden, O&M Asset & Production Manager at Belwind Offshore Energy, there is a big gain from this concept as the crew has the possibility to benefit from good weather gaps: "it means that we act faster and do not suffer from big planning risks – we are there immediately to take action and since we have the majority of spare parts on board the hotel service vessel we are able to act within 5 minutes." Frank Coenen (CEO of Belwind) says that his team were sceptical but were aware that innovative methods were needed to reduce the cost of maintaining the site, which is approximately 2 hours from the coast of Zeebrugge, Belgium.

89 BVG Associates, Offshore Wind Cost Reduction Pathways: Technology Workstream, June 2012.

90 AWS Truewind, *Offshore Wind Technology Overview*, NYSERDA PON 995, Task Order No. 2, Agreement No. 9998 For the Long Island - New York City Offshore Wind Collaborative, September, 2009, www.linycoffshorewind.com/PDF/AWS%20Truewind%20Offshore%20Wind%20Technology%20Final%20Report.pdf

91 Garrad Hassan and Partners (An EWEA project, WindFacts), *Wind Energy – The Facts,* Part 3: Economics, EWEA, March 2009, p. 110.

92 ORECCA, *Offshore Infrastructure – Ports and Vessels A report of the Off-shore Renewable Energy Conversion platforms – Coordination Action,* 2010-2011, p. 16, www.orecca.eu/c/document_library/get_file?uuid=6b6500ba-3cc9-4ab0-8bd7-1d8fdd8a697a&groupId=10129

To further improve the concept Coenen suggests keeping more spare parts on the vessel and improving safety.[93]

Floating hotels, such as the 145m Regina Baltica, a former cruise ferry providing accommodation for around 100 workers, have frequently been used at the construction of OWFs in the last decade. However, these types of vessels have proven not to be the most suitable vessels in offshore conditions at wind farm sites, as an incident with the Regina Baltica illustrated[94]. Furthermore, O&M does not require the large numbers of technicians these vessels can accommodate and are therefore not cost effective during the O&M life cycle stage of far-offshore wind farms.

A new type of vessel evolved to service far offshore wind farms, often referred to in literature and the industry as Service Operations Vessel (SOV). The SOV, sometimes referred to as mother vessel, may be supported by daughter vessels, with a helideck, a sheltered wet deck, cranes for loading, a turbine access system (walk-to-work technology) storage areas, workshops, and accommodation for up to 60 technicians to stay offshore for 2 weeks at a time. There are a number of SOV concepts on the market e.g. the Damen Walk-to-Work vessel [95] and the Ulstein Offshore Wind Vessel[96].

The Dutch offshore wind energy research consortium We@Sea developed the “harbour at sea” concept, where an artificial offshore platform is utilised as a forward O&M base[97], which could allow for the use of CTVs rather than the larger and more expensive SOVs. Siemens currently has an SOV in operation at the Gemini offshore wind farm off the coast of the Netherlands, and a second SOV will start servicing the Sandbank wind farm in the German North Sea in April 2017. Meanwhile, Dong Energy is having 2 SOVs built for the Racebank and Hornsea 1 wind farms in the UK. Experience of far-shore sites and cost-benefit analysis may be required to prompt more investment in these concepts.

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93 Vestas ‘Belwind: Vestas’ hotel service vessel pioneers the O&M market,’ www.vestas.com/en/wind-power-plants/towards-20-years-in-offshore/offshore-stories/belwind-vestas%E2%80%99-hotel-service-vessel-pioneers-the-o-m-market.aspx

94 https://www.youtube.com/watch?v=7d9OhgF_8pU

95 http://products.damen.com/en/ranges/walk-to-work-vessel/w2w-9020

96 https://ulstein.com/ship-design/offshore-wind

97 ORECCA, *Offshore Infrastructure – Ports and Vessels A report of the Off-shore Renewable Energy Conversion platforms – Coordination Action,* 2010-2011, p. 37, www.orecca.eu/c/document_library/get_file?uuid=6b6500ba-3cc9-4ab0-8bd7-1d8fdd8a697a&groupId=10129

Within the scope of the LEANWIND project a SOV is being designed[98], which will have capacity to accommodate up to 44 O&M technicians and 16 crews in single berth cabins and remain offshore for at least 30 days in UK Round 3 areas. Further details of challenges and solutions for O&M vessels and access systems can be found in D6.3

In addition to improving vessel operational capabilities and access systems, another solution is to improve weather forecasting to help make effective planning decisions and maximise activity during weather windows. According to the BVG Associates report, the accuracy of forecasts drops beyond five days. While extending this by any length would help, a 21 days forecast would particularly facilitate making the best use of resources, particularly heavy equipment such as jack-up vessels. The technical impact of this innovation is anticipated to be a 0.5% reduction in operational and planned maintenance cost and a 1% reduction in unplanned service cost. When fully realised, it is anticipated that this innovation has the potential to increase wind farm availability by 0.05%.[99]

With far-shore windfarms, industry must consider particularly the Health & Safety (H&S) as well as the cost implications of long personnel transfers and trying to return to shore in case of incident. There is a need to better understand the effect of weather and sea sickness on maintenance technicians as this will impact productivity. There is also a need to develop alternative strategies that reduce logistics time and costs. For example, travel time and weather windows required could be reduced by using mothership vessels or floaters.

[98] Please see LEANWIND report D3.4 for more information.

[99] BVG Associates, Offshore Wind Cost Reduction Pathways: Technology Workstream, June 2012.

4. ON-LAND AND PORT INFRASTRUCTURE

4.1. On-land and port infrastructure industry challenges

4.1.1. Introduction to on-land and port infrastructure challenges

Ports are the main connection point between on-land operations and offshore operations in the OWF installation process and thus play a significant role in offshore wind farm development. A global shift from fossil fuel energy to renewable energy requires some ports to adopt to new, renewables industries' demands. In the case of the offshore wind sector, availability of port infrastructure is a prerequisite[100], in order to accommodate offshore wind farm installation, operations and maintenance, and decommissioning stages. In general, offshore wind (OSW) projects delivery is unlikely to be constrained by a lack of installation ports availability, as identified by BVG Associates[100]. However, some ports, as well as on-land infrastructure, require some adaptation to ensure viability of some innovative component designs, such as self-buoyant Gravity Based Foundations (GBFs) that have a potential to minimise the use of expensive installation vessels, but require certain conditions related to water depth and harbour infrastructure that ports will need to provide, and on-land component transportation efficiencies.

It has been recognised throughout the LEANWIND project that common industry challenges are associated with technology innovation, in particular the growth in size and weight of wind farm components. This brings some technical challenges to port and on-land infrastructure, such as logistical challenges associated with transportation, storage and handling of large offshore wind components. In addition, industry's move to deeper waters and further from shore brings further challenges that are more associated to offshore operations rather than on-land operations. The following sections outline the main challenges related to on-land & port infrastructure as identified through the LEANWIND project as well as external industry reports.

4.1.2. Summary of challenges

A number of challenges have been identified in relation to on-land and port infrastructure, derived from LEANWIND project and external information sources. Both hard or technical challenges and soft challenges are discussed in subsequent sections. It has been recognised by the LEANWIND project, specifically D.5.3[101] that due to high costs of operations at sea during the installation stage, it is important to perform as much of the operation as possible on-land, in order to save time and reduce cost during installation

[100] BVG Associates (2013), *Offshore wind: a 2013 supply chain health check*, [pdf], BVG Associates, Cricklade.

[101] LEANWIND report D5.3 (PU), at www.leanwind.eu.

phase. Some on-land and port infrastructure limitations might impose challenges for existing operations as well as proposed LEANWIND novel innovations.

4.1.3. Challenges associated with research priorities

4.1.3.1. Regulation & Legislation challenges

Harmonisation and standardisation of road transport regulation aspects among European countries

As identified by D.5.4[102] the main challenge on-land and port infrastructures face in relation to regulation and legislation is that apart from European regulations, different regulations exist at the regional levels. The main differences between European and national regulations are concerned with Abnormal Indivisible Load (AIL) transportation, obtaining permits for AIL transportation and escort and signalling. These differences constrain cross-border transportation of heavy and oversized load transportation.

Main inconveniences concerning lack of standardisation and harmonisation of AIL transportation in different European countries are:

- Time needed to obtain authorisations (time to get authorisation varies from 2 working days up to 2 months)
- Obtaining permits for abnormal road transport (different countries have different permits that are necessary to be obtained, permit fees, the number of vehicles/registrations per permit allowed, waiting time and procedures required for permit granting, etc.)
- Differences in types of authorisation (diversity of authorisations that can be found depending on the country. This will determine the number of authorities to consult, local and or regional road authorities, bridge owners, and/or the police)
- Requirements for delivering a permit
- Escort normative (private or police escorts) (Currently each Member State has its own regime of police escorts. Rules related to escort vehicles appearance, vehicle type and signalling devices/lights are also different between the Member States)
- Safety signalling

Calendar dates limitations

Cargo transportation involves compliance with calendar limitations that vary from country to country. There are fixed date restrictions as well as non-fixed calendar limitations. There is no harmonisation in relation to fixed calendar date restrictions, such as night bans, weekend bans, holiday bans and public holidays. Similar problems exists in relation to non-fixed calendar date restrictions, such as commodity group, extreme weather, congestion

[102] LEANWIND report D5.4 (RE), at www.leanwind.eu.

related and ad hoc restrictions. The restrictions that lay within this category are those that are caused by unpredictable reasons such as weather, accidents or traffic congestion.

Simultaneous consenting of OSW farms

Simultaneous consenting of wind farms stretch road transport sector capacities, not only fleets (number of vehicles), but also loading capacities and technological capabilities required to overcome with the existing limitations of the road transport system[102].

4.1.3.2. Health & Safety challenges

Health and safety (H&S) challenges addressed by the LEANWIND project were predominantly related to the offshore operations of the wind farm construction rather than on-land infrastructure related H&S challenges, due to more challenging conditions faced by the workforce at sea. A number of different regulatory frameworks exist that are currently used by the offshore wind industry, which in itself poses some difficulties as it might create misalignment of expected work practices within the industry. The following section provides some general H&S challenges that on-land and port infrastructure faces as well as some offshore industry-specific hazards.

Visibility of Health and Safety standards and requirements for existing and potential OSW industry suppliers

It has been identified by Danilova et al (2016)[103] that there are stringent H&S requirements set by OSW developers and original equipment manufacturers related to both on-land and offshore operations. According to one development, engineering, construction, and operations & maintenance (O&M) services provider, the H&S compliance aspect is more important than firm financial performance, when assessing potential suppliers for the OSW industry. Members of the OSW supply chain are required to comply with minimum mandatory requirements such as environmental protection, health and safety, legal compliance and prohibition of corruption and bribery and human rights act compliance. Assessing competence, in order to ensure all supply chain parties have the right qualifications, experience, resources and capacity to deliver the job is a critical step in the OSW, according to Atkinson (2010)[104].

OHSAS 18001 (the Occupational Health and Safety Standard) was identified as one of the prerequisite common technical requirement that companies, including SMEs, are expected to comply with. OSW is an industry that involves diverse sub-industries or sub-sectors, for example, different types of surveys, specialist and professional services such

[103] Danilova, J., Grant, D. B. and Menachof, D. (2016), Enabling UK SME participation in the Humber offshore wind supply chain, HEIF5 research project, The University of Hull, UK.

[104] Atkinson, P. (2010), 'Securing the safety of offshore wind workers', Renewable energy focus, Vol. 11, No.3: pp. 34-36.

as working at heights and in harsh offshore environments, and various engineering, electrical and manufacturing companies. Each sector, thus, has its own technical specifications and standards with which to comply. At the same time, there are some common industry standards that businesses involved are expected to adhere to. These include ISO 9001 (Quality Management Standard) and ISO 14001 (Environmental Management Standard) in addition to OHSAS 1801. Making these requirements of standards visible to lower tier suppliers, especially potential suppliers, would allow top tier Original Equipment Manufacturers (OEMs) and developers to have their main requirements aligned with their sub-suppliers, which would improve overall quality of working practices throughout the whole OSW lifecycle, reducing risks associated with non-compliance of these standards and hence cost.

Providing offshore wind industry-specific H&S regulations

Given that there are many sub-industries involved each following their own H&S regulations compliance procedures, for example vessels that are regulated by the Marine and Coastguard Agency (MCA), in addition to the standard port and maritime safety rules (ISPS and SOLAS), have their own regulations to follow, there are no offshore wind industry-specific H&S regulations. Although it has been argued that the hazards found within a wind farm are not very different from those that exist in other industries[105], Atkinson (2010)[106] pointed out that there is a need for an industry regulator responsible for safety, as well as industry-specific regulations to provide standards and guidance for people working in the industry to help manage hazards and risks people face on a daily basis. It has also been supported by EASHW (2014)[105] that also recognised that there is a need for the development of international standards or guidelines for H&S risks management within the OSW sector, as harmonised procedures and guidelines would provide common occupational safety and health language ensuring best practices at work. Although it might be an unnecessary exercise, to produce OSW industry-specific H&S regulations in a broader sense, as there are a number of existing H&S frameworks and guidance that provide enough information, it would, however, be beneficial to specify these particular standards that are relevant to the OSW in the form of the offshore wind industry-specific document or report, for each country. Atkinson (2010)[106] adds that for those undertaking planning of offshore wind energy development, it has been advised to clearly define H&S arrangements and the responsibilities of all those involved in the work, related to different aspects of OSW construction in contractual terms. Furthermore, constant innovations in component structure design creates more challenges in ensuring safe working conditions.

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[105] European Agency for Safety and Health at Work (2014), E-fact 79: occupational safety and health in the wind energy sector, EU-OSHA, Spain.

[106] Atkinson, P. (2010), 'Securing the safety of offshore wind workers', Renewable energy focus, Vol. 11, No.3: pp. 34-36.

In the UK, one of the H&S regulatory bodies for new energy technologies, as identified by LEANWIND deliverable D3.3[107], is the HSE (Health and Safety Executive). "HSE has a statutory responsibility to help ensure the safe development, deployment, operation and maintenance of emerging energy technologies." [9:20]. The HSE's statutory powers and responsibilities are derived from the Health and Safety at Work etc. Act 1974 (HSWA) and associated relevant statutory provisions including the Docks Regulations 1988 and other related legislation. HSE has in-depth experience of working with the construction and offshore /port industries. HSE has identified the following potential offshore wind related H&S hazards:

Table 4 Potential Occupational hazards.

Potential Occupational Hazards
▪ Biological and chemical ▪ Confined spaces ▪ Construction related (e.g. lifting, excavation) ▪ Electricity related ▪ Fire and explosion, explosive atmospheres ▪ Machinery (e.g. entanglement) ▪ Mechanical and structural failures ▪ Working at height

According to HSE one of the key objectives is to encourage those involved in the OSW to address H&S conditions at an early stage of the project, for example as part of planning consent applications or related permissions to undertake a particular activity on a particular site. HSE suggested cross-sector learning among different countries and communication regarding H&S practices.

HSE has also pointed out that there is lack of safety data available to be used for risk assessment, derived for example from wind turbine failure rates. In addition, scaling up of technologies pose more uncertainties in terms of potential hazards. This suggests that there should be mechanisms in place for people to record the necessary data and information as they go along and as they build more experience in OSW deployment. It is assumed that due to the differences in infrastructures among EU countries some of these experiences will vary, hence specific H&S standards may vary too. At the same time, HSE has outlined general potential hazards that are applicable to all countries. Thus, it will be

[107] LEANWIND report D3.3 (RE), at www.leanwind.eu.

beneficial to provide a common H&S framework for the offshore wind industry and, in addition, outlining specific regulatory aspects for each country involved.

HSE also provides an Approved Code of Practice (ACOP) and guidance for safety in docks[108]. HSE has identified the following H&S challenges related to the docks industry in general without any reference to the offshore industry, however these are general challenges and areas of hazards that are relevant to any type of industry that uses dock facilities.

Table 5 General and specific challenges.

General challenges	▪ The number of different employers and/or contractors who can all affect each other's activities. These may include harbour authorities, dock operators, stevedoring firms, hauliers, ships' masters and crew; ▪ The changing nature of docks as workplaces. This may be due to tidal movements, weather and timing issues; ▪ The use of temporary workers who may be less familiar with the dock environment than permanent employees. Employer's duties to protect the health, safety and welfare of workers are the same whether they are full-time, part-time, permanent, non-permanent or temporary. This includes workers who are on short-term contracts or rolling contracts; ▪ The need to board ships and use ships' equipment. Workers should not be allowed to work in an area of a ship that is unsafe until it has been made safe or a safe method of work is in place. If dock workers are using ships' equipment, then their employer must ensure that this is safe. This may require the employer to check the equipment and ships' documentation; ▪ The presence of members of the public who visit dock premises. These may be either passengers or users of public rights of way. These people are more vulnerable as they may be unfamiliar with the premises and/or hazards; ▪ The need to converse with ships' crew and other parties, e.g. hauliers, whose first language may not be English.

108 HSE (2014), *Safety in docks: Approved Code of Practice and guidance*, Health and Safety Executive, UK.

Transport in docks	▪ Movement of vehicles and other plant on and around the dock ▪ Loading and unloading of vehicles ▪ Unsecured loads on vehicles ▪ Trailer coupling and uncoupling in the dock and on the ship ▪ Unsegregated vehicle/pedestrian access, e.g. ro-ro bridges and vessel ramps ▪ Reversing vehicles throughout the dock including adjacent to open quay edges ▪ Movement of vehicles in cargo storage areas, vehicle parks, ships' holds and quaysides ▪ Use of vehicles with limited visibility, including straddle carriers and reach stackers
Working at height	▪ Access to and from vessels by accommodation ladders, quayside ladders and gangways ▪ Container working – lashing and unlashing ▪ Loading and unloading some types of cargo, such as pipework, timber packs etc., can result in open edges from ships' decks, and from the cargo itself; ▪ Access to and from places of work on board vessels (holds, hatches, decks etc.) ▪ Falls from vehicles and trailers during loading/unloading and sheeting ▪ Maintenance and unplanned work ▪ Working adjacent to open edges of docks, wharves etc. ▪ Falls from plant and machinery ▪ Mooring points
Lifting operations	▪ Failure of lifting equipment ▪ Falling loads ▪ Workers being crushed by a moving load or lifting equipment
Slips and trips	▪ Working on uneven, wet or icy surfaces on loads ▪ Adverse weather conditions ▪ Badly stowed mooring ropes, lashing gear and other equipment ▪ Use of inappropriate flooring or surfaces on walkways, ramps and access steps

	▪ Discarded packaging and pallets ▪ Deck fittings and pipework on ship ▪ Poor or unsuitable lighting in work areas
Lighting	▪ Well-lit stairs, pedestrian and vehicle access routes ▪ Well-lit outside areas – for pedestrians and to help with activities such as loading/unloading at night, checking cargo and access to vessels ▪ Well-lit areas for working on board ship (e.g. in holds) ▪ Adequate lighting to allow safe access to small vessels ▪ Good light – use natural light where possible but try to avoid glare ▪ Suitable forms of emergency lighting
Musculoskeletal disorders	▪ Manual manoeuvring of lifting gear and attachments or slung loads ▪ Handling of twist locks and unlocking poles ▪ Lifting/manoeuvring of lashing bars ▪ Breaking out pre-packed or pallet loads ▪ Storage and warehousing activities ▪ Hauling mooring ropes ▪ Vibration transmitted through the seat or feet of employees who drive mobile machines, such as tugs and other similar vehicles, over uneven ground or on rails ▪ Use of pneumatic lashing systems
Confined spaces	▪ Lack of oxygen – this can occur in ships' holds, freight containers, lorries etc. because of the cargo or contents consuming the oxygen inside the space ▪ Fire and explosion (e.g. from flammable vapour/dust, excess oxygen etc.) ▪ Build up of poisonous gas, fume or vapour – possibly due to decomposing, leaking or oxidation of cargo (e.g. wood pellets), incomplete fumigation, inadequate cleaning processes, or welding/vehicle fumes ▪ Incomplete ventilation of fumes in containers, e.g. due to incomplete fumigation or build up of fumes given off by contents of containers while in transit ▪ Discharge of gases, fume or vapour from pieces of equipment including some fire suppression systems, exhaust fumes etc.

	▪ Liquids and solids which can suddenly fill the space causing drowning, or release gases into it, when disturbed. ▪ Hot conditions leading to a dangerous increase in body temperature
Personal Protective Equipment (PPE)	▪ Suitable PPE provision (PPE should be certified in accordance with the Personal Protective Equipment Regulations 2002)

Further information about occupational H&S risks, particularly related to the wind industry, have been outlined by the European Agency for Safety and Health at work or EU-OSHA (Occupational safety and health in the wind energy sector), E-fact 80 document[109]. E-fact 80 provides a hazard identification checklist in the wind energy sector, covering both on-land and offshore operations. The checklist is designed to provide guidance and initial steps to carrying out a risk assessment and does not prescribe any procedures as characteristics of different workplaces vary, therefore the document provides the checklist that should be adopted according to the specific workplaces' needs.

E-Fact 80 checklist covers the following H&S areas related to on-land operations:

Table 6 H&S areas covered by E-Fact 80 checklist.

Site management	Safety Co-ordination onsite
	Emergency procedures
	First Aid
OSH Management	Hazard management
	Training
	Communication and Employee participation
	Welfare
	Lighting conditions in and around the wind turbine
Manufacturing	Hazardous substances

[109] European Agency for Safety and Health at Work (2014), E-fact 80: hazard identification checklist: occupational safety and health (OSH) risks in the wind energy sector, EU-OSHA, Spain.

	Manual handling
Transportation onshore	Has a route survey that describes the transport route and points of transfer been carried out? The survey should have highlighted: ▪ If vehicle routes are sufficiently wide for the purpose ▪ If there are any restricted access routes, steep gradients, confined road corridors, road traction, or limited turning points ▪ If ground conditions on which vehicles operate are suitable for the purpose, properly constructed and well maintained ▪ If vehicle routes are free from obstructions and other hazards ▪ If there are poor sight lines or visibility problems on the route ▪ The form of communication that is best suited Are clear and appropriate hazard warning signs prominently displayed in the vicinity where vehicles manoeuvre e.g. directional, speed limit, give way, no public entry? Are additional safety controls provided e.g. provision of escorts? Escorts should be used: ▪ To provide and apply an element of control on road users along particular section of the route, for example when a load must impinge upon the centre like if a road or move along the wrong side of a roundabout ▪ To provide an element of warning and information for other road users about the imminent proximity of the convoy ▪ Assess and warn of potential hazards such as clearance, low hanging branches, junctions etc. Vehicle suitability and selection Driver competence and training
Construction /Demolition	Communication and coordination Weather conditions Temporary facilities

	Working at heights Lifting operations Driving operations Noise and vibration Harmful substances Musculoskeletal issues – manual handling; awkward postures; static postures; repetitive movements Confined spaces Slips, trips and falls
Disposal and recycling	

It has also been advised to use the construction (design and management) regulations or CDM in short[110], also provided by HSE, as this regulation provides a good framework of procedures for people involved in construction work, which has synergies with the offshore wind industry.

Uncertainties related to decommissioning stage

According to HSE (2010)[111] one of the major concerns is related to decommissioning stage at the end of OSW lifecycle. Industry's move to deeper waters and harsher offshore environments creates more risks for the workforce. LEANWIND deliverable D2.1.[112] has also pointed out that entire removal of foundations during decommissioning would involve an unacceptable risk to personnel. This uncertainty also relates to on-land and port infrastructure.

[110] Atkinson, P. (2010), 'Securing the safety of offshore wind workers', *Renewable energy focus,* Vol. 11, No.3: pp. 34-36.

[111] HSE (2010), *Health and safety in the new energy economy: meeting the challenge of major change*, Health and Safety Executive, UK.

[112] LEANWIND report D2.1 (PU), at www.leanwind.eu.

4.1.3.3. Training challenges

Training and authorisations for escort drivers and traffic directors

As identified by the LEANWIND deliverable D5.4[113], there is no common agreement between Member States regarding training and authorisations for escort drivers, acting or not as traffic directors. Because of this there is no common European framework for escort drivers and traffic directors' competence training.

Technology needs for training facilities

There are a range of different for profit and non-profit organisations that offer training services to bridge the gap between industry and education. Several examples of such organisations are based in Humberside area in the UK. For example, HETA (Humberside Engineering Training Association) HETA (2017)[114] provides training in engineering. HOTA (2017)[115] provides H&S training for offshore wind and other courses and is supported by GWO (Global Wind Organisation)[116], an organisation that provides Basic Safety Training specifically for wind industry needs, and Modal Training[117], among others, which provides purpose-built training centres to provide simulator courses in crane operations, marine simulator courses, maritime training etc. It was indicated by one of the training providers that technology is needed to improve the effectiveness and efficiency of specialist training in offshore wind.

Skills gap in STEM (Science, Technology, Engineering, Mathematics) qualified graduates

It has been identified by ETIP Wind (2016)[118] that there will be a need for human resource development within the wind energy sector, especially in the operations and maintenance area by 2030. More graduates will be required with STEM backgrounds (science, technology, engineering and mathematics). Similarly, SIEMENS (2014)[119] also pointed out that more STEM graduates are required to fulfil growing renewable energy industries' needs, referring to the UK market. SIEMENS (2014)[119] mentioned that the UK needs to

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113 LEANWIND report D5.4 (RE), at www.leanwind.eu.

114 HETA (2017), Available at: http://www.heta.co.uk/. [Accessed 05 Apr 2017].

115 HOTA (2017), 'Onshore, offshore and renewables training ', Available at: http://www.hota.org/. [Accessed 05 Apr 2017].

116 GWO (2017), 'Safety first', Available at: http://www.globalwindsafety.org/. [Accessed 05 Apr 2017].

117 Modal Training (2017), Available at: http://modaltraining.co.uk/. [Accessed 05 Apr 2017].

118 European Technology and Innovation Platform on Wind Energy (2016), *Strategic research and innovation agenda 2016*. Wind Europe, Brussels.

119 Siemens (2014), *Skills in energy, bridging the gap*. Raconteur, UK.

double its output of STEM graduates within the next decade as the issue is becoming strategically critical. It has been estimated that the UK will require at least 87,000 new engineers a year over the next decade, due to a pressing need to replace ageing and inefficient energy sources, however in 2013 the numbers reached only 50,000 of new graduates in engineering. Moreover, many of the existing skilled workers within engineering positions in the UK are reaching retirement age, with not many talents to replace them.

Skills gap of "mechatronics"

Apart from limited numbers of STEM graduates as described above, another area for concern in terms of skills is 'mechatronics', a combination of mechanical and electrical skills needed in areas such as hydraulics and turbine manufacturing and servicing. Growing wind and marine sectors in the UK currently employ around 18,000 full-time employees and around 16,000 more are involved in indirect jobs. It is projected that 50,000 workers will be needed by 2021[119].

Harmonisation of H&S training certification

As wind energy continues to grow and new recruits are employed, H&S becomes a very important concern[120], because new workers will have little knowledge and experience of H&S risks and hazards. This creates the need for wind energy relevant training in H&S due to lack of an industry standard in practical wind energy training. Current available trainings are often considered costly, especially for SMEs.

4.1.3.4. Environmental challenges

No apparent environmental challenges that may be posed by the OSW in relation to port and on-land infrastructure were identified within LEANWIND project. OSW impact on the marine environment is considered the main challenge of this renewable energy sector[121]. However, there are some areas of concern that need to be considered, including on-land cable laying and erection, land-fall risks, dredging implications, waste, generated during different offshore wind farm construction stages, management, implications of tidal floods to port assets, AIL transportation implications and wind farm components disposal.

On-land cable laying and cable erection

[120] European Agency for Safety and Health at Work (2014), E-fact 79: occupational safety and health in the wind energy sector, EU-OSHA, Spain.

[121] BSH (2007*), Standard: Investigation of the impacts of offshore wind turbines on the marine environment (StUK 3)*, Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg.

Like the offshore cable laying process, that can have an impact on benthic community and sediment spills, onshore cable laying also can have an impact on coastal ecosystems affecting different species, for example badgers, reptiles etc. Assessment of cable laying impact on environment is usually done by different wildlife survey companies[122]. With an expansion of different offshore renewable energy projects like wave and tidal developments, in addition to offshore wind, on-land cable laying can result in serious consequences for coastal ecosystems.

It has been recognised that removal of array cables from the seabed, similar to foundation removal, would cause disruption to the seabed ecosystem, thus, it has been suggested to leave cables in-situ, in line with IMO standards. A similar procedure is assumed for on-land cables, which poses a question of environmental impact of leaving cables underground, however, no information has been found to support this assumption.

Land-fall risks

Some areas of proposed power cable routes might be prone to land-fall. Lack of specialist assessment of land-fall risk prior to OSW construction can result in cable damage. This type of specialist assessment is normally done by coastal process survey[122]. The same risk exists for the development of ports to support OSW industry.

Dredging related disturbance

Depth of water in suitable departure ports has been identified as one of the main factors inhibiting the uptake of proposed buoyant GBFs that require large initial draft[123]. To increase the availability of ports able to accommodate these substructures, dredging the seabed can offer the solution, however it results in additional costs and potential environmental constraints. Harbour dredging is also performed to maintain shipping channels or facilities. With an increase of offshore wind developments more dredging is likely to be needed in different ports across Europe. However, dredging poses some environmental challenges. Dredging activities can alter local species diversity and population density. Recolonization of different species can take months and even years[124]. In addition, dredging activities increase water pollution because of siltation, which affects water ecosystems.

Waste and debris management

[122] The Crown Estate (2010), *A guide to an offshore wind farm*, BVG Associates on behalf of The Crown Estate, London.

[123] LEANWIND report D2.3, at www.leanwind.eu.

[124] Gill, A. B. (2005), 'Offshore renewable energy: ecological implications of generating electricity in the coastal zone', *Journal of Applied Ecology*, 42 (4): 605-615.

Offshore wind construction like any other construction activities will inevitably generate some waste. However, waste generated by offshore wind has only been addressed in relation to operations at sea, there is no waste management guidance provided for the offshore wind on-land operations. The OSPAR (Oslo and Paris Conventions, incorporating fifteen governments and the EU aiming to protect the marine environment of the North-East Atlantic) bans waste dumping at sea, except for dredged material and inert material of natural origin. It is expected that any waste not of natural origin is properly disposed of on land taking into consideration the waste management hierarchy i.e. reduce, re-use and recycle[125].

Risk of tidal floods

Tidal surges in December 2013 and March 2014 affecting predominantly the east coasts of the UK and port areas, have highlighted how significant the implications of floods can be to the port infrastructure, assets and coastal habitats. The Port of Immingham in the UK is an example of a port that experienced damages to critical infrastructure, its assets and disruptions in port operations, because of floods caused by the storm[126]. As a result of successful bidding for Environmental Agency (EA) funds, together with the support of Associated British Ports (ABP), North East Lincolnshire Council (NELC) and the Lead Local Flood Authority, the Port of Immingham is able to install outer lock gates, capable of being braced in position in the event of tidal surge.

AIL transportation

Size and weight increase of wind turbine components require some environmental considerations during on-land component transportation process. The LEANWIND deliverable D5.4[127] has outlined some necessary points that need to be considered during AIL transportation, among many points, there are some environmental aspects that need to be included in AIL transportation planning. Such points include weather conditions and low hanging trees. Although these are minor considerations that might require some alterations to the environment, like clearing the way of low hanging trees, it is still important to consider this during route planning decision.

Decommissioning of wind farm components

It has been highlighted throughout the LEANWIND project that there is lack of experience in the offshore wind decommissioning stage, which results in different logistical

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[125] OSPAR (2008), *OSPAR guidance on environmental considerations for offshore wind farm development*, OSPAR Commission, London.

[126] ABPmer (2014), *Ensurng Flood Resilience: An overview of 5/6 December 2013 UK storm surge*, ABP Marine Environmental Research, 1400/30.

[127] LEANWIND report D5.4 (RE), at www.leanwind.eu.

uncertainties as well as H&S challenges. For the same reason, there are no offshore wind industry specific environmental regulations in place about offshore wind components recycling procedures.

4.1.3.5. Financial challenges

Offshore wind farm component size and weight increase

Innovations in technology result in changes necessary to be made in the whole supply chain. For example, changes in size and weight of turbines and substructures require additional investment in appropriate transportation, both on-land and offshore, and installation equipment and infrastructure to support these innovations, which adds to the overall cost of offshore wind. Growing size of wind turbines will require vessels to be longer in size, up to 250 m long, to be able to transport future turbines. This subsequently will require some ports to upgrade their current infrastructure, to accommodate the offshore wind industry's requirements of vessels[128]. LEANWIND deliverable D2.3[129] has also recognised that it will be necessary to upgrade assembly and installation practices and related equipment to accommodate increasing size and weight of the future wind turbines. Some LEANWIND proposed innovations in substructure designs, more specifically, self-buoyant GBFs, will also require some ports to adopt to GBF's required conditions. Although this issue has not been raised as a challenge to any financial investment in relevant infrastructure, quite opposite, offshore wind development is rather taken as an opportunity by different kinds of businesses including port operators. Innovations in technology can however affect the industry's objective to reduce the LCOE, due to required infrastructure upgrades that result in more costs.

Capacity problems of available suppliers

There are some areas of the offshore wind supply chain that lack available suppliers. For example, it has been identified by deliverable D2.2[130] that there are only 6 heavy crane vessels available in the world that are capable to accommodate installation of GBFs, in addition not all 6 vessels are suitable for GBF transportation or installation. This results in high installation costs. Similarly, there are only few offshore wind turbine suppliers namely Siemens, Vestas, Areva and Senvion that hold barriers to entry to turbine production market quite high, which limits the availability of suppliers resulting in capacity problems

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[128] EWEA (2011), *Wind in our Sails, The coming of Europe's offshore wind energy industry*, [pdf], European Wind Energy Association, Available at: http://www.ewea.org/fileadmin/files/library/publications/reports/Offshore_Report .pdf. [Accessed 12 Apr 2017].

[129] LEANWIND report D2.3, at www.leanwind.eu.

[130] LEANWIND report D2.2 (CO), at www.leanwind.eu.

creating supply chain bottlenecks, due to turbine and vessel suppliers' backlog operations[131]. This suggests that more investment will be needed to increase competition levels in the offshore wind supply chain.

Offshore wind future market uncertainty

Lack of market confidence is one of the factors inhibiting key investment decisions. According to deliverable D2.2[130] , market uncertainty about the scalability of the offshore wind development and lack of firm orders are the main reasons foundation manufacturers and steel structures manufacturers cannot progress in investing in large-quantity production capacities. Deliverable D2.2[130] says that uncertainty about the scale of the market and the foundation concepts developers will prefer in the future means that any investment decision at this stage would be speculative. Further risk exists that in anticipation of firm orders, these manufacturing companies can decide to reallocate land or resources to serve other sectors[132]. Sustained demand and commitment in the market are required for OEMs to expand their manufacturing capacities, as identified by deliverable 2.2[130]. Similarly, Danilova et al (2016)[133] also mentioned that firms will not invest if there is not enough visibility that gives market confidence.

In a similar vein, high market confidence is also required for vessel construction. As it was mentioned in the supply chain capacity challenges section above, there are only a few heavy crane vessels available in the world. Production of specific vessels for the offshore wind industry may have limited market outside offshore wind, because industries like container shipping and oil and gas that also need this type of vessels, have different HLVs requirements. This impacts the investment case for new vessels production for offshore wind industry needs[130].

Market uncertainty also affects ports infrastructure development specifically for the offshore wind sector. Offshore wind farm O&M requires selected ports to stay committed for the whole duration of wind farm life span i.e. 25 years or more. This long term commitment without certain market confidence may weaken investment decisions in port facilities.

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[131] LEANWIND report D.8.1 (RE), at www.leanwind.eu.

[132] BVG Associates (2014), *UK offshore wind supply chain: capabilities and opportunities*, [pdf], BVG Associates, Cricklade.

[133] Danilova, J., Grant, D. B. and Menachof, D. (2016), Enabling UK SME participation in the Humber offshore wind supply chain, HEIF5 research project, The University of Hull, UK.

4.1.3.6. Other challenges

Suitable ports selection

According to BVG Associates[134], previous experience of offshore wind farms construction has showed that the project owners were able to secure the port spaces needed for wind farms development, in general. However, there are some proposed innovations by LEANWIND, specifically deliverable D2.4[135] that looked at optimisation of substructures, such as GBFs that require specific port conditions. Proposed self-buoyant GBFs require suitable ports with enough of water depths. There are not many suitable ports that have water depth for self-buoyant GBFs initial draft requirements. According to deliverable 2.4[135] this requirement is one of the limiting factors in the choice of suitable ports. This issue also affects viability of proposed self-buoyant GBFs, as a novel concept that has a potential to minimise the use of expensive heavy lift vessels for the installation phase of OSW projects (D.2.4 for more information).

In addition to the above, there is limited number of suitable dry docks with sufficient capacity and infrastructure for GBFs deployment. It has been identified that possible construction methods for GBFs could include dry docks or floating docks. The issue, however, is that location of dry docks is often far from OSW farms and have high rental fees and limited availability. The reason for that is that dry docks original function is the repair of cruiser ships or oil and gas tankers, thus their location is often far from wind farms. Ports hard infrastructure such as land availability and bearing capacity of the soil to resist the stresses caused by heavy weights of foundations is another important requirement, as discussed in deliverable 2.3[136]. These port requirements affect the feasibility of these types of foundations[135].

Moreover, O&M phases also have their own port requirements. This suggests that port assessment criteria should involve suitability assessment for different stages of the OSW farm development as well as suitability assessment for ability to accommodate different OSW components.

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[134] BVG Associates (2013), *Offshore wind: a 2013 supply chain health check*, [pdf], BVG Associates, Cricklade.

[135] LEANWIND report D2.4 (CO), at www.leanwind.eu.

[136] LEANWIND report D2.3, at www.leanwind.eu.

Use of alternative transportation modes

It was suggested that due to some road infrastructure limitations and restrictions posed by offshore wind farm component size and weight, alternative modes of transport need to be considered, such as inland waterways, in order to reduce road transportation that can be costly[136] . Inland water ways and rails provide reasonable alternatives to road transportation, however, a lot of rivers or canals are not deep enough for heavy load transportation. There are weight, height and length restrictions for rail and rivers/canals transportation.

Physical road limitations

Transportation of large and heavy components will most likely require vehicle and road infrastructure adaptations, which would result in more costs[136]. Some roads in different EU countries have some physical limitations due to point or linear infrastructure capacity or physical obstacles. Currently, there is no up-to date accessible information related to physical road limitations in different countries. Specific road surveys for cargo and routes must be performed on a project-by-project basis.

Standardisation of particular equipment and tool manuals and instructions

There are some restrictions imposed by manufacturing Handling Manuals. Decisions for the use of particular equipment and tools in specific operations is fixed by transport and handling instructions provided by the component manufacturers. Lack of standardisation of these instructions is a constraint for logistics optimisation[137]. Handling manuals provided by manufacturers, defining transportation procedures create additional restrictions to those imposed by conditions and requirements of road transport[127].

Port infrastructure upgrade/layout

Depending on the chosen strategy for on-land monopile foundations construction, i.e. using marshalling yard at port or factory to port strategy, port infrastructure may need to be upgraded. The challenge is to have enough space to accommodate this type of construction in the case when marshalling yard is used, and in the case when factory to port strategy is used there is a need for storage space for units waiting to be installed [D2.2]. This requires port space optimisation strategies. Moreover, there will be a need for coastal areas adaptation, specifically port layouts, in order to meet the requirements for the offshore wind industry [D2.3], similar to that of "Green Port Hull" project in the UK.

[137] LEANWIND report D5.1 (PU), at www.leanwind.eu.

4.2. On-land and port infrastructure industry solutions

4.2.1. Introduction to solutions

The following solutions that address challenges discussed, outline some LEANWIND innovations that can help to address some of those listed challenges. The solutions to the challenges identified come in many forms. From the purely qualitative to the highly quantitative mathematical modelling, sometimes combining both aspects to come up with minimally, a feasible solution, with an aim to an optimal solution to what may be a dynamic problem with the challenges changing over time. In the case were proposed LEANWIND innovations could not have assisted in providing solutions to specific challenges, solutions found from external information sources were provided.

4.2.2. Summary of solutions

Proposed solutions, associated with each research priority, contain solutions identified by LEANWIND project as well as solutions identified using external information sources. The table below specifically provides a summary of considered LEANWIND deliverables that provide direct or indirect solutions to the outlined challenges in previously discussed challenges section related to on-land and port infrastructure.

Table 7: LEANWIND innovations considered for specific solutions

LEANWIND Deliverable	Deliverable Description	Section where specific deliverable provide solution	Solutions specific deliverables can assist with
D5.3	Ports suitability assessment and port selection model	**Regulation and Legislation:** ▪ in relation to harmonisation and standardisation of road transport regulation aspects among European countries	Transport corridors selection by identifying port destination
		Financial: ▪ In relation to offshore wind farm component size and weight increase	Component size and weight increase impact on supply chain assessment using AHP methodology
		Other: ▪ In relation to suitable ports selection	Suitable port selection

D5.2	GIS database of manufacturing facilities, transportation links and port locations	**Regulation and Legislation:** ▪ in relation to harmonisation and standardisation of road transport regulation aspects among European countries	Transport corridors selection
		Environment: ▪ in relation to land-fall risks ▪ in relation to AIL transportation	▪ Cable route optimisation ▪ Transportation route selection
		Other: ▪ In relation to the use of alternative transportation modes ▪ In relation to physical road limitations	▪ Transportation mode selection ▪ Road limitation survey database
D5.7	Holistic supply chain optimisation model	**Environment:** ▪ In relation to decommissioning of components	Decommissioning plan
D8.2	Economics model	**Financial:** ▪ In relation to offshore wind farm component size and weight increase	Component size and weight increase impact on supply chain assessment

D8.1	OSW business models, financing and risk assessment	**Financial:** ▪ In relation to offshore wind farm component size and weight increase	Component size and weight increase impact on supply chain assessment
D2.2	Supply chain report	**Financial:** ▪ In relation to capacity problems of available suppliers	Reducing the need for expensive HLVs use
D5.5	Decision making model for port layout/configuration selection	**Other:** In relation to port infrastructure upgrade/layout	Port layout optimisation

4.2.3. Solutions associated with research priorities

4.2.3.1. Regulation & Legislation solutions

It has been recognised that the most relevant component of the policy strategy for the future of the offshore wind development is long-term targets. Long-term targets for offshore wind act as a motivation for the industry's growth. Clear government incentives like Contracts for Difference, coupled with long-term industry plans, provide a framework that allows for new investments potential and industry innovations[138].

Considering that the OSW area is still evolving it is important to allow some degree of flexibility in any static decision support systems developed by academia or industry, including LEANWIND developed decision support models, in order to be able to make any necessary changes or updates to the data, constraints or objectives without the need for total revision of proposed models[139]. It is also important to bare this in mind in relation to any regulation and legislation solutions.

In relation to harmonisation and standardisation of road transport regulation aspects among European countries

[138] Reichardt, K. and Rogge, K. (2016), 'How the policy mix impacts innovation: findings from company case studies on offshore wind in Germany', *Environmental Innovation and Societal Transitions*, 18 (Mar 2016):62-81.

[139] LEANWIND report D5.4 (RE), at www.leanwind.eu.

It has been identified that differences in road transportation regulations that exist on a European level but also regional levels constrain cross-border transportation of heavy and oversized loads. Making these regulations more standardised would help to streamline the logistics process of offshore wind components. One of the solutions towards more standardised transportation system is to establish transport corridors during offshore wind farm planning stage. This should be the task for all Member States who should work in collaboration in order to increase the efficiency of the on-land transport system in Europe. Identifying the most suitable transport corridors in advance would help route planners to obtain the necessary permits for heavy and oversized load transportation in good time. WP 5 of the LEANWIND project offers two logistical models that can help to assist in identifying the most suitable transportation routes. The LEANWIND deliverable D5.3[140] proposed a port selection model that can help to identify the most suitable port for the given wind farm. Knowing a port location, it would then be possible to plan and choose suitable transport corridor, using GIS tool provided by deliverable D5.2[141] that established main transportation networks by linking main manufacturing locations with suitable port locations. In addition, deliverable D5.4[139] has also suggested that simplified application procedures for AIL transportation corridors need to be considered. It is also important to make information available for all parties involved in heavy and oversized load transportation operations: hauliers, police, permit granting authorities, road, bridge and tunnel authorities, etc. This can be achieved through common online platforms.

In relation to calendar dates limitations

Calendar fixed and non-fixed restrictions can result in delays of the offshore wind farm construction, which ultimately results in more costs. It is very unlikely to achieve harmonisation in these calendar dates among EU member states, therefore it is suggested to just take these restrictions into consideration during component transportation planning. Previously mentioned road corridors would also help to minimise calendar restrictions by establishing specific AIL transportation time slots within those corridors.

In relation to simultaneous consenting of OSW farms

Increasing numbers of wind farms in Europe being constructed at the same time will stretch the road transport sector capacities[142]. This requires a holistic approach to offshore wind planning and consenting system.

The UK Offshore Energy Strategic Environmental Assessment (SEA) has identified nine zones for seabed leasing of offshore wind development with a potential capacity of up to

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[140] LEANWIND report D5.3 (PU), at www.leanwind.eu.

[141] LEANWIND report D5.2 (RE), at www.leanwind.eu.

[142] LEANWIND report D5.4 (RE), at www.leanwind.eu.

33 GW. This allows offshore wind farm developers to bid for exclusive rights to develop offshore wind farms within these pre-defined zones, as opposed to seeking for suitable sea areas for OSW development themselves, which can take a longer time to obtain all relevant consents for development. Zone appraisal and planning (ZAP) approaches help to engage relevant stakeholders at early stages of OSW development and encourage more consistent and transparent consenting process for OSW projects[143]. Stakeholder engagement in ZAP also helps to encourage information flow between stakeholders and developers on a regional level but it is also believed that it can improve information sharing on a European level, due to relatively small number of OSW developers. Information sharing between OSW stakeholders and developers on a European level would help to have a holistic approach to OSW development and consenting process, and thus minimise on-land and port infrastructure capacity challenges.

Knowing potential OSW development zones in advance would also help develop synergies between offshore renewable energy developers with the right incentives from the governments. Collaboration between developers would help to better manage resources and have less environmental impacts (see Environmental solutions section for more discussion).

4.2.3.2. Health & Safety solutions

H&S risks prevention through design process

It has been recognised that the design stage of the offshore wind industry life cycle should be used to 'design out' H&S related hazards and risks taking into consideration all stages of the offshore wind farms development, as more knowledge and awareness of different risks gained through existing experiences at the early stages of the wind farm design and planning can help to minimise H&S associated risks throughout the whole process of the wind farms' life cycle[144]. In order to do 'prevention through design', it requires a holistic approach to the design and planning stage as well as knowledge exchange with closely related industries like onshore wind for on-land procedures and oil and gas for offshore procedures and subsequently clearly defined H&S arrangements in contractual terms for each work involved. There is no evidence or available information from the OSW industry directly as to what procedures are taking place to minimise H&S risks apart from following stringent H&S standards like OHSAS 18001.

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[143] The Crown Estate (2010), *Round 3 zone appraisal and planning: a strategic approach to zone design, project identification and consent*, The Crown Estate, London. Available at: https://www.thecrownestate.co.uk/media/5702/ei-km-in-pc-method-052010-round-3-zone-appraisal-and-planning.pdf [Accessed 13 Apr 2017].

[144] European Agency for Safety and Health at Work (2014), E-fact 79: occupational safety and health in the wind energy sector, EU-OSHA, Spain.

Common online platform to provide visibility of H&S standards and requirements for existing and potential OSW industry suppliers

It has been suggested by this report, following previous studies about UK small and medium enterprises' participation in the offshore wind supply chain[145] that making industry requirements visible to lower tier suppliers would benefit the whole industry by ensuring quality supplies of products and services. One of the solutions to this problem is to provide a common online platform containing necessary information for interested parties. One of the examples of this type of platform is independent supplier pre-qualification system, such as Achilles known as UK vendor database system (UVDB) in the UK, Connexio in Germany, Sellihca for global categories and for the Nordic region that provides validated data of suppliers to interested buyers and provides suppliers with access to a broader range of potential buyers. As part of UVDB system in the UK, there is another system called Verify that provides an audit for H&S, Environment and Quality (SHEQ). The benefit of this type of system is that it provides transparency for businesses about the levels of H&S standards required, as well as other requirements, thus helping to bring highly qualified suppliers into the industry. However, this type of information might be less relevant for lower value contracts, as for some it would be unnecessary and for some obtaining the right H&S standard can be resource intensive, thus hard to justify in some lower value contracts, in addition, common challenge of these types of vendor database systems is accessibility. These types of organisations require businesses to become members first, which creates a barrier for potential suppliers.

Solutions in relation to providing OSW industry-specific H&S regulations

In order to compile OSW industry-specific H&S regulations and procedures, HSE (2010)[146] suggests cross-sector learning among different countries. This should involve communication and information sharing regarding H&S practices and potential hazards that have not been addressed by the existing regulators. In addition, there should be mechanisms in place to share information between OSW industry and H&S regulatory bodies for them to adjust their frameworks as the industry develops and as the industry meets any new H&S hazards.

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[145] Danilova, J., Grant, D. B. and Menachof, D. (2016), Enabling UK SME participation in the Humber offshore wind supply chain, HEIF5 research project, The University of Hull, UK.

[146] HSE (2010), *Health and safety in the new energy economy: meeting the challenge of major change*, Health and Safety Executive, UK.

The G+ Global offshore wind health and safety organisation (an association of nine offshore wind largest developers), aiming to create and deliver world class H&S performance in all areas of offshore wind industry, partly addresses this issue[147].

The Global Wind Organisation (GWO), an organisation of wind turbine owners and wind turbine manufacturers, also strives to set common standards in safety training and emergency procedures to provide injury free work environment[148]. GWO provides a GWO certificate for Basic Safety Training (BST) providers to ensure that work of any certified training provider is up to the required standard by the industry. GWO certified training providers are based in different locations across Europe.

Addressing decommissioning stage

Given that the Oil and Gas industry has some experience regarding decommissioning stage, it should be used to take examples from.

4.2.3.3. Training solutions

In relation to training and authorisations for escort drivers and traffic directors

Each member state has its own training for escort drivers and traffic directors consisting of both theoretical and practical elements[149]. Transportation of offshore wind components elements could be included into those training courses for all member states to form a common framework of escort and traffic directorship needs.

In relation to technology needs for training facilities

More investment is required into purpose built training facilities with all the equipment necessary to develop the right skills to carry out different operations in the offshore wind farms construction, in the best-case scenario. However, as mentioned in training challenges section, several organisations provide various training already. To ensure people are trained on the right equipment, it is necessary for OEMs like wind turbine manufacturers, for example, to spare their components to these types of organisations. An alternative solution to training with real life wind turbines or other equipment is training on virtual reality wind turbines. This has been made possible by The University of Hull 3D virtual reality 'cave', aiming to provide the offshore renewable energy sector with an

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[147] The G+ Global Offshore Wind Health and Safety Organisation (2017), Available at: https://www.gplusoffshorewind.com/ [Accessed 15 Apr 2017].

[148] GWO (2017), 'Safety first', Available at: http://www.globalwindsafety.org/. [Accessed 05 Apr 2017].

[149] European Commission (2008), *Abnormal road transport: European best practice guidelines*, Office for Official Publications of the European Communities, Luxembourg.

innovative training facility. The 3D cave will be based in the Hull Immersive Visualisation Environment (HIVE) at the Hull University department of computer science[150].

In relation to STEM skills gap

SIEMENS (2014)[151] report identified that redundant military service personnel in the UK that is undergoing downsizing, can potentially partly fulfil the skills gap in energy sector given their technical competence. Reductions in industries like shipbuilding, submarine and aircraft manufacturing also provide an opportunity for energy market to retain this skilled workforce. An assessment of skills transferability from those industries and offshore wind industry attractiveness assessment would help to propose required strategies to fulfil skills gap in the offshore wind industry. Cooperation is also needed between schools, employers, universities, institutions and government to develop a plan in order to ensure more STEM graduates.

In relation to 'mechatronics' gap

More collaborative initiatives are needed to stay informed about any skills shortages within the offshore wind industry and other energy providers. An example of one such collaborative initiative is Energy & Utility Skills, an employer-led scheme including gas, power waste management and water industries that helps to attract the right people and develop them up to the required standards[151]. This initiative helped to develop wind turbine technical training course at Ayrshire College and an overhead lines technician training course at Dumfries and Galloway College helping Scotland to grid connect new wind farms.

In relation to harmonisation of H&S training certification

One of the solutions is to develop a common offshore wind industry training standard. Harmonisation of training certification across the industry and across the EU would have the potential to reduce current H&S training costs. Part of the solution to contribute to common offshore wind training standard is first defining industry-specific H&S requirements, which was discussed in H&S challenges section.

4.2.3.4. Environmental solutions

In relation to on-land cable laying and cable erection

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[150] The Univerity of Hull (2017), 'Energy and the environment ', Available at: http://www2.hull.ac.uk/researchandinnovation/energyandtheenvironment/virtualrealitywindturbines.aspx. [Accessed 06 Apr 2017].

[151] Siemens (2014), *Skills in energy, bridging the gap*. Raconteur, UK.

Different developers of different offshore wind farms will each have their own on-land cable route plans, even though some of those routes might be in close proximity from one another. With growing number of the future offshore wind farm developments together with other offshore renewable industry developments, the number of cable laying routes will increase too, posing more risks to the on-land ecosystem. One of the solutions to this issue is to seek the ways for collaborative approaches to the on-land infrastructure planning between competing developers. Consider the possibility of using one cable laying route between several wind farms. In addition to that it is important to seek synergies with other offshore and onshore industries that share the same hinterland in terms of grid connection, in order to minimise environmental impact of on-land operations. This however will require some kind of incentives to encourage competing developers within the same industry to collaborate on this matter. The same challenge will exist to encourage collaboration between competing industries.

In relation to land-fall risks

Different specialist survey companies exist, each using their own expertise to perform different kinds of surveys including landfall to help design an optimal cable route and substation location. Onshore cable route corridors are determined using GIS software by some companies, for example Hornsea project one offshore wind farm, used GIS software to measure the distance of each route from the landfall to the grid connection point. LEANWIND D5.2 has also produced GIS visualizer, that can be used to incorporate cable laying and landfall risks in design and planning stage of on-land infrastructure.

In relation to dredging

It is important to look at ways to reduce dredging activities, although it is unlikely given the future demand for port activities due to offshore renewable energy development. However, collaborative approach between different port stakeholders and industries can help to derive more comprehensive information about the future needs of ports to meet their customer demands and assess the need for future dredging, in order to come up with an optimal solution that will meet all stakeholder requirements.

It is also important to look for sustainable ways of using dredged marine sediments, identify different ways and areas where and how this sediment can be re-used.

In relation to waste and debris management

As mentioned in environmental challenges section, there are guidance for waste management generated during offshore wind construction at sea, provided by OSPAR Commission. Similar guidance could be proposed for offshore wind on-land operations i.e. cable laying, on-land substation installation and maintenance.

In relation to tidal flood risk

In order to minimise risks of future floods, it is important to have short, medium and long term plans along with flood prevention measures to improve flood resilience. For the existing port infrastructures, improved flood defence systems and early warning systems need to be in place. For the future port developments that are planned to accommodate future offshore wind projects, flood resilience mechanisms need to be planned in planning and design stages of the development. In addition, the ability to predict and warn people of flood risks can help to minimise damage to infrastructure and assets, caused by floods, this therefore suggests that it is important to have reliable weather forecasting system. The importance of having reliable weather forecasting data and an access to online data from MET stations or buoys was also recognised by deliverable D2.3[152] that discussed reliability of weather forecasting to reduce weather down time (WDT) during OSW installation.

In relation to AIL transportation

Deliverable D5.2[153] focused on component transportation from manufacturing sites to the selected deployment port has provided GIS (Geographical Information System) spatial data of manufacturing locations, transportation links and port locations that helps to determine the mode of transportation i.e. road/rail/sea routes and distances. Although deliverable D5.2 did not directly address environmental aspect of route planning, GIS visualizer provided by deliverable D5.2 can assist in determining the best route for AIL transportation from manufacturing sites to selected ports as well as consider alternative modes of transportation like rivers and canals, as suggested by deliverable D5.1[154] and eliminate any obstructions like low hanging trees prior to AIL transportation, in a most environmentally friendly way.

In addition, deliverable D5.4[155] suggested that on-land transport would benefit from common platforms and data sharing infrastructure between heavy/big components manufacturers, transport equipment manufacturers, transportation companies, logistics services providers and relevant government agencies, which would allow for an integrated approach, resulting in an increase in efficiency. Information visibility about on-land transportation system would improve on-land AIL transportation.

In relation to decommissioning of components

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152 LEANWIND report D2.3, at www.leanwind.eu.

153 LEANWIND report D5.2 (RE), at www.leanwind.eu.

154 LEANWIND report D5.1 (PU), at www.leanwind.eu.

155 LEANWIND report D5.4 (RE), at www.leanwind.eu.

According to deliverable D5.7[156] scrapping and recycling is not viable for all components. One of the solutions would be to produce an offshore wind decommissioning programme or plan outlining available recycling options for all offshore wind components. Deliverable 5.7 has produced a model for optimal schedule for decommissioning that can assist in producing this plan. Examples can be taken from oil and gas industry that has experience in decommissioning of oil rigs.

It has also been suggested by this report to implement reverse logistics strategy and closed-loop strategy of the offshore wind components at the design stage. Reverse logistics has been defined as "the process of planning, implementation, and controlling the efficient, cost effective flow of raw materials, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal."[157]. Whereas closed-loop strategy refers to the system where every output can be returned to become an input of another product production[158]. This also includes considering design for environment (DfE) strategy, which implies production of more eco-friendly components by minimising the use of hazardous materials and considering to use of recyclable materials where possible[158].

4.2.3.5. Financial solutions

Related to offshore wind farm component size and weight increase

Size and weight optimisation of the wind turbines and substructures is seen as one of the solutions to address the problem of constant technology innovations that may result in more costs, due to the need of upgrading supporting infrastructure, such as on-land and offshore transport and port infrastructures, as a result of that. LEANWIND WP8 has produced the financial assessment model that assesses the merits of the technical innovations of the LEANWIND project, namely innovative foundations and innovative vessels. It also addresses efficiency and cost effectiveness of various component transportation options i.e. road, rail, air, inland waterways and offshore transport. Although, financial model presented in deliverable D8.2[159] does not attempt to address the financial impact of component size and weight increase on supporting infrastructure, it could be adopted to provide such analysis in order to help to propose an optimal wind turbine size and weight. Decision support system (DSS) for supply chain risk management

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[156] LEANWIND report D5.7 (CO), at www.leanwind.eu.

[157] Rogers, D. S. and Tibben-Lembke, R. (1998:2), *Going backwards: reverse logistics trends and practices*, Reverse Logistics Executive Council, Reno, NV.

[158] Grant, D. B., Trautrims, A., and Wong, C. Y. (2015), Sustainable logistics and supply chain management, [e-book], Kogan Page, London. Available at: https://www.vlebooks.com/vleweb/Product/Index/470215?page=0 [Accessed 13 Apr 2017].

[159] LEANWIND report D8.2 (CO), at www.leanwind.eu.

as developed by deliverable D8.1[160] can further assist in financial implications assessment of increasing wind turbine size and weight on the rest of the supply chain. It is also assumed that Analytical hierarchy process (AHP) that was used in port suitability assessment study[161] can also support this analysis.

Related to capacity problems of available suppliers

In order to address the issue of lack of available HLVs that have high charter rates, deliverable 2.2[162] suggests to reduce the reliance on HLVs by considering alternative options. One of the options, proposed by deliverable 2.2[163] is considering self-buoyant foundation concepts that can be floated and transported to the offshore location using tugs and then ballasted to the seabed, thus reducing the need for expensive HLVs use.

Considering the high levels of intellectual property protection efforts by the offshore wind turbine suppliers, it is unlikely that there will be an increase in competition between wind turbine suppliers. However, an increase in competition between lower tier suppliers to the wind turbine manufacturers can help to reduce some component costs. In order to increase offshore wind supply chain competition, wind turbine manufacturers as well as other OEMs and governments need to consider to provide supplier development programmes, similar to that of The Grow Offshore Wind, supplier development programme in the UK.

In relation to the offshore wind future market uncertainty

In order to reduce market uncertainty, governments across EU countries need to provide confidence in future offshore wind market by providing visibility of market scale. To achieve that, governments need to specify their long term decarbonisation plans and targets and provide favourable market mechanisms. UK's Round 3 offshore wind programme, which was announced in 2010, was a good motivator for industry investment decisions, but lack of realistic delivery plan of the Round 3 projects in given timescale together with disappointments in other European market, has led to some industry scepticism regarding future market size. Greater market visibility would also assist offshore wind developers in accessing lower cost of finance[164]. However, there is some evidence that OSW developers

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[160] LEANWIND report D.8.1 (RE), at www.leanwind.eu.

[161] LEANWIND report D5.3 (PU), at www.leanwind.eu.

[162] LEANWIND report D2.2 (CO), at www.leanwind.eu.

[163] LEANWIND report D2.2 (CO), at www.leanwind.eu.

[164] BVG Associates (2015), *Approaches to cost-reduction in offshore wind*, [pdf], BVG Associates, Cricklade.

remain optimistic of continued strong development, with Germany expecting to see subsidy-free offshore wind farms in operation by 2025[165].

4.2.3.6. Other solutions

In relation to suitable ports selection

LEANWIND WP5 has produced a set of technical models that all contribute to the holistic supply chain optimisation model produced by deliverable 5.7[166]. The LEANWIND deliverable D5.3[167] has specifically addressed an issue of suitable port selection to efficiently support the installation, O&M and decommissioning phases of the offshore wind farms. Study has proposed a decision-making model based on AHP theory of measurement through pairwise comparison that helps to select the most suitable port for a particular phase of wind farm lifecycle. That deliverable[167] can support the decision making of suitable port selection for the use of GBF proposed by deliverable 2.4[168]. However, it is recognised that in order to promote and commercialise innovative substructure designs and increased wind turbine size and weights, more ports will have to be upgraded to accommodate offshore wind innovations in technologies.

Industry would benefit from more initiatives like "Green Port Hull" in the UK, a port cluster incorporating manufacturing and assembly of products, supporting services, and academic links for R&D, training and skills provision. This would also help to build local economic value by allowing more businesses to promote their products and services to the renewable industries, creating more competitive environment, which would contribute to the offshore wind cost reduction strategy[169].

In relation to the use of alternative transportation modes

GIS database provided by deliverable D5.2[170] is a tool that can help to determine suitable route for transporting offshore wind components, as it helps to compare different routes and port options for different sites. By identifying suitable route using GIS database provided by deliverable D5.2 it can then be determined what modes of transportation are available in that selected route. Earlier discussed selected transport corridors, in regulation and legislation solutions section, can also provide a solution to reduce the need

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[165] https://www.bloomberg.com/news/articles/2017-04-13/germany-gets-bids-for-first-subsidy-free-offshore-wind-farms

[166] LEANWIND report D5.7(CO), at www.leanwind.eu.

[167] LEANWIND report D5.3 (PU), at www.leanwind.eu.

[168] LEANWIND report D2.4 (CO), at www.leanwind.eu.

[169] LEANWIND report D5.1 (PU), at www.leanwind.eu.

[170] LEANWIND report D5.2 (RE), at www.leanwind.eu.

for road transportation by choosing and designing relevant transportation corridors and make any alterations to alternative transportation modes, such as dredging to increase water depth in inland waterways.

In relation to physical road limitations

It has been suggested that there is a need for an up-to date accessible information database about physical road limitations in different EU countries. LEANWIND project does not offer this kind of information, however, it is assumed that GIS database of manufacturing locations and selected ports collated by deliverable D5.2 can be adopted to provide another road survey database detailing different physical road limitations and obstacles. The difficulty, however, is to keep this information up-to date, due to frequent road works that may change road conditions.

Other solutions would include:

- Modular component transportation mechanisms, which would require modular design of components[171].
- Alternative transport means (rivers, canals, rail, etc.).
- Developing special road corridors specifically for OSW components transportation.

In relation to standardisation of particular equipment and tool manuals and instructions

One of the solutions to minimise component transportation and handling restrictions posed by handling manuals is to work towards standardisation of these instructions. In addition, standardisation of handling equipment and tooling would also minimise restrictions in transportation procedures. Deliverable D5.1[172] suggested to develop versatile tools that could be used over several stages of transportation, port operations and installation, which would decrease operation time.

In relation to port infrastructure upgrade/layout

LEANWIND D5.5 has produced a port layout optimisation model for the OSW farm needs in order to minimise the transportation cost of the components movement within ports, servicing the offshore wind industry. Port layout model assists in finding the best layout for OSW component storage, staging and loading onto the installation vessels.

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[171] LEANWIND report D2.3, at www.leanwind.eu.

[172] LEANWIND report D5.1 (PU), at www.leanwind.eu.

5. VESSELS AND ACCESS SYSTEMS

5.1. Service vessels / access systems industry challenges

5.1.1. Introduction to challenges

SERVICE VESSELS AND ACCESS SYSTEMS

The following sections will outline the "near-technical" challenges (in this sense, challenges which require technical developments/modifications rather than organisation measures to be solved) which appear when developing a viability and implementation strategy regarding optimised utilisation of service vessels and access systems in the field of offshore wind energy. To propose solutions to those challenges the investigations and results as made in the LEANWIND project will be evaluated. Where particular issues are not covered by the LEANWIND R&D scope, proposals will be made about how solutions might be found by use of external information.

Basis for evaluation of the LEANWIND results against the challenges defined is the "Innovation list" as compiled in the "System Integration" work package (WP6) of the project.

5.1.2. Summary of challenges

5.1.2.1. Service vessels and access systems

Since the non-technical aspect (policy, regulation and legislation framework, etc.) are discussed in section "O&M", there remain two major areas of near-technical challenges with respect to the optimised viability and implementation of the utilisation of service vessels and access systems, as discussed below.

The main challenges in this field are the realisation of optimised organisation structures, which preferably should be implemented at least on a European level to cover the main areas of interest in offshore wind, i.e. the North Sea, Baltic Sea, Coast of Norway and the British Islands. An additional challenge may be caused here by the "Brexit" process. In general, harmonised structures will lead to more flexibility, a broader expert / specialised skilled technicians pool, better competition and, finally, lower O&M costs.

In particular, the following items should be addressed:

- Definition of an approach to (as far as possible) harmonise the different national legislations, policies, standards/guidelines to be proposed to the main stakeholders (politicians, standardisation organisations, industry associations, research funders); Results / innovations from the LEANWIND project should be used to support required technical definitions in standards;

- Identification of gaps in legislations, policies, standards/guidelines concerning the new (LEANWIND and others) developments. An approach shall be defined of how to overcome those gaps identified. Addressees for this approach are the same as above (This might not be covered to a significant extend by the LEANWIND scope, but should also be considered).

- Definition of research priorities with respect to improve the technical aspects of the organisation structure. This can be, with respect to LEANWIND results and innovations, mainly recommendations of the improvement of technical standards. This has been already discussed in previous sections.

Area 1: Technology improvements

In this area, technological innovations within the LEANWIND project will be addressed and their viability will be analysed with respect to:

- Extending the operational boundary for service vessels and access systems conditions (i. e. the maximum sea state at which it can be operated).

- New technologies, allowing faster transfer to/from site, positioning on site and access from SOVs to devices (personnel transfer as well as material/spare part unload/upload) with improved access systems

Area 2: Training / H&S aspects

- Analysis of how different service and access procedures and manners can by harmonised in the way they are used. The purpose of this is to reduce the training effort for personnel by having most flexible personnel at the same time

- Setup of simulator training for standard service and access procedures to gain maximum performance of O&M together with minimum risk for accidents

5.1.2.2. Regulation, legislation & standardisation challenges

Currently, more or less each country has its own bundle of regulations, standards, technical guidelines, H&S issues, etc. with respect to conduction O&M services in offshore wind farms. When looking on a region as the North Sea Area, one can easily be confronted with offshore wind projects in 5 or more different countries in a quite small area. This means for O&M service providers a significant effort to cope with the above-mentioned items.

The investigations undertaken in the LEANWIND deliverable D6.3 "Health & Safety risk control measures and required personnel skills"[173] show that standards, for example on the competencies of personnel working on O&M service vessels for offshore wind turbines, and/or on the turbines itself, are not yet defined to an extent that will satisfy the challenges.

Harmonisation of technical guidelines and standards dealing with O&M service provision is assured more or less adequate through the international standardisation process (IEC, EN, etc.). The challenge here is to identify local/country specific O&M service standards, which are not yet converted to an IEC/EN standard.

In the case of regulations and legislation, one must distinguish between EU wide regulations and country specific regulations about subjects, which do not require a mandatory EU wide regulation (i. e. country tax right, employment law, etc.) and, due to this, where no EU wide regulation/legislation exists (and is quite unlikely to be implemented). Challenge her is to find an approach of how all these different country specifics can be considered, e. g. by model contracts (for workers, equipment rental, O&M service vessel operation, etc.) which cover all specific regulations

These aspects are discussed in detail in the section 3.1.3.2.

5.1.2.3. Health & Safety challenges

During service, and especially during access from the service vessel to the device or vice versa, the analysis of possible accidents as prepared in the LEANWIND deliverable "Health & Safety risk control measures and required personnel skills" (D6.3[174], section 4.2.1.3) shows a large share of the highest consequence level 3 (which indicates a possible live threatening fatality, e.g. heart attack, hypothermia, etc.) for crew members. For example, about 56% of all accident scenarios with respect to a person falling into the water during device access are supposed to cause a consequence level 3. Therefore, the reliability and safety of access systems is extremely crucial for offshore wind service approaches. Apart from the technical progress, LEANWIND innovations with respect to service vessels and access systems need to be evaluated according to their reduction potential to H&S risks. This evaluation will be documented in the section 5.2.3.2 of this section.

5.1.2.4. Training challenges

The investigations undertaken in the LEANWIND D6.3[174] show that there is a lack of standardised training methods. For example, there is no standard DP operator training defined. Several entities provide their own DP training schemes. Similar problems exist for the training schemes of offshore crane operators, jack up-barge operators, etc. In most cases those training schemes are of a common character for all kinds of offshore

[173] LEANWIND public report for deliverable D6.3, see: www.leanwind.eu

operations. Therefore, the special requirements for the offshore wind industry need to be defined and incorporated in these training schemes. There are presently three different schemes in the world: The Nautical Institute (NI), DNV and OSVDPA (Mainly US at present). All these schemes can be used by operators of O&M vessels when operating vessel on Dynamic Positioning (DP) at regular intervals. When it comes to installation vessels, the NI scheme does not suit this type of operation, mainly due to the requirement for time at DP and the fact that DP is not used for a long time during installation phase when jacking. When it comes to crane training several competence schemes also exist, but industry needs to define the specific requirements.

A special training scheme for offshore wind specialists is not implemented. All persons who not belong to the ship crew are treated as "passengers". Currently, there are no rigid standards defined for personnel, not belonging to a ship's crew, but working on offshore wind turbines. A minimum requirement has been set by Global Wind Organisation (GWO) and includes basic trainings on how to maintain offshore wind turbines, how to give first aid, how to behave in the case of fire, etc. The benefits of a standardised training will be discussed in section 5.2.3.3 of this report.

5.1.2.5. Environmental challenges

While standard environmental protection in normal operation and in cases of emergency is widely regulated by laws and technical guidelines (see section 1.3.1), there are challenges beyond. Main challenge in this respect is the use of "renewable" fuels for the service ships. Since those ships are not that big and normally do not have extended sea times (like weeks or months) renewable fuels (CO2 neutral bio-diesel, hydrogen/methane from renewable energy, electrical batteries or hybrid solutions of these) could be an option to power the engines. In conjunction with the concept of client accommodation O&M service vessels, as described in a concept study in the LEANWIND deliverable D3.4 "Novel maintenance vessel, access systems and installation vessels design report"[174]. it might also be an option to power the SOV entirely from electrical power during the onsite operation (maintenance actions and accommodation phase). This would open opportunities with respect to H&S/comfort, environmental issues (see section 5.2.3.4) and finance success (see next section and 5.2.3.5). Moreover, seabed conditions are an important point for the performance of installation vessels. The risk of punch-through the seabed should be considered when analysing weather conditions.

A the moment, the above-mentioned challenges (or rather the solutions to them) will mainly contribute to the positive image of offshore wind projects but might also be economically profitable in the near future.

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[174] Executive summary of the LEANWIND report for D3.4, see: www.leanwind.eu

5.1.2.6. Financial challenges

The main financial challenge for offshore renewable projects is the cost reduction. Scope of this section is costs generated with respect to Service Vessels and Access Systems during the O&M phase of an offshore wind project. The main cost driver for O&M is the rental/payment of vessels, specialised equipment and personnel. The costs increase with the required duration, for which the above-mentioned items are in use. Duration can be reduced by the following measures:

- SOVs need to carry more materials and equipment at the same time to reduce the number of travels from the service port to the site and back. This will allow to maintain more wind turbines at within a given weather window;
- SOV and, AccSys, need to allow operation at more difficult sea states. This will extend the working windows on site and will shorten the rental duration and therefore the costs.

There are organisational as well as technical improvement required to address the above-mentioned challenges.

<u>Extending operational boundaries (Cargo capacity and sea state tolerance)</u>

The development of new vessel concepts in LEANWIND will consider the transport capabilities of Service Vessels. To underpin the importance of stretching the operational boundaries, an investigation with a cost estimation tool, developed in the EU project the DTOcean[175], has been performed. For a seabed fixed marine current turbine of the SeaGen type, the costs for the full O&M phase have been analysed. This type of turbine is comparable to offshore wind turbines with respect to the effort during the O&M phase with respect to the weights of spare parts / components (i. e. gearboxes, generators, electrical cabinets), required personnel/specialists (electricians, crane operators, cargo handlers) and required machinery/equipment.

For an array with 5 devices of the SEAGEN type, the condition based maintenance cost for a project duration of 20 years have been simulated at three different sea states (1m, 1.5m 2m H_s). The results are shown in figure 2 & 3 below. The achievable cost reduction can be up to 7% compared to the actual common sea state of Hs = 1m when looking at the entire O&M phase.

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[175] Homepage of the DTOcean projekt: http://www.dtocean.eu/

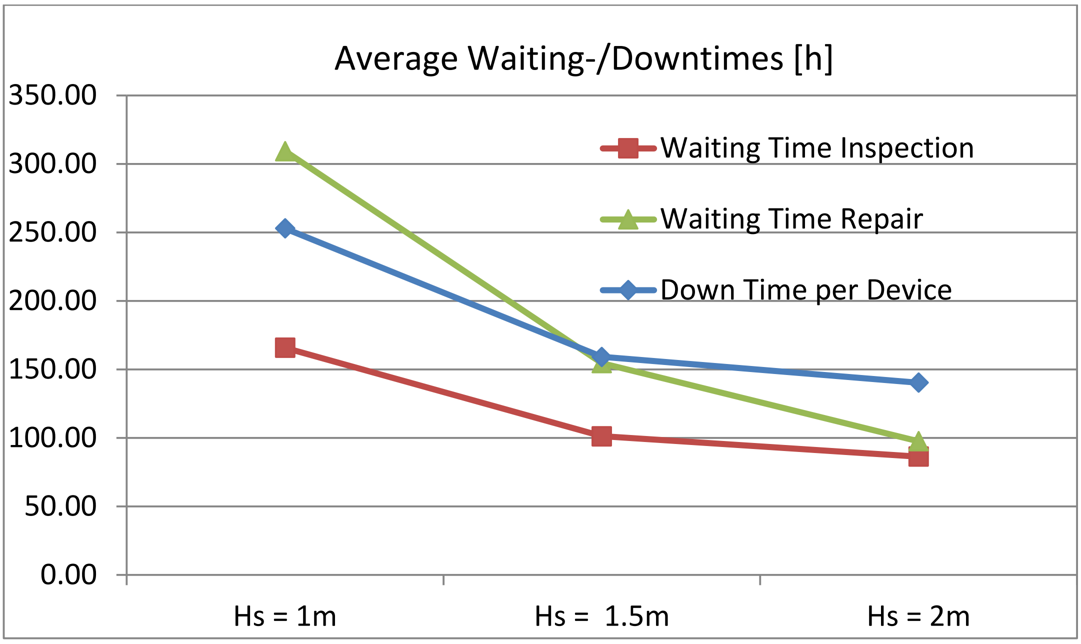

Figure 1 Average waiting times and device downtimes as a function of the sea state Hs.

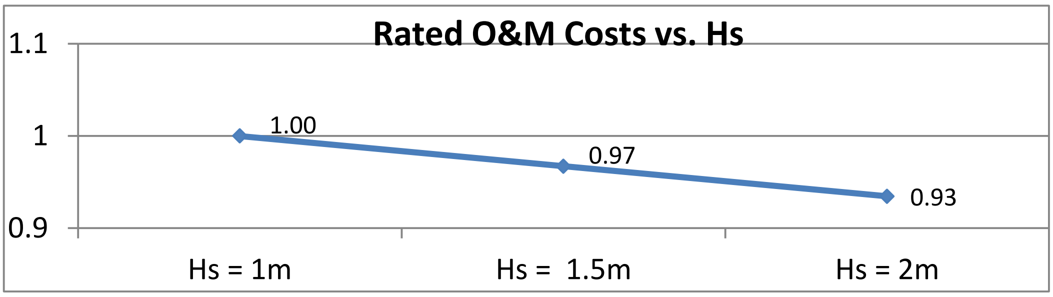

Figure 2 Cost reduction depending on the operational boundaries (sea state Hs).

The extension of the operational boundaries must not be achieved to the disadvantage of access and crew transfer safety (see H&S section 5.1.2.3 above).

<u>Client accommodation</u>

Client accommodation will allow to save the travel time from/to the service port. This will become significant when the sites of offshore wind farms are more remote. In LEANWIND D3.4[174], a concept for an SOV with client accommodation is defined. On site accommodation allows optimum deployment of weather windows for performing maintenance activities:

Bio fuel / electrical powering

The use of bio fuel might not save costs in the first place but may increase significantly the “environmental reputation” of offshore wind projects, which might lead to more financial success due to better attraction to investors, better acceptance to the common public, etc., which might support overall financial success of such a project.

Electrical powering of the SOV:

Powering of the SOVs functions with an electrical connection to the wind farms grid structure should be considered. Positive aspects of this could be:

- Saving of fuel costs during maintenance and accommodation phase. This might be even more interesting when thinking of the highly expensive on site re-fuelling using tanker vessels.
- Reduction of insurance costs due to avoidance of oil spill risk (on site re-fuelling)

Apart from the cost saving aspect, electrical powering will increase comfort (no noise and vibration from generator drives or from the main engine) during accommodation.

5.2. Service Vessel / Access System industry solutions

5.2.1. Introduction to solutions

This section will present proposed solutions for the challenges as addressed in the subsection above.

5.2.2. Summary of solutions

The proposed solutions to the challenges are deducted from the respective innovations and results of the research work within the LEANWIND work packages (WPs). Solutions to H&S challenges focus on the need for public available information about accidents and specialised training requirements for personnel using access systems (section 5.2.3.2). In section 5.2.3.3, solutions for setting up trainings are proposed to meet the defined requirements. Environmental aspects are discussed in section 5.2.3.4. Focus here is to propose solutions, which will improve the Eco balance of offshore wind farm projects. Finally, in section 5.2.3.5, the financial aspects of certain challenges and their proposed solutions will be discussed.

The following table provides an overview about innovations with relevance to the scope of this section, *i.e.* the service vessels and access systems.

Table 8: Innovations List (excerpt with relevance to service vessels / access systems).

Innovation	Description	WP	Relevance to SOV/AccSys
LEANWIND 8MW	The reference turbine consists of a power & thrust curve and contains details of design	2	a.) Dimensions/weights of turbine and main

Reference Turbine	frequencies and loads, dimensions and masses of the components		components (lifting heights and weights) b.) Access system on board (ladders, landing platforms, etc.)
Concept design for an O&M vessel	A specific vessel design will be analysed with respect to improved vessel operability and optimisation for design and cost.	3	c.) Transfer/Accommodation comfort (SOV/CTV motions during transit and on motherships (comfort/sea sickness), d.) Relative motions between vessels and boat landing, Motion compensating access systems
O&M scheduling and access improvement (based on D4.3 internal: “Safety assessment O&M access”)	Optimising scheduling to minimise the number of required O&M. The focus is on short term optimisation and mainly on the use of CTV (Crew Transport Vessels) and the related access systems	4	e.) Optimising of O&M scheduling means reduction of the number of O&M actions. This influences risk of injuries, personnel allocation, skill training, etc.,
Strategies and concepts for offshore wind service operations, including crew training procedures and assessment of safety and efficiency	Based on the approach defined in T6.3, a health & safety risk assessment will be applied to selected innovations as developed in LEANWIND. Aim of this assessment is to define possible control options and risk mitigation measures for each of the proposed innovations, if necessary	6	f.) Underpinning results for policy, legislation and standardisation recommendations with respect to H&S and accident prevention g.) Definition of simulator training setups for optimal preparation of personnel regarding O&M activities (access to devices, replacement of large components, etc.)

Financial life cycle cost model	A full life-cycle cost model for offshore wind farm development which can also be used as a series of independent modules for financial assessment of a project phase e.g. installation phase or O&M phase	8	h.) Costs estimation of O&M processes to identify and verify possible cost benefits (direct and indirect, e. g. by implementing saver procedures with less risk for man and machine). i.) Analysis of the boundary conditions for O&M activities (operational limits about sea/weather conditions, insurance costs, etc.)

5.2.3. Solutions associated with research priorities

5.2.3.1. Regulation & Legislation solutions

Covered by section "Regulation & Legislation solutions".

5.2.3.2. Health & Safety solutions

Some of the aspects raised in the corresponding section 5.1.2.3 are already discussed in the section 3 of this report. Some others, with special focus on service vessels and access systems, are mentioned below.

When starting the work for the D6.3[174], it became obvious that there is a lack of available information about the risk analysis in conjunction with offshore wind energy. Off course, accidents happen, but there is no communication about this really. This is comprehensible since accidents are a very critical issue and can damage the reputation of offshore service providing companies quite a lot, if published uncommented. Nevertheless, reliable information about the reasons for and consequences of accidents are crucial for reducing their overall numbers.

A possible solution, at least on a European level, could be to establish a common accident register for all events related to offshore work. This accident register could store anonymised information about accidents. Based on this, strategies to avoid those accidents could be developed and implemented. Data providers for such a register could be the offshore service providers itself, (health) insurance companies, workmen's compensation board organisation, etc. The data can be collected by an independent organisation, directly linked and responsible only to the European Commission, e.g. the EC mandates the "European Agency for Safety and Health at work".

Since identified as crucial, a special focus should be on the H&S aspects of personnel transfer between boats, boats<>OWTs (with different procedures: bump & jump, motion compensated platforms, etc.) Therefore, special training sessions will be defined in the frame of the LEANWIND Work Package 6, Task 6.4[176] to identify potential H&S risks with the newly introduced solutions for personnel transfer between SOV and OWT,

5.2.3.3. Training solutions

The information from an accident data base as mentioned in the section before, could be used to develop targeted training programmes, partly simulator based. As mentioned above, simulator training sessions will be developed in Task 6.4 to make personnel familiar with the technology and the corresponding transfer procedures. Basis for such training scenarios will be the results from the LEANWIND deliverables D3.4[175] (vessel and access system concepts) and D6.3[174] (H&S issues).

For the future, it should be discussed to have real world hardware simulators for training of the personnel transfer at extremely high sea states of up to 2.5m Hs. Even if this requires a significant technical effort for building basins, wave and wind machines, etc., this effort should be worth done in the sense of optimum preparation of personnel. Every accident during transfer is highly prone to end in a fall to a vessel deck or into the water, both coming with an extremely high risk for severe injuries or even death. Such training facilities are required for the initial/basic training as well as for refreshing of skills for OWT maintenance personnel.

Finally, the above-mentioned training approaches (simulator and real world hardware) should be standardised to the widest possible extend. This will increase the personnel mobility and will shorten the H&S briefings for offshore workers.

5.2.3.4. Environmental solutions

With respect to SOVs, the fuel consumption is a major issue for the environment. Especially when thinking of a SOV with accommodation facilities, there will be a 24/7 requirement to power up the main systems (the drives for DP positioning, power supply for the electrical systems, etc.). If using fossil fuel for this, the Eco balance of an entire wind farm project will be influenced negatively. This might be an issue during the planning phase, when people have to be convinced of the reasonability of offshore wind farm projects. Consequently, bio fuel or alternative fuels (hydrogen, Methane from power-to-gas processes, etc.) should be used for SOVs.

[176] Description of Work (DOW) of the LEANWIND project.

In conjunction with the accommodation approach of the SOVs, as defined in the novel SOV concept as described in D3.4, the electrical powering of the SOV seems to be an interesting option. Apart from the fuel saving aspects, the avoidance of air pollution in the close neighbourhood of the SOV's exhaust system and the significant reduction of noise and vibration will increase the comfort for crews staying on board, e.g. for a two-week-turn.

From the technical point of view, electrical powering is feasible:

- The capacity of the power cable is at least as high as the rated power of the connected wind turbine. The power consumption of an SOV as described in the concept study as presented in the LEANWIND deliverable D3.4[177] is approximately 3500 kW rated power. So, in case of an 8MW OWT, there should be plenty enough capacity to power the DP drives and the electrical power supply of the SOV during maintenance operations close to the OWT and during accommodation phase, e.g. close to the substation.
- Wet-mateable power connectors are available and well proven in offshore applications (e.g. as used for submerged sub-stations).
- There will be significant cost saving effects when using electrical energy rather than LPG or marine diesel for power supply.
- In case of a cable disrupt, backup batteries can power up the vessel until the main engine has been restarted. The required batteries are at reasonable size, price and weight, and can be easily integrated in the SOV concept.

5.2.3.5. Financial solutions

As discussed in the section 5.1.2.6, extending the number and length of weather windows for maintenance activities decreases O&M costs of offshore wind farm projects. A better deployment of weather windows is closely related to an extended operational window of vessels and equipment, i.e. by exceeding the maximum allowable sea climate "Hs". Therefore, a major design aspect of the SOV concept as defined in D3.4 was the Hs boundary. In the concept at hand, an Hs limit of 2.5m has been used as the design case. This should significantly extend the weather windows of potential use for O&M activities in offshore wind farms. This will be achieved by use of dynamic positioning in combination with a motion compensated access system. There will also be the possibility to use a daughter craft for personnel transfer SOV <> OWT, but this procedure is limited to a sea state of Hs=1.5m, so without deploying the full benefit.

Another way to extend the deployment of weather windows is to save the travel time from/to the service port. This can be done by use of SOVs with accommodation option. Since distances from offshore wind farm locations to service ports are expected to increase, the travel time will become a major issue. Therefore, on site accommodation will

[177] Executive summary of the LEANWIND report for D3.4, see: www.leanwind.eu

easily save several working days per turn and reduces costs for personnel working hours, vessel and equipment rental, downtime of OWTs, etc.

Finally, the electrical powering as described in the section above has a financial aspect.

Contrary to this, powering of the entire SOV be an electrical umbilical connected either to the wind farm's substation during accommodation phase or even to individual wind turbines during maintenance operation phases can save a significant amount of fuel. About an accommodation SOV, the cost for a ton of fuel might be significantly higher due to the need of offshore re-fuelling (i.e. with a tanker vessel) compared to fuelling in the port. Therefore, the cost saving effect is quite high. In addition, the risk of oil spills during offshore refuelling is avoided, which might reduce insurance costs. Avoidance of pollution is not yet a financial benefit now, but this might change soon.

When looking at a wind farm consisting of 8MW turbines (rated power), there should be enough cable capacity to power the SOV entirely via such an umbilical during all kinds of maintenance operations (see section above). The extra cost for the additional technical equipment (special connectors, umbilical, backup batteries, etc.) need to be investigated, but seem to be acceptable anyway when counting the other advantages mentioned for the electrical powering.

6. CONCLUSIONS: SUMMARY OF RECOMMENDATIONS

The previous sections identify the key industry challenges related to offshore wind O&M and the potential solutions identified within the LEANWIND project. These have been divided into non-technical categories to determine the business policy landscape required for the successful implementation of solutions. Considering the non-technical issues as well as finding technical solutions to challenges in the O&M sector can greatly increase the viability and potential industry up-take of project innovations.

The following summarises the policy and non-technical actions required to address the challenges in this sector:

Regulation & Legislation:

- Standardization of operations and maintenance activities and knowledge sharing to improve efficiency and lead to common European Union best practices, which ultimately reduces wasteful processes.

- Collaboration among offshore wind developers of all European Union member states and national authorities, as well as relevant stakeholders, is needed to achieve efficiencies in on-land and port infrastructure activities, such as on-land transportation, component handling and in developing proposed Abnormal Indivisible Load transportation corridors.

- Government incentives are required to encourage collaboration among offshore wind developers, port operators, and so forth, which are in fierce competition, to minimise the offshore wind industry's environmental and financial impacts due to on-land activities required for grid connection (i.e., cable laying and dredging in ports and inland waterways).

- Further studies are needed not only to assess the merits of the United Kingdom's zone appraisal and planning for offshore wind development, but also to evaluate options and benefits from having similar approaches in other European countries.

- Consideration should be given to the applicability of current emissions regulations to offshore wind installation vessels operating in Emissions Control Areas as such vessels follow very different routines to normal shipping.

- The wide variety of (often competing) regulations relating to vessel operations at a regional, national and European Union level needs to be rationalised and standardised to provide greater certainty of compliance.

Health & Safety

- To minimise health & safety hazards, a 'prevention through design' concept should be implemented. Offshore wind developers need to consider existing health & safety risk assessment criteria at the early stages of wind farm design.

- Establish a common online information platform for existing and potential suppliers to the offshore wind industry, detailing all the necessary offshore wind requirements in terms of required standards and licences to provide visibility of the offshore wind industry expected working standards.

- Cross-sector and cross-border learning are suggested to compile offshore wind industry specific health & safety regulations. Offshore wind industry players, at different levels and sub-industries, need to be encouraged to share their information with relevant health & safety authorities across European Union countries about any hazards, controls, regulations, monitoring activities, among other industry-specific health & safety aspects.

- There is a need to develop offshore wind specific health & safety guidelines considering current and future technologies as well as training programmes that include both health & safety and technical training.

- A guideline to safe and acceptable working hours for offshore wind crews should be created at a European Union level to ensure that the requirements of round-the-clock operations are met with no increase in risk to crew safety.

Training

- Some degree of standardisation and a common European framework are required for escort drivers' and traffic directors' competence training. Further information is required to assess the viability of introducing elements of offshore wind component transportation in such training courses.

- Implement virtual reality training facilities as an alternative to training facilities with real equipment, and encourage original equipment manufacturers to loan their equipment to training providers for specific training purposes.

- Cooperation is needed among schools, employers, universities, institutions and government agencies to ensure more suitably qualified graduates, as well as to address the 'mechatronics' skills gap. In addition, further assessment of skills transferability from military, shipbuilding, submarine and aircraft industries to offshore wind industry is needed.

- Further information is required about the possibility of cross-border offshore wind health & safety training standards.

- Training programmes should be implemented to develop diving skills specific to the requirements of offshore wind installation techniques.

Environmental

- Understanding and minimizing negative impacts of operations and maintenance activities on the environment is a necessary part of a wider goal to reduce greenhouse gas emissions. There is also currently a lack of understanding of the environmental effects of operations and maintenance activities.

- Waste management plans for the waste generated during on-land operations are required.

- Flood risk assessment and prevention measures in any new port development should be promoted.

- Common online information sharing platforms to help on-land transportation process would be of great value.

- Produce decommissioning programme or plan outlining available recycling options for all offshore wind components. Consider knowledge sharing with oil and gas industry in decommissioning of oilrigs.

- Further study into the impact of altered sedimentation during installation operations is required to ensure a minimal impact on marine life.

Financial

- The sector needs to invest further in decision-making tools and technical solutions that can help reduce costs considering current and future wind farms.

- Consider further study of wind turbine size and weight optimisation.

- More supplier development programmes are needed to increase the capacity of suitable suppliers and achieve economies of scale. This can be achieved through collaborative action among governments and offshore wind industry players.

- It is anticipated that significant cost reductions could be achieved through the development of innovative moorings and foundations solutions. Innovation programmes in this area should be instigated and actively supported.

Other

- Encourage industry players to have standardised ways of recording information related to cost of offshore wind farm development as well as methods of sharing such information for research and development, to work on cost optimisation strategies and related financial analysis.

- Active collaboration in standardisation groups (e.g. IEC61400-series) and discussions with certification bodies (e.g. DNV-GL) will help progress standardisation across the sector.

- Forming and establishing new research priorities, particularly regarding accident scenarios, public accident data bases and electrical powering of SOVs in offshore wind farms during maintenance/accommodation phase.

For further reference, the LEANWIND project has developed several innovations that could help solve these issues and is producing recommendations on the H&S, training[178] and mitigation actions for negative environmental impacts specific to these innovations[179].

[178] LEANWIND report D6.3, full report will be made available at www.leanwind.eu

[179] LEANWIND report D8.5, full report will be made available at www.leanwind.eu