Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m

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Definitions & Abbreviations

CRI	Commercial Readiness Index
EWEA	European Wind Energy Association
FOWT	Floating Offshore Wind Turbine
HAZID	Hazard Identification
HSE	Health, Safety and Environment
ISO	International Organisation for Standardisation
LCoE	Levelised Cost of Energy
MRA	Manufacturing Risk Assessment
OEMs	Original Equipment Manufacturers
O&M	Operation and Maintenance
TRA	Technology Risk Assessment
TRL	Technology Readiness Level

Executive Summary

This report summarises the deliverables produced in work package 6: Uncertainty and Risk Management. The report also gives an overview of all the dissemination activities that were carried out as part of the research, including publications and public presentations.

The work package has six deliverables, with each deliverable addressing a specific area of risk associated with the development of floating offshore wind substructure and floating offshore wind farm. The six key areas addressed in the work package are:

1. Methodology for risk management of deep water substructures.
2. Risk assessment of the substructures designed on the project.
3. HAZID risk report for the specific HSE implications of the design.
4. Operation and Maintenance risk register.
5. Review of key commercial risks.
6. Publication and Presentation of the Research Performed in the work package

There are four floating offshore wind substructure concepts supported on this project for further development. This work package helps the designers of each of the substructure concepts to understand the full profile of risks associated with their concept, from design to decommissioning. This knowledge will empower the designers to consider ways of mitigating the risks from the design stage.

Also, the project has its objective of selecting two concepts from the four concepts based on a number of criteria: levelised cost of energy, technical performance, environmental KPIs, and risk profile for optimisation through wind tunnel and ocean basin tests. So, risk profile of each of the substructure concepts was one of the key criteria used to assess the concepts for advancing to optimisation of the design.

Prior to this project, there was no existing specific methodology for assessment the risks of floating deep-water substructures, so the first deliverable on this work package is a methodology suitable for risk assessment of floating deep-water substructures.

However even though the methodology developed in this work package covers risk management, which includes risk identification, risk assessment, risk evaluation, and risk treatment, the subsequent deliverables do not include risk evaluation and risk treatment as it was considered to be beyond the scope of this work package. The intention was that the designers of each floating substructure concept would use the result of the risk assessment to determine how best to mitigate the risks associated with their technology. This is in recognition of the fact that one risk treatment or risk mitigation will not be suitable for different floating substructures.

Contents

1 Introduction: Uncertainty and Risk Management of Floating Offshore Wind Technologies

Risk assessment is an integral part of any large project, from helping to understand project risks to providing information for decision makers (ISO, 2010). In this project, the risks of four floating offshore wind turbine substructures are assessed and evaluated.

The risks assessed in this project are:

- Technology Risks,
- Commercialisation Risks,
- Health, Safety, and Environment Risks, and
- Manufacturing Risks.

Prior to this project, there was no specific methodology for the risk assessment of floating offshore wind substructures. Therefore, the first deliverable on this project was a methodology for the risk assessment of floating offshore wind substructures. This methodology laid the foundation for the assessment and evaluation of the four risk types listed above.

It is pertinent to note here that even though the methodology developed was used for the assessment of floating offshore wind substructures, it could be used on any other type of offshore substructure.

An assessment of the uncertainty of cost data that was used to calculate the Levelised Cost of Energy was carried out.

2 Deliverables in Work Package 6

As noted in Section 1, there are four key risk areas covered in this project. Three of the key areas lead directly to a deliverable while one of the key areas – manufacturing risks, does not lead directly to a deliverable. Also, there is a deliverable – Operations and Maintenance Risk Register, which does not have a specific key task. Below is a brief description of the five deliverables on the work package including the methodology which was used to deliver the risk assessments.

2.1 Methodology for Risk Management of Deep Water Substructures

This report provides an overview of risk management for deep water floating wind turbine substructures. It includes a description of a risk identification, analysis, evaluation and treatment process which can be applied to any floating wind substructure concept. The process utilises several standardised tools and references, including a risk register, risk impact and likelihood scales, and a risk matrix.

The methodology developed draws on good practice for risk assessment and risk management and is designed to be flexible enough to apply to different types of risk. This document deals with four categories of risk - technology risks; manufacturing risks; health, safety and environmental risks; and commercial risks. Each of these areas of risk is considered for all stages of the technology's lifecycle process - from design through to decommissioning. Although each of these types of risk have different dimensions or key indicators of risk to be measured, the principles of the risk assessment are the same for each. This is important as only the use of a consistent framework allows risks to be drawn together to form an understanding of overall risk.

- In the area of Technology Risk Assessment (TRA), a functional composition analysis of floating wind technology has been used to develop a standard functional taxonomy. This taxonomy allows a structured review of specific concepts to identify the relative novelty of each functional element. Risk assessment is then focused on the novel elements of the technology.

- In Health, Safety and Environment (HSE) risk assessment, standard parts of the technology lifecycle have been set alongside standard types of HSE risk. These can be utilised to perform a structured assessment of HSE risks.

- In the area of Manufacturing Risk Assessment (MRA), the concept of Manufacturing Readiness Levels (MRLs) has been used to develop a structured framework for assessment of manufacturing risks (including socio-economic risks).

- To assess commercialisation risks, the concept of a Commercial Readiness Index (CRI) has been employed to relate commercial and Technology Readiness Levels (TRLs) and develop a structured approach to identifying and assessing commercialisation risks.

The process has been developed following a literature review of current and relevant good practice documentation from across a range of industries. This includes international standards, national standards and guidance, certification standards and other industry guidance. It has been refined through engagement with a range of relevant stakeholders including independent engineers, certification bodies, public bodies, technology developers and testing centres.

2.2 Risk Assessment of the Substructures

This report reviews the technology risk assessment performed as part of the LIFES50+ project, where technology risks were assessed in terms of four types of consequence:

- Cost
- Availability
- Health and Safety
- Environment

The initial results presented in the report are those obtained by the substructure developers by performing technology risk assessments of their respective designs. The results that fed into the Phase I evaluation, together with the financial and life cycle assessments, may well differ from the ones presented in this report.

The work presented uses the methodology developed in task 6.1 *Definition of the methodology for risk assessment* and is shown in D6.1 (Proskovics, Hutton, Torr, & Fong, 2015). However, the methodology was updated, including redefined probability and consequences scales, to account for the decision made by the project partners to include technology risk assessment in the Phase I evaluation.

All results have been anonymised to preserve the confidentiality agreements between each substructure developer and the Evaluation Committee.

Risk identification was performed in three stages:

- Risk identification by the substructure developers using a HAZID form;
- One-to-one risk identification workshops;
- Risk identification consolidation.

The majority of risks identified were for functions that fall under the direct remit of the designers. Additionally, these risks were also seen as having a low novelty categorisation.

Risk analysis was also performed in three stages:

- Risk assessment form and manual development;
- Risk analysis by the substructure developers;
- Risk assessment form review and consolidation

The initial results displayed a very comparable average risk score across all functions. However, slightly higher average risk scores were displayed by those functions that fall under the direct remit of the substructure developers. The highest scoring risks were spread across all functions and were associated with severe failure effects, whilst the lowest scoring risks were limited to a few functions and only associated with failure effects of loss of power production and inadequate working environment.

2.3 HAZID risk report for the specific HSE implications of the design

This report provides an overview of health, safety and environmental hazards for different lifecycle phases of floating wind turbines. The lifecycle phases considered include:

- Manufacture
- Installation
- O&M
- Decommissioning

General hazards that cannot be attributed to a specific lifecycle phase were also considered. It is recognised that the design stage is an important lifecycle phase, but a decision was made to exclude it from the risk identification. Hazards inherent in a design only manifest in subsequent lifecycle phases, and the output of this hazard identification led to design iterations that aimed to eliminate or minimise the identified hazards to the barest practical minimum.

The results presented in the report were based on the information provided by the substructure developers on the project. These include:

- Phase I evaluation presentation by the developers
- Project deliverable D1.5: Marine operations
- Lifecycle macro descriptions produced by the designers in Phase I
- Process descriptions from Phase I Levelised Cost of Energy (LCoE) submissions
- Other information provided by developers (e.g. lifecycle process descriptions, substructure illustrations)

In this report, only risk identification was performed. Risk analysis and evaluation as well as risk treatment were not implemented.

Multiple activities that were judged to be confidential to specific designs were not included in the final list of hazards for health, safety and environment.

The main finding from analysis performed on the identified hazards is that except for the Operations & Maintenance (O&M) phase, the lifecycle phases do not contain hazards unique to floating wind.

2.4 Operations and Maintenance Risk Register

This report looks at the hazards associated with the Operations and Maintenance (O&M) of floating offshore wind turbines.

The work and results presented are based on the information provided by the substructure developers on the project. The study builds on the work performed as part of Task 6.3 Health, Safety and Environmental Risks of floating offshore wind farms, but specifically focusing on the O&M phase.

To facilitate the analysis, the O&M phase was split into two groups as shown below:

- Minor repairs and inspection
- Major repairs

Each of the above was split further into subsequent stages, showing tasks with hazards identified against these.

In this report, only risk identification was performed. Risk analysis and evaluation as well as risk treatment were not implemented.

Activities that were judged to be confidential to specific designs were not included in the final report.

Particular attention was paid to access to and egress from floating offshore wind turbines, working on them and the implication on those activities have on the wellbeing of crew technicians.

The main findings from the analysis performed are as follows:

- The majority of tasks within O&M for floating wind are not associated with hazards that have root causes unique to floating wind.
- The main difference in O&M hazards between bottom-fixed offshore wind turbine and floating offshore wind turbines is the motion associated with floating offshore wind turbines.
- This motion can influence the O&M of floating wind turbines in four ways:
    - More complicated access and egress;
    - Increased probability of motion sickness of the personnel;
    - Increased difficulty in performing O&M activities, which can lead to a reduced quality of work;
    - Increased likelihood of hazards being realised.

2.5 Review of Key Commercial Risks

This report offers a review of key commercial risks of floating offshore wind farms. It also offers a commercialisation risk assessment toolkit for a floating wind substructure developer. The toolkit can be used firstly to understand what a floating substructure developer requires in order to reach commercialisation and, secondly, to offer a reference point to see where a substructure developer is on the pathway to commercialisation, whilst identifying the risks that need to be addressed in order to reach that end point.

The pathway to commercialisation has been broken down into seven topics:

- Stakeholder acceptance
- Environmental/local acceptance
- Supply chain/manufacturability
- Substructure and wind turbine compatibility
- Technical performance
- Financial performance
- Market opportunity

All topics have their own set of risks/challenges. Each topic has been researched using a mixture of insight interviews with industry contacts in the expected four largest future floating wind markets of the UK, France, the US and Japan, combined with industry reports and consultancy with the substructure developers within the LIFES50+ project. In order to understand the potential commercialisation risks, it was imperative to obtain insight from the stakeholders who will be involved in each step of the commercialisation journey.

The seven risk topics associated with bringing the technology through to market have their own risk tables where a substructure developer will score between 1 and 5 depending on how likely they are to achieve commercialisation, 1 being unlikely and 5 being very likely. The higher the developer scores, the greater their chance of commercialisation. There has been no attempt to offer a total risk score as the topics will each carry a different weighting that would be difficult to tangibly quantify. The risk scores can however be used to highlight areas of commercial risk that need to be addressed.

The headline differentiators between substructure developers are as follows:

- Track record of operational performance
- Technology choices can limit the addressable market
- The ease of serial manufacture, transportation and installation
- The level of collaboration/coupled analysis with turbine OEMs and key component suppliers
- The presence of strong partners with large balance sheets to provide guarantees to the project (e.g. reduced premiums and/or wider risk coverage)
- Experience in raising and organising finance
- Exposure to price fluctuations (installation, key components, weather risk)
- Availability of resources to execute a commercial scale project

The headline market risks are:

- Lack of a subsidy scheme in key markets, no clear pathway to commercialisation
- High LCoE and competition with bottom-fixed wind
- Lack of turbine OEMs and project developers to partner with for new entrants

- Turbine OEMs unwilling to offer warranties available in bottom-fixed wind
- Technology risks regarding connecting and disconnecting a floating platform for O&M
- Consenting in emerging markets with limited track records of offshore construction
- Underdeveloped supply chain or supply chain in wrong location.

3 Dissemination Activities in Work Package 6

The deliverables achieved in the work package have been disseminated through appropriate channels. The dissemination activities have been carried out throughout the life of the project. Some deliverables are public deliverables while some are confidential deliverables. The public deliverables do not have constraints in terms of how widely they can be disseminated whereas the confidential deliverables are constrained on how widely they can be disseminated. The dissemination activities associated with the work package deliverables are as follows:

1. An abstract titled: Methodology for Risk Assessment of Floating Wind Substructures was submitted to DeepWind January 2016. It was accepted for publication and the full paper was subsequently published. The paper was written by ORE Catapult with contribution from Ramboll and reviewed by Ramboll.
2. Abstract submitted for ISOPE conference in June/July 2016. Title of paper is: Challenges in using Risk Assessments in Offshore Wind Asset Management. The paper was written by Ramboll with contribution from ORE Catapult and reviewed by ORE Catapult.
3. ORE Catapult contributed a Risk Assessment section to IREC's abstract titled Multi-criteria Assessment Tool for Floating Offshore Wind Power Plants for EWEA Annual Conference 27.09-30.09 2016 in Hamburg, Germany – abstract was accepted for an oral presentation.
4. ORE Catapult contributed a Risk Assessment section to University of Stuttgart's abstract titled State-of-the-Art Floating Offshore Wind Turbine design practice for EWEA Annual Conference 27.09-30.09 2016 in Hamburg, Germany – abstract accepted for a poster presentation.
5. ORE Catapult contributed and reviewed Ramboll's presentation titled Challenges of Implementing Risk Assessments in Offshore Wind Asset Management for the 26th International Ocean and Polar Engineering Conference 26.06-01.07 2016 in Rhodes, Greece – oral presentation.
6. ORE Catapult authored an abstract for FOWT 2017 conference titled: Relative Cost and Risk Assessment of Floating Versus Fixed Bottom Offshore Wind".
7. ORE Catapult presented an abstract to DeepWind Conference on presentation of "Results of a comparative risk assessment of different substructures for floating offshore wind turbines. The abstract was accepted for presentation which was subsequently delivered.
8. An article of risk analysis of floating wind foundations was written and published in Wind Tech International
9. ORE Catapult made a presentation of risk assessment of floating wind foundations at the floating offshore wind conference in Marseille in March 2017
10. ORE Catapult submitted an abstract for the FOWT'2018 conference – accepted for oral presentation
11. Published an Analysis & Insight paper titled "An Introduction to Risk in Floating Wind – Key risks and how to mitigate them

12. Wrote a confidential "Commercial risks in Floating Wind" report for the WP6 stakeholder interviewees.
13. A summary report of commercial risk assessment of floating wind technologies sent to participants who took part in the interviews that led to the development of commercial risk assessment of floating offshore wind technologies.
14. ORE Catapult presented on commercial risk assessment of floating offshore wind at 2018 FOWT Conference in Marseille.
15. ORE Catapult produced an editorial of commercial risk assessment for Windpower Monthly July 2018.
16. ORE Catapult Presented on commercial risk assessment of floating offshore wind at Wind Energy Investment and Development Europe conference on the 25th May 2018.