D5.4 Roadmap to commercial exploitation

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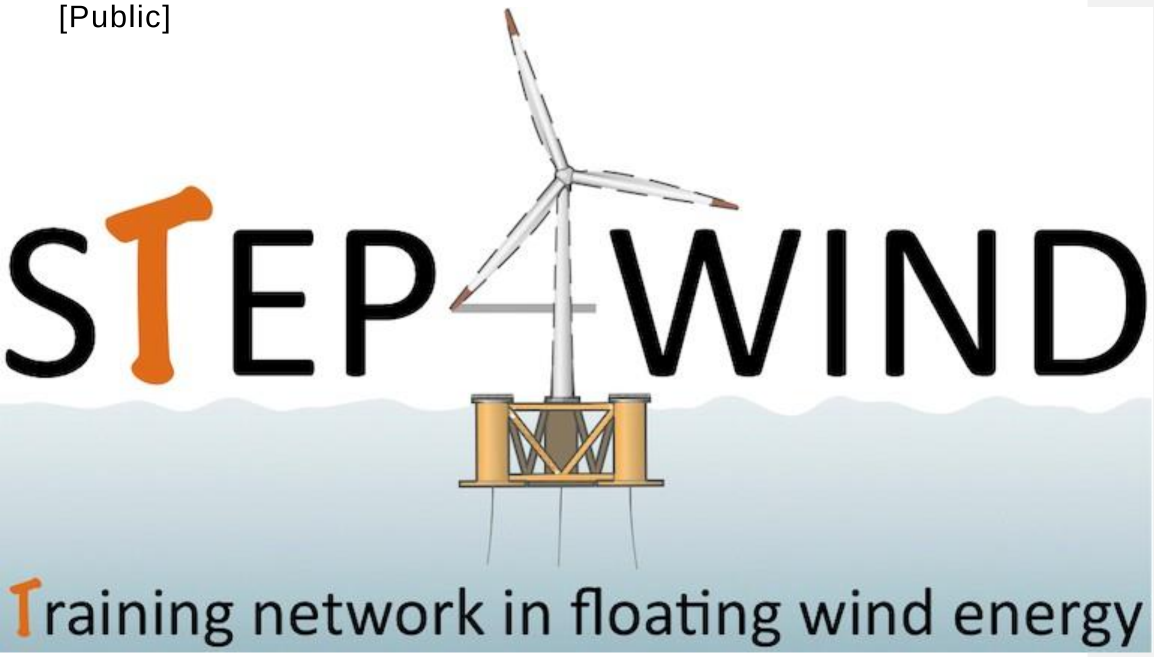

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Document History

Revision Nr	Description	Author	Review	Date
1.0	Roadmap to Commercial Exploitation	Jude Ugwu Roberts Proskovics Luke Eutough	Luke Eutough	30/11/2020

Abbreviations

ESR	Early Stage Researcher
FOW	Floating Offshore Wind
FOWF	Floating Offshore Wind Farm
FOWT	Floating Offshore Wind Turbine
HIL	Hardware-in-the-Loop
LCOE	Levelised Cost of Energy
MARIN	Maritime Research Institute Netherlands
MDAO	Multi-Disciplinary Analysis and Optimisation
OEM	Original Equipment Manufacturer
ORE Catapult	Offshore Renewable Energy Catapult
O&M	Operations and Maintenance
POLIMI	Politecnico di Milano
SGRE	Siemens Gamesa Renewable Energy
UCC	University College Cork

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1. Introduction to Step4Wind

1.1. Step4Wind overview

STEP4WIND is a European Industrial Doctorate project, granted under the H2020 Marie-Curie Innovative Training Network initiative, that brings together leading academics and industry experts in the offshore wind industry and floating wind turbines.

The primary aim of the project is to address both technological and economic challenges related to the development of floating offshore wind farms. In particular, tackling matters on the design performance and the high costs of the production and operation approaches

1.2. Step4Wind partners

There are seven (7) partners on the project:

a. TECHNISCHE UNIVERSITEIT DELFT (TU Delft)- coordinator (Netherlands)
b. POLITECNICO DI MILANO (POLIMI)- partner (Italy)
c. UNIVERSITY COLLEGE CORK - NATIONAL UNIVERSITY OF IRELAND, CORK(UCC)- partner (Ireland)
d. SIEMENS GAMESA RENEWABLE ENERGY AS (SGRE AS)- partner (Denmark)
e. PRINCIPLE POWER FRANCE (PPF)- partner (France)
f. OFFSHORE RENEWABLE ENERGY CATAPULT (OREC)- partner (UK)
g. EIRECOMPOSITES TEORANTA (EC)- partner (Ireland)

2. Review of research and development in floating offshore wind (FOW)

A review of research and development projects in floating offshore wind was carried out to establish a baseline which supports the objectives of Step4Wind project.

In undertaking this exercise, the ORE Catapult utilised a FOW taxonomy which it developed as part of the preparatory work for the Floating Offshore Wind Centre of Excellence. The taxonomy provides a framework for categorising and monitoring known research activity within the sector. The taxonomy comprises a hierarchy of research areas and research sub-areas and is structured as follows:

Fig 1. Hierarchy of research areas.

The research area and sub areas of the taxonomy are shown below:

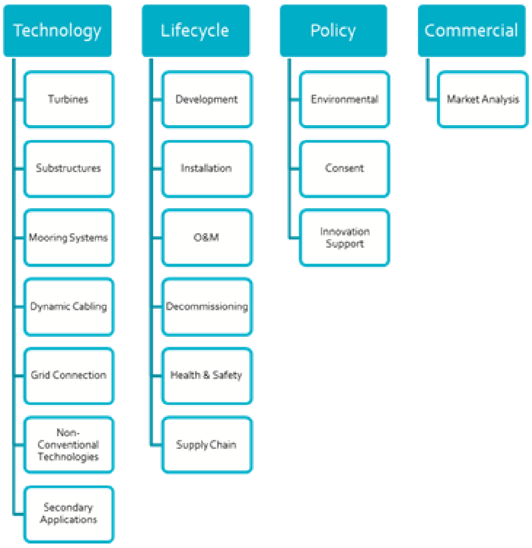

Fig 2: Taxonomy of FOWT

Further breakdown of the top-level taxonomy headings is shown below:

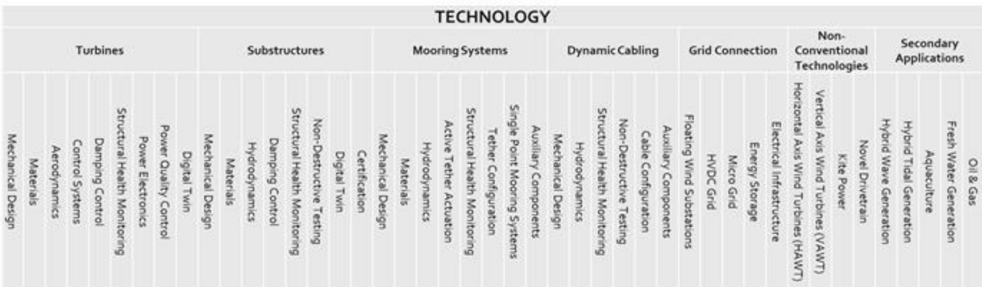

Fig 3a: Further breakdown of top-level taxonomy

LIFECYCLE																	POLICY						COMMERCIAL / MARKET ANALYSIS
Development		Installation				O&M							Supply Chain				Environmental			Consent			
Array Optimisation	Design Support Tools	Onshore/Inshore Assembly	Process optimisation	Novel Heavy Lift Solutions	Automation	Process optimisation	Smart Maintenance Software	Remaining Life Assessment	Corrosion Management	Marine Growth Management	**Decommissioning**	**Health & Safety**	Fabrication	Logistic Concepts	Guidance	Stakeholder Engagement	EIA	Resource Assessment	Other Sea Users	Regulatory Engagement	Guidance	**Innovation Support**	**Commercial / Market Analysis**

Fig 3b: Further breakdown of top-level taxonomy

2.1. Industrial and academic research review

All the industrial and academic research activities in FOW was analysed using the taxonomy shown in chapter 2. The result of the review as shown below shows that industrial research activities have concentrated on substructures, turbines, and O&M, while decommissioning, health and safety, and consenting have received the least attention.

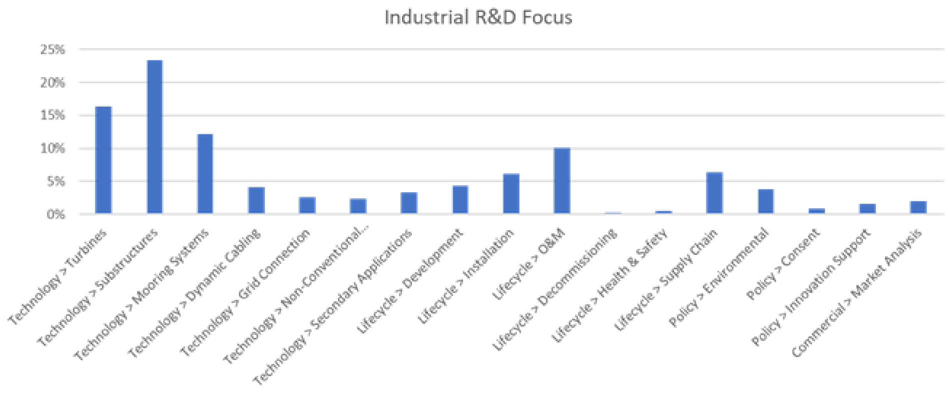

Fig 4: Industrial focus research and development

Likewise, academic research activities have focused activities on turbines, substructures, cabling, O&M, and supply chain while development, environmental, consenting, among others have received the least attention.

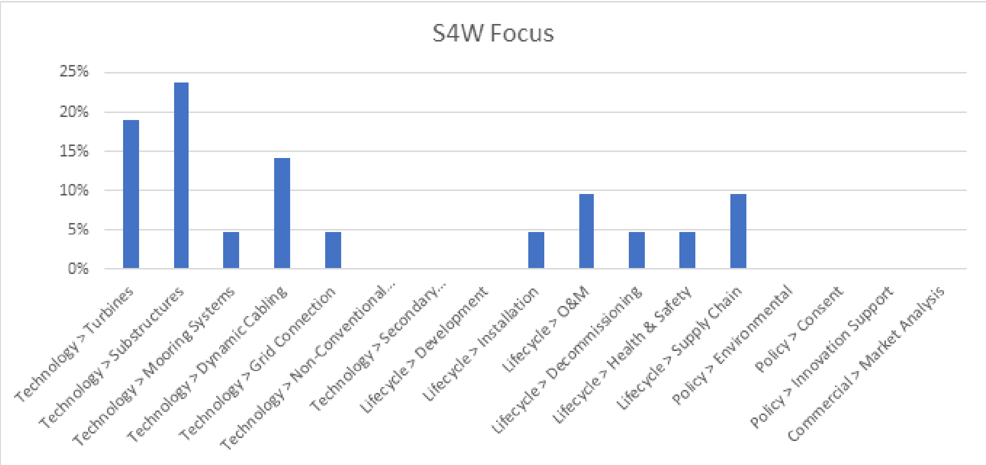

Fig 5: Academic focus research and development

2.2. The gaps that exist in research and development in FOW

Based on the review and analysis of the focus of industrial and academic research activities, the gaps that exist in research and development activities are shown below. These are the areas that have received the least focus and attention.

Taxonomy	Subcategory	Level of focus to date
Technology	Grid connection	Low
Technology	Non-conventional	Very low
Technology	Secondary applications	Very low
Lifecycle	Development	Very low
Lifecycle	Decommissioning	Very low
Lifecycle	Health and safety	Very low
Policy	Environmental	Very low

Policy	Consent	Very low
Policy	Innovation support	Very low
Commercial	Commercial analysis	Very low

Table 1: Gaps in FOWT research and development

2.3. Step4Wind technical innovations

A summary of the Step4Wind research focus areas is shown in the table below.

S4W Project	Title	Details	Research Topics
ESR1	algorithms to reduce computational cost of high-fidelity simulations	• Multi-scale numerical modelling of FOWTs • Use of OpenFOAM to understand the low-frequency behavior of the floater and improve the computational efficiency (e.g. mesh adaptivity, overset meshes)	• Technology > Substructures > Mechanical Design • Technology > Substructures > Hydrodynamics
ESR2	rotor design under unsteady conditions	• Aerodynamics of FOWTs undergoing large motions • CFD modelling for unsteady aerodynamics to create a database for model validation and advice for model-scale testing	• Technology > Turbines > Mechanical Design • Technology > Turbines > Aerodynamics
ESR3	bridge high-fidelity simulations to design tools	• Reduced-order models and machine learning for FOWT analysis and design • Use machine learning techniques to incorporate the results from CFD analyses into low-fidelity models	• Technology > Substructures > Mechanical Design • Technology > Substructures > Hydrodynamics
ESR4	integrated optimisation tool across the whole chain	• Multidisciplinary design analysis and optimisation framework for FOWTs • Extend an MDAO framework to FOWT farms, including dynamic anchoring systems. List the main drivers in cost reduction.	• Technology > Turbines > Mechanical Design • Technology > Substructures > Mechanical Design • Technology > Mooring Systems > Mechanical Design

ESR5	testing methods for HIL bridging wind tunnel and wave basin tests	• Development of new control methods and improved reliability of wind tunnel/wave basin complementary for HIL testing	• Technology > Turbines > Aerodynamics • Technology > Turbines > Control Systems
ESR6	automated manufacturing for long blades	• Automated manufacturing of carbon fibre reinforced composites for offshore wind turbine blades	• Technology > Turbines > Materials • Lifecycle > Supply Chain > Fabrication
ESR7	design methods for improved resilience and efficiency of dynamic cables	• Numerical models and experimental testing of dynamic cables for optimal design configuration and performance	• Technology > Dynamic Cabling > Mechanical Design • Technology > Dynamic Cabling > Hydrodynamics • Technology > Dynamic Cabling > Cable Configuration
ESR8	scaling up towing and logistics tools to large FOWT farms	• Analysis of towing and installation for large FOWTs, impact assessment of installation and decommissioning on cost, risk and environment	• Lifecycle > Installation > Process optimisation • Lifecycle > O&M > Process optimisation • Lifecycle > Decommissioning • Lifecycle > Supply Chain > Logistic Concepts
ESR9	robotic solutions for O&M of FOWTs	• Assess the potential impact of using robotics on the efficiency, cost and health & safety of O&M at sea	• Lifecycle > O&M > Process optimisation • Lifecycle > Health & Safety
ESR10	a cost-efficient hydrogen storage solution for FOWTs	• Design & development of new hydrogen energy storage for operating FOWT farms. • Investigation of hydrodynamic impacts	• Technology > Substructures > Hydrodynamics • Technology > Grid Connection > Energy Storage

Table 2: Innovations arising from Step4Wind project

2.3.1 ESR1: Multi-scale numerical modelling of floating offshore wind turbines

Academic Lead:	TU Delft	Industrial Partners:	ORE Catapult, MARIN

How does the innovation build on the existing technology?

New numerical techniques to reduce the computational cost of high-fidelity hydrodynamic analysis for FOWTs. This builds on existing numerical tools but will make their application for commercial development easier.

What is the target group identified to exploit this innovation?
Designer of FOWFs, developers of floating substructures.

What is the key driver(s) for the developing this innovation?
Reduction of computational cost

2.3.2. ESR2: Rotor design under unsteady conditions

Academic Lead:	TU Delft	Industrial Partners:	SGRE, MARIN

How does the innovation build on the existing technology?
It builds on existing mid- and high-fidelity tools for wind energy applications. It will use cutting-edge numerical algorithms to deliver high-fidelity data of the rotor aerodynamics, at an affordable computational cost.

What is the target group identified to exploit this innovation?
Wind turbine manufacturers, developers of FOWT concepts and wind turbine blade manufacturers.

What is the key driver(s) for the developing this innovation?
Better understanding of the flow physics and loads on the turbines.

2.3.3 ESR3: Reduced-order models and machine learning for FOWT analysis and design

Academic Lead:	TU Delft	Industrial Partners:	SGRE

How does the innovation build on the existing technology?
It allows development of new scientific models based directly on data, hence bridging existing data sources (high-fidelity numerical or experimental) with practical analysis and design.

What is the target group identified to exploit this innovation?
Wind turbine manufacturers; developers of FOWT concepts; scientific modellers.

What is the key driver(s) for the developing this innovation?
Lack of effective analysis and design tools for wind farms/turbines at a level of physical fidelity between high-resolution modelling (impractically expensive and time-consuming), and semi-empirical modelling (not predictive, limited application domain, uncertain predictions). This gap affects the ability to effectively and creatively exploit the wind resource.

2.3.4 ESR4: Integrated optimisation tool across the whole chain

Academic Lead:	TU Delft	Industrial Partners:	ORE Catapult

How does the innovation build on the existing technology?
Currently there no MDAO frameworks for floating offshore wind. This innovation will extend existing MDAO frameworks to their application to FOWFs. This will enable efficient use of the extensive existing knowledgebase for bottom-fixed offshore wind farms, while altering and adding specifics for FOWFs. It will assess the impact of the project innovations on LCOE and other relevant performance measures of FOW.

What is the target group identified to exploit this innovation?
MDAO frameworks would be used by OEMs and their suppliers as well as developers of FOWFs.

What is the key driver(s) for the developing this innovation?
Better design tools for FOWTs and farms and ability to assess the impact of component innovation on the system performance, particularly energy yield and costs.

2.3.5 ESR5: Testing methods for HIL bridging wind tunnel and wave basin tests

Academic Lead:	POLIMI	Industrial Partners:	MARIN

How does the innovation build on the existing technology?
The existing technologies for FOWTs controllers are not mature yet. There is no baseline controller for FOWTs, be it in academia or the industry. Furthermore, there is a lack of tools for designing and simulating, with high-fidelity, different control strategies. Therefore, HIL simulations in a scale-model allow real testing, even with its limitations related to the upscaling and the basin/wind tunnel environment. It is the closest that currently can be achieved in terms of simulation fidelity to a real FOWT. Improving such experimental model will lead to improvements in FOWT design, testing and validation.

What is the target group identified to exploit this innovation?
OEMs of wind turbines and floating substructure developers.

What is the key driver(s) for the developing this innovation?
The development of reliable tools for experimental testing and simulation of FOWTs will allow the testing and validation of new control strategies. As the main functions of a controller are the mitigation of structural loads and optimisation of the energy production, then the main driver is increased O&M performance. As a secondary driver, control strategies would also lead to cost reduction by allowing the use of alternative materials and floating substructures.

2.3.6 ESR6: Automated manufacturing for long blades

Academic Lead:	TU Delft	Industrial Partners:	Eire

How does the innovation build on the existing technology?
Currently, the processes for manufacturing wind blades are highly manual and labour intensive. The proposed project will focus on developing techniques for automation with the goal of reducing cost and increasing repeatability and quality.

What is the target group identified to exploit this innovation?
Wind blade manufacturers (although the technology could also have implications for other composite products such as aerospace and automotive).

What is the key driver(s) for the developing this innovation?
Cost and quality.

2.3.7 ESR7: Design methods for improved resilience and efficiency of dynamic cables

Academic Lead:	POLIMI	Industrial Partners:	ORE Catapult

How does the innovation build on the existing technology?
Dynamic cables are already used in the oil and gas industry but the numerical models need to be adjusted to account for the specific characteristics, dynamics and requirements of FOWT structures. In particular, subsea power cables on FOWT farms experience greater levels of mechanical stress due to the dynamic environment, leading to an increase in cable failures. This project will go beyond the state-of-the-art by optimising FOW power cable configuration, whist accounting for cable fatigue, and using unique testing facilities for model validation.

What is the target group identified to exploit this innovation?
The primary audience are wind farm developers and cable manufacturers. However, this tool will also be of value to O&M providers, academia, research organisations and consultants.

What is the key driver(s) for the developing this innovation?
Increased wind farm availability and reduced cost of cable repairs.

2.3.8 ESR8: Scaling up towing and logistics tools for large FOWT farms

Academic Lead:	UCC	Industrial Partners:	MARIN

How does the innovation build on the existing technology?
The innovations will be focussed on reducing the installation, maintenance and decommissioning costs as well as the environmental impact of these operations by building on the existing knowledge and technology in bottom-fixed wind, yet at the same time developing floating wind specific innovations.

What is the target group identified to exploit this innovation?
These innovations will be exploited by various energy agencies and companies in both the public and private sector, including wind farm developers and owners and operators.

What is the key driver(s) for the developing this innovation?
The key drivers for the innovations are reduced costs, lesser environmental impact and improved H&S.

2.3.9 ESR9: Robotic solutions for O&M of FOWTs

Academic Lead:	UCC	Industrial Partners:	ORE Catapult

How does the innovation build on the existing technology?
The proposed front-end engineering design (FEED) of the use of robotics and autonomous systems (RAS) leverages the existing technological developments and explores the application of robotics in floating offshore wind turbines. The novelty lies in the comprehensive technology assessment and cost modelling framework devised for the introduction of RAS in offshore conditions and hence, brings forward a detailed techno-economic analysis to be used by the associated stakeholders.

What is the target group identified to exploit this innovation?
Primarily, the target group are offshore wind farm operators that manage day-to-day operations of the floating wind turbines. Other stakeholders include policy makers, manufacturer of robotic systems, project managers, and risk analysts.

What is the key driver(s) for the developing this innovation?
The foremost key driver is the cost reduction during the phases of operations and maintenance (O&M). The proposed cost reduction is a direct result of the incorporation of RAS based solutions to perform the O&M tasks. This means that the manpower needed would be decreased along with a reduction in the usage of transport and service operation and fewer aerial trips to the offshore sites. This would also have positive impact on the H&S side.

2.3.10 ESR10: A cost-efficient hydrogen storage solution for FOWTs

Academic Lead:	UCC	Industrial Partners:	ORE Catapult

How does the innovation build on the existing technology?
Coupling offshore wind with hydrogen production and storage is something that has been tackled before. However, coupling floating offshore wind turbines has not yet been investigated in great detail. Combining floating wind and hydrogen production will help to meet decarbonisation targets.

What is the target group identified to exploit this innovation?
Fuel-cells operated vehicles, aviation and heavy vehicles fuels producers, electrolyser manufacturers, and hydrogen storage developers.

What is the key driver(s) for the developing this innovation?
Reducing electrolyser costs, hydrogen storage technology techno-economic evaluation, green hydrogen policies, and renewable energy policies in general.

2.4. The commercial value of the Step4Wind technical innovations

2.4.1 ESR1: Multi-scale numerical modelling of floating offshore wind turbines

What output will be exploited?
The numerical models.

What effect do you envisage the innovation to have on the industry?
Quicker and more reliable design analyses, reduction of safety margins and hence costs for the substructure, better understanding of the data from wave tank testing.

In which year do you think this innovation will be commercially exploited?
By 2024.

What is the best exploitation strategy for this innovation?
Collaboration with substructure developers for using and validating the tools.

2.4.2 ESR2: Rotor design under unsteady conditions

What output will be exploited?
The numerical models and the resulting knowledge on turbine loads and performance.

What effect do you envisage the innovation to have on the industry?
Reduction of safety margins and hence costs for the turbine, better control algorithms to mitigate the effects of motion, and more reliable performance predictions.

In which year do you think this innovation will be commercially exploited?
By 2024.

What is the best exploitation strategy for this innovation?
Collaboration with wind turbine manufacturers for using and validating the tools.

2.4.3 ESR3: Reduced-order models and machine learning for FOWT analysis and design

What output will be exploited?
The numerical algorithms and the resulting knowledge on parameters that drive the design of FOWTs.

What effect do you envisage the innovation to have on the industry?
Reduction of safety margins on FOWT designs, and hence costs for the turbine. Reduction of the dependence on high-fidelity tools. Improvement in layout and control of wind farms.

In which year do you think this innovation will be commercially exploited?
By 2024.

What is the best exploitation strategy for this innovation?
Collaboration with FOWT developers for using and validating the tools, as well as incorporating them into existing tool-chains.

2.4.5 ESR4: Integrated optimisation tool across the whole chain

What output will be exploited?
The MDAO framework and the resulting knowledge on parameters/innovations that drive the design of FOWFs.

What effect do you envisage the innovation to have on the industry?
Increasing economic viability of commercial floating wind farms. Better understanding of the impact of innovations on the development and operation of floating wind farms.

In which year do you think this innovation will be commercially exploited?
By 2024.

What is the best exploitation strategy for this innovation?
Collaboration with key commercial players in the supply chain and academic partners within the consortium.

2.4.5 ESR5: Testing methods for HIL bridging wind tunnel and wave basin tests

What output will be exploited?
The main scientific and industrial contribution of this project will be the improvement of the reliability and analysis tests of FOWTs scaled models. Therefore, the main point of exploitation would be the know-how obtained in order to generate higher fidelity real testing simulations which could be utilised by the industry to test new advanced designs, assess the uncertainties and validate control strategies.

What effect do you envisage the innovation to have on the industry?
To-date, the literature on FOWT is mainly focused on substructure design and stability analysis. Control strategies still have a lot more room for development and exploration of new concepts, and this is due to uncertainty in most numerical simulations. By improving and testing different control systems in scaled models, the experimental data obtained would play an important role in advancing the design of these systems.

In which year do you think this innovation will be commercially exploited?
Not clear at the moment.

What is the best exploitation strategy for this innovation?
Utilisation of the know-how gained in experimental testing simulation to validate new advanced control strategies.

2.4.6 ESR6: Automated manufacturing for long blades

What output will be exploited?
A technology for automated manufacture of wind blades (if the technology can be developed).

What effect do you envisage the innovation to have on the industry?
If the technology is successfully demonstrated it would enable a cost reduction and ultimately a reduction in LCOE.

In which year do you think this innovation will be commercially exploited?
Around 2025.

What is the best exploitation strategy for this innovation?
Initial demonstration during the project following by commercial development at Siemens Gamesa Renewable Energy.

2.4.7 ESR7: Design methods for improved resilience and efficiency of dynamic cables

What output will be exploited?
The key outputs will be: 1) A numerical model for a FOWT dynamic cable system, (2) An optimisation procedure to design the cables system solution for FOWTs, (3) An experimental database for numerical model validation.

What effect do you envisage the innovation to have on the industry?
It will allow the industry to optimise the overall FOW system and hence reduce the LCOE.

In which year do you think this innovation will be commercially exploited?
2024.

What is the best exploitation strategy for this innovation?
Work with dynamic cable designers and manufacturers to further verify the tool and subsequently improve dynamic cable designs.

2.4.8 ESR8: Scaling up towing and logistics tools to large FOWT farms

What output will be exploited?
Marine logistics tool.

What effect do you envisage the innovation to have on the industry?
Improved understanding of marine operation challenges and capability to model these.

In which year do you think this innovation will be commercially exploited?
In approximately 5 years from now.

What is the best exploitation strategy for this innovation?
Make sure that the government, industrial players, regulatory bodies and academia are aware of the technology developed and continue developing it, as well as use it to provide insights into challenges associated with marine operations in floating wind.

2.4.9 ESR9: Robotic solutions for O&M of FOWTs

What output will be exploited?
In this case, the output pertains to the lower values of levelised cost of energy (LCoE) and consequently, higher returns on investment in the otherwise capital-intensive offshore sector.

What effect do you envisage the innovation to have on the industry?
The proposed technology assessment and cost modelling shows that the industrial partners can reap the long-term benefits in terms of reduced downtime and transport costs along with smoother turbine operations with minimal need for human intervention. This also reduces the associated health and safety risks which are typically a constant cause of concern for employees working in the offshore sector. Hence, higher returns on investment can be attained.

In which year do you think this innovation will be commercially exploited?
The innovations in the use of RAS in offshore O&M are cross-sectoral and capital-intensive in nature and as such require time and sustained efforts to fully exploit them. It is envisaged that the adoption of RAS to perform a majority of O&M tasks on offshore turbines can be achieved as early as 2025.

What is the best exploitation strategy for this innovation?
The best exploitation strategy is based on de-risking technology in the laboratory environment followed by demonstration on a research turbine before taking these to commercial sites.

2.4.10 ESR10: A cost-efficient hydrogen storage solution for FOWTs

What output will be exploited?
Recommendations of parameters for the optimum operation of hydrogen production systems, and design of a hydrogen system suitable for semi-submersible floating wind platforms or floating substations.

What effect do you envisage the innovation to have on the industry?
I would expect an increased penetration of the floating offshore wind in the energy mix.

In which year do you think this innovation will be commercially exploited?
Around 2030.

What is the best exploitation strategy for this innovation?
Expansion of floating offshore wind share in the energy policies planning, as well as increased uptake of hydrogen as fuel for transportation.

3. Managing intellectual property rights (IPR)

Managing intellectual property rights is essential in ensuring that the results of both industrial and academic research projects are commercially exploitable. On this project, subsection 3 of the grant agreement specifies the rights and obligations of every party to the intellectual property generated on the project as well as background intellectual property brought into the project. The general principle is that ownership of IP reside with the party(ies) that generated it. And that where an IP is required to allow the exploitation of another IP generated by another party then the use of the required IP will be granted to the other party on reasonable terms.

4. Further developments required to aid commercial exploitation of results

4.1. Further technical developments required to support commercial exploitation of results

4.1.1 ESR1: Multi-scale numerical modelling of floating offshore wind turbines

Are there other future developments that this innovation relies on?
The further development of parallel computational infrastructure and algorithms.

Do you see any barriers that could slow down the time-to-market of this innovation?
Resistance from substructure developers to use high-fidelity tools.

Do you see any opportunities that could speed up the time-to-market of this innovation?
Collaborate on campaigns to validate the tools.

4.1.2 ESR2: Rotor design under unsteady conditions

Are there other future developments that this innovation relies on?
The further development of parallel computational infrastructure and algorithms will help.

Do you see any barriers that could slow down the time-to-market of this innovation?
Resistance from wind turbine manufacturers to use high-fidelity tools and lack of validation data.

Do you see any opportunities that could speed up the time-to-market of this innovation?
Collaboration on campaigns to validate the tools.

4.1.3 ESR3: Reduced-order models and machine learning for FOWT analysis and design

Are there other future developments that this innovation relies on?
The availability of high-fidelity numerical data and/or experimental data that the algorithms can learn from.

Do you see any barriers that could slow down the time-to-market of this innovation?
Large uncertainties surround the generalisability of these models. This risk is mitigated by the use of a solid physical-modelling foundation.

Commented [LE1]: “general applicability”?

Do you see any opportunities that could speed up the time-to-market of this innovation?
Availability of a large range of data and computational infrastructure to run the models. Coupling with industrial statement of bottlenecks in current processes.

4.1.4 ESR4: Integrated optimisation tool across the whole chain

Are there other future developments that this innovation relies on?
None.

Do you see any barriers that could slow down the time-to-market of this innovation?
Lack of data to validate the framework and to assess the real impact of innovations on large-scale farms. Acceptance of the use of the framework by OEMs and their suppliers, as well as developers, particularly when information and data exchange over stakeholder boundaries is required.

Do you see any opportunities that could speed up the time-to-market of this innovation?
A good collaboration with the different stakeholders will help, as well as data on the different components of floating wind farms.

4.1.5 ESR5: Testing methods for HIL bridging wind tunnel and wave basin tests

Are there other future developments that this innovation relies on?
No. However, development of high-fidelity numerical tools for FOWTs would assist experimental model testing.

Do you see any barriers that could slow down the time-to-market of this innovation?
The main barrier is the limitation of the results to scale-model systems. Validation of results using operational FOWTs would be required.

Do you see any opportunities that could speed up the time-to-market of this innovation?
Not clear at the moment.

4.1.6 ESR6: Automated manufacturing for long blades

Are there other future developments that this innovation relies on?
No.

Do you see any barriers that could slow down the time-to-market of this innovation?
Yes. The industry is quite conservative and slow to adopt new technologies. Even if the technology is successful in trials, industry may be slow to adopt it. Also, certification and qualification could be costly and could hinder the uptake of the technology.

Do you see any opportunities that could speed up the time-to-market of this innovation?
No.

4.1.7 ESR7: Design methods for improved resilience and efficiency of dynamic cables

Are there other future developments that this innovation relies on?
Further improvement in current capabilities of numerical simulation tools to accurately model hydrodynamic loading, particularly at extreme conditions.

Do you see any barriers that could slow down the time-to-market of this innovation?
No.

Do you see any opportunities that could speed up the time-to-market of this innovation?
Tool validation against in-field data such as Hywind Scotland or alike.

4.1.8 ESR8: Scaling up towing and logistics tools to large FOWT farms

Are there other future developments that this innovation relies on?
No.

Do you see any barriers that could slow down the time-to-market of this innovation?
Time required for laboratory testing of the developed innovations as well as receiving approvals from the governmental and regulatory bodies.

Do you see any opportunities that could speed up the time-to-market of this innovation?
Close collaboration of the academia and the industry can speed up the development and market availability of these innovations.

4.1.9 ESR9: Robotic solutions for O&M of FOWTs

Are there other future developments that this innovation relies on?
Developments in robotics and autonomous systems (RAS) are continually ongoing. On the hardware side, the focus lies on faster and agile robots with robust control systems and multi-agent coordination. On the other hand, software will benefit from the advancements in artificial intelligence and machine learning techniques with the aim to make RAS ever more intelligent and versatile that could perform a variety of tasks without active human intervention.

Do you see any barriers that could slow down the time-to-market of this innovation?
In the initial phases, development and capital expenditure (DECEX and CAPEX) could be higher due to the fact that many RAS based solutions are new to the market. Furthermore, the companies pursuing the most innovative of ideas are in need of constant funding in order to build prototypes and perform testing and validation. Nevertheless, the costs are bound to decrease over time as more companies are adopting RAS-based O&M solutions.

Do you see any opportunities that could speed up the time-to-market of this innovation?
The collaboration of academia and industry in this regard is crucial. Industrial partners can benefit from the academic expertise that could result in devising effective system design strategies, building prototypes and performing extensive testing and analysis. Furthermore, by opening up the space to other collaborators, the best practices from peripheral industries i.e. oil and gas can be adopted and hence, the time-to-market can be reduced.

4.1.10 ESR10: A cost-efficient hydrogen storage solution for FOWTs

Are there other future developments that this innovation relies on?
Further cost reduction and optimisation of the technology will be required to make it mainstream.

Do you see any barriers that could slow down the time-to-market of this innovation?
Through negative impact on the global economy, the ongoing pandemic could lead to reduced R&D spend on the technology and its uptake.

Do you see any opportunities that could speed up the time-to-market of this innovation?
Energy policies. Inclusion and ambitious targets for hydrogen would speed up the development of the technology and its commercialisation.

5. Conclusions and recommendations

There has been a significant body of research and development already done in floating offshore wind turbine (FOWT). However, there are still gaps in research and development in specific areas as highlighted in subsection 2.2, some of which the Step4Wind project address.

The results expected from the Step4Wind project are significant, leading to new tools, knowledge, methods, and procedures; all of which are commercially exploitable. But further work will be required to validate some of the results here in order to reach full commercial exploitation. The TRL for most of the results expected from this project will be between 2 and 3, and therefore will require further development to reach commercial maturity and full exploitation.

More work is required in the following areas:

- *a.* ESR1: Multi-scale numerical modelling of floating offshore wind turbines: Further development and validation of parallel computational infrastructure and algorithms
- *b.* ESR2: Rotor design under unsteady conditions: Further development and validatrion of parallel computational infrastructure and algorithms
- *c.* ESR3: Reduced-order models and machine learning for FOWT analysis and design: Development of high-fidelity numerical data and/or experimental data that the algorithms can learn from.
- *d.* ESR4: Integrated optimisation tool across the whole chain: The developmenbt of data to validate the framework and to assess the real impact of innovations on large-scale farms.
- *e.* ESR5: Testing methods for HIL bridging wind tunnel and wave basin tests: Development of high-fidelity numerical tools for FOWTs would assist experimental model testing.
- *f.* ESR6: Automated manufacturing for long blades: development of bigger prototypes and their infield demonstration.
- *g.* ESR7: Design methods for improved resilience and efficiency of dynamic cables: Further improvement in current capabilities of numerical simulation tools to accurately model hydrodynamic loading, particularly at extreme conditions.
- *h.* ESR8: Scaling up towing and logistics tools to large FOWT farms: Demonstration at infield site.
- *i.* ESR9: Robotic solutions for O&M of FOWTs: Ongoing developments and improvements in robotics and autonomous systems (RAS) and integrating artificial intelligence capabilities
- *j.* ESR10: A cost-efficient hydrogen storage solution for FOWTs: Further cost reduction and optimisation of the technology.