ETIPWind Roadmap

Floating offshore wind

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ETIP Wind
EUROPEAN TECHNOLOGY & INNOVATION PLATFORM ON **WIND ENERGY**

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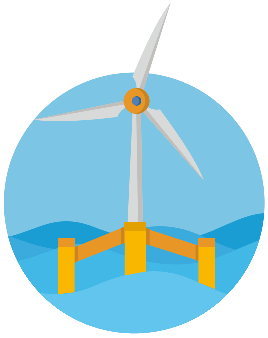

Floating offshore wind

Floating offshore wind is a rapidly maturing technology with the potential to cement Europe's leadership in renewables globally. European companies are floating pioneers and are leading three quarters of the more than 50 projects worldwide today. However, Asian markets are opening at an increasing pace and European plans for floating wind have lost momentum.

Europe still has the possibility to capitalise its first-mover advantage. To maximise the local economic benefits of a nascent floating offshore wind supply chain, the EU and Member States must act immediately as other countries (e.g. Japan, South Korea) are significantly increasing their investments in floating offshore wind.

EU support should ensure that cost reduction continues and that European companies are in a position to break global markets with European technology. To do so, the sector needs economies of scale (volumes), low financing costs and Research and Innovation (hereafter R&I) funding.

Challenge 1

Serial production

To make floating offshore wind cost-competitive with other energy sources, large volumes of floaters need to be produced and installed. The characteristics of offshore conditions vary across European waters, meaning there will not be a single "one size fits all" solution. As such the first step to industrialisation is to identify and select the best designs for each environment and market.

R&I is needed to develop deployment models, case studies and market assessments to identify which designs and concepts are marketable under which conditions. Ease of manufacturing, transportation, installation and operation in a variety of markets and environments should be clearly assessed. The priority is to develop the floating design that offers best value for money. A design that performs well and can be easily mass-produced at low costs.

Kick-starting a new supply chain will require detailed planning and harmonisation across many economic sectors. R&I support to increase the manufacturing capacities of the suppliers, upgrade port infrastructure, develop new maritime vessels and design new grid connections support will drive floating wind forward and create significant economic impact too.

Challenge 2

Floating wind farms

Wind and wave interactions cause floating wind turbines to oscillate much more heavily. Whereas bottom-fixed turbines have Eigen periods ~less than 3 sec., floating wind turbines will have natural periods of up to more than 100 sec. Better understanding of the wind and wave interactions at park is essential to optimise the layout of floating wind parks and the design of floating wind turbines. The need for accurate wind resource assessment in deep waters, where meteorological masts are proscribed, is also crucial.

The meandering wake and the wind field coherence inside the park also need to be well defined to optimally design the floating wind turbines. The larger motion of floating turbines creates a design challenge in terms of load fatigue to several components. The most obvious are the rotating components in the nacelle, the tower, blades, power cable and mooring lines. R&I in design models and control methods will alleviate load problems.

As the size of the turbines increases, assembly and heavy maintenance operations become a challenge. Regular jack-up vessels cannot be used for installation and heavy maintenance in a floating wind farm. Innovative solutions and concepts need to be developed to ensure low cost installation and maintenance operations. The installation and hook-up of the mooring system and the dynamic electrical cable is another crucial part of the installation process of floating wind farms.

Monitoring the aging of these components under cycling loads and marine growth can significantly contribute to cost reduction through lifecycle management. In waters deeper than 100m it is difficult to fix the array cables to the seabed. R&I will need to find solutions to overcome these challenges. Public funding and dedicated joint programming initiatives are instrumental to ensure Europe will lead the way in floating offshore wind.

Wider regulatory requirements

Expansion of floating offshore wind will allow Europe to tap into massive offshore resources and secure the technology leadership of European companies on the global market. In addition to supporting development of floating wind technology, large scale deployment of floating offshore wind farms will be paramount. The following recommendations will ensure floating offshore wind becomes a true European success story:

- Member States should set their ambitions for capacity, project pipelines and supporting policies for floating offshore wind in their National Energy and Climate Plans (NECPs) to 2030;
- The European Commission should publish the aggregated European volume of floating offshore wind projects to 2030 to enable a clear market visibility for investors and industry;
- Member States should coordinate their schedules of deployment and supporting policies for floating offshore wind in order to maximise regional cooperation in the development of a European supply chain;
- The EU should earmark funding instruments targeted to provide access to low cost financing for floating offshore wind projects and increase the funding to R&I focused on cost-competitiveness; and
- The EU should dedicate Cohesion Funds to support coastal areas and regions upgrading their infrastructure to facilitate development of floating offshore wind.

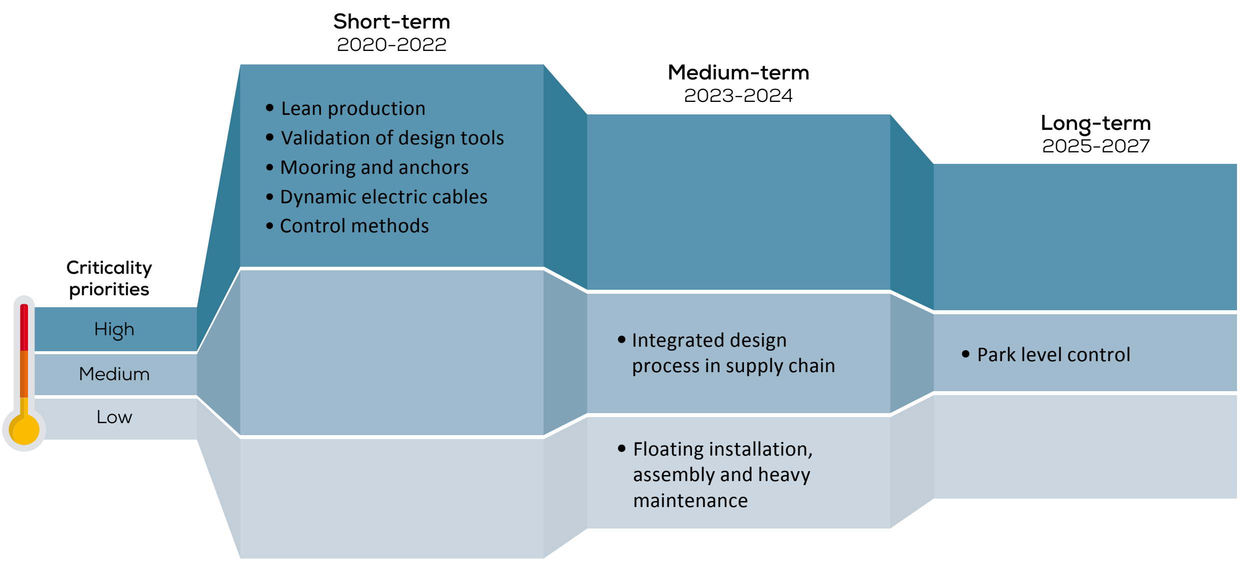

Figure 1 Research & Innovation action areas for floating offshore wind

Challenge 1.1

Serial production

Lean production	Short-term	High priority

Description and scope

Production of substructures for floating wind turbines are costly. This production methodology is adopted from the oil and gas industry, characterised by “one-off” production series and a lot of costly work. Cost reduction of floating offshore wind substructures depends on effective automated production of the different parts. Optimisation and standardisation of the different parts could reduce the cost of substructures significantly.

Recommended research actions

- Develop new material qualified for structure elements, mooring lines and electrical cables.
- Design and develop post efficient building elements for floating offshore wind turbines.
- Standardisation of transport methods and assembly.
- Support the development of high precision manufacturing lines of floating platforms for more efficient mass production.

Milestones

- Designs to have global reach for yards.
- Best practices for optimisation and production of floating wind substructures and components such as coned cylinders, pressure resistance of marine structure components, stiffness of towers and substructure, connections between columns and pontoons, bracing column/pontoon connections and anchors.

Challenge 1.2

Serial production

Validation of design tools	Short-term	High priority

Description and scope

A system is only as robust as its weakest link. For floating wind turbines the design process must account for various elements including the atmospheric flow, wind turbine aero elastic behaviour, hydrodynamics of the floating platform, anchors and mooring lines, electrical components and cables, and control systems.

The methods and tools used for design dictate what the architecture and dimensions of all the system's components will be, and how reliable these components are in operation. *Probability* and *experimentation* are central to the development of good design tools and ultimately reliable components.

Component reliability is achieved by characterising the probability of material or component failure limits as a function of the load regime and a probabilistic analysis of the operating load due to environmental conditions, control/operator commands, or faults.

Design methods are validated with a building-block approach, starting with small coupons of individual materials, and progressing upwards to sub-components, components, prototypes, and fleet experience. In commercial deployment of floating wind plants, there is currently a gap between small-scale experiments in ocean basin laboratories and full-scale deployment. This hinders the development of novel design methods and technologies.

Recommended research actions

- Identify best practices for holistic design and optimisation of floating wind energy systems, how to co-optimise the turbines, platform, moorings, and control systems.
- Develop probabilistic design methods, especially joint probabilities of operating states (wind/wakes/waves, plant control/ operator power commands, faults) and system limits (considering the interactions between components as they operate as a system).
- Identify plant-scale effects on loads and control.
- Validation of model tools against full scale measurements and model tests (need for high quality measurement data for validation, with low uncertainty. This applies both to model test and full scale measurements) to reduced uncertainty of simulation tools.
- Facilitate gaining access to full-scale prototype and fleet data, in order to validate system models.
- Development and deployment of experimental facilities that can be used to test and demonstrate designs.
- Facilitate open access to test results from experimental tests of complicated physical phenomena.
- Validation of new innovative concepts.

Milestones

- Define format for data sharing.
- Share data from floating offshore wind structures within 2019.
- Model testing methods need to be validated.
- Design tools validated to quantified accuracy.

Challenge 1.3

Serial production

Integrated design process in supply chain	Medium-term	Medium priority

Description and scope

A floating wind power plant is constructed from components made by various suppliers. Each component is designed and manufactured according to some overall specifications, which ensure that it can connect into the system and function as intended together with the other components (for example the wind turbine is designed according to stated limits on the tolerable nacelle angles and accelerations and the floating platform is designed to obey these limits).

Currently each supplier optimises their individual part, within the limits set by the overall specifications. This results in a sub-optimal performance for the system as unforeseen interactions between components can lead to poor performance and even failures. A better and more reliable overall performance is achieved by considering the impacts of each local design change on the entire system, through an integrated design and analysis framework. This would remove unnecessary contingency at each step in the design process.

Research is needed to establish best practices for the integrated design and analysis of floating wind power plants. From a supply chain perspective, some sort of "glue code", or framework, is needed that can integrate supplier-specific models into a system-wide analysis, or workflow. Initial steps towards such a framework have been made (for instance the FUSED-Wind software, and the work of IEA Wind Task 37) and these should be bolstered by an expanded and sustained development effort, geared towards commercial deployment.

Recommended research actions

- Development of holistic models that can capture the dynamics of the entire system.
- Assessment of the mechanical path from atmosphere to aerodynamics to structures to moorings.
- Research into the electrical path from drivetrain to generator to cables to substation to grid, and the feedback controls at the turbine and plant levels.
- Incorporation of assembly and installation needs in the glue code of the supply chain. Designs should suit scalability and should be optimised for industrialisation.

Milestones

- Development of holistic models that can capture the dynamics of the entire system by 2022.

Challenge 2.1

Floating wind farms

Mooring and anchors	Short-term	High priority

Description and scope

Mooring and anchors are challenging and costly for floating offshore wind. A specific challenge is to meet the lifetime expectations of 25 years. Faults in mooring lines are often caused during installation or due to corrosion. Improved assessment of stress and fatigue levels in mooring and anchoring lines is essential to the success of floating offshore wind.

The development and qualification of new innovative equipment, suited for specific floating wind applications, will further help optimise mooring and anchoring lines. The environment concepts have to be easy to handle and install, and should connect easily with devices.

Recommended research actions

- Development of new materials with required strength and stiffness (e.g. qualification of "new" fibre rope types, such as nylon).
- Dynamic interaction taut leg systems and floating wind structure.
- Development of cost-effective mooring system components, e.g. tensioners and new mooring systems (such as floater-to-floater mooring).
- Wind controller assisted mooring (thrust & motion).
- Models for dynamic behaviour of fibre ropes, and adaption of simulation tools for global analysis of fibre ropes.
- Anchors for multi-axial loading.
- Design tools for installation of innovative anchors (Torpedo, Deepla…) for improved installation (faster and cheaper).
- Experimental validation for innovation anchors.
- Assessment of the impact of extreme weather events (earthquakes and storms) on anchor design.

Milestones

- Novel mooring system enabling floating concepts at 50-100m water depth.
- Demonstrate control system to assist mooring system.

Challenge 2.2

Floating wind farms

Dynamic electric cables	Short-term	High priority

Description and scope

Cables for floating wind are a challenge in shallow water due to the dynamic motion of the floater. In deep water cables are a challenge due to cost, in particular for array cables.

Power cables for floating wind experience dynamic motion during service. Traditional high voltage submarine cable designs include a metallic barrier to prevent water from entering the cable cores and reducing the service life. Recently a recommendation by the International Council on Large Electric Systems (CIGRE) describes tests on high voltage submarine cables without metallic barriers. This calls for new designs with lower weight and reduced cost in particular for inter array cables but also for deep-water submarine cables.

When modelling electric characteristics of cables, it is in general assumed that they are straight (only Transverse Electromagnetic Mode – TEM) and do not change dimension along the way. This is not the case with dynamic cables. Therefore, it is necessary to validate the existing cable modelling tools and methods, especially when it comes to loss estimation, harmonics and transients. Additional topics are to investigate fault detection and localisation methods in dynamic cables.

Subsea electrical connectors should be also explored for better and faster installation of inter array cables, linked with static cables on the seabed, lowering the cost of deployment.

Recommended research actions

- Validated software for cross sectional analysis.
- Validate and develop cable modelling tools and methods, with regards to loss estimation, harmonics and transients and long-term performance of new dynamic designs.
- Qualify dynamic High Voltage Direct Current (HVDC) cable and assessment of the applicability.
- Long dynamic infield cables (e.g. bellows, floater-to-floater).
- Research on different configurations of dynamic cables with respect to water depth.
- New materials, structure and designs (e.g. non-metallic designs for submarine dynamic power cables, cost-effective and reliable bend stiffeners).
- Mechanical behaviour of bitumen, and use in cross-sectional structural analyses.
- Use of monitoring data from cable response and environment for on-board cable integrity assessment.
- Review non-metallic designs for submarine dynamic power cables.

Milestones

- Selection of new cable design(s) and materials to reducing manufacturing and installations cost.
- Established lifetime model(s).
- Performed long-term tests for validation of the models.
- Developed new modelling tools.

Challenge 2.3

Floating wind farms

Control methods	Short-term	High priority

Description and scope

Most types of floating wind turbine are subject to a control-driven instability involving platform pitch and control of the rotor speed. Auxiliary damping is often needed to stabilise the platform. The platform resonant modes, which may have frequencies below 0.05 Hz, pose a special challenge to the stable control of floating wind turbines: either the controller must have a very slow action, or else it must compensate actively for the platform resonance. Auxiliary damping is purely reactive, in response to platform motion.

There are unrealised opportunities to anticipate and actively reject or balance loads on the turbine and platform structures, beyond the damping of pitch resonance either through control methods or a reduced mooring system to reduce floater motion and fatigue damage.

Advanced model-based control algorithms can be used to find the ideal trade-off between conflicting control objectives, such as power production and load reduction.

Recommended research actions

- Improve the use of model-based control, in combination with advanced sensors like Lidar and wave cameras, to anticipate load fluctuations and accommodate them in an optimal way.
- Analyse side-to-side damping in cases of misaligned wind and waves, and in general counteracting the accumulated cycles and extremes of environmental loading, without sacrificing production.
- Test and use fleet operational data to provide the foundation for adaptive, machine-learning algorithms that can supplement or perhaps transcend model-based approaches.
- Explore the possibilities and limitations of machine-learning-based control algorithms, especially regarding the relationship between the data available for training and the reliability of the control response under various normal and abnormal operating conditions.
- Parametrisation of the methodologies to auto-tune controllers.

Milestones

- Protocol for motion controller interaction with turbine manufacturers.
- Develop and test new controllers for floating offshore wind to demonstrate reduced floating motion and fatigue damage.
- Integrated analysis tools be able to include controller functionalities.

Challenge 2.4

Floating wind farms

Floating installation, assembly and heavy maintenance	Medium-term	Low priority

Description and scope

Deepwater offshore wind sites exclude use of traditional jack-up vessels for assembly, installation, and heavy maintenance. Floating-to-floating solutions need to be further developed for use in floating offshore wind developments. These solutions will allow for efficient installation and heavy maintenance at site and help to reduce capital expenditure (CAPEX) and operational expenditure (OPEX).

Recommended research actions

- Floating-to-floating motion compensated lifting operation.
- Assess loads on components during crane/lifting operations.
- Adaptable substructures for float over installation or to avoid heavy high-lifts, (e.g. telescopic designs, ... etc.).
- Adapt Rotor-Nacelle-Assembly to allow for large tilting such that blades, nacelle and tower can be assembled horizontally on the ground, towed out, then flipped up vertically offshore for installation.
- Flexible and Rigid Body Dynamic modelling for improved marine operations.

Milestones

- Enable floating-to-floating lifting at 1,5 HS and 10 m/s wind.
- Software tools able to simulate six degrees of freedom motion compensation.

Challenge 2.5

Floating wind farms

Park-level control	Long-term	Medium priority

Description and scope

The plant supervisory controller can influence the operation of each individual wind turbine. Typically this takes the form of power set-point commands, although it is also possible to envision a more intrusive plant controller that dictates things like the target rotor speed or yaw angle.

The primary objective of the plant controller is to provide grid support functions, making the wind turbines act collectively, from the grid's perspective, as a virtual power plant.

By optimally coordinating the operation of the wind turbines, it is also possible to marginally increase production, or to reduce detrimental effects like wake turbulence. These secondary control objectives are difficult to attain because the expected effects are small, and the signals must propagate through the noisy, turbulent atmospheric boundary layer. A lack of suitable experimental facilities between the wind tunnel scale (plants with 10 cm-scale turbines) and full scale (plants with 100 m-scale turbines) hinders the development of novel plant control algorithms.

Floating wind turbines present special challenges for a plant controller. For example, if all the turbines are given a power command simultaneously, then, due to the low-frequency platform modes, this will tend to set them all in synchronous motion, which could result in unwanted power fluctuations.

Recommended research actions

- Develop holistic models of large-scale floating wind power plants that can be used in the design and simulation of plant control algorithms.
- Increase influence of accumulated turbine control actions on the atmospheric boundary layer, in particular how perturbations to the flow propagate downstream through large plants.
- Develop reduced-order models capable of predicting these effects in real-time.
- Develop optimal control algorithms that can detect changes in the flow conditions, such as wake turbulence, and adapt the operation of the turbines accordingly.
- Investigate and compare benefits and limitations of possible system architectures, including model-based, adaptive, and data-driven/machine-learning.
- Quantify the potential benefits of additional sensor data like lidars, as well as short-term wind forecasts.

Milestones

- Demonstration of a wind turbine as a wind speed observer, and reconstruct an estimate of the atmospheric flow from these observations. This could provide the capability to anticipate and react optimally to changing weather conditions, like the passage of weather fronts.
- Research on wind plant control would benefit from an experimental facility, representing a large wind power plant (>50 turbines) at a small scale (1 to 10 m diameter rotors), where different control algorithms could be tested and demonstrated.

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