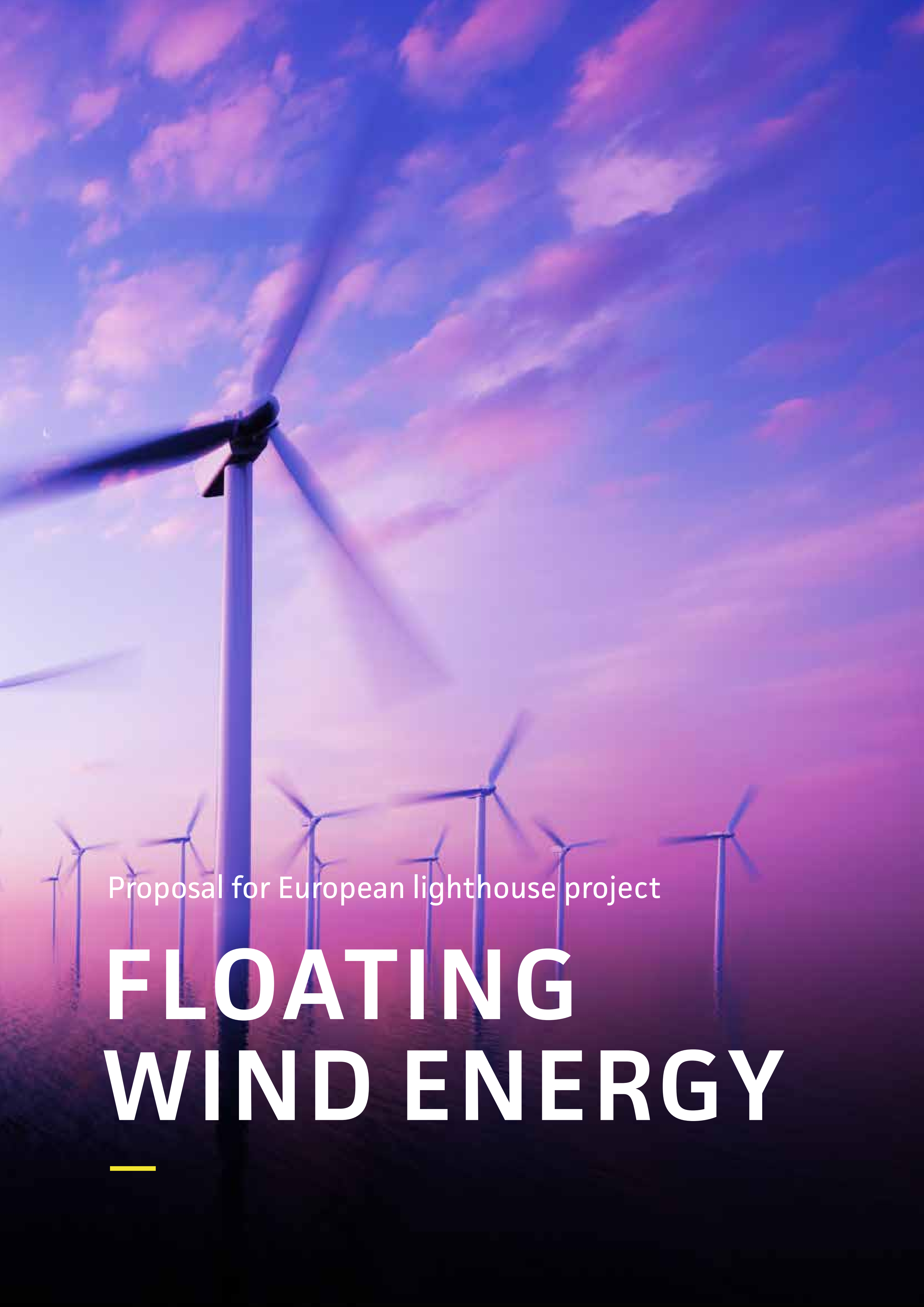


Proposal for European lighthouse project

FLOATING WIND ENERGY

Preface

This report is prepared as part of the EU SETWind project based on communication with key stakeholders. The process included dialogue, workshops, and presentations as listed below:

- Workshop at the EERA JP Wind and SETWind annual event in Amsterdam, September 2019
- Presentation for the SETWind Steering Committee, October 2019
- Session at WindEurope Offshore with presentation of the SETWind lighthouse initiative and panel debate with key stakeholders, in Copenhagen, November 2019
- Blog on offshore wind, December 2019
- Workshop at EERA DeepWind in Trondheim, January 2020
- Presentation for the SETWind Steering Committee, February 2020
- SETWind report on Lighthouse initiatives, May 2020
- Presentation for the SETWind Steering Committee, December 2020
- Presentation for EERA JP wind Steering Committee, May 2021
- Workshop with EERA JP Wind participants, May 2021
- Presentation for EERA JP Wind participants, September 2021

Workshop participants have included industry, public bodies and research representatives from Europe including members of the European Energy Research Alliance Joint Programme on Wind Energy (EERA JP Wind), the European Technology & Innovation Platform on Wind Energy (ETIPWind), the International Energy Agency (IEA Wind TCP) and the SETWind steering committee with representatives from the EC and public bodies. Their input is highly acknowledged.

January 2022

Authors:
- John Olav Tande (SINTEF)
- Jan Willem Wagenaar (TNO)
- Mikel Iribas Latour (CENER)
- Sandrine Aubrun (EC-Nantes)
- Arno van Wingerde (Fraunhofer IWES)
- Peter Eecen (TNO)
- Mattias Andersson (DTU)
- Stephan Barth (ForWind)
- Paul McKeever (ORE Catapult)
- Nicolaos A. Cutululis (DTU)

Summary and introduction

This report presents a proposal for a European lighthouse project on floating wind energy. It includes three main sections, namely Excellence, Impact, and Implementation.

The term "lighthouse project" refers in this context to a visionary, science-driven large-scale project with significant budget (tens of millions of Euros) and duration (5 years or more) that will address grand scientific and technical challenges that are crucial for the further advancement of offshore wind energy, providing new knowledge and basis for innovation.

The section on Excellence gives the state of the art and basis behind this proposal for a European lighthouse project on floating wind energy. In short, the reasoning is that 80 % of the global offshore wind resource is at sea depths beyond 60 m [1], thus, it is paramount to develop floating wind technology to be able to utilize this huge untapped resource. It is an essential part of the solution for reaching climate targets, both for Europe and globally, and it represents an opportunity for new green jobs and business. European industry and research are in the lead of the development, though to stay in the lead, a strong effort on research and innovation as proposed here is required.

The section on Impact explains the value of the proposed lighthouse project. Based on current plans for offshore development, the expectation is that 150 GW of floating wind will be installed in Europe by 2050. This represents an investment in the order of 450 billion EUR that will generate annually about 600 TWh of clean electric supply, corresponding to about 20 % of the electric consumption of EU in 2019. The lighthouse project will provide knowledge and solutions that will ensure the development of floating wind to be prepared in a sustainable and economic manner. A marginal 1 % saving in investments (4500 million EUR) is about 100 times the cost of the proposed lighthouse project on floating wind. In addition to this comes value from new green jobs in industry and supply of goods and services to markets outside Europe.

The section on Implementation outlines the scope of the lighthouse project and how it can be realized through international collaboration with public funding, for example as an EC call similar to the H2020 RIA calls. Indeed, compared to common RIA calls, the lighthouse project should come with an extended budget and duration.

The main objective for the proposed lighthouse project is to develop knowledge and innovations to overcome the barriers for large-scale deployment of floating wind energy for all European sea conditions. A main outcome and focal point of the activity is the development of an open-source reference multi-GW floating wind farm in collaboration with industry. Topics to be addressed include three overarching themes, namely sustainability, open access to data and knowledge sharing, and five technical themes, namely external conditions, integrated design, control, logistics and grid connection.

The Vision is that offshore wind power will be the cornerstone of the future energy system, developed with respect for nature and society, and providing prosperity with clean and affordable energy for all.

Floating wind turbines at Hywind Scotland, the world's largest floating wind farm, north-east of Aberdeen. Photo: Michal Wachucik, Equinor.

Excellence

This section gives the state of the art and reasoning behind the lighthouse project proposal on floating wind energy.

Europe towards net-zero emissions by 2050 – ‘Fit for 55, set for 2050’

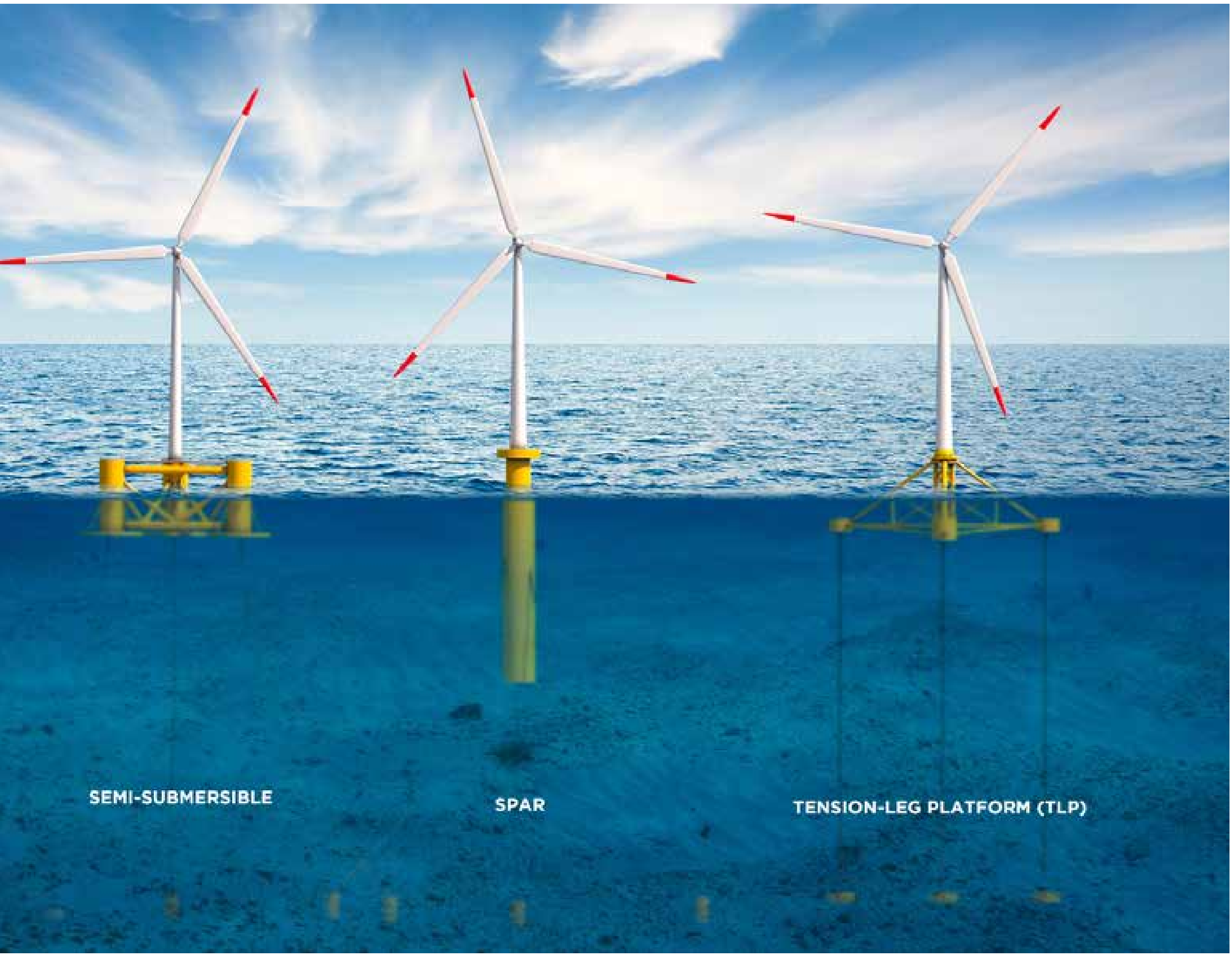
The Green Deal is an integral part of the European Commission's strategy to implement the United Nation’s 2030 Agenda and the sustainable development goals. To achieve net-zero CO_2 emissions by 2050, the European Commission will present an impact-assessed plan to strengthen the EU’s emissions reduction targets for 2030 to at least 50% and towards 55% compared with 1990 levels. A set of transformative policies are being designed. Electrification is a key measure to reduce emissions. This will cause an increase in the demand for electricity of 50 % by 2050 that must be supplied by CO_2-free electricity generation.

Offshore wind energy is identified as crucial to reach climate goals [1]. The EU Strategy on Offshore Renewable Energy has a target of 300 GW of offshore wind capacity by 2050 [2]. In addition to that come the installations in countries outside EU like the UK and Norway, that may bring total European offshore wind capacity close to 450 GW by 2050 [3]. This will be sufficient to supply about one third of the electricity demand.

In comparison, offshore wind capacity in Europe by the end of 2020 was 25 GW [4], supplying approximately 3 % of the electricity demand. A comprehensive overview on offshore wind technology is presented in reference [40].

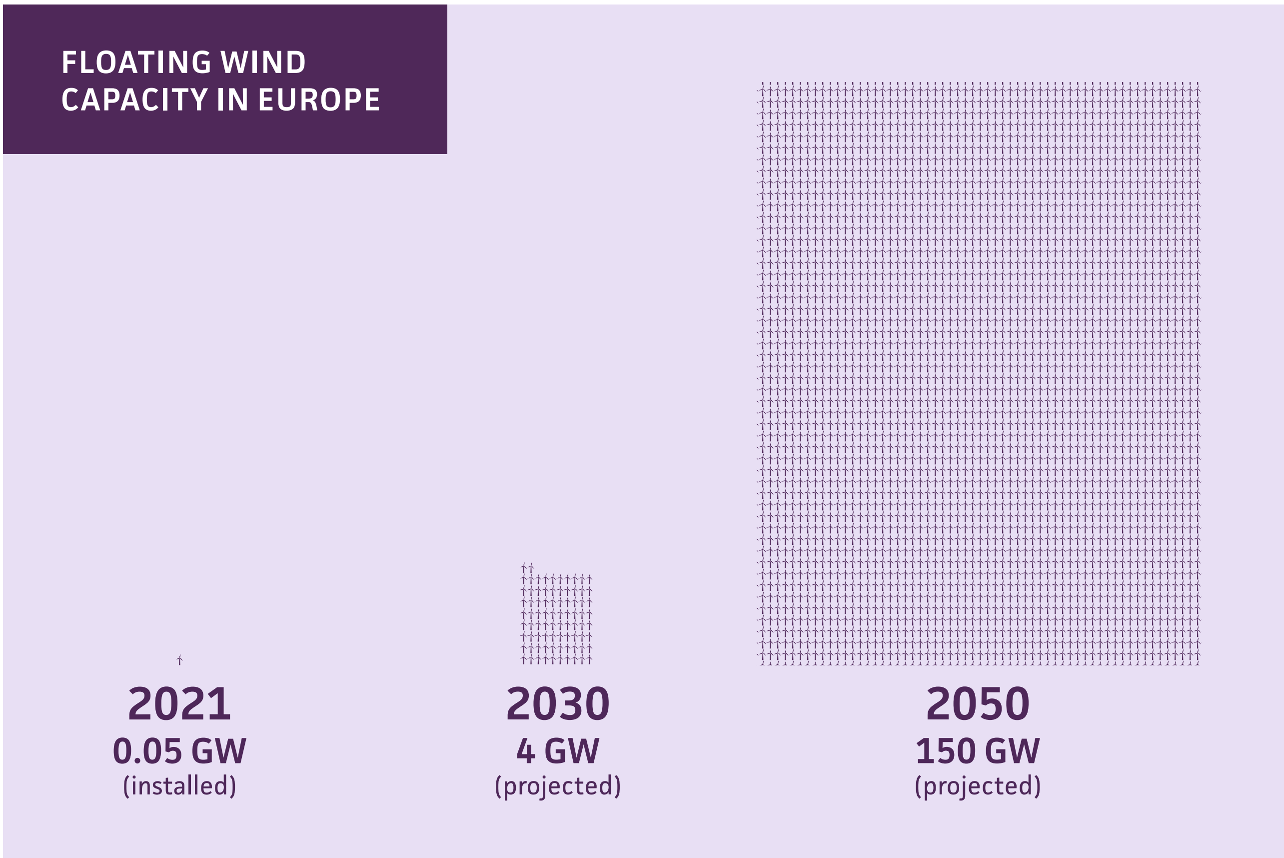
Floating wind presently constitutes of only a handful of pilot and demonstration projects, but with huge potential [32]. The International Energy Agency (IEA) estimates [1] that floating wind accounts for 80 % of the global offshore wind potential. The floating wind potential is about 336 000 TWh being 12 times greater than the global electricity demand of 2018. The expectation is that about one third of the offshore capacity to be installed in Europe will be floating by 2050. It is therefore necessary to further develop and mature floating technology, as it is a prerequisite for bringing offshore wind energy from the shallow waters of the North Sea to all of Europe, including deep sea and far-from-shore areas. It also represents a huge export market for technology and solutions as globally, in some markets, floating wind is the only viable solution because of sea depth.

Offshore wind substructures are available for any water depths. Illustration courtesy of Wind Europe.


SEMI-SUBMERSIBLE
SPAR
TENSION-LEG PLATFORM (TLP)

Wind energy hub Europe - from research to leading companies

In the last decade, new floating platform designs have arisen through research projects, new start-ups or well-established companies. Floating offshore wind turbines (FOWTs) are a fast-maturing technology with the potential of cementing Europe's leadership in renewables globally. European companies are the pioneers worldwide in the entire value chain of FOWTs, as they lead three quarters of the 50+ FOWT projects at different stages of development today. In Europe, at least eleven pre-commercial projects should be in operation within the next few years, reaching more than 350 MW installed by 2026. Further development is expected towards 2050, as shown in the illustration below. There are accelerated developments in the USA, China, Korea, Japan and in other countries globally. This demonstrates that floating technology is without doubt a significant component of the future of the energy transition. To maintain Europe's leading position and to make EU floating wind a success story will require deployment and innovation, but also knowledge development at a fundamental level.



Development of floating wind in Europe. Illustration by SINTEF. Please note the indicated 4 GW by 2030 does not include the result of the recent ScotWind auction [55] *that awarded licenses for 15 GW of floating wind capacity to be installed during the next ten years.*

The science of FOWT technology is still evolving and has not yet reached the same level of maturity as its onshore or bottom-fixed counterparts. The design and manufacturing practice for offshore bottom-fixed wind turbines and farms are still based on the separated considerations from turbine and foundation designers and manufacturers. This challenges the design of FOWT. The need for integrated design considering the strong coupling between wind turbines, floaters, mooring systems at the single turbine level and at the farm level, requires the common understanding of the system behaviour, the knowledge sharing and the cooperative framework by turbine designers and manufacturers, floater/mooring designers and manufacturers, and grid infra-structure designers. Moreover, the offshore wind industry is developing larger and larger turbines to reduce the LCoE, and this continuously challenges the design, transport and installation of floating wind turbines. All of this enhances the need for profound research and joint efforts of the entire wind energy community: from turbine manufacturers to floater and mooring design and manufacturing companies, via all their supply chainsw, to research centres, universities and certification entities.

Fortunately, Europe has established the best research community and strategic alliances with the industrial community. Clear proofs of this well-established community are EERA JP Wind and ETIPWind and the leading position of Europe in development of floating wind farms. To maintain European leadership and to have a flourishing industry supported by a strong and solid knowledge base, we must strengthen that knowledge base.

EERA JP Wind, the European Energy Research Alliance Joint Programme on Wind Energy, brings together a total of 50 major public research organisations in Europe that all have substantial research and innovation activity within wind energy. EERA JP Wind provides strategic leadership for medium to long-term research and supports the European wind energy industry and societal stakeholders. There is a strong interaction with the industry platform ETIPWind and with the SETPlan Implementation Working Group on offshore wind. EERA JP Wind supports the climate goal targets of a CO_2-free energy system in 2050 and steers the R&I efforts towards making wind energy to deliver more than 50% of the world's energy requirement in 2050. EERA JP Wind has defined the priorities, challenges and key action areas for wind energy research in its R&I strategy.

ETIPWind®, the European Technology and Innovation Platform on Wind Energy, connects Europe's wind energy community. Key stakeholders involved in the platform include the wind energy industry, political stakeholders and research institutions. ETIPWind was established in 2016 to inform Research & Innovation policy at European and national level. ETIPWind provides a public platform to wind energy stakeholders to identify common Research & Innovation priorities and to foster breakthrough innovations in the sector. Its recommendations highlight the pivotal role of wind energy in the clean energy transition. They inform policymakers on how to maintain Europe's global leadership in wind energy technology so that wind delivers on the EU's Climate and Energy objectives.

Impact

In this section, we outline the expected impact of realizing the lighthouse project.

Challenges and ambitions

Offshore wind energy has the potential to become the back-bone of the future zero-emission European power system. To be successful however, the supply of energy must be affordable and reliable, and the technology must be **sustainable, circular and ecologically friendly**. This lighthouse initiative has the ambition to ensure exactly this, through research and innovation.

Europe is a world leader in offshore wind energy. It has a leading industry, the largest installed offshore wind capacity and an outstanding research community. The continued strong commitment towards deployment, industry development, research and innovation will **secure and maintain European leadership** in offshore wind. The solutions for floating wind are important not only for implementation in Europe, but globally applicable with large potential for export and new jobs. Research and innovation as outlined in this lighthouse proposal are paramount to reach this ambition.

The project will target unsolved scientific challenges at relatively low Technology Readiness Level (TRL up to 5, that is laboratory scale validation). However, these challenges will be driven by industry needs, and addressing them is a step towards massive deployment of floating offshore wind turbines. The initiative should support reducing the risks in floating wind. This risk reduction will positively impact on the profitability of upcoming wind farms from 2030 to 2050. In this context, we have the specific goal to develop an **open-access data model of a multi-GW floating wind farm**, that can be used as a reference suitable for all European seas with alternative solutions for the floating substructure, anchoring, cabling, installation, operation and maintenance, control, etc.

Value proposition

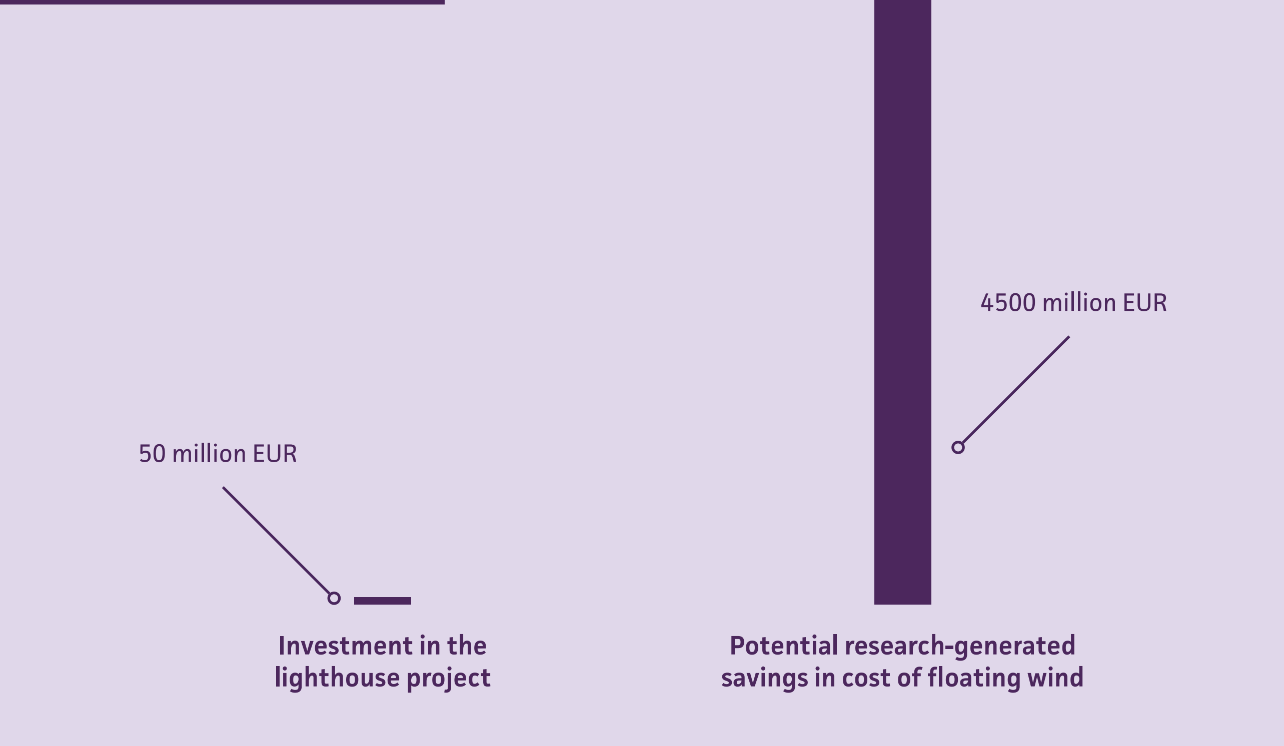
Over the last decade, bottom-fixed offshore wind energy in Europe has seen a **great cost reduction**. In 2010, the levelized cost of energy (LCoE) for bottom-fixed offshore wind was around 190 EUR/MWh and the sector targeted that by 2020 the cost could be reduced to 115 EUR/MWh [7]. Reality is that developments went much faster and today we see very competitive contract prices for bottom-fixed offshore wind farms, e.g., Dogger Bank A (1200 MW) reached financial closure with a strike price of 39.65 GBP/MWh (approx. 47.58 EUR) for delivery in 2023-24 [33].

Large scale deployment, market development and policy have together with research and innovation made this cost reduction possible. For example, the research in design tools [8]- [9] allowed for making larger wind turbines and this upscaling is one of the driving forces behind the reduction in LCoE. This proves the value of fundamental research.

Floating wind farms can likely achieve similar cost reductions. The cost of floating wind is already at a decline from about 200 EUR/MWh to 150 EUR/MWh for projects having been realized in Europe during the last few years [10], [32]. The cost will continue to decline with increased deployment, research and innovation expecting to achieve an LCoE of 40 – 60 EUR/MWh for floating wind projects at good sites by 2030. Further cost reductions can be expected as floating wind has costs advantages compared to bottom-fixed wind. These include possibilities for more standardized design and large series production of the substructure, less work offshore for installation, access to larger sea areas and better wind conditions.

Based on current plans for offshore development, the expectation is that 150 GW of floating wind will be installed in Europe by 2050. This represents an investment in the order of 450 billion EUR that will generate annually about 600 TWh of clean electric supply, corresponding to about 20 % of the electric consumption of EU in 2019. The lighthouse project will provide knowledge and solutions that will ensure the development of floating wind to be prepared in a sustainable and economic manner. A marginal 1 % saving in investments (4500 million EUR) is about 100 times the cost of the proposed lighthouse project on floating wind. In addition to this comes value from new green jobs in industry and supply of goods and services to markets outside Europe.

INVESTMENT IN RESEARCH PAYS OFF



The proposed lighthouse project is expected to give a return of about 100 times the investment: 1 EUR invested in the lighthouse project will give 100 EUR in floating wind cost savings. In addition comes the value of new green jobs and exports created as a result of the lighthouse project. Illustration by SINTEF.

Implementation

In this section, we will outline our suggestions for the implementation of the lighthouse proposal.

Programmatic and action-driven approach

The lighthouse project shall be a dedicated and ambitious long-term initiative on European floating wind energy research. There is currently a lack of knowledge, which must be solved to succeed in the development of floating wind. This will be the focus of the **lighthouse project** we are proposing.

The lighthouse project shall be **visionary, science-driven, and large-scale** with a significant budget (tens of millions of Euros) and a relatively long duration (5 years or more) that will address the grand scientific and technical challenges that are crucial to overcome for the further advancement of floating wind energy. The new knowledge that will be gained by this proposed project will form a basis for innovation to tackle European challenges in developing floating wind, not with incremental steps, but in an integrated and holistic way, creating the best value for money.

So far, various individual demonstration projects have been launched, mainly financed by public funding. The advances made through such projects benefit the individual party involved and are not necessarily shared. The proposed lighthouse project on the other hand will provide knowledge and solutions that will **benefit the European industry** as whole.

This proposal does not question the well-known Horizon Europe calls and projects, but rather aims to raise the ambition **bringing leading expertise together** striving for significant progress and impact through a large and coordinated effort on floating wind energy.

In short, this lighthouse proposal is to create a project that is

- visionary, science-driven and large-scale
- tackling EU challenges in an integrated and holistic way
- providing impact by bringing leading expertise together
- complementing existing EU calls.

To realize the lighthouse project, we propose a large strategic EU call that focuses on low to medium TRL to address the fundamental longer term industry challenges. We propose a scope with three overarching, conceptual themes and five technical themes that is further described in the next paragraphs.

Scope of research programme

The proposed scope is aligned with the priorities in the research agenda of ETIPWind [12] and EERA JP wind [13], and IEA Wind TCP [11], and it has been developed through dialogue, workshops and meetings with key stakeholders both from industry and research, see also [6].

1. Knowledge sharing

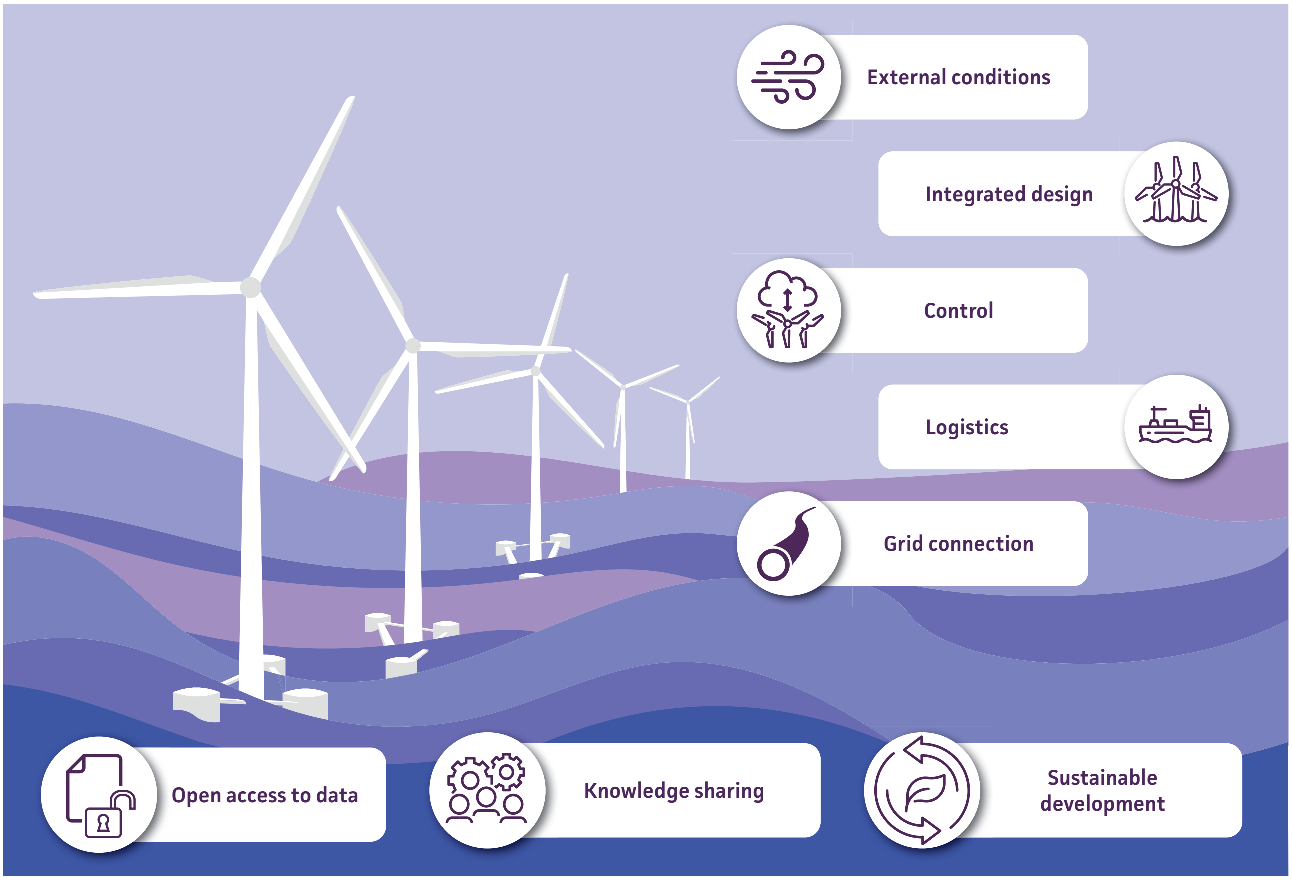
Excellent research is not the only requirement for creating a solid knowledge basis. We also need to create the tools and means necessary for researchers to share, discuss and disseminate findings with their peers. This also includes a mobility programme and access to research infrastructure, enhancing joint research. Cross-correlation with ongoing research in related projects on the themes below is identified and we will facilitate creating synergies. This stresses the overarching position of this lighthouse project.

2. Open access to data

To increase the impact of the project, we suggest full and open access to the research results. This will include a data model of a multi-GW floating wind farm, that can be used as a reference suitable for all European seas with alternative solutions for the floating substructure, anchoring, cabling, installation, operation and maintenance, control, etc. The data will be openly accessible to all European stakeholders according to the FAIR principles.

Gaining access to data from commercial wind farms has proven to be very difficult. Therefore, to ensure access to measurements for validation, laboratory experiments and research facilities are suggested as a main source of open data. Existing facilities will be used but proposed to be extended with an open-air scale model of a wind farm, consisting of 50 to 100 turbines each with a 2 m rotor diameter, i.e., a scale of about 1:100 of the biggest turbines of today.

Previous wind tunnel experiments on plant-scale wake flow have been conducted with cm-scale rotors. These experiments have been used among other things to validate LES simulations and study the effects of different turbine layouts. The scale-model wind farm will help to bridge the gaps between such small-scale wind tunnel experiments and full-scale operating wind farms.



Topics to be addressed in the lighthouse project include three overarching themes, namely Open access to data, Knowledge sharing and Sustainable development, and five technical themes, namely External conditions, Integrated design, Control, Logistics and Grid connection. Illustration by SINTEF.

This facility will provide testing, demonstration, and validation services to industry and academia. It will generate large amounts of open-access data with a level of detail that is presently non-existing and will accelerate technological advancement within the fields of wind power plant design, operation, and control. It will be essential for validation of the multi-GW floating wind farm data model.

The open-access scaled wind farm has a unique placement among existing facilities: it captures plant-scale phenomena related to flow and controls; emulates grid integration scenarios; and hits a "sweet spot" in size, large enough to capture essential physical phenomena but at moderate scale to keep flexibility high and costs at an affordable level.

3. Sustainable development

This is an overarching theme and paramount for the success of floating wind. We suggest developing knowledge and solutions on circularity, eco-friendliness, and social acceptance. The circularity of floating wind components needs to be assessed in a lifecycle perspective, and alternative materials need to be investigated and proposed to improve circularity and recyclability. The impact of such new materials will be assessed in terms of structural stability, fatigue lifetime and ease of maintenance. Also worthy of investigation is how the installation and operation of large floating wind farms can best be done in coexistence with nature and how best to improve environmental biodiversity. Stakeholders must be identified and analysed and coexistence strategies devised for deployment of floating wind farms in areas with multiple users. Strategies should be formulated to maximize social acceptance and positive socio-economic impact.

4. External conditions

To improve the understanding of the atmospheric and wind power plant flow physics is defined as the first of three grand research challenges in [11], published in the highly esteemed journal of Science based on work by IEA Wind Technology Collaboration Programme. It points out a need for a better understanding of linking the meso- and microscale weather processes, knowledge gaps related to atmospheric conditions, wind-wave interactions and modelling of wakes. In the lighthouse project, we suggest this to be addressed, and in addition, there is a need to improve knowledge of sea and seabed conditions. Modelling tools will be developed and validated against field measurements to better predict met-ocean conditions at sites for floating wind farms [14][15][16].

5. Integrated design

A floating wind farm constitutes complex interaction of hydro-, aero-, structural- and electrical dynamics. The second grand research challenge depicted in [11] is to better understand these complex interactions. We suggest this to be addressed in the light-house project, but include also other factors such as environmental impact, manufacturing, installation, grid connection, operation and maintenance, etc. This approach was successfully applied in the EU Lifes50+ project addressing *floating turbines* [34] but should be further developed for optimizing *floating wind farms* [35][36].

We suggest taking such a holistic approach will enable development of new and disruptive concepts. A prerequisite is a better understanding of the physical phenomena in play [11], then the development of integrated high-fidelity multidisciplinary modelling tools, and lastly, their validation against observations and measurements. Modelling of the hydrodynamics of different floating support concepts, mooring systems [41], floaters with alternative/multiple wind turbines, aerodynamics for rotors undergoing large motions [19] [20] [21], structural response, dynamic cables and power transmission, parametric tools and models; all must be developed further to overcome the barriers for multi-GW floating wind farms.

The developed models will be applied for development of the open data model of a multi-GW floating wind farm, that can be used as a reference suitable for all European seas with alternative solutions for the floating substructure, anchoring, cabling, installation, operation and maintenance, control, etc. This will be a focal point for the project as an overarching activity and an outcome of high value that will be open for the entire European offshore wind scientific and industry community.

Hydrodynamic laboratory testing of FWT has come far for single turbines [17, 18], however testing methodology to account for farm level effects has not yet been developed. The main effects that need to be accounted for are interaction between aerodynamic wakes and floater response, new low frequency modes of motion with low damping, and mechanically coupled systems, such as shared mooring systems. Development of such testing methodology will be decisive for farm development, as prototype demonstration will be too costly at farm level.

6. Control

Control technology is demonstrated to have a huge potential for LCoE reduction. Future controllers for floating offshore wind turbines and farms are expected to play an important role in ensuring their integrity, reliability, and LCoE reduction. Advances in control solutions will make it possible to develop new control algorithms to provide better dynamic stability, to improve power production and to avoid critical load aspects [22][23][37]. New advances will be based on wind, currents and waves measurements or estimators. New concepts, e.g., floaters with multiple turbines, open a new field of disruptive innovations in terms of control, by adding complexities and new degrees of freedom [24][25].

The added degrees of freedom of floating wind turbines and their associated complexities bring even more challenges in controlling such machines in large, multi-GW floating wind farms in terms of stable operation. Yet, this increased freedom also brings opportunities. As wind turbine wakes have been demonstrated to have a huge impact on wind farms, exploring wake effects on FOWT [26][27] and exploring intra-wind farm wake models for controlling is of great importance. Examples are wake induction control and wake steering [28][29], but also repositioning of floaters throughout the entire wind farm [30]. Reduced-order models for FOWT wake effects need to be developed in order to apply them for real-time wind farm control. Developing and testing floating wind farm controllers will greatly enhance production and reduce structural loading [38][39].

7. Logistics

The installation and operation of future GW-sized floating wind farms is a tremendous logistic challenge, but also holds opportunities for substantial cost reductions. Installation of floating turbines requires less work offshore and can be assembled inshore in a sheltered environment before being tugged to the site. The requirements towards the site for assembly depend however on the floating concept, and there will be a trade-off to be considered between choice of floater type, choice of assembly site and towing route. Other examples of open questions for consideration are what is the best O&M strategy, what ships and harbours are necessary and how should the supply chain be organized [44][45]?

Thorough planning is a must to ensure efficient, robust, and safe coordination of marine operations related to a floating wind farm. For the installation and decommissioning, research is scarce and more advanced methodologies are needed. Innovations are also needed to support the move from corrective/preventive to predictive maintenance during the operational phase [42][43].

Digital solutions are expected to result in substantial cost savings related to installation and operation of floating wind farms and will be developed through this project. A unified real-time framework for integration of weather windows, production profiles, logistic resources, and condition/remaining useful lifetime is missing. Hybrid uncertainty models based on physics of failures and data-driven approaches are required. The solutions that will be developed will optimize logistics for installation and operation, such as optimized routing for installation depending on weather and digital twin [46][47] models for real time estimate of the time to failure of key components, such as the mooring system, dynamic cables, power electronic converters, etc.

8. Grid connection

The electrical collection and transmission system, between the individual wind turbines and the point of common coupling at the shore, accounts for a significant share of the total cost of an offshore wind farm. For a far offshore floating wind farm this can account for up to 50 % of the LCoE but can be greatly reduced through research and innovation to bring forward new solutions [1].
This includes:

- new dynamic power cable technology to make them lightweight, affordable and robust
- development of subsea wet-mate connectors and subsea junction box technology enabling easy connect/disconnect of single turbines, and more cost-effective installation and maintenance
- solutions for subsea substations as an alternative to floating substations,
- advancement in transmission technology, both AC and DC solutions [48].

Grid connection of offshore wind farms is on the R&D roadmap for European TSOs [49] and wind developers. Point-to-point connections present strong limitations for large offshore wind clusters. Rather an offshore grid is envisaged but its planning and operation are technically challenging. Adverse grid/component interactions [50] will have to be addressed in a multivendor context and WFs will need to support the transmission system regulation with advanced ancillary services as grid forming capabilities [51]. An optimization framework should be established to coordinate these services and the power transfer according to grid needs [52], legal and market constraints [53], and energy carrier options [54], e.g., for floating wind farms far from any grid infra-structure, it can be an alternative to produce hydrogen that can be transported to shore by ships. Systems with floating wind farms and energy storage, e.g., subsea pumped hydro or batteries, should also be investigated. This can be an important solution to provide balancing services in a future energy system dominated by time-varying renewable generation, and it may reduce the cost of the grid connection by letting the energy storage shave off the peaks in the generation.

Floating wind turbines at Hywind Scotland, the world's largest floating wind farm, north-east of Aberdeen. Photo: Wachucik, Equinor.

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