North Sea Offshore Wind Ambitions, challenges, and collaboration

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GreenShift

Securing the European Green transition through Research, Business, and Government Collaboration

Preface

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This discussion paper is prepared as information material for the GreenShift project carried out by SINTEF Energy for the Norwegian embassies to Denmark, Belgium, the Netherlands, and Germany. The objective is to strengthen collaboration between research, business, and government to boost European momentum within key technologies for a clean energy transition. The GreenShift project will organise three focused events, addressing offshore wind, CCS and green maritime shipping, respectively, and one final summarising event.

This document specifically addresses offshore wind and serves as a background document for the offshore wind event that will take place in Amsterdam on 11 September 2023. It outlines national ambitions, strengths, and challenges related to offshore wind, key areas of industry research and innovation and how the research can be carried out more efficiently in a collaborative effort through the establishment of a European Centre of Excellence on wind energy.

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Introduction

Offshore wind is one of the most promising technologies in Europe's and the world's search for new renewable energy sources to deliver on the green energy transition. While the technology is available, and both floating and fixed offshore wind are already operating in the North Sea, there are several challenges to overcome to secure the development of offshore wind into a competitive, sustainable, reliable source of large quanta of energy.

With Fit for 55 and REPowerEU, the European Union set very ambitious goals for the green energy transition and pioneering the way towards net zero by 2050, see Figure 1. The Esbjerg Declaration, and more recently the Ostend declaration[1], constitute the response of the North Sea countries to these goals, and detail unprecedented targets of offshore wind and grid development.

Offshore wind capacity in Europe

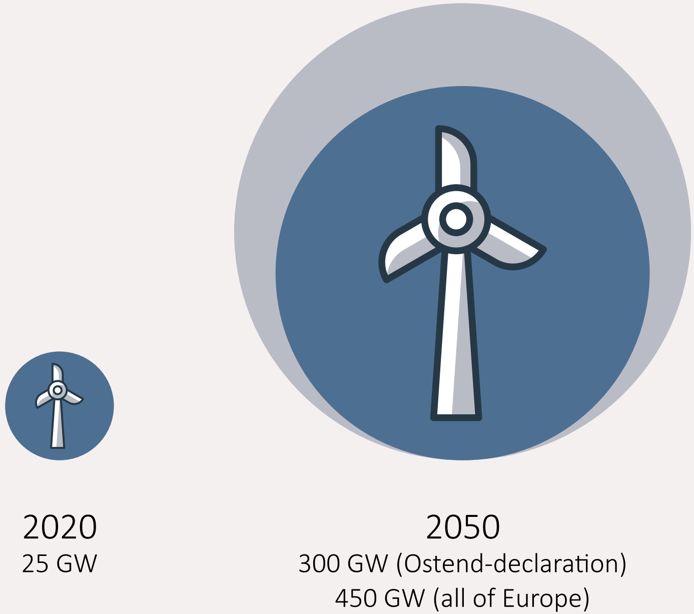


Figure 1: Illustration (SINTEF) of status and plans for offshore wind development in Europe.

National ambitions, strengths, and challenges

Together, the joint offshore wind ambitions of five nations neighbouring the North Sea (Belgium, Denmark, Germany, Norway and the Netherlands) sum up to more than 60 GW by 2030 and 200 GW by 2050. To achieve this, a strong development will have to take place across the entire wind energy value chain. For comparison, in 2022 European countries installed 2,5 GW offshore wind combined[2].

Wind farms have been supplying an increasing part of Europe's electricity since the 1990s, and now account for about 20% of the total supply[3]. The DNV Energy Outlook estimates that electricity from wind power will increase to about 50% by 2050, and that the total electricity production will double within the same time-frame[4]. To allow for this, a doubling of the installed grid capacity is also expected.

Key offshore wind figures and ambitions for the five countries are shown in the table on next page.

	Belgium	Denmark	Germany	Netherlands	Norway
Offshore wind capacity 2021 (GW)[5]	2,3	2,3	7,8	2,5	0,1
Offshore wind capacity 2030 (GW)[6]	6,0	5,3	26,4	21,0	3,0
Offshore wind capacity 2050 (GW)[7]	8,0	35,0	66,0	72,0	30,0
Offshore wind industry turnover 2021 (MEUR)	*	6000[8]	7400[11]	2700[10]	2 500[9]
Accumulated investments to reach 2050 goal for offshore wind (MEUR)	27 000	117 000	220 000	240 000	100 000
National R&D budget for wind energy 2021 (MEUR)[4]	*	19	67	26	11

*missing estimate

Table 1: Key offshore wind data for Belgium, Denmark, Germany, the Netherlands and Norway.

There is a stark contrast between the estimated accumulated investment and the R&D budgets.
R&D will ensure better solutions, as well as reduced environmental impact, raw material use and cost, though results will depend on the available budget. The limited budgets underline the importance of a pan-European collaboration on research and development to secure the biggest possible impact.

The five countries mentioned above are among the leading offshore wind developers in the world, reflected in the availability of key industries and infrastructure for offshore wind development. Vestas and Siemens Energy supply wind turbines to the entire world and are leading the development towards increasingly larger turbines. Nexans in Halden manufactures the subsea cable necessary to transmit wind energy to shore. Nexans recently won a 1700MEUR contract to connect three offshore wind farms to land in the German North Sea[12]. Aibel, in cooperation with Hitachi, manufactures and assembles offshore HVDC platforms. Fred. Olsen Wind-carrier are a leading provider of transport, installation, and service solutions for offshore wind farms. As floating wind scales up together with the development of a subsea grid in the North Sea, the subsea competence and experience of oil and gas companies and their sub suppliers will become increasingly important for offshore wind.

The research facilities and wind energy expertise are significant among the five countries. DTU, TNO, Fraunhofer, SINTEF and KU Leuven are examples of internationally leading research organisations. Test centres like Norther and Northwester in Belgium, Høvsøre and Østerild in Denmark, WINSENT in Germany and MET Centre in Norway all provide opportunities for full scale testing of wind turbines. MARINE in the Netherlands and SINTEF in Norway operate world-class ocean basin laboratories for testing and development of marine structures.

World-class expertise and the supplier industry necessary for wind power development are already available in Europe, but their further success will

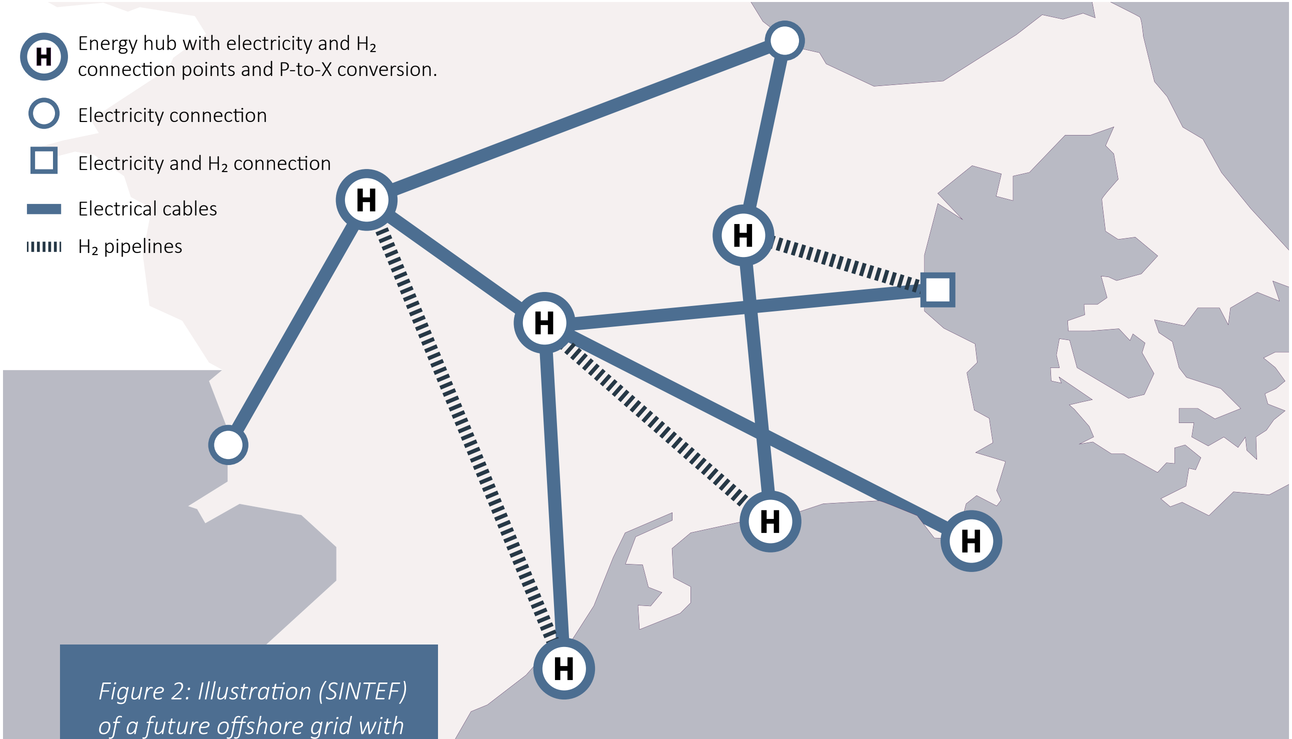


Figure 2: Illustration (SINTEF) of a future offshore grid with transmission of electricity and hydrogen.

depend on the ability to scale up exponentially to meet ever-growing demands. This is valid both for the wind industry and adjacent sectors like the electricity grid and hydrogen infrastructure.

After decades of limited grid construction across Europe, the grid supplier industry has been significantly reduced. That includes both production facilities and skilled manpower for design and construction. While production facilities are insufficient, but scalable, access to raw materials is another important concern. Metals and minerals have been sourced to a large degree outside Europe and from single-country suppliers. The EU Critical Raw Materials act[13] sets the strategy for increased self-sufficiency and reduced risk in supplying the necessary materials for the green transition. The Fen Complex in Norway is one example of possible rich deposits of rare earth materials in Europe[14].

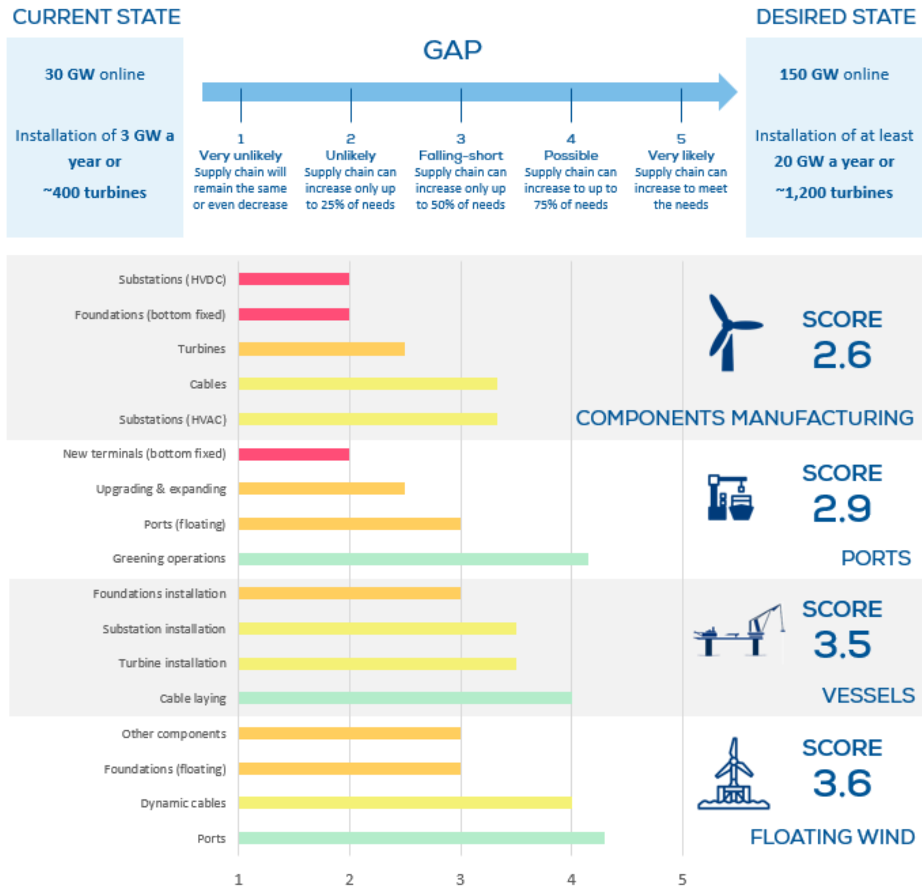
The offshore grid development includes massive investments and technology development for transmission of both electricity and hydrogen (Figure 1), e.g. Tennet recently announced a contracting package of about 30 billion EUR for a total of 14 offshore grid connection systems[15], and the H2opZee project plans to build electrolysers with a capacity of 300 to 500 megawatts far out at sea to produce hydrogen in the Dutch part of the North Sea[16].

Facilitating smooth and coordinated processes for grid development permitting is crucial to get the wind power to shore and to the consumers. To be able to establish an offshore, mainly HVDC-grid in the North Sea, ensuring interoperability and establishing grid codes for operation is a tremendous task where the research community and governments will have to collaborate.

A summary of the status, challenges and opportunities of the European offshore wind supply chain is shown in Figure 2. It shows clearly that the supply chain needs to be developed to be able to deliver on Europe's ambitions for offshore wind. The starting point is indeed very good. Europe has an excellent foundation for success within the offshore wind industry and is able to deliver on its ambitious goals. Success however is not given, and to achieve that within a limited timeframe with shortage of manpower, facilities and raw materials, collaboration between researchers, businesses and governments is the key.

Summary of findings

Part 1. GAP Analysis



MAIN OUTCOMES

Under current market conditions and without further support **Europe's supply chain could only deliver half of the gap needed to deliver the 2030 targets.** But even this might be further limited by foundations and ports which have the lowest scores of all, indicating the largest gaps.

Feedback from workshop participants on the current and desired state of the supply chain:

- The **current supply chain capacity** is now **600 foundations a year** (updated after the workshop from 250-300).
- **Global manufacturing capacity of 7 GW in ideal conditions, however size restricted** (e.g., not for 12+ MW turbines).
- **3-4 ports for floating are enough** (updated from 6).
- **5 new terminals in strategic locations** (updated from 15-20).
- **Vessel cost assumptions have increased 30% on average**, except for **substation installation vessels** which **are now more than double the cost**.

Main outcomes of the gap evaluation to deliver targets:

- **Foundations and turbines** are the components that **need the most urgent manufacturing expansion.**
- **Ports will be scarce, and they have the longest permitting lead time (~7 years).**
- **New vessels for installing foundations and turbines** are the most complex and need to be ordered as soon as possible (~3-4 years lead time).
- **Raw materials** (copper, steel, etc.) **and technician availability can delay project delivery.**

Figure 3: Summary of offshore wind supply chain workshop, 2023[17], organised by Wind Europe.

Industry research and innovation

The five countries together have world leading industries covering the full offshore wind value chain. This includes wind turbine manufacturers and subsuppliers, but also large offshore companies that are transitioning from oil and gas to offshore wind and other new markets.

Coinciding with the fact that the same countries are among the world's most ambitious offshore wind developers, this makes for an enormous business opportunity.

The competition is strong around the world, and several markets are fighting for position in global green industries. The American "Inflation Reduction Act" has made it very lucrative for green businesses to establish themselves in the United States. The EU has responded to this with the "European Green Deal".

Research and innovation are paramount for the industry to be competitive. This was highlighted at a recent meeting between the industry-driven European

Technology and Innovation Platform on Wind Energy (ETIPWind) and the Chief Technology Officers from the wind industry's leading companies (Figure 3)[18]. Their priorities on offshore wind may be summed up as follows:

- Societal acceptance and environmental design of offshore wind are a "licence to operate". Recycling, circularity, space constraints and shortage of labour need to be addressed.

- Technology and solutions must be developed for efficient and stable operation of the power system with large amounts of offshore wind and other variable generation. Important challenges include grid forming capabilities, flexibility, digitalisation, hybrid plants and long-term storage.

- The offshore wind technology, bottom-fixed and floating, must be developed and industrialised, including logistics of large components, automation of manufacturing, and O&M issues. Floating wind is at an early stage of development but with a huge global potential.

These topics are further described in the following subsections.

Figure 4: Meeting between ETIPWind Steering Committee and CTOs of leading wind industry companies at Wind Europe Annual Event in Copenhagen April 2023.

Sustainability

Sustainability is an overarching theme and paramount for the success of offshore wind development. New knowledge and solutions are needed on circularity, eco-friendliness, and social acceptance. Important issues are spatial planning, multi-use of the sea, interaction with other industries, and design of solutions to improve marine life and minimise negative impacts on ecosystems. Strategies need to be developed that that maximise social acceptance and positive socio-economic impact.

Societal acceptance, mutually beneficial co-existence with other users of the sea and environmental design that minimise any negative impact of offshore wind are ”licence to operate”, and companies mastering this will have a competitive advantage. The trend is clear and rational: Competitions on wind farm developments are moving from almost only focusing on cost, to include in the competition environmental impact, co-existence, and possibly other aspects such as grid support capabilities. The current European (EERA JP Wind[19]) research agenda on sustainability is summarised below.

3. Research gaps

Sustainability, Social Acceptance, Economics and Human Resources

Identifying how wind energy can create even higher value for society, both on the market side (high value energy at low cost), on the societal side (maximising socio-economic benefits, avoiding negative impacts), depending on the interactions between market, technological, environmental issues within the overall policy and regulatory framework.

Assessing and quantifying the contribution of wind energy to the UN Sustainable Development Goals (SDG), and their broad array of indicators.

Developing technologies and designs to improve recycling and end-of-life solutions.

Identifying skills and training needs required for developing and handling future wind turbine designs and develop best practices for high quality training programs.

Assessing the economic and societal impact of research and innovation projects for wind energy.

Applying life-cycle assessment and estimating requirements of resources for the energy transition, including the availability of resources in power systems with very high shares of wind energy.

Transferring the understanding of mechanisms behind social acceptance into implementable approaches and demonstrating their value for project realisation.

Key action areas

IDENTIFY THE MOST PROMISING AREAS FOR VALUE CREATION BY WIND ENERGY IN THE FUTURE	Assessment of new ideas such as alternative routes to market (e.g. through hydrogen production), regulation and market design (e.g. to reduce barriers, adequate financial mechanisms to support wind investment), new business models (e.g. aggregator services), profit-sharing mechanisms (e.g. local ownership schemes).
STANDARDISED METHODS FOR QUANTITATIVE IMPACT ASSESSMENTS IN RESEARCH PROJECTS	Develop a method for broader socio-economic impact assessments to support prioritising technology innovation activities and project funding decisions (including cost indicators and value creation indicators).
RESEARCH-BASED AND TARGETED CONTINUING EDUCATION AND TRAINING	Identify industry needs and required research-based education and training actions to develop adequate human resources with the right skills and competences that are key to Europe's continued global leadership in wind energy. New skills are required as the technology evolves.
RECYCLING AND CIRCULAR ECONOMY	As wind power increases its share in the energy mix, it needs to address issues related to its environmental and social footprints. An environmental and community friendly design also includes the 'afterlife' of a turbine. We need to develop technologies that are easily recyclable, create designs that are good for recycling and embrace circular economy concepts in our research and development.
SHOW-CASE BEST PRACTICES TO EMPOWERING CITIZENS AND PUBLIC ENGAGEMENT IN WIND POWER PROJECTS	Extensive wind onshore deployment is increasingly impacting citizens, who need be included in the planning and design process. During the past years, we have started to understand mechanisms and solutions for effective participatory processes and create acceptability. We now need demonstration projects on how to build the 'acceptable' onshore wind plant.

Figure 5: EERA JP Wind research agenda on sustainability (2020 edition, in revision).

Large-scale integration

The integration of the enormous offshore wind resources in Europe is a key for the decarbonisation of the energy system. The 2050 target of 300-450 GW means to move offshore wind from being a rather marginal source of energy (25 GW in 2020) to supply about 35 % of the electricity demand. This represents a fundamental change in the European power system, and the European Network of Transmission System Operators for Electricity (ENTSO-E) has identified five pillars for a successful offshore development[20]. These are:

- Holistic planning and timeliness
- A modular and stepwise approach based on consistent planning methods
- Interoperability, unlocking smarter integrated and secure system operations
- Keeping energy bills and environmental footprint low through innovation
- A future-proof regulatory framework

Research and innovation are needed to secure the development of:

- **offshore grid infrastructure** to transport massive amounts of energy from the offshore wind farms to supply domestic and industrial loads,
- new solutions for the **operation and design of the offshore wind farms** to enhance their contribution to the stable operation of the power system,
- new **flexibility technologies** to ensure a reliable supply of energy independently of wind and demand variations, including offshore wind energy **coupled to hydrogen** production and other power-to-x technologies.

A case for using the NorthSea as the springboard for the green transition was presented at COP26[21].

The current European research agenda on grid integration is summarised on next page.

Floating wind turbines near Gulen, Norway, undergoing the last preparations before being towed out at sea to the Hywind Tampen floating wind farm.

Photo: Daniel Albert, SINTEF

2. Research gaps

Grid integration and energy systems

Validated energy systems models for assessing the value of wind power with 100 % variable renewable energy supply. Various scenarios / hourly timestep models exist, but with more or less crude assumptions, e.g. on wind variations, balancing capabilities, regional transportation bottlenecks, etc. New methods, metrics and tools to assess the adequacy of supply.

System friendly wind power. Wind power plants need to move towards being the backbone of the electricity system, being able to provide services like grid forming and black-start.

Behaviour and control of large HVDC connected clusters is vital for enabling future development of large interconnected offshore grids, serving to connect wind farms to different national markets and offshore loads, as well as power/energy exchange between regions. Essential aspects are strategic grid planning, optimal power flow, reliable operation and protection schemes and supporting the interconnected terrestrial grids.

Dynamic performance of very large wind power clusters needs to maintain power quality and stability in offshore wind farm grids that are fully based on power-electronic converters in order to guarantee reliable and efficient wind farm operation.

Degradation and failure mechanisms of cables, transformers and power electronic converters call for extensive research and testing to be fully understood and enable reliable grid solutions, including mitigating measures.

Advanced system services from wind power, providing reserve power for frequency support, reactive power for (dynamic) voltage support, mitigate or actively compensate harmonics for maintaining power quality and providing black start (grid forming operation) for increasing security of supply and helping system restoration, etc.

Key action areas

DESIGN AND CONTROL OF WIND POWER PLANTS FOR 100% RES POWER SYSTEM

Technical solutions for wind power plants to enable safe and efficient power system operation with 100% renewable generation.

POWER MARKET DESIGN, ENERGY MANAGEMENT AND BALANCING

The energy system transition requires development of tools for energy management, taking into account wind forecast uncertainty, and supporting the interaction between wind power, other generation, conversion and storage, demand-response and grid capacity limitations.

SUSTAINABLE HYBRID SOLUTIONS, STORAGE AND CONVERSION

Combining wind with other renewables, utilizing complementary generation patterns, contributes to improving the security of supply and lowering grid integration costs. Conversion and storage is essential to realize the required generation flexibility and security of supply, both in the short term as well as seasonal. Furthermore, integrating of these solutions in offshore wind farms is needed to facilitate their large-scale and economic integration, including off-grid approaches, i.e. using gas or other alternative energy carriers.

INCREASED PERFORMANCE OF WIND POWER VIA DIGITALIZATION

Use of field data, big data analytics and AI combined with system modelling for monitoring, control and performance optimization of wind power in the energy system.

OFFSHORE ENERGY HUBS

Development of energy hubs for offshore wind will lower the cost, augment inter-connection capacity and increase the resilience of the power system.

Figure 6: EERA JP Wind research agenda on grid integration (2020 edition, in revision).

Offshore wind technology

Offshore wind technology has been in rapid development during the last decade, and large bottom-fixed wind farms have been put in operation to constitute a global accumulated capacity of 63 GW by the end of 2022[22]. There is still very significant need for research and innovation to further develop the technology and bring down the cost. Floating wind presently constitutes of only a handful of pilot and demonstration projects. The cost is maybe twice the cost of bottom-fixed at the moment, but can be reduced to be on level with bottom-fixed by development of the supply chain and the technology. The potential is huge. The IEA[23] estimates that floating wind accounts for 80% of the global offshore wind potential and can potentially generate 14 times the global electricity demand. Realistically, the expectation is that about one third of the offshore capacity to be installed in Europe will be floating by 2050, i.e. about 100 GW. Floating wind 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.

The current European research agenda on offshore wind is summarised on next page.

Figure 7: Final blade being installed at 1.5 GW Hollandse Kust Zuid.

4. Research gaps

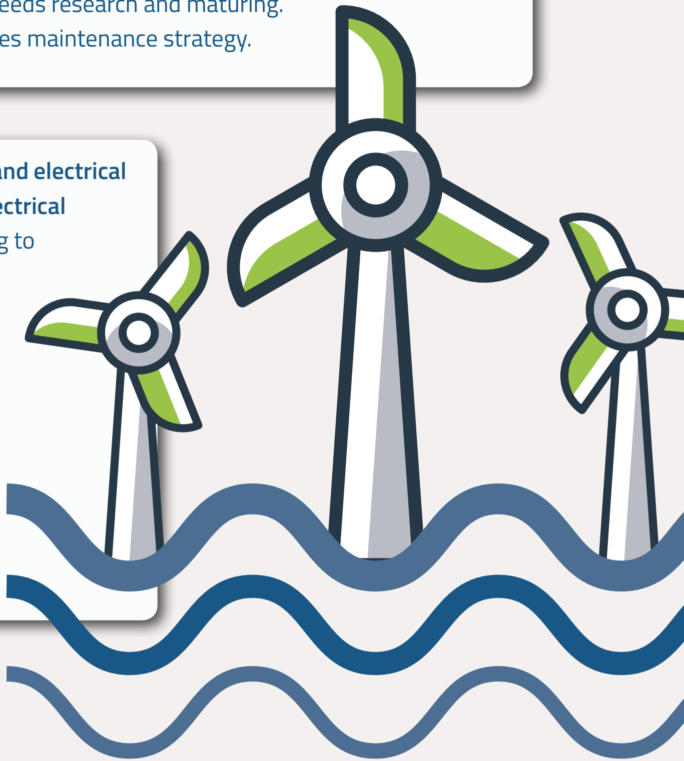
Offshore wind (bottom fixed + floating)

Validation of integrated design models for floating wind plants is needed to ensure cost effective designs and to maximize the opportunities for floating foundations optimization based on wind turbine load control technology.

Offshore physics (soil damping, breaking waves, soil-structure-fluid interaction, air-sea interaction). The limited understanding of physics phenomena and model uncertainties affecting offshore balance of plant technology prevents accurate design models and optimal cost-effective designs. Proper data sets are lacking.

Efficient multi-disciplinary optimization offers to achieve cost effective and reliable foundations, accounting for a wide range of design parameters and needs research and maturing. Platform and mooring lines maintenance strategy.

Site-specific structural and electrical design conditions for electrical infrastructure are lacking to better understand the loading and operational conditions of key electrical components like cables or power converters, enabling improvements in reliability.



Key action areas

ENABLING FLOATING WIND

Develop design model for integrated aero-hydro-elastic optimisation including cost optimisation. Develop technology to enhance mass-production and installation of floating platforms. Develop smart and disruptive solutions for (dynamic) mooring.

EXPERIMENT FOR VALIDATION OF DESIGN AND MULTI-DISCIPLINARY OPTIMIZATION MODELS FOR OFFSHORE WIND FARMS (FLOATING AND FIXED). CREATING OPEN ACCESS DATA SETS

Execute large-scale floating experiment to create open access experimental datasets for effective design model validation and uncertainty calculations, leading to faster improvements of design tools and more accurate designs. Develop an effective coupling of offshore design models (i.e. balance of plant - wind turbine) and metocean models to enable overall system optimization.

UNDERSTANDING AND MODELLING OFFSHORE PHYSICS FOR WIND FARM DESIGN AND OPERATION

The improvement of models focused on key physical phenomena (i.e. soil-structure-fluid interaction) is needed to develop better design tools for industry, able to capture a broader spectrum of failure modes.

UNDERSTANDING THE MECHANICAL AND ELECTRICAL DESIGN CONDITIONS FOR ELECTRICAL INFRASTRUCTURE FOR FLOATING WIND FARMS

Develop more accurate and site-specific load models accounting for metocean conditions (i.e. hydrodynamic forces on dynamic cables) as well as the electrical operational conditions and interactions for improved layout including connections, transformers and inter-array cables.

DEEP SEA FAR OFFSHORE LOCATIONS

Call for new cost-effective solutions for grid connection of floating wind farms, and design of electrically isolated power to X wind farm systems. New knowledge, models and solutions should be developed for inter-array solutions, subsea technologies and solutions for transmission, including alternative wind farm designs for power to X.

IMPACT ON SEA-LIFE AND POSSIBILITIES FOR MULTI-USE

Should be assessed, and models and solutions for environmentally friendly holistic design and operation of offshore wind farms should be developed.

Figure 8: EERA JP Wind research agenda on offshore wind (2020 edition, in revision).

Collaboration: European Centre of Excellence

Collaboration is an absolute necessity to succeed with the European offshore wind ambitions. Industry, authorities, and research need to pull together in a joint international effort. Collaboration is already ongoing through projects and networks but needs to be enhanced. Specifically, the European Energy Research Alliance Joint Programme on Wind Energy, EERA JP wind, is in development to become a European Centre of Excellence (ECoE) on Wind Energy.

EERA JP Wind brings together about 50 major research organisations and universities in Europe within wind energy.

EERA JP Wind is an excellent network. It represents a unique pool of knowledge, capabilities, and research facilities, and it has been successful in preparing a joint research strategy and communicating research needs to the European Commission.

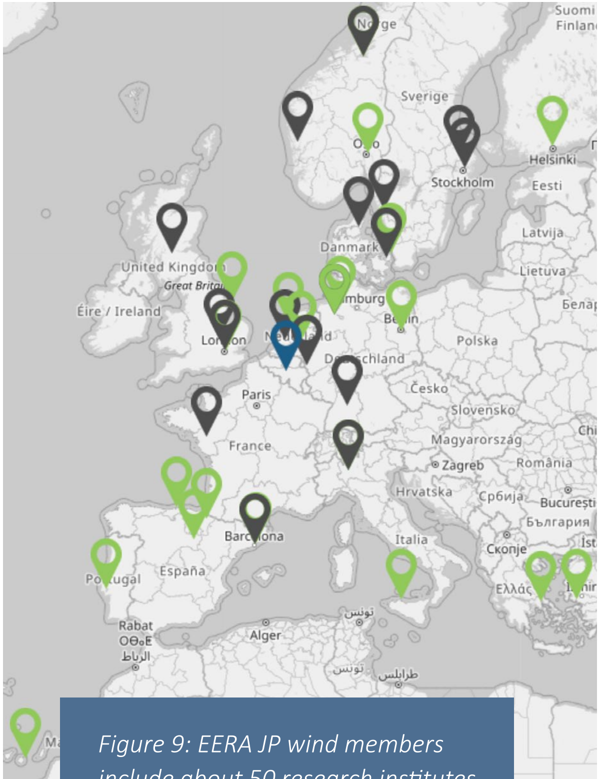


Figure 9: EERA JP wind members include about 50 research institutes and universities across Europe.

EERA JP Wind is organised with a General Assembly (GA), a Steering Committee (SC), and a management team. The management team handles the day-to-day operation and activities according to mandate by the SC. The activities are organised into eight subprogrammes, though under revision as part of the process of transforming into a ECoE.

The **objective of the ECoE** is to foster more efficient international collaboration on research and innovation, thereby saving costs and accelerating the development to meet European targets.

The ECoE will build on the already existing collaboration between leading research and industry partners in Europe, but strengthened with a more mission-oriented structure rather the current ad-hoc project-by-project approach. Project management would be aligned, and open results would be shared. In summary, the ECoE will:

- Facilitate the collaboration on wind energy research across Europe, including collaborative research projects within a co-funded research programme;
- Enable an effective planning of wind energy research, including the European Union, national and regional levels;
- Develop and maintain a research program for wind energy extending until 2050;
- Monitor the status of wind energy research in Europe;
- Accelerate the development of wind energy to achieve the green transition goals.

The ECoE will be developed in a stepwise approach in which it may start as a pilot with a limited scope and participants, but in the long run evolve to include all members and to address the full scope of EERA JP Wind.

The expected outcome is to maintain long-term European leadership in wind energy research by enabling effective coordination, collaboration, and funding leverage.

Figure 10: EERA JP wind summary of ECoE.

Notes

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