Proposal for European lighthouse initiative

INTEGRATION OF LARGE-SCALE OFFSHORE 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 JPWIND 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.

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Summary and introduction

This report presents a proposal for a European lighthouse initiative on integration of large-scale offshore wind energy. It includes three main sections, namely Excellence, Impact, and Implementation.

The term "lighthouse initiative" 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 initiative on integration of large-scale offshore wind energy. In short, the reasoning is that offshore wind energy is identified as crucial to reach climate goals and can supply large amounts of clean energy [1] and in Europe plans indicate that by 2050 offshore wind will supply about 35 % of the electricity demand. Compared with the situation of today, this represents about a twentyfold increase in the offshore wind capacity and will make offshore wind a dominating source of energy in Europe. It will cause a fundamental change in the European power system and require research and innovation to secure the development of offshore grid infrastructure, new solutions for the operation and design of the offshore wind farms, new flexibility technologies and offshore wind energy coupled to hydrogen production. **Large scale integration of offshore wind is essential to reach climate targets, to secure the energy supply and to enhance a competitive European industry** that will bring new green jobs and business. European industry and research are in the lead of the development, though to stay in the lead, an enhanced effort on research and innovation as proposed here is required.

The section on Impact explains the value of the proposed lighthouse initiative. To reach the EU ambitions for offshore wind development by 2050, investments in the order of 800 billion EUR are expected [2]. The lighthouse initiative will provide knowledge and solutions that will ensure the development to be prepared in a sustainable and economic manner. A marginal 1 % saving in investments represents 8000 million EUR and is about 200 times the cost of this proposed lighthouse initiative on integration of large-scale offshore wind energy. In addition to this comes value from more reliable and efficient operation of the power system, 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 initiative and how it can be realised 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 initiative should come with an extended budget and duration.

The main objective for the proposed lighthouse initiative is to develop solutions to ensure reliable and affordable power system operation with offshore wind energy to supply one third of the European electricity in 2050. The research and innovation will develop solutions for offshore wind farms, grid infrastructure and flexibility technologies to ensure the future zero-emission European power system will be reliable and affordable.

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.

Excellence

This section gives the state-of-the-art and reasoning behind the lighthouse project proposal on the integration of large-scale offshore wind energy.

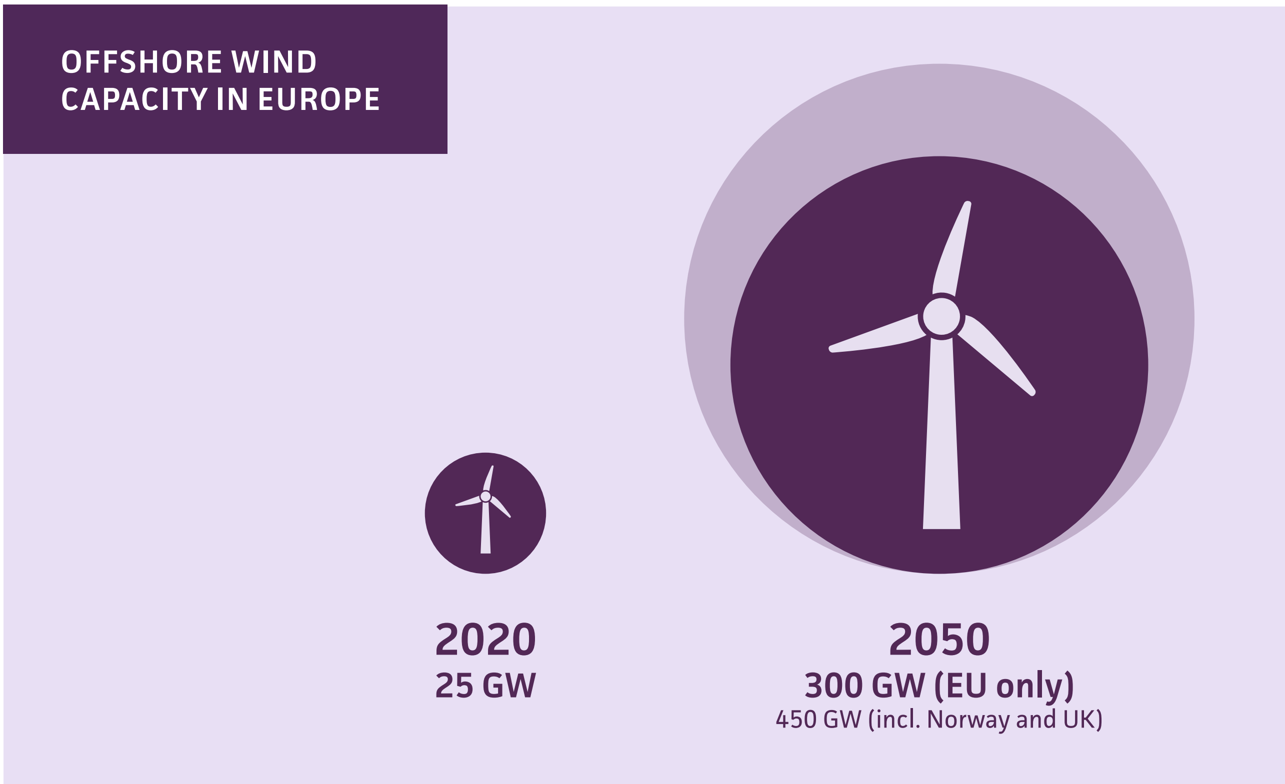
Europe towards net-zero emissions by 2050 – 'Fit for 55, set for 2050'

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. The desired greenhouse gas emission reductions are even more challenging in the light of the expected 50% increase of electricity consumption by 2050.

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 the UK and Norway, that may bring total European offshore wind capacity close to 450 GW by 2050 [3]. This corresponds to about 35 % of the electricity demand. In comparison, offshore wind capacity in Europe by the end of 2020 was 25 GW [4], supplying only a marginal part of the electricity demand. This expected development of offshore wind represents a fundamental change in the European power system. Such a change comes with a need for research and innovation to secure the development of:

Sheringham Shoal Wind Farm.

Photo: Jose Vega-Lozano © Equinor



- **offshore grid infrastructure** to transport massive amounts of energy from the offshore wind farms to supply domestic and industrial loads [5, 6, 7],
- new solutions for the **operation and design of the offshore wind farms** to enhance their contribution to the stable operation of the power system [8, 9],
- new **flexibility technologies** to accommodate for reliable supply of energy independently of wind and demand variations [10, 11],
- offshore wind energy **coupled to hydrogen** production to help decarbonise the energy system [12, 13]

A case for using the NorthSea as the springboard for the green transition was presented at COP26 [32].

Wind energy hub Europe - from research to leading companies

As many European countries are developing offshore wind, the issues that come with it in the context of massive deployment and operation are best tackled at a European level. The paradigm shift of going from individual offshore wind farms connected to their 'home' countries to **large offshore power clusters interconnected to each other** – all the while safeguarding the reliable operation of an interconnected European power system – requires knowledge development at a fundamental level.

The research and development field of wind power integration has traditionally been based on the concept of an existing (thermal power station based) power system into which new wind farms are added as external inputs. This mindset has served the community and industry well for decades, but it will not provide a suitable basis for Europe's ambitions towards 2050. In a future sustainable and decarbonised energy system, wind power will not be "input to the system" or "integrated into the system" but will be supplying a major share of the demand. To facilitate the conceptual change of the role of **offshore wind power**, from "input to the system" towards "**foundation of the system**", new challenges [14, 15, 16] arise that demand solutions which cannot be derived as incremental steps from the state of the art of wind power integration and the traditional wind power integration mindset. Fundamental conceptual changes require fundamental research.

Fortunately, Europe has an excellent research community and a leading industrial community. Clear proofs of this well-established community are EERA JP Wind, ETIPWind, EAWE and the great participation and leadership of different European institutions on the IEA wind tasks. To maintain European leadership and 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 realising 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 **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 large-scale integration of offshore 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 initiative are paramount to reach this ambition.

Offshore wind energy will be the cornerstone of Europe's future energy system as massive amounts of wind energy need to be fed into the energy system, sent to shore and provided to the market at a suitable price. We need to develop the solutions that are necessary for **offshore wind power to become the backbone of the future European energy system**. As part of this, we suggest developing new solutions for the operation and design of the offshore wind farms to enhance their contribution to the stable operation of the power system. We expect this to include solutions for offshore wind farms to have black-start capabilities [19] and fast frequency response [20, 21], but also to develop advanced control and monitoring systems that will both greatly improve the prediction of power production and markedly optimise the operation of wind farms.

The future European energy system will likely be a hybrid system in which electricity and hydrogen (or other energy carriers) operate together in a closely **integrated energy system**. Using offshore wind power to produce hydrogen is one option; another is to use offshore wind farms as a power supply for extracting hydrogen from natural gas with carbon capture and storage. The use of **hydrogen provides for system flexibility** to ensure a reliable supply of energy independently of wind and load variations. Other options for achieving system flexibility include load management, controllable generation, energy storage, grid development and sector coupling [22], such as using coupling with the transport sector. Offshore wind farms can be developed to produce hydrogen or ammonia as a fuel for zero-emission ships and other needs within transport or industry processes. There is already a large system of pipes to transport natural gas between countries (such a network is in place in the North Sea), and this may be used in a future **offshore grid infrastructure combining electricity and gas**, see also figure on next page. This lighthouse initiative will assess such combined offshore grid infrastructure and provide knowledge, tools, and technologies to accelerate the sustainable development of such an infrastructure.

To summarise, our ambitions are to
- develop circular and ecology friendly solutions for the wind energy industry
- assure and maintain European leadership
- develop technologies for a wind-dominated, European energy system
- develop technologies for wind energy conversion and storage among which using hydrogen
- control wind energy input optimally for a stable power system

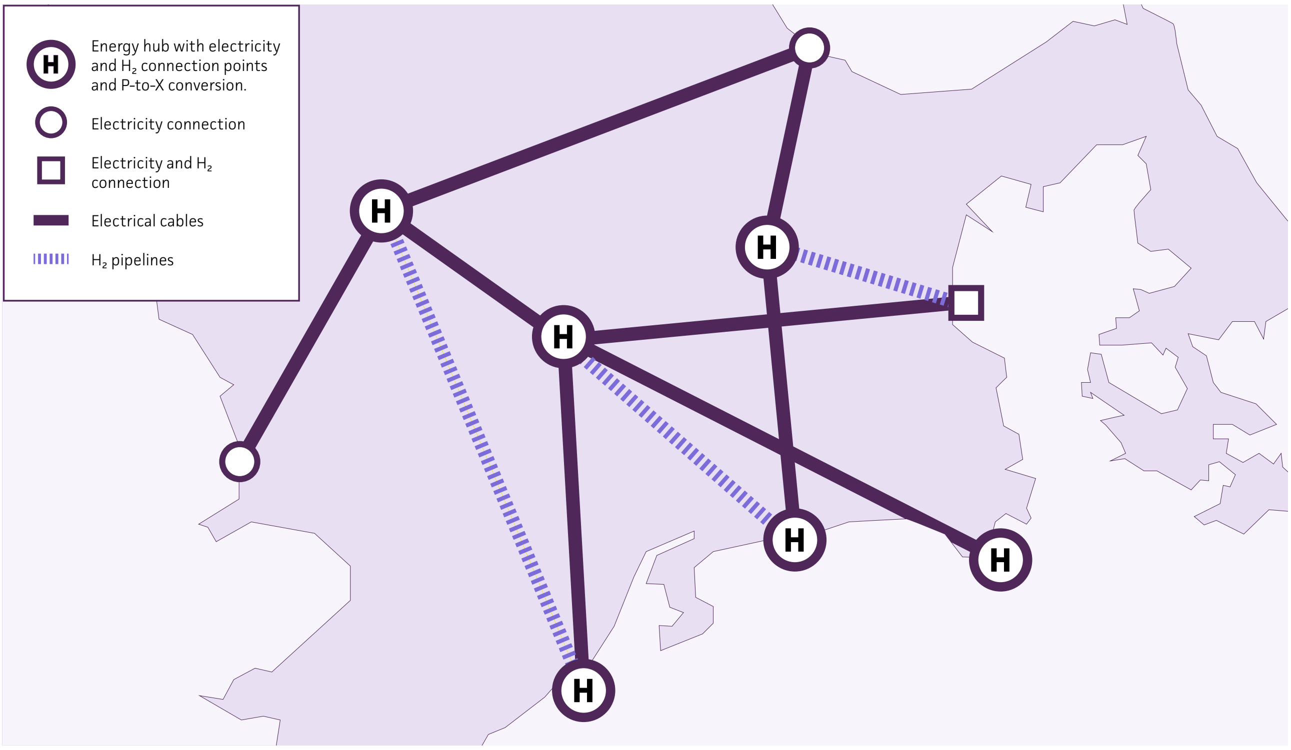


Illustration of an offshore grid with transmission of electricity and hydrogen.

Value proposition

Over the last decade, bottom-fixed offshore wind energy in Europe has seen a **drastic cost reduction**. In 2010, the levelized cost of energy (LCoE) was around 190 €/MWh and the sector targeted a cost reduction of 40% in 2020, at around 115 €/MWh [13]. Reality is that developments went much faster and nowadays we see prices as low as 49 €/MWh with several subsidy-free tenders in the Netherlands and in Germany. One can safely say that offshore wind is cost-competitive with electricity from fossil fuels, at least in the shallow coast of the North Sea.

Several factors played a role in this development, such as a maturing market, favourable market conditions and policy making. R&D also played a significant role. For example, the research in design tools [23, 24] 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.

As argued above, with this lighthouse initiative we aim for a zero-emission, reliable and affordable wind-dominated European energy system. At the wind technology level, great cost reduction has been achieved – and the costs will continue to drop. But significant cost reductions can also be achieved on the system approach level. The ENTSO-E's Ten-Year Network Development Plan 2020 [25] points out that by addressing system needs 110 TWh of curtailed energy can be saved each year and 55 Mtons of CO_2

Hywind Tampen floating wind farm.

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emissions can be avoided each year until 2040.

To reach the EU ambitions for offshore wind development by 2050, investments in the order of 800 billion EUR are expected [2]. The lighthouse project will provide knowledge and solutions that will ensure the development to be prepared in a sustainable and economic manner. A marginal 1 % saving in investments represents 8000 million EUR and is about 200 times the cost of this proposed lighthouse project on integration of large-scale offshore wind energy. In addition to this comes value from more reliable and efficient operation of the power system, new green jobs in industry and supply of goods and services to markets outside Europe.

The value of this lighthouse initiative is also coupled with the case of hydrogen production, transport and use. In the future energy system, electricity and hydrogen will likely be much closer tied together to form an integrated energy system [26, 27]. Production of hydrogen can be utilised as a controllable load to support balancing of demand and generation in the power system. The same goes for use of hydrogen to generate electricity. Hydrogen is also attractive as a means to transport large amounts of energy, and can be an alternative to HVDC transmission. The efficiency of conversion between hydrogen and electricity is however limited, thus, to maximise power system efficiency, the research suggested in this lighthouse proposal to enable offshore wind power to be the cornerstone of the future energy system is paramount.

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 research about the integration of large-scale offshore wind energy. There is currently a lack of knowledge, which must be solved to succeed in the development of offshore wind. This will be the focus of the **light-house initiative** 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 offshore 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 offshore 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 the integration of offshore 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 realise 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 [29] and EERA JP wind [30], and IEA Wind TCP [28], and it has been developed through dialogue, workshops and meetings with key stakeholders both from industry and research, see also [18].

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 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 will facilitate creating synergies. This stresses the overarching position of this lighthouse initiative.

2. Open access to data

To increase the impact of the initiative, we suggest further stimulating knowledge sharing by facilitating full and open access to the research results. All knowledge developed in the initiative (publications, tools, methods, data, etc.) should be made openly available to all European stakeholders according to the FAIR principle. The initiative should also create the tools and means necessary for researchers to share, discuss and disseminate findings with their peers.

Gaining access to data from commercial wind farms and grid systems 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 in existence 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 and will be an important facility for investigating wind farm operation and control for supporting the power system operation and stability. The 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.

3. Sustainable development

This is an overarching theme and paramount for the success of the offshore wind development. The initiative will develop knowledge and solutions on circularity, eco-friendliness, and social acceptance. Emphasis will be on issues related to spatial planning, multi-use of the sea space, interaction with other industries, and design of solutions to improve marine life and impact on ecosystems. Strategies shall be developed that that maximize social acceptance and positive socio-economic impact.

4. Flow physics of wind farms

The flow physics of wind farms is grand research challenge [28]. There is a need for a better understanding of linking the meso- and microscale weather processes, and to close knowledge gaps related to atmospheric conditions, wind-wave interactions and modelling of wakes [39]. In the lighthouse project, we suggest addressing these challenges, with particular emphasis on studies to better predict and control the operation of the wind farms to provide a reliable energy supply and an enhanced power system stability.

5. Grid connection

The future offshore grid will be a complex system. There are economic and technical risks. If it's not properly designed, there can be stability issues. An optimisation approach considering multi-stage investments and uncertain parameters will enable better here-and-now offshore grid investment decisions with lower economic risks. The issue represents a grand research challenge [28].

Development of an optimisation model to provide decision support for a stepwise offshore grid buildout including offshore energy hubs and hybrid AC/DC grids is suggested as an important research task. The purpose of the model is to identify good here-and-now investment choices considering uncertainties and the long lifetime of the infrastructure. A multi-stage stochastic mixed-integer linear programming or alternative approaches may be applied. Relevant uncertainties to consider includes future connected wind capacity, hydrogen demand, power wholesale prices etc. [40].

To design and optimally operate the future European grid, we need to understand the wind turbine's behaviour and that of its components. At a higher level, we need to develop technologies for connecting offshore wind farms to each other, to energy hubs and to the shore. As such, we foresee a future power-electronic-converter-based grid, and we will assess the demands and design requirements for it. HVDC interoperability of a multi-vendor offshore transmission grid is a key challenge to be addressed [37, 38, 41, 44].

The future offshore energy system will include both bottom-fixed and floating wind farms. The grid connection of the latter requires dynamic electrical cables, and either floating or subsea substations to connect the wind farm to the offshore transmission grid [34]. Subsea collection systems for grid connection of large floating wind farms are new technology in development and an important area of research. Solutions for long HVAC transmission as an alternative to HVDC should also be investigated as a possibility for reducing costs in the development of future offshore grid [35].

Faults in offshore grid components such as cables, transformers and high-voltage direct current (HVDC) converters can be critical and bring loss in revenue. There are big potential gains to be achieved by being able to predict component failure. Therefore, we suggest investigating the degradation and failure mechanisms of cables, transformers and HVDC converters to enable reliable grid solutions. This will include the use of digital twin technology and AI to give a real-time estimate of the time to failure of key components.

We need to be able to model the power system at a high resolution. This will allow us to simulate a power system with large amounts of offshore wind energy and observe the effects this has on balancing and flexibility in the system. Accurate models of electric components in offshore wind farms and the connected system are needed for harmonic interaction and stability analyses [31, 42, 43, 45, 46]. Such high-fidelity models are essential to ensure proper system design and smooth operation of large complex offshore grids.

6. Control

The use of advanced control systems and digital solutions are key enablers to achieve reliable and efficient operation of the future power system. The possibility to control the wind farms not only to maximise their individual energy output, but to operate in an individual or collective manner to improve the power system performance, should be investigated. Research should also address enhancement of wind farm support to grid stability, including damping of power oscillations, support of grid frequency and grid-forming capability of large-scale offshore wind farms [33]. The control of the wider grid and power system assets, such as HVDC converter stations, energy storage, demand flexibility, hydrogen etc. are also important areas of research.

7. Market solutions

An understanding of the implications of potential energy market designs and sector coupling is needed for assessing profitability of offshore wind farms and the development of an offshore grid. Stronger interaction between power and hydrogen will emerge, and system modelling needs to account for both conversion technologies as well as transport and transmission infrastructure. An important goal of the research will be to quantify the impacts of different market designs for offshore infrastructure developments, including a European context and effects of price variations on wind farm profitability. The initiative will also be assessing new markets and market models and developing a market system for a 100 % renewable energy system potentially leading to new definition and new design of ancillary services.

8. Power to X

In designing the electrical infrastructure, we must take into account sector coupling. Specifically, the initiative will consider what technological requirements wind energy puts on conversion to hydrogen, or other power to x options. Similarly, it will develop technologies to add storage options like batteries, pumped hydro subsea storage or compressed air. The re-use of the existing gas infrastructure and the connection to offshore hubs either floating, bottom-fixed, subsea or in the form of artificial islands or energy islands, are also relevant topic of research. Small-scale demonstrations will show the validity of the explored technologies. Special emphasis is suggested to be put on modelling the effects of an emerging hydrogen market with the associated grid infrastructure, including the interaction between power and hydrogen to represent the inherent flexibility and market effects. It is assumed that hydrogen becomes an intrinsic part of an integrated energy system with large scale investment in offshore wind production. The market should ensure optimal power and hydrogen infrastructure to transport multi-carrier energy from areas with large renewable potential to demand centres located possibly in other parts of the European energy system.

Artist's representation of a power-to-hydrogen facility connected to an offshore wind farm.

Illustration: Shutterstock


H2 HYDROGEN POWER
CLEAN ENERGY OF THE FUTURE

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