corewind

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Final market assessment and development needs

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List of abbreviations

ABS	American Bureau of Shipping
BV	Bureau Veritas
CAPEX	Capital expenditures
CfD	Contract-for-Difference
DLC	Design load case
DNV	Det Norske Veritas (Note: company name changed from DNV GL to DNV in 2021)
EBL	Electricity business license
EIA	Environmental impact assessment
FLS	Faitigue limit state
FOWT	Floating offshore wind turbine
LCOE	Levelized Cost of Energy
IEC	International Electrotechnical Commission
O&G	Oil and gas
O&M	Operations and maintenance
OPEX	Operational expenditures
RCS	Recognized classification society
RNA	Rotor nacelle assembly
TC	Technical committee
TLP	Tension leg platform
ULS	Ultimate limit state
WSD	Working stress design

1 EXECUTIVE SUMMARY

This Deliverable D7.2 provides the final market assessment and development needs report for the COREWIND project. The report is an update of Deliverable D7.1 from August 2021.

In section 3 of the report, the current state of international standards and guidelines for floating offshore wind turbines (FOWT) is reviewed. It was agreed to use the technical specification IEC TS 61400-3-2 (Design requirements for floating offshore wind turbines) and DNVGL ST-0119 (Floating wind turbine structures) as main reference standard for the concepts in the COREWIND project. The content of both IEC 61400-3-2 and DNVGL ST-0119 is presented in detail. In addition, an overview on the main similarities and differences of the guidelines of other certification bodies is given.

IEC TS 61400-3-2 specifies additional requirements to assess the external conditions at a FOWT site and essential design requirements to ensure the engineering integrity of floating offshore wind turbines. The standard is intended to be fully consistent with the design requirements for wind turbines in general and for fixed offshore wind turbines according to IEC 61400-1 and 61400-3-1:2019, respectively. Although the focus is on the engineering integrity of the structural components of the FOWT, the technical specification also addresses subsystems such as control and protection mechanisms, internal electrical systems and mechanical systems.

The DNV offshore standard ST-0119 provides principles, technical requirements and guidance for design, construction and in-service inspection of support structures and station keeping systems for floating wind turbines. DNV ST-0119 covers the structural design of FOWT structures and specifies the design principles and overall technical requirements. Wherever possible, the standard makes reference to requirements in DNV-ST-0126 for support structures for wind turbines. Provisions are given for the control systems for the floater motion and for the wind turbine, as well as for transportation, installation and inspection – to the extent necessary in the context of structural design. DNV ST-0119 does not cover design of wind turbine components such as nacelle, rotor, generator and gearbox. For structural design of wind turbine components for which no DNV standard exists, the IEC 61400-1 standard applies.

By now, only few floating offshore wind projects have been realized, mostly single-unit prototypes or first demonstration and pilot projects. Consequently, there has not yet been the need for country-specific regulations for floating offshore wind projects. Currently, new FOWT project are therefore mainly realized on the basis of existing international standards and guidelines.

The review also includes a detailed description of the certification requirements for FOWT. As with the standards, the main certification schemes for (floating) offshore wind farms are provided by IEC and DNV.

Finally, identified gaps and challenges related to FOWT standards have been documented in the final report.

Section 4 gives an overview of identified development needs and design practice recommendations. The design recommendations of COREWIND lead to further demands on industry, as the requirements of the up-scaled 15+ MW concept for FOWT are different from current practice and experience from operational fixed-bottom offshore wind farms. Main challenges with regard to development needs have been identified from a holistic view, considering the following aspects for floating offshore wind farms, based on COREWIND designs:

- design practice
- manufacturing and pre-assembling
- transport and installation
- operation and maintenance

The analysis is focused on wind turbine, floater, mooring/anchoring and dynamic cables. Regarding design practice, it is required to develop optimized integrated designs considering wind turbine, floater and mooring. For the wind turbine, tower design and the development of advanced control systems are important aspects, while interaction between turbine and floater dynamics is of special interest for the floating substructure. For mooring/anchoring, material impact and combined/shared moorings are most relevant. Finally, there is a need for optimized solutions regarding maximum excursion limits and bending stress for dynamic cables.

With regard to manufacturing and pre-assembling, the key challenge for the industry is to establish standardization, and to build capacity that is optimized for floating wind but that today is not demanded at scale.

For transport and installation of wind turbine and floater, concepts for work between multiple floating objects are required. Incidentally, this also applies to O&M work. Furthermore, optimized solution must be developed for the installation of both, mooring/anchoring and dynamic cables. In general, a need for additional installation assets and for advanced tugs and barges was identified for transport, installation and O&M work.

Furthermore, the final status of COREWIND design practice recommendations is presented in section 4. The documentation has been provided from work packages WP1, WP2, WP3 and WP4 of the COREWIND project and specifies in detail the relevant findings.

Section 5 provides an analysis of the global market for floating offshore wind. So far, the offshore wind business is clearly dominated by fixed-bottom offshore wind farms, while only few FOWT are operational. However, the offshore wind market for fixed-bottom structures is constrained due to limited locations with shallow waters.

By the end of 2022, a total of 189.8 MW of floating wind capacity was operational worldwide. Most FOWT projects installed to date have been single-unit demonstration projects. Hywind Scotland, WindFloat Atlantic 2 and Kincardine are the first pilot projects with three to five FOWT, and Hywind Tampen, a floating offshore wind farm comprising eleven wind turbines with a system capacity of 88 MW, is currently the only precommercial FOWT project.

An overview of operational and planned FOWT projects and of current commercial offerings is presented in the report. Developments for floating offshore wind substructures can be classified in three main concepts: semi-submersible, spar-buoy and tension leg platform. Currently, more than 80 different FOWT concepts are at various stages of development. Almost two-thirds of projects in development are planned with different semi-submersible technologies, while the majority of operational FOWT demonstrators have been equipped with spar floaters.

Recently, several partnerships of big players in the energy and oil industry were formed to enter the emerging floating offshore wind sector. This trend can be seen as an important step to further develop specific FOWT concepts, to realize more pre-commercial projects and to commercialize the floating offshore wind sector.

An assessment of market opportunities in terms of monetary value, profitability, and growth potential has been added in the final report. According to ETIP Wind/WindEurope, the levelized cost of energy for floating offshore wind may decrease by 65% until 2030 and by 78% until 2050.

Following GWEC's Market Outlook, a floating offshore wind capacity of 18.9 GW is likely to be built by 2030, and it is expected that floating wind will become fully commercialized towards the end of the decade. A study published by ORE Catapult in 2022 has identified near-term floating offshore markets in Europe (Norway, UK, Ireland, France, Spain, Portugal, Poland), in Asia (South Korea, Japan, Mainland China, Taiwan) and in the U.S.

In addition to the primary option of generating and selling grid-connected electricity, floating offshore wind offers a significant potential for other energy sectors, especially for the production of green hydrogen by electrolysis and for the power supply of offshore oil and gas platforms.

The final report includes an updated review of country-specific frameworks in main global FOWT markets in Europe, Asia and America. Finally, research opportunities as well as main opportunities and threats for FOWT have been identified.

The main opportunities can be summarized as follows:

- In view of international targets to increase the contribution of renewable energies for energy supply and to decrease global CO_2 emissions, exploitation of floating offshore wind will be essential for energy transition.
- FOWT will enable to use 60% (USA) to 80% (Europe, Japan) of offshore wind resources in deep waters.
- The use of floating wind technology opens up deeper waters sites with higher average wind speeds, which improves the capacity factor and potentially the LCOE of offshore wind power generation.
- Floating offshore wind has the potential for new businesses and export for the offshore wind industry. Furthermore, it is an opportunity to provide more sustainable job alternatives to workforce from the offshore Oil and Gas and shipyards industry.
- FOWT can be installed on top of the floater at suitable port facilities and the fully assembled structure can be towed to the offshore site. This is expected to reduce installation costs significantly, as tugboats can be employed instead of expensive heavy lift jack-up and dynamic positioning vessels.

The following aspects were identified as most relevant threads:

- The pace and scale of FOWT deployment will depend on whether floating wind technology can be successfully deployed in large-scale projects to enable significant cost reductions.
- Key challenge for the industry is to build capacity for manufacturing and assembly that is optimized for floating solutions but that today is not demanded at scale. Building up the supply chain for floating wind is needed as well as huge investments in port infrastructure
- Increasing engagement of big multi-national energy firms creates a pressure on floating wind technology to deliver utility-scale power generation within a relatively short timescale. In this regard, public sector support for full-scale demonstration is seen as critical to reducing the pressure for floating wind to be deployed prematurely on a commercial basis.
- Due to the lack of operational floating offshore wind projects there are a lot of uncertainties for the evalution of the cost of a commercial FOWT project.
- The installation process for floating wind structures needs to be further refined and optimized.

2 INTRODUCTION

This Deliverable D7.2 is an update of Deliverable D7.1 from August 2021 and provides the final market assessment and development needs report for the COREWIND project. The review of existing standards and guidelines for floating offshore wind turbines (FOWT) in section 3 has been updated and completed by a presentation of certification requirements (0). In addition, gaps and challenges related to FOWT standards have been identified (3.6). In section 4, an update of identified development needs and design practice recommendations is presented, considering the progress and final status of the COREWIND project. An update of the development of the offshore wind market, current FOWT projects and commercial offerings is included in section 5. In addition, an assessment of market opportunities in terms of monetary value, profitability, and growth potential has been added in 5.4. Finally, this final report presents an updated documentation of country-specific frameworks in main global FOWT markets (0), and it identifies main opportunities and threats (5.6) as well as research opportunities for FOWT, in section 6.

3 REVIEW OF EXISTING INTERNATIONAL STANDARDS AND GUIDELINES FOR FOWT

In this section, the current state of existing international standards and guidelines for floating offshore wind turbines (FOWT) in general, with a special focus on developments concerning mooring/anchoring and dynamic cables, is reviewed.

Various international standards organizations and certfication bodies develop, publish and maintain technical standards to meet the requirements of the offshore wind industry. The respective standards are developed in close collaboration with related technical committees, which often work across countries and companies.

The most comprehensive series of offshore wind standards are provided by the international standardization organization IEC (International Electrotechnical Commission) and the classification society DNV (Det Norske Veritas). It is common practice in the industry to apply these standards. However, it should be noted that local authorities may publish additional regulations, requirements and standards.

Main IEC standards which cover wind energy generation systems are the IEC 61400-series. The most important standard for the design of wind turbine or “Rotor Nacelle Assembly (RNA)” is IEC 61400-1 (Design requirements). The standards in the 61400-series are maintained by IEC Technical Committee (TC) 88.

Besides, DNV has provided a complete set of standards and recommended practices for wind turbines. The DNV documents make use of available standards and provide additional guidelines, where subjects are not addressed in existing international standards.

An overview of relevant standards in the field of offshore wind energy is given in the table in the appendix to this report, that also includes specific guidelines, recommended practices, rules and service specifications. It should be noted that the table does not claim to be complete, and that other standards which are not wind specific may also be applied in the wind energy sector.

It was agreed to use the technical specification IEC TS 61400-3-2 (Design requirements for floating offshore wind turbines) and DNV-ST-0119 (Floating wind turbine structures) as main reference standard for the concepts in the COREWIND project.

However, a quick overview on the main similarities and differences of relevant FOWT guidelines and standards published by certification bodies/recognized classification societies (RCS) such as the American Bureau of Shipping (ABS), Bureau Veritas (BV) and Nippon Kaiji Kyokai (Class NK) is given as well. Furthermore, available information on existing country-specific regulations in main global FOWT markets are presented.

An overview of the certification of floating offshore wind turbines is presented in section 0.

3.1 IEC TS 61400-3-2 Design requirements for floating offshore wind turbines

IEC TS 61400-3-2 specifies additional requirements for the assessment of the external conditions at a FOWT site and essential design requirements to ensure the engineering integrity of floating offshore wind turbines.

The technical specification IEC TS 61400-3-2:2019 – Wind energy generation systems – Part 3-2: Design requirements for floating offshore wind turbines (Edition 1.0 2019-04) – is intended to be fully consistent with the requirements of standard IEC 61400-1:2019, Wind energy generation systems – Part 1: Design requirements and standard IEC 61400-3-1:2019, Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines.

Although the focus is on the engineering integrity of the structural components of a FOWT, the technical specification also addresses subsystems such as control and protection mechanisms, internal electrical systems and mechanical systems.

According to IEC TS 61400-3-2, FOWT encompasses five principal subsystems: the rotor nacelle assembly (RNA), the tower, the floating substructure, the station-keeping system and the on-board machinery, equipment and systems that are not part of the RNA. The following types of floating substructures are explicitly considered in IEC TS 61400-3-2: ship-shaped structures and barges, semi-submersibles, spar buoys and tension-leg platforms/ buoys. The document is applicable to unmanned floating structures with one single horizontal axis wind turbine.

The following documents are referred to in IEC TS 61400-3-2 in such a way that some or all of their content constitutes requirements of this technical standard:

- IEC 61400-1:2019, Wind energy generation systems – Part 1: Design requirements
- IEC 61400-3-1:2019, Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines
- ISO 19901-1:2015, Petroleum and natural gas industries – Specific requirements for offshore structures – Part 1: Metocean design and operating conditions
- ISO 19901-4:2016, Petroleum and natural gas industries – Specific requirements for offshore structures – Part 4: Geotechnical and foundation design considerations
- ISO 19901-6:2009, Petroleum and natural gas industries – Specific requirements for offshore structures – Part 6: Marine operations
- ISO 19901-7:2013, Petroleum and natural gas industries – Specific requirements for offshore structures – Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units
- ISO 19904-1:2006, Petroleum and natural gas industries — Floating offshore structures — Part 1: Monohulls, semisubmersibles and spars
- ISO 19906:2010, Petroleum and natural gas industries – Arctic offshore structures
- IMO Resolution MSC.267(85), International Code on Intact Stability, 2008 (2008 IS CODE)
- API RP 2FPS: 2011, Recommended Practice for Planning, Designing, and Constructing Floating Production Systems
- API RP 2T (R2015): 2010, Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms

3.1.1 Design methods

The design methodology summarized in IEC 61400-3-1 can basically be applied to floating offshore wind turbines, but the design of the FOWT support structure shall additionally include the design of the station-keeping system per clause 14 and consider floating stability per clause 15 of IEC TS 61400-3-2.

According to IEC TS 61400-3-2 a comparison of loads and deflections calculated for the specific FOWT support-structure and the specific site conditions with those calculated during the initial RNA design is required, in order to demonstrate that the RNA structural integrity is not compromised.

Structural design of the FOWT support structure shall be based on either the partial factor design format per IEC 61400-3-1, Subclause 7.6, or the working stress design (WSD) format. As per ISO 19904-1, the partial factor design format and the WSD format are treated as parallel requirements. For the fatigue design of the FOWT support structure in accordance with ISO 19904-1, all partial safety factors are set to unity, so the partial safety factor format is equivalent to the WSD format.

The possible influence of the increased dynamic response of FOWT systems is considered in clause 8 of IEC TS 61400-3-2 for the design of the control and protection system, the mechanical systems (clause 9) and the tower.

The FOWT shall be designed in accordance with IEC TS 61400-3-2, clause 7 "structural design". Additional requirements relevant to the design of floating substructures shall follow ISO 19904-1.

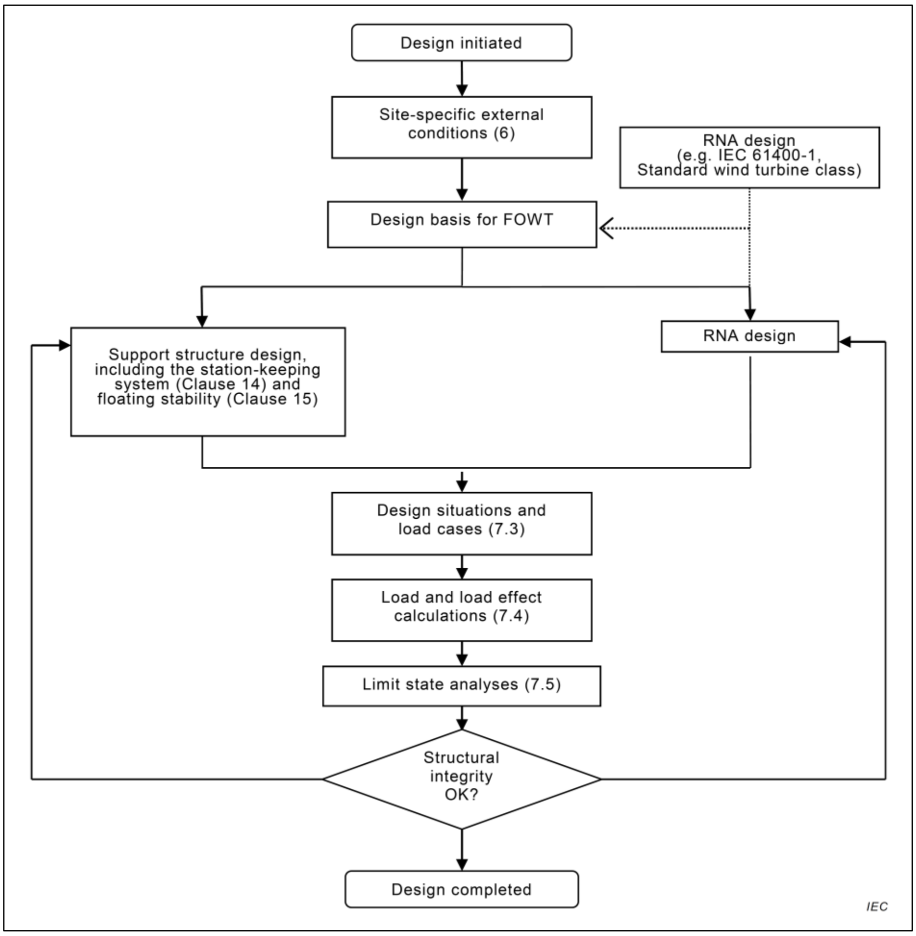


Figure 1: Design process for a floating offshore wind turbine (FOWT) [Source: IEC TS 61400-3-2]

According to Annex A of IEC 61400-3-2, the following key design parameters for a floating offshore wind turbine shall be documented:

- A.1 Floating offshore wind turbine identifiers
- A.1.1 General
- A.1.2 Rotor nacelle assembly (machine) parameters
- A.1.3 Support structure parameters
- A.1.4 Wind conditions (based on a 10-min reference period and including wind farm wake effects where relevant)
- A.1.5 Marine conditions (based on a 3-hour reference period where relevant)
- A.1.6 Electrical network conditions at turbine
- A.2 Other environmental conditions
- A.3 Limiting conditions for transport, installation and maintenance

3.1.2 External conditions

The external conditions defined in IEC 61400-3-1 can basically be applied. However, some additional aspects regarding wind, wave and other external conditions have to be considered for floating FOWT support structures.

Wind conditions

An adequate representation of wind in the low-frequency range must be ensured, considering power spectral density in the low-frequency range as well as adequate models for representation of gust events, in particular the extreme operating gust (EOG) as defined in IEC 61400-1. Gust event durations defined in IEC 61400-1 may be inadequate for FOWT design due to possible FOWT motion natural frequencies that are considerably lower than for fixed-bottom offshore structures and shall be evaluated, if relevant.

Marine conditions

It is recommended in IEC TS 61400-3-2 not to disregard important sea states for the definition of combined wind and wave input to the load simulations. Furthermore, the influence of swell spectra should be included in addition to known wave spectra from fixed-bottom systems, as swells can be important in conjunction with low-frequency responses of FOWTs. Special attention for FOWT should be paid to windwave misalignment cases leading to bi-directional wave loading.

Earthquakes and Tsunamis

With reference to ISO 19904-1 and ISO 19901-2, it is stated in IEC TS 61400-3-2 that actions arising from **earthquakes** are not normally of concern for the design of floating structures. However, specific attention should be paid to the assessment of the seismic analysis in the case of TLP/TLB-type floating substructures.

It is mentioned in IEC TS 61400-3-2, that earthquakes can lead to dynamic mooring line tension loading. In case of tendon or taut-line station-keeping systems, large stiffness may cause the inertial force to be transferred to the floating substructure and potentially surge and sway motions for taut-line station-keeping systems. Thus, IEC TS 61400-3-2 recommends for floating substructures with more than one taut line or tendon to consider the phase of forcing at separate anchor points that can induce rolling and pitching motions.

Referring to ISO 19901-1 it is mentioned in IEC TS 61400-3-2 that **tsunamis** in most cases are dominated by extreme wind-generated waves. The very long periods of tsunami waves can result in substantial loads on moored floating structures, and special care should be taken at shallow water sites near complicated bathymetry or near semi-enclosed features like bays.

According to IEC TS 61400-3-2 the external condition for FOWT loaded by a tsunami can be represented by variance of water surface elevation and horizontal current because FOWT is basically installed in deep water. Resonant responses of the station-keeping system should be evaluated in cases where the natural period of station-keeping system is close to the period of tsunami waves.

IEC 61400-3-2 also provides a detailed annex, including a numerical model of tsunami.

3.1.3 Loads

According to IEC TS 61400-3-2 the specifications for **gravitational and inertial loads** and **aerodynamical loads** in IEC 61400-3-1 are generally applicable for FOWT. The aerodynamic interaction between the airflow and the FOWT is of special importance due to their additional compliance and increased dynamic response. It is recommended in IEC TS 61400-3-2 to consider the interaction of potentially large translational and rotational motions of the floating substructure with the aerodynamic loading of the RNA and tower, including aeroelastic effects and the associated global and local dynamic and unsteady aerodynamic effects.

IEC TS 61400-3-2 point out that the **hydrodynamic loads** and station-keeping system loads acting on the floating substructure of a FOWT are important, as the tower and RNA may be affected directly as a consequence of dynamic response of the support structure and are in general not negligible and can be important.

It is recommended in IEC TS 61400-3-2 to have a minimum value of 1,5 m for the air gap. The air gap shall be determined by appropriate model tests and/or calculated using detailed global performance analyses that account for relative motions between the floating substructure and waves. Referring to API RP 2FPS, local wave crest elevation shall be considered, as appropriate. In addition to IEC 61400-3-1, strength for wave impact load including slamming, sloshing and green water in accordance with ISO 19904-1 shall be assessed.

For calculation of hydrodynamic loads, subclause 7.5.3 of IEC 61400-3-1 is generally applicable. However, IEC TS 61400-3-2 recommends to consider the potentially large volume and large motions of floating substructures used for FOWTs for calculations where appropriate. In addition, IEC TS 61400-3-2 refers to ISO 19904-1 and the following RCS rules for the calculation of hydrodynamic loads for FOWTs, including hydrostatics, radiation, diffraction, and viscous effects:

- ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations
- BV, NI572, Classification and Certification of Floating Offshore Wind Turbine
- DNV, DNV-OS-J103, Design of Floating Wind Turbine Structures*
  (*Note: DNV-OS-J103 was superseded by DNV-ST-0119)
- Nippon Kaiji Kyokai (ClassNK), Guidelines for Floating Offshore Wind Turbines

In terms of **ice load** of floating support structures, IEC TS 61400-3-2 refer to ISO 19906, while IEC 61400-3-1 assumptions are not regarded as applicable to FOWT. In addition, sea ice loads shall be considered in combination with motions of the FOWT due to loads from ice, wind, wave or current processes. The flexibility of the station-keeping system shall be considered when determining sea ice loads. If sections of the station-keeping system and electrical cable are exposed to sea ice loads, such loading shall be considered. An ice-management system may be used to reduce loading due to ice action. The effect of ice management on the behaviour of the FOWT shall be taken into account in the design.

IEC TS 61400-3-2 recommends to consider **wake effects** from neighbouring FOWTs during power production. As large asymmetric loads can be produced on the downwind rotor, these loads and resulting response from dynamic motion may be especially important in FOWTs that are soft in yaw as a result of their station-keeping system configuration. According to IEC TS 61400-3-2, the floating substructure motion shall be accounted for when applying wake models described in IEC 61400-1.

3.1.4 Design load cases for FOWT

In addition to the **design load cases** (DLC) listed in IEC 61400-3-1, specific DLC for FOWT are defined in IEC TS 61400-3-2 that shall be considered. Misalignment of wind, wave, swell and current require consideration if higher loading is to be expected. Furthermore, faults of active control systems of the support structure shall be considered in fault conditions.

As normative references for the design of floating substructures and the definition of the limit state analysis method described in IEC 61400-3-1 and ISO 19904-1:2006 differ, Annex N of IEC TS 61400-3-2 provides clarification on how the differences can be resolved.

A **serviceability analysis** shall also be performed as part of the ultimate limit state analysis of a FOWT. Thus, it is stated in IEC TS 61400-3-2, that the designer shall propose appropriate limiting values to ensure the integrity and serviceability of the FOWT and related infrastructure and it shall be verified that these limiting values are not exceeded in all design load cases for FOWT.

For **simulation requirements** IEC 61400-3-1, subclause 7.5.6 is generally applicable to FOWT. In addition, specific load cases of FOWT are included in IEC TS 61400-3-2 and further considerations, listed in 7.6.3, shall be addressed where appropriate.

According to IEC TS 61400-3-2 the following **other requirements** shall also be considered where relevant:

- the behaviour of the control and protection system of the wind turbine and floating substructure;
- vortex-induced vibrations and motions of the floating substructure and station-keeping system;
- influence of nonlinearities and dynamics, including damping, in catenary, semi-taut or taut station-keeping systems (refer to ISO 19901-7, or for tendons, API RP 2T);
- nonlinear interaction of mooring lines and anchors with seabed;
- dynamic excitation (whipping) and vibration (springing) of the floating substructure from slam impulse;
- sloshing.

3.1.5 Control system

In addition to the IEC 61400-1 requirements the IEC 61400-3-2 recommends for the control and protection systems of the FOWT support structure the activation of the protection system at least in the following dangerous events:

- failure of the control function of the FOWT support structure,
- motions and accelerations of the floating substructure exceed operational limits,
- tower inclination angle exceeds operational limits.

3.1.6 Mechanical and electrical system

IEC 61400-3-2 states for the mechanical system, that the inclination angle of the floating substructure due to pitch and roll motion is of particular importance. That is why this dynamic motion and mean static inclination must be considered in the design, wear, and lubrication of the mechanical systems.

Electrical systems of the FOWT support structure shall be in accordance with IEC or RCS rules.

3.1.7 FOWT Foundation and substructure design

According to IEC 61400-3-2, Annex E of IEC 61400-3-1 does not apply to FOWT. Instead, it is recommended to use the following RCS rules for the design of anchor foundations for FOWTs:

- ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations
- DNV, DNV-OS-J103, Design of Floating Wind Turbine Structures*
  (*Note: DNV-OS-J103 was superseded by DNV-ST-0119)

3.1.8 Assembly, installation and erection

For assembly, installation and erection IEC 61400-3-2 refers to IEC 61400-3-1 and ISO 19901-6, which in particular should also be considered for floating unique items such as wet tow, ballasting, mooring hook-up, etc..

It is stated in IEC 61400-3-2, that stability and structural integrity of the FOWT during assembly, transportation and installation operations should be designed to withstand the loads caused by the most adverse environmental conditions defined in IEC 61400-3-1. This also applies for towing conditions, the towed object, including cargo and securing arrangements.

Regarding the planning, IEC 61400-3-2 just mentions, that procedures for the installation of stationkeeping systems, electrical cables and floating substructure shall be included.

3.1.9 Commissioning, operation and maintenance

IEC 61400-3-2 refers to ISO 19901-6 for more floating-specific guidance regarding commissioning, operation and maintenance. The commissioning of the onboard machinery, equipment and systems that are not part of the RNA shall include both functionality and capacity trials in accordance with approved procedures. According to IEC 61400-3-2, commissioning tests prior to operation shall be sufficient, to prove reliability for in-service conditions for those onboard machinery, equipment and systems that have no redundancy.

Emergency procedures plan for FOWTs must consider the increased risk for structural damage in the event of mooring line or tendon breaking event and failure of FOWT support structure control functions.

Additional requirements that apply to marine operations of FOWT support structures are specified in ISO 19904-1 as part of the marine operations manual. Referring to IEC 61400-3-1, the description of the subsystems of the FOWT and their operation should also be covered in the manual.

3.1.10 Station-keeping systems

Basically IEC 61400-3-2 refers to the ISO 19901-7 standard for the design of a catenary, semi-taut or taut station-keeping system and for tendons to API RP 2T, respectively. In the case of non-redundant station keeping systems, an increase in safety factors shall be considered. The station-keeping system of the FOWT is considered to be non-redundant if the FOWT cannot maintain its position required for operation.

IEC 61400-3-2 recommends, that the design of chain stopper, fairleads and their foundation (i.e., structural reinforcement) in the floating substructure should be based on maximum tension experienced by the mooring line together with appropriate safety factors rather than the strength of the mooring line, if mooring line capacity is increased due to other factors than minimum required breakstrength.

For tendon systems, at least the same level of safety as the FOWT shall be achieved for the design criteria for tendon bodies and connectors, if tendon bodies not comprising tubular steel are used. This also applies for the definition of the return period of environmental conditions for the robustness check.

For specific guidance on the design of the non-redundant station-keeping systems IEC 61400-3-2 refers to the following RCS rules:

- ABS, Guide for Building and Classing Floating Offshore Wind Turbine Installations
- BV, NI572, Classification and Certification of Floating Offshore Wind Turbine
- DNV, DNV-OS-J103, Design of Floating Wind Turbine Structures

  (*Note: DNV-OS-J103 was superseded by DNV-ST-0119)

3.1.11 Floating stability

Regarding floating behaviour, IEC 61400-3-2 recommends to be consistent with the requirements for stability in all conditions including intact and damaged configurations, for both temporary and in-service conditions. In this regard IEC 61400-3-2 refers to the applicable parts of IMO intact stability code, Resolution MSC.267(85) or other recognized standards.

In addition, damage stability criteria are defined in IEC 61400-3-2. The damage stability considerations for which the joint probability of total loss of the structure is assessed should address any single watertight compartment. According to IEC 61400-3-2 damage stability may not be required if human safety, marine environment and neighbouring FOWT and facilities are not compromised and if the joint probability of loss of stability and subsequent total loss of the structure does not exceed the probability of failure corresponding to the safety level used for assessing the structural integrity of the structure.

3.1.12 Other requirements

With regard to **material** requirements for station-keeping systems and floating substructures, IEC 61400-3-2 refers to ISO 19904-1 and ISO 12944-9. This also applies for FOWT **corrosion protection** systems and how these are accounted for in the design.

For **marine support systems**, IEC 61400-3-2 in general refers to ISO 19904-1. Regarding ballast system, reference is made to the IMO intact stability code, Resolution MSC.267(85) for further guidance, as appropriate.

3.2 DNV-ST-0119 Floating wind turbine structures

The offshore standard DNV-ST-0119 – Floating wind turbine structures (Edition June 2021) – provides principles, technical requirements and guidance for design, construction and in-service inspection of support structures and station keeping systems for floating wind turbines. The most significant change in the June 2021 update is a completely revised section on floating stability. In addition, various clarifications and updates have been implemented throughout the standard which was first introduced in 2018.

In DNV-ST-0119, the structural design of FOWT structures is covered, and the design principles and overall technical requirements are specified. Wherever possible, DNV-ST-0119 makes reference to requirements set forth in DNV-ST-0126 (Support structures for wind turbines).

DNV-ST-0119 gives provisions for the control systems for the floater motion and for the wind turbine, as well as for transportation, installation and inspection – to the extent necessary in the context of structural design. The structural design of the tower is covered by the standard, regardless of whether a type approval of the tower exists and is to be applied. The actual stiffness and mass distribution of the floating system shall be considered in the design of both the tower and the substructure.

DNV-ST-0119 does not cover design of wind turbine components such as nacelle, rotor, generator and gearbox. For structural design of rotor blades DNV-ST-0376 (Rotor blades for wind turbines) applies. For structural design of wind turbine components for which no DNV standard exists, the IEC 61400-1 standard (Wind energy generation systems – Part 1: Design requirements) applies.

The requirements for the following criteria are specified in DNV-ST-0119:

- design principles
- selection of material and extent of inspection in manufacturing yard
- design loads
- load effect analyses
- load combinations
- structural design
- station keeping
- anchoring
- floating stability
- corrosion protection
- transport and installation
- in-service inspection
- power cable design

3.2.1 Design principles

According to the safety philosophy in DNV-ST-0119, the structure to be designed is classified into consequence classes based on the failure consequences, as follows:

- Consequence class 1, where failure is unlikely to lead to unacceptable consequences such as loss of life, collision with an adjacent structure, and environmental impacts.
- Consequence class 2, where failure may well lead to unacceptable consequences of these types

The floating structure shall be designed to consequence class 1, as it is unmanned during severe environmental loading conditions. This also applies for all structural components in the station keeping system of the floating support structure, such as mooring lines and tendons. However, without redundancy, the design of the various components of the station keeping system shall be carried out to consequence class 2.

DNV-ST-0119 is based on the design by partial safety factor method, while working stress design (WSD) format is not considered applicable, unlike in IEC 61400-3-2. However, for limit state design of cables, WSD is used as per custom. Furthermore, DNV-ST-0119 also allows design assisted by testing and probability-based design.

In DNV-ST-0119 design requirements are considered for limit state conditions. According to the standard a structure or structural component will no longer satisfy the design requirements beyond limit state.

The following limit states are considered in DNV-ST-0119:

- Ultimate limit states (ULS) corresponding to the maximum load-carrying resistance.
- Fatigue limit states (FLS) corresponding to failure due to the effect of cyclic loading.

- Accidental limit states (ALS) corresponding to survival conditions in a damaged condition or in the presence of abnormal environmental conditions.
- Serviceability limit states (SLS) corresponding to project-defined criteria applicable to intended use.

Regarding design assisted by testing, DNV-ST-0119 states, that design by testing or observation of performance is in general to be supported by analytical design methods. To the extent that testing is used for design, the testing shall be verifiable.

Model tests shall be carried out to validate software and to check the structure if unforeseen phenomena could occur. The tests shall be as realistic as possible with respect to scaling of wind, wave and current loading. In this regard, DNV-ST-0119 states, that it may be necessary to properly represent the effect that the wind turbine control system has on the wind forces, and also to consider a correct representation of the turbulence spectrum and spatial coherence of the wind.

DNV-ST-0119 recommends to carry out full-scale tests, as these are important and necessary in order to achieve an optimal design. Full-scale tests or monitoring of existing structures may be used to give information on response and load effects to be utilized in updating and refinement of structural design procedures.

For probability-based design, DNV-ST-0119 refers to specifications and requirements in DNV-ST-0126.

3.2.2 Environmental conditions

For guidance on environmental conditions, DNV-ST-0119 generally refers to standard DNV-ST-0437 (loads and site conditions for wind turbines), and additionally to recommended practice DNV-RP-C205 (environmental conditions and environmental loads).

Regarding **wind, waves and current**, DNV-ST-0119 gives requirements in addition to DNV-ST-0437 as follows:

- Simultaneous wind, wave and current data are important to allow for time domain analyses that may be necessary in order to carry out fatigue analyses.
- As part of the specification of an environmental class or of site-specific environmental data, the correlation between wave data and wind data for use in fatigue design shall be established. In addition, the distributions of the wave energy content and the wind energy content over frequencies shall be established. In the short term, these distributions can be represented by the power spectral densities for waves and wind, for which DNV-ST-0119 refers to DNV-RP-C205.
- An adequate representation of dynamics may require a more thorough and improved representation of simultaneous wind, waves and current than the one which is currently given in DNV-ST-0437.

The extreme operating gust (EOG) specified in DNV-ST-0437 for design of fixed-bottom wind turbines and their support structures is based on a duration of 10.5 s. According to DNV-ST-0119 this should always be considered for the design of tower, but this EOG is inadequate for design of most floating support structures. Thus, gust events with longer durations shall be defined and used in design to reflect the needs in design under due consideration of the frequencies encountered for the dynamics of the floating unit. In this context gust characteristics should consider duration of gust event, maximum wind speed, and rise time of wind speed to maximum. In particular for large rotors, the spatial correlation of the wind field is an important issue to consider when appropriate gust events for use in design are to be defined.

For floating wind turbine structures which can be excited by swells and which are to be designed to an environmental class which includes swells, DNV-ST-0119 recommends to use a two-peaked power spectrum model for representation of the power spectral density.

Furthermore, it is stated in a guidance note that the ratio between the 50-year wave height and the 50-year significant wave height may reach a value of about 2.0 in deep waters that FOWT structures usually are to be designed for.

Regarding vortex-induced vibrations, vortex-induced motions and modelling of current, DNV-ST-0119 refers to DNV-RP-C205.

The level of **seismic activity** in the installation area of the FOWT structure shall be assessed on the basis of previous records of earthquake activity as expressed in terms of frequency of occurrence and magnitude. For details of seismic design criteria, DNV-ST-0119 refers to DNV-ST-0437 and ISO 19901-2.

Regarding **tsunamis**, DNV-ST-0119 states that the assessment of effects of tsunamis caused by earthquakes can be critical for the design of station keeping systems and that the effect of tsunamis is related to water depth.

For design of station keeping systems and their components, such as anchors and mooring lines, DNV-ST-0119 requires to define of a range of **ground conditions** as part of the definition of an environmental class for the design. For each particular site-specific wind farm project, the design of these station keeping systems and their components shall be qualified for application on the actual site. Ground conditions shall be established for the foundation positions where the station keeping systems of the floating structures are anchored or otherwise transfer the floater loads to the seabed soils. In this context a table of typical ranges of soil parameters for soils is included in DNV-ST-0119, classified as cohesionless and cohesive, respectively. For soil investigations, the requirements and recommendations given in DNV-ST-0126 and DNV-RPC212 apply. For definition and estimation of characteristic soil properties it is additionally referred to DNV-RP-C207.

It is stated in DNV-ST-0119 that **marine growth** on structural components in water and in the splash zone shall be accounted for design as specified in DNV-ST-0437. To consider the effect in terms of its weight in water as well as its effect in terms of increased dimensions of the affected structural members, marine growth shall be assessed for site specific conditions, considering structures and power cables.

3.2.3 Loads

For loads and load effects of FOWT, the standard generally refers to the requirements given in DNV-ST-0437 (loads and site conditions for wind turbines) and the recommended practice DNV-RP-0286 (coupled analysis of FOWT), respectively.

DNV-ST-0119 specifies in detail loads, load components and load combinations to be considered in the overall strength analysis for design of floating support structures for wind turbines. Requirements for the representation of these loads and their combinations as well as their combined load effects are given.

DNV-ST-0119 points out in a guidance note, that a careful assessment of the combination of aerodynamic damping, wave damping and structural damping under different wind and wave directions and in particular under wind and wave misalignment is important for determination of the floater motions. All relevant motion components are important and must be determined carefully. In this context, the influence of the turbine controller on the aerodynamic loads and in particular on the aerodynamic damping needs to be considered. For further details, DNV-ST-0119 refers to DNV-RP-0286, DNV-RP-C205 and DNV-RPF205.

According to DNV-ST-0119 extreme loads and fatigue damage of floating support structures will be a larger challenge than of fixed-bottom structures, since the wind will imply global motions that in turn will cause forces and stresses in the structure.

With regard to transportation, DNV-ST-0119 points out to take care with floating wind turbine structures not fully assembled or with temporary supporting structures installed during transport conditions. Transportation loads must be considered for designing the towing attachment pad eyes, with reference to standards DNV-ST-0054 and DNV-ST-N001.

As basis for characteristic loads for use in design, the following load categories are defined in DNV-ST-119:

- permanent loads
- variable functional loads
- environmental loads
- accidental loads
- deformation loads
- pressure loads on hull
- abnormal wind turbine loads (loads associated with fault situations for the wind turbine).

The basis for selection of characteristic loads or characteristic load effects shall apply in the temporary and operational design conditions, respectively. Temporary design conditions cover design conditions during transport, assembly, maintenance, repair and decommissioning of the wind turbine structure. Operational design conditions cover steady conditions such as power production, idling and stand-still as well as transient conditions associated with start-up, shutdown, yawing and faults of the wind turbine.

In addition to the proposed design load cases provided in DNV-ST-0437, floater-specific design load cases listed in DNV-ST-0119 shall be considered. Furthermore, an applicable current model shall be included for all load cases in DNV-ST-0437, including the ones where no current is specified.

For design against ULS and for ALS, DNV-ST-0119 provides load factors depending on the load case considered, while the load factor γf is 1.0 for all load categories for the analysis of FLS and SLS.

3.2.4 Material selection and structural design

For selection of both, structural steel and concrete materials for design and construction of floating support structures, DNV-ST-0119 refers to the materials section of DNV-ST-0126, and for selection of concrete materials to DNV-ST-C502 as well. Floating concrete FOWT support structures shall be designed in accordance with DNV-ST-0126 together with either DNV-ST-C502 or EN 1992-1-1 as the basic design standard.

For requirements related to fabrication and construction of concrete structures DNV-ST-0119 refers to DNV-ST-C502, while partial safety factors shall be taken in accordance with specifications given in DNV-ST-0126. Regarding in-service inspection and maintenance of concrete structures the standard refers to both, DNV-ST-0126 and DNV-ST-C502.

According to DNV-ST-0119, general considerations with respect to methods of analysis and capacity checks of semi-submersibles are given in DNV-OS-C103 and DNV-RP-C103, and for analysis and capacity checks of spars in DNV-OS-C106 and DNV-RP-C205, respectively.

Specific load factor requirements for design of **mooring lines** as a function of consequence class are defined in DNV-ST-0119. For further details of principles for design of mooring lines, the standard refers to DNV-OS-E301.

For the **anchor foundations**, DNV-ST-0119 addresses the design of the various anchor types and provides material factors for the anchor considered.

Finally, it is outlined in DNV-ST-0119 how to ensure a sufficient air gap for floating wind turbine structures in the structural design, with reference to the standard DNV-ST-0126.

3.2.5 Floating stability

The section on floating stability was revised in the update of DNV-ST-0119 from June 2021 to make it better suited for wind turbine applications: allowing for time domain simulations and use of site specific metocean data, better integration with DLCs and including new categorisation of floater types etc.

According to DNV-ST-0119, sufficient floating stability is an absolute requirement in the intact condition, for the operational phase as well as for any temporary phases in the following service modes:

- operation, i.e. a normal working condition with the wind turbine operating
- survival condition, i.e. conditions during extreme storms
- fault conditions, i.e. faults causing abnormal behaviour of the wind turbine with supporting systems
- temporary conditions, i.e. such as installation and changing of draught
- transit, in particular tow-out.

It shall be demonstrated that the floating structure can maintain stability for all conditions expected through the operational lifetime including installation and decommissioning. Sufficient stability shall be documented for all load cases as defined in tables provided in DNV-ST-0437 and DNV-ST-0119. In addition, a selection of load cases is given in DNV-ST-0119 that for most units span the critical cases regarding stability.

The stability requirements for intact and damage conditions are given for both static and dynamic stability.

A stability manual and an emergency response plan shall be included as part of the operational manual for the floating unit. Both documents shall contain sufficient information specified in DNV-ST-0119.

For floating units that are unmanned during extreme environmental conditions and normal operation of the wind turbine, damage stability requirements are not mandatory, but an option which should be considered.

For concrete floating units which do not fulfill the requirements for water tightness, specific requirements for damaged stability given in DNV-ST-0119 shall also be considered. Finally, specific requirements for intact stability as well as damaged stability, are defined in the standard for different floaters, i.e. barge, semi-submersible, spar and tension leg platforms.

3.2.6 Control system

According to DNV-ST-0119, it is a prerequisite that the wind turbine operation and safety are governed by a control and protection system as required by DNV-ST-0438.

The combined control system shall be demonstrated to be both safe and robust when applied to the combined wind turbine and floating system. It is recommended to demonstrate the overall performance of the complete control system by means of analysis of the entire system in the time domain, e.g. by simulation.

Regarding requirements for control systems, the standard refers to specification in DNV-ST-0076, for instru-mentation and control systems to DNV-OS-D202 and for safety shutdown systems to DNV-OS-A101.

3.2.7 Transport and installation

In general, DNV-ST-0119 refers to the requirements for planning and execution of marine operations for transport and installation given in DNV-ST-N001 – for load transfer, sea transports, offshore installation, lifting operations and subsea operations – and in DNV-ST-0437.

The requirements for vessel stability in DNV-ST-N001 are applicable for vessels and barges used for transport and installation, but not for the floating wind turbine structures themselves. For FOWT structures the requirements for floating stability have to be considered (see 3.2.5).

3.2.8 Power cable design

DNV-ST-0119 also includes a comprehensive section with criteria, requirements and guidance for structural design and analysis of power cable systems exposed to dynamic loading for use in the floating wind industry. In this context, the standard refers to a number of available design codes of relevance for power cable design.

According to DNV-ST-0119, the design and qualification of subsea cables considering electrical, functional and environmental aspects shall be in accordance with the requirements given in DNV-ST-0359.

The following topics are covered in the power cable section of DNV-ST-0119:

- Introduction
- Overview of relevant standards
- Design principles
- Functional requirements
- Analysis methodology
- Loads and load effects
- Resistance
- Design checks
- Other issues

3.2.9 Others

DNV-ST-0119 provides general requirements for various **mechanical systems** which are necessary for maintaining the normal operation of a floating wind turbine unit. For design of mooring equipment, the standard refers to structural design procedures specified in DNV-OS-E301.

The requirements for **corrosion control** given in DNV-RP-0416 generally apply to floating wind turbine structures. In DNV-ST-0119, recommended minimum corrosion allowance for chain used for mooring lines is defined.

DNV-ST-0119 requires to have a **lightning and earthing system** in place which shall be designed in accordance with the requirements of DNV-OS-D201 Ch.2 Sec.2. Furthermore, the standard refers to relevant parts of IEC 61892-6 and DNV-ST-0076.

Regarding **in-service inspection and maintenance and monitoring**, DNV-ST-0119 states that in general the provisions set forth in DNV-ST-0126 shall apply. However, DNV-OS-E301 shall apply for anchors, mooring chain and steel tendons, and DNV-OS-E303 for fibre ropes, tethers and tendons made from synthetic fibre yarns.

3.3 Comparison with other standards and guidelines

Next to the main standards as applied through this research and development project, other certification bodies/recognized classification societies (RCS) such as the American Bureau of Shipping (ABS), Bureau Veritas (BV) and Nippon Kaiji Kyokai (Class NK) offer certification services according to their own standards and guidelines.

In the following, a quick overview on the main similarities and differences of the guidelines is given.

3.3.1 ABS Guide for building and classing floating offshore wind turbines

The ABS Guide for Building and Classing of Floating Offshore Wind Turbines from July 2020 provides guidance for the design, construction, installation and survey of floating offshore wind turbines. In this context, three principal areas are considered for the classification of FOWT: floating substructure, stationkeeping system, and onboard machinery, equipment and systems.

Technical requirements are addressed for the same topics as shown in the IEC and DNV guidelines.

The following sections are considered in the ABS guide:

- Conditions of classification
- Materials and welding
- General design requirements
- Environmental conditions
- Loads
- Global performance analysis
- Design of floating substructures
- Design of stationkeeping systems
- Stability and watertight/weathertight integrity
- Machinery, equipment and systems
- Surveys

In addition, the document includes three appendices:

- Wind spectra and coherence functions
- Tropical cyclones wind speed profile, standard deviation, tubulence intensity and gust factor
- Fatigue analysis for floating support structures

According to the ABS guide the structural design can be based on Load and Resistance Factor Design (LRFD) or the Working Stress Design (WSD) method which may yield different levels of safety. Regarding the station-keeping system reference is made to external standards (American Petroleum Institute – API) within the ABS guide for building and classing. In addition to the IEC and DNV main standards, ABS is providing guidance on classing of floating wind turbines (see 3.5.4).

3.3.2 BV Guidance note NI 572 Classification and certification of FOWT

The Guidance Note NI 572 from January 2019 provided by Bureau Veritas considers technical requirements for certification and also (like the above ABS guide) for classification of floating platforms designed as support of FOWT. Requirements and recommendations may be applied in compliance to requirements from the IEC 61400 series standards.

Guidance Note NI 572 is intended to cover four categories of floating platforms supporting single or multiple turbines with horizontal or vertical axis: column stabilized units (incl. semi-submersibles), spar, tension leg and barge platforms.

The following station keeping systems are considered: catenary mooring system, taut mooring system and tension leg system (tendon system).

The BV guidance note NI 572 does not cover the top structure, i.e. tower, rotor, blades and nacelle design (their influence on floating platform and mooring system is however considered).

The document is divided into the following sections:

- General
- General arrangement
- Material
- Corrosion
- Design conditions and loads
- Stability
- Structure design
- Hull scantlings
- Other structures
- Station keeping
- Soil and foundation
- Marine systems

In addition, the guidance note includes these appendices:

- External conditions
- Structureal analysis
- Turbine mechanical components
- Life cycle

3.3.3 NKRE-GL-FOWT01 Guidelines for floating offshore wind turbines - classification survey

The "NKRE-GL-FOWT01 Guidelines for floating offshore wind turbines - classification survey" was issued in December 2021 by classification society Nippon Kaiji Kyokai (ClassNK) as a full revision of the ClassNK Guidelines from July 2012.

The revision is based on the reference standards "Technical Standards for Floating Offshore Wind Power Generation (Safety Policy Division, Maritime Bureau of Land, Infrastructure, Transport and Tourismn, Kokkaian No. 286, March 3, 2020)" and IEC 61400-1:2019, IEC 61400-3-1:2019 and IEC TS 61400-3-2:2019.

The following content is covered in the ClassNK guidelines:

- General
- External conditions
- Loads
- Materials and welding
- Structural design
- Mooring system
- Stability and waterline, etc.
- Surveys of FOWT

The guidelines specify the requirements for the materials, welding, stability, structure, equipment, machinery, electrical equipment, mooring system, and waterline of offshore wind power generation vessels as defined in Part P (Mobile Offshore Drilling Units and Special Purpose Barges) of ClassNK's "Rules for the Survey and Construction of Steel Ships" (including RNA, tower and mooring system referred to "FOWT" in the guideline) which are continuously moored at designated sites during their service life.

The ClassNK guidelines mainly include technical aspects but also provides guidance on surveys for classing. Given safety levels with regard to various aspects appear to be based on different standards adopted from other classification and certification bodies as well as international standards (mainly IEC 61400-1 and IEC 61400-3).

3.4 Country-specific regulations in main global FOWT markets

To date, only few floating offshore wind projects have been realized, mostly single-unit prototypes or first demonstration and pilot projects. Consequently, there has not been the need for country-specific regulations for floating offshore wind projects yet. Currently, new FOWT projects are therefore mainly realized on the basis of existing international standards and guidelines.

An overview of standards and technical guidelines commonly used in the offshore wind industry is shown in Figure 2, incl. specific guidelines for China [25]. Note: DNV-OS-J101 has been superseded by DNV-ST-0126.

In addition, it should be mentioned for China, that the State Administration for Market Regulation (SAMR) and the Standardisation Administration of China has published the National Standard GB/T 51308-2019 Design of Offshore Wind Farms that is applicable to offshore wind power projects. This National Standard aims to promote the standardisation of engineering design and to ensure the safe operation of offshore wind farms in China, but it is not mandatory [57].

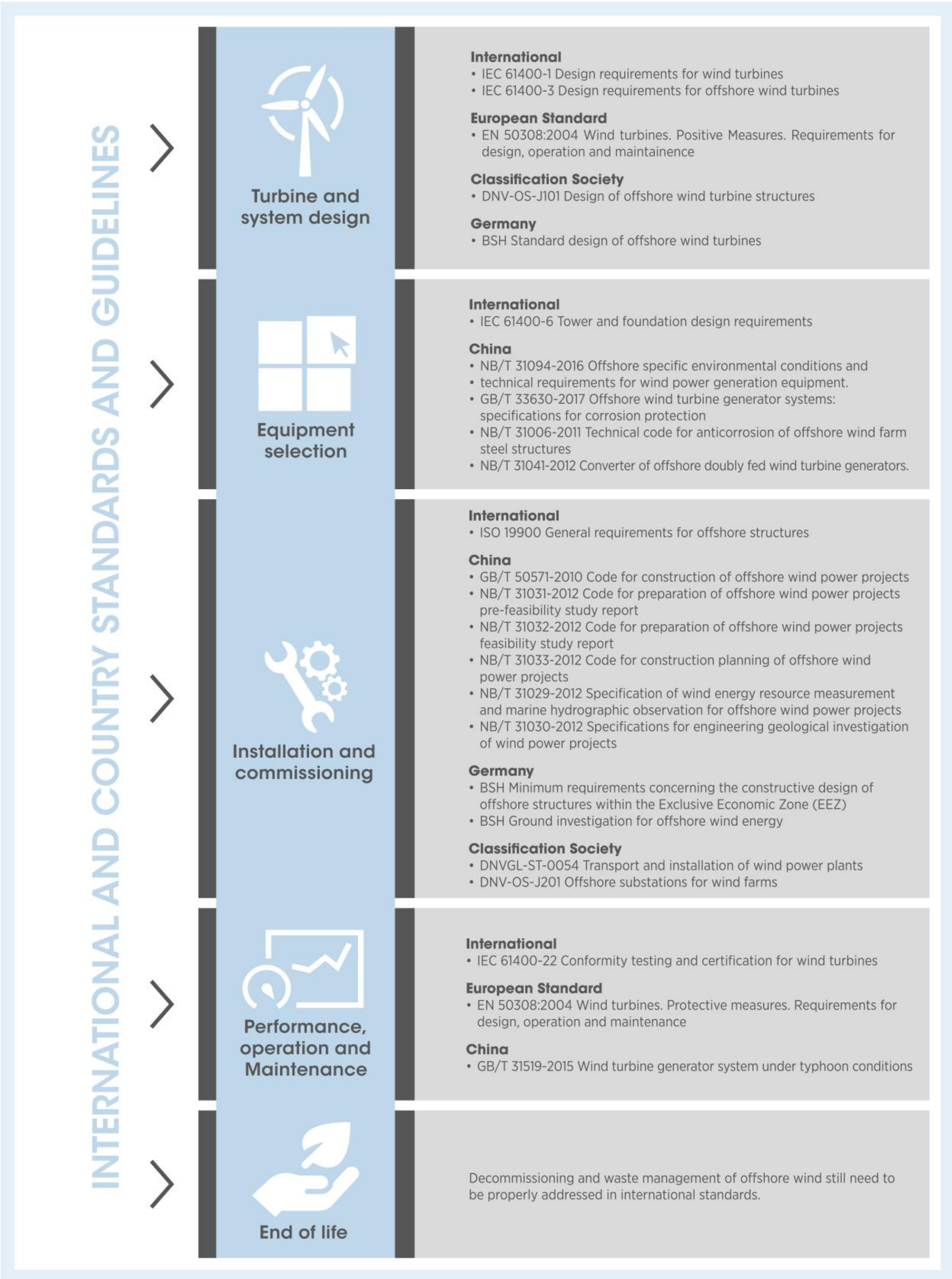


Figure 2: Standards and technical guidelines applicable to the offshore wind value chain [25]

3.4.1 U.S. Offshore Wind Standards initiative

In the U.S., a guidance for offshore wind projects was published in 2012 by the American Wind Energy Association (AWEA), later renamed American Clean Power Association (ACP).

Since the “AWEA Offshore Compliance Recommended Practice (OCRP) 2012” no longer adequately addressed the regulatory requirements, the ACP Wind Technical Standards Committee formed the U.S. Offshore Wind Standards initiative in 2017 to develop a comprehensive set of consensus-based guidelines and standards that can be used to guide the safe and orderly deployment of offshore wind, considering the different regional U.S. offshore conditions. Five working groups (WG) were established:

- WG 1 – Offshore Compliance Recommended Practices (OCRP) Edition 2
- WG 2 – US Floating Wind Systems Recommended Practices
- WG 3 – US Offshore Wind Metocean Conditions Characterization Recommended Practices
- WG 4 – US Recommended Practices for Geotechnical and Geophysical Investigations and Design
- WG 5 – Recommended Practices for Submarine Cables

In June 2022, the new standard "ANSI/ACP OCRP-1-2022, The American Clean Power Association Offshore Compliance Recommended Practices (OCRP) Edition 2” received approval from the American National Standards Institute (ANSI) Board of Standards Review, the lead organization that oversees standards and conformity assessment activities in the United States [27].

OCRP-1-2022 is the first of five documents to be published and was written by a consensus-based group of more than 100 offshore wind energy industry members.

Pointing to more than 200 existing industry standards and guidelines focused on the requirements for the development of a U.S. offshore wind energy project, OCRP-1-2022 heavily leans on IEC standards, but covers all stages of offshore wind farm development – including design, manufacturing and fabrication, transportation and installation, operations and in-service inspections, and life-cycle planning.

The new guidance carefully adheres to a preestablished ANSI/ACP consensus standards development process. Because of that, OCRP-1-2022 is expected to be officially recognized by regulators and referenced within the U.S. regulatory approval process.

Combined, the five guidance documents are intended to facilitate safe designs and the orderly deployment of U.S. offshore wind energy by accounting for unique U.S. geophysical, administrative, and environmental constraints, providing the U.S. Department of the Interior with recommendations for industry best practices.

The four companion documents are are expected to be publicly reviewed and approved by ANSI in 2023.

Finally, it should be noted that any marine activities must also comply with the national laws and regulations for the sea area in which FOWTs will be installed or transported. Activities in the exclusive economic zone (EEZ) that are relevant in terms of use of seabed, safety at sea, etc. are regulated by both national and international law. Irrespective of existing international standards, local authorities may publish additional regulations, requirements and standards.

3.5 Certification of floating offshore wind turbines

Certification is commonly applied in the offshore wind industry to assure by an independent and qualified third-party, that an offshore wind farm including its assets (e.g. wind turbines incl. support structure, substation and power cables) is operating safely and reliably.

In some countries, certification is a mandatory requirement by national or local authorities, e.g. in Taiwan and the USA. Independently, project certification is often an indirect requirement by financial investors and insurances in connection with investments, e.g. in France and UK.

A third-party conformity assessment activity is performed by an accredited certification body or "conformity assessment body" (cf. ISO/IEC 17000), that has proven towards the accreditation body to be independent of the provider of the objective of certification. The requirements for accreditation bodies accrediting conformity assessment bodies (certification bodies) are specified in the standard ISO/IEC 17011:2017.

In addition, the accredited certification body shall also comply with the conformity assessment requirements defined in standard ISO/IEC 17065:2012.

It is specified in the appendix of the accreditation certificate (issued by the accreditation body) for which standards the certification body is accredited.

In general, an accreditation facilitates the acceptance as certification body by the national and local authorities.

The added value for the offshore wind industry of a third-party assessment providing conformity to defined requirements in standards and guidelines has been summarized in [28] as follows:

- mitigation environmental, personnel and damage risks
- increasing confidence in technical integrity and reliability
- supporting quality management
- minimising financial project risks
- securing investments and optimise return of investment
- securing better insurance/policy rates;decrease contingencies
- increasing trust in the project by independent approval in the relevant phases (development, construction to operations)
- reducing costs by early detection of non-conformities
- supporting interface management between assets, stakeholders and project phases
- confirming that requirements from project developers, investors, operators, manufacturers, governmental and non-governmental organizations are fulfilled
- proving that the national and international acknowledged state of the art requirements are met
- utilising statements and certificates to support authorisations by governmental institutions
- providing stepwise documentation of the maturity of the wind power project

The compliance of wind turbines and respective assets towards defined requirements (e.g., an applicable standard) is typically confirmed by two types of certification: type certification of rotor-nacelle assembly (RNA) and its components, and project certification for complete wind turbine including support structure at a specific site. It is common practice that a type-certified wind turbine is used for project certification and thus for site-specific assessment.

As with the standards, the main international certification schemes for offshore wind farms are provided by the International Electrotechnical Committee (IEC) and the classification society Det Norske Veritas (DNV).

In 2018, a new IEC System for Certification to Standards relating to Equipment for use in Renewable Energy applications (IECRE System) was launched. As a result, for example, the Operational Documents (OD) IECRE OD-501 (Type and component certification scheme) and IECRE OD-502 (Project certification scheme) were introduced to replace the existing IEC 61400-22 certification standard for wind turbines. However, the new IECRE system has not yet gained market acceptance as expected by stakeholders.

In the IECRE certification process, conformity shall be assessed for IEC or ISO standards, if available.

Although the IECRE certification schemes apply for wind turbines intended for both onshore and offshore installation, it should be noted that floating offshore wind turbines are not mentioned in either IECRE OD-501, IECRE OD-502 or IEC 61400-22.

3.5.1 Type certification according to IECRE OD-501/IEC 61400-22

Type certification shall confirm that the wind turbine type is designed in conformity with the design assumptions, specific standards and other technical requirements. It shall also confirm that the manufacturing process, component specifications, inspection and test procedures, and corresponding documentation are in conformity with the design documentation and that the manufacturer operates an accepted quality system. Furthermore, it covers the type testing of the wind turbine. The type certification scheme according to IEC 61400-22 and IECRE OD-501 consists of five mandatory modules and three optional modules (Figure 3).

The design basis shall identify all requirements, assumptions and methodologies, which are essential for the design and the design documentation. This can be done by referencing the applicable IEC 61400 series standards and other applied codes and standards, or by listing specific design aspects and parameters.

The purpose of design evaluation is to examine whether the wind turbine type is designed and documented in conformity with the design basis, i.e. the applicable standards in the IEC 61400 series and other applied codes and standards. In this context, loads and load cases shall be evaluated for compliance with IEC 61400-1 or IEC 61400-3 by an independent analysis of the certification body.

The purpose of the manufacturing evaluation is to assess if a specific wind turbine type is manufactured in conformity with the documentation design verified during the design evaluation. In this context, the evaluation shall include a quality system evaluation and a manufacturing inspection.

The purpose of the type testing is to prove the performance of the wind turbine in terms of power production and to verify the load calculations as well as the rotor blade design and manufacturing.

The purpose of the final evaluation is to provide documentation of the findings from the evaluation of all elements of the type certification. [Source: IECRE OD-501]

Type certification for offshore wind turbines is usually focused on the rotor-nacelle assembly (RNA). Typically, tower, foundations and components such as offshore substations and power cables are not included in the type certification, as site-specific design is always required for these components at offshore sites.

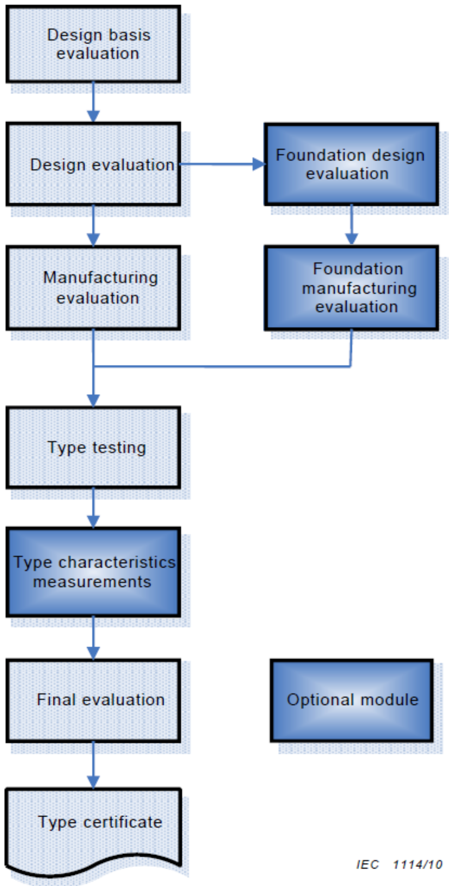


Figure 3: Modules of type certification [Source: IECRE OD-501]

IECRE OD-501 provides only a few guidance notes specifically related to offshore wind turbines. In general, for offshore wind turbines, it is recommended to also consider the substructure connecting the foundation to the tower in terms of the requirements for foundation design, foundation design evaluation and foundation manufacturing evaluation. In addition, it is mentioned that personnel safety aspects may include provision for emergency stay in an offshore wind turbine for one week and offshore-specific safety equipment.

As stated above, it should be noted that floating offshore wind turbines are not mentioned in IECRE OD-501.

The type certification procedures defined in IECRE OD-501 can also be applied to component certification for specific wind turbine components or systems, such as gearbox or condition monitoring system. In this case, the specific content of a certification module depends on the actual component. Component certificates may be issued for components designed and evaluated for conformance with the technical requirements of the applicable standards in the IEC 61400 series. For floating support structures, component certification will typically be relevant for e.g. mooring components.

Finally, IECRE OD-501 also covers prototype certification to enable testing of a new wind turbine type not yet ready for serial production, at a specific site and for a limited period not exceeding 3 years. Prototype certification consists of the modules basic design evaluation (design basis evaluation and turbine design evaluation), prototype test evaluation (on basis of elements described above for type testing) and safety and function test. It should be noted that prototype certification does not include a site assessment. However, site conditions must be provided by the applicant in a manner that is sufficient for the design evaluation.

3.5.2 Project certification scheme according to IECRE OD-502

IECRE OD-502 describes a project certification scheme for conformity assessment related to design, manufacturing, transportation, installation, and operation of a complete wind farm or individual installations associated with the wind farm. The purpose of project certification is to evaluate that the wind farm (wind turbine, support structures, etc.) is in conformity with applicable standards for a specific site.

IECRE OD-502 specifies procedures with respect to specific standards and other technical requirements, related to safety, reliability, performance, construction, and interaction with electrical power networks.

An overview of the project certification modules defined in IECRE OD-502 for type-certified wind turbines/RNA is shown in Figure 4. It should be noted that the availability of a type certificate for the wind turbine according to IECRE OD-501 is a prerequisite for a project certificate. If there is no type certificate issued for the wind turbine, the mandatory modules for type certification shall be fulfilled within the project certification. For this purpose, the project and site-specific conditions shall be evaluated.

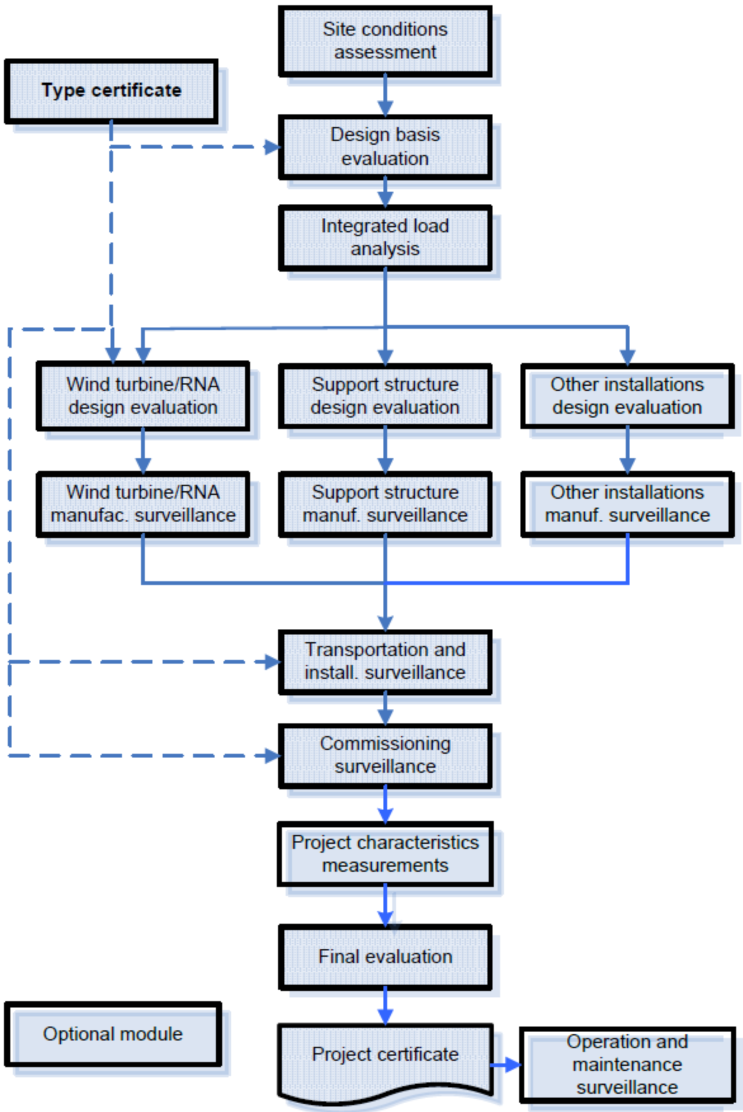


Figure 4: Modules in project certification [Source: IECRE OD-502]

3.5.3 DNV-SE-0422 – Certification of floating wind turbines

DNV has provided a complete set of service specifications for offshore wind turbines, including DNV-SE-0422 for the certification of floating wind turbines.

DNV-SE-0422 was introduced in 2018 as an extension to the DNV service specifications for type and project certification for bottom-fixed onshore and offshore wind turbines. It should be considered in combination with DNV-SE-0441 (Type and component certification of wind turbines) and DNV-SE-0190 (Project certification of wind power plants). DNV-SE-0422 addresses the specific requirements for floating offshore wind turbines that are not covered by DNV-SE-0441 and DNV-SE-0190. It specifies the certification of FOWT and related components from floating concept, prototype installation, begin of a serial production to development and operation of a complete floating wind power plant.

The DNV certification scheme for floating offshore wind turbines is divided into five levels: concept, prototype, site type, project and in-service. Each certification level includes certification modules with verification activities related to design assessment, test and measurement and surveillance of critical processes. The intention of DNV's certification scheme is to make use of previous certification deliverables as much as possible, to take advantage of synergies in the certification process and to avoid examing same items more than once.

The certification of the RNA of a floating wind turbine is in line with the scheme of DNV-SE-0441 which defines the following RNA certification levels:

- D level = RNA concept level certification
- C level = RNA prototype level certification
- B level = RNA provisional type level certification
- A level = RNA type level certification (complete, no open issues)
- Site level = RNA site type level certification

For the implementation of an RNA design into a floating wind turbine certification the RNA levels shall be referenced for the corresponding certification levels of floating wind turbines. An overview of the mandatory RNA certification levels is shown in Table 1.

Floating wind turbine certification according to DNV-SE-0422	DNV-SE-0441 *(DNV type and component certification)*	DNV-SE-0074 *(IEC type certication)*	DNV-SE-0190 *(DNV project certification)*	DNV-SE-0073 *(IEC project certification)*
Statement of feasibility (concept level)	RNA D level certification			
Prototype certificate	RNA C level prototype certification	IEC 61400-22 prototype certificate		
Provisional site type certificate	RNA B level type certification	IEC 61400-22 provisional (class B) type certificate	Provisional project certificate	IEC 61400-22 provisional project certificate
Site type certificate	RNA A level type certification	IEC 61400-22 type certificate	Type certificate, site-specific	
Project certificate	RNA A level type certification		Project certificate	IEC 61400-22 project certificate

Table 1: Mandatory RNA Certification levels for floating wind turbines [Source: DNV-SE-0422]

A project certificate may be based on a completed site type certificate. In case a site type certification does not exist, all certification modules of the site type are part of the corresponding project certification. For the RNA an A level type certificate according to DNV-SE-0441 shall be provided covering the floating specific requirements for the RNA given in DNV-ST-0119. In addition, a condition monitoring system (CMS) shall be in place and shall be certified according to DNV-SE-0439 (Certification of condition monitoring).

Figure 5 gives an overview of the project certification phases according to DNV-SE-0422 for a single FOWT or a floating offshore wind farm.

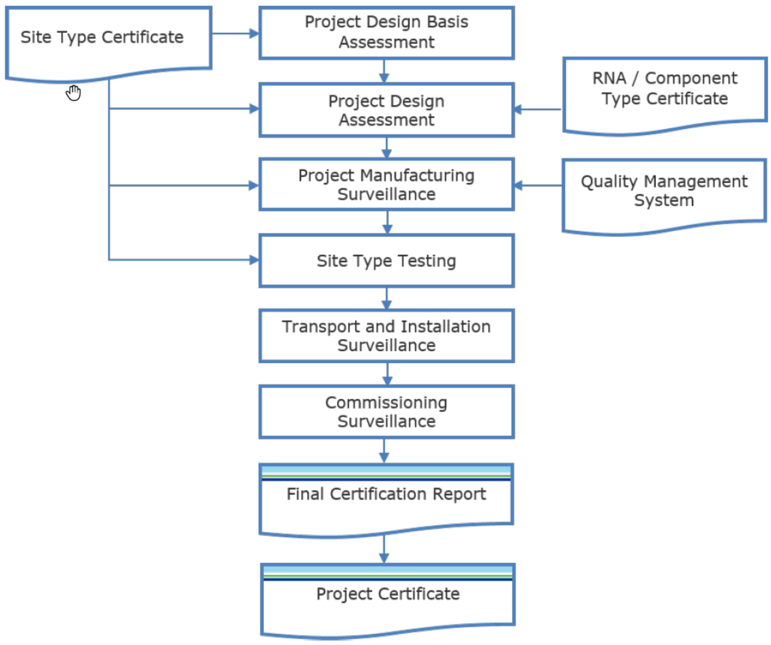


Figure 5: Project certification phases [Source: DNV-SE-0422]

3.5.4 Offshore classification

For the sake of completeness, it should be mentioned that an offshore classification, as applied in the marine industry, can be offered as an alternative to the project certification for FOWT. In general, rules for classification provide procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the classification society as basis for classification.

In this context, e.g. DNV provides the rules for classification DNV-RU-OU-0512 Floating offshore wind turbine installations from October 2020 to be used as part of the design, construction and operation of a FOWT project. Generally, the rotor-nacelle assembly (RNA), tower for RNA including slewing ring/yaw bearing, power transmission system for RNA and interarray and power export cables are not covered by these rules. DNV-ST-0119 is referenced in the rules as main design standard.

The American Bureau of Shipping (ABS) provides a class notation A1 Offshore Wind Turbine (Floating) with additional notations possible about the RNA, the lifetime and lifetime extension etc.. The rotor-nacelle assembly may be included in the classification and is then subject to the ABS Type Approval requirements of the ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1). When the RNA is not included in the classification, a type certificate according to IEC 61400-22/ IECRE or other recognized standards is required for the RNA installed on the floating structure.

As mentioned before, Bureau Veritas (BV) also offers classification/certification. According to the BV Guidance Note, a classification approach will result in the structural type notation offshore special type unit (FOWT).

3.6 Identification of gaps and challenges related to FOWT standards

It is common practice in the offshore wind industry to apply existing offshore wind standards provided by the international standardization organization IEC and the classification society DNV, respectively. The series of standards also include specifications for floating offshore wind turbines, in particular IEC TS 61400-3-2 and DNV-ST-0119 (see above).

In addition, a certification scheme is commonly applied to assure by an independent third-party, that an offshore wind farm including its assets is operating safely and reliably. Thus, the compliance towards defined technical requirements, such as e.g. standards IEC TS 61400-3-2 and DNV-ST-0119, can also be assessed for floating offshore wind projects.

In principle, existing international standards provide a suitable framework for the use of floating wind turbines. In this context, it should be noted that in case of missing practical experience with new technology, such as FOWT, reference is made to several basic requirements in standards for established technologies in the wind business or the O&G industry.

At present, only few prototypes and demonstration projects using FOWT are operational, and there is a lack of experience with standardized concepts for design, manufacturing, transportation, installation and operation of floating wind farms.

Furthermore, various floating concepts are currently being developed, which differ significantly in some cases. It is therefore impossible to predict which concepts will succeed on the market and establish a future standard.

The need for standardization in the floating wind industry is reflected in the following challenges:

- No long-term experience with operation of offshore wind turbines > 10 MW
- Limited experience with operation of floating offshore wind farms
- No serial production for components, such as floating structures, station keeping systems, power cables
- Special challenges for far-offshore sites:
    - Environmental conditions (wind, wave)
    - Accessibility, weather windows for transport, installation, O&M
    - Deep water installation, testing and O&M for station keeping systems, dynamic cables
    - Power transmission (HVDC technology, floating substations and converter platforms)
    - Long-distance transport of wind turbines, floaters and large components (tow-out/tow-in)
    - Installation and O&M work in deep waters (floater-to-floater)
- No experience with offshore facilities for production of hydrogen, PtX, etc.

With regard to standards and guidelines, the following gaps have been identified:

- The existing standard documents for FOWT structures, IEC TS 61400-3-2 and DNV-ST-0119, are only applicable for the support structure and the station keeping system, but not for the wind turbine.
- The standard DNV-ST-0119 also covers (mechanical) requirements for dynamic power cables. However, currently, a complete standard for dynamic power cables is not available [28].
- The common practice of using a type-certified wind turbine mounted on a foundation cannot be applied to floating offshore wind substructures. Instead, a site and floater specific assessment of wind

turbine, incl. adjusted control system, and tower is typically required to ensure safe and reliable operation of a certain turbine type on a specific floating foundation at the designated offshore site.

- IEC TS 61400-3-2 explicitly considers barges, semi-submersibles, spar buoys and tension-leg platforms. It is noted in the standard, that floating substructures can have a great range of variability in geometry and structural forms. Therefore, other structural types not specifically listed, can be only partly covered by the requirements of IEC TS 61400-3-2.
- The standard IEC TS 61400-3-2 is applicable to unmanned floating structures with one single horizontal axis turbine. Therefore, IEC TS 61400-3-2 specifically points out that additional considerations might be needed for multi-turbine units on a single floating substructure, vertical-axis wind turbines, or combined wind/wave energy systems.
- A Ramboll study on mooring systems [2] has highlighted the need to develop suitable standards and guidelines for
  - Fatigue analysis of mooring systems in floating offshore wind
  - Qualification of most promising synthetic mooring line materials
  - Monitoring and inspection regimes in floating wind farms
- Current design standards for FOWTs recommend running a full set of Ultimate Limit State (ULS) and Fatigue Limit State (FLS) DLCs which test the response of the FOWT to extreme and repeated loads respectively. To reduce the number of simulations, without reducing the accuracy of the results, guidelines to identify the critical design driving load cases should be included in standards [29].
- In light of identified gaps for the realization of floating offshore wind farms, DNV has initiated Joint Industry Projects (JIP) [30] to develop additional standards and guidelines addressing the following topics:
  - Floating Substations (target: close the gaps in available substation standards)
  - Mooring and cables (target: establish a safety level for FOWT that balances cost and reliability)
  - Concrete floating structures (target: optimize and align industry on FOWT developments)

Finally, a gap analysis from Ramboll, published in an ORE Catapult report in 2021, also identified certain design aspects that are not covered in standards or are covered only to a limited extent. A summary of the gap analysis is documented in Table 2 [65].

Category	Gap
Anchor Design and Installation	• There is some lack of alignment regarding standards for geotechnical anchor design, as well as installation of anchors.
Concrete Design	• More consistency and additional guidance regarding concrete design requirements for floating wind would be beneficial to reduce uncertainties.
Commissioning	• The commissioning phase of a FOWT project is not sufficiently covered by most governing technical standards resulting in a lack of guidance.
Decommissioning	• The decommissioning phase of a FOWT project is not sufficiently covered by most governing technical standards resulting in a lack of guidance.
Floating Offshore Substations	• There is a general lack of explicit guidance in the governing standards on floating offshore substations.
Floorings	• The standards lack information on requirements on flooring design including impact of dropped objects, flooring material selection and inspection.

Category	Gap
Global Loads and Local Structural Analysis	• Currently no specific guidance and requirements exist regarding a consistent process to apply loads from the coupled global performance analysis of the full design load case set to local structural checks, particularly for fatigue. • Another aspect related to global performance analysis relates to interpretation of the design load case table. • Floating wind specific guidance regarding the consideration of wave run-up on structures is lacking in the governing standards.
HSE	• The floating wind specific aspect of the effect of floater motions on O&M personnel health and safety, as well as workability (e.g. from sea sickness) is not well addressed.
Innovative Floating Wind Turbine Concepts	• Novel technologies specifically developed for floating wind with no equivalence in the O&G world, such as counterweight concepts, twin-hull weathervaning barge concepts or TLPs with inclined tendons where the restoring principle differs from typical TLPs are not explicitly covered by the standards. • Shared anchor (where one anchor supports multiple mooring lines) and interconnecting mooring system solutions (mooring lines connecting multiple units) are not explicitly covered in standards. • Floating specific requirements on novel turret mooring systems (single point mooring) are not included in standards. • Some FOWT concepts also include innovations in the tower and wind turbine, which are not covered by any of the established wind turbine standards.
Major Component Lifts	• While it is acknowledged that the T&I contractor will develop project and floater specific procedures for major component lifts, generally it is found that further alignment and more consistency across the standards would be beneficial.
Power Cable	• Floating wind specific guidance on the dynamic part of the power cable is not included in any of the other standards, where umbilical standards from O&G would then have to be applied.
Safety Level and Characteristic Loads	• For novel floating wind turbine concepts with significantly non-linear behaviour, the intended safety level may not be fulfilled / or exceeded if following current rules.
Slack Line Regulations	• Guidance on slack line regulation is considered beneficial as there is some difference amongst current standards.
Software Calibration, Performance Validation and Testing	• Overall, there is limited explicit guidance in which cases and how software shall be calibrated and validated. • There is little guidance on validating the performance of FOWTs once installed. • There is limited guidance on application of model scale and prototype testing.
Synthetic Mooring Lines	• Floating wind specific guidance on synthetic mooring lines are not included in all standards and guidance on novel materials for permanent applications are not explicitly covered.
Tower	• Standards do not provide detailed guidance on tower design and relevant specific standards for floating wind.
Tropical Cyclones	• There is some lack of alignment between standards on consideration of tropical cyclones.
Wind Farm Level Effects	• Standards are lacking explicit guidance on floating specific aspects of wind farm level effects.
Wind-Wave Statistics and Simulation Times	• Uncertainties associated with non-physical load case definition from independently gathered wind and wave measurements need to be investigated as standards lack specific guidance on mitigations.
WTG-Floater Interaction & Control	• The interaction of floater or mooring control systems with the wind turbine system is not explicitly addressed in standards and some additional guidance can be beneficial.

Table 2: Summary of a gap analysis for aspects that are not covered in standards to a full extent [65]

It should be noted that the IEC Technical Committee (TC 88: Wind energy generation systems) has prepared a technical revision of IEC TS 61400-3-2:2019 during the COREWIND project period. It is intended to replace the first edition of the technical specification from 2019 by an international standard IEC 61400-3-2. In December 2022, a Committee Draft for Vote (CDV) document has been sent to the national committees for comments.

The standard IEC 61400-3-2 is expected to be published during 2023 and will include the following significant technical changes:

- The revised IEC 61400-3-2 (Design requirements for floating offshore wind turbines) will be a self-standing document that does not have to be read directly in conjunction with the standard IEC 61400-3-1 (Design requirements for fixed offshore wind turbines). However, the new standard continues to be applicable only in conjunction with standard IEC 61400-1 (Wind turbines - Part 1: Design requirements).
- Several modifications regarding metocean conditions will consider the nature of FOWT and the designated offshore site, particularly covering wave directional spreading and the characteristic of swell.
- A revised DLC table and its related descriptions will be included, together with further updates related to guidance and necessities provided on load calculations and simulation requirements.
- An updated guidance on fatigue assessment along with clarifications on serviceability analysis and the applicable material for WSD will be added, as well as a new annex for clarification of the safety factors and load and load effect approach for floating substructures.
- The concept of floater control system that will interact with the wind turbine controller will be introduced.
- A more detailed clause regarding concrete design and an additional annex will be added.

4 DEVELOPMENT NEEDS AND DESIGN PRACTICE RECOMMENDATIONS

4.1 Development needs

The COREWIND project focuses on the cost reduction of floating offshore wind turbines through the optimization of mooring and dynamic cable design. Two floater types are considered for the analyses: WindCrete as a monolithic concrete spar platform including both the tower and the floater in a unique concrete member spar, and ACTIVEFLOAT which is based on a semi-submersible-type configuration. Both concepts are designed to carry a 15 MW wind turbine. Three sites with different environmental conditions and water depths are selected for designing the solutions: West of Barra Island, Scotland (UK) with 100 meters design depth, Gran Canaria Island (Spain) with 200 meters design depth and Morro Bay (USA) with a design depth of 870 meters.

The design recommendations of COREWIND lead to further demands on industry, as the requirements of the upscaled 15 MW concept for FOWT are different from current practice and experience from operational fixed-bottom offshore wind farms.

In this section main challenges with regard to development needs are identified from a holistic view, considering the following aspects for floating offshore wind farms, based on COREWIND designs:

- design practice
- manufacturing and pre-assembling
- transport and installation
- operations and maintenance (O&M)

The analysis is focused on wind turbine, floater, mooring/anchoring and dynamic cables.

This overview is based on evaluations from experts of the COREWIND consortium. In addition, findings from Carbon Trust's “Floating Offshore Wind: Market and Technology Review" [1] and the summary reports of the “Floating Wind Joint Industry Project" [2], [3] are considered.

4.1.1 Design practice

With regard to floating structures, station keeping systems and dynamic cables, the existing design concepts for FOWTs are mostly developed based on the offshore experience from the oil and gas industry. However, interactions between wind turbine, control systems, floating support structure and station keeping system are a challenge for the design practice of FOWTs. Thus, from a holistic view, there is a need for the development of optimized integrated designs in order to consider the coupled dynamics between turbine, floater, mooring systems and dynamic cables.

4.1.1.1 Wind turbine

COREWIND analyses are considering a 15 MW wind turbine. The most powerful floating offshore wind turbines currently in operation are five Vestas V164-9.5 MW, commissioned in 2021 at the Kincardine project in Scotland. The new generation of 13-15 MW wind turbines is expected to be available from 2024. Currently, long-term experience with the operation of floating offshore wind turbines is still missing.

According to the findings in studies from Ramboll for [3], the tower and the control system are the primary wind turbine components affected by being installed on a floater. The tower for floating wind substructures needs to be redesigned due to loads increasing from floater motions and the global 1st tower bending eigenfrequencies increasing into the 3P region due to free-free boundary conditions.

Advanced control systems will need to be developed to optimize power production, to reduce fatigue loads, and to dampen floater motion, which can support a smaller platform size [1]. Furthermore, the effect of turbulence and non-uniform rotor thrust on the coupled dynamics of FOWT also requires investigation [2].

For wind turbine design practice, the development of optimized integrated designs, taking into account the coupled dynamics of the whole system, is very important. Thus, engaging OEMs early in the design phase will be critical to developing optimal integrated solutions [1].

Due to the large scale components of 15 MW FOWTs, there is also a need for a more modular design.

4.1.1.2 Floater

Currently, experience for floater is limited to the oil & gas industry and the operation of few FOWT prototypes.

The need for the development of optimized integrated designs is also relevant for the floater design. Efficient design methods to account for the interaction between turbine and floater dynamics are needed at different project stages to arrive at a similar level of maturity as fixed-bottom projects [3].

Fail-safe floater design solutions must be developed to minimize risks, e.g. the risk that wave frequency resonates with floater eigenfrequency.

Finally, long life design that includes changes due to environmental impacts like corrosion, marine growth, extremes, etc. must be considered to avoid issues in long-term operation of the floater. Restoring properties (i.e. waterplane characteristics or ballasting) shall account for change in pitch due to turbine thrust.

4.1.1.3 Mooring/anchoring

Experiences with mooring/anchoring at offshore sites are mainly based on applications in the oil & gas industry.

An optimized integrated design which takes into account the coupled dynamics between turbine, floater, mooring systems and dynamic cables must also be considered for the station keeping system. According to [2], the coupled behaviour of FOWT introduces new load characteristics with a potential material impact on the mooring system which are currently not covered by design standards.

In order to mitigate the probability of mooring line failures, there is a need to consider floating-specific load characteristics for fail-safe design or to factor in acceptable levels of redundancy for FOWT operation [2]. In this regard, risk of collisions is a special challenge.

For design practice, there is a need for the development of optimized solutions for combined/shared moorings.

Finally, long-lasting and site-adapted design for mooring/anchoring is also important, taking into account soil conditions and marine growth.

4.1.1.4 Dynamic cables

For dynamic cables, there is also a lack of experiences for FOWT operation, while considerable expertise exists from applications in the oil & gas industry.

Maximum excursion limits and bending stress are relevant factors with regard to the design of dynamic cables.

For design practice of dynamic cables, site optimized long-term design is needed, considering the protection on seabed and the loading at the connection point. Furthermore, negative impacts from marine growth due to the variation of weight in water over time must be avoided.

4.1.2 Manufacturing & pre-assembling

When it comes to manufacturing and pre-assembling of wind turbine, floater, station keeping systems and power cables, the main demands on industry are standardization and the need to establish serial production of large components. In this context, the key challenge for the industry is to scale up and build capacity for manufacturing and assembly that is optimized for floating solutions but that today is not demanded at scale. WindEurope has recently estimated that Europe's ports will need to invest €6.5bn between now and 2030 to support the expansion of offshore wind, with a significant focus on floating [42].

In addition, there is a need for development of optimized safeguard measures for offshore transport.

4.1.3 Transport & Installation

Offshore transport of large FOWT components and installation work between multiple floating objects in harsh environmental conditions at offshore locations far from shore are critical challenges for the realization of FOWT projects.

4.1.3.1 Wind turbine

Relevant demands on industry for offshore transport and installation of 15 MW wind turbines are to develop optimized solutions for handling the length and weight of the large components. This includes the need to develop customized transport and installation equipment and to provide additional installation assets.

An important aspect for wind turbine installation is the development need for optimized solutions for the installation between multiple floating objects, e.g. offshore service vessels and floater, and the related safety requirements.

The optimal installation strategy shall be evaluated in a case to case study, as it highly depends on different factors such as environmental conditions, supply chain and port infrastructure, vessel availability, local regulations, etc. Innovative assets with increased weather limits for specific operations like cable pull-in, anchor installation or mooring line to anchor connection could mitigate weather induced down times for challenging sites.

Finally, there is also the need to optimize methods for pre-assembly of 15 MW wind turbine on a platform and safeguard measures for offshore transport, depending on weather windows.

4.1.3.2 Floater

So far, only few FOWTs have been installed in pilot projects for floating offshore wind farms. Thus, with regard to transport and installation of the floating structures there is a need for additional assets.

As with wind turbines, transportation and installation of foundations depend on suitable weather windows.

For semi-submersible concepts such as ACTIVEFLOAT, for which offshore transport of the entire platform (with the pre-assembled wind turbine mounted on top) from the port is envisaged, optimized solutions must be developed in terms of ballasting and stability requirements.

In addition, concepts must be developed for towing operation of the structure (with wind turbine on top) to the offshore site and for ballasting of foundation till its final operation draught.

For the WINDCRETE spar conception, a customized solution for the installation of rotor blades at the offshore site with submerged structures is an important development need.

4.1.3.3 Mooring/Anchoring

Main challenges for the station keeping systems are the floating deep water installation of mooring lines/anchoring, for which optimized solutions are needed, depending on site-specific demands. In this context, the development of low cost installation methods for large-scale floating wind farms, which are expected to consist of hundreds of mooring lines and anchors, were identified as one of the priority innovation needs in [2].

Furthermore, the pre-loading to factorized ULS design loads is needed for the mooring/anchoring systems.

4.1.3.4 Dynamic cables

As with stationkeeping systems, optimization of floating deep water installation is also needed for the dynamic cables. Furthermore, there is a need for optimized solutions for the deep water conjunction of dynamic and static cables.

New concepts are needed to fulfill the specific installation requirements for FOWT applications, e.g. pull-in to moving floater. In this context, testing of the array cables is also important.

Finally, length of the cables and detachment are challenges for FOWT applications which require innovative solutions.

4.1.4 Operations and maintenance (O&M)

The operation of large-scale floating offshore wind farms require optimized O&M concepts, considering weather windows, accessibility and maintainability.

A risk-based inspection and maintenance program shall be established with the aim to reduce cost and maintenance related downtime of the wind farms. In combination with a monitoring concept a low risk level of the different components shall be ensured.

Digital models (e.g., BIM models) of the floating wind turbine asset allow to reduce the number of required accesses, repair time, and to make asset information easily accessible and transparent.

Digital twins for the structural integrity of the floating wind turbine increase the number of early failure detections, reduce the number of unscheduled activities and thus potentially improve the lifespan of the assets and their availability.

4.1.4.1 Wind turbine

For FOWT operation, there is very few experience in estimating the performance of floating wind turbines at large inclination angles by now. Thus, there is an urgent need to understand the impact of wake effects on commercial-scale arrays of floating wind turbines given the expected lateral movement of the floaters (semi-submersal and spars) [1].

As with the wind turbine installation, it is important to develop optimized solutions for O&M work between multiple floating objects, e.g. OSV and floater, and corresponding safety aspects.

Innovative concepts for large component replacements should be assessed and evaluated with regard to their impact on OPEX and wind farm availability.

According to [1], one of the most important development needs for potential cost savings is to prove feasibility and to define procedures for port-side major repairs, which is relevant especially for semi-submersible floaters. An O&M strategy with tow-in to harbor for repair will require cost- and time-efficient methods of unhooking the structure from its mooring and electrical cables, towing it to port, and reversing the process for re-connection [1].

The optimal major component exchange strategy shall be evaluated in a case to case study, as it highly depends on the environmental conditions, distance to port and wind farm size.

Representative wind turbines shall be equipped with a monitoring concept based on the risk assessment and criticality level of the components.

4.1.4.2 Floater

With regard to the floater, concepts for the subsea inspection must be optimized. In this context, there is also a need for further investigation of the impact/limits of marine growth in order to develop optimized O&M concepts.

4.1.4.3 Mooring/Anchoring and Dynamic cables

Optimized concepts for subsea inspections are also needed for stationkeeping system and dynamic cables.

In addition, it is important to develop concepts to prevent incidences on mooring lines and/or dynamic cables through fishing industry.

Related to port-side O&M strategies (see above), a new dimension for mooring and anchoring systems will be the need to develop connections that allow for easy disconnect and reconnect of the platform [1].

For the dynamic cables, solutions are required to avoid coating abrasion through longitudinal and vertical movements in J-tube.

4.1.5 Conclusions

As a result of the investigation, the following aspects should be highlighted as most relevant development needs.

Regarding design practice, it is required to develop optimized integrated designs considering wind turbine, floater and mooring. For the wind turbine, tower design and the development of advanced control systems are important aspects, while interaction between turbine and floater dynamics is of special interest for the floating substructure. For mooring/anchoring, the need to consider floating-specific load characteristics for fail-safe design and to optimize combined/shared moorings are most relevant. Finally, there is a need for optimized solutions regarding maximum excursion limits and bending stress for dynamic cables.

With regard to manufacturing and pre-assembling, the key challenge for the industry is to establish standardization, and to build capacity that is optimized for floating wind but that today is not demanded at scale.

For transport and installation of wind turbine and floater, concepts for work between multiple floating objects are required. Incidentally, this also applies to O&M work. Optimized solutions are needed in terms of ballasting and stability for transport of pre-assembled wind turbines, and for floating deep-water installation of station-keeping systems and cables.

An O&M strategy with tow-in to harbor for repair will require cost- and time-efficient methods of unhooking the structure from its mooring and electrical cables, towing it to port, and reversing the process for re-connection.

In general, a need for additional installation assets and for advanced tugs and barges was identified for transport, installation and O&M work.

4.2 COREWIND design practice recommendations

In this section the final status of COREWIND design practice recommendations is presented. The documenttation has been provided from work packages WP1, WP2, WP3 and WP4 of the COREWIND project and specifies in detail the relevant findings.

4.2.1 FOWT design (WP 1)

COREWIND Subtask	Component / Topic	Design target	Status
1.1.1: Design of land-based turbine and numerical model	**Minimum rotor speed**	**4.6 rpm**	**Completed**
Description / relevance for practice: Avoiding coincidence of the blade-passing frequency (3P) with the tower natural frequency.			
1.1.1: Design of land-based turbine and numerical model	**Bend-twist coupling**	**Included**	**Completed**
Description / relevance for practice: Bend-twist coupling is a mechanism for passive load alleviation in very flexible blades. It can be used to reduce the bending moment at the tower bottom and to increase the blade-tower clearance.			
1.1.3: Frequency domain model for floater upscaling	**Damping (aerodynamic and hydrodynamic)**	**It is important to include the appropriate damping in linearized frequency-domain models**	**Completed**
Description / relevance for practice: The system response and associated loads are very dependent on the amount of damping.			
1.2.2: Define load cases for the integrated design level for moored/ cabled FOWTs	**Amount of structure submerged during erection (WindCrete)**	**90 %**	**Completed**
Description / relevance for practice: Reduction of tower bending moment and easier installation of rotor-nacelle assembly without large crane vessels			
1.2.2: Define load cases for the integrated design level for moored/ cabled FOWTs	**Maximum significant wave height during transport and installation**	**2.0 m**	**Completed**
	Maximum wind speed (10-min average at 10 m above water) during transport and installation	**12.0 m/s**	**Completed**
Description / relevance for practice: Transport conditions may govern aspects of the structural design of the floating platforms, or some localized areas. Since the project is focused on the cost reduction of the mooring and dynamic cable systems, it is adviced that a high level assessment of the transport phase is performed in order to allow for the necessary contingencies. It must be noted that these operations are normally weather restricted operations in which metocean loads can be adjusted to platform capacities.			

1.2.2: Define load cases for the integrated design level for moored/ cabled FOWTs	**Hydrostatic stability for semi-submersible platform (ActiveFloat)**	**The area under the righting moment curve to the second intercept or downflooding angle, whichever is less, shall be equal to or greater than 130% of the area under the wind heeling moment curve to the same limiting angle.** **The righting moment curve shall be positive over the entire range of angles from upright to the second intercept.**	**Completed**
	Hydrostatic stability for spar-buoy platform (WindCrete)	**The metacentric heigh GM shall be equal to or greater than 1.0 m. The metacentric height GM is defined as the difference between the vertical level of the metacentre and the vertical level of the centre of gravity and shall be calculated on the basis of the maximum vertical center of gravity VCG**	**Completed**
Description / relevance for practice: These guidelines may be used in early stages of design. For a detailed design the dynamic-response based intact stability is to be considered.			
1.2.2: Define load cases for the integrated design level for moored/ cabled FOWTs	**Max floater pitch in operation**	**10 deg** **Be aware of total rotation of pitch and roll – this value must also be kept below the given limits. Eventually the limiting pitch is a load aspect, for example for the tower base bending moment.**	**Completed**
	Mean (10 min) floater pitch in operation	**5-8 deg** **Subject to load considerations. Fatigue. ULS.**	**Completed**
	Std (10 min) floater pitch in operation	**Governed by max value of 10 deg and is again really determined by loads.**	**Completed**
	Max floater roll in operation	**As pitch but will typically be much smaller. Beware that limiting values should apply also to the total rotation (angle from combined pitch and roll – add as vectors).**	**Completed**

	Std (10 min) floater roll in operation	**As pitch but will typically be much smaller. Beware that limiting values should apply also to the total rotation (angle from combined pitch and roll – add as vectors).**	**Completed**
	Max floater yaw in operation	**Governed by production and loads**	**Completed**
	Std (10 min) floater yaw in operation	**Governed by production and loads**	**Completed**
	Max floater pitch in idling condition	**15 deg** **Total rotation of roll and pitch to be kepth within this limit. Loads to be considered, e.g. tower base moment.**	**Completed**
	Mean (10 min) floater pitch in idling condition	**Governed by loads**	**Completed**
	Max floater pitch in emergency stop	**15 deg** **Be aware of transient loads**	**Completed**
	Acceleration in XY and in Z in operation	**0.30 g** **It is the loads that matters**	**Completed**
	Acceleration in XY and in Z in operation	**0.45 g** **It is the loads that matters** **Some damage on equipment may occur for such an acceleration**	**Completed**
Description / relevance for practice: Limiting values of pitch, roll and acceleration are indicators for loads. In reality, it is the internal loads in e.g. gear box, tower bottom and blade root that matters. This can be both as extreme loads and as fatigue loads. Hence the limits on motion and acceleration shall only be seen as helpful indicators in the design process prior to full load validation.			
1.2.2: Define load cases for the integrated design level for moored/ cabled FOWTs	**Mean horizontal offset in operation**	**15m (for water depth 100m)** **30m (for water depth 200m)** **52m (for water depth 870m)**	**Completed**
	Max horizontal offset in parked conditions	**30m (for water depth 100m)** **60m (for water depth 200m)** **104m (for water depth 870m)**	**Completed**
Description / relevance for practice: Excursions are usually restricted by the power cable or the windfarm layout. The maximum excursions limits of the platform are the subject of several tasks within the COREWIND project, therefore, the following are indicative limits for excursions limits.			

1.3.1: Upscaling of floater and tower to the 15MW turbine	**Maximum static floater pitch due to rated thrust**	**4 deg (WindCrete)**	**Completed**
Description / relevance for practice: To avoid excessive mean pitch angles due to wind loads			
1.3.1: Upscaling of floater and tower to the 15MW turbine	**Active ballast system**	**Included (ActiveFloat)**	**Completed**
Description / relevance for practice: To compensate the floater mean pitch caused by the wind loads			
1.3.1: Upscaling of floater and tower to the 15MW turbine	**Minimum natural period in surge**	**80 s (WindCrete)**	**Completed**
	Minimum natural period in heave, pitch and roll	**30 s (WindCrete)**	**Completed**
Description / relevance for practice: To avoid resonance due to wave loads			
1.3.1: Upscaling of floater and tower to the 15MW turbine	**Minimum natural period in yaw**	**10 s (WindCrete)**	**Completed**
	Hub height	**135 m (WindCrete and ActiveFloat)**	**Completed**
Description / relevance for practice: Allows a more cost-efficient design			
1.3.1: Upscaling of floater and tower to the 15MW turbine	**Tower natural frequency**	**Above 3P range (WindCrete)**	**Completed**
Description / relevance for practice: To avoid resonance due to blade-passing frequency			
1.3.1: Upscaling of floater and tower to the 15MW turbine	**Heave plates**	**Included (ActiveFloat)**	**Completed**
Description / relevance for practice: To limit the heave and pitch motions			
1.3.1: Upscaling of floater and tower to the 15MW turbine	**Mooring line layout**	**Maximum surge is 15 m and no vertical loads on anchors (ActiveFloat)**	**Completed**
Description / relevance for practice: To limit the horizontal excursions and avoid anchor pull-out			

1.3.2: Wind turbine controller adaptation and public FAST model	**Blade pitch controller gains**	**Ensure stability above rated wind speed**	**Completed**
1.4.3: Incorporation of wake effects in the models	**Wake interactions in floating wind farms**	**It has been observed that the wake recovery is enhanced by the floater motion, since the motion accelerates the mixing and breakdown of the tip vortices. Slow rotor oscillations are more beneficial than high frequency ones. This beneficial effect disappears as the ambient turbulence intensity is increased.** **A floating wind turbine can cause resonance of downwind turbines through the wake. This wake-induced resonance can build up along a row of turbines when operating above rated wind speed.**	**Completed**

4.2.2 Station keeping systems (WP 2)

COREWIND Task	Component / Topic	Design target	Status
2.2: Design analysis and optimization of mooring and anchoring system for floating wind turbines (Innovations and breakthroughs)	**Mooring design optimisation**	**Offer the possibility to design mooring system adapted to the floater and site and optimised in term of cost**	**Completed**
Description / relevance for practice Mooring design is a long process as each configuration has to be tested on a large batch of design load cases. For now this process is manual and once a working configuration is found no further optimisation is done. A need was then identified to offer the possibility to perform this cost optimisation automatically to reduce the engineering time and mooring costs.			
2.2: Design analysis and optimization of mooring and anchoring system for floating wind turbines (Innovations and breakthroughs)	**Integrated / combined mooring dynamic cable design**	**Combine mooring and dynamic cable optimization**	**Completed**
Description / relevance for practice Mooring and dynamic cable design are usually done in parallel by different entities. This leads to a lack in the optimisation of the dynamic cable that is designed after the mooring system. Performing the design in combination could help to find the most optimised solution for both.			

2.2: Design analysis and optimization of mooring and anchoring system for floating wind turbines (Innovations and breakthroughs)	**Optimal mooring**	**Optimise the design of fairleads on concrete floaters**	**Completed**
Description / relevance for practice Fairlead design on concrete floater is a complicated task as the mooring loads have to be distributed into the concrete elements. Several reinforcements have to be integrated and optimized.			
2.2: Design analysis and optimization of mooring and anchoring system for floating wind turbines (Innovations and breakthroughs)	**Installation techniques**	**Optimisation of installation techniques**	**Completed**
Description / relevance for practice Mooring installation is a costly phase as it needs offshore installation vessel. Optimising the mooring installation is a good opportunity to reduce drastically the mooring cost.			
2.3: Exploration of innovations and breakthroughs of station keeping systems for FOWT	**Technological benefits regarding peak loads reduction**	**Optimise the mooring design cost by using peak loads reduction system**	**Completed**
Description / relevance for practice Mooring tensions can be really high during harsh environmental conditions. It leads to the utilisation of large mooring lines. Several developers are working on peak loads reduction systems that can help reducing the mooring line tension and thus their size. This might help reducing the cost of mooring systems.			
2.3: Exploration of innovations and breakthroughs of station keeping systems for FOWT	**Investigations of solutions for mooring footprint reduction**	**Optimise the mooring footprint**	**Completed**
Description / relevance for practice Mooring footprint can limit the number of wind turbine installed on a farm. Reducing the footprint might help increasing the number of Wind Turbine on a farm and increase the rentability.			
2.3: Exploration of innovations and breakthroughs of station keeping systems for FOWT	**Investigations of tuning of the controller to reduce mooring fatigue**	**Investigate turbine control strategy to optimise mooring design**	**Completed**
Description / relevance for practice Fatigue can lead the mooring design. Investigating wind turbine torque and pitch control strategies might help to reduce the mooring fatigue and thus help optimizing the mooring design.			

<table>
<tr><td>2.3: Exploration of innovations and break-throughs of station kee-ping systems for FOWT</td><td>Design at farm level: use of shared anchors, shared mooring lines or multiple turbines on a floater</td><td>Investigate the possibility of sharing anchors and mooring lines</td><td>Completed</td></tr>
<tr><td colspan="4">Description / relevance for practice

Mooring systems are representing a non negligible part of the global cost of floating wind turbine farms. The possibility of sharing anchors and mooring lines with several floater might help the reduce the global price of mooring systems at farm level.</td></tr>
</table>

4.2.3 Power Cables (WP 3)

<table>
<tr><th>COREWIND Task</th><th>Component / Topic</th><th>Design target</th><th>Status</th></tr>
<tr><td>3.2</td><td>Power transmission through dynamic wind farm array</td><td>Suitable electrical design of dynamic array cables</td><td>Completed</td></tr>
<tr><td colspan="4">Description / relevance for practice

Power transmission requirements inform power core definition, which then drives the overall physical size of the dynamic cable. For Corewind this has been considered based on available information and assumptions defined within D3.1. Further information will be included in D3.4.</td></tr>
<tr><td>3.5</td><td>Substation design (static foundation / floating) and philosophy power transmission from the windfarm to shore</td><td>Design of suitable export cables (export voltage / static or dynamic cable)</td><td>Completed</td></tr>
<tr><td colspan="4">Description / relevance for practice:

Power transmission requirements inform power core definition, which then drives the overall physical size of the export cable. As identified in D3.1 distance from shore and wind farm designer cost preferences of the substation influences what export cable design will be required.

Cable configuration designs at the substation is not currently within the WP3 Corewind modelling scope. After reviewing topography and wind farm layout, developers determination of whether the substation can be designed with static foundations or whether it will be floating will dictate if dynamic export cabling is required, and windfarm layouts including redundancy cabling. Wind farm power transmission requirements may demand export cabling of greater voltage than 66kV wet-tolerant cable design proposed in Corewind for array cable analysis. For export cabling, no higher voltage dynamic wet-tolerant solutions have been developed within industry. This highlights a dynamic export cable development opportunity where a floating substation is employed. Known research projects which are supporting development of dynamic export cabling include CT HCIAC and HV DEC JIP. Development of a dynamic export cable is limited at this time and outside project scope, but current limits and options for further development research will be re-evaluated towards end of the project and discussed further within D3.4 as part of task T3.5.</td></tr>
<tr><td>3.5</td><td>Substation design (static foundation / floating) and philosophy power transmission from the windfarm to shore</td><td>Multi-array cable configuration approach to substation</td><td>Completed</td></tr>
<tr><td colspan="4">Description / relevance for practice:

Cable configuration designs at the substation is not currently within the WP3 Corewind modelling scope. After reviewing topography and wind farm layout, developers determination of whether the substation can be designed with static foundations or whether it will be floating will dictate if dynamic array cabling is required and management strategy selection considering options of mid water arch or multi-string separate buoyancy approach to manage the multiple dynamic array cable feed in to the station while adhering to cable proximity</td></tr>
</table>

restrictions. Options will be discussed further within D3.4.			
3.2	**Thermal restrictions**	**Cable system hardware**	**Completed**
Description / relevance for practice: Consideration for cable thermal restrictions in designing hardware and managing proximity/layout of cabling fall outside the project scope of WP3 assessments but will require site specific review on commercial scale projects. Recommendations identified during hard ware review will be provided within D3.4.			
3.2	**Deeper water depth application (e.g. Site C)**	**Qualification testing of cable design**	**Completed**
Description / relevance for practice: Power cores for deep water applications may require additional qualification testing compared to typical REC cores which have been employed for shallower water applications. Deep water installation also require greater tensile capacity of cable design. Testing cable tensile capacity required for deep water installation will be discussed within D3.2. Existing REC qualification has been limited based on project developments to date.			
3.2	**Marine Growth thickness and weight**	**Dynamic cable system configuration, hardware requirements, and O&M strategy**	**Completed**
Description / relevance for practice: Marine growth is a significant influencer of variation between cable configuration in start of life conditions and the end of life conditions (where marine growth added weight and drag contribution is considered) and thus significant driver over ancillary hardware considerations and system cost. A sensitivity performed within WP3 will demonstrate the scale of the issue within D3.2 and implications for prediction and accuracy of assessment considerations of site marine growth captured within D3.4. Informed discussion based on feedback from WP5 marine growth testing will also be included.			
3.2	**Floater connection point**	**Bend management (j tube, bend stiffener etc) and avoiding interference / clash**	**Completed**
Description / relevance for practice: Connection point study conducted within T3.2 used to inform connection point for modelling within T3.3 and will provide the basis for discussion and recommends in D3.4.			
3.3	**Cabling system buoyancy**	**Hardware costs and installation costs**	**Completed**
Description / relevance for practice: Buoyancy module size dictates required quantities. Larger modules see increased drag loading, but fewer units to install to reduced fitting time during installation (less human intervention on vessel time). Sensitivity study will be performed under T3.3 and T3.4 to demonstrate cost alternative on optimised models and results captured within D3.4.			
3.2	**Standardisation of cables, hardware and configuration across sites**	**Cost effective cable configuration for large scale applications**	**Completed**
Description / relevance for practice: Consistent and standardised hardware and cables reduces risk of increased cable loading due to incorrect installation, and is likely to make installation both more efficient, predictable, reduce spare parts required for			

O&M, and influence bulk purchasing price of system. Discussion on standardisation will be captured within D3.4, informed by T3.2 and T3.4.

3.3	**Greater wind, wave and current environmental loading conditions (per water depth)**	**Avoidance of on bottom migration of cables and avoidance of clashing within the water column**	**Completed**
Description / relevance for practice: Cost of system shown to increase with harsher environmental loading environments where greater dynamic motion of cabling system is induced (within water column or in the vicinity of the touchdown point) or seabed stability is unachievable without additional hardware. Cable platform exit angles and elevations are considered within modelling to reduce risks, however significant cable motion may sets requirements for tether clump weight hardware to restrict movement and mitigate risk on system. Optimised system for Site A will capture this within T3.3 and results documented in D3.2. D3.4 will discuss further options and challenges which may exist for sites with a dominant environmental characteristic.			
3.3	**Wind, wave and current environmenttal loading occurrences and directionality considerations in conjunction with moored platform motion**	**Appropriate cable fatigue prediction**	**Completed**
Description / relevance for practice: To optimise cable design, and reduce cable costs, fatigue assessment should be representative of cable operational condition. Probability of environmental loading cases occurring and subsequent duration expected where cable will be exposed to each excursion point of moored platform (with turbine wind loading) should be carefully considered. If device does not spend equal time in all offsets (near, far, trans 1. Trans 2), cable fatigue assessment should reflect this. DLC probability raised within the Corewind group and will be considered within the optimised model fatigue assessment within T3.3 and results documented in D3.2. Approach for fatigue assessment can be simplified, which may decrease computational time for assessments, but may increase system / hardware cost due to conservatism.			
3.1	**Wet mate-able connector availability**	**Installation and O&M strategy**	**Completed**
Description / relevance for practice: Lack of high voltage wet mate-able connectors for large cores limits installation and O&M strategies for dynamic wind cabling. Currently this limits wind farm cabling design and dictates installation practice to be noted within D3.4. Study and development of a HV wet mate-able connector is outside project scope but is a potential opportunity for commercial scale FOW applications. This is of particular interest when developers and operators review risks and cost for cabling for dynamic to static transition for export cables, and potentially for array structure maintenance strategies.			
3.2	**Stability strategy for on bottom sections**	**Cable design and O&M strategy**	**Completed**
Description / relevance for practice: Stability of static cabling is not within the WP3 modelling assessment scope, but will be discussed within D3.4. FOW may be employed in harsh rock seabeds which were previously unfeasible for fixed-bottom static wind infrastructure, resulting in additional considerations/detail quality when assessing seabed during site surveys to consider cable lay route, restraint points to limit lateral movement and potential cable damage in service e.g. abrasion, cut resistance, etc. This may require additional cable testing and design modifications to suit site specific environment. Due to increase in risks depending on site conditions, O&M inspection intervals and strategy may be influenced as highlighted to WP4 (July 2020). Currently no standard captures requirements for assessing cables on rocky seabed, although a British international standard is in development to address this. Assessment to this standard cannot be performed under Corewind task T3.2 but when it is published it will be discussed within D3.4.			

4.2.4 Operation & Maintenance (WP 4)

COREWIND Task	Component / Topic	Design target	Status
4.1	**Motion criteria definition**	**Enable the assessment for critical motion response of floating substructure**	**Completed**
Description / relevance for practice: Different methodologies exist to assess the human comfort with regard to low frequent whole body vibrations (Scheu et al. 2018). For offshore application a standardized method is missing. Further the motion criteria to evaluate structural motions are scarce and incomplete (Schwarzkopf, 2018). A precise definition of these motion criteria be the first step to enable the assessment for critical motion response of floating substructures.			
4.1	**Human Comfort: Increased Vibration dose value during offshore operation**	**Avoid critical motion response of floating substructure**	**Completed**
Description / relevance for practice: Wind farms further offshore require longer transit times. The vibration dose value (VDV) of technicians for low frequency motions described in VDI 2057-1/3 needs to be studied during design phase. A high VDV constitutes a health risk and negatively impacts the performance. Vibrations from the boat transits and those accumulated during the stay on the wind turbine need to be taken into consideration.			
4.1	**Landing zone for motion compensated gangway**	**O&M friendly design: Ease landing of motion compensated gangway on external platform**	**Completed**
Description / relevance for practice: In the oil and gas industry V-shaped landing funnels are used to make it easier for the pilot of the motion compensated gangway to land it safely on the platform. In the light of floating wind where the landing zone is now moving too, a design solution like the V-shaped funnel would ease the access. A reftrofitting campaign for such funnels would be very cost intensive and maybe technically not feasible.			
4.1	**Follow-target mode**	**O&M friendly design: Standardized optical target to translate relative motions into motion compensation**	**Completed**
Description / relevance for practice: A camera captures an standardized optical target on the floating platform close to the landing zone. This allows to capture the motions of the floating asset or of another ship respectively and to translate it into compensation. The optical target does not need to be a QR code- it needs only to be contrasted for the camera to focus on it. This technology would also allow a save transfer from ship to floater or ship.			
4.1	**Inspection of components**	**Risk-based inspection scheme for floating wind**	**Completed**
Description / relevance for practice: A classification scheme as usually used in O&G defines very prescriptive inspection intervals. For floating wind, a risk-based inspection scheme can be the preferred solution for large floating wind farms, for example, using a clustered approach for mooring line inspections than scheduled maintenance or replacements. More floating wind specific guidance (in standards) on inspections during the operational phase would be beneficial for floating wind as long term experience is still missing.			

4.2	Offshore on-site lifting or tow-in to port for major component exchange	O&M friendly design: Impact of FOWT and vessel motions on weather windows for offshore lifting or tow-in	Completed
Description / relevance for practice: The technical and operational requirements and the implications on costs for offshore lifting operations for maintenance of major components such as rotor blades are associated to high uncertainties also due to lack of practical experience with large floating wind farm arrays. In addition, lifting operations are not covered in detail by all governing floating wind specific standards (such as IEC TS 61400-3-2). Tow-in to port can be an alternative maintenance strategy but whether it is beneficial will depend on many aspects, such as distance to shore, vessel availability, required infrastructure for maintenance, possible weather windows, etc. The motion characteristics of the FOWT and the maintenance vessel will impact the possible weather windows for offshore lifting operations. It is understood that this aspect should be considered for an O&M friendly design, which is getting more important for large floating wind farms far offshore.			

5 IDENTIFICATION OF MARKET OPPORTUNITIES

5.1 Development of the global offshore wind market

By the end of 2022, the global offshore wind market has reached a capacity of 64.3 GW [4], with only three countries accounting for 84% of the installed capacity: China (49%), the UK (22%) and Germany (13%). The offshore wind market has grown from 4.4 GW in 2018 to 8.8 GW in 2022, bringing its market share in global new installations from 9% to 11%. In 2022, new installations were lower than 2021, primarily due to new installations slowing down in China after an incentive-driven installation rush, see Figure 6 [4], [26].

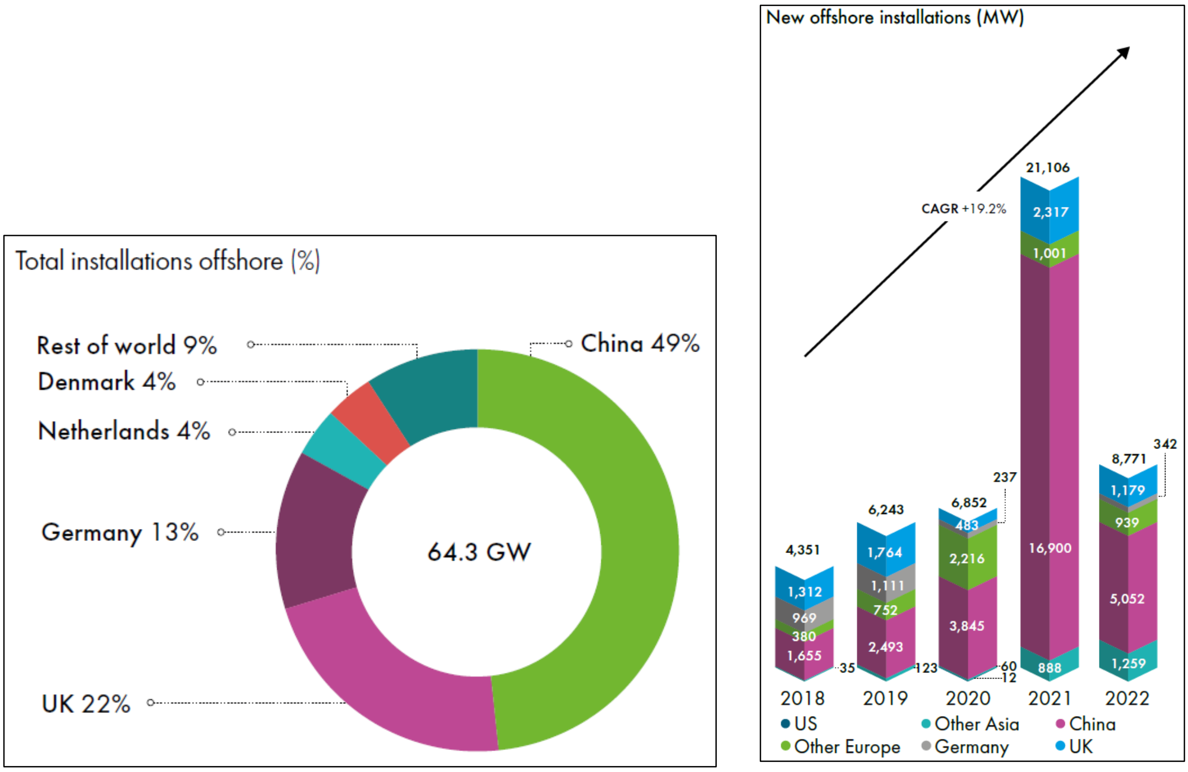


Figure 6: Total global offshore wind installations by end of 2022 and new installations 2018-2022 [4]

So far, the offshore wind business is clearly dominated by fixed-bottom offshore wind farms, while only few floating offshore wind turbines are operational. The majority of operating offshore wind farms were built in coastal regions in Europe and in China with relatively shallow water depths of less than 50 m and within 100 km distance to shore. However, the offshore wind market for fixed-bottom structures is constrained due to limited locations with shallow waters.

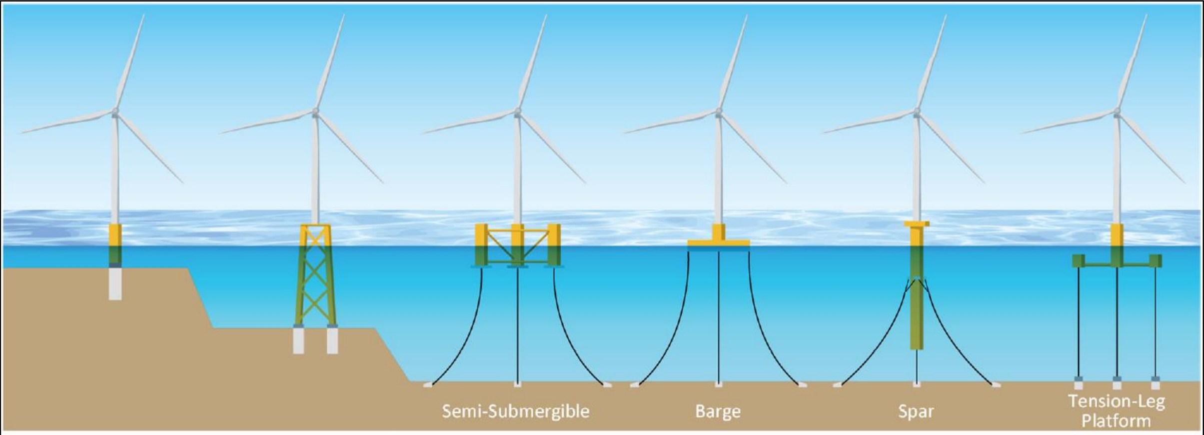
The offshore market is characterized by the motivation to use of the largest wind turbines available, as project costs are lower with larger units. Currently, the leading suppliers are developing offshore wind turbines with a capacity of up to 18 MW. The new generation of 15 MW wind turbines is expected to be available from 2024.

In December 2022, Vestas commissioned the prototype V236-15.0 MW at the Østerild test center in Denmark, followed by Siemens Gamesa's prototype SG 14-236 DD (up to 15 MW with Power Boost), which delivered first power in March 2023 at the same site. GE Renewable Energy has received a full type certificate in December 2022 for its Haliade-X 14.7 MW-220 prototype that has been tested and validated in Rotterdam since 2019. Furthermore, GE has announced the development of a 18 MW Haliade-X in March 2023, shortly after two Chinese wind turbine manufacturers, Mingyang Smart Energy and CSSC Haizhuang Wind Power, unveiled plans to develop a 18 MW offshore wind turbine [31].

To date, all offshore wind turbines used in floating applications have been designed for fixed-bottom applications. According to the 2018 Offshore Wind Technologies Market Report, conceptual engineering studies suggest a greater value proposition for lightweight FOWT turbine components, which may help reduce overall system weight [5]. However, demand for customized offshore floating wind turbine designs will only increase with the establishment of a large future FOWT market.

Currently, the offshore wind market is clearly dominated by fixed-bottom foundations. Monopiles are typically considered to be most cost-effective at up to 35 m water depth, while jacket structures are preferred in deeper waters with up to 56 m for economic reasons. For deepwater offshore sites exceeding 50 m there is evidence to suggest that the cost of fixed-bottom wind turbines becomes less economically viable [6].

Figure 7 illustrates the different types of substructures for offshore wind turbines [63].



Semi-Submersible	Semi-submerged floating body
Barge	Barge-style floating body
Spar	Cylindrical floating body with a low center of gravity
Tension-Leg Platform	Semi-submersible floating body fixed by tension mooring

Figure 7: Types of substructures for offshore wind turbines [63]

To date, it is more expensive to build offshore wind farms with floating foundations, but FOWT have many advantages and the potential to offer a cost of energy comparable to fixed-bottom offshore wind farms. There is a huge potential for floating offshore wind in many markets with extensive wind resource at offshore sites with water depths beyond 50 m. In particular, the potential for FOWT in Japan, the United States, and a number of European countries including the UK, Norway, France, Portugal, and Spain is significant [1].

5.2 Operational and planned FOWT projects

In 2009, the 2.3 MW Hywind Demo project was the world's first MW scale floating offshore wind turbine which was gridconnected by Equinor in Norway. By the end of 2022, a total of 189.8 MW of floating wind capacity was operational worldwide (Table 3).

Most FOWT projects installed to date have been single-unit demonstration projects. HywindScotland, WindFloat Atlantic 2 and Kincardine are the first pilot projects with three to five floating offshore wind turbines.

Hywind Tampen, a floating offshore wind farm comprising eleven wind turbines with a system capacity of 88 MW, is currently the only pre-commercial FOWT project. In 2022, the first seven Siemens Gamesa SG 8.0-167 DD (upgraded from 8 to 8.6 MW) have been commissioned, on floating concrete structures with a shared anchoring system to supply renewable power to offshore oil and gas platforms in the Norwegian North Sea.

Table 3 provides an overview of the floating offshore wind turbines currently in operation, including those FOWT that have been decommissioned in the meantime. As shown in the table, floating wind projects are operated in the UK, Norway, Portugal, France, as well as in Japan and China.

Commissioning	Project (Developer)	Country	Water depth	Distance to shore	FOWT	Capacity	Floater concept (Developer)
2009	Hywind Demo / Unitech Zephyros (Equinor)	NO	220 m	12 km	1	2.3 MW	Hywind (Equinor)
2011 *(2016)**	WindFloat Atlantic 1 (EDPR, Repsol, Chiyoda, Mitsubishi)	PT	n/a	n/a	1	2 MW	WindFloat (Principle Power)
2013	Kabashima / Sakiyama (Toda Corporation)	JP	76 m	1 km	1	2 MW	Hybrid Spar (Toda Corporation)
2013 *(2021)**	Fukushima Mirai (Marubeni)	JP	n/a	23 km	1	2 MW	Semi-Sub (Mitsui Engineering)
2015 *(2020)**	Fukushima Shimpuu (Marubeni)	JP	32 m	23 km	1	7 MW	V-Shape Semi-Sub (Mitsubishi Heavy Ind.)
2016 *(2021)**	Fukushima Hamakaze (Marubeni)	JP	48 m	23 km	1	5 MW	Advanced Spar (Japan Marine United)
2017	Hywind Scotland (Equinior)	UK	95-120 m	25 km	5	30 MW	Hywind (Equinor)
2018	Kincardine Pilot (Pilot Offshore, Cobra)	UK	60-80 m	15 km	1	2 MW	WindFloat (Principle Power)
2018	FloatGen, SEM-REV test site (BW IDEOL)	FR	33 m	22 km	1	2 MW	Damping Pool (BW IDEOL)
2018	Hibiki Demo, Kitakyushu (BW IDEOL, Hitachi Zosen)	JP	55 m	15 km	1	3 MW	Damping Pool (Steel) (BW IDEOL)
2019-2020	WindFloat Atlantic 2 (EDPR, ENGIE, Repsol, PPI)	PT	85-100 m	20 km	3	25 MW	WindFloat (Principle Power)
2021	Yangxi Shapa III Demo (China Three Gorges (CTG))	CN	30 m	28 km	1	5.5 MW	Semi-Sub (Wison Offshore & Marine)
2021	Kincardine (Scotland) (Pilot Offshore, Cobra)	UK	60-80 m	15 km	5	48 MW	WindFloat (Principle Power)
2021	TetraSpar demonstrator, METCentre (RWE, Shell, TEPCO, Stiesdal OT)	NO	200 m	10 km	1	3.6 MW	TetraSpar (Stiesdal OT)
2022	Fuayo prototype (Haizhuang Wind Power)	CN	50-70 m	13 km	1	6.2 MW	Fuyao, Semi-Sub (Haizhuang Wind Power)
2022	Hywind Tampen (Equinor)	NO	260-300 m	140 km	7 (of 11)	60.2 MW	Hywind (Equinor)
** (Year of decommissioning)*		FOWT in operation (status 2022/12/31):				**189.8 MW**	

Table 3: Operational floating offshore wind turbines

A list of upcoming floating offshore wind project is presented in Table 4. It should be noted, that this overview does not claim to be complete.

According to GWEC data (as of July 2021), almost two-thirds of projects in development are planned with different semi-submersible technologies, while 56% of operational FOWT demonstrators have been equipped with spar floaters [33].

Commissioning *(expected)*	Project (Developer)	Country	Water depth	Distance to shore	FOWT	Capacity	Floater concept (Developer)
2023	Hywind Tampen *(88 MW system capacity for 11 FOWT)* (Equinor)	NO	260-300 m	140 km	4 (of 11)	34.4 MW	Hywind (Equinor)
2023	CNOOC Guanlan, Hainan province China National Offshore Oil Corporation (CNOOC)	CN	100+m	136 km	1	7.25 MW	Semi-Sub (n/a)
2023	DemoSATH, BiMEP test site (Saitec, RWE Renewables)	ES	85 m	3 km	1	2 MW	SATH (Saitec)
2023	SeaTwirl S2x 1MW pilot, METCentre (SeaTwirl)	NO	n/a	0.7 km	1	1 MW	SeaTwirl (SeaTwirl)
2023	FLAGSHIP, METCenter (Iberdrola, Core-Marine, Cener, IHC)	NO	220 m	10 km	1	10+ MW	OO-Star Wind Floater (Olav Olsen)
2023	Hybrid floating wind-wave platform, PLOCAN test site (Floating Power Plant)	ES	n/a	n/a	1	8 MW	Hybrid floating wind-wave energy platform (Floating Power Plant)
2023	EFGL - Golfe du Lion (Ocean Winds, Caisse de Dépôts, RTE)	FR	75 m	16 km	3	30 MW	WindFloat (Principle Power)
2023	Provence Grand Large (EDF Renouvelables, Enbridge)	FR	100 m	17 km	3	25 MW	Tensioned line floats (SBM Offshore, IFP Energies Nouvelles)
2023	Hexafloat demonstrator, Mistral test site (SAIPEM)	FR	n/a	n/a	1	3 MW	Hexafloat (SAIPEM)
2023	TwinWay demonstrator, METCentre (Hexicon, Worley)	NO	n/a	n/a	2*2	6 MW	TwinWind (Hexicon)
2023	MPS wind/wave hybrid demonstrator; BiMEP test site (Marine Power Systems)	ES	n/a	n/a	1	2 MW	PelaFlex/PelaGen wind-wave TLP platform (Marine Power Systems)
2024	New England Aqua Ventus I (Mitsubishi, RWE)	US	n/a	3 km	1	11 MW	VolturnUS (University of Maine)
2024	EolMed - Gruissan (Qair Marine)	FR	55 m	18 km	3	30 MW	Damping Pool (BW IDEOL)
2024	Goto floating wind farm; Nagasaki (Toda, Eneos, Osaka Gas, Inpec, Kansai/Chubu Electric Power)	JP	n/a	n/a	8	16.8 MW	Hybrid-spar (Toda)
2024	EOLINK demonstrator, SEM-REV test site (EOLINK)	FR	n/a	n/a	1	5 MW	EOLINK (EOLINK)
2024	SENSE PelaStar demonstrator, Kinkardine (Scotland) (SENSEWind, Glosten, Subsea Micropile)	UK	n/a	n/a	1	2 MW	SENSEWind / PelaStar TLP (SENSEWind, Glosten)
2024	Bluewater TLP demonstrator; METCentre (Bluewater)	NO	n/a	n/a	1	n/s	Tension leg platform (Bluewater)
2025	NextFloat, X90 platform prototype, Mistral test site (X1 Wind)	FR	n/a	n/a	1	6 MW	X90 platform / TLP / PivotBuoy (X1 Wind)
2025	TwinHub demonstration project, Celtic Sea (Hexicon, Bechtel)	UK	50-60 m	16 km	2*2	32 MW	TwinWind (Hexicon)
2025	Pentland floating demonstrator, Scotland (Copenhagen Infrastructure Partners, Hexicon)	UK	n/a	7.5 km	1	n/s	TetraSub (Stiesdal OT)
2025	BLOW project, Black Sea/Bulgaria (EOLINK)	BG	n/a	n/a	1	5 MW	EOLINK (EOLINK)
2025	ERM Dolphyn wind-to-hydrogen project (Environmental Resources Management)	UK	n/a	n/a	1	10 MW	WindFloat (Principle Power)

Table 4: Pipeline of upcoming floating offshore wind projects

5.3 Current commercial offerings for FOWT substructures

Developments for floating offshore wind substructures can be classified in three main concepts (see Figure 7):

- Semi-submersible and barge
- Spar-buoy
- Tension leg platform (TLP)

Besides, there are different variations of these concepts, including semi-submersible barge configurations and multi-turbine platforms as well as hybrid devices for the combined use of wind and wave technologies.

Currently, there are more than 80 different floating wind concepts [32] at various stages of development. An overview of most advanced floating wind concepts identified by Carbon Trust is shown in Figure 8 [3].

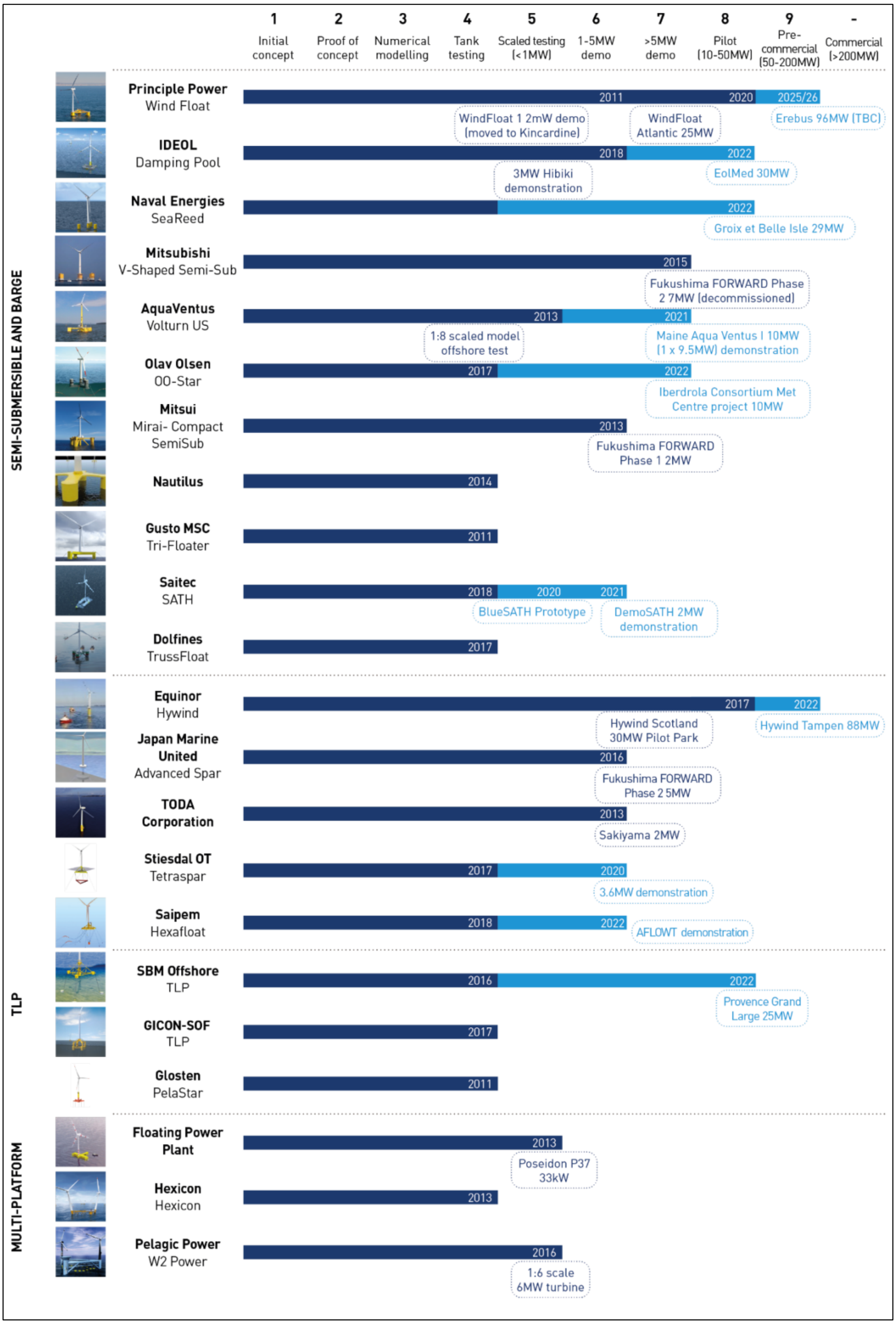


Figure 8: Overview TRL status of advanced concepts for floating wind technology [3]

5.3.1 Semi-submersible and barge

The semi-submersible platform is anchored to the seabed with catenary mooring lines and floats semi-submerged on the surface of the ocean. The floater is stabilized by buoyancy which usually requires a large and heavy structure, but a low draft allows for more flexible application and simpler installation [1].

Semi-submersible platforms need a large and/or sufficiently spread water plane area. For semi-submersible configurations, several columns are connected by bracings, producing a number of smaller areas far from the inclination axis. A barge configuration usually achieves this through one large waterplane area [6].

Reference Projects

- **WindFloat (Principle Power)**

  WindFloat is the most matured semi-submersible platform design concept for FOWT. Principle Power developed the design which consists of a semi-submersible hull with three columns, one of which supports the turbine.

  In 2011, a full-scale prototype with a 2 MW wind turbine was installed for WindFloat Atlantic 1 in Portugal. After several years of successful operation, the unit has been moved to Scotland for the Kincardine Pilot project, which is operating since 2018.

  Windfloat Atlantic 2 with three 8.4 MW wind turbines was the world's first semi-submersible floating wind farm, commissioned in 2020.

Figure 9: WindFloat semi-submersible floating foundation for Kincardine offshore wind farm [Source: COBRA Group]

  Additional five 9.525 MW FOWT with WindFloat floating structures have been built by COBRA Group for the Scottish Kincardine project. At the time of commissioning in 2021, Kincardine was the world's largest floating offshore wind project with the most powerful operational FOWT.

  In addition, the 30 MW French floating offshore wind project "Les Eoliennes Flottantes du Golfe du Lion" with three 10 MW Vestas FOWT on WindFloat floating foundations is scheduled to be commissioned in 2023.

  The 1.2 GW KF Wind project offshore Ulsan, South Korea is the first industrial-scale floating wind project with WindFloat foundations, currently under development and expected to be operational in 2028.

- **Damping Pool (BW Ideol)**

  Damping Pool, developed by BW Ideol, is a modified semi-submersible design, classified as a caisson/ barge concept. The floating platform is a square concrete hull with a central opening to create the "damping pool" system that uses the entrapped water to minimize floater motions, resulting in strong hydrodynamic performance. Due to the low floater motion only minor modifications for towers and control systems of conventional offshore wind turbines are required to align the floater's behaviour [1].

  In 2018, two full-scale prototypes with Ideol's damping pool floating foundation were commissioned in the FloatGen 2 MW demo project at SEM-REV offshore test site, off the Atlantic coast – the first offshore wind turbine in France, and in the Hibiki 3 MW demo project in Kitakyushu, Japan.

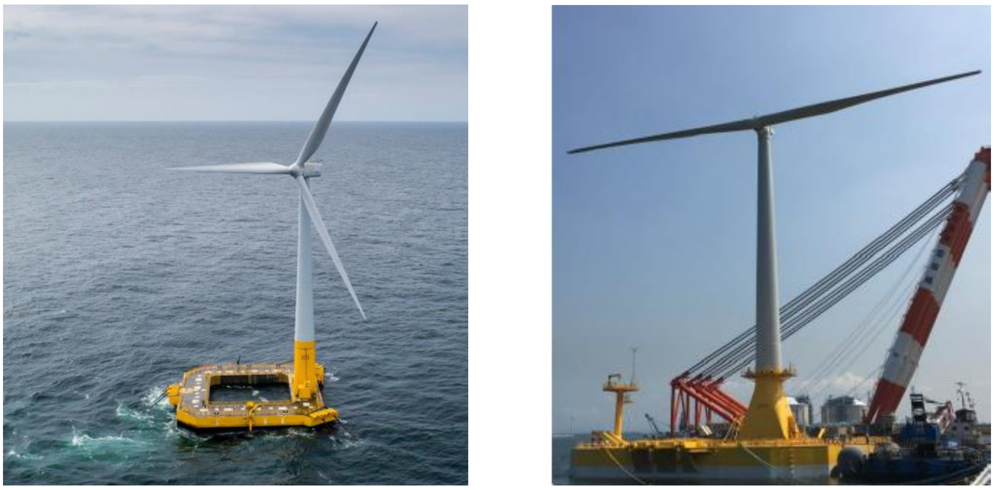


Figure 10: Damping pool floating foundation at FloatGen (left) and Hibiki (right) demo projects [Source: BW Ideol]

  The 30-MW EolMed project with three Vestas V164-10.0 MW on damping pool floaters is scheduled for commissioning in 2024. The pilot project will be installed more than 18 km off the French coast of Gruissan in the Aude region and anchored at an average depth of 60 m [8].

- **Yangxi Shapa III Demo**

  In 2021, Shanghai-headquartered Wison Offshore & Marine has commissioned China's first floating wind foundation platform off the coast of Yangjiang City in Guangdong Province. The unit comprises a MySE5.5MW typhoon-resistant turbine developed by MingYang Smart Energy and a semi-submersible floating foundation built by Wison Offshore & Marine. This floating wind turbine is the first in the world connected to a fixed-bottom turbine, using a 35 kV dynamic cable [21].

Figure 11: Sail-out of China's first FOWT off the coast of Yangjiang City, July 2021 [Source: MingYang Smart Energy]

- **Tetraspar (Stiesdal OT)**

  Developed by RWE, Shell, TEPCO and Stiesdal OT, the 3.6 MW TetraSpar demonstrator project started operation at Marine Energy Test Centre (METCentre) in 2021 near Stavanger, Norway. The TetraSpar concept has a modular layout that consists of a tubular steel main structure with a suspended keel. It is expected to offer competitive advantages with the potential for leaner manufacturing, assembly and installation processes with lower material costs.

Figure 12: TetraSpar Demonstrator at METCentre test site, Norway [Source: The TetraSpar Demonstrator Project ApS]

- **Fuayo** (CSSC)

In 2022, the China State Shipbuilding Corporation (CSSC) has commissioned China's largest floating wind turbine south of Guangdong Province. The floater, called Fuyao and developed by CSSC's subsidiary Haizhuang Wind Power, is equipped with a 6.2 MW typhoon-resistant wind turbine with a rotor diameter of 152 metres. The site has been chosen to test the floater concept under challenging conditions: water depths between 50 and 70 metres, complex seabed topography, strong typhoons that occur frequently in summer, and strong ocean currents [43].

Figure 13: Fuyao semi-sub floater, equipped with a 6.2 MW typhoon-resistant wind turbine [Source: CSSC]

- **Others**

  Two FOWT prototypes on semi-submersible floater designs were operated in Japan in the ***Fukushima FORWARD*** project. While the 2 MW FOWT from 2013 performed well, the 7 MW FOWT from 2015 had a very low profitability caused by initial troubles cumulating in low availability and low output as well as expensive operational and maintenance costs. As a consequence, the decommissioning of all FOWT in the Fukushima Forward project has been considered necessary.

Planned prototypes / demonstration projects

- **CNOOC Guanlan (China National Offshore Oil Corporation)**

  In March 2023, China's first offshore wind power project with a water depth of over 100 meters and an offshore distance of over 100 kilometers has been installed, according to the news on the Chinese Government's website. The semi-submersible floater platform, named CNOOC Guanlan, is owned by the China National Offshore Oil Corporation (CNOOC), and will be operated in an oil field, located 136 kilometres from Wenchang in Hainan province. The system will be connected to the offshore oilfield group's power grid providing sustainable energy for oil and gas production. CNOOC Guanlan features Mingyang Smart Energy's MySE 7.25-158 hybrid drive typhoon-proof wind turbine [44].

- **SATH (Saitec)**

  The DemoSATH prototype project is currently under construction in the Port of Bilbao, Spain. DemoSATH is a 2 MW wind turbine mounted onto a concrete floating foundation, developed by Saitec Offshore Technologies. The structure, which will be approximately 30 metres wide and approximately 67 metres long, will be assembled in the port of Bilbao. DemoSATH shall be tested for two years in real marine conditions anchored in the BiMEP test facilities (Biscay Marine Energy Platform). SATH Technology (Swinging Around Twin Hull) is based on a twin hull made of modularly prefabricated and subsequently braced concrete elements. The float can align itself around a single point of mooring according to the wind and wave direction. In August 2020, Saitec has already installed and commissioned the BlueSATH floating wind platform – a 1:6 scaled prototype of a 10 MW wind turbine – for offshore test operation near El Abra del Sardinero (Santander, Spain) in summer 2020.

  In June 2021, Saitec announced the start of the environmental impact assessment (EIA) process for the 45 MW GEROA (Green Energy Research for Offshore Atlantic) project, scheduled to be operational in 2025. The wind farm is planned to have three 15 MW turbines mounted on Saitec's SATH concrete floating platform technology, installed some 10 kilometres off Bilbao in Basque Country [17].

- **OO-Star Wind Floater (Olav Olsen)**

  A prototype of a floating semi-submersible concrete structure based on Olav Olsen's patented and design protected OO-Star Wind Floater concept is scheduled to be commissioned in 2023 at METCentre, Norway. In 2020, the demonstration project for a prototype received funding through the EU's Horizon 2020 programme within the FLAGSHIP project to develop and fabricate the first 10+ MW floating offshore wind turbine. FLAGSHIP will focus on the testing of a cost-effective concrete floating platform and anchoring system for a 10+ MW wind turbine, including electrical connection in a demanding site location of the North sea, in order to pave the way towards the mass production and installation in a worldwide range of commercial scenarios [13]. According to the developer, the floater concept is well suited for modular fabrication, it has great potential for industrialization through standardisation and mass fabrication. OO-Star Wind Floater can be constructed from concrete and/or steel to meet local fabrication requirements, and to optimize cost and durability. The complete unit can be fully assembled at quayside by land cranes at a water depth depth of only 10 m [14].

- **Wind-wave-energy platform (Floating Power Plant)**

  In June 2020, Dansih company Floating Power Plant has secured the formal approval to access the PLOCAN test facility in Gran Canaria with its hybrid floating wind and wave energy device. The company intends to operate a commercial-scale version of its P80 wind-wave energy platform from 2023. The P80 wind-wave energy platform hosts a single 8 MW wind turbine and integrates a wave energy device with a capacity between 2 MW and 3.6 MW, depending on the wave resource. The patented FPP platform is moored at a single point allowing the platform to passively rotate to face the waves securing a safe offshore boat landing and transfer aft of the platform.

- **Hexafloat (SAIPEM)**

  To secure the possibility of deployment of a full-scale FOWT on SAIPEM's Hexafloat floating structure by the end of 2023, a demonstrator shall now be deployed along the French Mediterranean coast at the MISTRAL test site. Initially, the project was planned for 2022 for testing off the west coast of Ireland at a Sustainable Energy Authority of Ireland (SEAI) test site near Belmullet, Co. Mayo. Funding for the AFLOWT (Accelerating market uptake of Floating Offshore Wind Technology) project has been secured in May 2019 from Interreg North West Europe to accelerate the uptake of floating offshore wind [19]. Hexafloat is a semi-submersible floating pendulum foundation for FOWT developed by SAIPEM. The Italian company holds the proprietary patent of Hexafloat.

- **VolturnUS (University of Maine)**

  The full-scale 11 MW VolturnUS "Aqua Ventus I" project is scheduled to start in 2023 in Maine/USA. VolturnUS is a semi-submersible platform developed at the University of Maine's Advanced Structures and Composites Centre through the DeepCWind Consortium. A first VolturnUS 1:8 platform, a one-eighth scale, fully operating version of the full-scale concept was launched on May 31, 2013. VolturnUS 1:8 was the first grid-connected offshore wind turbine in the Americas, operated off the coast of Castine, Maine. It successfully completed its 18 month deployment as planned, and was retrieved for post-deployment analysis by UMaine in November 2014.

- **Wind Semi (Equinor)**

  According to Equinor, the low draft semi-submersible concept has been developed specifically for Equinor's projects in Korea since 2019. Equinor has worked closely with the Korean offshore industry to develop Wind Semi, considering the regional supply chain and the demanding conditions offshore Korea. Typhoons are a dimensioning-criteria for the mooring system, and the mooring system is designed specially to suit the water depth in the Ulsan area. Equinor has received electricity business licenses for two projects located outside Ulsan, the 200 MW Donghae-1 floating offshore wind farm and the 800 MW Firefly project, scheduled to be commissioned by 2026 and 2027, respectively.

5.3.2 Spar-buoy

A spar-buoy is a ballasted cylinder structure which gains its stability from having the centre of gravity lower in the water than the centre of buoyancy. The foundation is kept in position by catenary or taut spread mooring lines with drag or suction anchors. The technology is adapted from the oil and gas industry, where platforms based on the spar concept have been deployed in water depths of over 2000 m [6].

The simple design of the spar-buoy allows for a fairly easy manufacturing process and provides good stability. However, the large draft requirement can create logistical challenges during assembly, transportation, and installation, and needs water depths of more than 100 m [1].

Reference Projects

- **Hywind (Equinor)**

  Hywind is the most matured spar-buoy concept for FOWT, developed by Equinor. In 2009, the Norwegian Hywind 2.3 MW demo project was the world's first commissioned MW scale floating wind turbine. Unitech Offshore took over the ownership in 2019 and it was renamed Unitech Zefyros, making the turbine available for research and technology development as a part of the Sustainable Energy Katapult. The turbine is also used as a part of the infrastructure at the Karmøy METCentre test site [15].

  In 2017, Hywind Scotland became the first floating offshore wind pilot project with five 6 MW FOWTs.

  As mentioned before, the 88 MW Hywind Tampen project, comprising eleven wind turbines on floating concrete structures with a shared anchoring system, is currently the only pre-commercial FOWT project, scheduled to be completed in 2023 after commissioning of the final four FOWT.

Figure 14: Hywind Scotland floating wind farm [Source: Equinor, Øyvind Gravås / Woldcam - Statoil ASA]

- **Hybrid spar (Toda Corp.)**

  The world's first full-scale hybrid spar-type prototype was commissioned in 2013 in the Kabashima demo project, Japan's first commercial-scale FOWT, located off the coast of Kabashima Island, Goto City, Nagasaki Prefecture. For the Kabashima demo project a 2 MW FOWT was installed on a hybrid spar floater developed in Japan by Toda Corporation. The floating structure consists of steel on the upper part, and concrete at the lower part. The project group includes Toda Corp., Hitachi Ltd., Fuyo Ocean Development & Engineering Co., Kyoto University, and the National Marine Research Institute [10]. Following its demonstration period, the FOWT has been relocated to a new position off of the coast of Fukue Island and has been renamed as the Sakiyama Floating 2 MW Wind Turbine [11].

  In October 2022, offshore work started for the installation of the first hybrid spar-floater for the 16.8 MW Goto wind farm, located in Japan's Nagasaki prefecture. The wind farm with eight Hitachi 2.1 MW wind turbines is expected to be fully commissioned in January 2024 [18].

Figure 15: 2 MW FOWT on a hybrid spar foundation in Sakiyama, Japan [Source: Toda Corporation]

- **Others**

  For the Fukushima Hamakaze project (Fukushima FORWARD II, Japan) an ***advanced spar*** floater concept, developed by Japan Marine United, was used for a 5 MW FOWT prototype, which was operated since 2016. However, due to low profitability caused by initial troubles cumulating in low availability and low output as well as expensive operational and maintenance costs, the decommissioning of this prototype has been considered necessary.

Planned prototypes / demonstration projects

- **SeaTwirl S2**

  SeaTwirl S2, a 1-MW full scale demonstrator, is planned to be tested at one of METCentre's test locations in 2023. The SeaTwirl wind turbine uses a vertical-axis wind turbine with a tower connected to the sub-sea structure, consisting of a floating element and a keel [15]. SeaTwirl S2 is a natural evolution of the 30 kW SeaTwirl S1 floating test unit, which was deployed off the coast of Lysekil, Sweden in 2015. As the energy of the wind causes the turbine to rotate, the structure of SeaTwirl S2 maintains its stability by using the keel and the counter turning moment. The wind turbine, the tower and the sub-sea part are assembled and rotate as one unit. Around the tower, above the water surface but below the wind turbine, is an enclosed, stored generator housing that is static or nonrotating. The generator housing and the wind turbine are anchored safely to the seabed by several catenary mooring lines. According to the develpoper, advantages of SeaTwirl S2 are simple, robust design with a minimum of breakable moving parts, easy access, stable structure due to the low centre of gravity and reduced stress on the bearings, as the water supports the weight of the FOWT [16].

5.3.3 Tension leg platform (TLP)

The design of a tension leg platform (TLP) is characterized by a semi-submerged buoyant structure which is anchored to the seabed with tensioned mooring lines, which provide stability.

The shallow draft and tenson stability allow for a smaller and lighter structure. However, the TLP design increases the stresses on the tendon and anchor system, and thus also operational risks if a tendon fails [1]. Depending on the design, a special purpose vessel may be required for the TLP installation [7].

Reference Projects

- **X30 platform/PivotBuoy (X1 Wind)**

In March 2023, the only floating wind platform currently installed with a tension-leg platform mooring system has been commissioned in the Canary Islands, Spain. According to developer X1 Wind, the PivotBuoy Project focuses on demonstrating an innovative mooring system configuration that combines the advantages of a SPM (single point mooring) with a small TLP mooring system, allowing the ability to reach deeper waters and minimizing the footprint and impact on the seabed. The X30 floater is a 1:3 scale prototype that integrates the PivotBuoy mooring system, a Vestas V29 turbine adapted for a downwind configuration, and all the required control systems. The downwind configuration creates a passive 'weathervaning' effect that eliminates the need of an active yaw system.

By 2025, the NextFloat project is planned for the Mistral test site in France, with a 6 MW wind turbine on a X90 platform.

Planned prototypes / demonstration projects

- **SBM Offshore and IFPEN**

A first TLP pilot project with 3 Siemens-Gamesa SWT-8.4-154 is scheduled for commissioning in 2023 in the French 25.2 MW Provence Grand Large project. The TLP design was developed by SBM Offshore and IFP Energies Nouvelles, a leading French research and innovation organization in the field of offshore wind energy.

According to SBM offshore, the new TLP floater solution is light and modular, has low motions and accelerations at nacelle level, it requires no construction or port infrastructure and can be installed with standard means.

- **Hexicon**

In May 2021, Swedish developer Hexicon announced to develop the TwinWay project based on Hexicon's technology in METCentre's deep water area in Norway. The TwinWay project, scheduled for 2023, is a pilot to commercialize Hexicon's offshore floating wind technology, which comprises a floating foundation with the TLP type mooring system. The intention of the pilot project is to show proof of concept for Hexicon´s floating wind foundation through twin wind-turbines pilot unit designed for, installed, and operated at the METcentre test site. Hexicon has signed a conditional site exclusivity agreement with a reservation of 6 megawatt [20].

- **Bluewater**

  In October 2022, METCentre and Bluewater Energy Services have signed an agreement for a berth option to deploy Bluewater's TLP floater concept at the METCentre offshore test site in Norway. According to Bluewater, the TLP foundation is scalable, lightweight, and supports wind turbines with minimal floater-induced nacelle motions. It was developed for the industrial deployment of wind turbines in floating offshore wind farms, with a focus on harsh environments.

All classified floating foundation concepts for FOWT and associated devices for mooring/anchoring, etc. are based on designs traditionally used in the oil and gas industry. However, unlike the requirements in the oil and gas industry, FOWT applications require a large number of smaller structures to be installed, which has a major impact on the design, fabrication, installation, and operating characteristics of the structures [1].

A concise overview of characteristics, benefits and challenges of the different foundation concepts for FOWT is given in Table 5 [33]. It should be noted, however, that in most cases the project-specific assessment is determined by the specific site conditions.

Spar	Semisubmersible	TLP	Barge
Overview: • Simplest concept and attractive dynamics • Minimum depth 80m during whole installation process • Achieves stability through ballast installed below its main buoyancy tank • Complex manufacturing and Weight for 6 MW: ~3.500 t	**Overview:** • Most popular concept, already proven, with good dynamic stability • Achieves static stability by distributing buoyancy widely at the water plane • Weight for 6 MW: 1800-2200 depending on site conditions	**Overview:** • Attractive dynamics but not widely deployed • Achieves static stability through mooring line tension with a submerged buoyancy tank • Typically requires purpose-built installation vessel • Weight for 6 MW: ~2.000 t	**Overview:** • The shallowest draft of all the floating foundation types • Square footprint • Some barge designs include a moonpool to suppress wave-induced loading. • Weight for 6 MW: 2.000-8.000 t depending on materials
Benefits: • Inherent stability • Suitable for even higher sea states • Soil condition insensitivity • Cheap & simple mooring & anchoring system • Simple fabrication process • Low operational risk • Little susceptible to corrosion	**Benefits:** • Depth independence. • Soil condition insensitivity • Cheap & simple mooring & anchoring system • All heavy lifting performed in port • Simple installation & decommissioning as no specialised vessel required • Broad weather window for installation • Simple tow-to-shore maintenance (at quayside)	**Benefits:** • High stability, low motions • Having a good water-depth flexibility • Small seabed footprint and short mooring lines • Simple & light structure, easy for O&M • Lower material costs due to structural weight of the substructure • Onshore or dry dock assembly possible	**Benefits:** • Operable at depths starting 30 meters to accommodate complex seabed conditions • Buildable in steel or concrete, or hybrids between steel and concrete, offering flexibility in using the highest local content near the project • Simple shape will employ equally simple fabrication techniques • Scalable to support heavy substation
Challenges: • High cost, 5-8 mEUR/MW (based on the 30 MW demo) • Heavy weight, with long mooring lines and long & heavy structure • Deep drafts limit port access and large seabed footprint • Relatively large motions • Assembly in sheltered deep water challenging and time-consuming • High fatigue loads in tower base • Specialised installation vessels needed	**Challenges:** • Complex fabrication as more welds (but high potential for modularization) • Large footprint requiring space in transport and final assembly yard	**Challenges:** • Unstable during assembly, requiring the use of special vessel • High vertical load moorings • Complex & costly mooring & anchoring system making it the most expensive floater design type • Mooring tendons presenting higher operational risk in case of mooring failure and add requirements on site seabed conditions	**Challenges:** • Particularly exposed to wave, so having greater motions • Demanding more robust mooring systems, increasing complexity

Table 5: The benefits and challenges associated with four dominant floater concepts [33]

In addition, it must be mentioned that the selection of the floating foundation concept will depend on various aspects, like specific site conditions, turbine design and factors such as political need, opportunity for localization and local infrastructure. A clear shift to semi-submersible floaters can be observed in floating offshore wind projects.

Finally, Table 6 shows selected developments for floating solutions that can host multiple wind turbines or integrate other renewable energy technologies such as wave energy and Power-to-X production on the same platform. However, none of these concepts, all based on semi-submersible floaters, has reached the commercialization stage yet [33].

Company	Concept or project name	Solutions	Scale of concept	Type of floater	Current stage of development
Hexicon	TwinWind	Multi-turbines (twin-rotor)	Up to 10 MW + (Project pipeline in 6 markets picked up this concept)	Semi-submersible	Model test completed in June 2021 with full-scale test expected in 2023
Aerodyn & EnBW	Nezzy2	Multi-turbines (twin-rotor)	Up to 15 MW	Semi-submersible	1:10 prototype tested in 2020
Pelagic Power	W2Power	Multi-turbines (twin-rotor) + Wave energy	Up to 10 MW including 3 MW wave energy	Semi-submersible	1:6 scale tested in 2016
Bombora and TechnipPMC	InSPIRE (Integrated mWave™)	Single turbine +wave energy	Up to 12 MW wind + 6 MW wave power	Semi-submersible	A 4 MW wind +2 MW wave demon planned
Floating Power Plant (FPP)	FPP Flatform	Single turbine + wave (or plus hydrogen)	4-15 MW wind + 2-4 MW wave power	Semi-submersible	Small scale floater tested in 2020
ERM, Tractebel Engie, Principle Power	ERM Dolphyn	Single turbine + hydrogen	10 MW wind + integrated hydrogen	Semi-submersible	A 2 MW proof of concept unit up and running by 2024
Acciona lead consortium including Wunder Hexicon	OCEANH2	Floating wind+ solar + hydrogen	Integrated floating power plant with multiple floaters	Semi-submersible	Spanish government funded R&D project in 2021

Source: company news and GWEC Market Intelligence, July 2021

Table 6: Selected multi-turbine and integrated floater concepts [33]

Recently, several partnerships of big players in the energy and oil industry were formed to enter the emerging floating offshore wind sector. In this context, it should be noted that many companies are actively looking to diversify and adapt their products and services for the renewables sector. This trend can also be seen as an important step to further develop specific FOWT concepts, to realize more pre-commercial projects and to commercialize the floating offshore wind sector.

Some recently reported industry partnerships include:

- In late 2019, oil giant Shell acquired French floating offshore wind developer EOLFI. According to Shell, the acquisition is seen as an opportunity to leverage its offshore and project management expertise, and it also enables Shell to move into the French market. EOLFI is part of a consortium that is developing the Groix & Belle-Île pilot floating offshore wind project. Furthermore, Shell is engaged, together with RWE Renewables and Stiesdal Offshore Technologies, in a partnership to build the TetraSpar floating offshore wind demo project in Norway.

  [Source: https://www.offshorewind.biz/2019/11/05/shell-buys-eolfi/]

- In 2020, TotalEnergies, one of the world's largest energy companies, revealed its joint floating wind project with Simply Blue Energy in Wales, the 96 MW Erebus wind farm which secured seabed rights in summer 2020. Furthermore, Total announced to enter the South Korean floating wind market by teaming up with Macquarie's Green Investment Group on the development of five floating offshore wind farms. In October 2020, the company bought a 20 per cent stake in the EolMed floating wind offshore pilot project in France. TotalEnergies intends to become one of the world leaders in the emerging sector of floating offshore wind.

  [Source: https://www.offshorewind.biz/2020/10/07/total-adds-another-floating-wind-project-to-its-portfolio/]

- Wind turbine manufacturer GE has unveiled a 12 MW floating wind turbine concept featuring the company's Haliade-X model with a 12 MW output and tension-leg platform technology from Glosten.

  [Source: https://www.offshorewind.biz/2021/05/25/ge-glosten-present-12-mw-floating-wind-turbine-concept/]

- The ScotWind leasing round attracted bids from most of the major offshore wind developers and major energy companies such as Shell and Iberdrola; Ørsted, Renantis, and BlueFloat Energy; bp and EnBW; Vattenfall and Fred. Olsen Renewables; SSE, Marubeni, and Copenhagen Infrastructure Partners; TotalEnergies; Eni and Red Rock Power; Ocean Winds and Aker Offshore Wind; Macquarie and RIDG; RWE; and others.

  [Source: https://www.offshorewind.biz/2021/07/16/shell-and-iberdrola-bid-for-large-scale-floating-wind-farms-offshore-scotland/]

- Energy company RWE has formed several partnerships to engage in different floating offshore wind developments. RWE Renewables cooperates with Saitec Offshore Technologies in the joint DemoSATH pilot project in Spain, and with University of Maine and Mitsubishi in the Aqua Ventus I pilot project in the US. Furthermore, RWE Renewables is also engaged in the TetraSpar floater demo project in Norway.

  [Source: https://www.offshorewind.biz/2021/07/19/rwe-highlights-floating-wind-as-it-files-scotwind-bids/]

5.4 Assessment of market opportunities in terms of monetary value, profitability and growth potential

5.4.1 Learning curves for future LCOE analysis

Substantial cost reductions for novel technologies are achieved by standardization and industrialization. Currently, experience in floating wind is mainly based on prototypes or demonstration projects with only a few floating offshore wind turbines. Therefore, significant cost reductions can be expected by establishing manufacturing processes and by scaling up production.

The tendency of declining costs for new technologies is shown in learning curves. A cost learning curve for FOWT is presented in Figure 16.

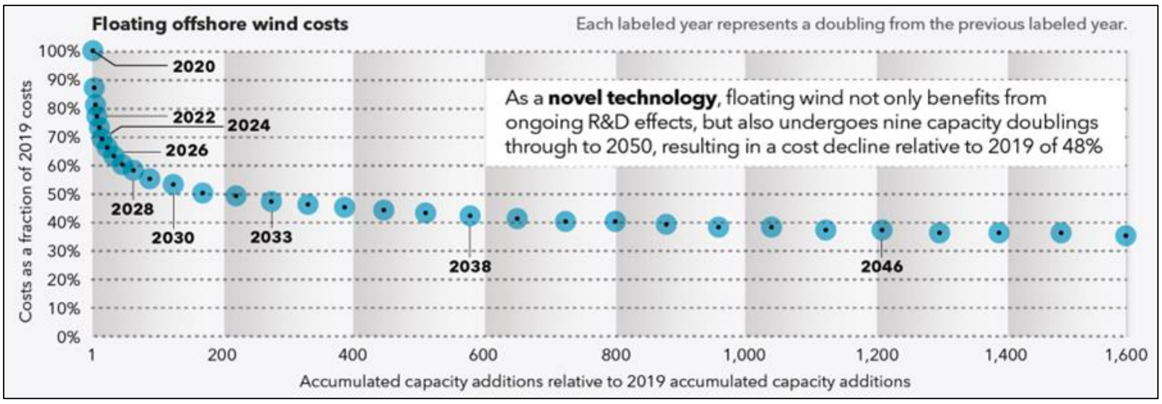


Figure 16: Cost learning curve for FOWT [37]

A learning rate indicates the fixed cost reduction rate for each doubling of the cumulative production.

The cost reduction achieved by learning is not autonomous. In fact, technological improvements (R&D and innovations) and increasing experience with the technology (production, deployment and supply chain) are needed to achieve learning curve cost reduction.

According to IRENA, available data indicate that for demonstration and pre-commercial floating wind projects, total installed costs could fall by 70% between 2010 and 2024, from USD 14,161/kW to USD 4,310/kW. By 2024, the projects being built have an implied LCOE (Levelized Cost of Energy) of around USD 0.13/kWh (see Figure 17). It should be noted, however, that data for demonstration and pre-commercial projects need to be treated with caution, as they are not representative of what commercial floating offshore wind farm costs might be [38].

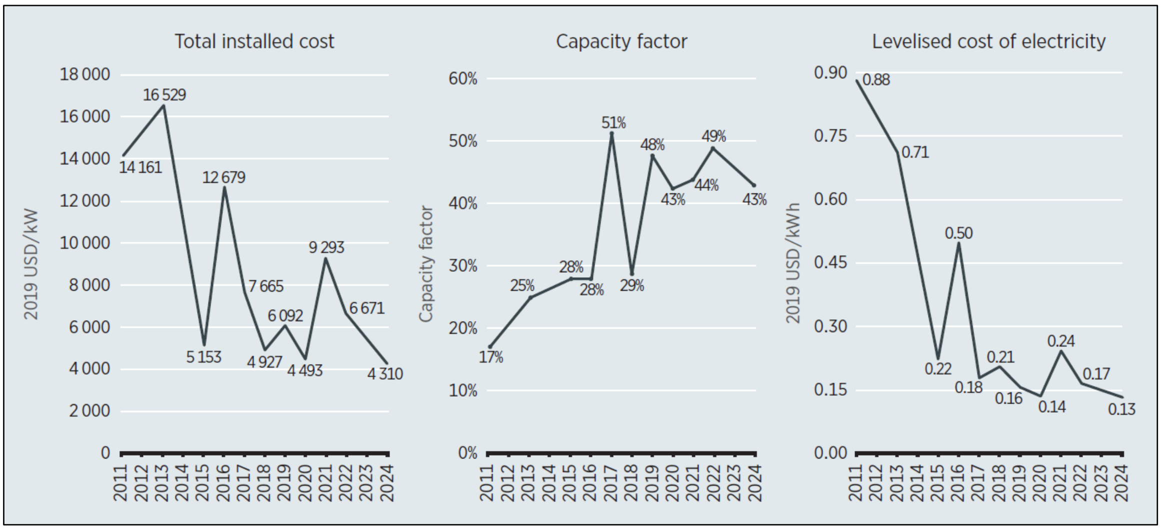


Figure 17: **Global weighted average total installed costs, capacity factors and LCOE for floating offshore wind, 2010–2022 (mostly pre-commercial projects) [38]**

In the DNV Energy transition outlook 2022 [39], massive cost reductions are expected for floating foundations compared to bottom-fixed foundations, from five times higher (today) to two times higher in 2030 – as a result of technology optimization, standardization and supply chain. At the same time, OPEX (operational expenditures) costs are expected to drop down to levels nearly equivalent of those currently experienced with bottom-fixed offshore wind turbines. According to the DNV Energy transition outlook 2022, the reductions in LCOE for bottom-fixed and for floating offshore wind from 2020 to 2050 will be 39% and 84%, respectively (Figure 18).

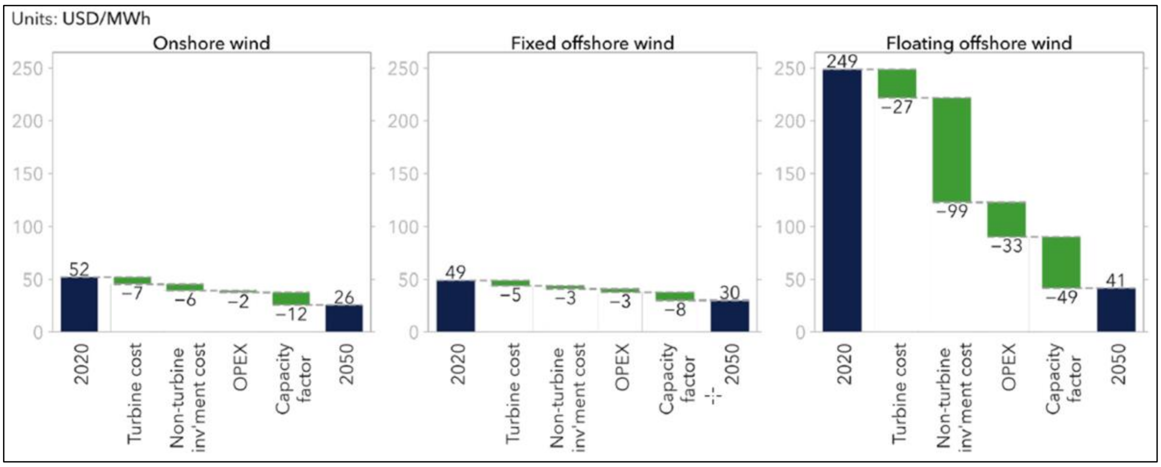


Figure 18: **Drivers of change for the global average levelized cost of wind between 2020 and 2050 [39]**

Figure 19 shows the wind energy cost reductions from 2020 to 2050 expected from ETIP Wind/WindEurope [40]. According to the outlook published in 2021, the levelized cost of energy for floating offshore wind will decrease by 65% until 2030 and by 78% until 2050. The cost reduction is mostly driven by lower CAPEX (capital expenditures) resulting from industrialization of the floating technology. The LCOE for FOWT is expected to reach a level of 30-53 €/MWh, slightly above the respective LCOE for bottom-fixed offshore wind turbines.

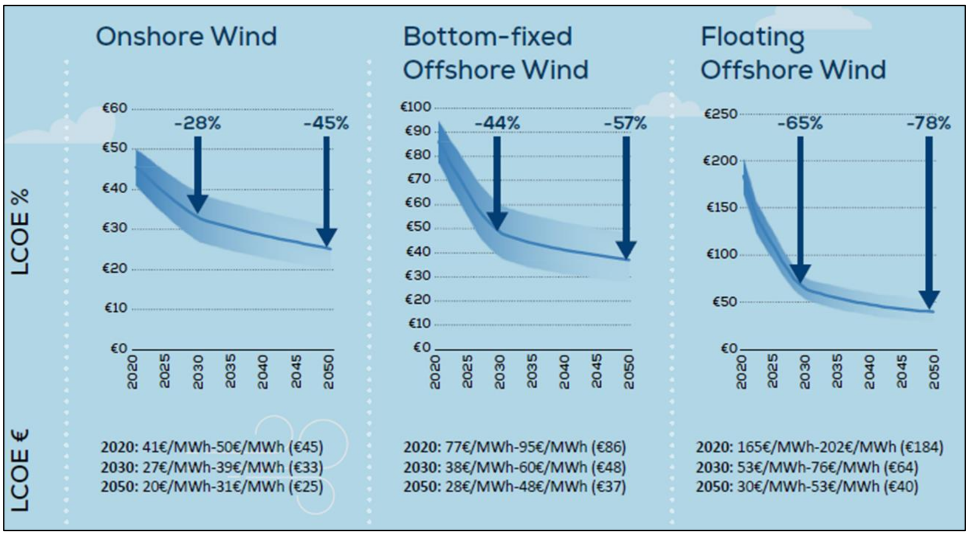


Figure 19: Wind energy cost reduction [40]

The estimated cost reductions depend on the learning rates applied to the cost decline. For novel technologies, cost learning rates cannot be easily established with reference to that technology. With regard to floating offshore wind turbines, core technologies, such as wind turbines, are well established, while there is no experience with supporting technologies, e.g. control systems for FOWT. Consequently, this must be considered by separated learning cost rates.

Based on historical trajectories, the best estimates in the DNV Energy transition outlook 2020 for learning rates are 16% for wind turbines for every doubling of cumulative additions and 30% for O&M costs of offshore wind farms. For "other fixed costs" (non-turbine material costs, as well as labour, overhead and tax costs) learning rates of 11% have been considered for floating offshore wind [37].

The relative weight of component in the wind farm CAPEX is shown in Figure 20 for onshore wind, bottom-fixed offshore wind and floating offshore wind [40].

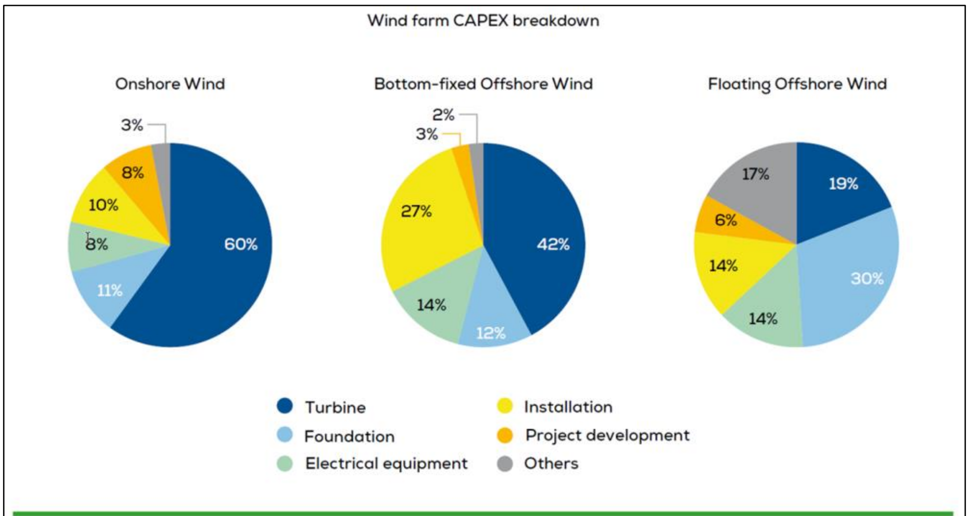


Figure 7. Relative weight of component in the wind farm CAPEX. Source: IRENA and BVG/InnoEnergy for onshore, BVGA for offshore (1 GW farm assumed with 10 MW turbines), ETIPWind for pre-commercial floating offshore wind (others include mooring and anchoring and port services).

Figure 20: Relative weight of component in the wind farm CAPEX [40]

It can be seen that “foundation” and “others” (including 5% mooring/anchoring and 4% port services) are significant contributors to the CAPEX breakdown for floating offshore wind. Consequently, industrialization of floater and station keeping technologies are key segments for cost reduction resulting in lower CAPEX.

In conclusion, essential aspects for cost reduction through standardization/industrialization can be summarized as follows:

- **Moving from single prototype design to serial production**
  - Standardization in designs of components
  - Optimized manufacturing and assembly concepts and technologies
  - Optimized floating offshore supply-chain
  - Modularization
- **Improvements resulting in lower CAPEX**
  - Optimized integrated designs
  - Increasing size of wind turbine components and better performance under varying wind conditions lead to higher capacity factors
  - Material research to reduce relative weight and consequently the costs of components
  - Realization of commercial-scale floating offshore windfarm projects
- **Increasing experience in the installation and operation of FOWT**
  - Optimized concepts for wind farm control for FOWT
  - Optimized concepts and procedures for O&M

5.4.2 Growth potential in main global markets

Figure 21 shows a map of the global offshore wind technical potential for floating foundations (purple) and for fixed foundations (pink). The technical potential for offshore wind was assessed by the World Bank considering data on water depths and wind speeds at country level.

Figure 21 illustrates the large technical potential for floating offshore wind, particularly in the coastal regions in Europe, Asia and America.

The international opportunities for floating offshore wind in the period 2022-2050 were mapped in a study published by ORE Catapult in 2022 [36]. The analysis identified 22 markets for near-term floating offshore wind and 32 longer-term markets. Each market was assessed using weighted criteria spanning technical and policy drivers, commercial investment landscape, and market facilitators. These factors were scored to evaluate the “readiness” of that market for offshore wind and the speed of market development. The identified near-term floating offshore markets (2022-2030/35) are shown in Figure 22.

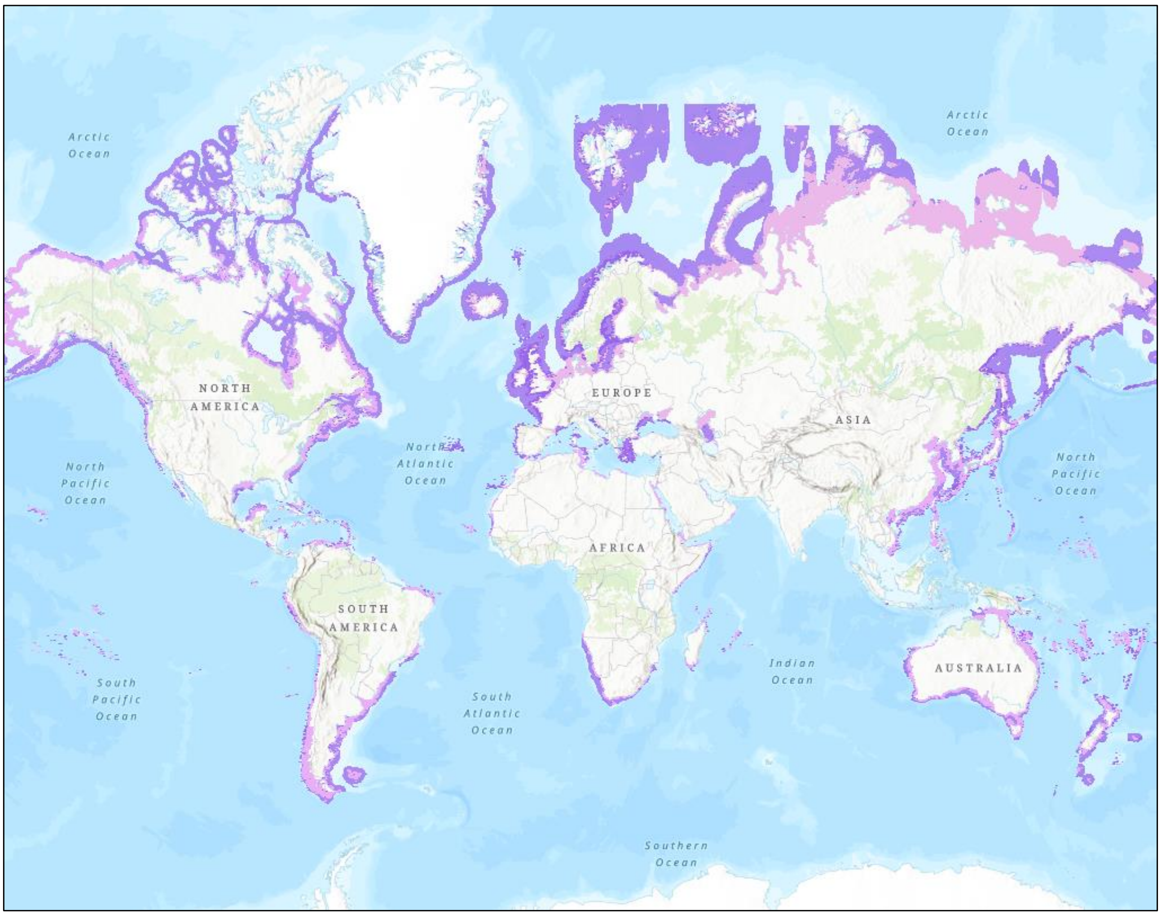


Figure 21: Global offshore wind technical potential for fixed (pink) and floating (purple) foundations [35]

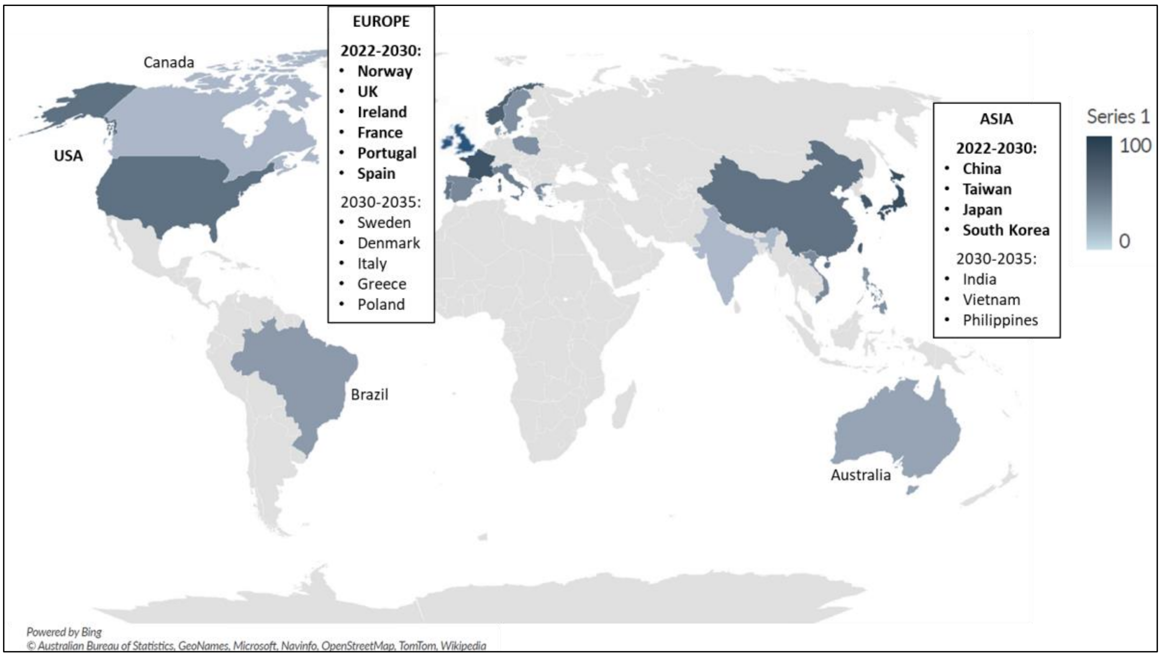
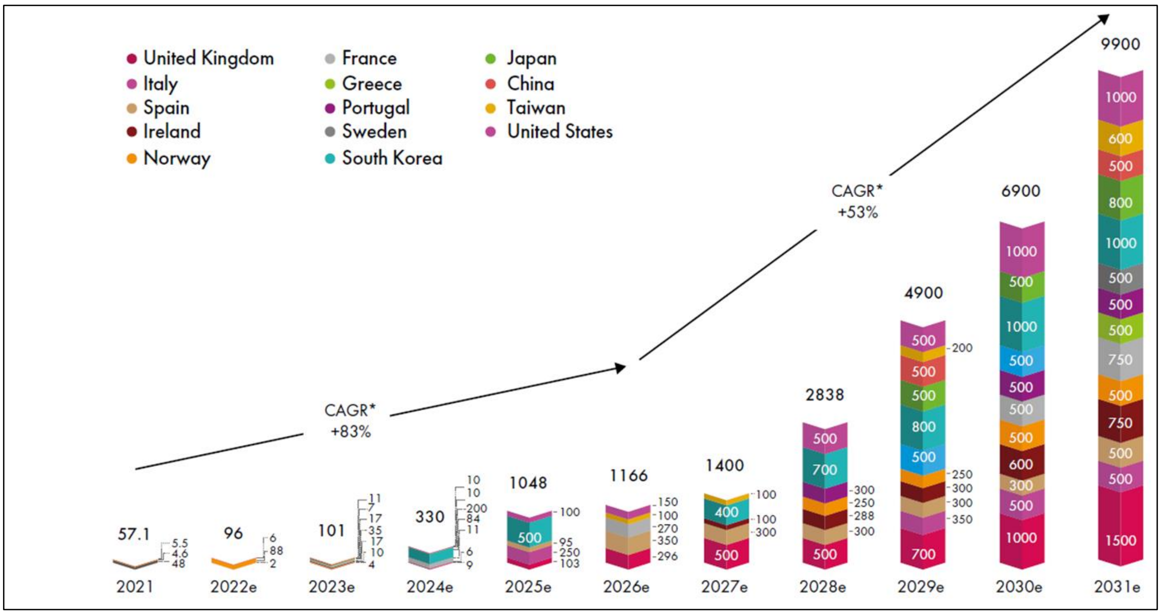


Figure 22: Map of near-term floating offshore wind territories (2022-2035) [36]

According to GWEC's Market Outlook 2022-2031, a floating offshore wind capacity of 18.9 GW is likely to be built by 2030. Figure 23 shows that GWEC expects floating wind to become fully commercialized towards the end of the decade. Consequently, less than 10% of the new FOWT capacity (or 2.7 GW) is predicted to be built in the first half of the 2022-2031 period.



*CAGR = Compound Annual Growth Rate

Figure 23: New floating wind installations, Global (MW) [33]

A review of country-specific frameworks in main global FOWT markets identified for the period 2022-2030 is presented in section 5.5.

5.4.3 Floating wind opportunities for Power-to-X and green hydrogen production

In addition to the primary option of generating and selling grid-connected electricity, floating offshore wind offers a significant potential for other energy sectors, especially for the production of green hydrogen by electrolysis and for the power supply of offshore oil and gas platforms (see 5.4.4).

As offshore wind power production increases, costs and technical constraints may cause that not all generated energy will be fed into the power grid. Especially for far-offshore projects in deep waters, the cost of power transmission will rise due to the need for high-voltage direct current (HVDC) systems with larger and more costly offshore transformer and converter substations, and for long cable routes to shore [36]. Consequently, the costs for transporting green hydrogen through gas infrastructure might be more cost-effective in some cases than transmission via power cables [33].

In addition, as the cost of electrolysers are expected to decline, they can also be used to produce green hydrogen in cases where electricity generation would otherwise be lost because the supply of renewable energy exceeds the demand on the grid.

The installation of electrolysers near floating offshore wind farms, enabling the production of green hydrogen, offers an alternative to grid-connected electricity. Wind energy has the greatest potential for sustainable hydrogen production of all renewables due to its economic competitiveness. Together with other Power-to-X applications, green hydrogen production is seen as a promising technology to enable solutions for flexibility, storage at varying durations and responsive management of demand and supply, and to minimize waste and maximize efficiency. That is why several countries have ambitious roadmaps in place to integrate hydrogen into their long-term climate strategies.

Power-to-X comprises different options for the use of stored electricity. In this context, the sector-coupling approach of Power-to-X is an option for "hard-to-electrify" sectors, such as heavy trucks, shipping, aviation, steel and cement production and chemicals manufacturing [33].

Electricity from wind power can be electrolyzed into green hydrogen (Power-to-Gas)

- to be used as feedstock to produce bulk chemicals like methanol or ammonia for industrial purposes (Power-to-Chemicals)
- to be combined with captured CO_2 to make carbon-neutral liquid fuels like aviation fuels (Power-to-Liquid Fuels) or to generate heat through heat pumps or electric boilers (Power-to-Heat),
- can be contained in underground formations like salt domes and fed back to the grid when needed (Power-to-Power)

Figure 24 gives an overview of green hydrogen production, conversion and end uses across the energy system.

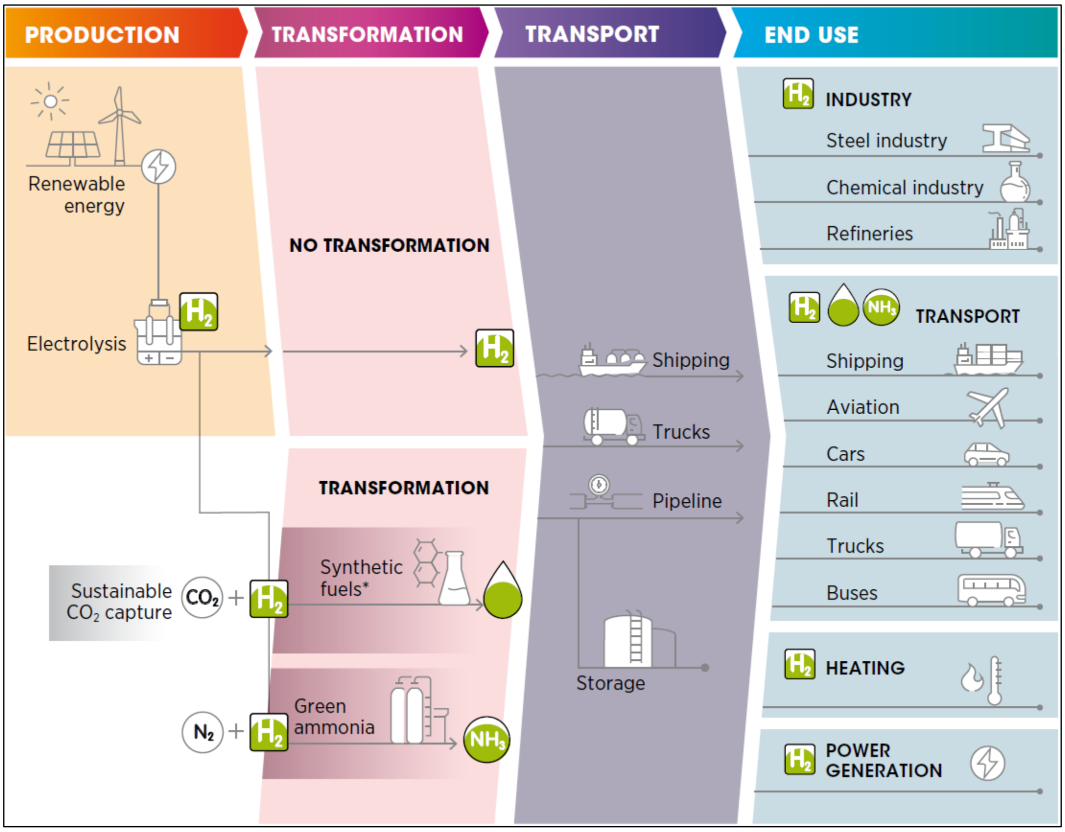


Figure 24: Green hydrogen production, conversion and end uses across the energy system [41]

For offshore wind farms, there are primarily two options for green hydrogen production. Green hydrogen can be electrolyzed directly at sea (and optionally converted to synthetic natural gas/methane), before being compressed, stored in a tank system and shipped to end-users. Alternatively, electrolyzers can be deployed in coastal areas connected to substations via subsea cables, to transport the green hydrogen by truck or via pipelines after compression.

Finally, offshore wind can also power electrolyzers located on oil and gas platforms that produce green hydrogen using seawater. In this case, the green hydrogen is blended into the gas (up to 20% hydrogen) and transported onshore via the existing infrastructure [33].

Current FOWT demonstration projects for green hydrogen production

In September 2022, BW Ideol has announced a pioneering offshore hydrogen production project to be connected to the 2 MW FOWT on a Floatgen substructure operating since 2018 at SEM-REV test site in France. The "Sealhyfe" hydrogen project, led by Lhyfe, a leading manufacturer and supplier of green hydrogen for mobility and industry, aims to demonstrate the reliability of an electrolyzer on the offshore test site that meets all the necessary conditions for validating offshore H_2 production technology before large-scale deployment [67].

Environmental Resources Management (ERM), developer of the Dolphyn technology, is planning a 10 MW floating wind-hydrogen demonstration project in Scotland. The ERM Dolphyn concept employs a modular design integrating electrolysis and a wind turbine on a moored floating semi-submersible platform which uses Principle Power's WindFloat technology to produce hydrogen from seawater. Expected to begin operations in late 2025, the 10 MW demonstrator project is a key step in proving the Dolphyn concept prior to commercial-scale deployment. ERM has announced in 2022, that commercial-scale projects of over 300 MW are under development in the Celtic Sea, UK and could be delivered before the end of the decade which could be followed by large-scale (GW) deployment in 2030 [68].

In terms of technology development, Siemens Gamesa and Siemens Energy announced in 2021 to develop an innovative solution that fully integrates an electrolyzer into an offshore wind turbine as a single synchronized system to directly produce green hydrogen. Siemens Gamesa is adapting its SG14-222 DD offshore wind turbine to integrate an electrolysis system seamlessly into its operation. Siemens Energy is developing a new electrolysis product that meets the needs of the harsh maritime offshore environment and is in perfect sync with the wind turbine. The companies intend to provide a full-scale offshore demonstration of the solution by 2025/2026. The developments are funded by the German Federal Ministry of Education and Research as part of the ideas competition "Hydrogen Republic of Germany" [69].

Finally, it should be noted that Power-to-X and green hydrogen production are promising new technologies that are at an early stage of development, like floating offshore wind. The infrastructure and economic viability for offshore applications still need to be established for a good match with floating offshore wind. Although the opportunities for floating wind is promising, there are several challenges with offshore production of hydrogen by electrolysis of sea water. The foremost technical challenge for producing renewable hydrogen offshore is the development of electrolyser modules, which are compatible with that environment, while being sufficiently compact to achieve very high rates of hydrogen production per platform or per wind turbine, and are able to survive long term when connected directly to an intermittent variable renewable power supply. In addition, different specific conditions, including the marine environment, stringent safety requirements, commercial terms of existing delivery contracts and difficult accessibility are very challenging [36].

5.4.4 Floating wind opportunities for power supply of oil and gas platforms

The power supply of oil and gas platforms is another opportunity for floating offshore wind.

Currently, oil and gas platform operations depend on gas-fired or diesel power generation systems. Therefore, there is great potential to use floating offshore wind turbines to replace the fuel- and carbon-intensive power supply. In addition, the projects to supply power to oil and gas platforms offer a favorable opportunity for O&G companies to gain experience with floating offshore wind power.

Hywind Tampen, the first pre-commercial floating offshore wind project (see 5.2), is an example for the supply of offshore oil and gas platforms in the Norwegian North Sea with renewable power from eleven FOWT.

In China, the China National Offshore Oil Corporation (CNOOC) has installed the first deep-sea floating wind platform, named CNOOC Guanlan, in an oil field located 136 kilometres from Wenchang in Hainan province, as reported on the Chinese government's website in March 2023 [44]. The system features Mingyang Smart Energy's hybrid typhoon-proof wind turbine MySE 7.25-158 and will be connected to the offshore oil company's power grid to provide sustainable energy for oil and gas production.

In Scotland, first awards have been made in March 2023 under Crown Estate Scotland’s Innovation and Targeted Oil and Gas (INTOG) leasing round for offshore wind projects that provide low-carbon electricity to oil and gas platforms. Flotation Energy and Vårgrønn, a joint venture between Plenitude (Eni) and HitecVision, have been awarded exclusivity for areas to develop a total of up to 1.9 GW of floating offshore wind capacity across two projects, Green Volt (560 MW) and Cenos (1,350 MW). The power and grid-connection supplied through these windfarms will provide renewable energy to oil and gas platforms in the surrounding areas, replacing power currently generated by gas turbines. Simultaneously, up to 7 TWh of energy from the projects will be supplied to the UK grid annually, providing consumers with renewable electricity. According to Floating Energy, the Green Volt and Cenos windfarms could begin generating first power from 2027 and 2028 respectively, making them the most advanced projects for electrification and decarbonisation of oil and gas platforms with floating offshore wind in Europe [70].

In addition, Cerulean Winds and Frontier Power International have been awarded three lease options in the Central North Sea with a total capacity of 1,008 MW each in the INTOG leasing round. According to Cerulean Winds, large floating offshore windfarms can now be developed to decarbonize oil and gas assets at the awarded sites. The scale of the development will enable a UK wide offshore transmission system, that can offer green energy to offshore assets in any location and create a beneficial export opportunity [71].

5.5 Review of country-specific frameworks in main global FOWT markets

5.5.1 Europe

5.5.1.1 United Kingdom (UK)

Background

The United Kingdom (UK) has been the world's largest offshore wind market for a long time, but China has taken over that position with an unprecedented growth of offshore wind installations in 2021.

In April 2022, then-UK Prime Minister Boris Johnson presented a plan to increase the previous 40 GW target up to 50 GW of operating offshore wind capacity by 2030, including 5 GW of floating wind. According to the government, this was made in response to rising global energy prices caused by increased demand following the pandemic and Russia's invasion of Ukraine [45].

Floating wind projects and auctions

Two floating wind power pilot projects are operated in Scotland, Hywind Scotland and Kincardine. The 30 MW Hywind Scotland project is online since 2017 and comprises five turbines of 6 MW each. The 50 MW Kincardine project started as a pilot in 2018 with a 2 MW turbine, and was extended by five 9.5 MW turbines in 2021. It is the second largest operational floating offshore wind project after Hywind Tampen in Norway.

In July 2021, the Crown Estate has selected three floating offshore wind demonstration projects through its leasing opportunity for early commercial-scale floating wind projects in the Celtic Sea. Offshore Wind Ltd (OWL), a joint venture between Cobra and Flotation Energy, was selected as a preferred bidder to develop its 100 MW Whitecross floating wind farm. Floventis Energy Limited, a newly established joint venture of SBM Offshore and Cierco, has been chosen to build two 100 MW demonstration projects, Llŷr and Llŷr 2, with two different floating substructure concepts. The projects are expected to start energy production in 2026/27 [46].

At the beginning of 2022, the Pentland Floating Offshore Wind Demonstrator was awarded GBP 9.6 million of UK government funding to develop and demonstrate a suite of UK-manufactured innovative floating wind technologies for the first time. The Pentland floating wind project, developed by Highland Wind Limited, a joint venture of Copenhagen Infrastructure Partners and Hexicon, will be constructed in two stages. The first consists of a single turbine demonstrator that will showcase new floating wind technology with a high potential for localisation in Scotland, with deployment planned in 2025. The remaining turbines shall be installed in 2026. The exact floating technological solutions for the 100 MW Pentland floating wind project are yet to be determined [47].

According to WindEurope, "a huge breakthrough for floating offshore wind" has been reached, when Crown Estate Scotland announced the results of the "ScotWind" seabed tender in January 2022. The majority of offshore projects winning development rights in the "ScotWind" seabed tender were awarded to floating offshore wind farms, totalling 15,071 MW. The successful projects have been offered option agreements with the right to develop offshore wind farms on specific areas of seabed. They will pay an option fee to Crown Estate Scotland, as a one-off payment capped at £100,000 in exchange for these rights. Awarded projects include consortia led by Scottish Power Renewables, Renantis, DEME, Vattenfall, Shell New Energies, OceanWinds, BP Alternative Energy Investments, SSE Renewables, BayWa, Offshore Wind Power, Northland Power, and Magnora. Developers had to submit a Supply Chain Development Statement, showing how at least 25% of project-related expenditure will be made in Scotland [48]. In August 2022, the awarded capacity for floating offshore wind increased to 17,871 MW, when seabed rights were offered for three additional floating projects after completion of the clearing process for the ScotWind sea bed leasing round [72].

In July 2022, the Crown Estate announced that five “Areas of Search” for the development of floating wind in the Celtic Sea have been identified as part of the work toward holding a seabed leasing round in mid-2023. The identified Areas of Search have been refined into potential Project Development Areas. The areas designated for floating offshore wind farms will be auctioned in 2023 and are planned to deliver 4 GW by 2035 [49].

The TwinHub Floating Offshore Wind Project, a new 32 MW floating wind demonstrator project in the Celtic Sea developed by Hexicon, has been awarded in July 2022 the first ever dedicated award for floating wind in the UK in the fourth Contract-for-Difference (CfD) auction round (AR4) for renewables. Pot 2 of AR4 was dedicated to less established technologies, including floating offshore wind, tidal stream, geothermal, wave energy and remote island wind projects. According to Hexicon, the TwinHub Floating Offshore Wind Project is expected to be commissioned and exporting clean power between 2025 and 2027.

The UK Government will run CfD auctions every year, and the current draft for auction rounds 5 and 6 also includes a pot dedicated to floating wind/less established technologies.

The first floating offshore wind farm in Wales has received the planning consent in March 2023. The 96 MW Erebus project, developed by Blue Gem Wind, a joint venture from TotalEnergies and Simply Blue Group, is located 40 kilometres off the coast of Pembrokeshire and will feature seven 14 MW FOWT. The Erebus project which is part of a first phase of the above 4 GW renewable energy development in the Celtic Sea, still needs to compete in the next CfD auction round and will probably be commissioned by 2027/28 [51].

In March 2023, three floating offshore wind projects have been offered seabed exclusivity rights under the innovation arm of Crown Estate Scotland’s INTOG (Innovation and Targeted Oil & Gas) auction process (see 5.4.4). The small-scale innovative (IN) projects comprise the two 99 MW floating wind projects Sinclair and Scaraben developed by BlueFloat Energy and Renantis and the 100 MW Salamander floating wind farm which is developed by Ørsted, Simply Blue Energy and Subsea 7.

Finally, the European Marine Energy Centre (EMEC) announced in October 2022, that it has concluded concept design for a new 100 MW floating offshore wind test and demonstration site, about 20 km west of Orkney, Scotland. EMEC’s proposed test site will comprise six berths for floating offshore wind turbines of up to 20 MW rated capacity. Four of the six berths will be grid-connected, while the final two berths will be reserved for alternative applications such as hydrogen generation [52].

Planning requirements and planning authority

An overview of development and consenting processes for offshore wind farms in each of the UK’s administrations is presented in Table 7 [50].

Aspect of Process	England	Scotland	Wales
Licensing and enforcement authority	Marine Management Organisation (MMO) responsible for licensing in English waters and in Northern Ireland's offshore waters. Planning Inspectorate responsible for the Development Consent Order (DCO) process for Nationally Significant Infrastructure Projects (NSIPs).	Scottish Ministers responsible for licensing in Scottish territorial waters and, by executive agreement, in Scottish offshore waters. MS-LOT is licensing and enforcement authority.	Welsh Ministers are licensing and enforcement authority in the Welsh Inshore Region. Majority of licensing and environmental permitting functions delegated to Natural Resources Wales. DCO process undertaken for NSIPs in Welsh offshore area.
Seabed ownership and development area leasing process	The Crown Estate awards leases for sites in English waters. Subject to outcome of a plan-led HRA, successful developers granted leases for their chosen sites.	Crown Estate Scotland awards leases in Scottish waters once all key consents and permissions have been obtained from relevant regulatory authorities. Plan-level HRA undertaken for sites made available for development via ScotWind.	The Crown Estate awards leases for sites in Welsh waters. Subject to outcome of a plan-led HRA, successful developers granted leases for their selected sites.
Pre-development spatial planning and screening	A screening and/or scoping opinion can be requested at any time before submission of a planning application.	Applications for renewable energy structures that exceed 10,000 square metres should carry out a public pre-application consultation with 6 weeks' notice of event.	NRW's bespoke pre-application service is open to all users to allow the agreement of requirements in advance of an application.
Environmental Impact Assessment ***Data gathering***	MMO aims to issue screening opinions on need for EIA for Marine Licence applications within 8 weeks of application and scoping opinions on the extent and content (i.e. scope) within 13 weeks. DCO process has its own timescales.	Screening and scoping opinions require 28 day periods of public consultation. The consultation period for the Environmental Report is 42 days and can occur simultaneously with that for the Marine Licence.	Screening and scoping opinions are considered on a case-by-case basis with the option to consult further to inform NRW's opinion. The process is not subject to public consultation. The DCO process for proposed projects in Welsh waters has its own timescales.
Marine Licence application	Although no statutory timescale for determining marine licence applications, MMO aims for a decision within 13 weeks of receiving all relevant information and fee. DCO process has its own timescales.	MS-LOT aims for 14 weeks from application submission.	No statutory timescales for determining Marine Licence applications for ORE projects, which are considered as 'Band 3' projects, i.e. complex applications, and will be decided on a case-by-case basis. DCO process has its own timescales.
Additional consents that may be required	Wildlife licence, seabed survey licence, SSSI consent, Harbour Works licence from relevant authorities, EPS licence.	Other approvals and consents may be needed from Transport Scotland, Scottish Environmental Protection Agency, Harbour Authorities and NatureScot.	Wildlife licence, seabed survey licence, SSSI consent, Harbour Works licence from relevant authorities.

Table 7: Summary of development and consenting processes for offshore wind farms in each of the UK's administrations [Source: ORE Catapult, 2021]

The Crown Estate's Round 4 (for reference only) is a three-stage tender process, evaluating both bidders' capability and their proposed projects, before using option fees to determine award; a fair, objective and transparent process which reflects the maturing offshore wind market. Developers are encouraged to incorporate technological innovations in their projects including integrating offshore wind with other interconnection or energy generators and data sharing to continue improving operational performance.

1	2	3	4	5
Pre-qualification Questionnaire (PQQ)	Invitation to Tender Stage 1 (ITT Stage 1)	Invitation to Tender Stage 2 (ITT Stage 2)	Plan-Level Habitats Regulations Assessment (HRA)	Agreement for Lease
	Spring 2020 - Summer 2020	**Autumn 2020 (first phase), Early 2021 (second phase)**	**Spring 2021 – Spring 2022**	**Spring 2022**
Assesses potential Bidders' financial capability, technical experience and legal compliance, with successful Bidders pre-qualifying for the ITT Stage 1 process (becoming a Pre-qualified Bidder).	Assessing the financial and technical robustness of projects submitted by Pre-qualified Bidders. Projects that pass then become eligible to take part in the ITT Stage 2 process (becoming Eligible Bidders with Eligible Projects).	A multi-cycle bidding process in two phases, with issue of the ITT Stage 2 tender documentation in late 2020, followed by Bidding Cycles in early 2021. Using option fees bid by Eligible Bidders to determine award, one project is awarded per daily Bidding Cycle, with Bidding Cycles continuing until the 7 GW is awarded or exceeded (up to 8.5 GW).	Estimated to take between nine and 12 months, the HRA assessment is undertaken by The Crown Estate in its role as a Competent Authority, and considers the possible impacts of Round 4 on the network of protected areas covering the UK's most valuable species and habitats. Learn more about the Round 4 HRA process.	We expect we could enter into a Wind Farm Agreement for Lease with successful Bidders in Spring 2022, subject to the outcome of the HRA.

Table 8: Round 4 leasing process [Source: The Crown Estate (2021)]

5.5.1.2 Ireland

Background

To date, Ireland has only one offshore wind farm, the 25.3 MW Arklow Bank project with seven 3.6 MW wind turbines, operational since 2004.

In response to the Russian aggression against Ukraine and the resulting energy price and security of supply crises, the Irish government is accelerating the ambition to increase the use of offshore renewable energy. According to the government's commitment from March 2023, Ireland will target at least 5 GW of grid connected offshore wind to be delivered by 2030. In the longer-term, Ireland's offshore wind targets will increase to 20 GW by 2040 and at least 37 GW by 2050. To make these longer-term goals a reality, a revised Offshore Renewable Energy Development Plan, an updated National Policy Statement on Electricity Interconnection, a net zero electricity system pathway and a Green Hydrogen Strategy shall be developed and published during the next 12 months.

Floating wind projects and auctions

In addition to the 5 GW target for the deployment of (fixed-bottom) offshore wind farms by 2030, the government has committed to create a distinct programme of work to provide systems to enable a further 2 GW of floating offshore wind for additional non grid use that will be in development by the end of this decade. This will also include development of floating offshore wind dedicated to production of green hydrogen, as well as electricity for export to the European Union and the UK. The Irish government intends to develop an Enduring Regime for Offshore Wind policy, together with a Phase 3 policy, and a specific route to market for floating wind projects within these designated areas. This is scheduled to be opened in 2024.

In December 2022, Ireland's Minister for the Environment, Climate and Communications, Eamon Ryan TD, has issued Maritime Area Consents (MACs) to the first phase of seven offshore renewable energy projects. The award of a MAC enables Phase One projects to participate in the ORESS 1, the first auction for offshore wind under the Renewable Electricity Support Scheme (RESS). ORESS 1 is expected to procure approximately 2.5

GW of electricity generating capacity. The process for the ORESS 1 auction was launched in December 2022 by EirGrid, Ireland's operator of the national high voltage electricity grid, and will be completed by June 2023.

The first auction to take place for Phase Two offshore wind farms, ORESS 2, will launch by the end of 2023. With Phase Two projects, the Irish government plans to select further capacity needed to reach the 5 GW target of offshore wind generation capacity by 2030. Unsuccessful ORESS 1 participants will be afforded a strictly limited period by the Commission for Regulation of Utilities (CRU) within which to secure a Corporate Power Purchase Agreement (CPPA), and beyond which projects will be required to relinquish their Grid Connection Assessments.

Planning requirements and planning authority

The award of a Maritime Area Consent follows a comprehensive assessment, by the Department of the Environment, Climate and Communications, into each project's financial and technical competency. The awarded MACs enable all Phase One projects to begin their pre-planning application engagement with An Bord Pleanála, the national independent statutory body to determine appeals on planning. Phase One projects are expected to apply for planning permission later in 2023 after competing in Ireland's first offshore renewable energy auction.

In March 2023, the Irish government has approved a new framework for offshore wind project procurement and development that will be in effect for auctions and projects that will follow after the upcoming ORESS 1 tender. The new framework includes two main changes. First, all future offshore wind farms must be built in Designated Marine Areas, which have yet to be identified. And second, future offshore wind farms shall not be connected to points on land but to offshore substations that would be designed and built by EirGrid [55].

5.5.1.3 Norway

Background

In May 2022, Prime Minister Jonas Gahr Støre announced that Norway aims to allocate 30 GW of offshore wind capacity by 2040. Norway doesn't have any commercial-scale offshore wind farms to date. However, two areas worth 4.5 GW have already been identified for offshore wind development, one of which is for floating wind. In addition, the Norwegian Water Resources and Energy Directorate (NVE) has started working to identify other zones and to simplify the permitting procedures for offshore wind farms [53].

Floating wind projects and auctions

Norway's Unitech Zefyros (installed in 2009 as Hywind demo) remains the oldest operational floating offshore wind project. The 2 MW turbine is located at the Marine Energy Test Centre (METCentre), where the 3.6 MW TetraSpar demonstrator went online in 2021, and where different demonstration projects are scheduled to be commissioned in the next two years. Flagship, SeaTwirl S2, TwinWay and BlueWater TLP – they all use different floating concepts that aim at reducing the cost of floating wind technology.

The Hywind Tampen project (94.6 MW) is currently under construction and it will become the largest floating offshore wind farm in the world when all turbines are operational in 2023. The project with 88 MW system capacity for eleven turbines of 8.6 MW each will electrify floating offshore applications.

The offshore wind areas identified by the government include Utsira Nord and Sørlige Nordsjø II (Figure 25). The Utsira Nord site with an average water depth of around 265 metres, is designated for 1.5 GW of floating wind and will be auctioned in 2023 in three areas of 500 MW each.

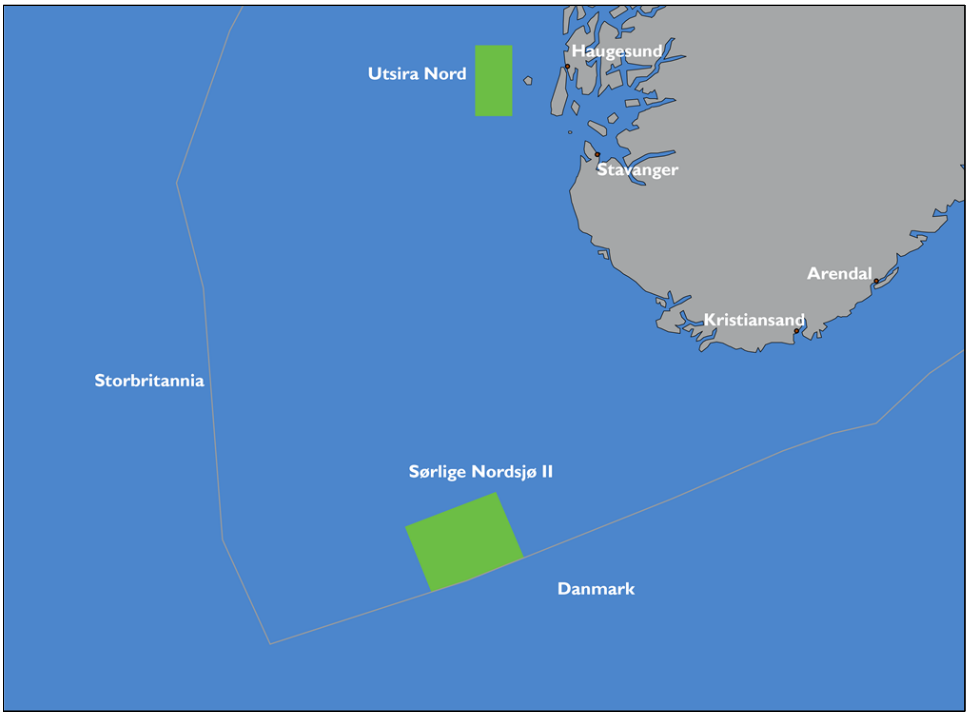


Figure 25: Norway's areas to be auctioned [Source: Norwegian Ministry of Petroleum and Energy, 2021]

Planning requirements and planning authority

The Ministry of Petroleum and Energy will be the designated authority for carrying out the administrative process and it will resemble a one-stop shop approach. The ministry has provided details about the requirements and the auction model for further consolidation [66].

For Utsira Nord the main proposal is to award three areas of acreage rights, each with a project capacity of 500 MW. To reduce wake effects there will be at least five kilometers between each area. In total it will offer 1,400 – 1,500 MW, but the transmission capacity network is only 1,400 MW.

The support model will be based on a contract for difference (CfD). A bilateral contract for difference is a long-term agreement with the state that gives the producer risk relief in the form of a guaranteed power price, where the state will pay the difference between the bid price and the reference price when the reference price is lower than the bid price, and the developer pays the state when the reference price is higher than the bid price.

The state will carry out basic investigations for Utsira Nord during 2023. The successful applicants who are allocated land will each cover a third of the costs of the basic surveys, which are estimated at NOK 27.5 million.

The seabed license will be possibly granted for a 30-year period. The government is evaluating to increase the awarded capacity to 750 MW.

5.5.1.4 France

Background

In November 2022, the first commercial offshore wind project in France has been commissioned, the 480 MW Saint-Nazaire offshore wind farm which is bottom-fixed.

France is expected to build around 850 MW of floating offshore wind by 2030. This includes demonstrators and the first wave of commercial projects tendered in 2021 and 2022, which are intended to reduce the cost of floating wind to at least 110-120 €/MWh.

Several plans define the ambitions of wind energy development in France.

At the national level, the multi-annual energy plan (plan de programmation pluriannuelle de l'energie, PPE) sets the priorities for action by the authorities in the energy field and also in the development of renewable energies. Adopted on 23 April 2020 for the period 2019-2028, the PPE decree sets a capacity target for off-shore wind power of 2.4 GW in 2023 and 5.2-6.2 GW in 2028.

In February 2022, President Emmanuel Macron has announced that France will have around 40 GW of off-shore wind capacity in operation by 2050. In addition, one billion euros shall be set aside for the development of new technologies such as floating wind turbines.

At the regional level, among other schemes and plans, two plans specifically concern wind energy develop-ment:

- The regional wind energy scheme (SRE) whose objective is to define zones favourable to the develop-ment of wind energy, i.e. which reconcile energy objectives with environmental issues. The regional scheme is annexed to the regional air, climate and energy scheme (SRCAE) (R.222-2 Env code). It must take into account both the wind energy potential and the various spatial constraints (especially the rules for the protection of natural areas as well as the natural and cultural heritage, the specific land-scaped areas, and the regional orientations). It draws up a list of the communes in which these areas are located.
- Regional grid connection plans for renewable energies (S3EnR) aim to reserve specific grid capacities for renewables and pool the costs of connection work between different producers within a region. They therefore make it possible to plan wind power sites with regards to the actual capacities for connection to the electricity networks. Each scheme is drawn up by RTE, the French TSO.

Floating wind projects and auctions

The 2 MW Floatgen is the only floating demonstrator in operation to date in France. Since 2018, it is located in the SEM-REV test site, which is operated by the École Centrale de Nantes and the CNSR.

The government has granted four demonstrator projects for floating wind with a generation capacity of 25 MW each. They were awarded in 2015 and will receive support of €240/MWh for 20 years. In November 2022, Shell and its partners decided to cancel the only FOWT demonstrator project in the Atlantic Ocean, Eoliennes Flottantes de Groix (28.5 MW), due to constantly increasing costs, inflation, and supply chain issues. The remaining projects are in the Mediterranean Sea, where Port-La-Nouvelle will become installation hub: EFGL (30 MW, WindFloat/Principle Power), EolMed (30 MW, Damping Pool/BW Ideol) and Provence Grand Large (25 MW, tensioned line floats/SBM, IFP), with three FOWT each. All projects have reached financial close and will be operational by 2024.

In 2021 and 2022, the government has started three auctions for 250 MW floating wind each. They have cap prices of €120/MWh and €110/MWh, respectively (Figure 26) and a Feed-In-Premium will be granted to the successful bidders. The winners of the competitive bidding procedures will be selected in 2023 and the three floating wind farms are expected to be commissioned by 2030. The French National Commission for Public Debate is evaluating the possibility to give a 500 MW extension to each of the 3 x 250 MW floating commercial wind farms, this would add 1.5 GW additional to the current 750 MW.

Objectif d'augmentation des capacités installées d'éoliennes en mer et mesures pour les atteindre

	2016	PPE 2016 objectifs 2018	2023	2028
Objectif éolien en mer (GW)		0,5	2,4	5,2-6,2

Mesure : lancer les appels d'offres ci-dessous pour les éoliennes en mer, avec des prix plafond supérieurs de 10 à 20 €/MWh aux prix cibles.

Date d'attribution de l'AO	2019	2020	2021	2022	2023	>2024
Eolien flottant 750MW			250 MW *Bretagne Sud* (120 €/MWh)	2 x 250 MW *Méditerranée* (110 €/MWh)		1 000 MW par an, posé et/ou flottant, selon les prix et le gisement, avec des tarifs cibles convergeant vers les prix de marché sur le posé
Eolien posé 2,5 à 3 GW	600 MW *Dunkerque* (45 €/MWh)	1 000 MW *Manche Est Mer du Nord* (60 €/MWh)*	500 – 1 000 MW *Sud-Atlantique*** (60 €/MWh)		1 000 MW (50 €/MWh)	

** Pour ce projet, la date de 2020 est la date de lancement de la procédure de mise en concurrence.*

***Dans ce cadre, un projet éolien en mer au large d'Oléron pourrait être attribué.*

Figure 26: Offshore wind energy auctions in France [Source: PPE (2020)]

France planned to hold 1 GW regular auctions from 2024 onwards, but it has not been decided yet if they will be for floating or bottom-fixed technology. This will be determined based on the auction results from 2021 and 2022. Additionally the country passed a Renewable Energy Acceleration Bill, which targets at least 18 GW of offshore wind by 2035 and 40 GW by 2050. To do so it aims to double the capacity auctioned to 2 GW a year from 2025 onwards.

Finally, there are also plans to install three additional FOWT prototypes in France in the years 2023-2025: a 3 MW-Hexafloat demonstrator at the Mistral test-site, a 5 MW-EOLINK demonstrator at the SEM-REV test site, and the 6 MW-NextFloat project with a X90 platform prototype at the Mistral test-site.

Planning requirements and planning authority

The permitting procedure for a wind farm is subject to several regulations under the Energy Code, the Town Planning Code and the Environmental Code. It depends on the height of the wind turbines and the power of the installation (see table below).

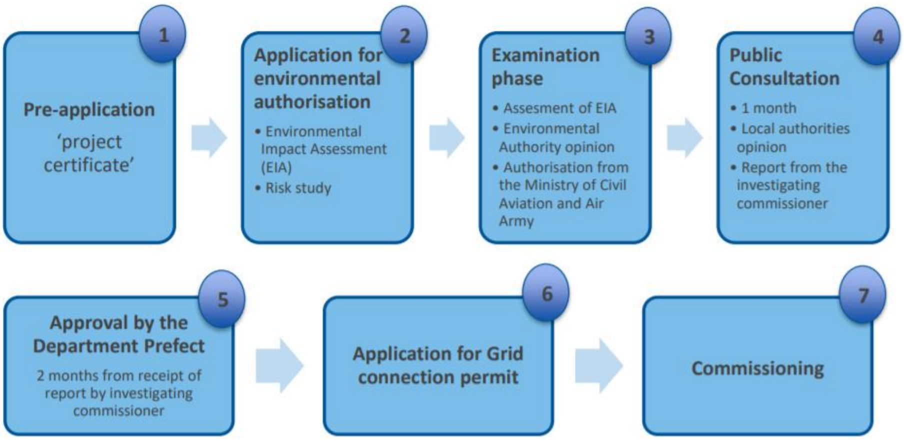
Projects that fall under the Water Act (offshore) follow the "environmental authorisation" procedure. The purpose of this procedure is to gather all the environmental authorisations which are necessary for the project in one single authorisation. The granting of such authorisation also exonerates the project from the granting of a building permit. This one-stop-shop via the ICPE regime was introduced on 1 March 2017.

Town planning authorisation	No building permit (L.421-5 + R. 421-8-1 TP code)
Environmental legislation	Environmental authorisation (Water Act) or specific authorisation in the Exclusive Economic Zone
Energy authorisation	For projects > 50 MW (L. 311-1 Energy code) + grid connection permit (L. 342-1 Energy code)
Public domain authorisation	+ authorisation for the right to use public domain area (L 2124-1 CG3P)

The 'préfet de département' (Department Prefect) is the planning authority which grants the "environmental authorisation." The Environmental Authority is consulted and provides its opinion on the Environmental Impact Assessment.

Environmental authority	CGEDD (General Council of the Environment and Sustainability – Ministry level)
Planning authority	Department Prefect

Key steps in environmental authorisation



France specifies that every geographical area should be subject to public consultation before tendering; this is done through the National Public Debate Commission. Public debates allow the commission to address concerns and questions from the general public. Getting both project developers and local residents involved is very useful in clearing up public concerns. However, it has been proven that the public debates and further zoning out of areas is the part of the administrative process slowing down the French auction system the most.

5.5.1.5 Spain

Background

Offshore wind activities in Spain have so far been limited to pilot projects, such as the 2 MW floating Demo-SATH prototype which is currently under construction. However, the government approved an Offshore Wind Roadmap in December 2021 which aims to install up to 3 GW of floating wind in Spanish waters by 2030. Due to deep waters in coastal regions, the potential for offshore wind in Spain is focused on floating wind.

In February 2023, the Spanish Maritime Spatial Plan (POEM – Planes de Ordenación del Espacio Marítimo), has been adopted by the government after long negotiations. It establishes plans for each of the five Spanish marine subdivisions: Nordatlántica, Sudatántica, Estrecho y Alborán, Levantino-Balear and Canaria (see Figure 27).

Floating wind projects and auctions

The 2 MW DemoSATH prototype is currently being installed in the BiMEP test facilities (Biscay Marine Energy Platform), and shall be tested for two years in real marine conditions in Spain. The only missing part is the grid connection which should be finalised in summer 2023. In addition, a 225 kW turbine is tested on a X30 platform, developed by X1 Wind, at the Spanish PLOCAN test site.

IberBlue, a joint venture of Ireland-based floating wind developer Simply Blue Group and Spanish companies Proes Consultores and FF New Energy Ventures, has recently announced plans for the development of two floating offshore wind farms in Spain. In November 2022, the company informed about plans for the 990 MW Nao Victoria floating wind farm, to be built with 55 FOWT with 18 MW each, off the coasts of Cadiz and Malaga, in the westernmost part of the Mediterranean Sea. In addition, the development of the 522 MW Juan Sebastián Elcano floating wind farm has been announced by IberBlue in April 2023, consisting of 29 turbines with a nominal capacity of 18 MW each. The site of this project is located within the delimitations of the new Maritime Space Management Plan, in the Nordatlántica area [54].

The Maritime Spatial Plan (POEM) defines the areas where the different activities at sea can be carried out. In the case of offshore wind, the necessary delimitation of maritime areas is due to the fact that the areas of the marine space must meet the following requirements:

- Suitable wind resource to generate enough energy and make the offshore wind farm viable
- Favorable physical characteristics that make the facilities technically and economically viable. Among the parameters to take into account are the emplacement depths, distances to the coast, slope and characteristics of the seabed
- Allow the coexistence of offshore wind power with other uses and activities of the maritime space (biodiversity, defense, fishing, aquaculture, navigation, tourism, etc.)

In general, the areas that allow a more efficient development of offshore wind projects are those that simultaneously meet the following criteria:

- Having a good wind resource (average wind speed > 9m/s), which allows obtaining high capacity factors.
- Be located at reasonable depths (< 200m).
- Have a large size (> 150-200 km^2). Due to economies of scale, increasing the size of the projects allows reducing costs.
- Stay a short distance from the coast. Although it is not the most determining factor, short distances allow the length of the evacuation line to be reduced and can eliminate the need to install a floating

substation. On the contrary, greater distances reduce the visual impact, which facilitates the processing of projects.

- Have acceptable accessibility conditions that do not make maintenance operations too expensive. The main accessibility factor is temporary sea state windows that allow safe access for crew transfer ships.
- In addition, it is necessary that there is evacuation capacity available in the vicinity, whether existing, planned (Planning of the Transportation Network 2021-2026) or in nodes classified as Just Transition.

[Source: https://www.evwind.es/2023/02/28/the-development-of-offshore-wind-power-in-spain-represents-considerable-progress-in-the-energy-transition/90436]

Figure 27: Spain marine regions for maritime spatial planning [Source: POEM]

For an estimation of the floating wind potential, the following table gives a breakdown of the relevant areas with up to 100 m and 100-200 m water depth.

Offshore Wind	Total area	Water depth < 100 m		Water depth 100-200 m	
		Area	Offshore Wind Potential [3 MW/km^2]	Area	Offshore Wind Potential [3 MW/km^2]
Water depth max. 200m	1,059 km^2	61 km^2	182 MW	998 km^2	2,993 MW

[Source: Spanish Wind Energy Association (AEE), 2023]

Considering today's floating wind technology is cost and technically feasible up to 200 m, Spain has designated areas that will allow to build about 3.2 GW of floating wind. However this relies on a very low energy density assumption, and it is expected that these areas provide space for more capacity.

Planning requirements and planning authority

Currently, the Spanish government is reviewing and updating the regulation to allow for offshore wind auctions. There are at least three regulations that are likely to be modified:

- RD 1028/2007 – administrative process for authorisation of offshore wind farms in territorial waters
- RD 960/2020 – support regime for renewable energy.
- RD 738/2015 – regulation for energy production and dispatching procedure in non-peninsular territories

5.5.1.6 Portugal

Background

Similar to the situation in Spain, the potential for offshore wind in Portugal is mainly focused on floating wind, due to deep water conditions in coastal regions at the Atlantic Ocean. According to the government's Industrial Strategy for Ocean Renewable Energies (EI-ERO), the total potential for floating wind is estimated at about 40 GW and it exceeds the fixed-bottom offshore wind potential by far [3]. Portugal has a target of 10 GW of offshore renewable energy by 2030.

Floating wind projects and auctions

Portugal already has one floating offshore wind farm up and running, the 25 MW Windfloat Atlantic, operational since July 2020.

The first offshore wind auction in Portugal is scheduled to be held in the last quarter of 2023. The auction was initially planned in 2022 with the target to award 3-4 GW offshore wind capacity. However, it was postponed due to the complex tendering procedure for offshore wind that needs to take into account aspects such as the industrialisation of ports. In addition, the capacity to be procured has been increased several times during 2022, as part of the Portuguese government's plan to speed up the country's energy transition. In September 2022, Portugal's Environment Minister announced that the capacity to be offered through the country's first offshore wind auction was increased to 10 GW.

Three working groups have been established that work on design and requirements for the first auction for offshore wind in Portugal:

- Group 1 – led by DGRM (Marine) to allocate the areas in the Maritime Spatial Plan and map main connection points.
- Group 2 – led by DGEG (Energy) to propose action model, who pays for the grid and who builds it.
- Group 3 – led by APP (Portuguese ports association) to understand infrastructure needs, particularly for ports.

In January 2023, Portugal's Ministry of Economy and Maritime Affairs, the Ministry of Infrastructure, and the Ministry of Environment and Climate Action have released draft areas for offshore wind development as part of the government's plan to award 10 GW of capacity that would be grid-connected by 2030 (Figure 28).

Six areas have been identified for floating offshore wind in water depths of 75-200 m, and two areas for fixed-bottom offshore wind farms in depths of up to 50 m. Most areas for floating wind have a potential of 1-2 GW, while one area with a potential of 4 GW has been identified. The closest distance to shore is roughly 10.4 km and the furthest is roughly 55.6 km.

The draft areas for offshore wind were chosen based on energy resources, easements and administrative restrictions and abiotic factors. Efforts have been made to minimise interference with the common uses of the maritime space, namely local fishing and the navigation of leisure craft [57].

In February and April 2023, IberBlue Wind, a joint venture created to promote floating offshore wind farms in the Iberian Peninsula (see 5.5.1.5), has revealed plans for the development of two floating offshore wind projects with 18 MW wind turbines in Portugal, located within the areas proposed by the government for offshore wind farm development. The 990 MW Botafogo wind farm with 55 wind turbines is planned off the coast of Figueira da Foz, and the Creoula floating wind farm with 80 turbines and a capacity of 1,440 MW is planned off the coast of Viana do Castelo [54].

This follows an announcement from BayWa r.e. in October 2022, that the company has officially applied to secure the rights for an exclusive use of the seabed in Portugal for a commercial-scale floating offshore wind project with 30 turbines and up to 600 MW in the dedicated zone off the coastline of Viana do Castelo, which the company said will be the first subsidy-free floating wind farm in the world [56].

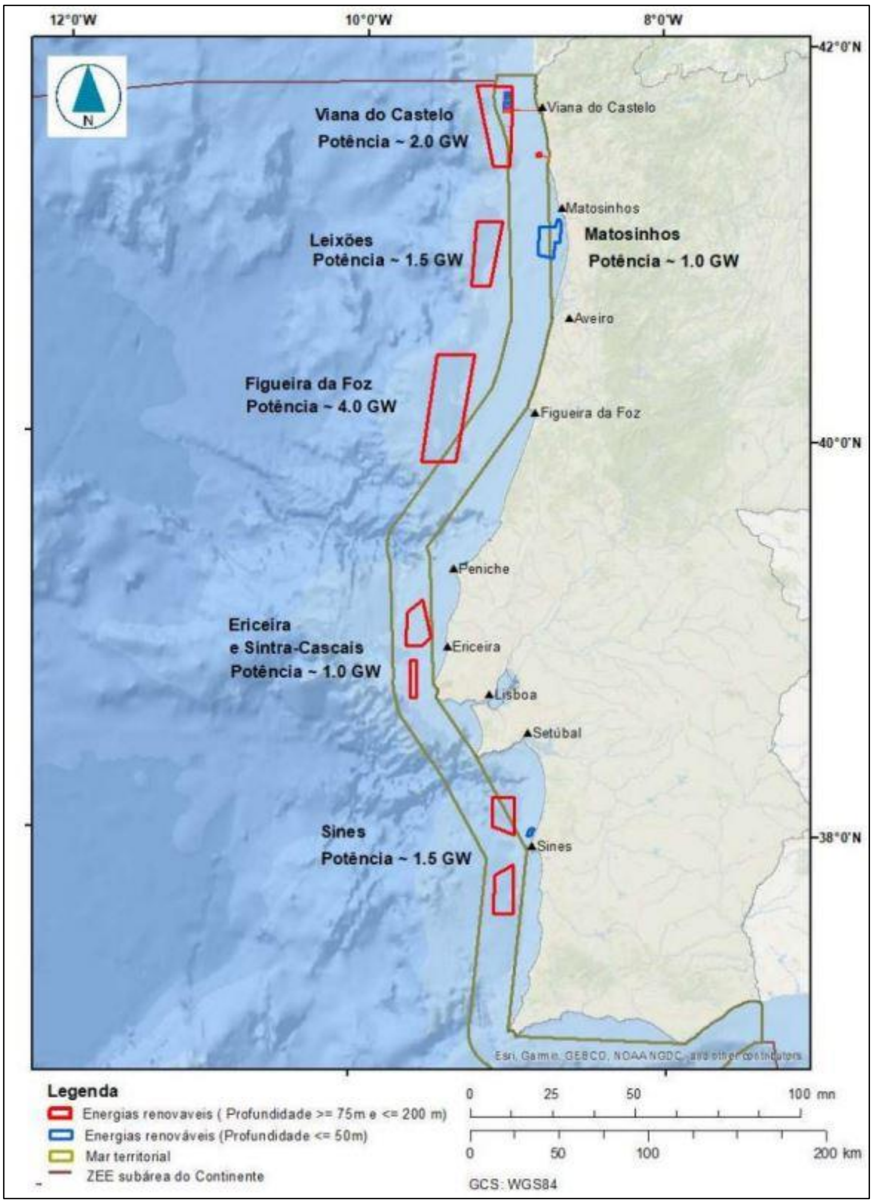


Figure 28: Preliminary proposal of the spatial areas for the offshore wind auction in Portugal (Source: Portuguese Ministry of Economy and Maritime Affairs, from: [57])

Planning requirements and planning authority

The consultation process to define the framework conditions for the first offshore wind auction is still ongoing.

5.5.1.7 Italy

Background

In Italy, only one offshore wind farm is in operation, which has been commissioned in 2022 in the Apulia region. The 30 MW Beleolico offshore wind farm features ten 3 MW (bottom-fixed) wind turbines delivered by MingYang Smart Energy. The Beleolica project marks not only the first operational offshore wind farm in the Mediterranen Sea, but also the first project for which a Chinese OEM has supplied wind turbines for the European offshore wind market.

Italy's 2019 National Energy and Climate Plan which is due for revision in 2023, only foresees 900 MW of offshore wind installed capacity by 2030.

A draft market framework published in March 2023 sets out a schedule of auctions and price support mechanisms for the development of 3.5 GW of offshore wind in Italy between 2023 and 2026. Most of the development will be off the coasts of Sardinia, Sicily, and in the Adriatic and upper Tyrrhenian seas where deeper waters are likely to favour floating structures.

Floating wind projects and auctions

During 2022, Italy's electricity transmission system operator, Terna, has seen a strong growth of requests for connection to the national transmission grid regarding offshore wind plants, reaching approximately 95 GW in October 2022, an increase of more than 200% compared to requests for grid connection in December 2021. Around 80% of the requests are from southern-Italian regions and the main islands, which are favorable for floating offshore wind. However, it is expected that at best only 8 to 10 GW of the submitted grid connection requests could materialise into concrete projects.

The planned FER 2 (FER = Fonti Energetiche Rinnovabili) auction scheme aims to allocate support for 3.5 GW of offshore wind by 2030. It is expected, however, that additional capacity will be tendered to accommodate the remainder floating offshore projects that show potential to become a reality.

The FER 2 Auction Decree (aimed at more cost-intensive renewables) is expected to confirm that 3.5 GW of floating offshore wind is to be tendered between 2022 and 2026 in two or three phases. The support scheme is likely to be in the form of contracts for difference (CfD) with an agreed strike price, mooted at €165/MWh. The lowest bids will be awarded the available capacity.

The Decree was recently sent to the European Commission and should be approved in four to six months. It has suffered significant delays and it is still not clear how the 2022-2026 window will apply, i.e., whether the window period will be extended or whether more tenders will be squeezed in the same window.

Planning requirements and planning authority

A lack of concrete legislation and transparent, efficient permitting processes threaten the scheme's success. No projects have yet secured all of the permits required to participate, despite ample interest, and the process for obtaining permits is unclear. Eligible projects need to have a grid connection agreement, issued by Terna, a seabed concession, issued by the Ministry of Sustainable Infrastructures and Mobility, and an environmental impact assessment, issued jointly by the Ministry of Environment and Energy Security and the Ministry of Culture. The correct order for submitting and receiving permits is not clear. In December 2022, projects with a total capacity of 14 GW had submitted requests for all three permits [73].

5.5.2 Asia

5.5.2.1 South Korea

Background

In 2020, South Korea set out a target of 12 GW offshore wind capacity by 2030 and to become one of the world's five largest offshore wind generating countries. This ambitious target was issued in the "OSW Collaboration Plan", that also pledges to implement policies to share the economic benefits of offshore wind development with local residents and Korea's fishing industry [58]. The "OSW Collaboration Plan" is based on the Green New Deal for Korea, an investment program in green energy sectors to achieve carbon neutrality by 2050.

Due to an abundance of suitable deep-water sites, floating wind technology is expected to be an important segment to reach the targets for offshore wind in South Korea.

Floating wind projects and auctions

At the end of 2021, South Korea had an operational offshore wind capacity of only 188 MW. However, ambitious plans for the world's largest offshore wind projects have been announced in 2021, comprising the 8.2 GW bottom-fixed OWF off the coast of Shinan and the 6 GW floating offshore wind project off the coast of Ulsan.

The 6 GW wind farm will be built at the site of the Donghae 1 gas field which is scheduled to end production in 2022. Several project developers have already obtained electricity business licenses (EBL) from the Ministry of Trade, Industry and Energy of Korea for various project stages of the floating wind projects offshore Ulsan.

In 2021, Corio Generation and TotalEnergies obtained an EBL for 504 MW for the first phase of the Ulsan Gray Whale 3 floating offshore wind project. The wind farm is one of the three phases of the 1.5 GW offshore wind project that the partners are developing in the Ulsan region [Source: https://www.offshorewind.biz/2022/10/05/totalenergies-corio-award-feed-contract-for-floating-wind-project-offshore-south-korea/].

In November 2021 and in March 2022, a joint venture between Shell and Hexicon received three EBLs for a total capacity of 1.3 GW for the MunmuBaram floating offshore wind project. Subject to future investment decisions, the MunmuBaram floating wind farm will be developed in phases [Source: https://www.offshorewind.biz/2022/03/08/shells-south-korean-floating-wind-project-cleared-for-1-3-gw-capacity/].

In 2022, Korea Floating Wind (KF Wind), a joint venture of Ocean Winds (established by EDP Renewables and Engie) and Aker Offshore Wind, has secured two EBL for 870 MW plus 450 MW for its 1.2 GW floating wind project offshore Ulsan. [Source: https://www.offshorewind.biz/2022/03/03/ocean-winds-aker-offshore-wind-secure-1-2-gw-floating-capacity-in-south-korea/].

Finally, Equinor has also received electricity business licenses for two projects located outside Ulsan, namely Firefly (800 MW) and Donghae-1 (200 MW), and is also pursuing other early phase projects in the country [Source: https://www.offshorewind.biz/2022/12/05/geoview-completes-geophysical-survey-for-equinors-floating-wind-project-offshore-south-korea/].

According to GWEC's Market Intelligence forecast, South Korea is set to emerge as the top floating offshore wind market in East Asia with a capacity of 3.6 GW expected to be commissioned by 2030 [34].

Due to the ambitious targets and good conditions for offshore wind in Korea, various international companies such as Ørsted, Corio Generation, Total Energies, Shell, Equinor, EDP, Aker Solutions, Copenhagen Infrastructure Partners have entered into joint agreements with local partners. In addition, large Korean industry players like Samsung, Hyundai, Doosan and STX are interested in renewable energy project development and equipment supply [34].

Planning requirements and planning authority

South Korea has an extensive permitting process for offshore wind. To develop and operate an offshore wind project, a project developer (i.e. only companies established in Korea) must obtain an electricity business licence (EBL) from the Ministry of Trade, Industry and Energy, specifying generation capacity, location and a "preparation period" during which the operation of the proposed project must be commenced. An EBL for an offshore wind farm will only be issued after collecting at least one year of meteorological data for a specific site. The installation of a meteorological measurement device requires a public waters occupancy permit (PWOP) from the public waters management authorities.

Following issuance of an EBL, a second PWOP is required for the installation of the wind turbines, for a period of up to 30 years. To obtain this PWOP, an approval of the construction plan and, for wind power projects with at least 100 MW, an environmental impact assessment (EIA), see below, are required. The developer may also need to conduct a marine traffic safety examination and a cultural heritage survey.

After receipt of the second PWOP, the applicant must obtain approval of a public waters occupancy implementation plan, prior to commencing construction. Developers have a 4-year preparation period from the issuance of the EBL to obtain all the necessary permits and complete construction or request a permission extension. [58].

In South Korea, it is important for projects to consider requirements of the local Enivironmental Impact Assessment (EIA) to meet Korean regulations, alongside the requirements of an International ESIA to obtain finance when embarking on the development.

Offshore wind developers in South Korea seeking permits for the construction of renewable energy projects listed under the EIA Act are required to prepare an EIA. This requirement includes not only input from residents located in the vicinity of the project but also a fundamental baseline survey of 4 seasons (12 months) considering seasonal characteristics and changes in marine environment and ecological systems. The EIA application should be submitted to the relevant government authority, the Ministry of Trade, Industry and Energy (MOTIE), along with the necessary consenting and permitting process in accordance with the guidelines and regulations of the local EIA Act. The MOTIE must send a request for consultation to the Ministry of Environment (MOE) before granting the permit. The MOE has the main responsibility and authority to review the EIA report together with other relevant parties and must notify the result of its review, which is typically made in the form of "approval", "not approved" or "conditional approval". The applicant must consider the results of this consultation and their impact on its construction plans with proper mitigation plans/actions or alternative solutions [62].

5.5.2.2 Japan

Background

Japan has a target of 10 GW installed offshore wind capacity by 2030 and 30-45 GW by 2040, including floating wind. According to the Japan Wind Power Association the 2030 offshore capacity target of 10 GW will comprise 4 GW for floating offshore wind farms [23]. Since 2020 Japan started to auction 1 GW of offshore wind capacity a year onwards to meet the target of 10 GW by 2030.

Due to its long coastline, Japan has an enormous potential for offshore wind power. As water depths increase quickly (on average up to 200 m) relatively close to the shore, Japan is also expected to be a leading market for floating wind. However, no large-scale commercial offshore wind farm is yet in operation.

Japan has taken a pioneering role in demonstrating several floating wind concepts in the Fukushima Forward project (see 5.3.1). However, deployment of FOWT has since slowed in response to the high initial costs of these prototypes, as well as several market and regulatory barriers, namely: a lack of clarity on energy policy post-Fukushima, onshore grid transmission constraints, and a slow and fragmented consenting regime [3].

Floating wind projects and auctions

The tenders for offshore wind auctions in Japan are initiated by METI (Ministry of Economy, Trade and Industry) and MLIT (Ministry of Land, Infrastructure, Transport and Tourism).

In June 2021, a consortium of Japanese companies, led by Toda Corporation, was awarded in Japan's first floating offshore wind tender for 16.8 MW capacity in the Goto area, in Nagasaki prefecture. The Goto wind farm will feature eight Hitachi 2.1 MW wind turbines installed on hybrid SPAR-type, three-point mooring floating foundations. Offshore work for the installation of the first spar-floater started in October 2022, and the wind farm is expected to be fully commissioned in January 2024 [18].

Planning requirements and planning authority

Japan's government has recently implemented reforms to strengthen the regulatory framework for offshore wind in order to incentivise and give greater certainty to developers. In 2019, the Offshore Wind Promotion Law (Law No. 89 of 2018) came into force, and guidelines for the auction process (the "General Sea Areas Public Auction Implementation Guidelines") were published [23]. Since the enactment of the new legislation, five new areas for offshore wind projects have been designated by the national government as "Promotion Zones"[58].

The new Offshore Wind Promotion Law does not address environmental processes specifically. However, commentators note that with the new designated promotion zones, which will require government agencies to engage with all relevant stakeholders, it is hoped that this added development will significantly shorten environmental approval processes [23].

5.5.2.3 Taiwan

Background

GWEC expects Taiwan to achieve more than 12 GW of installed offshore wind capacity, becoming the second largest offshore wind market in Asia after mainland China within the next decade [34]. Taiwan has considerable wind resource in deep waters relatively close to shore that are suitable for floating wind technology.

By end of 2021, only two offshore wind projects under Taiwan's Demonstration Incentive Program were online: Formosa 1 with 128 MW and the 109 MW Changhua Demonstration project. In 2022, however, Taiwan saw a huge increase in offshore wind energy, according to the statistics from the Global Wind Energy Council (GWEC): 145 new turbines in four offshore wind farms have been connected to the grid last year, totaling 1,175 MW of new offshore wind capacity [4].

In 2021, the Taiwanese government announced to increase its offshore wind ambitions with a further allocation of 15 GW over the 2026-2035 period. While the original 5.7 GW tranche was procured across a selection round and auction, the next 15 GW (termed Round 3) will likely be conducted across two phases; the first phase (2026-2031) will prioritise projects at water depth of less than 50 metres [34].

Floating wind projects and auctions

Based on information from the Ministry of Economic Affairs (MoEA), Figure 29 gives an overview of the progress of the offshore wind auctions in Taiwan.

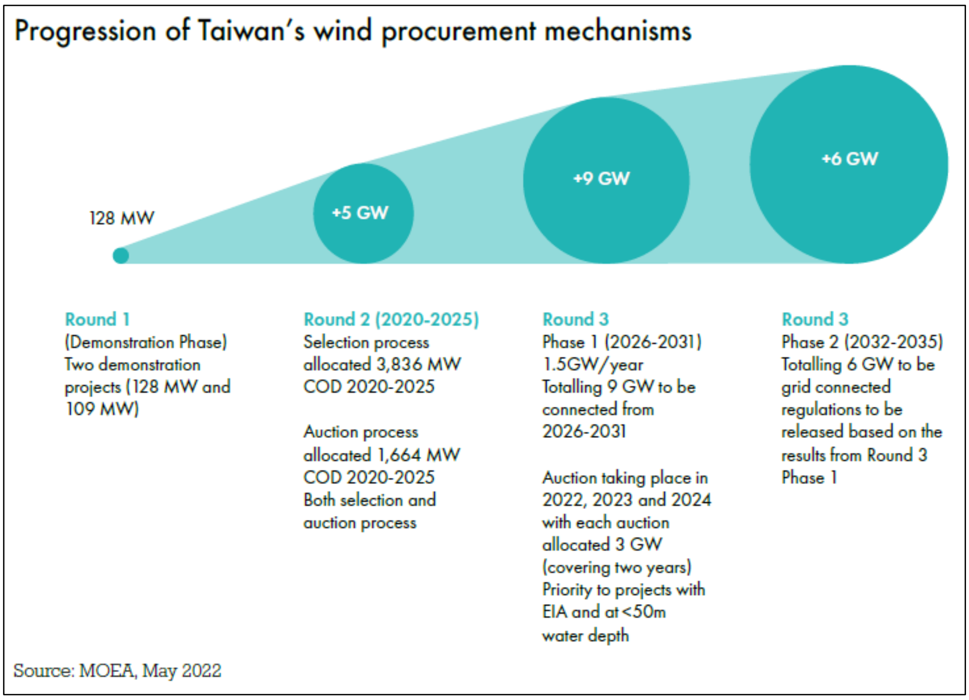


Figure 29: Progression of Taiwan's wind procurement mechanisms [34]

The Round 3 offshore wind tenders in Taiwan are procuring project development for wind farms scheduled to go online from 2026 to 2035. At the end of 2022, MOEA announced that five projects have been selected in the the Round 3.1 auction, which will add 3 GW of new offshore wind capacity in Taiwan and will come online in 2026 and 2027 [24].

The Round 3.2 auction (for 2027-2028 capacity) is scheduled to be held later in 2023, and will be followed by a Round 3.3 auction (for 2030-2031 capacity) scheduled for 2024.

Currently, developers with existing floating wind sites are preparing to enter the Round 3.2 auction, including Spain-based BlueFloat Energy which unveiled plans for its 1 GW floating wind project called Winds of September in May 2022. The Winds of September floating farm is located 25 km off the coast of Hsinchu County and Hsinchu City in water depths of 64-96 m [64].

According to GWEC, the government's localisation strategy, which aims to consolidate the entire supply chain in Taiwan, from turbine components to submarine cables to shipbuilding, will be critical to the steady progression of the offshore wind market [34].

Planning requirements and planning authority

The permitting procedures for electricity enterprises is regulated by the Electricity Business Registration Regulations (EBRR), that details the rules and procedures regarding the key electricity business permits and licences in Taiwan. Developing an offshore wind project involves the following five key permits and authorisations (in chronological order):

- the issuance of an environmental impact assessment (EIA) Approval
- the issuance of an Establishment Permit (EP)
- the issuance of a Recordation Approval
- the issuance of a Construction Permit
- the issuance of an Electricity Business Licence.

The Ministry of Economic Affairs and the Bureau of Energy (BOE) under the MOEA are the primary regulatory authorities in charge of the electricity industry and the renewable energy generation industry. In addition to BOE, however, renewable power projects are subject to regulation by certain central and/or local authorities. State-owned Taiwan Power Company ("Taipower") is in charge of the required consent for grid connection [58].

5.5.2.4 Mainland China

Background

By the end of 2022, cumulative offshore wind installations in China exceeded 30 GW. China took over the UK's previous global lead in offshore wind in 2021, when nearly 17 GW of new capacity came online in just one year. This astounding level of growth was driven by the expiry of Feed-in-Tariffs for offshore wind at the end of 2021.

Offshore wind in China enjoyed fast development during the 13th Five-Year Period (2016-2020), increasing from about 1 GW to 10 GW installed capacity by 2020. In addition, summing up targets released by all coastal provinces in their 14th Five-Year Plans, China will add a total of 40-50 GW of offshore capacity during the 2021 to 2025 period, according to data published by GWEC [34].

Floating wind projects and auctions

Since 2021, several demonstrators using single wind turbines mounted on semi-submersible floating structures have been installed in China (see 5.3.1). However, no commercial-scale floating offshore wind farm is yet in operation.

Planning requirements and planning authority

The regulatory framework for offshore wind projects in China is particularly challenging because it is comprised of a complex set of rules at the national and local level (sometimes inconsistent with each other) and requires the developers to go through many formalities with multiple authorities at different stages of development. The figures below provide a general overview of the required regulatory permits and the main authorities and their role in China's regulatory framework for offshore wind farm [58].

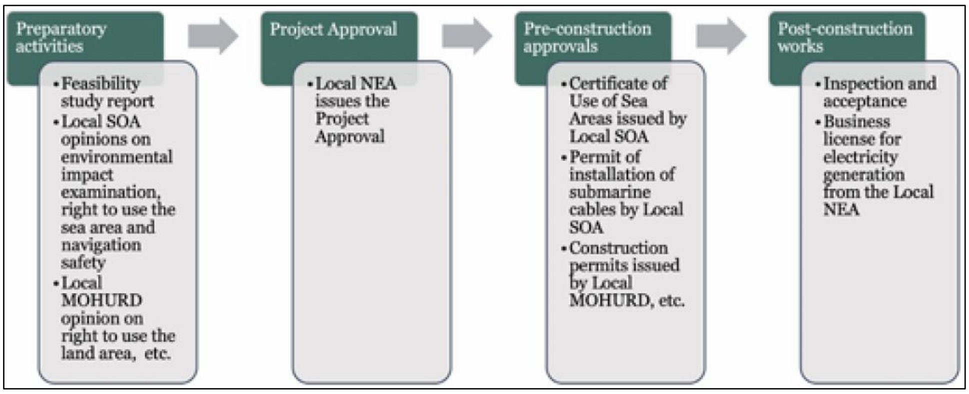


Figure 30: Regulatory permits required for the construction and operation of the offshore wind farm in China [58]

Main Authorities	Role
NEA	• Issuing Offshore Wind Power Plan • Administration of planning, development and construction • Selection of projects through competitive bidding • Issuing Project Approvals • Issuing business license for electricity generation
SOA	• Approving sea areas and providing use right • Approving installation of submarine cables • Approving navigation and environmental safety
NDRC	• Determining tariff
MOF	• Distributing subsidies and funds
MOST	• Promoting technology in energy sector
MOHURD	• Land construction approvals and permits
SAMR	• Issuing national technical standards • Registration of project company

NEA = National Energy Administration; SOA = State Oceanic Administration; NDRC = National Development and Reform Commission; MOF = Ministry of Finance; MOST = Ministry of Science and Technology; MOHURD = Ministry of Housing and Urban-Rural Development; SAMR = State Administration for Market Regulation;

Table 9: Main authorities and their role in China's regulatory framework for offshore wind farm [58]

5.5.3 America

5.5.3.1 United States (U.S.)

Background

So far, only two smallscale offshore wind projects are in operation outside of Europe and Asia. Both are located in the U.S.: the 30 MW Block Island project and the 12 MW Dominion Virginia demonstration project.

However, a number of other U.S. offshore wind farm projects are under development, at various stages of the federal permitting process, and two commercial scale projects are expected to start delivering electricity in 2023.

In March 2021, President Joe Biden announced an offshore wind goal of 30 GW by 2030 in a manner that protects environmental assets and creates employment. Through a coordinated multi-agency approach, Biden plans to fast track the deployment of utility scale offshore wind.

In addition, the U.S. market continues to expand rapidly, with the landmark Inflation Reduction Act (IRA) introduced in 2022, which GWEC says is "heralding a new era in the international race for offshore wind and a green economy" [4].

In September 2022, the Biden-Harris Administration announced new actions to expand U.S. Offshore Wind Energy, aiming at positioning the U.S. to lead the world on floating offshore wind technology. It also announced a new goal to deploy 15 GW of installed floating offshore wind capacity by 2035 – enough clean energy to power over five million American homes. This builds on the Administration's goal to deploy 30 GW of offshore wind by 2030, which will be largely met using fixed-bottom technology. The Bureau of Ocean Energy Management (BOEM) will advance lease areas in deep waters for floating technology, starting with a lease auction off the coast of California end of 2022. Bringing floating offshore wind technology to scale will unlock new opportunities for offshore wind power off the coasts of California and Oregon, in the Gulf of Maine, and beyond [59].

The commitment for a 15 GW floating offshore wind target in the U.S. follows an announcement from August 2022 in which the California Energy Commission set a long-term Offshore Wind Planning goal of up to 25 GW by 2045 to deploy offshore floating wind in federal waters off the California coast.

Floating wind projects and auctions

The Bureau of Ocean Energy Management is the US organisation that manages and is responsible for the offshore wind market in federal waters. To position the domestic offshore wind industry to meet the 2030 target, BOEM has issued 25 commercial and 10 competitive offshore wind energy leases in the Atlantic Ocean, ranging from Massachusetts to North Carolina.

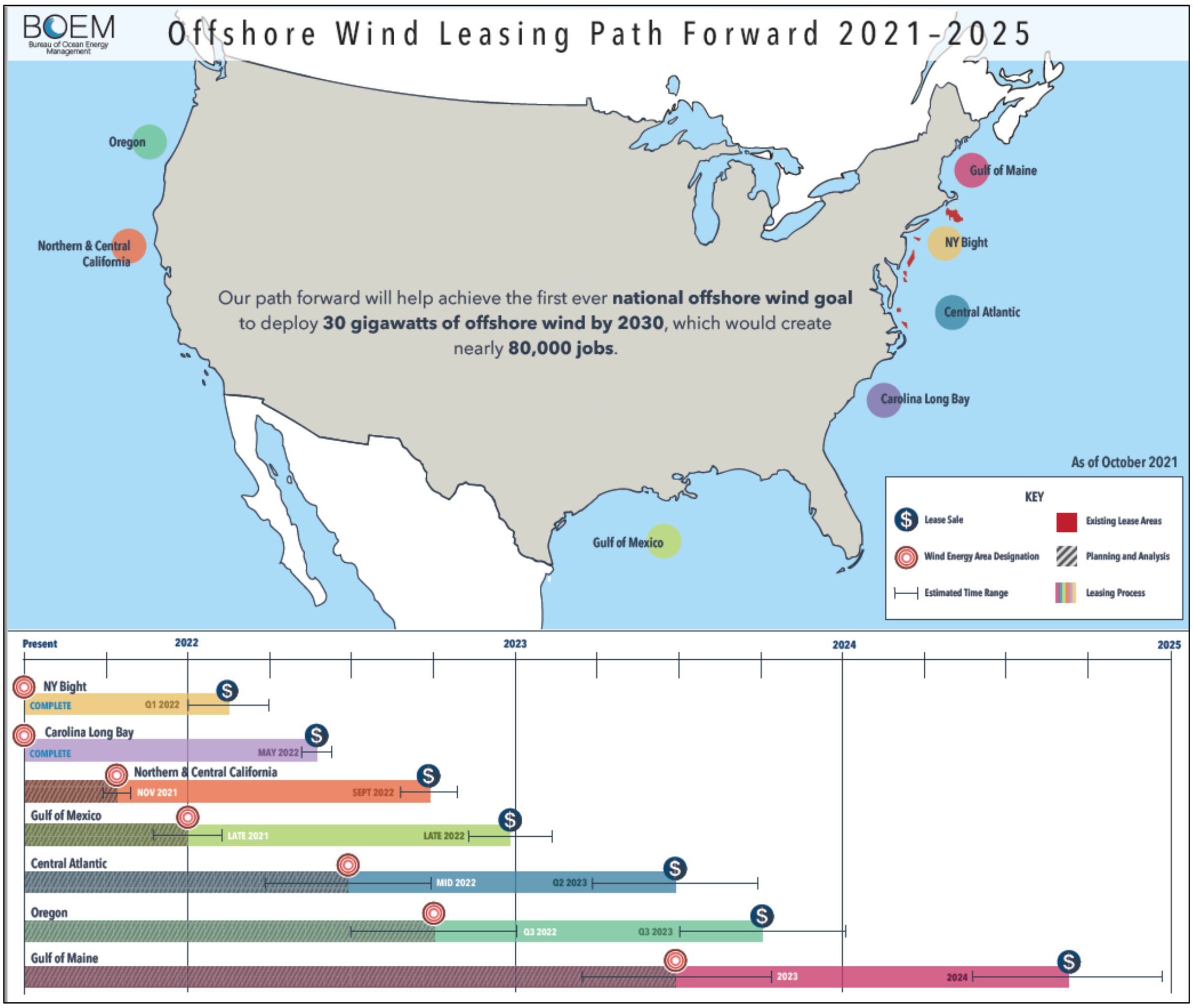


Figure 31: Proposed leasing schedule for offshore wind farms in the U.S. [Source: BOEM, 2021]

In December 2022, BOEM conducted the first offshore wind lease sale off America's West Coast and the first that will require floating turbine technology to develop. Overall, it was the second largest auction in terms of total funding, and BOEM generated $757 million in revenue for five leases on the Outer Continental Shelf off central and northern California. The five lease areas total approximately 373,268 acres and have the potential to generate over 4.6 GW of floating offshore wind (Figure 32).

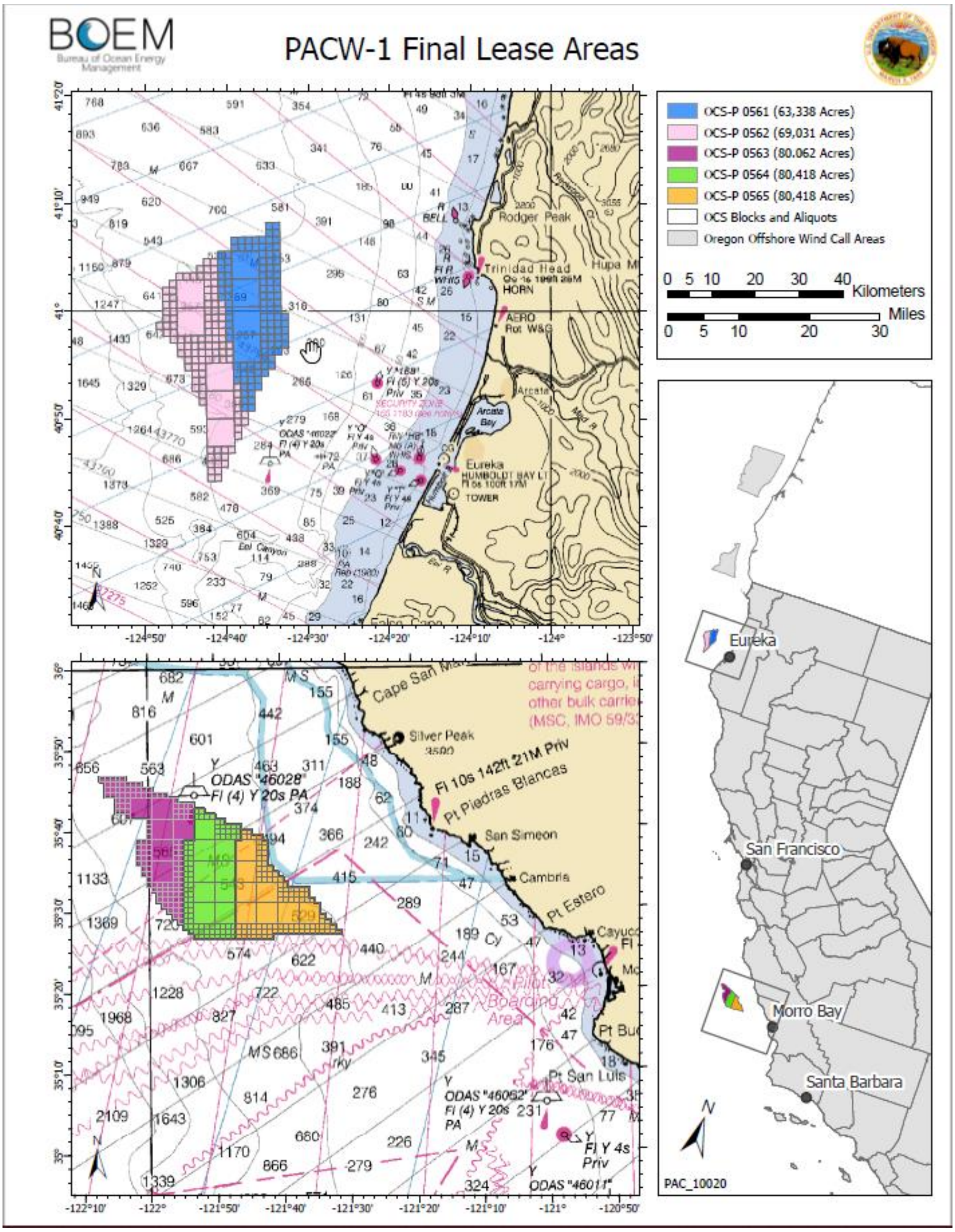


Figure 32: **Five lease areas off the U.S. West Coast in the offshore wind auction in December 2022 [Source: BOEM, 2022]**

The following bidders were named as provisional winners of the auction: RWE Offshore Wind Holdings, LLC (OCS-P 0561), California North Floating, LLC (OCS-P 0562), Equinor Wind US, LLC (OCS-P 0563), Central California Offshore Wind, LLC (OCS-P 0564) and Invenergy California Offshore, LLC (OCS-P 0565)

[60].

Planning requirements and planning authority

The United States has the authority to permit and regulate offshore wind energy development within the offshore areas under its jurisdiction. The federal government and coastal states each have roles in the permitting process, and those roles depend on whether the project is located in state or federal waters. Section 388 of the Energy Policy Act of 2005 (EPAct; P.L. 109- 58) amended the Outer Continental Shelf Lands Act (OCSLA) to address previous uncertainties regarding offshore wind projects. Under the EPAct, the Secretary of the Interior has ultimate authority over offshore wind energy development. The statutory authority granted by Section 388 is administered by the Bureau of Ocean Energy Management, which is an agency within the Department of the Interior. Since the passage of EPAct, BOEM has promulgated rules and guidelines governing the permitting and operation of offshore wind facilities. In addition, several federal agencies have roles to play in permitting development and operation activities [61].

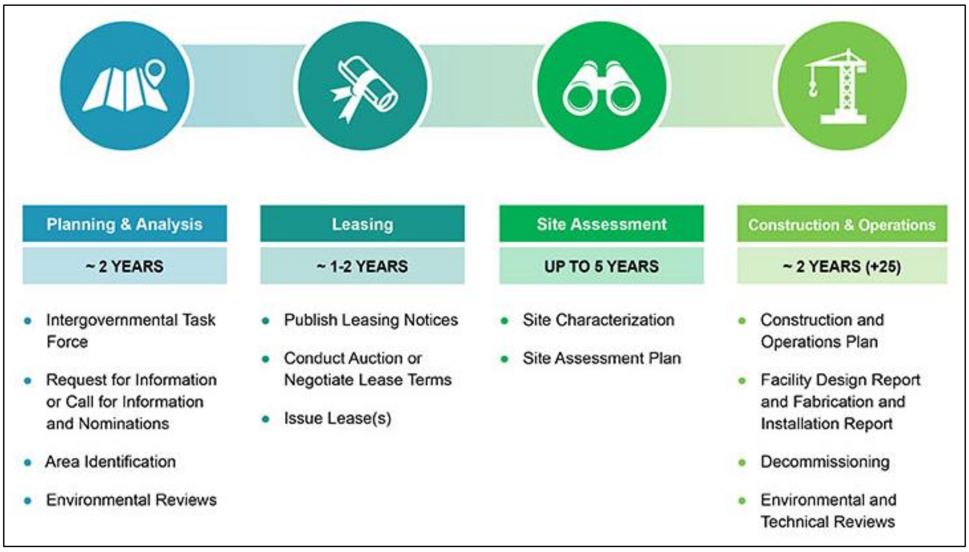


Figure 33: Regulatory Roadmap for the development of offshore wind projects in the U.S. [Source: BOEM, 2023]

5.6 Market opportunities and threads

This section gives an overview of identified opportunities and threads for floating offshore wind deployment, based on information from diverse public available sources.

5.6.1 Opportunities

- In view of international targets to increase the contribution of renewable energies for energy supply and to decrease global CO_2 emissions, wind power is expected to become the largest renewable energy source. Thus, exploitation of floating offshore wind will be essential for energy transition.
- The offshore wind market for fixed-bottom structures is constrained due to the limited locations with shallow waters. Since floating offshore wind turbines are considered technically feasible in water depths from 50 m to 1,000 m, FOWT will enable to use 60% (USA) to 80% (Europe, Japan) of offshore wind resources in deep waters (> 50 m) [1].
- Floating wind technology opens up deeper waters and creates opportunities for developers to take advantage of deepwater sites, both nearshore and offshore. In addition, deeper, more remote waters offer higher average wind speeds, which improves the capacity factor and potentially the LCOE of offshore wind power generation [6].
- However, FOWT can also facilitate the development of more deep water sites closer to shore, which are not suitable for fixed-bottom structures, avoiding the need to develop shallow sites far from shore, which create challenges for electrical transmission, installation, and O&M [1].
- In addition to the primary option of generating and selling grid-connected electricity, floating offshore wind offers a significant potential for other energy sectors, especially for the production of green hydrogen by electrolysis and for the power supply of offshore oil and gas platforms.
- Based on the expertise of the fixed-bottom offshore wind sector, floating offshore wind has the potential for new businesses and export for the offshore wind industry. Floating offshore wind requires specific needs for mooring, electrical cabling and installation, which depends on a local supply chain and will therefore drive job growth in marine industries. Furthermore, floating offshore wind is an opportunity to provide more sustainable job alternatives to workforce from the offshore Oil and Gas and shipyards industry [12].
- The geographic spread of deep water sites for FOWT is an opportunity to smoothen offshore wind generation and to contribute to the adequacy of the electrical system [12].
- For most floating structure concepts, FOWT can be installed on top of the floater at suitable port facilities and the fully assembled structure can be towed to the offshore site. This is expected to reduce installation costs significantly, as tugboats can be employed instead of expensive heavy lift jack-up and dynamic positioning vessels [1]. Furthermore, this can potentially also increase the flexibility of the installation procedure and widen the typically very small weather windows associated with installing fixed-bottom wind farms [6].
- For major repairs, O&M, and decommissioning of FOWT, significant cost reductions are expected for concepts for plugging and unplugging electrical and mooring systems, allowing the structure to be towed back to port without using costly specialized vessels [1]. In addition, this is associated with a reduction in health and safety risk as less work is carried out offshore [6].
- Floating offshore wind reduces the impact on the marine environment during installation. The lack of piling noise is an added benefit related to FOWT which can ease the consenting process and avoid the need for noise mitigation measures [1]. Not at least, floating offshore wind farms could also become safe havens for recovering marine fauna [12].

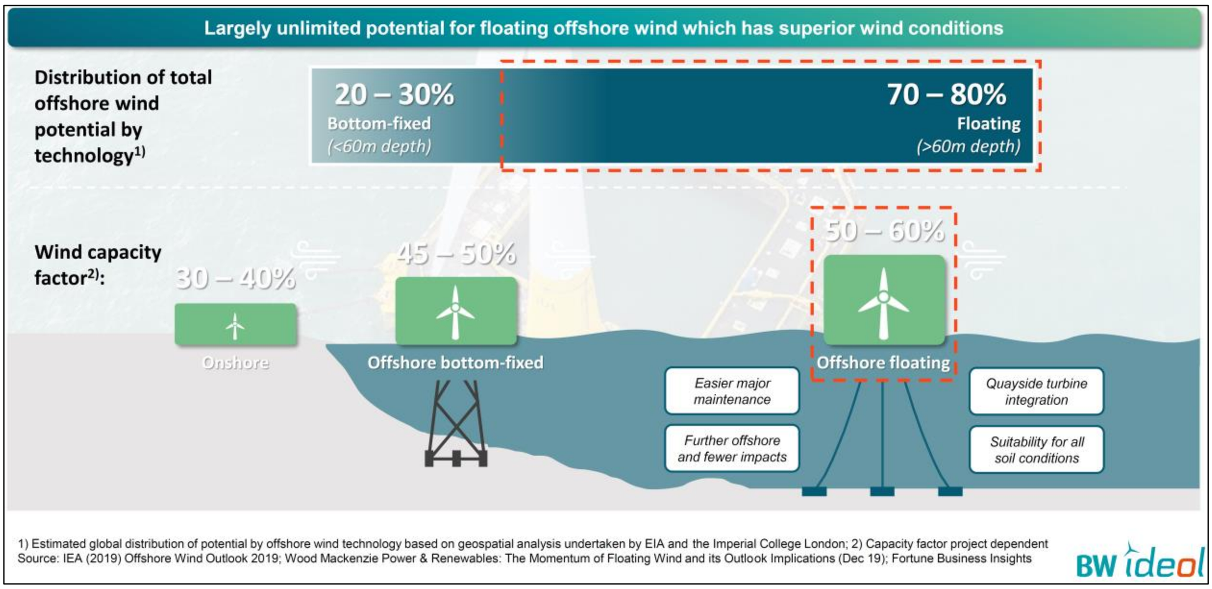


Figure 34: Potential and opportunities for floating offshore wind [Source: BW Ideol, March 2021]

5.6.2 Threads

- The pace and scale of FOWT deployment will depend on whether floating wind technology can be successfully deployed in large-scale projects to enable significant cost reductions. Furthermore, market growth will also be dependent on the level of political commitment in key lead markets. Without support, floating wind power could be limited to niche applications, struggling to compete in auctions with more mature competitive technologies [3].
- Key challenge for the industry is to establish standardization, and to build capacity for manufacturing and assembly that is optimized for floating solutions but that today is not demanded at scale. Building up the supply chain for floating wind is needed as well as huge investments in port infrastructure [42].
- According to [6], big multi-national energy firms from the gas & oil industry, energy utilities and OEMs, which have engaged strongly in both floating foundation design and project development are playing a key role for the FOWT market growth. However, it also creates a pressure on floating wind technology to deliver utility-scale power generation within a relatively short timescale. In this regard, public sector support for full-scale demonstration is seen as critical to reducing the pressure for floating wind to be deployed prematurely on a commercial basis [6].
- Due to the lack of operational floating offshore wind projects there are a lot of uncertainties for the evalution of the cost of a commercial FOWT project. In [1], platform size and weight of floating structures were identified as the most critical challenges which could deliver the greatest cost savings. For significant OPEX savings, concepts for port-side repairs of major components are required to gain an advantage over fixed-bottom wind farms [1].
- For design optimization, detailed match-making and tuning between wind turbine generator and floating substructure will need to be developed to reach most cost-effective solutions, e.g. optimized turbine control systems for FOWT. Therefore turbine costs for floating wind projects could increase [1].
- The installation process for floating wind structures needs to be further refined and optimized [1]. A special challenge is the installation and operation of floating offshore wind farms in deep waters at far-offshore sites, with significantly harsher conditions, more intense wave action and higher winds which can together cause extensive damage [6].
- There is a need to develop optimized solutions for the installation of power cables for FOWT in deep waters using mating cable connections with a floating substructure, as well as implementing an unplugging system that allows to tow back the structures to port for O&M procedures [6].

6 IDENTIFICATION OF RESEARCH OPPORTUNITIES

Regarding the identification of research opportunities, reference is made to the following DNV publications.

A DNV whitepaper published in 2022 has analyzed the below research needs for floating wind turbines:

- High-fidelity flow modelling for floating wind turbines
- Advanced multi-body multi-degree of freedom simulation tools taking aerodynamic and hydrodynamic flow and loads into account. Validation data from full-scale floating offshore wind turbines.
- Control of floating wind turbines
- Better understanding of the consequences of yawing motion. Exploration of novel concepts. Remote sensing of wind and waves for feed-forward contribution to control actions.
- Wind measurements
- At the fundamental level a better understanding of the flow in the marine boundary-layer and above. Understanding of the uncertainties of floating LiDARs used for wind speed and turbulence intensity measurements.
- Extreme wind conditions
- Data and modelling of extreme winds - in particular in connection to tropical cyclones, and the consequences of climate change.
- Wake modelling
- Wake models that take the special floating conditions (multiple degrees of freedom) into account.

[Source: DNV (2022): FLOATING RENEWABLES – Part one: An analysis of research gaps]

At the same time, DNV has published another report specifically focusing on identified research needs related to mooring systems. The following topics are addressed for floating wind:

- Mooring analysis software

  Many existing software programs do not have capability of modelling fully coupled dynamics including floating structures, mooring lines and power generation systems. Mooring analysis software programs are optimized for analysing floating oil and gas installations, and sub-optimal assumptions/simplifications are often made when applying the software to other applications, e.g. FOWT.

- Design for challenging site conditions

  Difficulty in coupled mooring and cable design for challenging environments and water depths:

  - shallow water depths (50-100m) due to more complex wave kinematics and the lack of geometric compliance of mooring lines in storm events,
  - ultra-deepwater (≥ 1000 m) due to additional weight and cost of extremely long mooring lines,
  - challenging seabed conditions including very hard, soft or complex soils, or liquefaction during seismic events.

  Standardization in mooring design types is also more difficult for specific environmental conditions.

- Mooring component/equipment innovation

  Fibre rope with low stiffness (e.g., nylon) presents benefits for shallow water offshore mooring, however further effort is required to address potential integrity issues with fibre rope being in contact with the seabed, floating on the surface between buoys, UV degradation, etc. It is also required that mooring analysis software is able to reflect the fibre rope viscoelastic behaviour.

- Installation

  Lack of cost-effective and efficient (and accurate) installation campaigns without expensive vessels and long installation times considering the large number of units and mooring lines, and lack of tensioning capabilities at the floating wind turbine platform.

  Extreme forces on large mooring lines requiring bigger size mooring equipment and larger/more expensive installation vessel.

- O&M

  How to establish a tailormade integrity management scheme for the entire mooring system.

  Floating wind units are un-manned which may lead to potentially high mobilizations costs and challenges with vessel availability for O&M, e.g., inspection (annual inspection of above-water parts and 5-year inspection of subsea parts), tow-to-port maintenance, etc. For reducing O&M cost and implementting advanced O&M strategies, monitoring systems are a key enabling technology. A risk-based inspection framework is also needed.

[Source: DNV (2022): MOORING SYSTEMS – Floating wind and solar research needs]

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APPENDIX: Relevant standards in the field of (floating) offshore wind energy

	Dynamic Cables	Mooring / Anchoring	Stationkeeping Systems	FOWT / Structures
	Country-specific laws, regulations, authority requirements			
	Project specific requirements, like Design Basis			
Standards	IEC 61892-4 - Mobile and fixed offshore units - Electrical installations - Part 4: Cables	ISO 20438 - Ships and Marine Technology – Offshore mooring chains	ISO 19901-7 - Petroleum and natural gas industries — Specific requirements for offshore structures - Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units	**IEC TS 61400-3-2 - Wind energy generation systems - Part 3-2: Design requirements for floating offshore wind turbines**
	IEC 63026 - Submarine Power cables with Extruded insulation and their accessories for rated voltages from 6kV (Um = 7.2 kV) up to 60 kV (Um = 72.5 kV) – Test methods and requirements.	DNVGL-OS-E301 - Position mooring	ISO 18692 - Fiber ropes for offshore stationkeeping – Polyester	ISO 19904-1 - Petroleum and natural gas industries - Floating Offshore Structures - Part 1: Monohulls, Semi-Submersibles and Spars
	DNVGL-ST-0359 - Subsea power cables for wind turbines	DNVGL-OS-E302 - Offshore mooring chain		**DNVGL-ST-0119 - Design of floating wind turbine structures**
		DNVGL-OS-E304 - Offshore mooring steel wire ropes		
Technical and professional requirements	DNVGL-RP-0360 - Subsea power cables in shallow water	API RP 2I - In-service Inspection of Mooring Hardware for Floating Structures	API RP 2SK - Design and Analysis of Stationkeeping Systems for Floating Structures	API RP 2FPS - Planning, Designing, and Constructing Floating Production Systems
	DNVGL-RP-F401 - Electrical power cables in subsea applications	API RP 2MIM - Mooring Integrity Management	API RP 2SK 4th Edition - An Updated Stationkeeping Standard for the Global Offshore Environment	API RP 2FSIM - Floating Systems Integrity Management
		API RP 2SM - Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring		ABS-82 - Rules for Building and Classing - Floating Production Installations
		API Spec 2F - Mooring chain		ABS - Guide for Building and Classing Floating Offshore Wind Turbines
		ABS-39 - Guide for the Certification of Offshore Mooring Chain		BV-NI 567 - Risk based verification of floating offshore units
		ABS-90 - Guidance Notes on the Application of Fiber Rope for Offshore Mooring		BV-NI 572 DT R02 - Classification and Certification of Floating Offshore Wind Turbines
		ABS-286 - Guidance Notes on Nearshore Position Mooring		DNVGL-SE-0422 - Certification of floating wind turbines
		ABS-292 - Guide for Position Mooring Systems		ClassNK (2012) - Guidelines for Offshore Floating Wind Turbine Structures
		ABS-294 - Guidance Notes on Mooring Integrity Management		
		BV-NR493 - Rules for the classification of mooring systems for permanent and mobile offshore units		
		DNVGL-RP-E304 - Damage assessment of offshore fibre ropes for offshore mooring		

General standards:

API Spec 9A	Wire rope
API RP 2A	Recommended practice for planning, designing and constructing fixed offshore platform-Load and resistance factor design
API SPEC 17E	Specification for subsea umbilicals
IEC 61400-1	Wind energy generation systems - Part 1: Design requirements
IEC 61892 SER	Mobile and fixed offshore units - Electrical installations - ALL PARTS
IEC 61892-2	Part 2: System design
IEC 61892-3	Part 3: Equipment
IEC 61892-5	Part 5: Mobile units
IEC 61892-6	Part 6: Installation
IEC 61892-7	Part 7: Hazardous areas
ISO 19900	Petroleum and natural gas industries — General requirements for offshore structures
ISO 19901	Petroleum and natural gas industries — Specific requirements for offshore structures
ISO 19901-1	Part 1: Metocean design and operating considerations
ISO 19901-2	Part 2: Seismic design procedures and criteria
ISO 19901-3	Part 3: Topsides structure
ISO 19901-4	Part 4: Geotechnical and foundation design considerations
ISO 19901-5	Part 5: Weight control during engineering and construction
ISO 19901-6	Part 6: Marine operations
ISO 19901-8	Part 8: Marine soil investigations
ISO 19901-9	Part 9: Structural integrity management
ISO/DIS 19901-10	Part 10: Marine geophysical investigations
ISO 19903	Petroleum and natural gas industries — Fixed concrete offshore structures
ABS-3	Rules for Conditions of Classification - Offshore Units and Structures
ABS-29	Rules for Building and Classing - Offshore Installations
ABS-115	Guide for Fatigue Assessment of Offshore Structures
ABS-120	Guide for Risk-based Inspection for Floating Offshore Installations
ABS-126	Guide for Buckling and Ultimate Strength Assessment for Offshore Structures
ABS-160	Guide for Building and Classing - Mobile Offshore Units
ABS-231	Guide for Load and Resistance Factor Design (LRFD) Criteria for Offshore Structures
ABS-232	Guide for Buckling and Ultimate Strength Assessment for Offshore Structures (LRFD Version)
ABS-248	Guidance Notes on Design and Installation of Drag Anchors and Plate Anchors
ABS-249	Guidance Notes on Air Gap Analysis for Semi-Submersibles
BV-NI 423	Corrosion Protection of Steel Offshore Units and Installations
BV-NI 432	Certification of fiber ropes for deepwater offshore services
BV-NI 594	Design and construction of offshore concrete structures
BV-NI 631	Certification scheme for Marine Renewable Energy technologies
BV-NR445	Rules for the classification of offshore units
BV-NR494	Rules for the classification of offshore loading and offloading buoys
DNVGL-DS-J102	Design and Manufacture of Wind Turbine Blades, Offshore and Onshore Wind Turbines
DNVGL-GL-IV-1	Guideline for the Certification of Wind Turbines
DNVGL-GL-IV-2	Guideline for the Certification of Offshore Wind Turbines
DNVGL-OS-B101	Metallic materials
DNVGL-OS-C101	Design of offshore steel structures, general - LRFD method
DNVGL-OS-C103	Structural design of column stabilised units
DNVGL-OS-C301	Stability and watertight integrity
DNVGL-OS-C106	Structural design of deep draught floating units - LRFD method
DNVGL-OS-C201	Structural Design of Offshore Units (WSD Method)
DNVGL-OS-C401	Fabrication and testing of offshore structures
DNVGL-OS-D101	Marine and machinery systems and equipment
DNVGL-OS-D201	Electrical installations
DNVGL-OS-E303	Offshore fibre ropes
DNVGL-OS-H101	Marine Operations, General
DNVGL-OS-H102	Marine Operations, Design and Fabrication
DNV-OS-H201	Load Transfer Operations
DNV-OS-H202	Sea Transport Operations
DNV-OS-H203	Transit and positioning of offshore units
DNV-OS-H204	Offshore Installation Operations
DNV-OS-H205	Lifting Operations
DNV-OS-H206	Loadout, Transport, and Installation of Subsea Objects
DNVGL-OS-J101	Design of Offshore Wind Turbine Structures
DNVGL-OS-J102	Design and Manufacture of Wind Turbine Blades, Offshore and Onshore Wind Turbines
DNVGL-OSS-102	Rules for Classification of Floating Production, Storage and Loading Units
DNVGL-OSS-304	Risk Based Verification of Offshore Structures
DNVGL-OSS-901	Project Certification of Offshore Wind Farms
DNVGL-RP-A205	Offshore Classification Projects—Testing and Commissioning
DNVGL-RP-B101	Corrosion Protection of Floating Production and Storage Units
DNVGL-RP-B401	Cathodic protection design
DNVGL-RP-0286	Coupled analysis of floating wind turbines
DNVGL-RP-0416	Corrosion protection for wind turbines
DNVGL-RP-C103	Column-stabilised units
DNVGL-RP-C201	Buckling strength of plated structures
DNVGL-RP-C202	Buckling strength of shells
DNVGL-RP-C203	Fatigue design of offshore steel structures
DNVGL-RP-C204	Design against accidental loads
DNVGL-RP-C205	Environmental conditions and environmental loads
DNVGL-RP-C212	Offshore soil mechanics and geotechnical engineering
DNVGL-RP-C502	Concrete Standard
DNV-RP-E303	Geotechnical Design and Installation of Suction Anchors in Clay
DNVGL-RP-E305	Design, testing and analysis of offshore fibre ropes
DNVGL-RP-F205	Global performance analysis of deepwater floating structures
DNVGL-RP-H103	Modeling and Analysis of Marine Operations
DNVGL-SE-0477	Risk based verification of offshore structures
DNVGL-ST-0126	Support structures for wind turbines
DNVGL-ST-0437	Loads and site conditions for wind turbines
DNVGL-ST-C502	Offshore concrete structures
DNVGL-ST-E273	Portable offshore units
DNVGL-ST-N001	Marine operations and marine warranty
DNVGL-ST-N002	Site specific assessment of mobile offshore units for marine warranty
EN 1090-2	Execution of steel structures and aluminium structures. Technical requirements for steel structures
Eurocode 3	Design of steel structures, e.g. EN 1993-1-6: General rules - Strength and stability of shell structures, EN 1993-1-8: Design of joints
Eurocode 7	Geotechnical design, EN 1997
EN 50160:2007	Voltage characteristics of electricity supplied by public distribution networks
EN 50308:2004	Wind turbines – Protective measures – Requirements for design, operation and maintenance
IEC 61024	Protection of Structures Against Lightning
IEC 61400-21	Wind energy generation systems - Part 21-
IEC 61400-24	Wind energy generation systems - Part 24: Lightning protection
IEC 62305	Lightning protection standard
IMO MODU Code	Code for the construction and equipment of Mobile offshore drilling units
ISO 12944-2	Paints and varnishes — Corrosion protection of steel structures by protective paint systems
ISO 14713:2009	Zinc Coating - Guidelines and recommendations for the protection against corrosion of iron and steel in structures.
ISO 20340: 2009	Paint and varnishes - Performance requirements for protective paint systems for offshore and related structures
ISO 3834: 2006	Quality Requirements for Welding