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D7.1 Preliminary market assessment and development needs

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1 EXECUTIVE SUMMARY

Deliverable D7.1 provides a work-in-progress report for the COREWIND project on preliminary market assessment and development needs. A review of the current state of existing standards and guidelines for FOWT and other offshore activities is included in the present report. As the project is still ongoing, however, an analysis with respect to COREWIND solutions and recommendations for updates to standards will be included only in the final report on market assessment and development needs in deliverable D7.2 in February 2023.

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.

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 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 a FOWT, the technical specification also addresses subsystems such as control and protection mechanisms, internal electrical systems and mechanical systems.

The DNV-GL 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. DNVGL 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 DNVGL-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. DNVGL 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 GL 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.

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 upscaled 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 are identified from a holistic view, considering the following aspects for the realization of an offshore wind farm which is 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.

Serial production of large components and optimized solutions for pre-assembly and safeguard measures for offshore transport were identified as most relevant development needs with regard to manufacturing and pre-assembling.

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 work-in-progress status of COREWIND design practice recommendations is presented in section 4. The documentation is based on the current state as of June 2021, 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 2020, a total of 73.3 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 the 88 MW Hywind Tampen project is currently the only pre-commercial FOWT project, scheduled for commissioning in late 2022. An overview of operational and planned FOWT projects is presented in section 5. Developments for floating offshore wind substructures can be classified in three main concepts: semi-submersible, spar-buoy and tension leg platform. Currently, there are approx. 40 different FOWT concepts at various stages of development.

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.

Finally, a review of country-specific frameworks in main global FOWT markets in Europe, Asia and America and an overview of opportunities and threads for floating offshore wind deployment are presented in the report.

Main opportunities were identified 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.
- 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

Deliverable D7.1 provides a work-in-progress report for the COREWIND project on preliminary market assessment and development needs. It should be noted that some topics could not yet be covered as the project is still ongoing. For this reason, the review of existing standards and guidelines does not include an analysis with respect to COREWIND solutions and recommendations for updates to standards. In addition, it lacks an assessment of market opportunities in terms of monetary value, profitability, and growth potential, as well as a consideration of further research opportunities. The relevant content will be included in the final report on market assessment and development needs in deliverable D7.2 in February 2023.

3 REVIEW OF EXISTING INTERNATIONAL STANDARDS AND GUIDELINES FOR FOWT

In this chapter, 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. As the project is still ongoing, the present review of standards and guidelines does not include an analysis with respect to COREWIND solutions and recommendations for updates to standards. Identification of gaps and challenges related to FOWT standards will be part of the update in report D7.2.

An overview of relevant standards in the field of offshore wind energy is given in the table in the appendix to this report.

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.

However, a quick overview on the main similarities and differences of relevant FOWT guidelines and standards published by classification societies ABS, Bureau Veritas and Class NK is given as well. Furthermore, available information on existing country-specific regulations in main global FOWT markets are presented.

As the work for the COREWIND project is still in progress while this report was prepared, the content of this deliverable is focused on a review of existing standards and guidelines. An analysis with regard to COREWIND solutions and recommendations for updates of standards will be included in the final report on market assessment and development needs in deliverable D7.2 in February 2023.

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 standard IEC TS 61400-3-2:2019 – Wind energy generation systems – Part 3-2: Design requirements for floating offshore wind turbines – is intended to be fully consistent with the requirements of IEC 61400-1:2019, Wind energy generation systems – Part 1: Design requirements and 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.

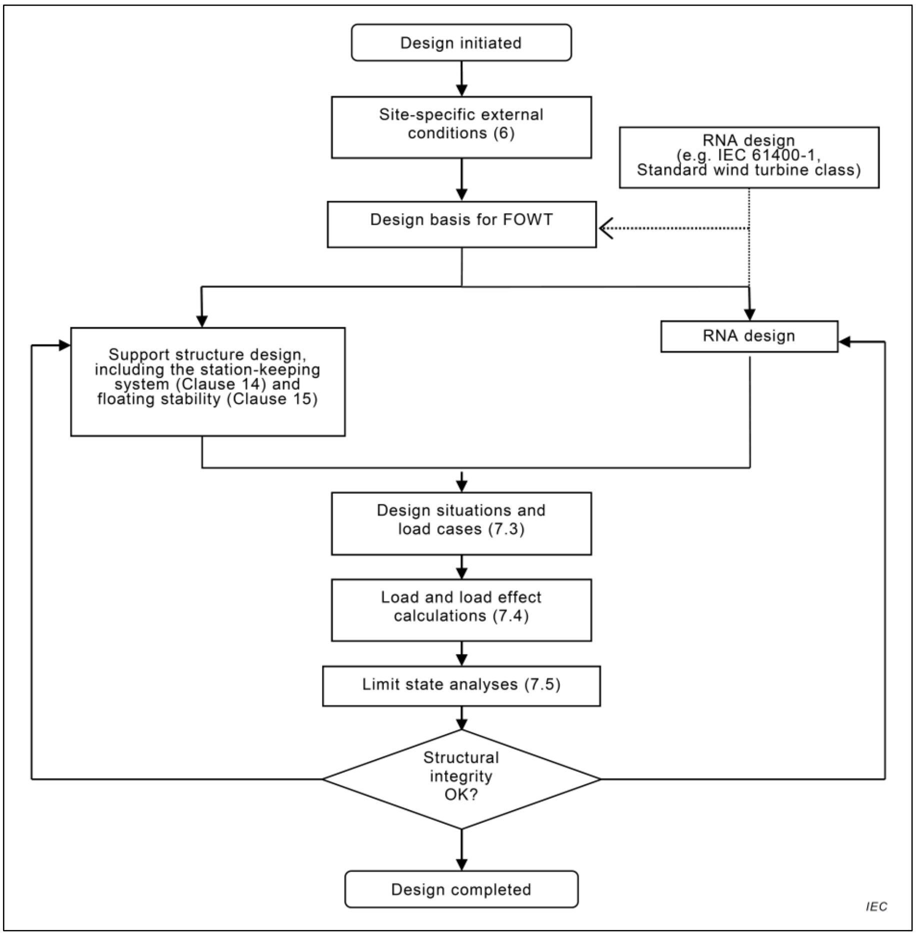


Figure 1: Design process for a floating offshore wind turbine (FOWT) [Source: IEC TS 61400-3-2]

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 DNVGL-ST-0119)
- Nippon Kaiji Kyokai (ClassNK), Guidelines for Offshore Floating Wind Turbine Structures

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 DNVGL-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

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 DNVGL ST-0119 Floating wind turbine structures

The DNV-GL offshore standard ST-0119 (Floating wind turbine structures) provides principles, technical requirements and guidance for design, construction and in-service inspection of support structures and station keeping systems for floating wind turbines. DNVGL ST-0119 supersedes the June 2013 edition of DNV-OS-J103, which was developed by DNV-GL and industry partners in a joint industry project.

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

DNVGL 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.

DNVGL ST-0119 does not cover design of wind turbine components such as nacelle, rotor, generator and gearbox. For structural design of rotor blades DNVGL-ST-0376 (Rotor blades for wind turbines) applies. For structural design of wind turbine components for which no DNV GL 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 DNVGL 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
- corrosion protection
- transport and installation
- in-service inspection
- power cable design

3.2.1 Design principles

According to the safety philosophy in DNVGL 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.

DNVGL-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, DNVGL-ST-0119 also allows design assisted by testing and probability-based design.

In DNVGL-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 DNVGL-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, DNVGL-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, DNVGL-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.

DNVGL-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, DNVGL-ST-0119 refers to specifications and requirements in DNVGL-ST-0126.

3.2.2 Environmental conditions

For guidance on environmental conditions, DNVGL-ST-0119 generally refers to standard DNVGL-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**, DNVGL-ST-0119 gives requirements in addition to DNVGL-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 DNVGL-ST-0119 refers to DNVGL-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 DNVGL-ST-0437.

The extreme operating gust (EOG) specified in DNVGL-ST-0437 for design of fixed-bottom wind turbines and their support structures is based on a duration of 10.5 s. According to DNVGL-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, DNVGL-ST-0119 recommends to use a two-peaked power spectrum model for representation of the power spectral density.

Furthermore, it is stated 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, DNVGL-ST-0119 refers to DNVGL-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, DNVGL-ST-0119 refers to DNVGL-ST-0437 and ISO 19901-2.

Regarding **tsunamis**, DNVGL-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, DNVGL-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 DNVGL-ST-0119, classified as cohesionless and cohesive, respectively. For soil investigations, the requirements and recommendations given in DNVGL-ST-0126 and DNVGL-RPC212 apply. For definition and estimation of characteristic soil properties it is additionally referred to DNVGL-RP-C207.

It is stated in DNVGL-ST-0119 that **marine growth** on structural components in water and in the splash zone shall be accounted for design as specified in DNVGL-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

DNVGL-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.

DNVGL-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, DNVGL-ST-0119 refers to DNVGL-RP-C205 and DNVGL-RPF205.

According to DNVGL-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.

As basis for characteristic loads for use in design, the following load categories are defined in DNVGL-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 DNVGL-ST-0437, floater-specific design load cases listed in DNVGL-ST-0119 shall be considered. Furthermore, an applicable current model shall be included for all load cases in DNVGL-ST-0437, including the ones where no current is specified.

For design against ULS and for ALS, DNVGL-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, DNVGL-ST-0119 refers to the materials section of DNVGL-ST-0126, and for selection of concrete materials to DNVGL-ST-C502 as well. Floating concrete FOWT support structures shall be designed in accordance with DNVGL-ST-0126 together with either DNVGL-ST-C502 or EN 1992-1-1 as the basic design standard.

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

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

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

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

3.2.5 Floating stability

According to DNVGL-ST-0119, sufficient floating stability is an absolute requirement in the intact condition, for the operational phase as well as for any temporary phases. The floating structure shall also be capable of maintaining stability during standstill of the wind turbine in severe storm conditions. During extreme environmental conditions and during normal operation of the FOWT, sufficient floating stability is not required for unmanned floating wind turbine units in the damaged condition, but it should be considered as an option.

For floating stability DNVGL-ST-0119 requires to meet the following service modes as deemed applicable for the unit or concept in question:

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

Specific requirements for intact stability as well as damaged stability, are defined for different floaters, i.e. barge, semi-submersible, spar and tension leg platforms.

3.2.6 Control system

According to DNVGL-ST-0119, it is a prerequisite that the wind turbine operation and safety are governed by a control and protection system as required by DNVGL-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 DNVGL-ST-0076, for instrumentation and control systems to DNVGL-OS-D202 and for safety shutdown systems to DNVGL-OS-A101.

3.2.7 Transport and installation

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

The requirements for vessel stability in DNVGL-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

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

The following topics are covered in the power cable section of DNVGL-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

DNVGL-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 DNVGL-OS-E301.

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

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

Regarding **in-service inspection and maintenance and monitoring**, DNVGL-ST-0119 states that in general the provisions set forth in DNVGL-ST-0126 shall apply. However, DNVGL-OS-E301 shall apply for anchors, mooring chain and steel tendons, and DNVGL-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 such as the American Bureau of Shipping (ABS), Bureau Veritas (BV) and Class NK offer certification services according to their own standards and guidelines.

In the following, a quick overview on the main similarities and differences 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.

Technical requirements are addressed for the same topics as shown in the IEC and DNVGL guidelines. According to ABS the structural design can be based on LRFD or the WSD method which may yield different levels of safety. Regarding the stationkeeping system reference is made to external standards (API) within the ABS guide for building and classing. In addition to the IEC and DNVGL main standards, ABS is providing guidance on classing of floating wind turbines.

3.3.2 BV Guidance note NI 572 classification and certification of FOWT

The Rule Note NI 572 DT R02 E from January 2019 provided by Bureau Veritas considers technical requirements for certification and also classification (like ABS). The guidance note is focused on the floating structure only providing no guidance on the design of the RNA.

3.3.3 Class NK Guidelines for offshore floating wind turbine structures

The Class NK Guidelines from July 2012 are not presented as detailed as the main standards considered throughout the COREWIND project. It mainly covers technical aspects but also gives 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

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.

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 DNVGL-ST-0126.

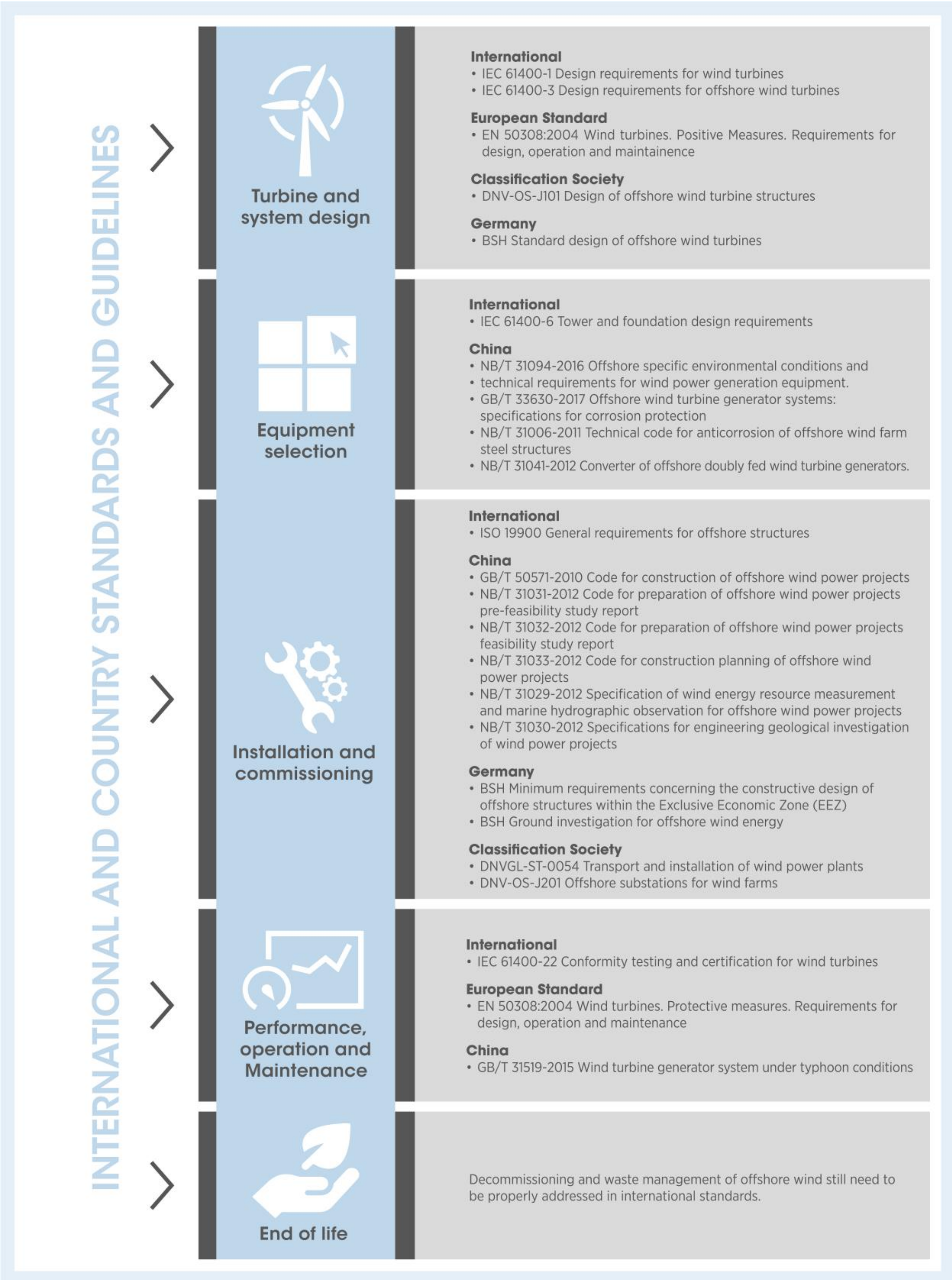


Figure 2: Standards and technical guidelines applicable to the offshore wind value chain [Source: IRENA (2018)]

In the U.S., a guidance for offshore wind projects was published in 2012 by the American Wind Energy Association (AWEA). The Offshore Compliance Recommended Practices (AWEA OCRP) are based on existing standards from International Electrotechnical Commission (IEC), International Organization for Standardization (ISO) and the American Petroleum Institute (API) and guidelines from the American Bureau of Shipping (ABS) and DNV GL.

Currently, the "Offshore Wind Technical Advisory Panel" is working below the AWEA Wind Standards Committee 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. Final publication of recommended practice documents approved by American National Standards Institute (ANSI) is scheduled for December 2021 [22].

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 semisubmersible-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 chapter main challenges with regard to development needs are identified from a holistic view, considering the following aspects for the realization of an offshore wind farm which is 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.

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 three Vestas V164-8.4 MW, commissioned in 2020 at the Windfloat Atlantic 2 project in Portugal. 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 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 optimise 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~~s~~ 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.

The following table gives an overview of the identified development needs for design practice.

	Challenges / development needs
Design practice	
Wind turbine	Upscaling 8 MW --> 15 MW critical DLC control system for FOWT interaction with floater and station keeping system design needs to be more modular
Floater	Few experiences for FOWT operation critical DLC interaction with WT operation risk of wave frequency to resonate with floater eigenfrequency marine growth
Mooring/Anchoring	Few experiences for FOWT operation critical DLC interaction with WT operation marine growth soil conditions redundancy with regard to mooring line damage risk of collisions combined / shared moorings
Dynamic cables	Few experiences for FOWT operation maximum excursion limits bending stress, decoupling from floater motion critical DLC protection on seabed loading at the connection point marine growth (weight in water variation over time)

Table 1: Development needs with regard to design practice of FOWT

4.1.2 Manufacturing & pre-assembling

With regard to manufacturing and pre-assembling of wind turbine, floater, station keeping systems and power cables, the main demands on industry address standardization and the need to establish serial production of large components.

Furthermore, there is a need for development in terms of optimized methods for pre-assembly of the wind turbine and 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.

In order to maximise the available weather window for offshore operations, there is a need for using more advanced tugs and barges as well as better weather monitoring offshore [1].

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

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

By now, 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 the 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 Operation and maintenance

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

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.

Concepts for large component replacements must be optimized.

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-effective methods of unhooking the structure from its mooring and electrical cables, towing it to port, and reversing the process for re-connection [1].

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 the stationkeeping system and the 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, 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.

Serial production of large components and optimized solutions for pre-assembly and safeguard measures for offshore transport were identified as most relevant development needs with regard to manufacturing and pre-assembling.

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.

4.2 COREWIND design practice recommendations

In this section the work-in-progress status of COREWIND design practice recommendations is presented. The documentation is based on the current state as of June 2021, provided from work packages WP1, WP2, WP3 and WP4 of the COREWIND project.

It should be noted that the level of details varies for the different work packages, depending on the status of the progress. The COREWIND design practice recommendations will be updated and specified in more detail for the final report on market assessment and development needs in deliverable D7.2 in February 2023.

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**	
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**	
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**	
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 %**	
Description / relevance for practice: Reduction of tower bending moment and easier installation of rotor-nacelle assembly without large crane vessels			

<table>
<tr><td>1.2.2: Define load cases for the integrated design level for moored/ cabled FOWTs</td><td>Maximum significant wave height during transport and installation</td><td>2.0 m</td><td></td></tr>
<tr><td></td><td>Maximum wind speed (10-min average at 10 m above water) during transport and installation</td><td>12.0 m/s</td><td></td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td>1.2.2: Define load cases for the integrated design level for moored/ cabled FOWTs</td><td>Hydrostatic stability for semi-submersible platform (ActiveFloat)</td><td>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.</td><td></td></tr>
<tr><td></td><td>Hydrostatic stability for spar-buoy platform (WindCrete)</td><td>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</td><td></td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td>1.2.2: Define load cases for the integrated design level for moored/ cabled FOWTs</td><td>Max floater pitch in operation</td><td>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.</td><td></td></tr>
</table>

	Mean (10 min) floater pitch in operation	**5-8 deg** **Subject to load considerations. Fatigue. ULS.**	
	Std (10 min) floater pitch in operation	**Governed by max value of 10 deg and is again really determined by loads.**	
	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).**	
	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).**	
	Max floater yaw in operation	**Governed by production and loads**	
	Std (10 min) floater yaw in operation	**Governed by production and loads**	
	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.**	
	Mean (10 min) floater pitch in idling condition	**Governed by loads**	
	Max floater pitch in emergency stop	**15 deg** **Be aware of transient loads**	
	Acceleration in XY and in Z in operation	**0.30 g** **It is the loads that matters**	
	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**	
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)**	
	Max horizontal offset in parked conditions	**30m (for water depth 100m)** **60m (for water depth 200m)** **104m (for water depth 870m)**	
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)**	
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)**	
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)**	
	Minimum natural period in heave, pitch and roll	**30 s (WindCrete)**	
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)**	
	Hub height	**135 m (WindCrete and ActiveFloat)**	
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)**	
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)**	
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)**	
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**	
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.**	

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 loads 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.			

<table>
<tr><td>2.2: Design analysis and optimization of mooring and anchoring system for floating wind turbines (Innovations and breakthroughs)</td><td>Integrated / combined mooring dynamic cable design</td><td>Combine mooring and dynamic cable optimisation</td><td>In progress</td></tr>
<tr><td colspan="4">Description / relevance for practice

Mooring and dynamic cable design are usually done in parallel by different entities. This leads to lack in the optimisation of the dynamic cable that is design after the mooring system. Performing the design in combination could help to find the most optimised solution for both.</td></tr>
<tr><td>2.2: Design analysis and optimization of mooring and anchoring system for floating wind turbines (Innovations and breakthroughs)</td><td>Optimal mooring</td><td>Optimise the design of fairleads on concrete floaters</td><td>In progress</td></tr>
<tr><td colspan="4">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 reinforcement have to be integrated and optimized.</td></tr>
<tr><td>2.2: Design analysis and optimization of mooring and anchoring system for floating wind turbines (Innovations and breakthroughs)</td><td>Installation techniques</td><td>Optimisation of installation techniques</td><td>Not started</td></tr>
<tr><td colspan="4">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</td></tr>
<tr><td>2.3: Exploration of innovations and breakthroughs of station keeping systems for FOWT</td><td>Technological benefits regarding peak loads reduction</td><td>Optimise the mooring design cost by using peak loads reduction system</td><td>In progress</td></tr>
<tr><td colspan="4">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 system that can help reducing the mooring line tension and thus their size. This might help reducing the cost of mooring systems</td></tr>
</table>

2.3: Exploration of innovations and breakthroughs of station keeping systems for FOWT	**Investigations of solutions for mooring footprint reduction**	**Optimise the mooring footprint**	**Not started**
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**	**Not started**
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.			
2.3: Exploration of innovations and breakthroughs of station keeping systems for FOWT	**Design at farm level: use of shared anchors, shared mooring lines or multiple turbines on a floater**	**Investigate the possibility of sharing anchors and mooring lines**	**Not started**
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.			

4.2.3 Power Cables (WP 3)

COREWIND Task	Component / Topic	Design target	Status
3.2	**Power transmission through dynamic wind farm array**	**Suitable electrical design of dynamic array cables**	**Completed**
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.			

<table>
<tr><td>3.5</td><td>Substation design (static foundation / floating) and philosophy power trans-mission from the windfarm to shore</td><td>Design of suitable export cables (export voltage / static or dynamic cable)</td><td>Not started</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 trans-mission from the windfarm to shore</td><td>Multi-array cable configuration approach to substation</td><td>Not started</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 restrictions. Options will be discussed further within D3.4.</td></tr>
<tr><td>3.2</td><td>Thermal restrictions</td><td>Cable system hardware</td><td>Not started</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td>3.2</td><td>Deeper water depth application (e.g. Site C)</td><td>Qualification testing of cable design</td><td>In progress</td></tr>
<tr><td colspan="4">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.</td></tr>
</table>

3.2	**Marine Growth thickness and weight**	**Dynamic cable system configuration, hardware requirements, and O&M strategy**	**In progress**
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**	**In progress**
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**	**Not started**
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**	**In progress**
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**	**In progress**
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 environment-tal loading occurrences and directiona-lity considerations in conjunction with moored platform motion**	**Appropriate cable fatigue prediction**	**Not started**
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**	**Not started**
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)

<table>
<tr><th>COREWIND Task</th><th>Component / Topic</th><th>Design target</th><th>Status</th></tr>
<tr><td>4.1</td><td>Motion criteria definition</td><td>Enable the assessment for critical motion response of floating substructure</td><td>Not started
(identified as develop-ment need in T4.1)</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td>4.1</td><td>Human Comfort: Increased Vibration dose value during offshore operation</td><td>Avoid critical motion response of floating substructure</td><td>Not started</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td>4.1</td><td>Landing zone for motion compensated gangway</td><td>O&M friendly design: Ease landing of motion compensated gangway on external platform</td><td>Not started</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td>4.1</td><td>Follow-target mode</td><td>O&M friendly design: Standardized optical target to translate relative motions into motion compensation</td><td>Not started</td></tr>
<tr><td colspan="4">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.</td></tr>
</table>

4.1	**Inspection of components**	**Risk-based inspection scheme for floating wind**	**Not started**
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**	**Not started**
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 2020, the global offshore wind market has reached a capacity of 35.3 GW [4], with only three countries accounting for 79% of the installed capacity: the UK (29%), China (28%), and Germany (22%). In 2019 and 2020, just over 6 GW of offshore wind capacity was installed, compared to about 4.4 GW in 2017 and 2018, see Figure 3 [4], [26].

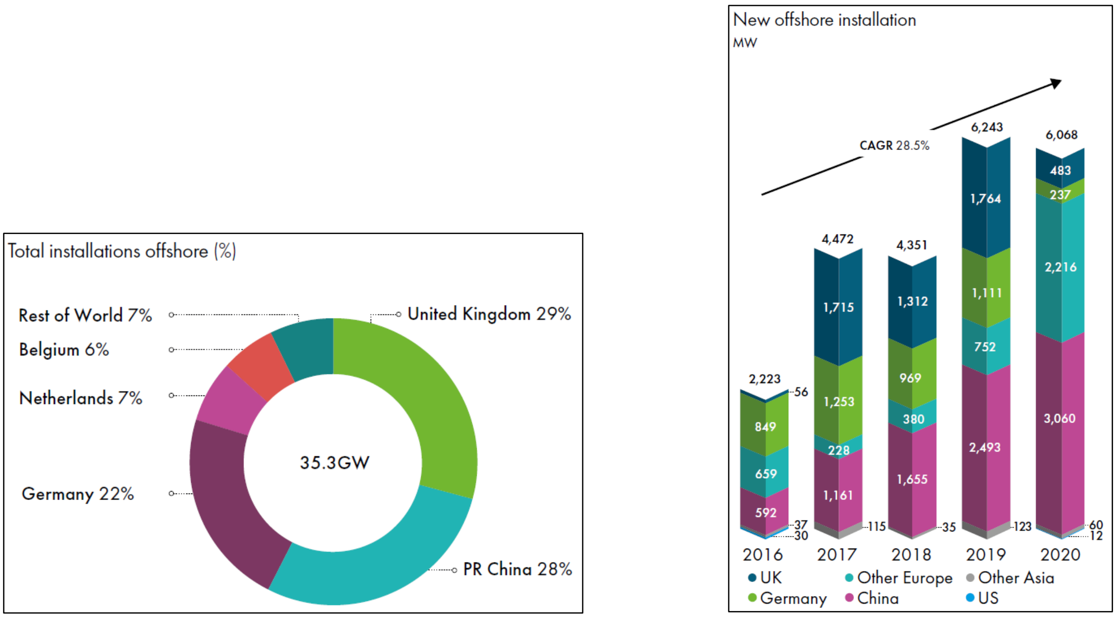


Figure 3: Total global offshore wind installations by end of 2020 and new installations 2016-2020 [Source: GWEC (2021)]

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 10 MW+ offshore wind turbines with a capacity of up to 15 MW. The new generation of 13-15 MW wind turbines is expected to be available from 2024.

In November 2019, GE commissioned the first prototype of the 12 MW Haliade-X-12 MW wind turbine in Rotterdam. In January and February 2020, the first prototypes of the MHI Vestas V174-9.5 MW and the Siemens Gamesa SG 11.0-193 DD Flex were erected in Denmark. The prototypes were built for test operations at land-based sites. In May 2020, Siemens Gamesa released its SG14-222 DD model which can reach 15 MW with Power Boost and will be commercially available from 2024.

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 4 illustrates the common fixed-bottom and floating structure concepts for offshore wind foundations.

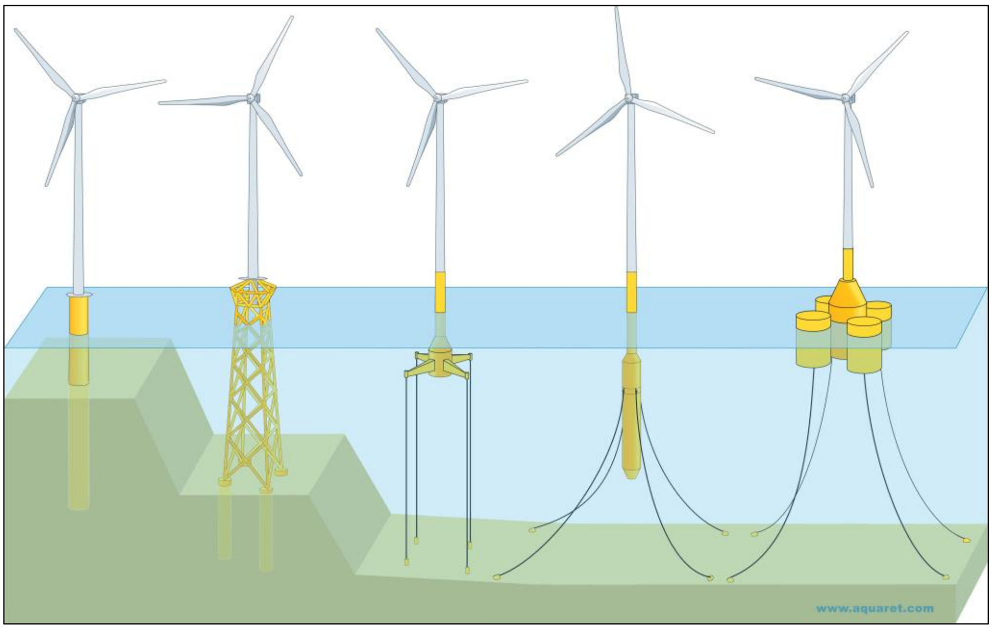


Figure 4: Common fixed-bottom and floating structure concepts for offshore wind turbines. From left to right: monopile – jacket – tension leg platform – spar buoy – semi-submersible platform [Source: www.aquaret.com]

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 2020, a total of 73.3 MW of floating wind capacity was operational worldwide (**¡Error! No se encuentra el origen de la referencia.**).

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 floating offshore wind turbines.

Hywind Tampen, an 88 MW floating offshore wind farm, is currently the only pre-commercial FOWT project. In October 2019, the financial investment decision was taken for the construction of eleven 8 MW FOWT to supply renewable power to offshore oil and gas platforms in the Norwegian North Sea. Commissioning of Hywind Tampen is scheduled for the third quarter of 2022 [9].

Commissioning	Project (Developer)	Country	Water depth	Distance to shore	FOWT	Capacity	Floater concept (Developer)
2009	Hywind Demo / 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 exp.)**	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 exp.)**	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 (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)

** (Year of decommissioning)*

Commissioning *(expected)*	Project (Developer)	Country	Water depth	Distance to shore	FOWT	Capacity	Floater concept (Developer)
2021	Yangxi Shapa III Demo (China Three Gorges (CTG))	China	30 m	28 km	1	6 MW	Semi-Sub (Wison Offshore & Marine)
2021	Kincardine (Pilot Offshore, Cobra)	UK	60-80 m	15 km	5	48 MW	WindFloat (Principle Power)
2021	TetraSpar demonstrator (RWE, Shell, TEPCO, Stiesdal OT)	NO	200 m	10 km	1	4 MW	TetraSpar (Stiesdal OT)
2021	DemoSATH (Saitec, RWE Renewables)	ES	85 m	3 km	1	2 MW	SATH (Saitec)
2022	Hywind Tampen (Equinor)	NO	260-300 m	140 km	11	88 MW	Hywind (Equinor)
2022	FLAGSHIP (Iberdrola, Core-Marine, Cener, IHC)	NO	220 m	10 km	1	10+ MW	OO-Star Wind Floater (Olav Olsen)
2022	PLOCAN P80 wind-wave (Floating Power Plant)	ES	n/a	n/a	1	8 MW	P80 wind-wave energy (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	EolMed - Gruissan (Qair Marine)	FR	55 m	18 km	3	30 MW	Damping Pool (BW IDEOL)
2023	Provence Grand Large (EDF Renouvelables, Enbridge)	FR	100 m	17 km	3	25 MW	TLP (SBM Offshore)
2023	AFLOWT (European Marine Energy Centre)	FR	63 m	5 km	1	6 MW	Hexafloat (SAIPEM)
2023	Aqua Ventus I (Mitsubishi, RWE)	US	n/a	3 km	1	11 MW	VolturnUS (University of Maine)
2023	TwinWay (Hexicon)	NO	n/a	10 km	1	6 MW	Hexicon (Hexicon)
2024	Groix & Belle-Ile (Eolfi, CGN, Caisse de Dépôts)	FR	60 m	14 km	3	28,5 MW	Sea Reed (Naval Energies)

Table 2: Pipeline of operational and 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 4):

- 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 approx. 40 different floating wind concepts at various stages of development. An overview of most advanced floating wind concepts identified by Carbon Trust is shown in Figure 6 which is taken from [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 5: WindFloat semi-submersible floating offshore wind foundations at Windfloat Atlantic 2 (left) [Source: https://www.powermag.com/floating-platforms-are-an-offshore-wind-gamechanger/] and for Kincardine offshore wind farm (right) [Source: https://www.grupocobra.com/en/proyecto/kincardine-offshore-floating-wind-farm /]

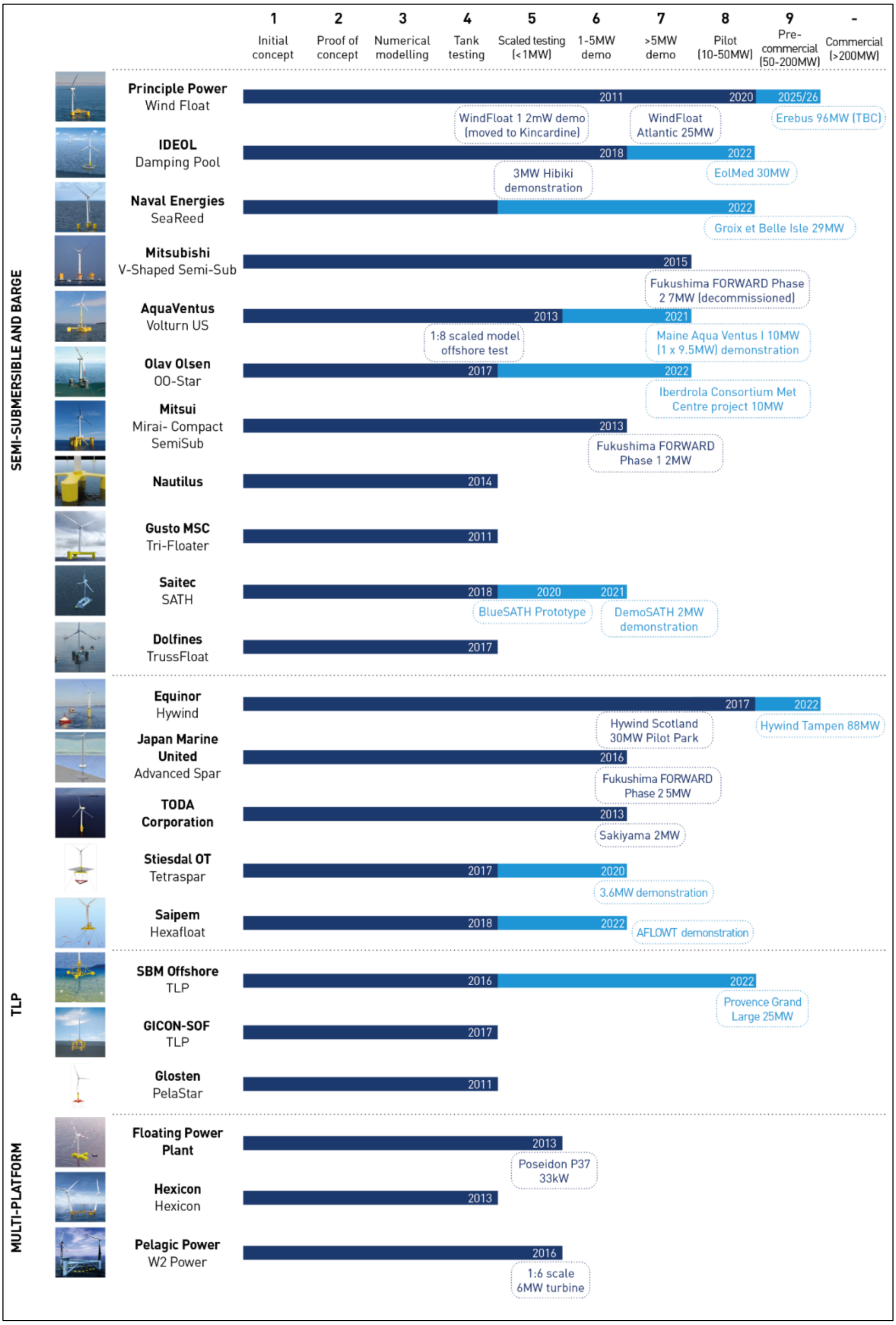


Figure 6: Overview TRL status of advanced concepts for floating wind technology [Source: Carbon Trust (2020)]

Currently, additional five 9.525 MW FOWT with WindFloat floating structures are being built by COBRA Group for the Scottish Kincardine project. Commissioning of the wind farm is expected in summer 2021. Upon completion, the 50 MW project will be the world's largest floating offshore wind project with the most powerful FOWT currently in operation.

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, according to current planning status.

- **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 Centrale Nantes offshore test site, SEM-REV, off the Atlantic coast – the first offshore wind turbine in France, and in the Hibiki 3 MW demo project in Kitakyushu, Japan.

  The 30-MW EolMed project with three Vestas V164-10.0 MW on damping pool floaters is scheduled for installation in 2023. 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].

Figure 7: Ideol's damping pool floating foundation at FloatGen (left) and Hibiki (right) demo projects [Source: BW Ideol]

- **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

- **Yangxi Shapa III Demo**

  In July 2021, Shanghai-headquartered Wison Offshore & Marine has shipped out China's first floating wind foundation platform from its yard in Zhoushan towards its installation site 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 will also be the first in the world to be connected to a fixed-bottom turbine, using a 35 kV dynamic cable [21].

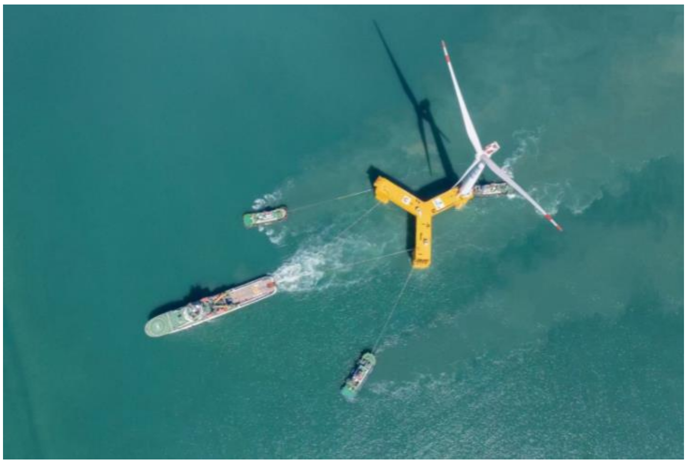


Figure 8: Sail-out of China's first FOWT off the coast of Yangjiang City, July 2021. [Source: MingYang Smart Energy]

- **Tetraspar (Stiesdal OT)**

  The 3.6 MW TetraSpar Demonstrator will start the test period in Q3/2021 at Marine Energy Test Centre 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.

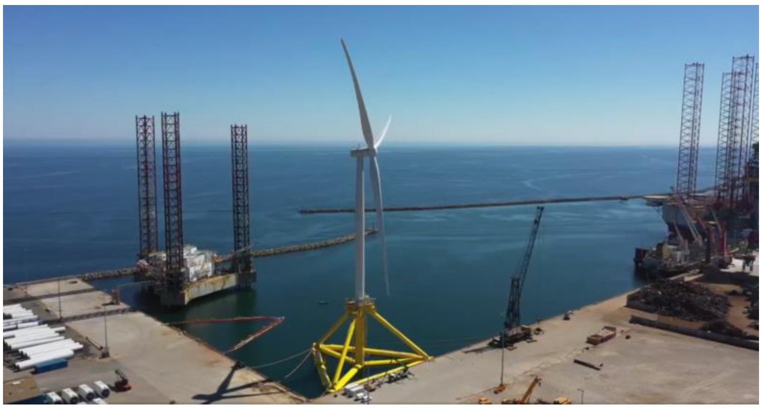


Figure 9: TetraSpar Demonstrator at the Port of Grenaa in Denmark, June 2021 [Source: www.offshorewind.biz/]

- **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 bei 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, which is 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 installed and commissioned at Metcentre outside Karmøy, Norway, by the end of 2022. 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 rane 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 2022. The P80 wind-wave energy platform hosts a single wind turbine ranging from 5 MW to 8 MW 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)**

  Subject to consenting, deployment of a full-scale floating wind turbine on a hexafloat floating structure is 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.

- **SeaReed (Naval Energies)**

  First SeaReed floaters will be used for the 28.5 MW pilot project "Les Eoliennes Flottantes de Groix et Belle Île" in France with three 9.5 MW wind turbines which is scheduled to be operational in 2024. SeaReed is a semi-submersible floater with four columns, one of which is central, connected by metal structures. The floater’s stability is primarily ensured by a ballasting system that allows part of the foundation to be immersed. The design basis of Naval Energies’ SeaReed floaters, applicable to the Groix & Belle-Ile wind farm, and calculation and design methods applicable to its floaters in general are certified by DNV GL. In June 2021, Saipem announced the signing of an agreement to acquire Naval Energies' floating wind turbine business, consisting in Naval Energies' engineering know-how on floating units, intellectual property rights and and its expertise in modelling and simulation.
  [Source: https://www.saipem.com/en/media/press-releases/2021-06-04/saipem-and-naval-energies-sign-agreement-acquisition-naval-energies].

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 offshore 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, consisting of five 6 MW FOWTs on Hywind floaters.

  As mentioned before, the 88 MW Hywind Tampen project is currently the only pre-commercial FOWT project, scheduled to be commissioned in the third quarter of 2022.

Figure 10: Hywind spar-buoy floaters at Hywind Demo, Norway (left) [Source: Unitech] and Hywind Scotland (right) [Source: Equinor, Øyvind Gravås / Woldcam]

- **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 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. It is highly likely that Toda Corporation's floating hybrid concrete/steel spar structure will be used [18].

Figure 11: 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.

  The ***SWAY*** spar floater concept was developed by Inocean, the founder and partner of the floating Norwegian wind turbine company SWAY. The general continuous spar type floating tower concept is exclusively patented by Sway worldwide both for tension leg moorings and slack moorings. The floating tower is anchored to the seabed with a tension-torsion leg equipped with a passive underwater yaw pivot. In the SWAY concept, the entire tower yaws together with the turbine when the wind changes direction. A first one-fifth scale prototype was commissioned in 2011 off the coast of Bergen, Norway. However, no full-scale MW prototype project has yet been realized on a SWAY spar float.

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 2022. 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 subsea 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 non-rotating. 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 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

To date, no reference FOWT project with a TLP concept is in operation.

Planned prototypes / demonstration projects

- **TLP (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 IFPEN, 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 Metcentre. Hexicon has signed a conditional site exclusivity agreement with a reservation of 6 megawatt [20].

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 general strengths and weaknesses of the different foundation concepts for FOWT is given in Table 3 which is taken from [1]. It should be noted, however, that in most cases the project-specific assessment is determined by the specific site conditions.

Typology	Strengths	Weaknesses
Semi-submersible	✓ Flexible application due to the ability to operate in shallow water depths ✓ Low vessel requirement – only basic tug boats required ✓ Onshore turbine assembly ✓ Amenable to port-side major repairs	× High structural mass to provide sufficient buoyancy and stability × Complex steel structures with many welded joints can be difficult to fabricate × Potentially costly active ballast systems
Spar-buoy	✓ Simple design is amenable to serial fabrication processes ✓ Few moving parts (no active ballast required) ✓ Excellent stability	× Constrained to deep water locations × Offshore turbine assembly requires dynamic positioning vessels and heavy-lift cranes × Large draft limits ability to tow the structure back to port for major repairs
Tension leg platform	✓ Low structural mass ✓ Onshore turbine assembly ✓ Few moving parts (no active ballast required) ✓ Excellent stability	× High loads on the mooring and anchoring system × Challenging installation process × Bespoke installation barge often required
Multi-turbine platform	✓ Net reduction in structural mass per turbine ✓ Platform can be used to site auxiliary equipment and facilities	× Wake effects can reduce yield × Large platform could be susceptible to higher bending loads × Large platform can cause fabrication and installation challenges
Hybrid wind/wave	✓ Merging wind and wave technologies can reduce intermittency of supply and increase total power output	× Challenge to integrate two energy generation systems × Increased floater motion can increase turbine loads × High structural mass × Complex O&M

Table 3: Strengths and weaknesses of different foundation concepts for FOWT [Source: Carbon Trust (2015)]

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 [Source: https://www.offshorewind.biz]:

- 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, Falck Renewables, 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 Review of country-specific frameworks in main global FOWT markets

Currently, only the UK, Portugal and Japan have FOWT installations on a significant scale. According to expectations from the Global Wind Energy Council (GWEC), South Korea, France and Norway are likely to become the leading floating offshore wind markets by the end of the decade [4].

Figure 12 shows the long-term forecast of Carbon Trust for global floating wind deployment by regions, with an expected total capacity of around 11 GW by 2030 and 70 GW by 2040. According to this forecast, Japan, South Korea and China (Asia), the U.S. (North America), the U.K. and France (Europe) are the most promising FOWT markets, with each estimated to deploy more than 7,000 MW by 2040 [3].

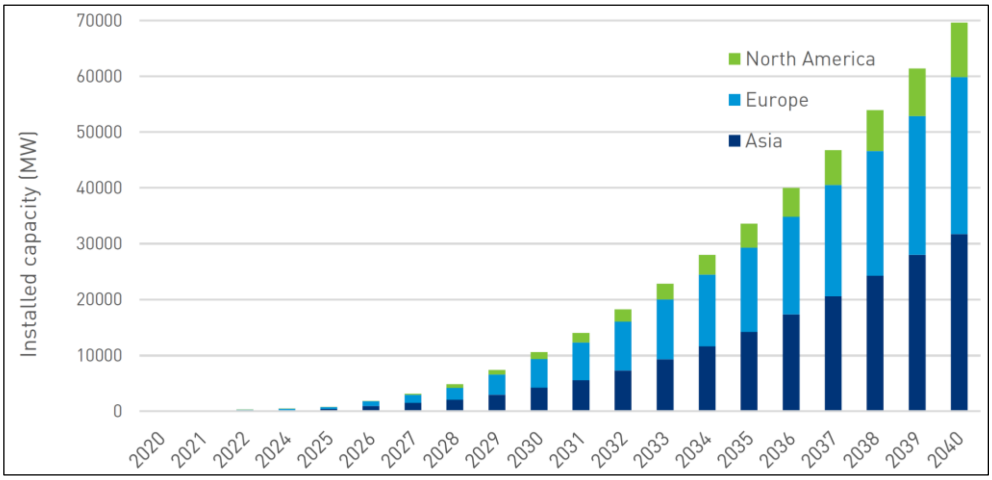


Figure 12: Global floating wind deployment by 2040 [Source: Carbon Trust (2020)]

This section outlines the framework for floating offshore wind farms in key global markets.

5.4.1 Europe

5.4.1.1 France

Background

France will build nearly 900 MW of floating offshore wind in the next decade. This includes demonstrators and the first wave of commercial projects, which are being tendered in 2021 and 2022 and expect to reduce the cost of floating wind to about €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 offshore wind power of 2.4 GW in 2023 and 5.2-6.2 GW in 2028.

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

- The regional wind energy scheme (SRE) whose objective is to define zones favourable to the development 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 landscaped 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

Floatgen is the only floating demonstrator, it has a capacity of 2 MW and it is located in the SEM-REV test site since 2018. The site is operated by the École Centrale de Nantes and the CNSR.

The government has granted four projects for floating wind with a generation capacity of 25 MW each. Eoliennes Flottantes de Groix (28.5 MW), EFGL (30 MW), EolMed (30 MW) and Provence Grand Large (25 MW). The first one is in the Atlantic Ocean between the islands of Groix en Belle-Ile-en-Mer. The rest of the projects are in the Mediterranean Sea, where Port-La-Nouvelle will become installation hub. The four demonstrators were awarded in 2015 and received support of €240/MWh for 20 years. They will be operational by 2022/23.

The government will host three auctions in the next two years for 250 MW each. They have cap prices of €120/MWh and €110/MWh respectively (Figure 13) and a Feed-In-Premium will be granted to the winners. 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.

France will hold 1 GW regular auctions from 2024 onwards but it has not decided yet if they will be for floating or fixed technology. This will be determined based on the auction result of the next three years.

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

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).

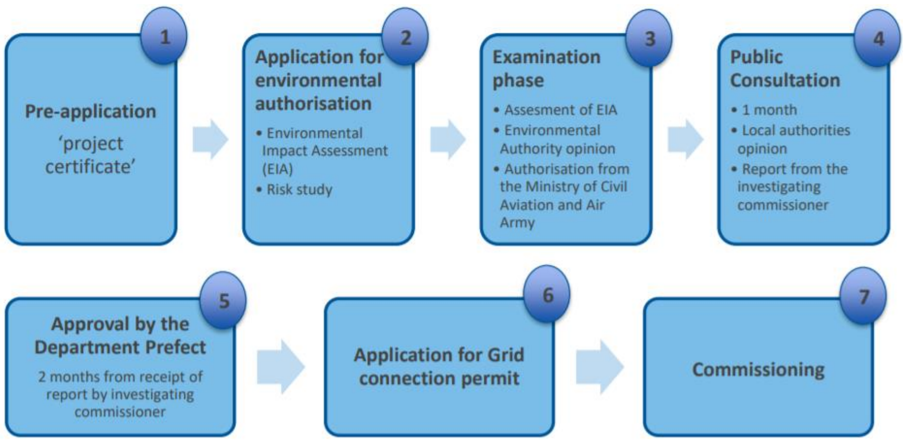
Projects that fall under the Water Act (offshore) follow the "environmental authorisation" procedure. The purpose of this procedure is to gather all the environmental authorisations which are necessary for the project in one single authorisation. The granting of such authorisation also exonerates the 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



5.4.1.2 United Kingdom

Background

The United Kingdom (UK) has committed to deploy at least 1 GW of floating wind as part of the country's plan to build 40 GW of offshore wind by the end of the decade. Although Renewable UK representing the industry called on the government to raise the target to 2 GW.

Floating wind projects and auctions

The UK is home of what it is still today the largest project online, Hywind Scotland. The 30 MW project is online since 2017 and comprises five turbines of 6 MW each. Kincardine is currently under construction and started as a pilot in 2018 with the installation of a 2 MW turbine. Five turbines of 9.5 MW each are being installed.

In summer 2020 seabed rights were granted for the 96 MW Erebus floating wind farm in Wales. According to current plans, construction of the Erebus project is expected to start in 2027.

The UK will lease sites for floating wind and will develop areas in Scotland and England depending on the results from the future rounds.

The Crown Estate has confirmed it will allow floating wind to compete in a separate pot in the current Contracts for Difference (CfDs). The scheme is likely to be available for Round 5 onwards depending on the maturity level of projects competing. This pot will be dedicated to emerging technologies and will have a different strike price to allow the technology to deploy commercially. The Crown Estate is currently determining the rules for the new floating wind lease in the Celtic Sea and is constantly inviting industry members to provide input. Sites leased could be 300 MW.

There are at least two projects in the pipeline of floating offshore wind projects in Scotland. That includes the Pentland project (100 MW) of Dounreay, and Salamander project (200 MW) off Peterhead. The Crown Estate Scotland launched the first offshore wind leasing in a decade. The areas allocated are technology-neutral, but bidders can propose various types of projects – fixed-bottom and floating. ScotWind will lease up to 10 GW or 8,600 km^2 (Figure 15) to be leased in total and is expecting to have floating wind applications. All areas leased correspond to the adopted Maritime Spatial Planning (MSP).

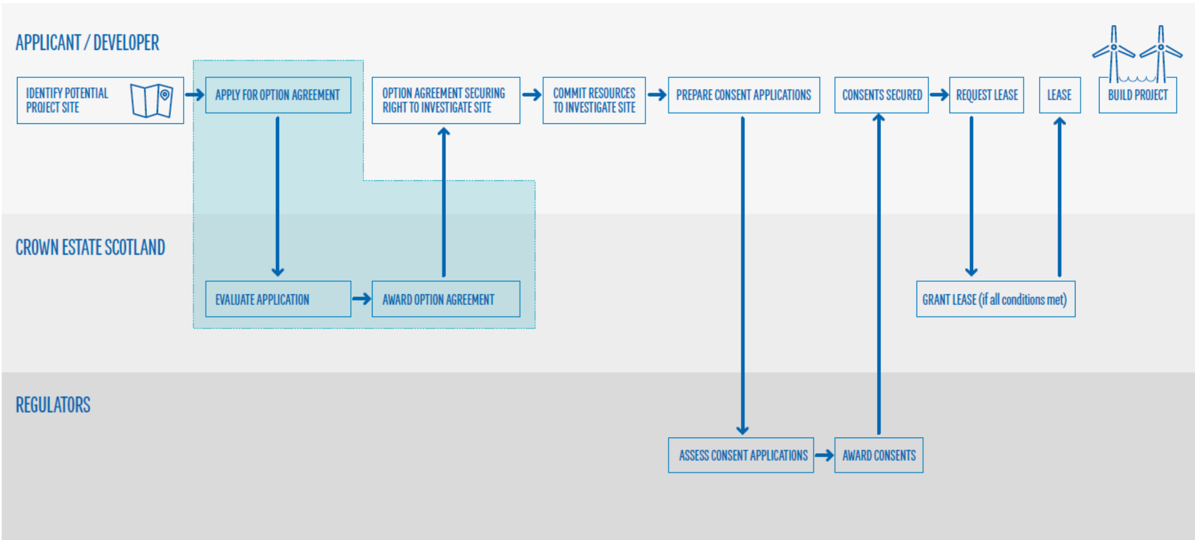


Figure 14: ScotWind Leasing process overview

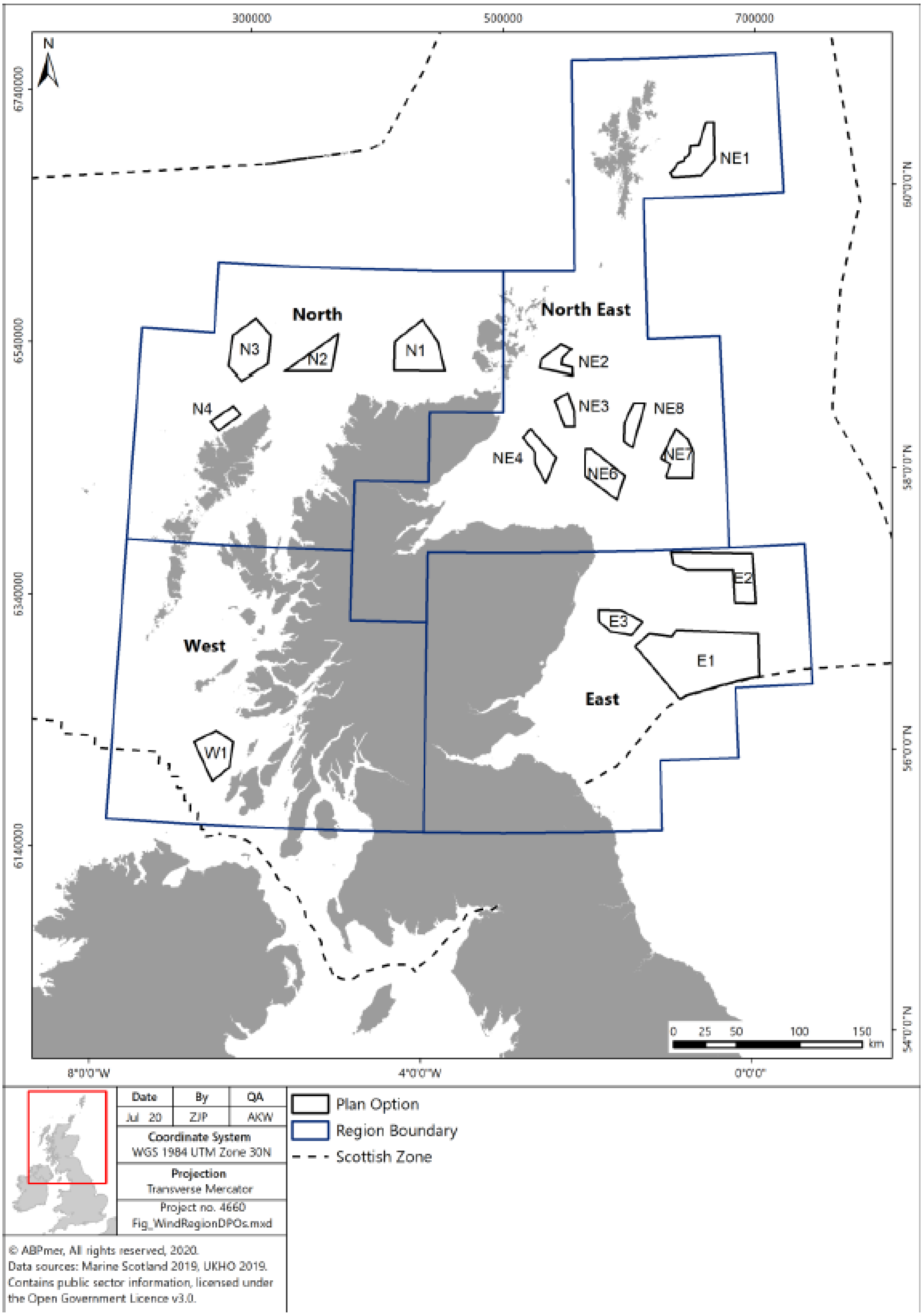


Figure 15: Sectoral Marine Plan Scotland, 2020

Planning requirements and planning authority

In Scotland, licensing is organised by a one-stop-shop model managed by the Marine Scotland Licensing Operations Team. No further details are available regarding the adoption of this system for floating wind.

In England, floating wind will follow the same process for offshore wind but will have a separate strike price under the pot of emerging technologies. Further details and the level of support will be announced later.

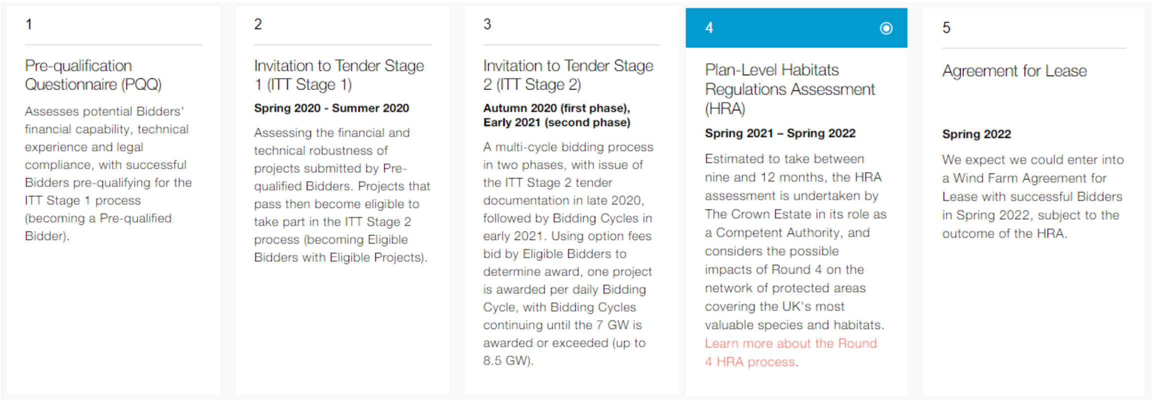


Figure 16: Round 4 leasing process [Source: The Crown Estate (2021)]

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.

5.4.1.3 Norway

Background

Tina Bru, Minister of Petroleum and Energy in Norway announced in June 2021 that Norway will open two areas worth 4.5 GW for the development of offshore wind in Norway, of which up to 1.5 GW will be floating. This is a guideline, not a binding target.

Floating wind projects and auctions

Norway's Hywind demo (2 MW) remains the oldest operational floating project. The turbine is located at the Marine Energy Test Centre (Metcentre), where different demonstration projects will be commissioned in the next two years. The TetraSpar Demonstrator, the Flagship project and the SeaTwirl S2 – they all use different floating concepts that aim at reducing the cost of floating wind technology.

The Hywind Tampen (88 MW) is currently under construction and next year it will become the largest floating offshore wind project in the world. The project features eleven turbines of 8 MW each and will electrify offshore applications.

The areas announced by the government include Utsira Nord and Sørlige Nordsjø II (Figure 17). The first area will develop up to 1.5 GW of floating. The details on the framework for this auction are still under discussion but the government is considering supporting the floating wind area. The area will be divided and auctioned into 3-4 smaller areas and the seabed license will be possibly granted for a 30-year period.

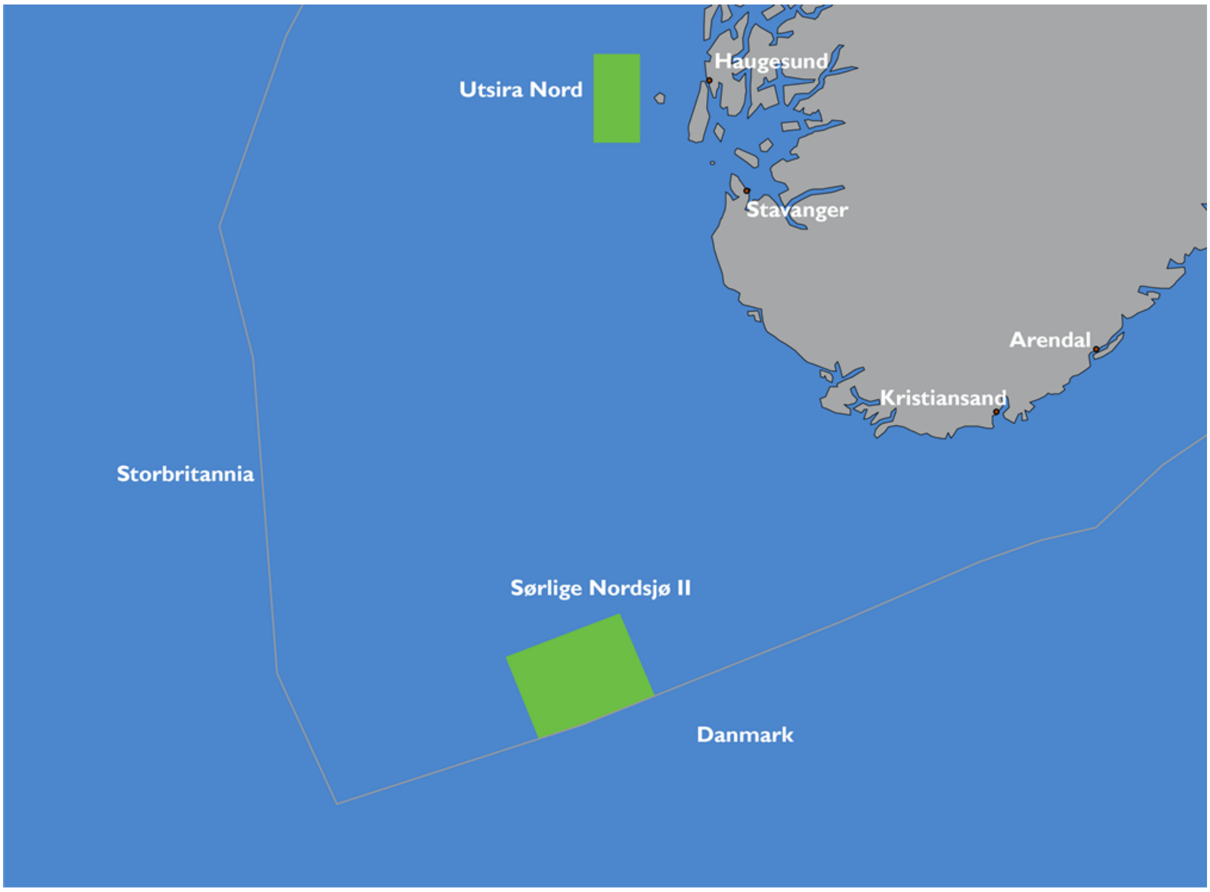


Figure 17: Norway's areas to be auctioned (2021)

Planning requirements and planning authority

The government will provide more details about the permitting process. The Ministry of Petroleum and Energy will be the designated authority for carrying the administrative process and it will resemble a one-stop shop approach.

5.4.1.4 Spain

Background

The government is about to approve the Maritime Spatial Plan (POEM) and has launched its Offshore Wind Roadmap. The draft – currently under consultation until August 6 – proposes a target of 1-3 GW of floating wind in Spain by 2030. Even though the National Energy and Climate Plan does not have a breakdown between onshore and offshore, the Canary Islands Energy Strategy has the goal of developing 310 MW of floating offshore wind by 2025. The Spanish Wind Energy Association is pushing the government to at least 3 GW at sea and mostly floating given the water depth conditions, and to hold a floating wind auction in the Canary Islands next year to reach this target.

Floating wind projects and auctions

The current Maritime Spatial Plan allocates nearly 8,000 km^2 combining both “Priority use” and “High potential” areas. Spain’s MSP is divided into five regions: Nordatántica, Sudatántica, Estrecho y Alborán, Levantino-Balear and Canaria (Figure 18).

Figure 18: Spain marine regions for maritime spatial planning

Spain labelled zones for all uses into two categories:

1. "Zonas de Uso Prioritario (ZUPER)" or priority access: Areas identified to concrete economic activities which will have priority access. The seven sectors that can have access to these are: biodiversity, extraction, cultural heritage, R&I, Defence, Shipping and Wind Energy. ZUPER areas are dedicated to commercial wind farms and will be given priority also for allocating support mechanisms. There are currently 2,316 km^2 which could host 7 GW.

2. "Zonas de Alto Potencial (ZAPER)" or high potential: Areas identified with high potential or interest in certain activity that could be developed in the future. The five sectors that can have access to these are: biodiversity, R&I, Defence, Ports Activity, Aquaculture and Wind Energy. It is unclear whether they could receive support mechanisms from competitive auctions. There are currently 5,569 km^2 which could host an additional 17 GW.

In both cases zones designated to wind energy meet the following conditions:

- Wind speed >7.5m/s at 100m height for peninsular regions and 140m for Canaria,
- Water depth 1,000m at most,
- Minimise overlapping with aquaculture and fishing areas.
- Does not collide with MPAs, Natura 2000, defence, submarine heritage sites nor shipping routes.

Additionally, they have colour coded areas into red (incompatible with wind energy mostly due to biodiversity), yellow (the outcome will depend on an EIA evaluation) and green (wind allowed).

In terms of how much of this could be floating, table gives a breakdown of the two types of areas according to water depth.

Water depth	Priority Use area (km²)	High Potential area (km²)
<100m	9	133
100-200m	990	526
200-500m	299	2,463
500-1000m	873	2,158
>1000m	145	289
TOTAL	**2,316**	**5,569**

Considering today's floating wind technology is cost and technically feasible up to 200m Spain has designated areas that will allow to build 5 GW of floating wind[1].

Planning requirements and planning authority

Spain 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

[1] AEE and industry members have used an energy density of 3 MW/km² to factor the different sub-areas that could be provided in each development area.

5.4.1.5 Other

In **Ireland**, the potential for 27 GW from floating offshore wind within Irish waters has been identified in the government's offshore renewable energy development plan, with 2.9 GW under active development [3]. Deployment of a full-scale FOWT demonstrator on a hexafloat floating structure is 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 within the AFLOWT (Accelerating market uptake of Floating Offshore Wind Technology) project [19].

Portugal has a target of 200 MW of floating by 2030 (National Energy and Climate Plan) of which 25 MW are already in operation with the Windfloat Atlantic. According to the government's Industrial Strategy for Ocean Renewable Energies (EI-ERO), total potential for floating wind is estimated at about 40 GW and exceeds the fixed-bottom offshore wind potential by far [3].

Italy has a target of 900 MW of offshore wind by 2030 (National Energy and Climate Plan). There is no specific breakdown for -on and offshore technology but considering the water depths in the region floating could be used.

Greece has a wind energy target of 7.05 GW by 2030 (National Energy and Climate Plan) without specific breakdown for -on and offshore technology. Currently the country is in an advanced stage for developing an offshore wind framework that will allow to auction, permit, and build new projects. Considering the water depths in the region floating could be used. Developers like Ocean Winds and Terna have expressed public interest in developing together 1.5 GW of offshore wind using floating technology.

5.4.2 Asia

5.4.2.1 South Korea

Background

South Korea wants to install 12 GW of offshore wind capacity by 2030. But offshore wind capacity is only currently about 125 MW, and total offshore and onshore capacity is 2 GW, or about 0.5% of the nation's current power capacity, IHS Markit data show[2].

Due to an abundance of suitable deep-water sites, floating wind technology is expected to be an important segment to reach the ambitious targets for offshore wind in South Korea. To get the ball rolling on floating wind, a group of companies and entities from the city of Ulsan teamed up in May 2021 with President Moon Jae-in to unveil plans for a 100-MW demonstration facility that is expected to turn into 6 GW of capacity by 2030[3].

South Korea announced plans to invest KRW 36 trillion (USD 32.1bn/EUR 26.6bn) in the construction of the world's largest offshore wind park on floating foundations.

The complex will be built by 2030 off the coast of Ulsan City and will have a total capacity of 6 GW. President Moon Jae-in stated that the overall investment will come from both the public and private sectors and that the project will create some 210,000 jobs.

Planning requirements and planning authority

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[4].

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

[2] IHS Markit. South Korean focus on floating wind intensifies (2021). Available at https://ihsmarkit.com/research-analysis/south-korean-focus-on-floating-wind-intensifies.html
[3] Remarks by President Moon Jae-in at Strategy Presentation for Floating Offshore Wind Farm in Ulsan (2021). Available at http://english1.president.go.kr/BriefingSpeeches/Speeches/984

[4] RPS Group. Offshore wind Korea: obtaining a local and international licence to operate (2021).

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[5].

The revised Equator Principles, known as EP4, apply to more financial products, and project financings globally. These Principles require project-related risks to be evaluated against the IFC Performance Standards and not simply the assessment of compliance with domestic laws.

The IFC Performance Standards provide a framework for ensuring sustainable development in emerging economies. From an Environmental and Social Sustainability perspective, they define a developer's responsibility for managing the environmental and social risks and impacts of a project. The standards are designed to help avoid, mitigate, and manage risks and impacts as a way of doing business in a sustainable way. There are eight Performance Standards that the client is to meet throughout the life of an investment:

- Performance Standard 1: Assessment and Management of Environmental and Social Risks and Impacts
- Performance Standard 2: Labour and Working Conditions
- Performance Standard 3: Resource Efficiency and Pollution Prevention
- Performance Standard 4: Community Health, Safety, and Security
- Performance Standard 5: Land Acquisition and Involuntary Resettlement
- Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources
- Performance Standard 7: Indigenous Peoples
- Performance Standard 8: Cultural Heritage

5.4.2.2 Japan

Background

Japan currently has a target of 10 GW installed offshore wind capacity by 2030 and started since 2020 to auction 1 GW of offshore wind capacity a year onwards to meet this target.

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. According to the Japan Wind Power Association the total offshore capacity will comprise 4 GW for floating offshore wind farms [23].

[5] Ibid.

Japan has taken a pioneering role in demonstrating several floating wind concepts in the Fukushima Forward project. 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].

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].

The tenders for auctions 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. It is highly likely that Toda Corporation's floating hybrid concrete/steel spar structure will be used [18].

5.4.2.3 Other

Taiwan is expected to become the second largest offshore wind market in Asia, with more than 7.8 GW of offshore wind capacity in the project pipeline at present and plans to increase this figure to 15.5 GW by 2035. Taiwan has considerable wind resource in deep waters relatively close to shore that are suitable for floating wind technology.

The Ministry of Economic Affairs (MoEA) has announced plans for three offshore wind auctions with a combined capacity of 5 GW by 2023. The auctions are expected to be held in the second quarter of 2021 for a capacity of around 1 GW and in 2022 and 2023 respectively, for 2 GW. The projects selected in the three auction rounds are expected to be commissioned between 2026 and 2030 [24].

In **China**, offshore wind is expected to become the largest market worldwide, which will focus predominantly on fixed-bottom offshore wind farms for their initial projects. However, according to estimations from Carbon Trust, China will likely become also market leader for floating offshore wind as they have in the fixed-bottom offshore wind sector.

In July 2021, China's first demonstrator of a floating wind foundation platform was installed as part of the Yangxi Shapa III offshore wind farm project off the coast of Yangjiang City in Guangdong Province. The unit comprises a 5.5 MW typhoon-resistant wind turbine and a semi-submersible floating foundation [21].

5.4.3 America

5.4.3.1 United States

Background

Currently, most U.S. wind energy facilities are based on land. There is just one commercial offshore wind facility in U.S. waters: the Block Island Wind Farm, located approximately three miles off the coast of Rhode Island. However, a number of other offshore projects have been proposed and are at various stages of the federal permitting process[6].

In late March, President Joe Biden announced an offshore wind goal of 30 GW by 2030 in a manner that protects environmental assets and creates employment[7]. Through a coordinated multi-agency approach, Biden plans to fast track the deployment of utility scale offshore wind.

The Biden administration announced that it will open up parts of the Pacific coast to commercial-scale offshore renewable energy development for the first time. The geography of the West Coast poses huge technical challenges for wind energy. But rising to meet those challenges is a big opportunity to meet the US clean energy goals.

There are two areas now slotted for development off the coast of Central and Northern California — one at Morro Bay and another near Humboldt County. Together, these areas could generate up to 4.6GW of energy, enough power for 1.6 million homes over the next decade, according to a White House fact sheet[8].

Because the outer continental shelf falls away much more quickly into much deeper waters in the Pacific than it does in the Atlantic Ocean, new floating offshore wind technology will be deployed in offshore California waters.

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

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[6] Wind Energy: offshore permitting. Congressional research services. Available at https://fas.org/sgp/crs/misc/R40175.pdf

[7] FACT SHEET: Biden Administration Opens Pacific Coast to New Jobs and Clean Energy Production with Offshore Wind Development. Available at https://www.whitehouse.gov/briefing-room/statements-releases/2021/05/25/fact-sheet-biden-administration-opens-pacific-coast-to-new-jobs-and-clean-energy-production-with-offshore-wind-development/

[8] Ibid.

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 (BOEM), 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[9].

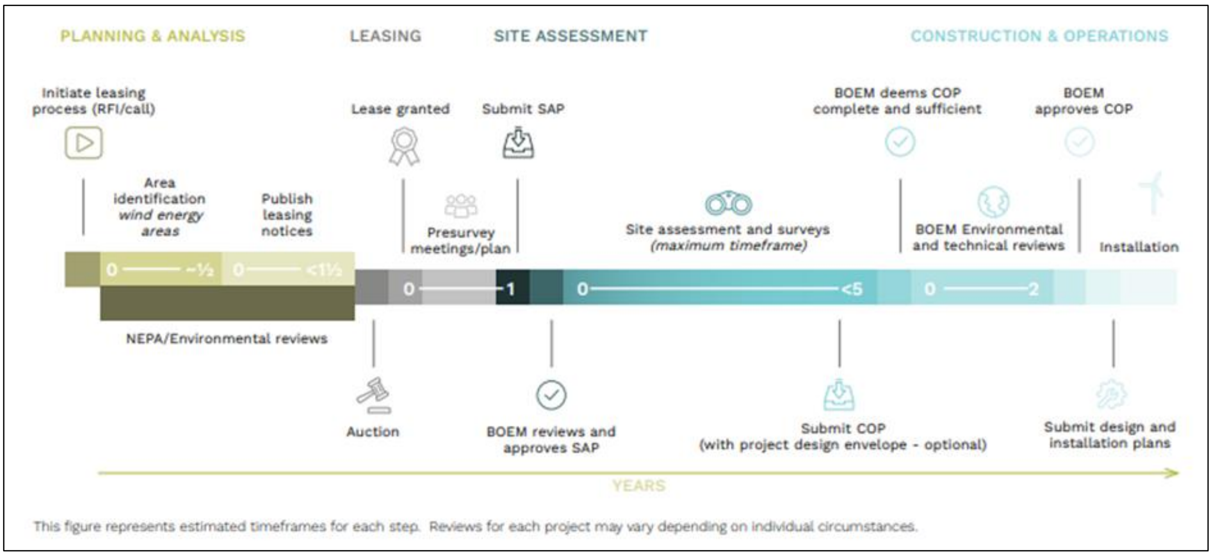

Figure 19: Leasing and permitting process in the us (BOEM)

[9] Ibid.

5.5 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.

As the work for the COREWIND project is still in progress while the report was prepared, this preliminary market assessment does not include an assessment of opportunities in terms of monetary value, profitability and growth. A respective analysis will be included in the final report on market assessment and development needs in deliverable D7.2 in February 2023.

5.5.1 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].
- 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].

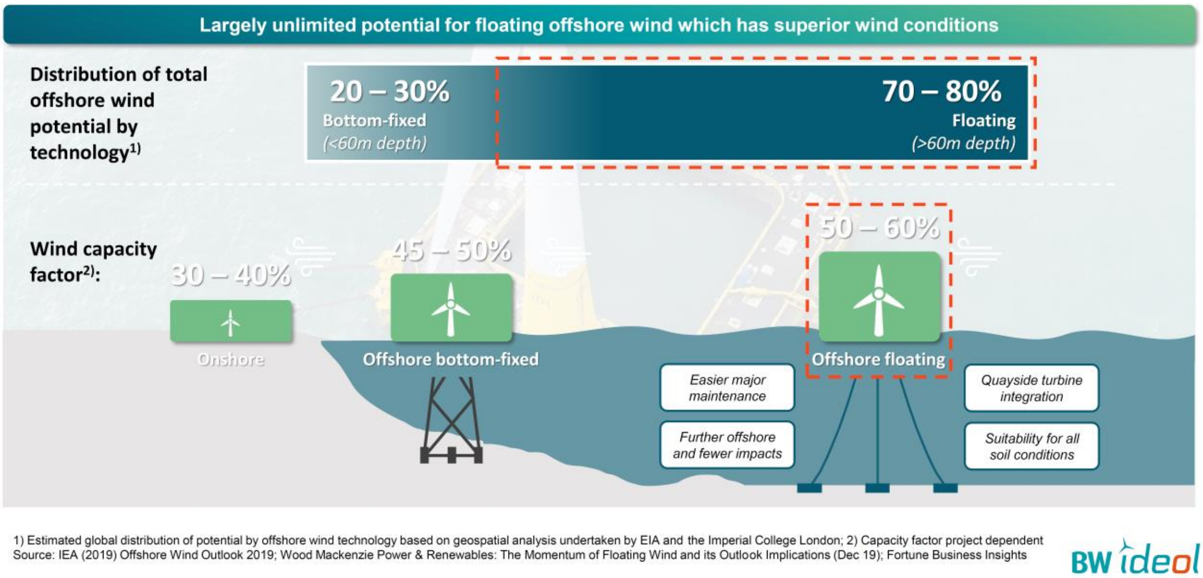

Figure 20: Potential and opportunities for floating offshore wind [Source: BW Ideol company presentation, March 2021]

5.5.2 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].
- 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].
- In terms of FOWT design optimization detailed match-making and tuning between the wind turbine generator and floating substructure will need to be developed to reach the 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 REFERENCES

[1] Carbon Trust (2015): Floating Offshore Wind: Market and Technology Review, June 2015 https://prod-drupal-files.storage.googleapis.com/documents/resource/public/Floating%20Offshore%20Wind%20Market%20Technology%20Review%20-%20REPORT.pdf

[2] Carbon Trust (2018): Floating Wind Joint Industry Project - Phase I Summary Report, May 2018 https://www.carbontrust.com/resources/floating-wind-joint-industry-project-summary-report-phase-1

[3] Carbon Trust (2020): Floating Wind Joint Industry Project - Phase II Summary Report, July 2020 https://www.carbontrust.com/resources/floating-wind-joint-industry-project-phase-2-summary-report

[4] GWEC (2021): Global Wind Report 2020; Global Wind Energy Council, Brussels, 25 March 2021 https://gwec.net/global-wind-report-2021/

[5] DOE (2019): 2018 Offshore Wind Technologies Market Report; U.S. Department of Energy, August 2019 https://www.energy.gov/sites/prod/files/2019/09/f66/2018%20Offshore%20Wind%20Technologies%20Market%20Report.pdf

[6] Hannon, M. Topham, E. MacMillan, D. Dixon, J. Collu, M. (2019): Offshore wind, ready to float? Global and UK trends in the floating offshore wind market; University of Strathclyde, Glasgow, 2019

[7] Irena (2016): Floating Foundations: A game changer for offshore wind power, International Renewable Energy Agency, Abu Dhabi, 2016 https://www.irena.org/publications/2016/Dec/Floating-foundations-A-game-changer-for-offshore-wind

[8] Bureau Veritas (2021): Bureau Veritas's expertise in offshore wind farms reaffirmed with EOLMED project certification; Press release Bureau Veritas, Paris, March 9, 2021

[9] Equinor (2021): Hywind Tampen facts; Equinor website: https://www.equinor.com/en/what-we-do/hywind-tampen.html

[10] Japan for sustainability: News, published on January 16, 2014, website: https://www.japanfs.org/en/news/archives/news_id034598.html

[11] 4C offshore.com (2016): Japanese floater gets relocated, published on April 21, 2016 at: https://www.4coffshore.com/news/japanese-floater-gets-relocated-nid3670.html

[12] ETIP (2020): How floating wind is making Europe climate-neutral; ETIP Wind Fact Sheet, 2020

[13] Offshorewind.biz (2020): 10+ MW Floating Wind Turbine Project Kicks Off, published on Sept. 30, 2020 at: https://www.offshorewind.biz/2020/09/30/10-mw-floating-wind-turbine-project-kicks-off/

[14] The Explorer (2021): Floating offshore wind turbines; https://www.theexplorer.no/solutions/offshore-floating-wind-turbines/

[15] Metcentre (2021): Projects at Marine Energy Test Centre, Norway; https://metcentre.no/projects/

[16] SeaTwirl (2021): SeaTwirl product information; https://seatwirl.com/products/

[17] Offshorewind.biz (2021): Saitec unveils floating wind projet off Bilbao; published on June 18, 2021 at: https://www.offshorewind.biz/2021/06/18/saitec-unveils-floating-wind-project-off-bilbao/

[18] Windpower Monthly (2021): Japan picks winner for first floating offshore wind tender https://www.windpowermonthly.com/article/1718984/japan-picks-winner-first-floating-offshore-wind-tender

[19] Interreg North-West Europe (2019): €31m project secured for floating wind project in North West Europe; published on March 20, 2019 at: https://www.nweurope.eu/projects/project-search/aflowt-accelerating-market-uptake-of-floating-offshore-wind-technology/news/31m-project-secured-for-floating-wind-project-in-north-west-europe/

[20] Hexicon (2021): Hexicon to develop twinway project for floating wind in norway; Company announcement, published on May 10, 2021; https://www.hexicon.eu/mfn_news/hexicon-to-develop-twinway-project-for-floating-wind-in-norway/

[21] Offshorewind.biz (2021): China's first floaing wind turbine installed; published von July 15, 2021 at: https://www.offshorewind.biz/2021/07/15/chinas-first-floating-wind-turbine-installed/

[22] NREL (2019): U.S. Offshore Wind Standards Initiative; Presentation by W. Musial (NREL) on Business Network for Offshore Wind International Partnering Forum 2019 New York, NY April 10, 2019

[23] CMS (2021a): CMS expert guide to renewable energy – Japan; https://cms.law/en/int/expert-guides/cms-expert-guide-to-renewable-energy/japan

[24] CMS (2021b): CMS expert guide to renewable energy – Taiwan; https://cms.law/en/int/expert-guides/cms-expert-guide-to-renewable-energy/taiwan

[25] IRENA (2018): Nurturing offshore wind markets: Good practices for international standardisation, International Renewable Energy Agency, Abu Dhabi.

[26] WindEurope (2021): Offshore wind in Europe - Key trends and statistics 2020; February 2021; Offshore wind in Europe – key trends and statistics 2020 | WindEurope

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