Interreg
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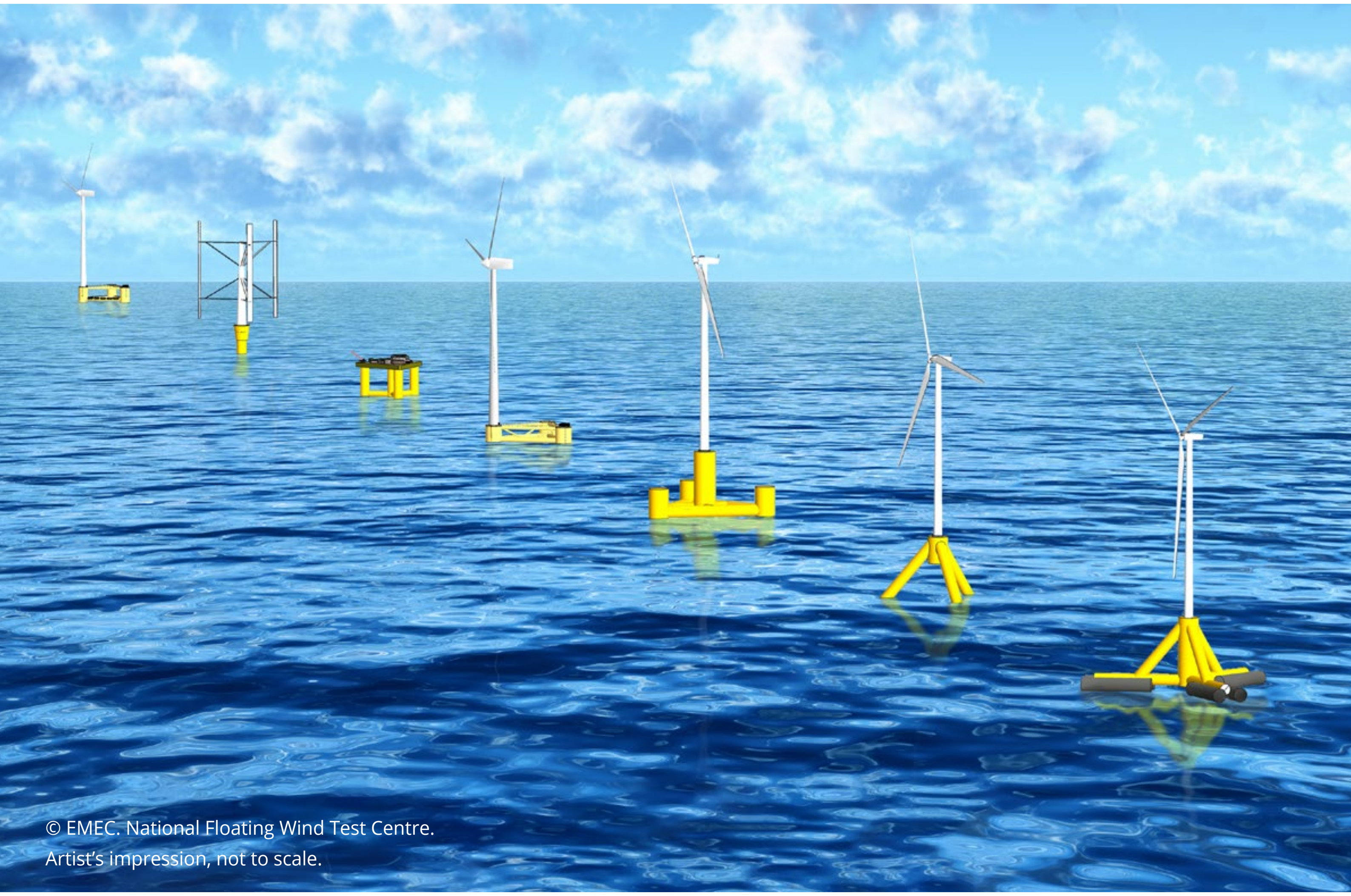
THEMATIC PRIORITY
LOW CARBON

Floating Offshore Wind Development Plan

AFLOWT: Accelerating market uptake of Floating Offshore Wind Technology
Deliverable Long Term Work Package



Artist's impression, not to scale.

Floating Offshore Wind Development Plan

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Disclaimer

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List of Abbreviations

AFLOWT	Accelerating market uptake of FLoating Offshore Wind Technology
AMETS	Atlantic Marine Energy Test Site
APAC	Asia-PACific
AR	Allocation Round
BEIS	Department for Business, Energy & Industrial Strategy
BFOW	Bottom-Fixed Offshore Wind
BiMEP	Biscay Marine Energy Platform
CCC	Climate Change Committee
CCUS	Carbon Capture, Utilisation, and Storage
CEF	Connecting Europe Facility
CfD	Contracts for Difference
CoE	Centre of Excellence
CRI	Commercial Readiness Index
DECC	Department of Environment, Communications, and Climate
DESNZ	Department for Energy Security and Net Zero
DNV	Det Norske Veritas
DOE	Department Of Energy
EC	European Commission
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EMEC	European Marine Energy Centre
EPC	Engineering, Procurement, and Construction
ESB E&MP	Electricity Supply Board Engineering & Major Projects
ETS	Emission Trading System
EU	European Union
EuGB	European Green Bonds
FEED	Front End Engineering Design
FID	Final Investment Decision
Fraunhofer IWES	Fraunhofer Institute for Wind Energy Systems IWES
FOW	Floating Offshore Wind
FOWDP	Floating Offshore Wind Development Plan
FPSO	Floating Production Storage Offloading
FSO	Floating Storage Offloading
GHG	GreenHouse Gas
HSE	Health, Safety, and Environment
HV	High Voltage
IRENA	International Renewable ENergy Agency
LAT	Lowest Astronomical Tide
LCCC	Low Carbon Contracts Company
LCOE	Levelised Cost Of Energy
MARIN	Stichting MAritiem Research Instituut Nederland
METCentre	Marine Energy Test Centre

MPPS	Marine Planning Policy Statement
MRE	Marine Renewable Energy
NDT	Non-Destructive Testing
NIMBY	Not In My Back Yard
NK	Nippon Kaiji Kyokai
NSEC	North Sea Energy Cooperation
NWE	North-West Europe
NZIP	Net Zero Innovation Portfolio
O&M	Operation and Maintenance
ORE	Offshore Renewable Energy
ORESS	Offshore wind Renewable Electricity Support Scheme
PPE	Programmation Pluriannuelle de l'Énergie (Multiannual Energy Programme)
QHSE	Quality, Health, Safety, and Environment
R&D	Research and Development
RCEA	Redwood Coast Energy Authority
RED	Renewable Energy Directive
RESS	Renewable Electricity Support Scheme
ROV	Remotely Operated Vehicle
SCP	Supply Chain Plan
SEAI	Sustainable Energy Authority of Ireland
SIDS	Small Island Developing States
SME	Small and Medium Enterprise
SOV	Service Operation Vessel
TLP	Tension Leg Platform
TRL	Technology Readiness Level
TSO	Transmission System Operator
UCC	University College Cork
UK	United Kingdom
UN	United Nations
WG	Working Group
WP	Work Package

Executive Summary

AFLOWT, short for 'Accelerating market uptake of FLoating Offshore Wind Technology', was an Interreg North-West Europe (NWE) project running from 2019 to 2023. As indicated by the project name, AFLOWT aimed to accelerate the uptake of floating offshore wind (FOW). This was done by creating dedicated test and demonstration facilities to support innovative FOW technologies get to market and demonstrate their survivability and cost-competitiveness. In addition, the 'Long Term' work package supported the overall project objective by addressing the current market obstacles that are apparent in the wide scale market uptake of FOW and taking countermeasures, such as educating project developers and investors on FOW technology maturity and investability, stimulating a favourable policy environment, and developing an active supply chain. These topics were investigated in three working groups with the support of an advisory board.

The main objective of the first working group on technology maturity and investability was the education of project developers and investors. Therefore, it was aimed to identify developer and investor knowledge requirements and critical risk areas in relation to FOW developer engagement. The report demonstrates the specific market opportunity of the AFLOWT project and highlights the significance and role of the test site as a final stage of demonstrating technology maturity. Also, the robustness and reliability of the development process for FOW has been examined. To establish the readiness of FOW farm developers and FOW technology developers, two separate surveys were carefully designed. Their main objectives were to outline risks and challenges associated with the development of FOW technologies and farms, identify potential hurdles and feasible approaches for investing in FOW technologies and farms, assess the FOW developers' and investors' knowledge requirements with respect to open ocean test sites, highlight the critical risk areas in relation to FOW developer engagement and test site experience, and identify alternative approaches to existing test sites. The results are presented in this report.

The second working group focused on developing policy with the objective of creating a favourable policy environment. There are many ways to develop FOW infrastructure across the NWE region. To achieve the environmental targets of the European Union, the policy currently in place in the countries within the NWE region were examined in order to understand the status and determine what needs to be accomplished to encourage and progress FOW in this region. Furthermore, gaps in consenting, funding, and support legislation in NWE were identified and considered. Given the geographical location, NWE has a natural potential for FOW energy. Countries are developing policy for FOW projects by building upon years of experience from bottom-fixed offshore wind turbine infrastructure, grid connection, and a world-leading network of test centres. Policies that allow for fiscal supports, multi-use of sea space, and streamlined transparent application processes can help to accelerate FOW take up.

Finally, the third working group had the focus on the development of an active supply chain in the NWE region, which has some of the strongest wind and ocean resources in the world. The overall objective of the third working group was to ensure maximum economic benefit for the NWE region. The complex and long-lasting development of an active supply chain can be broken down into single steps: At first, critical procurement issues need to be highlighted, then the procurement value of different supply chain segments for the FOW market as well as the opportunities that are available for supply chain companies within the NWE region are to be defined. With further identification of investments that could help bring down the supply chain costs, finally engagement with key stakeholders on these issues should take place. Within the AFLOWT project, a high-level and refined list of potential suppliers in the NWE region were identified for seven commodity groups and corresponding sets of commodity codes. Within the supply chain analysis, gaps and additional development needs were identified, which would help the FOW industry in NWE to compete on international market standards.

1. Introduction

The European Commission (EC) recently ratified a target of 32% of renewable energy by 2030 and signalled further increases in ambition, in association with a target of a 55% reduction of carbon reduction from 1990 levels by 2030 through the 'Fit for 55' ambition [1].

North-West Europe (NWE) needs to decarbonise its energy system. Wind energy is currently the most mature and cost-effective means of renewable energy generation; however, land space and access to the shallow offshore sites (less than 60 m of water depth) are limited. Space for future deployments is a major issue for further increasing wind generation capacity. Floating offshore wind (FOW) will play an instrumental role in NWE achieving its long-term goals for renewable energy production as it opens up vast areas of offshore resources. Over 80% of the offshore wind capacity in the European Union (EU) in waters deeper than 60 m where traditional bottom-fixed offshore wind are currently less likely to be deployed.

The Interreg NWE project AFLOWT, aiming at 'Accelerating market uptake of FLoating Offshore Wind Technology', was designed specifically to help bring this market opportunity to reality, working with partners from Germany, France, the Netherlands, the United Kingdom (UK), and Ireland [2]. Widespread market uptake of wind energy in deep water sites requires three key elements:

1. Work with key stakeholders in the partner regions to **support the establishment of a long term marketplace** for FOW to flourish in NWE.

2. Create **floating wind test and demonstration facilities** to support further innovative FOW technologies get to market.

3. Demonstrate the **survivability and cost-competitiveness** of FOW technology.

Thus, the AFLOWT project aimed to provide a comprehensive analysis and detail a structured methodology to accelerate FOW development and deployment in the NWE region. The project was analysing the investability, maturity, and cost-competitiveness of FOW technology for the NWE region, including the Atlantic Ocean. It also focused on identifying and supporting the development of an active supply chain in the NWE region, which has some of the strongest wind and ocean resources in the world. As the FOW industry is in its infancy, the following outcomes will contribute to bringing confidence and certainty to the technology and industry:

- Enhancement of the infrastructure available for the test and demonstration of FOW technologies in NWE to enable FOW project and technology developers to practice deployments, prove new concepts, refine performance, and generally test, demonstrate, de-risk, and certify their technologies in the correct metocean conditions prior to serial production and deployment into commercial-scale FOW projects across the NWE region and elsewhere. This will make use of pre-consented areas with the necessary facilities to reduce the time, cost, and risk for companies to undertake pre-commercial trials. This is brought together across four locations:

1. The development of the Atlantic Marine Energy Test Site (AMETS), off the coast of County Mayo (Ireland), was driven forward by procuring the onshore infrastructure and a floating Lidar buoy.
2. The EMEC National Floating Wind Test Centre off the West coast of Orkney (the UK) was prepared for development, including completion of necessary surveys and a detailed site development plan to unlock the maximum capacity at the site and enable the FOW test and demonstration site to be consented and delivered.
3. The development work on the Mistral Test Site, off the south coast of France, was progressed with site front end engineering design (FEED), test site characterisation, and grid connection procurement contractualisation.
4. The MARIN (Stichting Maritiem Research Instituut Nederland) Offshore Basin was upgraded to accommodate very large wind turbines and enable innovative testing methods, including a wireless measurement system and an open-source floater design for a 20-25 MW wind turbine.

- Creation of a shared political and industry vision for the development of FOW across the entire NWE region.
- Publication of an NWE FOW Development Plan (FOWDP) to coordinate a change in the private sector's perception of FOW's investability while also creating a supportive policy and an active supply chain across the NWE region.
- Demonstration of the investability with at least 20 investors and project developers to raise awareness and promote the uptake of FOW.

This report represents the FOWDP which is an output of the 'Long Term' work package (WP) of the AFLOWT project. This WP will assist in addressing the current market failings that are apparent in the wide scale market uptake of FOW, notably:

- education of project developers and investors on FOW technology maturity and investability,
- stimulation of a favourable policy environment, and
- development of an active supply chain.

This WP was led by the Fraunhofer Institute for Wind Energy Systems IWES (Fraunhofer IWES) as many of the project developers, investors, and supply chain are based in Germany, the Netherlands, and Luxembourg. So having this activity led by a German partner, it is expected that the impact to these areas will be strengthened.

To achieve the WP's objectives, this FOWDP is produced and published to show an agreed vision of future FOW development in NWE. The FOWDP has been created by an advisory board. All project partners together with associate partners from the NWE region formed the advisory board, which was jointly chaired by the Sustainable Energy Authority of Ireland (SEAI) and Fraunhofer IWES. Thus, from the AFLOWT project consortium, these are the following project partners (listed in alphabetical order), of which Fraunhofer IWES and SEAI had a leading role in preparing the FOWDP:

- Electricity Supply Board Engineering & Major Projects (ESB E&MP) from Ireland,
- European Marine Energy Centre (EMEC) from the UK,
- EMEC Ireland from Ireland,
- Febus Optics from France,
- Fraunhofer IWES from Germany,
- Kraken Subsea from France,
- MARIN from the Netherlands,
- OPEN-C from France,
- Saipem from France,
- SEAI from Ireland, and
- University College Cork (UCC) from Ireland.

And the following associate partners were additional members of the advisory board (listed in alphabetical order), who mainly participated in meetings of the advisory board and working groups (WGs), especially for WG 3, and contributed by providing input to surveys and content covered in the WGs:

- Agence régionale Pays de la Loire from France,
- Aquatera from the UK,
- Atlantic Technological University from Ireland,
- BlueWise Marine from Ireland,
- Carbon Trust from the UK,
- Crown Estate Scotland from the UK,
- DP Energy Ireland Limited from Ireland,
- Highlands and Islands Enterprise from the UK,
- Mainstream Renewable Power from Ireland,

- Marine Institute from Ireland,
- Monterey Renewable Fund – KMG SICAV SIF SA from Luxembourg,
- Offshore Renewable Energy (ORE) Catapult from the UK,
- Provinciale Ontwikkelingsmaatschappij West-Vlaanderen from Belgium,
- Steel Inspect GmbH from Germany,
- TKI Wind oop Zee from the Netherlands,
- University of Rostock/Chair for Wind Energy Technology from Germany,
- WEAMEC from France, and
- WindEurope from Belgium.

The FOWDP is based on the results of three WGs:

1 The first WG (cf. Chapter 2) is on the technology maturity and investability with a focus on **education of project developers and investors** on FOW technology maturity and investability.

2 The second WG (cf. Chapter 3) has the objective of **creating a favourable policy environment.**

3 The third WG (cf. Chapter 4) has the focus on **developing an active supply chain.**

The entire work is focused on NWE. This region comprises the following countries, based on the Interreg NWE Programme Area:

- Belgium,
- France,
- Germany,
- Ireland,
- Luxembourg,
- the Netherlands,
- Switzerland, and
- the UK.

This document, i.e. the FOWDP, is specifically intended for use by

- Interreg NWE – setting out new programme content and research needs to be addressed in future proposals,
- AFLOWT advisory board for the 'Long Term' WP,
- Investors – supporting the development of multiple platform designs, and
- FOW platform technology developers.

2. Technology Maturity and Investability

The main objective of WG 1 'Technology Maturity and Investability' is the education of project developers and investors on FOW technology maturity and investability. Thus, WG 1 aimed at identifying developer and investor knowledge requirements and critical risk areas in relation to FOW developer engagement. For the successful realisation of the WG objectives, liaisons and collaborations with other related projects should be established. As well as demonstrating the specific market opportunity of the AFLOWT project and highlighting the significance and role of the test site as a final stage of demonstrating technology maturity, the robustness and reliability of the development process for FOW should be demonstrated.

2.1 Knowledge Requirements

Offshore wind reaches a higher and more consistent speed due to the lack of obstructions which subsequently improves the energy production of the wind turbines. FOW has a high potential and strategic added value, both at an environmental and socioeconomic level, making it one of the renewable energy sources that will play an essential role in reducing CO_2 emissions. Rather than structures being founded on the seabed, FOW turbines are integrated onto floating platforms which are held in position using mooring lines and anchors. This allows FOW farms to be located in deeper water (> 60 m) mostly further from shore where there is much greater wind resource.

The primary requirement for FOW is that the platform on which the turbine is mounted provides a stable base such that power can be efficiently produced due to minimised motions. Furthermore, the following aspects need to be considered among others:

- requirements regarding the wind turbine generator, such as accelerations of the rotor-nacelle assembly;
- requirements regarding the tower, such as tower base ultimate and fatigue (bending) loads;
- requirements regarding the mooring system, such as ultimate and fatigue loads resulting from the platform motions; and
- a lifetime of typically 25 years.

2.1.1 Six Degrees of Motion of a FOW Platform

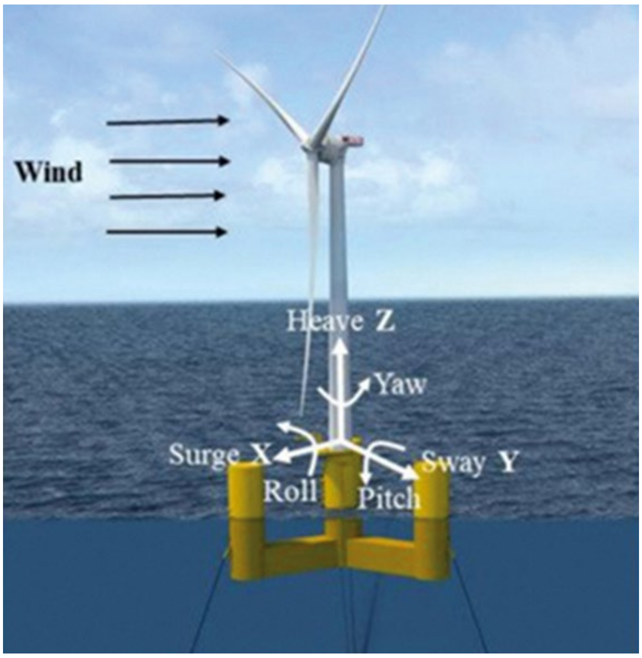
A FOW platform can experience six different types of movements (cf. Figure 1), which are:

1. Surge is the horizontal movement of the platform along its front-to-back axis, which is parallel to the direction of the main wind (and waves).
2. Sway is the horizontal movement of the platform along its side-to-side axis, which is perpendicular to the direction of the main wind (and waves).
3. Heave is the platform's vertical movement due to the waves up-and-down motion.
4. Roll is the rotational movement of the platform

around its longitudinal axis, which is parallel to the direction of the main wind (and waves).

5. Pitch is the rotational movement of the platform around its transverse axis, which is perpendicular to the direction of the main wind (and waves).
6. Yaw is the rotational movement of the platform around its vertical axis, which is perpendicular to the water surface.

Figure 1: Six degrees of motion of a FOW platform [3, p. 3]

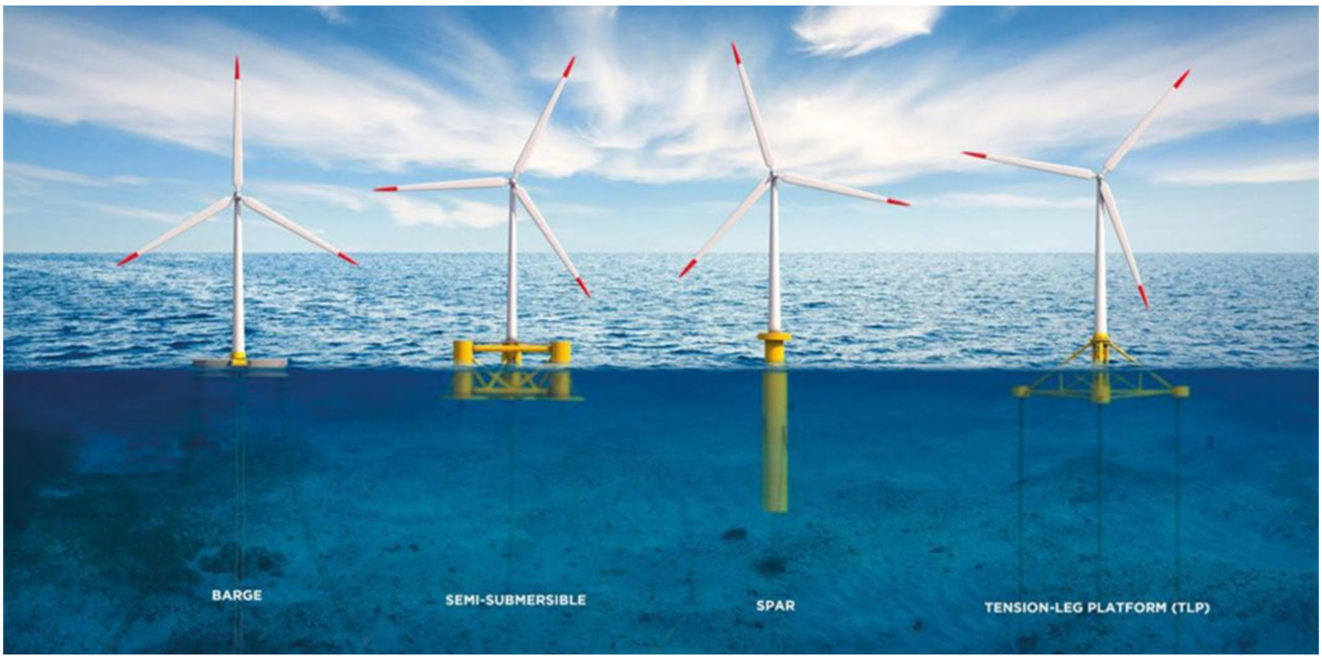


It is important to study the FOW turbine system behaviour in an integrated manner, such that all requirements listed under Section 2.1 can be assessed adequately. Thus, the system's motions affect the position of the hub, which can be over 150 m above sea level. A small angular displacement at the FOW platform level translates into a large linear movement at the structure's highest point, which, if not managed, can damage and diminish the lifetime of the mechanical components located in the nacelle, and can also lead to higher ultimate and fatigue loads experienced by the blades and structure. However, a more compliant FOW platform design, where larger motions are allowed, could reduce tower base loads as the force is turned into inertia rather than structural load. In the end, all structural (ultimate and fatigue) and functional requirements must be met on the FOW turbine system. There may be multiple working solutions depending on the integrated behaviour and, hence, different FOW platform design solutions.

2.1.2 Types of FOW Structures

FOW platforms are the structures on which the wind turbines are mounted and are designed to keep – among others – turbine accelerations, platform pitch angles, offsets and motions (of the floating platform as well as for the mooring system and power cables), tower (base) loads, and air gaps below or within certain threshold levels. There are four main categories of FOW platforms (cf. Figure 2) and most concepts

Figure 2: Four main types of floating offshore wind turbine platforms [4]



developed to date fall into one of these categories:
1. barge-type,
2. semi-submersible,
3. spar-buoy, and
4. tension leg platform (TLP).

Choosing a suitable platform may depend on, among others, metocean conditions at the site, water depth, seabed conditions, depth and proximity of installation harbour, wind turbine size and type (e.g., multiple turbines, downwind or upwind design, two- or three-bladed turbine), costs, manufacturing facilities, and the availability of equipment and materials.

2.1.2.1 Barge-Type Platform

A barge-type platform, as shown in Figure 3, consists of a large flat-bottomed barge similar to that of a ship. The beam and length are significantly larger than the draught and have a very large deck area to carry the wind turbine(s). The structure has a large surface area in contact with the water and achieves stability via distributed buoyancy by taking advantage of the weighted water plane area for righting moment (i.e. buoyancy stabilised) [5]. Conventional catenary anchor chains can be used to moor barge-type platforms.

Barge platforms are relatively simple and inexpensive to construct [8], making them a promising choice for smaller wind turbines and prototype projects. Furthermore, barges are mostly smaller with respect to the outer dimensions compared to a semi-submersible for the same wind turbine [9]. Barge platforms can be deployed in water with depths as shallow as 40 m. Construction can be completed either in dry dock or onshore (cf. Figure 4) and the turbine can be installed onto the platform at the quayside or offshore, both dependent on the wind turbine size. Using conventional tugs, the complete structure is towed out to the installation site.

However, due to the large surface area in contact with the water, barge platforms are quite sensitive to wave loading. Thus, in rougher sea conditions, high heave, roll, and pitch motions may be experienced. To deal with these motion responses, taut spread mooring systems are utilised, or heave plates are fitted below the waterline to minimise movements which are designed to prevent overstressing of the structure. Furthermore, the wind turbine that is to be supported by a barge-type platform might need to be specifically designed for withstanding even large tower motions [9] or the barge-type platform needs to be designed to result in lower motions.

Figure 3: Ideol's barge-type platform installed [6, p. 2]

Figure 4: Ideol's steel floating wind platform ready for tow-out off Japan [7]

2.1.2.2 Semi-Submersible Platform

Semi-submersible platforms are made up of a number of large columns linked together by connecting pontoons (cf. Figure 5) and/or (non-buoyant) braces (cf. Figure 6). The columns provide stability – due to the inertia of the waterplane area – as well as buoyancy. The pontoons are often ballasted (cf. Figure 5), as they would add too much buoyancy, and are mainly structural elements, and hence, could be also replaced by braces. The centre of gravity is above the centre of buoyancy and stability is achieved by the restoring moment of the columns (i.e. buoyancy stabilised) [10]. The mooring system consists of catenary or taut spread mooring lines and drag or suction anchors, which keep the structure in position. The wind turbine can be located at the centre of the floating platform, as in the example in Figure 5, or on top of one column, as shown in Figure 6. More ballast is required to counterbalance the weight of the turbine when it is positioned on top of one column or different column diameters may be used to account for this 'asymmetry'.

Semi-submersible platforms are suitable for a wide range of water depths as shallow as 40 m.

Similar to a barge-type platform, the semi-submersible platform can be constructed onshore or in a dry dock. Depending on the platform and wind turbine size and the capabilities of the yard, the complete turbine may be installed onto the platform at the quayside. The fully assembled system can then be towed out to the site using conventional tugs, avoiding the costly offshore installation.

However, this type of platform is sensitive to waves due to the large waterplane area, but not as high critical wave-induced motions are experienced as with barge-type platforms. Nevertheless, heave plates and/or a geometry designed for wave-cancellation may help reducing the wave-induced motion responses [13]. An active ballast system may improve the system behaviour with respect to its static pitch angles. The weaknesses of requiring more material – at least compared to a TLP – and being quite complex to manufacture can be mitigated by, for example, a braceless design. But still, semi-submersibles represent larger structures in comparison to other concepts, and hence, require considerable space for manufacturing and storage [9].

Figure 5: Elements of a semi-submersible floater [11, p. 8]

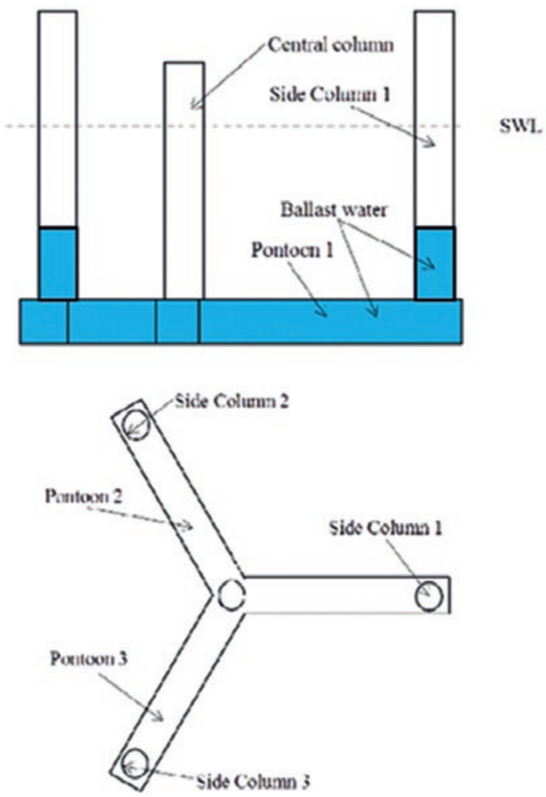
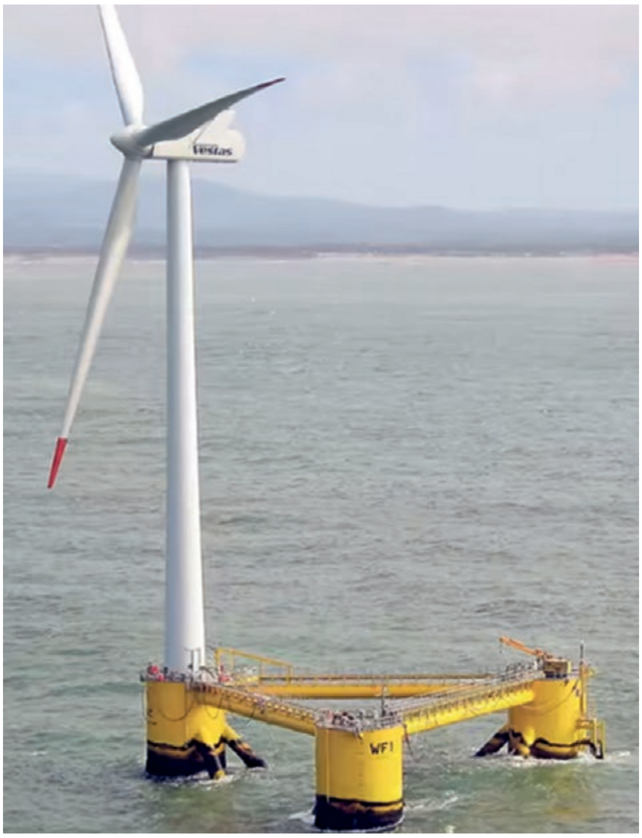


Figure 6: Installed semi-submersible platform [12]



2.1.2.3 Spar-Buoy Platform

Spar-buoy platforms, as shown in Figure 8, are cylinder-shaped structures with a low water plane area. The spar-buoy is ballasted to keep the centre of gravity below the centre of buoyancy, with most of the weight placed at the lowest possible point providing stability. The geometry of the cylinder provides buoyancy and stability is achieved by the weight at the lowest point (i.e. ballast stabilised). The platform is secured in position by catenary or taut spread mooring lines with suction or drag anchors (cf. Figure 7).

A spar-buoy is a relatively simple design and is highly comparable to monopile or tower structures in terms of manufacturing. Due to its quite slender geometry, a spar-buoy has a low sensitivity to wave loading, and hence, might be even suitable for more severe sea states [9, 13].

However, as the platform is so long, it needs to be towed horizontally from the port to a deeper location and upended in sheltered water of sufficient depth. Heavy lift vessels are required to complete these offshore operations and install the turbine. Relatively calm and deep water of more than 100 m are necessary. As turbines become bigger, very long cylinders are required to compensate for the weights, which makes this solution more difficult to manufacture, transport, and install, and limits the deployment to deep water sites.

2.1.2.4 Tension Leg Platform

TLPs normally consist of highly buoyant columns and pontoons (cf. Figure 9 and Figure 10) and can be recognised by their unique mooring system. Tensioned vertical tendons secure the buoyant platform to piled or suction anchors on the seabed and provide stability to the structure (i.e. mooring line stabilised). This phenomenon is known as 'pull down' as the (excess) buoyancy in the platform acts upwards. As TLPs are vertically restricted, they are stiffer in heave, pitch, and roll, and thus less dynamic in their response to waves when compared to other types of platforms. This limits the vertical and rotational motions, but they are still affected by horizontal movements (which, however, are coupled through the tendons to a resulting small heave motion).

Some TLP platforms may be assembled in a drydock with the wind turbine being subsequently fitted at the

Figure 7: Schematic drawing of a spar-buoy platform [14]

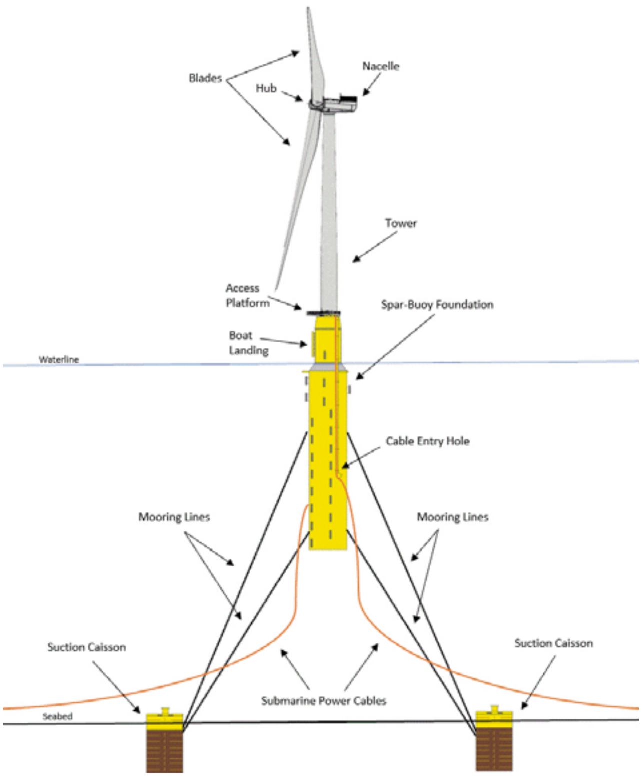


Figure 8: Spar-buoy FOW turbine installed [15]

Figure 9: Components of a tension-leg platform [16, p. 4]

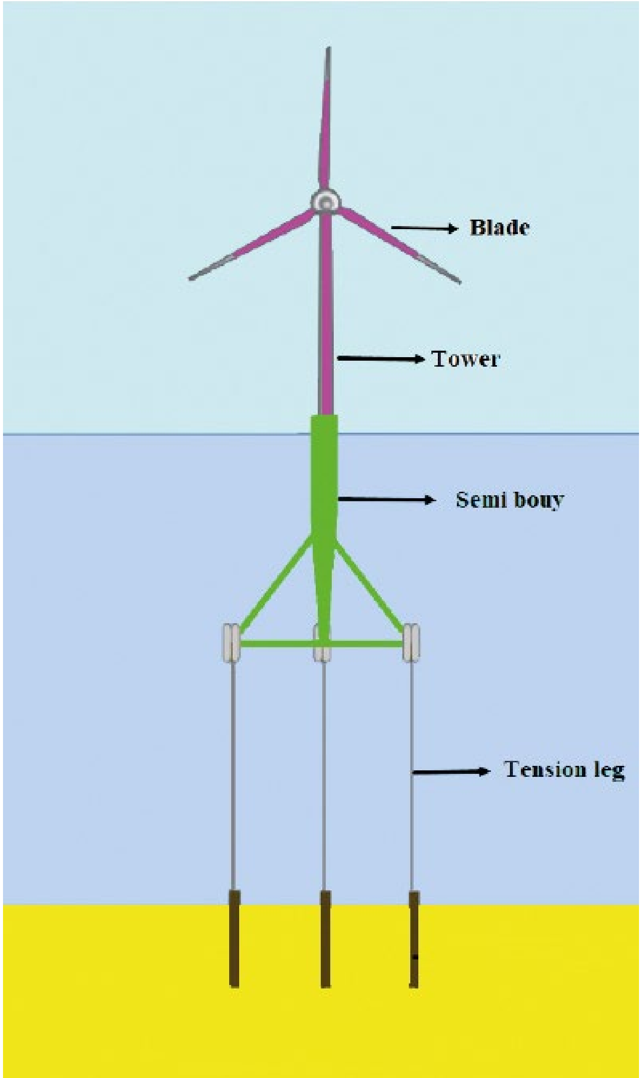
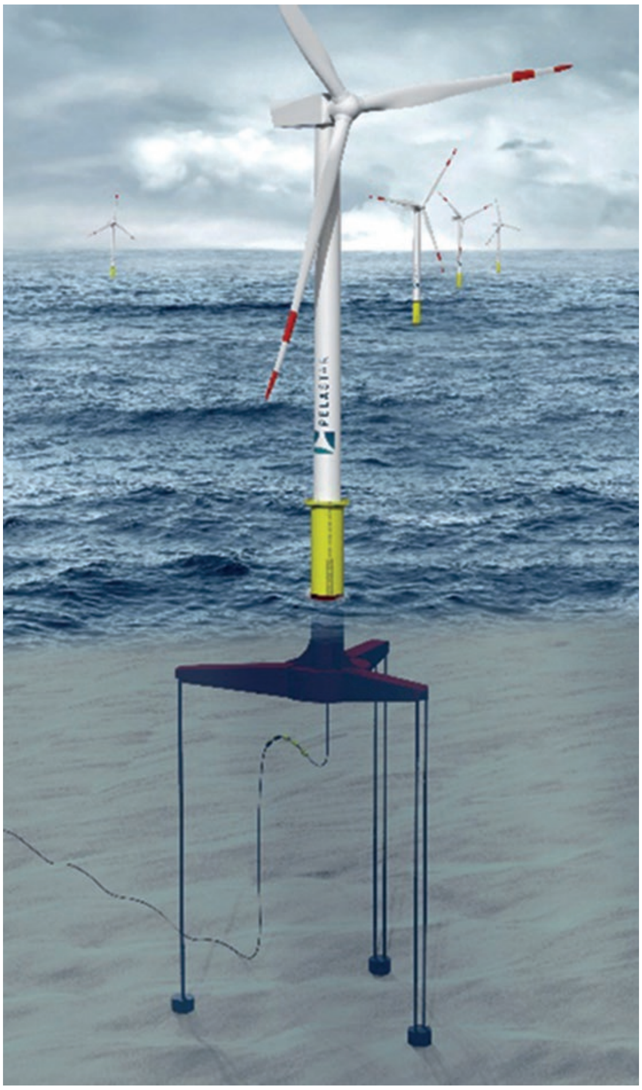


Figure 10: Drawing of an installed tension-leg platform [17]



quayside and the fully assembly system being towed to the installation site with the help of a stabilising system during transport. However, the complex installation process of the (not inherently stable) TLP at the offshore site may even require an offshore assembly of the wind turbine onto the TLP. In both options, special purpose installation vessels are required [13]. TLPs can be installed in a broad range of water depths from as little as 80 m [9]. Its stability advantage allows for lower material costs as a TLP's size can be much smaller than a semi-submersible. Furthermore, TLPs have a small seabed footprint due to the vertical mooring lines [13].

Even if a TLP is a proven concept from the oil and gas industry, it is the newest concept in FOW turbine platform designs, and hence, the maturity and technology readiness level (TRL) in the application of FOW are lower. Due to the high stresses in the tendon design, TLPs are vulnerable to high-frequency dynamic loads (e.g., due to waves or 3P excitations of the wind turbine), which may generate resonant heave and pitch motions resulting in damage to the tendons. TLPs have the most expensive anchoring system in terms of fabrication and installation. They are also difficult to keep stable during transport and installation. For tow out to site in order to maintain stability, temporary reusable floats are secured to the TLP, or a specifically designed installation vessel is used. This allows it to be safely towed to the installation site. Once there, tensioned steel cables or tendons are attached, and the temporary floats are disconnected and reused on the next TLP.

2.1.3 Advantages of FOW Platforms

As bottom-fixed offshore wind (BFOW) turbines are restricted by the depth and complex seabed topography there are many advantages to FOW platforms.

2.1.3.1 Access to Higher Wind Speeds

As wind and weather systems are established over the oceans, they gather momentum. With no obstacles to reduce the speed and frequency of the wind, there is more energy available at sea before it reaches the land.

2.1.3.2 Wider Range of Installation Depths

FOW farms can be installed at depths that BFOW cannot reach for economic or technical reasons. It is technically feasible to install FOW platforms between 60 m and 300 m. Research is underway to extend this range to deeper waters, up to 800 m, and shallower waters of 30 m. Assessing the economic viability will determine the actual range of water FOW can operate within, specifically in locations where seabed conditions pose a risk to installing BFOW turbines.

2.1.3.3 Site Availability

As FOW turbines can operate at much greater depths than BFOW turbines they have a much greater availability in terms of potential sites. At the moment, BFOW turbines are limited to about 60 m depths where FOW can be deployed in up to 800 m [18]. This opens up far more potential sites further offshore, which also reduces the visual impact on coastal views.

2.1.3.4 Fabrication and Assembly

Most of the fabrication and assembly work can be completed in port. Once assembled, the floater is towed to the offshore installation site using conventional tugs. This avoids the use of special installation vessels required for BFOW turbines, such as jack-up vessels. These are expensive and lack of special vessel availability can influence the installation times and costs. The installation of FOW platforms mainly requires relatively standard and cheaper tugboats and cable-laying vessels.

2.1.3.5 Broader Advantages

The development of a FOW industry can create new jobs and stimulate economic growth in regions with suitable wind resources, contributing to a more sustainable energy future. Often these jobs are occupied by people in coastal communities where there may be fewer and a smaller range of opportunities.

By diversifying the energy mix and reducing dependence on imported fossil fuels, FOW technologies can enhance energy security and improve resilience to energy supply disruptions. In the past, countries have had to import much of their energy, however now they can avail of their natural energy resources increasing their energy independence. The importance of energy independence has become even more apparent since the war stated in Ukraine in 2022.

2.1.4 Offshore Wind Turbine Infrastructure

Dynamic offshore cables play a crucial role in the FOW industry by connecting FOW turbines to the electrical grid. The cables are designed to accommodate the movements and stresses caused by the constant motion of floating platforms due to waves, currents, and wind. Unlike traditional BFOW farms where cables are static and buried, dynamic offshore cables are engineered to withstand the unique challenges of floating structures. They need to be flexible and robust to prevent damage or failure, while maintaining a consistent power transmission between the turbines and onshore or offshore substation. To achieve this, dynamic cables often incorporate specialised materials and designs, including armour layers, protective coatings, and specialised connectors [19]. These features help to ensure the cables can endure the harsh marine environment and the dynamic forces exerted on them. Dynamic offshore cables are a critical component that enables the efficient and reliable operation of FOW farms.

Electricity generated by FOW turbines is transmitted to the end customer through a complex network of cables and transmission infrastructure. It needs to be synchronised and transformed to the required voltage at an offshore substation located near the wind farm. This electricity is then transmitted to an onshore substation through underwater cables. Underwater cables are typically made of copper or aluminium and are designed to withstand the harsh conditions of the ocean environment. At the onshore substation, the voltage of the electricity is increased through a transformer which minimises power losses during transmission. The high-voltage electricity is then distributed through a grid network of overhead and underground power lines to a local distribution substation. At the local distribution substation, the voltage is reduced through another transformer, and the electricity is shared with the end customer through a network of power lines and transformers.

2.1.5 FOW Development Process

Typically, renewable electricity projects, whether offshore wind, onshore wind, or solar, go through four main steps:

- planning,
- grid offer,
- route-to-market, and
- construction/delivery.

The associated development stages for an offshore wind farm, including the corresponding timeline, are summarised in Figure 11. It is important to note that the development process can be complex and may involve multiple iterations and adjustments at various stages to account for technical, environmental, and regulatory considerations.

The development process for FOW projects typically involves several key stages. While the specific steps may vary depending on various factors, such as location, regulations, and project scale, the following outline provides a general overview of the process.[1]

2.1.5.1 Early-Stage Assessment

This initial stage involves identifying potential sites for the FOW farm based on factors like wind resource, water depth, proximity to electrical infrastructure, environmental considerations, and regulatory aspects. Project developers conduct preliminary assessments and feasibility studies to evaluate the project's viability.

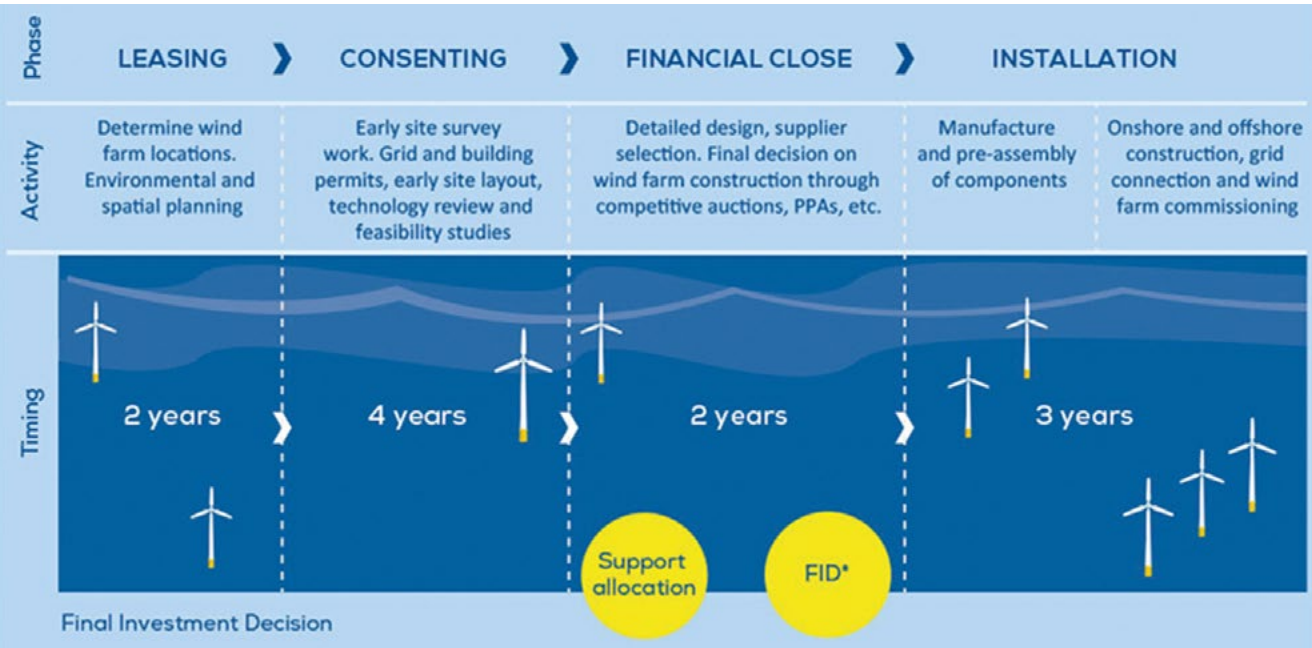
2.1.5.2 Site Characterisation

Once a potential site is identified, developers conduct detailed site assessments and surveys to gather essential data. This may include wind resource assessment, geophysical surveys, bathymetric surveys, seabed analysis, and environmental impact assessments. The data collected helps finalise the project's design and engineering aspects.

2.1.5.3 Technology Selection

FOW farms utilise different floating foundation technologies, such as TLPs, semi-submersibles, spar-buoys, or floating barges. During this stage, developers assess various technology options based on factors like water depth, wave and wind conditions,

Figure 11: Offshore wind farm development stages [20, p. 31]



1 It has to be mentioned that grid development must also happen in tandem as it can take up to eight years for a single grid project. Similarly, infrastructure required to deploy FOW platforms, such as port upgrades, should be developed at suitable times so as to not cause delays. The generic timelines involved for a FOW farm (including the corresponding infrastructure) to pass through the various development steps are summarised in the ten consent steps presented in Table 14 in Section 3.3.2.

installation requirements, and cost considerations. The chosen technology should be suitable for the specific site conditions and provide the required stability and support for the wind turbines.

2.1.5.4 Permitting and Regulatory Approvals
FOW projects require various permits and regulatory approvals. This involves engaging with relevant government agencies, environmental authorities, coastal zone management authorities, and other stakeholders. Environmental impact assessments, public consultations, and stakeholder engagement activities are often conducted to address concerns and ensure regulation compliance.

2.1.5.5 Financing and Project Development
Securing financing is crucial in the project development process. Developers work on securing funding from investors, financial institutions, and other sources. This stage involves conducting financial analysis, risk assessments, and developing a business plan to demonstrate the project's economic viability and return on investment.

2.1.5.6 Design and Engineering
Detailed design and engineering work is carried out based on the chosen technology and site-specific requirements. This includes designing the floating foundations, mooring systems, electrical infrastructure, subsea cables, and other components necessary for the wind farm. Turbine selection, based on factors like capacity, rotor diameter, and manufacturer, is also finalised during this stage.

2.1.5.7 Construction and Installation
Once the necessary permits and financing are in place, the construction and installation phase begins. This involves manufacturing or procuring floating foundations, wind turbines, and other infrastructure components. The onshore electrical infrastructure is also developed, including substations and grid connections. The installation process includes transporting and anchoring the floating foundations, installing the turbines, laying subsea cables, and connecting the turbines to the electrical infrastructure.

2.1.5.8 Testing and Commissioning
After installation, the wind turbines undergo testing and commissioning to ensure their proper functioning and performance. This includes conducting performance tests, grid connection tests, and other technical assessments. The testing phase may also involve verifying the stability and safety of the floating foundations under operational conditions.

2.1.5.9 Operation and Maintenance
Once the wind farm is commissioned and operational, ongoing operation and maintenance activities are carried out. Regular inspections, monitoring, and maintenance are performed to ensure the optimal performance, reliability, and longevity of the wind turbines and other infrastructure components. This includes periodic maintenance, troubleshooting, repair work, and, if required, component replacements.

2.1.6 Key Enablers to Driving Down Cost
While the potential benefits of FOW are undeniable, the industry faces significant challenges, particularly in terms of cost. As with any emerging technology, initial investments and operational expenses are relatively high. However, driving down costs is crucial to ensure FOW's long-term viability and scalability, making it an economically competitive energy source.

It is necessary to explore the key enablers that can effectively contribute to reducing costs in the FOW industry. By examining various technological, operational, and regulatory factors, we seek to identify the critical pathways to achieving cost reduction targets and unlocking the full potential of this renewable energy sector. To speed up the deployment of FOW, key enablers to driving down the cost need to be identified and addressed.

2.1.6.1 Port Infrastructure
European ports require considerable infrastructural upgrades to make them compatible with green deal ambitions and enable a more affordable energy transition. These upgrades include expanding port land, reinforce heavy-loading quaysides, enable deep-sea harbours, and carry out other civil works. To facilitate the effective delivery of EU offshore targets €6.5bn in investment by 2030 is needed. The return on this investment may be as little as five years, and both electricity users and society at large would benefit greatly from the savings [21]. This investment would allow at least 45 ports to have their facilities built or upgraded before 2030 [22]. The infrastructural upgrade plan, including BFOW business, renewable hydrogen production, and energy islands in addition to FOW, is outlined in Figure 12.

This is an example of providing financial backing for the development of port infrastructure as a key

Figure 12: Overview of investment needs and costs for infrastructure works in ports [21, p. 25]

INVESTMENT ITEM	COST PER INVESTMENT	NUMBER OF INVESTMENTS (NO OF PORTS)	TOTAL INVESTMENT
Upgrading/extending facilities for a port already in the bottom-fixed offshore wind business	€20-80 million	30	€1 billion
Building a new energy port/terminal for bottom-fixed offshore wind (around 15-20ha)	€80 - 110 million	15-20[6]	€2 billion
Building a decommissioning facility/ refurbishing an existing facility in the port	€5-10 million	5	€50 million
Floating port adaptations or new terminal	€200 million	6	€1.5 billion
Infrastructure for renewable hydrogen production in ports	€100 million	10	€1 billion
Accommodating energy island operations, products, and related infrastructure	€500 million	2	€1 billion

element in the FOW supply chain, and in supporting the transition of moving from fossil fuels to renewable sources.

2.1.6.2 Stable Policy and Consent Process

Clear and stable policies, including appropriate market incentives and support mechanisms, can drive cost reduction in the industry. Favourable policies that encourage research and development, streamline permitting processes, and provide long-term market visibility can attract investment and reduce uncertainties for project developers. A clear support mechanism improves planning certainty and positively impacts industry investment. Some examples of types of support mechanisms are covered in Section 3.2.1. [22]

2.1.6.3 Standardisation

Developing industry-wide standards and guidelines for FOW systems helps streamline the design, manufacturing, and installation processes. Developing standards involves establishing and implementing a common set of rules, guidelines, and specifications that ensure consistency, interoperability, and quality across this global industry. Technical standards in stationkeeping systems and electrical cable systems ensure performance and safety standards are upheld [23]. These standards protect the integrity of the industry as they prevent accidents. Should an accident occur, an investigation should commence, and the standardisation guidelines need to be adjusted where required to prevent another accident. Standardisation enables the use of mass-produced components which reduces costs and improves overall project efficiency. It aims to promote uniformity and compatibility in FOW industry.

2.1.6.4 Operations and Maintenance Optimisation

FOW maintenance procedures are changing to keep up with the progress of the industry. Bigger turbines and more distant wind farm sites require new equipment and approaches. Given available technology, tow-to-port may be the best case for performing heavy FOW maintenance, such as nacelle or blade replacement. However, this may not be a feasible approach for certain commercial-scale FOW projects, which is why new solutions for onsite maintenance are required. Add-on cranes can be placed on the FOW platforms and perform the major component replacement from the unit, thereby eliminating relative motions between the floater and a vessel crane. In addition to a well-planed heavy maintenance and spare parts strategy, developing strong inspection and monitoring regimes that can enable 'predictive maintenance' will impact positively on the industry. Monitoring technologies remotely with the use of sensors, big data, and digital twins can help projects identify early signs of fatigue or failure. Inspection or maintenance activities can then be scheduled as necessary and around favourable weather conditions. [24]

By addressing these key enablers, the FOW industry can overcome the cost barriers and pave the way for rapid growth and widespread adoption. Through a comprehensive analysis of these enablers, we aim to contribute to the collective knowledge and drive the transition to a cleaner, more sustainable energy future powered by FOW.

2.1.7 FOW Risks

As with any burgeoning industry the risks and challenges involved in FOW must be carefully considered. From technological uncertainties to environmental concerns, the FOW industry needs attention and proactive mitigation strategies to ensure safety and sustainability.

Some of the key risks involved include the following:

- technical risks,
- societal risks,
- political risks,
- supply chain risks,
- economic risks,
- environmental risks, and
- climate change risks.

2.1.7.1 Technical Risks

FOW platforms are subject to harsh environmental conditions, such as high waves, strong currents, and powerful winds. These conditions can cause significant wear and tear on components and increase the likelihood of failure or malfunction. Ensuring stability and precise control of the platform is crucial to maintain the structural integrity of the turbines and maximising the energy production. Mainly due to structural failures and material fatigue, rotor blades on FOW platforms are the components that are most likely to fail, resulting in highest percentage of downtime. The yaw and pitch system, which are used to control the angle of the blades are the most common wind turbine blade problems. Developing reliable and cost-effective mooring systems that secure the FOW platforms in various sea conditions is a significant challenge as well. These systems need to resist corrosion and withstand extreme forces. [25]

To remain competitive and improve energy efficiency, ongoing technological innovation is essential. This includes developing more efficient turbine designs, improving materials, and optimising energy capture.

2.1.7.2 Societal Risks

FOW projects may face opposition from local communities, which could delay or even derail project development. FOW turbines can change the visual landscape of an area, which may have an impact on tourism, recreation, and the aesthetic value of the surrounding environment. Therefore, some people within the coastal community may have concerns about the potential impact a proposed FOW farm will have on coastal scenery and tourism in the area. However, as FOW farms can be installed in deeper water when compared to BFOW, this issue can be alleviated by positioning them further offshore and out of site from the shore. [26]

Public opinion has been well understood with several opinion polls being conducted over the years concerning the social attitude to wind power installations. The findings show that although the public supports wind energy in general, parameters, such as noise and visual impacts, contribute to social oppositions. The term 'NIMBY' (not in my back yard) defines this mentality [26]. However, if the turbines cannot be seen from the coast there is less opposition from the general public; but traditional industries, like fisheries, shipping, and ferry operators, still remain concerned if fishing and navigation practises are disrupted.

2.1.7.3 Political Risks

Like all large infrastructure projects, FOW farms can face various political risks. Obtaining the necessary permits and approvals from government agencies can be a lengthy and uncertain process. Changes in government, regulations, or political priorities can impact project timelines and could impact the financial viability of projects. Policies that change regularly can make planning decisions difficult. The financial viability of FOW projects often depends on government subsidies, tax incentives, and favourable policies. Changes in government support can impact project profitability and attractiveness to investors.

One prominent example for these political risks occurred in February 2023, when – despite the Irish government commenting that the "future is offshore" and offshore energy projects are essential "to decarbonise our energy supply and securing energy independence" – the Department of Environment, Climate, and Communications (DECC) announced at an industry conference that they would accelerate a move to a government regime, meaning that developers would no longer be able to choose their own sites for offshore projects. [27]

Disputes over maritime boundaries or cross-border energy projects can create diplomatic tensions. Political decisions regarding the decommissioning and clean-up of FOW facilities at the end of their operational life can impact project economics and environmental responsibilities. FOW farms require a reliable connection to the onshore electricity grid. Delays or disputes related to grid infrastructure can disrupt project plans. In Ireland, a disagreement between the grid operator (i.e. EirGrid) and the national road authority (i.e. Transport Infrastructure Ireland) has occurred over plans to install cables beneath the roads. EirGrid proposed to use parts of the road network to lay high voltage underground cables beneath them. [27]

To mitigate these political risks, developers of FOW farms often engage in extensive stakeholder consultation and environmental impact assessments, and liaise with coast communities. They may also seek long-term power purchase agreements to provide revenue certainty and reduce exposure to fluctuating energy markets. Additionally, political risk insurance and careful consideration of the regulatory environment can help manage uncertainties associated with these projects.

2.1.7.4 Supply Chain Risks

The FOW industry is still relatively new. There is currently a limited supply chain for the components and equipment required to build and maintain FOW turbines. Furthermore, the number of ports suitable for construction works and assembly of FOW turbine systems is still limited and there are not always ports available close to the envisaged FOW farm site. All this could lead to supply chain bottlenecks or disruptions that could delay project development or increase costs. Some detailed investigations on how to support the development of an active supply chain, including a status-quo review of the existing supply chain in the NWE region, are covered by WG 3 (cf. Chapter 4).

2.1.7.5 Economic Risks

Since 2020, much of the world is experiencing high rates of inflation due to the impact of COVID-19, the war in Ukraine, and strong consumer demand. The result is rising costs across all industries and sectors. Inflation can impact the FOW industry across its production, assembly, deployment, and financial supports. The cost of materials, such as steel, fibre glass, and copper, which are crucial for constructing wind turbines and floating platforms, as well as an increase in labour costs, which affect the cost of building and maintaining FOW installations, can increase the overall project cost. Central banks may raise interest rates to combat inflation. This can lead to higher borrowing costs for companies involved in the industry, potentially affecting project financing and profitability. Furthermore, inflation can exacerbate supply chain disruptions, which have already been a challenge for various industries due to the COVID-19 pandemic. Delays in the delivery of components can impact project timelines and costs.

In response to changes in the economic condition governments may adjust their policies and incentives for renewable energy projects. Shifting or modifying subsidies or regulatory frameworks can affect the attractiveness of FOW investments. Having a national 30-year master that government is explicitly committed to despite the economic situation is essential for portraying certainty.

The rise in energy prices due to inflation could impact the demand for renewable energy sources like offshore wind. High energy costs might make renewable energy more appealing to consumers, but it could also affect their ability to invest in such technologies. Also, this relatively new industry requires diesel powered machinery for its transport, assembly, and installation. Therefore, higher fuel costs will make these processes more expensive. In September 2023, Damen announced plans to introduce a fully electric service operation vessel (SOV) for the offshore wind farm sector [28]. The idea is that this SOV will be an emission free vessel and will charge its batteries once a day between dropping and collecting service technicians to the FOW platforms. Although it is capable of sailing exclusively on electrical power it will have diesel generators on, enabling it to take on other duties if required. As the FOW industry progresses, we are noticing more solutions to eliminate CO_2 from the heavy machinery side of development.

FOW projects often involve international collaboration and financing. Exchange rate fluctuations driven by inflation can affect project costs and returns, and adds an element of uncertainty to international partnerships. There are many examples of international collaborations mentioned in Section 2.2.1.6. These partnerships can take many years to establish and at times can fall through. In 2012, Principle Power was awarded a grant to support a FOW demonstration park off the coast of Oregon [29]. The project comprised three 8 MW FOW turbines installed in depths of 450 m. The objective was to advance FOW technology and reveal the huge resources on the west coast of the USA. Although the enormous potential of FOW was realised, the project was eventually discontinued highlighting how volatile international collaborations can be.

The impact of inflation can vary by region, depending on the local economic conditions and government policies. Additionally, the FOW industry's resilience and ability to adapt to economic challenges will also play a significant role in mitigating the effects of inflation.

2.1.7.6 Environmental Risks

The construction and operation of FOW turbines can have negative impacts on the marine environment, including habitat disruption, and the risk of oil spills or other environmental incidents.

2.1.7.6.1 Marine Ecosystem Disturbance

FOW platform anchors and mooring cables can have a physical impact on the seabed and surrounding ecosystem. The installation and operation of the turbines may lead to the disturbance of fish and marine mammal habitats, migration patterns, and feeding behaviours.

2.1.7.6.2 Secondary Entanglement

Combined with abandoned fishing gear, underwater cables used to connect FOW turbines to shore can pose a risk to marine life. Entanglement on FOW's mooring lines and cables likely poses a low threat because these are relatively rigid and large. However, lost, abandoned, or discarded fishing gear and other marine debris could become tangled in mooring lines and cables, where it may trap whales, dolphins, turtles, fish, and diving seabirds. This is known as secondary entanglement and poses an additional hazard to already stressed animals. Entanglement is a threat to many species of marine wildlife and often causes catastrophic injury or death to marine mammals or sea turtles. [30]

Mooring anchors and cables can also damage the habitat of benthic organisms that live around the seafloor. Developing the FOW industry responsibly to ensure that local and regional biodiversity is protected will help alleviate the biodiversity crises.

If FOW turbines are placed in essential habitats, avoidance by sea life can have serious consequences. When displaced from foraging or feeding grounds, sea life must expend more energy finding food elsewhere, which can compromise their survival. Additionally, avoidance by one species may affect other species in the region because ocean food networks are complex.

Risks can vary depending on the location and design of the FOW turbines, and some measures can be taken to minimise their impact on the environment. Environmental impact assessments, monitoring programs, and mitigation measures can be used to identify and manage potential risks.

2.1.7.6.3 Collision Risk

The rotating blades of a FOW turbine can pose a collision risk to birds and bats in the surrounding environment. Many FOW turbines will be installed further offshore, where winds blow at higher speed. Birds show different flight behaviours in faster-blowing winds, which may increase turbine collision risk. [31]

Vessel collisions are a leading cause of mortality for sea turtles and marine mammals. Constructing and operating FOW turbines will increase traffic as vessels are needed to transport personnel and equipment to and from wind farms. With increased traffic, and with increased speed, comes a higher risk of collision with whales, sea turtles, and other marine wildlife. [32]

2.1.7.6.4 Potential Oil Leaks

FOW turbines and service vessels contain lubricants and hydraulic fluids that could leak into the ocean, leading to environmental pollution and damage to marine life.

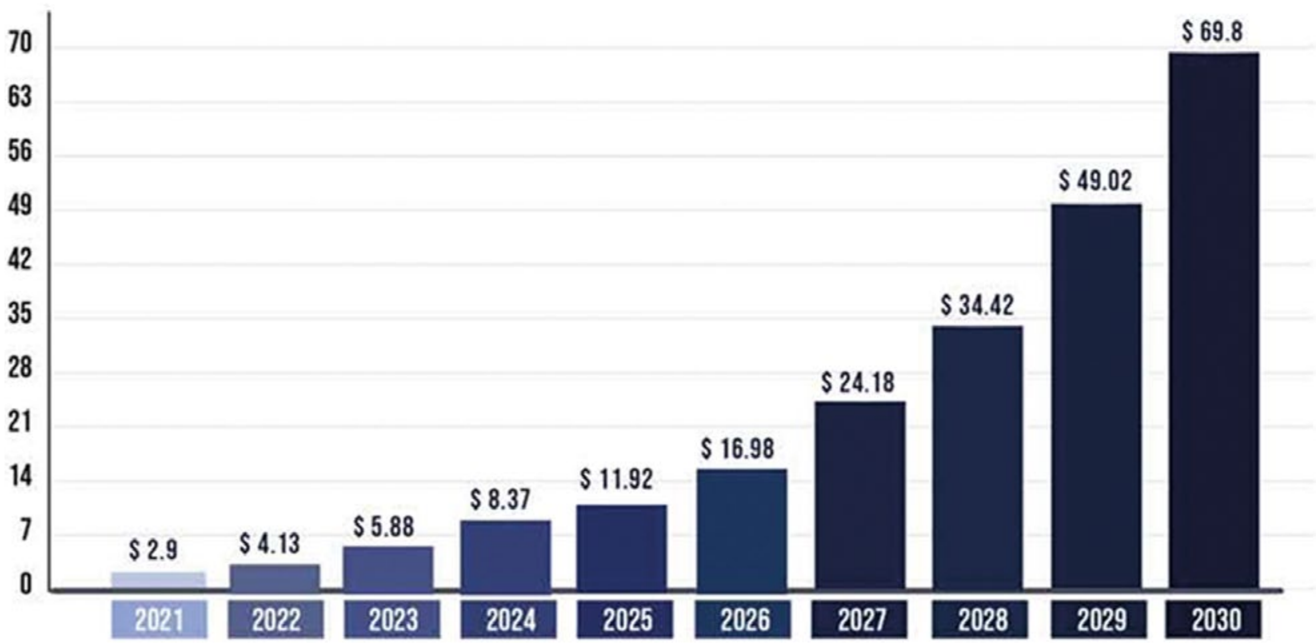
2.1.7.7 Climate Change Risks

Climate change is affecting how most industries operate today. Changes in climate can lead to a distortion in wind patterns, which could potentially increase wind resources in certain offshore areas. This could make FOW farms more productive. However, there are some negative effects associated with climate change that could make operations and maintenance more expensive. Rising sea levels due to climate change can pose a threat to the infrastructure of FOW farms. Additional engineering and construction measures may be required to ensure the stability and longevity of quayside infrastructure for platform and turbine assembly. Changes in weather pattern can lead to more frequent and severe storms, which can damage or disrupt FOW farms. Climate change is certain to impact wind energy resources. "Wind power density is proportional to the wind speed cubed; therefore, any changes in wind speed are greatly amplified" [33, p. 2]. The industry may need to invest in stronger and more resilient structures. Climate change also contributes to ocean acidification, which can harm marine ecosystems, potentially affecting the placement and maintenance of FOW farms. As nations adapt to climate change, regulations governing offshore wind may evolve, impacting the permitting and development processes for FOW projects.

2.2 Market Opportunity

FOW has a huge potential when it comes to mitigating climate change. Accessing offshore wind can play a significant role in reducing CO_2 emissions by replacing fossil fuels with clean, renewable energy sources. As part of the overall aim to move to renewable resources there are other benefits to FOW when compared to BFOW turbines. About 80% of the world's offshore wind power potential lies in waters deeper than 60 m [34]. FOW will be vital for some countries with little space left on land and steep coastal shelves to decarbonise their power sectors. The global FOW power market size was €2.7bn in 2021 and is expected to reach around €65.3bn by 2030 [35], as shown in Figure 13. As pilot projects have commenced, from 2030 we expect to see a rapid acceleration of FOW. Many of the emerging offshore markets, such as Europe, US, and China are predominantly suitable for FOW turbines. Mature markets are increasingly looking at FOW as they run out of seabed areas suitable for BFOW projects.

Figure 13: Floating wind power market size, 2021 to 2030 (USD bn) [35]



2.2.1 Market Opportunity Factors

The market opportunity for FOW in Europe can be assessed based on several factors, such as:

- technological advancements,
- abundant wind resources,
- policy support,
- market size and growth,
- job creation and economic benefits, and
- export opportunities.

2.2.1.1 Technological Advancements

There has been significant progress in FOW technology, making it an increasingly viable and cost-effective renewable energy source. Innovations in floating foundation designs, mooring systems, and installation techniques have improved the industry's prospects.

2.2.1.2 Abundant Wind Resources

Europe has extensive offshore wind resources, and FOW turbines can access wind energy in deeper waters where BFOW turbines cannot be installed. FOW opens up additional areas for development, increasing the overall potential for renewable energy generation.

2.2.1.3 Policy Support

European countries have supported offshore wind development through favourable policies, including feed-in tariffs, auctions, and financial incentives. Governments recognise the importance of transitioning and are actively pursuing renewable energy sources to reduce greenhouse gas (GHG) emissions, creating a favourable regulatory environment for the industry.

2.2.1.4 Market Size and Growth

Europe's offshore wind sector has grown rapidly. According to industry reports, Europe accounted for the majority of the global FOW capacity in 2020. The EC has set targets for an installed capacity of at least 60 GW of offshore wind and 1 GW of ocean energy by 2030. The corresponding targets to be achieved by 2050 are 300 GW and 40 GW, respectively.

2.2.1.5 Job Creation and Economic Benefits

The expansion of the FOW industry in Europe would create jobs across the value chain, including manufacturing, construction, installation, and maintenance. It can also benefit coastal regions economically, attracting investments and fostering local industries. Tens of millions of new skilled jobs could be created worldwide thanks to wind energy [34].

2.2.1.6 Export Opportunities

Europe's expertise in offshore wind technology positions the region to become a leader in FOW. One of the best methods for decarbonising electricity networks, wind energy has proven to be effective. Lack of rapid wind deployment runs the danger of driving up costs due to increased exposure to the volatility of fossil fuels, higher carbon emissions, and geopolitical pressure. By generating millions of highly skilled jobs worldwide, wind power has the ability to positively impact society. Economically, it can act as a catalyst for trillions of dollars of investment globally [34].

There are many examples of EU based companies exporting FOW technologies and services to other regions worldwide, further driving the market growth. Some of the key players are presented in the following.

2.2.1.6.1 Principle Power

Principle Power is a Portuguese FOW company. The company's mission is to make the WindFloat® the most cost-effective, secure, dependable, and environmentally friendly technology for deep-water offshore wind projects, while helping the worldwide offshore wind markets to flourish and develop their local offshore wind resources. By utilising local renewable energy sources, the climate targets can be met and energy independency reached, while launching a new industry with revivified economic growth.

With offices located in Portugal, France, UK, USA, and Japan, Principle Power is extending its expertise across the world. Since 2007, Principle Power has been developing WindFloat® with installations off the coasts of Portugal, Scotland, and France.

For the development of a FOW project in Northern California, the Redwood Coast Energy Authority (RCEA) held a competitive tender in 2018. The goal of the tender was to choose a partner to build a public-private partnership. In addition to Principle Power, Ocean Winds, Aker Offshore Wind, H. T. Harvey & Associates, and Herrera Environmental Consultants Inc. were also included in the consortium that the RCEA chose. The FOW farm, which is 40 km from the coast and situated in 700–900 m of water, is anticipated to generate its first power in 2026. 10 MW-class wind turbines will give the FOW farm a capacity of between 100 and 150 MW. [36]

Principle Power and its partners Renova and Mitsui Engineering and Shipbuilding were selected by Japan's

New Energy and Industrial Technology Development for a demonstration project 29 km from the Akita Prefecture shore, utilising a single 5 MW Hitachi wind turbine generator. ClassNK (Nippon Kaiji Kyokai) issued an Approval in Principle for Principle Power's FEED design, demonstrating that WindFloat® is prepared for Japan's harsh environment, including exposure to both typhoons and seismic occurrences. [37]

2.2.1.6.2 BW Ideol

BW Ideol is a Norwegian business with more than 10 years of design, development, and deployment experience in the FOW market. Based on the engineering expertise and proprietary FOW technology of Ideol S.A., BW Ideol is a leading fully integrated platform. Currently, there are two full-scale FOW turbines operating in Japan and France. [38]

A formal contract was signed in 2022 between BW Ideol and Tohoku Electric Power Co., Inc., which was founded in 1951 and is one of the largest Japanese utility firms. They started the requisite feasibility studies to jointly create a commercial-scale FOW farm together off Kuji city's shore. The two businesses hope to proceed to the early commercialisation of cost-competitive FOW power in Japan through this Iwate prefecture initiative. [39]

2.2.1.6.3 Hexicon

Hexicon is a pioneering project-developer in FOW; it was established in Sweden in 2009. The technology provider with the unique floating wind concept TwinWind™ is opening up new markets in deep water regions. Hexicon operates in a number of markets across Europe, Africa, Asia, and North America and its dual business strategy promotes the global shift to sustainable energy. [40]

Currently, Hexicon is engaged in work on the MunmuBaram project in South Korea, named after the joint venture between Shell and Hexicon. The Ministry of Trade, Industry, and Energy approved the project all three electricity business licenses in 2022 to forward development toward the project's goal of 1,300 MW output. Millions of Korean households will receive clean, affordable power from the project, once having reached a FOW farm on a commercial scale. [41]

Hexicon is creating links with South Africa as the Department of Environmental Affairs considers renewable energy to be the most practical way to meet the objective, which South Africa has committed to achieving by cutting carbon emissions by 40% by 2025. For the purpose of creating large-scale FOW projects, Hexicon has partnered with the local company Genesis Eco-Energy Developments to form GenesisHexicon. The development of renewable energy projects in South Africa has been Genesis' area of expertise for more than 20 years. [42]

2.2.2 Market Opportunity Overview

The worldwide market for wind energy is predicted to increase on average by 15% per year. Annual offshore wind installations are expected to reach 18 GW in 2023. The compound annual growth rate for offshore wind in the next five years is 32%. With such a promising growth rate, new installations are likely to double by 2027 from 2023 levels. China and Europe will be the two key contributors to near-term growth, making up more than 80% of new additions in 2023 and 2024. The US and emerging markets in Asia-Pacific (APAC) will start gaining sizeable market share from 2025 with 7–8 GW of new offshore wind expected to be added every year over the rest of the forecast period. In total, 130 GW of offshore wind is expected to be added worldwide in 2023–2027, with expected average annual installations of nearly 26 GW. [34]

2.2.2.1 Ireland

Ireland has a sea area of 490,000 km^2, approximately seven times the size of its landmass (cf. Figure 14), and has one of the best marine renewable energy (MRE) resources in the world. With most of the area having depths greater than 60 m and consistent Atlantic winds, FOW presents an exceptional opportunity to harness some of the best wind resources in Europe. The Irish government is committed to have 5 GW of offshore wind power developed by 2030 with additional 2 GW of FOW under development.

Four successful bidders in Ireland's first ever auction to generate electricity from offshore wind were announced in May 2023. Three will be located in the Irish Sea and a fourth off the west coast (cf. Figure 15). They will have a combined capacity of more than 3 GW. The auction occurred under the Offshore Renewable Electricity Support Scheme (ORESS), which guarantees future prices. The successful projects, which are all BFOW farms, include the 824 MW Dublin Array situated in the Kish and Bray banks in the Irish Sea. Further down the east coast, Codling Wind Park, which stretches along the coast from Greystones to Wicklow Town, was also successful. This is the biggest project at 1,300 MW. Meanwhile, on the north Dublin coast, off

Skerries, a 500 MW project has been granted. Finally, a 450 MW farm on the Sceirde Rocks off the coast of Galway was awarded. All the successful bidders must go through the planning process. [43]

2.2.2.2 Europe

To reach the objectives of Europe's new energy security strategy, REPowerEU, Europe needs to build on average 30 GW of new wind energy capacity (onshore and offshore) each year until 2030 (cf. Figure 16). The targets, funding, and urgency is in place, providing a huge market opportunity for FOW farm developers within the EU.

Figure 14: Irish Exclusive Economic Zone limit [44, p. 2]

Figure 15: Locations of ORESS 1 provisionally successful projects, adapted from [45, p. 10]

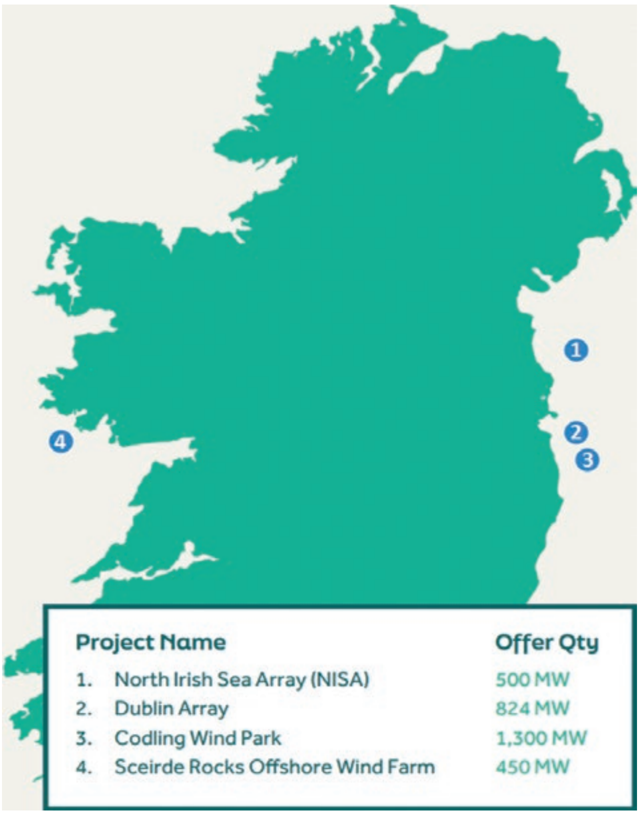
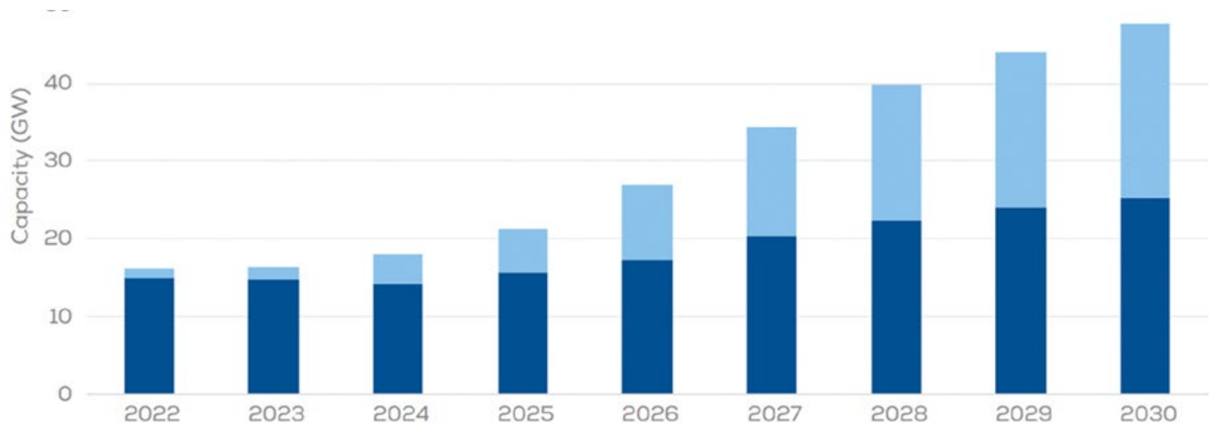


Figure 16: Evolution of wind energy build out in EU-27, based on the REPowerEU Scenario [46, p. 52]



	2022	2023	2024	2025	2026	2027	2028	2029	2030
Onshore wind	14.9	14.7	14.2	15.7	17.2	20.3	22.3	23.9	25.2
Offshore wind	1.2	1.8	3.8	5.7	9.8	14.1	17.5	20.1	22.4

The EC established and actualised the REPowerEU plan to riposte the hardships and global energy market disruption caused by the war in Ukraine. Implemented in May 2022, this plan was aimed to help the EU to

- save energy,
- produce clean energy, and
- diversify its energy supplies.

Despite the efforts to roll-out renewable energy sources and diversify energy supplies, EU countries installed just 100 MW of new offshore wind capacity in 2022, as shown in Figure 17.

Wind turbine orders reduced by 47% each year since 2020 and in 2022 there were just two FOW final investment decisions (FIDs). Both based in France, they were demonstrators of 30 MW each, as presented in Figure 18. Inflation and costs were cited as the cause for several offshore wind farms to delay their FID. 2022 saw the lowest financial activity since 2007 with just €419m for two FOW projects at 60 MW in total.

2.5 GW (i.e. 306 turbines) were connected to the grid across seven wind farms in 2022. This is the lowest capacity connected to grid in a single year since 2016 and 30% less than forecasted. Construction activity took place at 14 wind farms, representing 8.5 GW of new capacity.

The UK commissioned the world's largest wind farm Hornsea Two at 1,386 MW. France commissioned its first commercial wind farm at 480 MW capacity. Italy's first offshore wind farm at 30 MW is now online. The most powerful turbines ordered in 2022 were 14 MW in the UK, while the average power rating for connected turbine to the grid was 8 MW.

Figure 17: Investment in offshore wind 2013-2022 [47, p. 21]

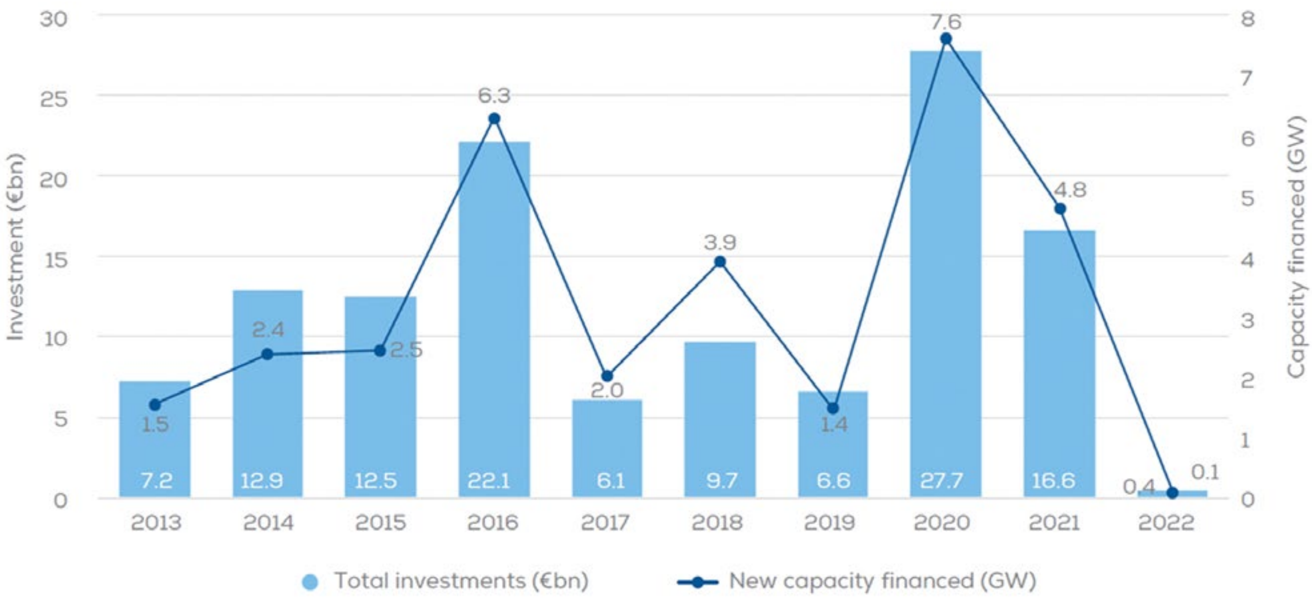
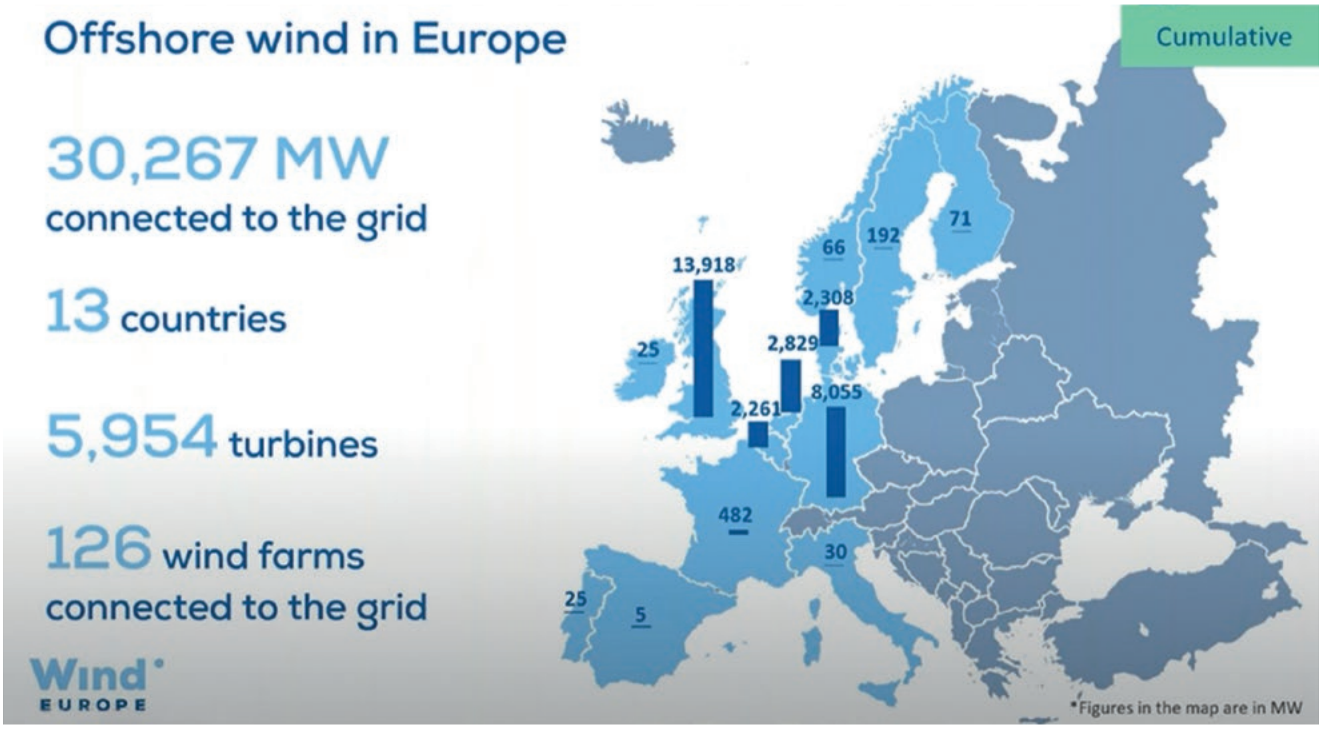


Figure 18: Final investment decisions for EU offshore wind farms in 2022 [48, p. 35]

COUNTRY	WIND FARM	CAPITAL RAISED (m€)	CAPACITY (MW)	CAPEX (m€/MW)	FINANCIAL INVESTMENT DECISION	COMMISSIONING DATE
FRANCE	EFGL	208	30	7.1	January 2022	2024
	EolMed	211	30	5	May 2022	2023
TOTAL		**419**	**60**			

Figure 19: Offshore wind in Europe, as of 2022 [48, p. 10]



Europe's installed offshore capacity now stands at 30 GW (cf. Figure 19). At 13,918 MW, the UK has the most installed offshore wind capacity in Europe. Germany and the Netherlands have 8,055 MW and 2,829 MW installed, respectively, making them the second and third in Europe.

2.2.2.3 USA

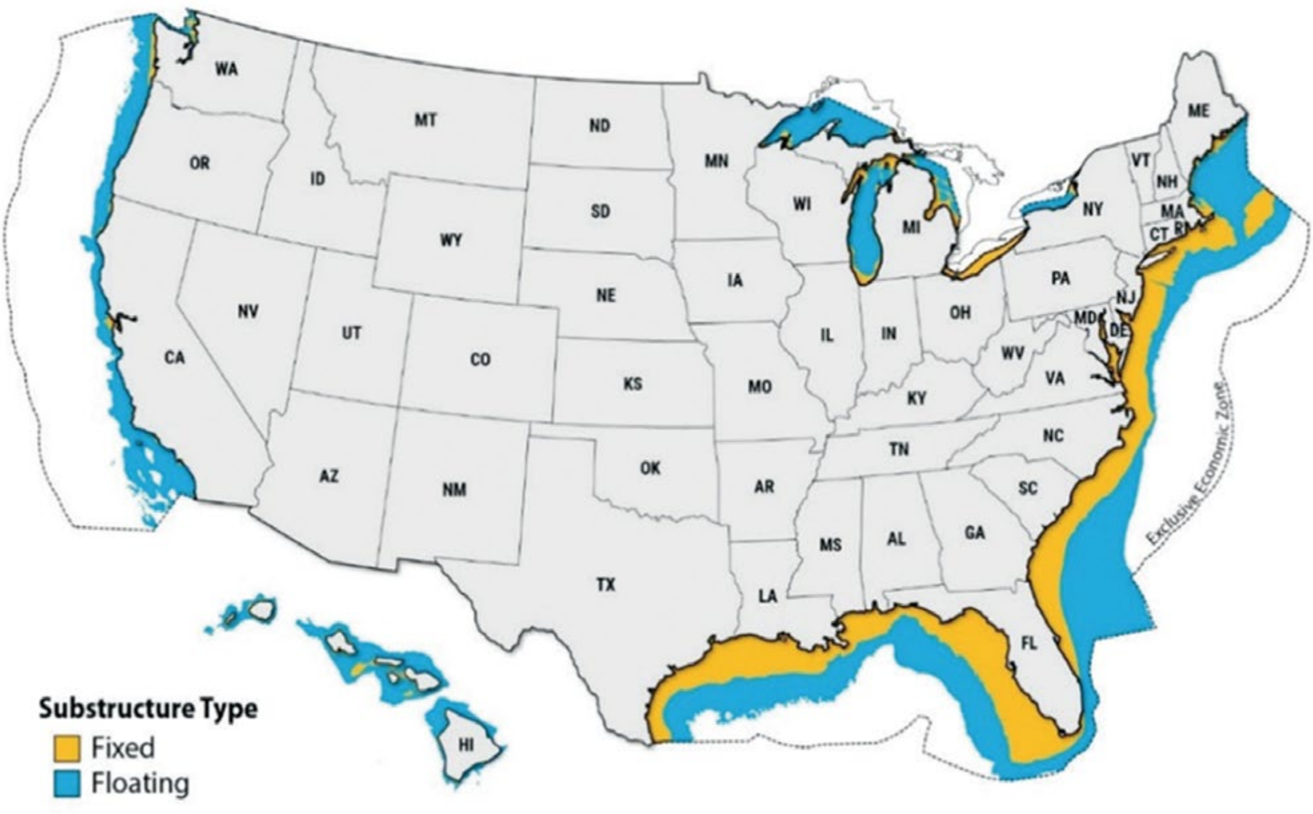
The USA has set a goal to deploy 15 GW of installed FOW capacity by 2035, which is enough energy to power over 5 million American homes. Investing in FOW will help to develop a clean energy future by tapping into 2.8 TW of potential power – more than double the current US electricity consumption.

The FOW market in the USA represents a significant opportunity for renewable energy development. While traditional BFOW farms have gained momentum in Europe and other regions, the USA has unique conditions that make FOW a promising option, as presented in Figure 20. The Atlantic and Gulf coasts are suitable for BFOW installations near the shore. Waters along the Pacific coast, Gulf of Maine, and around Hawaii, as well as waters further from shore along the Atlantic and Gulf coasts, would require FOW turbines. About two-thirds of the US' offshore wind potential exists over bodies of water too deep for BFOW turbine [49]. The continental shelf features waters with depths in excess of 60 m which are more suitable to FOW turbines.

The development of a FOW market in the USA could have significant economic benefits. It has the potential to create numerous job opportunities, stimulate local economies, and attract investment. The supply chain also presents opportunities for American companies to participate in manufacturing, installation, and maintenance.

Despite the promising market opportunities, the FOW market in the USA is still in its early stages. Several pilot projects and demonstration sites have been initiated. Aikido Technologies is preparing to launch a 2 MW pilot project at the end of 2024 and aims to install a demonstrator project with a turbine of 10 MW or 15 MW capacity in 2026 or 2027. Aikido Technologies has developed a floating foundation that enables the installation of fully assembled wind turbines from ports, regardless of height restrictions. In the US, this encompasses 80% of port areas. This technology is also suitable for ports with shallow waters with its low transit draught. In terms of plans for the market, they are assessing larger commercial-scale global projects coming online by the end of the decade, including those in California, Scotland, other floating wind markets in Europe and the US, as well as Asia Pacific.

Figure 20: BFOW and FOW locations in USA [49, p. 2]



In March 2023, nine US FOW projects won $1.6m from the Department of Energy (DOE) in phase one of the floating offshore wind readiness price. Each project will receive $100,000 in funding and $75,000 in vouchers for technical support provided by DOE national laboratories. The winners include:

- Aikido Technologies,
- Beridi USA,
- Aker Solutions and Principle Power,
- OCG-Wind (Ocergy),
- PelaStar,
- Technip Energies,
- Tetra Triple-One,
- VolturnUS+ (University of Maine), and
- WHEEL U.S.

Continued research, policy support, and investment will be crucial for the sector to unlock its full potential and contribute significantly to the nation's renewable energy goals.

2.2.2.4 Asia-Pacific

The Asia-Pacific FOW power market is expected to witness a compound annual growth rate of around 6% during the forecast period. Over the short term, the Asia-Pacific FOW power market is expected to grow as the governments of the Asian countries are keen on expanding the renewable energy capacities in their respective countries. Increased flexibility in offshore wind operations is expected to facilitate this growth. The focus of many countries like Japan, Taiwan, and South Korea on the development of a FOW power market is expected to create many lucrative opportunities for the market. China is expected to witness a faster growth due to the government's plans to expand the FOW industry.

2.2.2.4.1 APAC FOW Market Trends

There are several upcoming projects in the Asian countries expected to drive the market.

Many Asian countries have identified their potential to exploit the FOW power technology, specifically when the availability of water depths for BFOW structures is narrowing. For example, the Japanese government recently identified around 424 GW of FOW potential, which is three times more than its BFOW potential. In order to exploit it, the country has developed a number of plans. Japan's current wind power generation capacity stands at 8.2 TWh, as of 2021 (cf. Figure 21). The country already has an ambitious plan in place to install about 10 GW of offshore wind power by 2030, and by 2040 between 30 and 45 GW. FOW projects will play a part in achieving this goal. For example, in May 2022, BW Ideol and Tohoku Electric Power agreed to jointly develop a FOW power plant off the coast of Kuji city in Iwate prefecture in Japan. Currently, the project is in the feasibility study phase.

Furthermore, in November 2022, the South Korean government announced a new plan to build the world's biggest FOW farm in the country, with around 6 GW capacity. The government disclosed the planned investment as $40bn for the project. The project will be located southeast of the country, off the coast of Ulsan, an industrial city.

Such developments are expected to steer the FOW power market in the Asia-Pacific region in the coming years.

2.2.2.4.2 China

China was positioned to be the leader in the offshore wind installed capacity at the global level, in the year 2021. In 2021, there were 27 GW of operational offshore wind capacity in the country. When the country made such remarkable growth in the BFOW power sector, the FOW power has not gone unnoticed.

China's wind power generation share was around 655.6 TWh (cf. Figure 22), the highest among all the renewables. The Chinese government has made many plans to increase the share along with the FOW power installations. With approximately 5.5 MW of installed FOW capacity, China is now in fifth place; by 2026, it plans to reach a capacity of around 477 MW. Thus, many new projects have already commenced to achieve this target.

The South China Sea's Beibu Gulf is home to China's first deep-water offshore wind farm, which was put into operation by China National Offshore Oil Corporation. In May 2023, the Haiyou Guanlan

Figure 21: Renewable energy generation mix in Japan in 2021, in TWh [50]

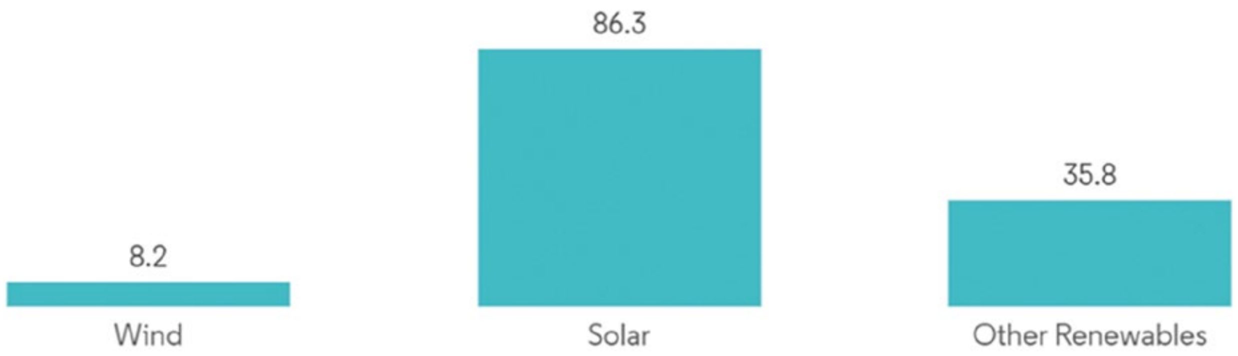
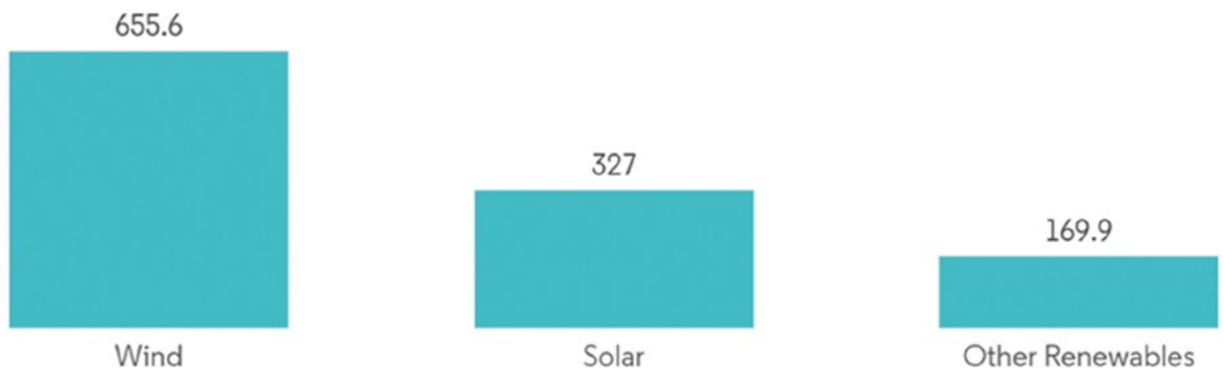


Figure 22: Renewable energy generation mix in China in 2021, in TWh [50]



floating wind turbine was connected to the grid, supplying electricity to South China Sea offshore oil and gas production facilities. Located 136 km from Wenchang in Hainan province, the floater has a capacity of 7.25 MW. The platform is moored by nine anchor chains and fixed in water depths of 120 m. A five-kilometre dynamic cable connects the turbine to the grid of the Wenchang oil complex. The FOW turbine is designed to generate 22 million kWh per annum of electricity, which will reduce carbon dioxide emissions and save 10 million m³ per annum of natural gas.

Additionally, in December 2021, the country got another FOW farm project installed. Sanxia Yinling Hao, a FOW turbine, was successfully commissioned as part of the 5.5 MW Yangjiang wind project. China Three Gorges and Mingyang Smart Energy developed this project.

Acknowledging these developments implies China will be the frontrunner in the Asia-Pacific FOW energy market.

2.2.2.4.3 APAC FOW Technology Development

In November 2022, Osaka University in Japan announced plans to develop the country's largest FOW turbine. The Japanese civil engineering company Toda will develop the wind turbine, and it is expected to have a capacity of 15 MW and 200-meter-long turbine blades.

In October 2022, the Chinese wind turbine manufacturer, CSSC Haizhuang, introduced plans to develop a FOW turbine installed in Guangdong Province's waters. The CSSC subsidiary Haizhuang Wind Power developed the floater known as Fuyao, which supports a 6.2 MW wind turbine that is resistant to typhoons and has a rotor diameter of 152 m.

2.3 Technology Development Process

The technology development process of the FOW industry typically involves several stages, including research and development (R&D), demonstration, and commercialisation.

During the R&D stage, researchers and developers explore new ideas and technologies that could be used in FOW. They conduct studies on materials, design, and construction methods to find ways to build reliable and cost-effective improvements and solutions. This stage can involve simulations, small-scale testing, and laboratory experiments.

Once promising technologies have been identified through the R&D stage, they move into the demonstration phase. This involves testing the technology in real-world conditions to determine if it can withstand the marine environment and operate efficiently. Typically, this stage involves testing the technology on a small scale, using a single turbine or a small array.

If the demonstration phase is successful, the technology can move into the commercialisation phase. This involves scaling up the technology and building larger wind farms with multiple turbines. At this stage, the focus is on reducing costs, improving reliability, and increasing efficiency.

These are the general stages of development, however, the TRLs index is a more specific, industry wide, globally accepted method of developing robust technologies effectively.

2.3.1 Technology Readiness Levels

TRLs index is a globally accepted benchmarking tool for tracking progress and supporting development of a specific technology through the early stages of the technology development chain. They allow stakeholders to have a consistent reference datum for understanding the technology growth, regardless of their technical knowledge. There are nine levels in total. TRL1 is the concept/idea of the technology. After meeting certain criteria the technology proceeds through to the next level. The final stage is TRL9, which is a proven full-scale device ready for commercialisation.

There are various TRL rating scales that may be applicable to various technologies. The following scale, presented in Table 1, can be used for renewable energy technologies. [51]

Table 1: Technology readiness levels, based on [51]

Stage 1	**Concept developed and validated. Numerical modelling. Tank testing at 1:30 – 1:50 scale in large water tank. Prove the basic concept in test tank.**
TRL1	**Basic principles observed and reported:** Transition from scientific research to applied research. Essential characteristics and behaviours of systems and architectures. Descriptive tools are mathematical formulations or algorithms.
TRL2	**Technology concept and/or application formulated:** Applied research. Theory and scientific principles are focused on a specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.
TRL3	**Analytical and experimental critical function and/or characteristic proof of concept:** Proof of concept validation. Active research and development are initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brass board implementations that are exercised with representative data.
Stage 2	**Further design development and validation of design. Subsystem testing at intermediate scale. Computational fluid dynamics; finite element analysis; dynamic analysis; engineering design (prototype); feasibility and costing; further tank testing.**
TRL4	**Component/subsystem validation in laboratory environment:** Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.
Stage 3	**Testing operational scaled models at sea and subsystem testing at large scale, e.g., 2 or 5 MW.**
TRL5	**System/subsystem/component validation in relevant environment:** Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.
TRL6	**System/subsystem model or prototyping demonstration in a relevant end-to-end environment:** Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.
Stage 4	**Full scale prototype tested at sea**
TRL7	**System prototyping demonstration in an operational environment:** System prototyping demonstration in operational environment. System is at or near scale of the operational system with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.
TRL8	**Actual system completed and qualified through test and demonstration in an operational environment:** End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and validation completed.

Table 1: Technology readiness levels, based on [51] (continued)

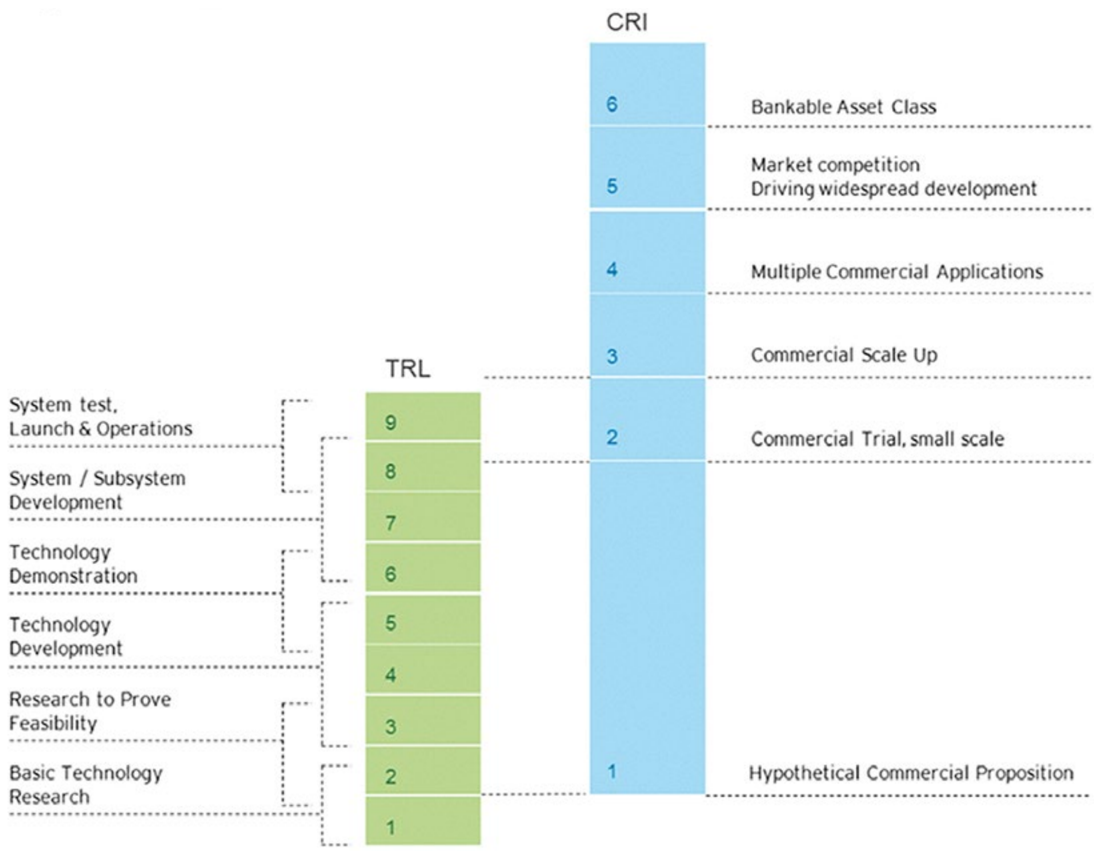
Stage 5	Economic validation; several units of pre-commercial machines tested at sea for an extended period of time.
TRL9	**Actual system proven through successful operations:** Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

2.3.2 Commercial Readiness Index

The commercial readiness index (CRI) is a tool used to assess the maturity and viability of emerging technologies or industries for commercial deployment. In the context of the FOW industry, the CRI provides a structured framework to evaluate the readiness of FOW technology for widespread commercialisation. The relationship between the CRI and TRLs is shown in Figure 23.

The CRI considers various factors to assess the commercial readiness of FOW. These factors typically include technological maturity, cost competitiveness, supply chain development, policy and regulatory support, and market demand. By evaluating these factors, the CRI provides a comprehensive assessment of the commercial readiness of FOW technology. This assessment helps industry stakeholders, policymakers, investors, and developers make informed decisions regarding investment, technology advancement, and market development strategies. It also aids in identifying areas requiring further research, development, and collaboration to accelerate the commercialisation of FOW and contribute to the global transition to clean energy sources.

Figure 23: Technological readiness level and commercial readiness index [51, p. 2]



2.3.2.1 Technological Maturity

The CRI evaluates the technical readiness of FOW technology. It considers aspects, such as turbine design, platform stability, mooring systems, and power transmission. The maturity of these components determines the reliability, performance, and maintenance requirements of the floating wind farms.

2.3.2.2 Cost Competitiveness

The CRI assesses the cost-effectiveness of FOW compared to other renewable energy sources and traditional fossil fuel-based generation. Factors, such as capital expenditure, operational costs, and levelised cost of energy (LCOE), are considered. Lower costs increase the attractiveness and competitiveness of FOW in the energy market.

2.3.2.3 Supply Chain Development

The CRI examines the development of a robust and competitive supply chain to support the manufacturing, installation, and maintenance of FOW farms. A mature supply chain helps reduce costs, ensures necessary components' availability, and accelerates project deployment.

2.3.2.4 Policy and Regulatory Support

The CRI considers the existence of supportive policies, regulations, and incentives from governments and regulatory bodies. Favourable policies can include feed-in tariffs, renewable energy targets, grid connection mechanisms, and streamlined permitting processes. Such support encourages investment and mitigates regulatory uncertainties.

2.3.2.5 Market Demand

The CRI assesses the potential market demand for FOW energy. Factors, such as energy market dynamics, electricity demand, and offshore wind resource potential, are considered. A strong market demand for clean and renewable energy enhances the commercial prospects of FOW.

2.3.3 Levelised Cost of Energy

LCOE is a metric used to evaluate the cost-effectiveness of different energy generation technologies. In the context of the FOW industry in Europe, LCOE is a critical factor in assessing the competitiveness and economic viability of FOW projects.

The LCOE calculation considers various factors, including capital costs, operational and maintenance expenses, the expected electricity generation over the project's lifetime, and the cost of financing. It estimates the average cost per unit of electricity generated (typically measured in kWh or MWh).

For the FOW industry, the LCOE is influenced by several factors specific to this sector. The most relevant factors are described in the following.

2.3.3.1 Capital Costs

The initial investment required for FOW projects is generally higher compared to traditional BFOW farms. The cost of floating foundations, mooring systems, and other specialised equipment contributes to the higher capital costs.

2.3.3.2 Technological Development

As FOW is a relatively nascent technology compared to onshore or BFOW, there is still ongoing innovation and optimisation in the design and construction of floating platforms. Advancements in technology can lead to cost reductions and improved efficiency over time.

2.3.3.3 Installation and Maintenance

FOW farms often face additional challenges during installation and maintenance due to the dynamic nature of floating structures. The costs associated with installation vessels, maintenance operations, and access to remote locations can affect the overall LCOE.

2.3.3.4 Resource Assessment

Accurate assessment of wind resources is crucial for projecting electricity generation and estimating the LCOE. FOW farms may have different wind characteristics compared to onshore or bottom-fixed offshore sites, which need to be accounted for in resource assessments.

2.3.3.5 Policy and Regulatory Framework

Government policies, support mechanisms, and grid connection infrastructure significantly influence the LCOE. Favourable policies, such as feed-in tariffs or renewable energy certificates, can help reduce the LCOE and increase the competitiveness of FOW.

2.3.4 LCOE Formula

The LCOE formula is used to calculate the average cost of producing electricity over the lifetime of a power generation project. The formula is given in the following, while the used parameters are named in Table 2 and described in more detail hereinafter.

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Table 2: Parameters of the LCOE formula

Parameter	Description
I_t	Investment expenditures in the year *t*
M_t	Operations and maintenance expenditures in the year *t*
F_t	Fuel expenditures in the year *t*
E_t	Electrical energy generated in the year *t*
r	Discount rate
n	Expected lifetime of system or power station
t	Running index for considered year

It is important to note that LCOE is not a static value and can vary depending on project-specific factors, regional conditions, and technological advancements. As the industry matures and more FOW projects are deployed, economies of scale, technological innovation, and increased experience are expected to contribute to reducing the LCOE, making FOW increasingly cost-competitive with other forms of energy generation.

By following the TRL progress steps the technology being developed is more likely to reach an investible stage and become commercially viable. Creating technologies that are efficient in assembly, operation, maintenance, and power production will help to lower the LCOE of FOW.

2.3.4.1 Investment Expenditure

The investment expenditure (I_t) is the total capital costs or upfront investments required to build and install a power generation system or a renewable energy project in a given year (t). These expenditures can include the cost of land, equipment, construction, labour, permits, and other expenses incurred during the development, installation, and commissioning of the energy project.

2.3.4.2 Operations and Maintenance Expenditure

The operations and maintenance expenditure (M_t) is the ongoing costs that are incurred each year to keep the power plant running smoothly. These costs may include things like routine maintenance, repairs, labour costs, fuel costs, and other expenses related to operating the plant.

2.3.4.3 Fuel Expenditure

The fuel expenditure (F_t) is the amount of money spent on purchasing the fuel needed to generate electricity from the power plant during a specific year (t). In other words, it represents the cost of the fuel inputs required to produce a unit of electricity during the year in question.

2.3.4.4 Electricity Generated

The electrical energy generated (E_t) is the total amount of electricity that the power plant produces in a given year (t). This is typically measured in kWh or MWh and represents the total amount of energy that is delivered to the grid or consumed by the end-users.

2.3.4.5 Discount Rate

The discount rate (r) reflects the opportunity cost of investing capital in a given project. It takes into account factors such as inflation, interest rates, and the perceived level of risk associated with the project. The higher the perceived risk, the higher the discount rate, and the higher the cost of capital.

The discount rate in this LCOE formula is the rate at which future costs and benefits are discounted to their present value. The interest rate used to transform future expenses and gains into their current worth is called the discount rate. This is necessary because money has a time value – a Euro received today is worth more than a Euro received a year from now because the Euro received today can be invested and earn interest over the next year.

The choice of discount rate in the LCOE formula is important, as it can have a significant impact on the calculated cost of electricity. A higher discount rate will result in a lower present value of future costs and benefits and therefore, a lower LCOE, while a lower discount rate will result in a higher LCOE.

2.3.4.6 Expected Lifetime

The expected lifetime (*n*) is the length of time the power plant will operate for and is given in years.

2.4 Test Sites

FOW test sites are locations where prototype or full-scale FOW turbines can be deployed and evaluated in real-world conditions. These sites provide an area for testing FOW turbines' design, technology, and performance before they are commercialised. Offshore test sites are required to appropriately test technologies which have arrived at final or near-final TRLs in real offshore conditions. Suitable test locations enable accelerated performance testing and mitigate forecasts of more extreme storm events for technology deployment in other locations. Technologies that are at the early stages of development are tested in state-of-the-art facilities that can portray scaled real-life conditions on to a scaled model. Sophisticated equipment and sensors are used to evaluate the performance.

2.4.1 Test Site Significance

Testing technologies is crucial for understanding their capabilities. However, technologies also need to be tested in extreme ocean weather conditions to prove their structural integrity and performance in strong winds, high seas, and reoccurring storms. Proving structures are capable in extreme conditions will be reassuring for investors and funders in understanding that their investment can not only survive in harsh weather conditions but continue to harvest clean energy. Downtime and damaged turbines do not generate revenue and waiting for weather windows to perform maintenance operations can be costly. Testing FOW technologies in extreme weather conditions is crucial to ensure that the technology is safe, reliable, and capable of withstanding the harsh offshore environment. These test sites are crucial for advancing the development of FOW technology and accelerating the adoption of renewable energy sources for a more sustainable future.

2.4.2 Benefits of Test Sites

Test sites have various benefits. The most important ones are detailed in the following.

2.4.2.1 Accelerating Technology Development

Testing new FOW technologies allows for real-world evaluation of their performance and reliability, which can accelerate the development process and improve the design.

2.4.2.2 Assessing Performance

Testing can help assess the performance of a FOW platform under various environmental conditions, such as wind speeds, wave heights, and currents. This information can be used to improve the design and optimise the performance of the system.

2.4.2.3 Reducing Risks

Testing helps to identify potential risks associated with the technology and address them before full-scale implementation. Identifying and mitigating potential environmental impacts can reduce risks to marine life and ecosystems. Test sites can also offer developers the opportunity to prove performance and de-risk technologies in energetic metocean conditions, via structured approaches in preparation for commercialisation.

2.4.2.4 Cost Reduction

Testing allows for the identification of potential design improvements and the optimisation of the overall system, leading to reduced costs in the long run. This can make the technology easier to construct or deploy thus becoming more economically competitive with other renewable energy sources.

2.4.2.5 Improving Durability

Testing can help identify any weaknesses in the system and improve the durability of the technology. This can lead to a longer lifespan of the turbines, reducing maintenance costs and increasing overall efficiency.

2.4.2.6 Developing Maintenance Procedures

Maintenance procedures can be developed in a test facility and allow developers to determine best practices for effective and efficient operation and maintenance practices. Cost reductions will be realised when the technology is scaled up and mass produced. Installation as well as operation and maintenance accounts for nearly one third of LCOE. These crucial aspects can be tried and improved upon during the testing process, resulting in more efficient practises being developed. Consequently, there is a large potential for reducing LCOE through testing.

2.4.2.7 Academic Opportunities

Test sites can attract additional research activities from commercial and academic industries. Having partnerships with research centres and universities gives technologies a certain level of accreditation by association.

2.4.2.8 Independent Verification and Certification

FOW technology developers need to test and validate technology to build credibility. To progress the technology to a commercial stage a proven track record validated by an accredited party is more attractive to funders and investors in financing large commercial projects. Test sites allow an opportunity for the technology to be certified independently.

2.4.3 Test Site Examples

As the significance of a test site is well understood in the ORE industry many test centres have already been established across the world. The following are examples of test sites that cater for technologies in the final TRLs.

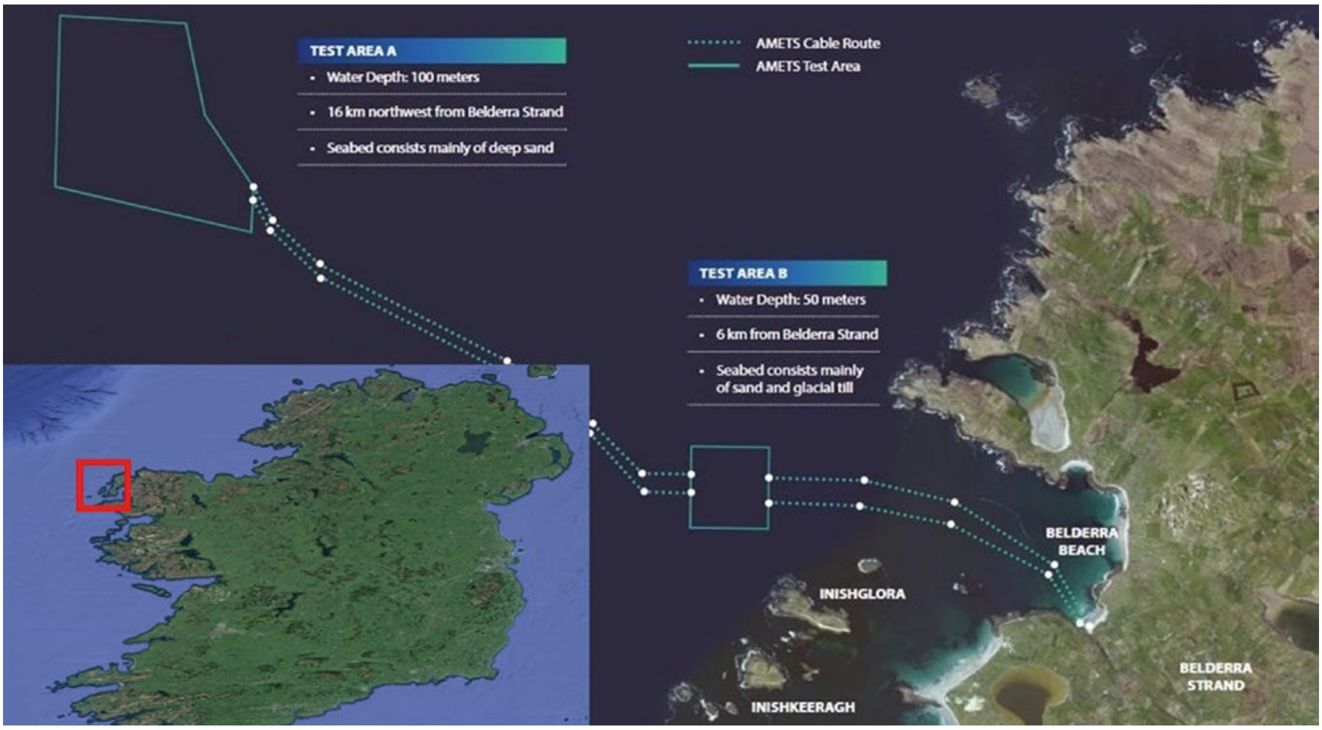
2.4.3.1 Atlantic Marine Energy Test Site in Ireland

AMETS is located off the west coast of Ireland. It is currently being developed and will provide testing opportunities for MRE devices at two sites: test site A and test site B. The main characteristics of both test sites are presented in Table 3, while the locations are shown in Figure 24.

Table 3: Characteristics of test sites A and B at AMETS

Parameter	Test Site A	Test Site B
Water depth	100 m	50 m
Distance from shore	16 km	6 km
Area	6.9 km²	1.5 km²
Grid connection	Subsea cables and onshore substation	Subsea cables and onshore substation
Annual mean significant wave height	3.2 m	2.9 m

Figure 24: AMETS location, Beldera Strand, Co. Mayo [52, pp. 4-5]



AMETS will offer FOW developers the opportunity to prove performance and de-risk technologies in energetic metocean conditions, via structured approaches in preparation for commercialisation. The site will be suitable for TRL7 to TRL9.

2.4.3.2 European Marine Energy Centre in the UK

Established in 2003 in Orkney, Scotland, EMEC was founded to help kick-start the ocean energy industry in the UK and advance economic growth in the Highlands and Islands.

Celebrating 20 years of operation in 2023, EMEC is now the world's leading facility for demonstrating and testing wave and tidal energy converters and is the only test centre accredited by the International Electrotechnical Commission for testing of wave and tidal energy converters in the world.

In addition to 'nursery' and full-scale grid-connected wave and tidal test sites, EMEC has also developed full-scale demonstrators for innovative clean technologies including flow-batteries, wind- and tidal-powered green hydrogen production, storage, distribution, and use, and leads or supports a wide variety of partners developing alternative energy solutions, such as synthetic aviation fuels. In the majority of cases these have been 'first of a kind' projects globally, and as such EMEC has been deeply involved in the development of new international test and demonstration standards that others now follow.

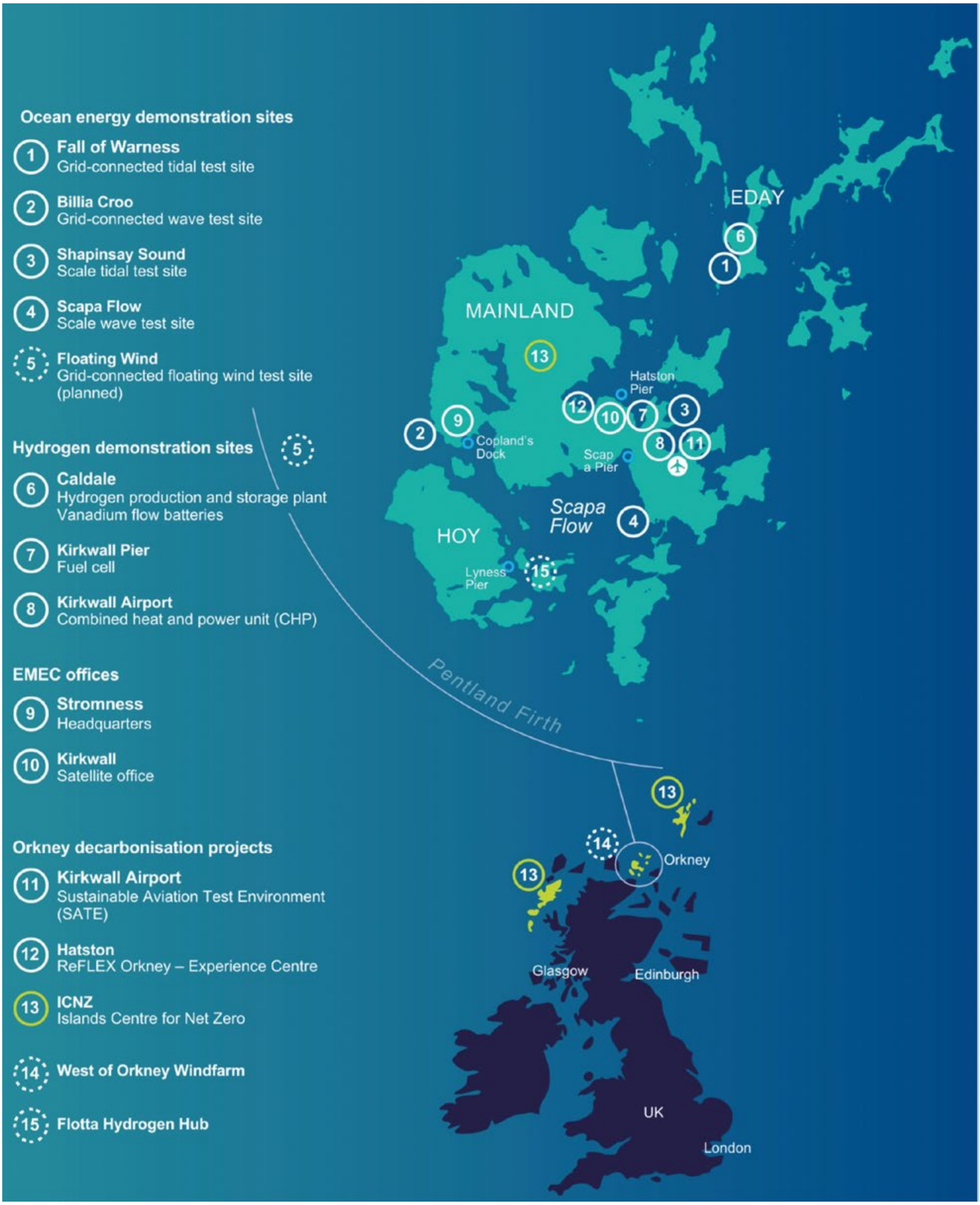
As a successful research, development, and innovation model EMEC's approach has been replicated in a number of other countries – with the support of the experienced team at EMEC – and EMEC itself has extended well beyond its original test centre brief to provide a wide range of innovation support services to technology developers across the offshore renewables sector, including how these integrate with or replace existing onshore applications, such as data centres or more sustainable domestic heating. The most recent of these is the push to develop a multiple berth test centre for FOW technologies in the energetic waters west of Orkney capable of accommodating the next generations of FOW technologies up to 20 MW per device.

A very wide range of marine renewable energy technologies can be tested at several specialised sites, each with differing energy profiles and characteristics and capable of hosting multiple technologies. These are summarised on the map shown in Figure 25 and more details are available at www.emec.org.uk.

In summary EMEC offers a wide range of cost effective and readily available test facilities in areas with abundant wind, wave, and tidal resources. Technology developers learn by doing in facilities designed to make testing as easy as possible, are supported by EMEC's teams of experts, and receive confidential environmental, metocean, and performance data as part of the package of services offered to test clients, project partners, and berth-holders.


© EMEC. National Floating Wind Test Centre.
Artist's impression, not to scale.

Figure 25: EMEC's test site locations [53, p. 1]



2.4.3.3 OPEN-C Foundation in France

Created in March 2023, the OPEN-C Foundation consists of five independently developed and operated test sites in France. The foundation was set up to accelerate a rapid energy transition and enhance France's position on environmental strategic issues. The OPEN-C Foundation will develop, coordinate and manage offshore testing. The five test sites, presented in Figure 26, include:

- Paimpol-Bréhat,
- Sainte Anne du Portzic,
- SEM-REV,
- SEENEOH, and
- MISTRAL.

2.4.3.3.1 Paimpol-Bréhat

The Paimpol-Bréhat site is located off the island of Bréhat in the Côtes d'Armor. It is an offshore test site for the development of the tidal turbine industry. Established in 2008, the Paimpol-Bréhat test site offers technology developers with extensive experience in real ocean conditions (cf. Table 4). The test site is significant due to its demanding characteristics (turbulence, tides), experience, expertise, and infrastructure including grid connection.

Figure 26: OPEN-C test site locations [54]

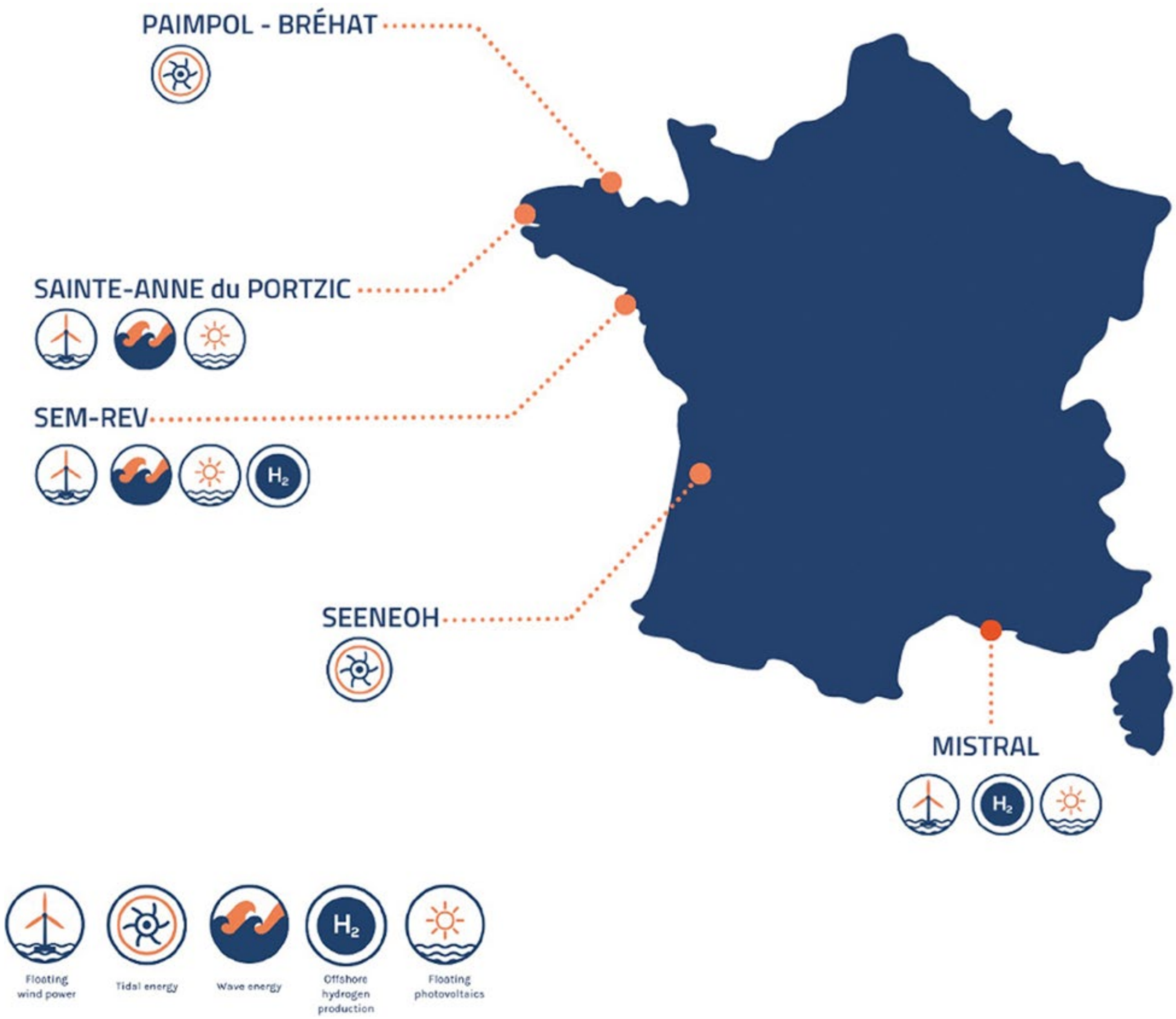


Table 4: Characteristics of the Paimpol-Bréhat test site

Parameter	Value
Water depth	35 – 40 m lowest astronomical tide (LAT)
Significant wave height	8 – 9 m
Maximum depth-average velocity over the test site – Exceptional spring tide – Medium spring tide – Neap tide	 [2.4 m/s : 3.1 m/s] [2.1 m/s : 2.8 m/s] [1.1 m/s : 1.5 m/s]
Seabed	Rocks
Others	Strong biofouling activity for severe environmental testing

The test site is connected to the French national grid and can take up to 3 MW. There is an alternating current power export with 15 km of cable. Furthermore, there is a drymate connection and a maximum of 12 optical fibres.

2.4.3.3.2 Sainte Anne du Portzic

Located in Brest harbour, the test site Sainte Anne du Portzic is used to test various types of MRE equipment in real sea conditions. The prototypes tested there are on a 1:10 scale and include floating wind turbines.

The main characteristics of the test site Sainte Anne du Portzic are provided in Table 5.

2.4.3.3.3 SEM-REV

SEM-REV is located 20 km off the coast of Le Croisic, France, and covers an area of 1 km² in the Atlantic Ocean. It is a marine restricted area about 20 nautical miles from St-Nazaire harbour. It was Europe's first grid connected site for multi-technology offshore testing. It has all the necessary offshore and onshore equipment to develop, test, and improve MRE devices catering for wind and wave sources in particular. It is fully equipped to measure weather and sea conditions (swell, wind, and local parameters). The offshore test site comprises:

- electric infrastructure to connect the system to the medium-voltage network via an 8 MW 25 km-long cable;
- a hub enabling the simultaneous connection of three technologies; and
- a research centre, located at Penn-Avel and staffed by a dozen researchers and engineers, to receive and analyse data and control the test devices.

The test site is equipped with three Datawell buoys for wave, two acoustic Doppler current profiler systems for current and tide as well as two meteo-buoys for wind measurements. Additionally, the test slots comprise 24 optical fibres. The environmental conditions at the test site are summarised in Table 6.

Table 5: Characteristics of the Sainte Anne du Portzic test site

Parameter	Value
Water depth	5 – 20 m
Tidal range	Maximum 7 m
Current speed	Maximum 2 m/s
Waves (crest to trough)	Maximum 4 m
Temperature (seasonal range)	7 – 19°C

Table 6: Characteristics of the SEM-REV test site

Parameter	Value
Water depth	32 – 36 m LAT
Tidal range	6.2 m
Maximum tidal current (10 years)	0.7 m/s
Mean wave energy	12 kW/m
10-years extreme significant wave height	8.3 m
50-years extreme significant wave height	9.6 m
1-hour averaged mean wind velocity at 10 m height	7.5 m/s
50-years 1-hour averaged extreme wind speed at 10 m height	29 m/s
Seabed	Sand (0.2 – 0.5 mm)

New investments were made in the site's development in 2022 (to install an offshore floating sub-station, improve the site's capacity for grid injection, build an MRE exhibition centre, and create an MRE business incubator), allowing new customers access to the infrastructure.

2.4.3.3.4 SEENEOH

The site is located, downstream from the Pont de Pierre in Bordeaux in the Garonne River. Due to the Bay of Biscay's daily tidal cycle, it is subject to strong currents. The site is utilised to test tidal turbines for rivers or the ocean on an intermediate scale.

The hectare test site is fully permitted and accessible by boat within 10 minutes. It exhibits ideal characteristics for testing prototypes of river or marine tidal turbines. There are several anchoring solutions available and a connection to the power grid is available. Overall, SEENEOH brings together environmental, mechanical, and electrical skills and facilitates access to commissioning and maintenance operations.

2.4.3.3.5 MISTRAL

Mistral test site is located 5 km off the coast of Port-Saint-Louis-du-Rhône in the Mediterranean. It is currently under construction and authorisation has been given for the installation of two FOW turbines.

2.4.3.4 Marine Energy Test Centre in Norway

The Marine Energy Test Centre (METCentre) was set up in 2009 and has since become a world leading test centre in the North Sea. The test site provides concessions, infrastructure, and services required for testing and caters for the development of marine renewable energy technologies, such as solar energy, wave energy, and floating wind power, in different and unique natural conditions for test of floating technologies (depth, currents, and wind).

METCentre's test area for FOW at 200 m water depth is located 10 km offshore (cf. Figure 27). However, there is another shallow water berth at water depths of 20 – 40 m, just 1 km from the shore. The geographical location of the METCentre is close to yards, ports, several deep-water quays, and the large markets in the North Sea. The test site is equipped with a 22 kV / 15 MW export cable; an additional cable for 66 kV is planned to be added. Furthermore, fibre for data communication is available. Additionally, METCentre serves as the governing body for the Norwegian Offshore Wind Cluster, which has more than 370 member companies and is the country's largest offshore wind cluster.

2.4.3.5 Biscay Marine Energy Platform in Spain

Located off the coast at Armintza, the Biscay Marine Energy Platform (BiMEP) is a purpose-built facility for testing ocean energy technologies and auxiliary equipment on the open sea. The test site has grid connection for the demonstration and validation of wave energy converters and FOW platforms (cf. Figure 28). The area has optimal wave and wind resource, with depths between 50 and 90 m and quick access due to its proximity to the port.

Established in 2015, BiMEP provides technology developers with suitable wave and wind resources for testing the technical and economic viability of different MRE concept designs, offering security before advancing to the full-scale commercial phase.

Figure 27: METCentre test site locations [55]

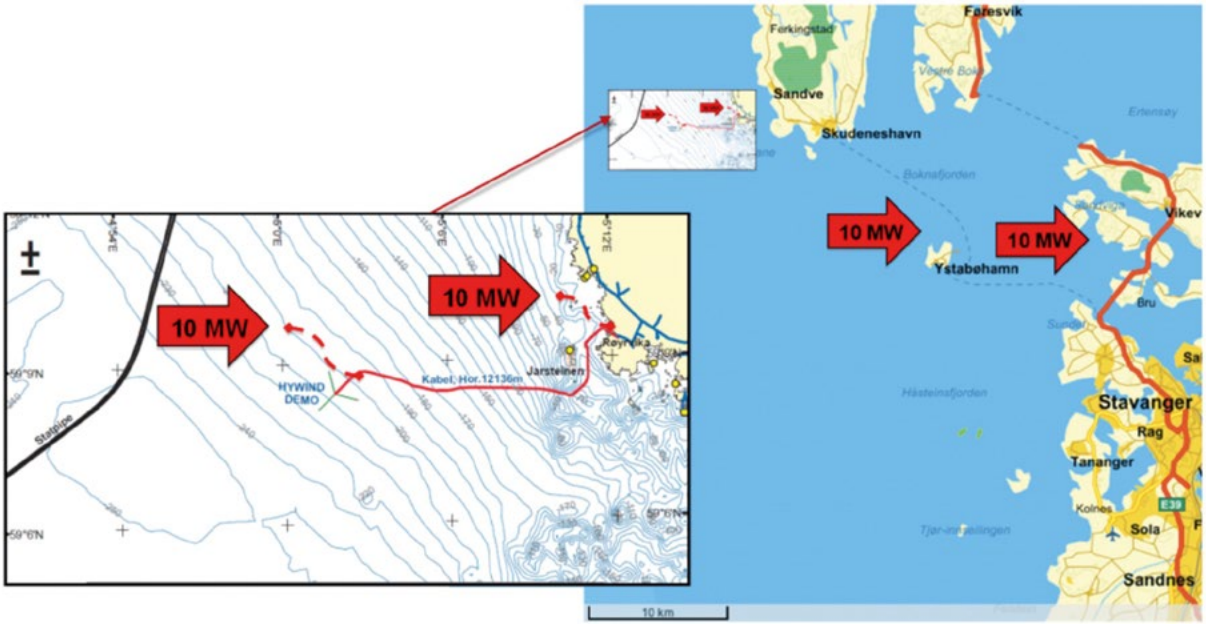
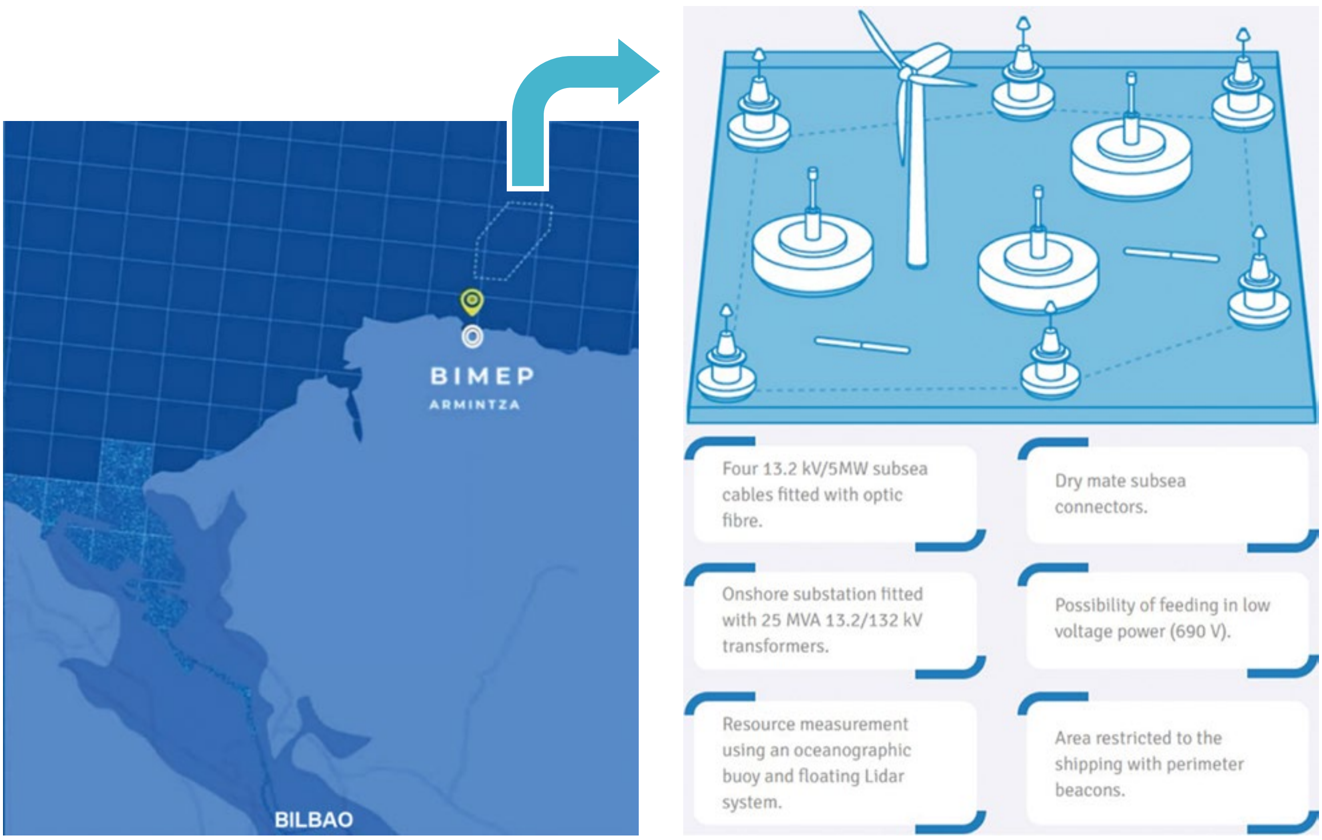


Figure 28: BiMEP test site, adapted from [56, 57]



2.5 Concluding Remarks on the Technology Maturity and Investability of FOW

The FOW industry presents many exciting opportunities and challenges, requiring a comprehensive understanding of several key aspects. Successful engagement in this industry requires a solid knowledge base encompassing the principles of wind energy generation, offshore engineering, and the infrastructure needed for assembly and installation. Remaining up to date with emerging research, industry trends, and regulatory frameworks is essential when navigating this dynamic industry. As such, wind farm developers should remain current on the types of FOW platforms available and their suitability for different ocean and weather conditions.

Countries that have a transparent development process will be able to develop FOW quickly. Outlining the steps involved, from early assessment to construction and commissioning, and defining specific departments responsible for each stage and the expected timeline will help developers plan and execute projects more efficiently. Developing worldwide industry standards and guidelines will streamline the construction of FOW farms.

The market opportunity for FOW looks promising. With growing energy demands and an increasing focus on renewable energy sources, FOW will undoubtedly be part of the energy mix. Countries with expansive coastlines and limited shallow water can benefit from this industry, unlocking vast offshore wind resources that were previously inaccessible. Investments in the sector have been increasing steadily, driven by government policy, private enterprises, and international collaborations, thus fuelling the market's potential for long-term expansion.

Creating dedicated test sites for FOW technologies is vital for the growth of this industry. These test sites are invaluable for assessing new concepts and prototypes' performance, reliability, and environmental impact. They provide opportunities to validate technological advancements, optimise designs, and gather essential data to refine deployment strategies. Thorough testing will allow developers to establish practices that help to reduce the LCOE of FOW energy. As outlined previously in Section 2.4, there are many test sites in NWE where FOW developers can avail of the equipment, infrastructure, and expertise that have accumulated over the years. Collaborative efforts between governments, industry, and research institutions are instrumental in establishing such test sites. Test sites will play a part in developing better, more robust, efficient devices.

2.6 Floating Offshore Wind Readiness Surveys

To establish the readiness of FOW farm developers and FOW technology developers, two separate surveys were carefully designed. Their main objectives were to

- outline risks and challenges associated with the development of FOW technologies and farms;
- identify potential hurdles and feasible approaches for investing in FOW technologies and farms;
- assess the FOW developers' and investors' knowledge requirements with respect to open ocean test sites;
- highlight the critical risk areas in relation to FOW developer engagement and test site experience; and
- identify alternative approaches to existing test sites.

The surveys were (mostly[2]) executed online through a Survey Monkey platform. The AFLOWT project partners contributed to a list of contacts and were asked to disseminate and encouraged suitable contacts to take part. Thus, beyond the members of the AFLOWT advisory board, there were personal contacts, new established contacts approached at conferences and exhibitions, as well as several other networks and network clusters in the list of contacts. These covered both technology developers and site developers as well as operators, research performing institutions, certification bodies, and investors.

The surveys were available from December 2022 until April 2023. The surveys consisted of multiple-choice, open comment, or priority type questions.

2 In some cases, one-to-one interviews based on the content of the survey were performed.

2.6.1 FOW Farm Developers Survey

The survey on FOW farm developers' readiness consisted of 36 questions, grouped into the following categories:

- organisational details,
- technical details,
- technology selection,
- risk and challenges, and
- investability.

2.6.1.1 Respondents to the FOW Farm Developers Survey

For the FOW farm developers survey, eight responses have been received. Six of the respondents came from multinational corporations with 250 employees or more and two were from small and medium enterprises (SMEs) with between 50 and 249 employees.

The following are the positions of professionals who completed the survey:

- project manager,
- grid manager,
- project director – floating wind,
- portfolio engineer,
- senior wind analyst,
- technical project manager, and
- offshore wind technical director.

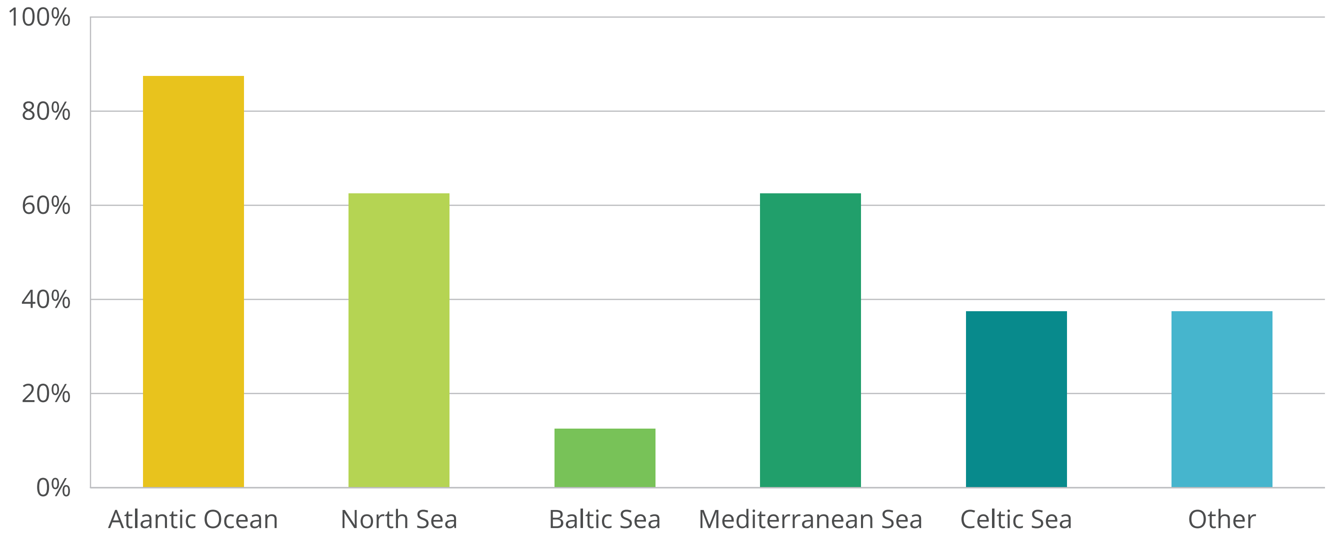
All respondents have either developed or are in the process of developing a FOW farm and some even in multiple locations. This shows that there is traction in the FOW industry. The specific FOW farm locations are presented in Figure 29 and Table 7.

75% of the companies have been working on FOW projects for between three and six years while 25% are working on FOW projects for less than three years. This implies that the companies are young and experience may be low, as no respondents have been operating for more than 6 years.

Table 7: Other FOW farm locations

Location	Number of Respondents
Irish Sea	1
Pacific Ocean	1
Indian Ocean	1
Sea of Japan	1

Figure 29: FOW farms locations



2.6.1.2 Technical Details from the FOW Farm Developers

The semi-submersible platform is the most popular type of FOW platform (88%), followed by TLP (25%) and barge (12%). The full distribution of FOW platforms utilised is shown in Figure 30.

For the answer option 'Other' no specific platform designs were highlighted, however the following comments were provided:

- *Subject to detailed engineering and metocean studies.*
- *As the FOW projects are in early-stage development, the FOW platform being utilised hasn't been finalised. All platform types have been investigated, with the type of technology being brought forward varying depending on the installation/fabrication site constraints.*

50% of respondents are developing FOW farms of 1 GW or more (cf. Figure 31), while 12.5% are each developing FOW farms in the following categories:

- < 100 MW;
- 100 MW to < 400 MW;
- 400 MW to < 700 MW; and
- 700 MW to < 1,000 MW.

Figure 30: Popularity of FOW platforms being developed

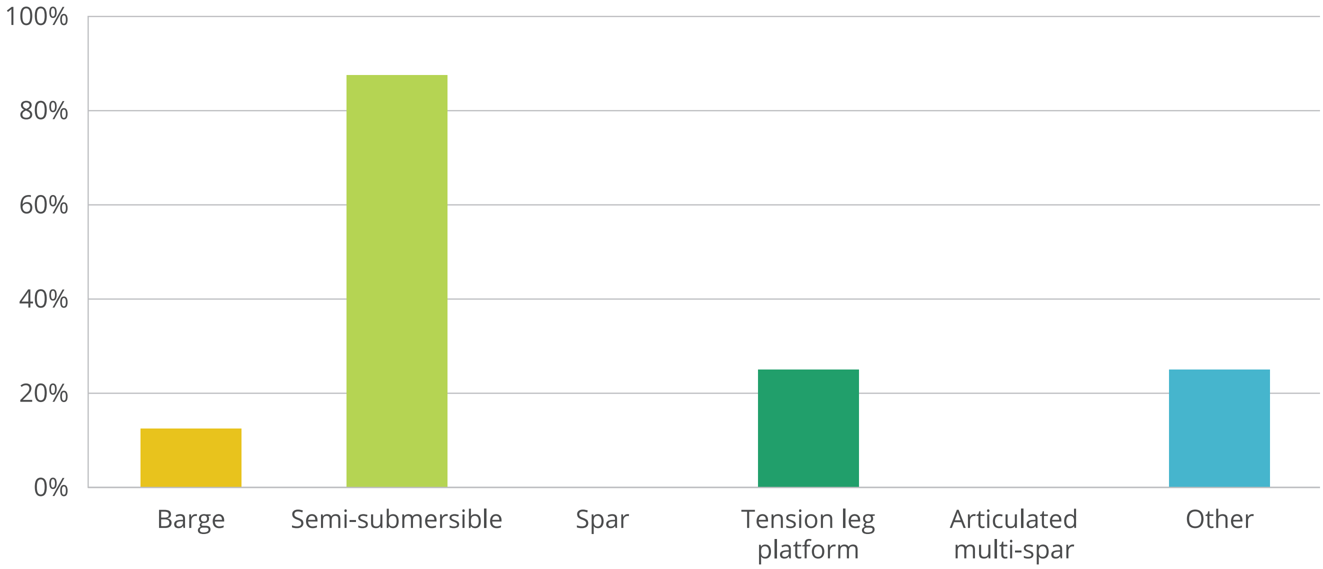
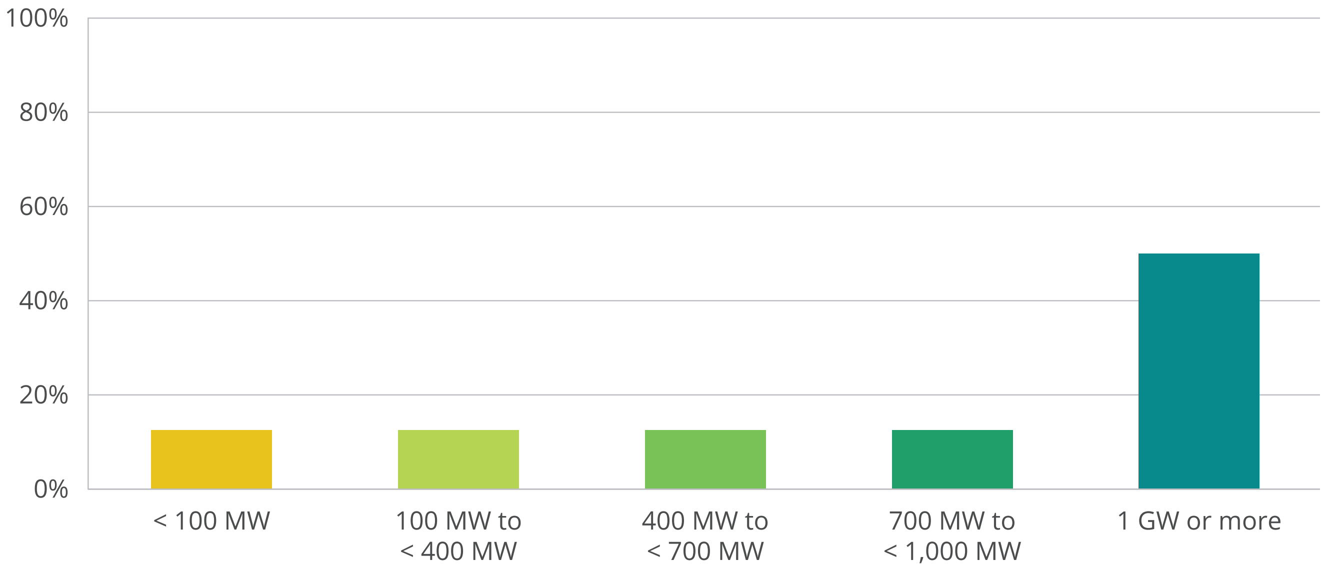


Figure 31: Size of FOW farms being developed



63% will deploy or have deployed wind turbines greater than 15 MW, 12% will deploy or have deployed turbines between 12 MW and 15 MW, and 25% have not decided yet, as summarised in Figure 32.

In terms of deployment depths, Table 8 and Figure 33 outline the responses to the depth of water FOW farms will be or have been deployed in. Thus, half of the respondents are or were developing FOW farms at a variety of water depths ranging between 50 – 200+ m.

Table 8: Water depth at deployed FOW farm

Water Depth	Number of Respondents
< 50 m	0
50 m to < 100 m	3
100 m to < 200 m	1
200 m or more	0
Various depths	4

Figure 32: Size of FOW turbines being deployed

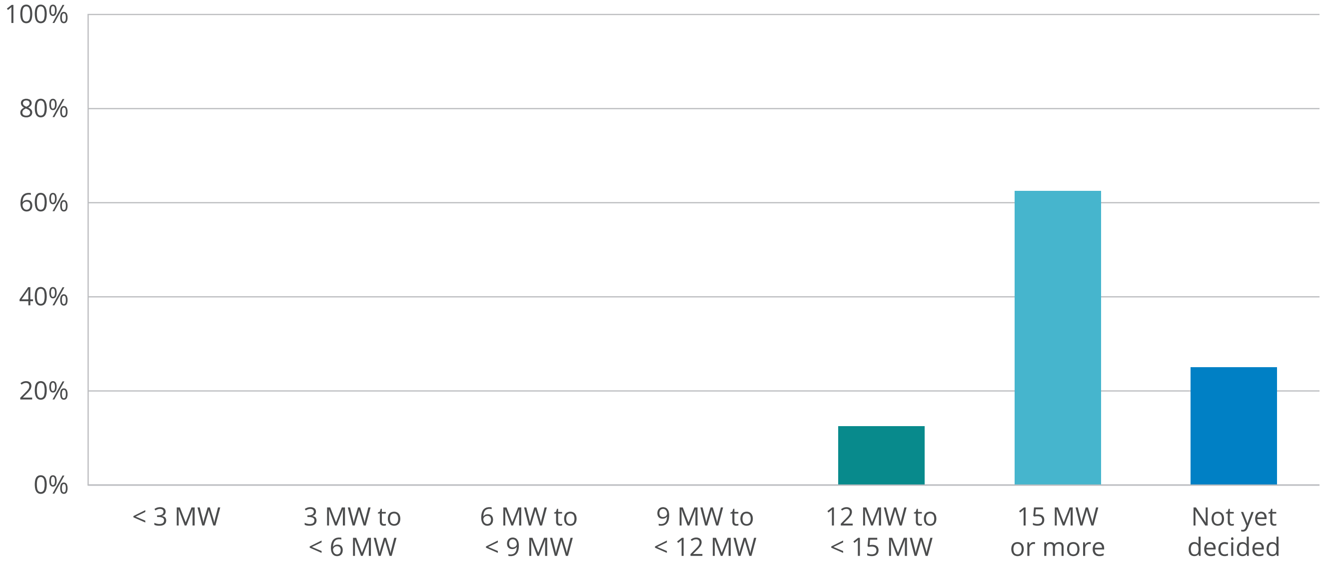


Figure 33: Water depth in which FOW platforms can be or are deployed

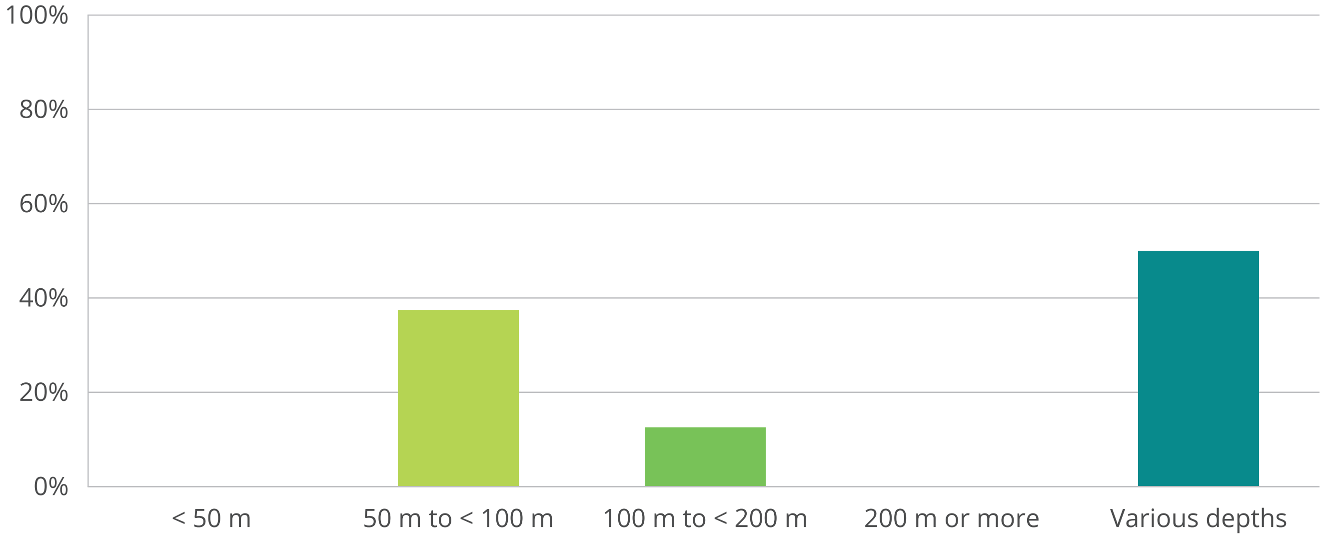
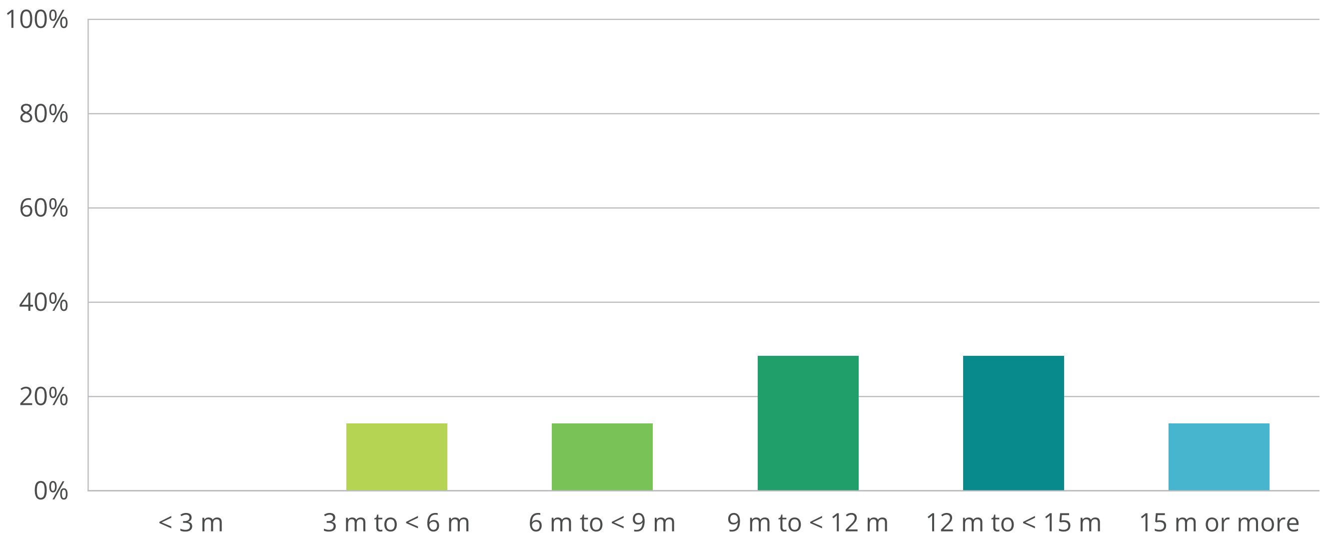


Figure 34: Quayside depth required for deployment



83% of respondents will assemble the FOW turbines at the quayside, and 17% require an intermediate safe harbour zone with a minimum depth of 9 m for assembly. In terms of quayside depth for deployment, respondents require various depths as shown in Figure 34.

Ports with depths of more than 9 m are required for most quayside deployments and tow out. Developers were not able to identify suitable ports at the time of answering the survey. Some of the comments included were as follows:

- *Various ports are still under consideration. Ideally are local ports, but this is not always feasible. Ports are not suitable for many reasons: limited water depths, commitments to existing sectors, navigation constraints, etc.*
- *To be confirmed.*
- *The specific port to be used is currently under investigation. For projects where there isn't sufficient existing infrastructure nearby, there are investigations ongoing to possibly develop a FOW specific port.*

2.6.1.3 Technology Selection by FOW Farm Developers

In terms of platforms most suitable for Atlantic/Celtic Sea conditions, the platforms were ranked as follows:

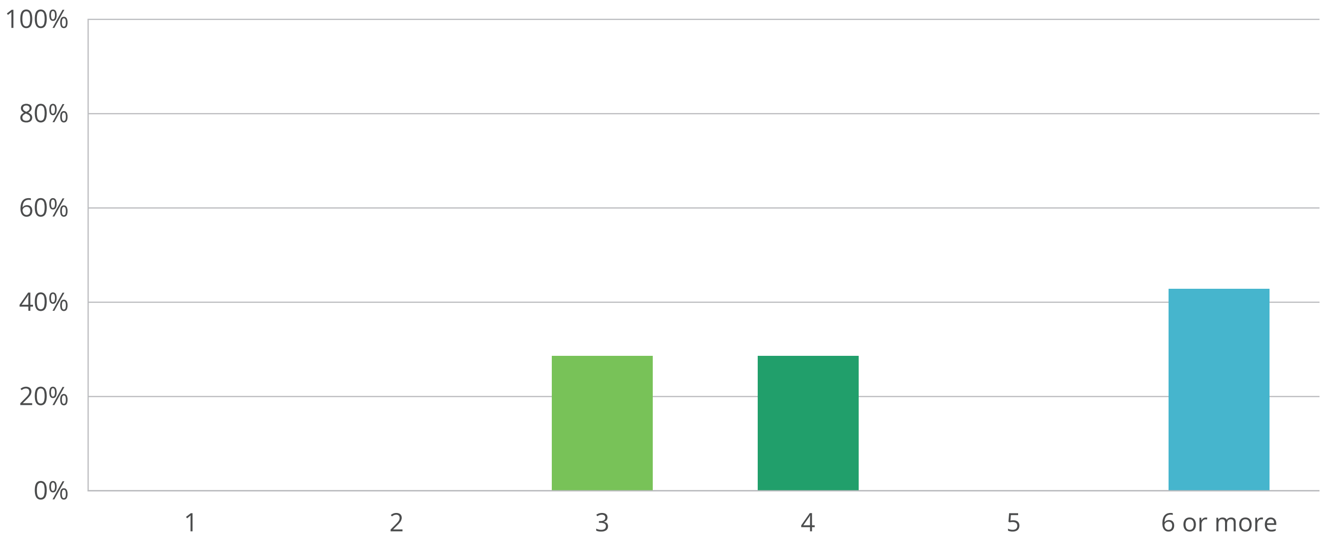
1. semi-submersible,
2. TLP,
3. barge, and
4. spar.

During the technology evaluation process, 43% of the respondents have evaluated more than six different types of FOW technologies, while 28.5% have evaluated three and a further 28.5% have evaluated four FOW technologies, as summarised in Figure 35.

When considering a technology's suitability, the following comments were collected:

- *In order of priority:*
  1. *manufacturing, standardisation, transport, and logistic issues (cost);*
  2. *bathymetry and seabed conditions – on this TLP and spar can be dismissed; and*
  3. *performances.*
- *In-house (joint venture partner) floating team who carry out dimension analysis, dynamic studies, stationkeeping studies etc.*
- *We undertake a multi-disciplinary technology and commercial review.*
- *Whether they are suited to the site, considering:*
  1. *water depth;*
  2. *site condition (significant wave height, wind speed etc.);*
  3. *supply chain (if there is a local supply chain or whether much of it would need to be imported); and*
  4. *fabrication/installation port facilities.*
- *TRL, logistics aspect in particular port infrastructure, and compatibility with wind turbine generator requirements.*
- *By its capability to be built and installed by the existing supply chain in the project area, and competitiveness.*

Figure 35: Number of different types of FOW technologies evaluated for use in the FOW farm



When asked for the importance of aspects and essential characteristics of FOW turbines, the following ranking was determined:

1. cost;
2. faster assembly;
3. easier deployment;
4. less materials required;
5. statement of feasibility by a certified international organisation, e.g., Det Norske Veritas (DNV);
6. reduced mooring loads;
7. stability characteristics;
8. operation and maintenance (O&M) requirements; and
9. good accessibility.

Cost, as expected, was the most important consideration when developing a FOW farm. It was interesting that O&M and accessibility were ranked at the bottom, and it might be because these aspects of FOW have not yet been considered in detail. Developers appear to be determined to deploy quickly and worry about maintenance later.

2.1.6.4 Risk and Challenges seen by FOW Farm Developers

43% of the respondents believe that the FOW technology and industry are ready for and advanced enough to immediately deploy 1+ GW wind farms in terms of large-scale commercial roll out in Atlantic Ocean sites. However, 57% suggest that a more gradual approach and increase in farm size to reach 1+ GW size over a five- to ten-year period is more acceptable and the best way to proceed.

When asked to rank the risks associated with FOW developments, the following ranking was determined:

1. supply chain issues;
2. shortage of skilled personnel;
3. inadequate port infrastructure;
4. poor availability of deployment vessels and machinery;
5. license process complications;
6. process involved in grid connection;
7. inflation/increased costs;
8. lack of weather windows for deployment;
9. lack of weather windows for O&M; and
10. insufficient technology testing process.

Other risks outlined by respondents include:

- *Lack of data for the wind turbine generator characterisation and availability of the wind turbine generator developers for the floating support structure and wind turbine generator compatibility analysis.*
- *Government/transmission system operator confidence in floating technology in a 2030/2025 timeframe, and at a cost that is roughly comparable to fixed wind.*
- *Adequacy of subsidy support mechanism. Work with industry group to promote skills initiatives. Identify innovations with the potential to reduce mean time for deployment.*
- *Conflicts in marine space usage.*

Developers have identified supply chain issues, shortage of skilled personnel, and inadequate port infrastructure as the main risks associated with building FOW farms. Weather windows for deployment and O&M were considered the least risky ahead of insufficient testing process. Only 50% had developed an O&M strategy for their windfarms. Again, this implies that developers feel the technology is ready for development.

In addition, the following comments were received in the open comment section:

- *The operation and maintenance strategy is based on the condition monitoring system and the digital twin for the forecasting of the operations. Other inspections according to the original equipment manufacturer instructions will be also operated.*
- *O&M strategy is ongoing. Noted that EirGrid will be the offshore 'transmission asset owner' and will be responsible for O&M of assets from the offshore substation to the onshore project substation which is the interface for ESBN as onshore 'transmission asset owner'.*
- *It is expected that initially O&M will be similar to fixed wind with the additional complexity of return to port requirement for major component replacement.*
- *No O&M strategy has been finalised, however strategies, such as tow-to-port O&M, have been investigated.*

2.6.1.5 Investability Opinions by FOW Farm Developers

72% of the respondents are planning a wind farm lifetime of between 30 to 35 years. 14% plan for a lifetime of 35 years or more, and 14% are planning for 20 to 25 years. No respondent is planning for less than 20 years or between 25 and 30 years. All respondents expect a return on their investment of 10 to 15 years. When asked to rank the difficulty of securing investment, 60% of the respondents described it as neither easy nor difficult and 40% described it as difficult. When asked what government supports, or policy would encourage investment, developers suggested the following;

- *Clear regulation, legal certainty, simplicity in the permitting, awareness of the local population of the commitment to renewable energy.*
- *Port build-out, policy clarity, a grid connection process for Phase 2 and enduring offshore projects (post 2030), more interconnection targets, clarity on the DECC hydrogen strategy which will pave the way for future renewable integration, specific sections of the ORESS auction set aside for FOW until cost parity has been reached with fixed wind.*
- *Clear stable support mechanisms which are accessible and have sufficient budget to support the high cost of initial floating wind deployment at pre-commercial scale such that investors can rapidly build the confidence required to underwrite industrial scale deployment.*
- *Support identifying and securing seabed exclusive rights.*

2.6.1.6 FOW Farm Developers Survey Conclusion

The FOW farm developers survey results are based on the answers of eight respondents.

The respondents have deployed or are planning to deploy FOW farms at various locations across the world including, Atlantic Ocean, North Sea, Baltic Sea, Mediterranean Sea, Celtic Sea, Irish Sea, Pacific Oceans, Indian Ocean, and Sea of Japan. These locations are vast areas with lots of wind energy providing an extensive market opportunity.

As all respondents have been working on FOW projects for less than six years, it shows that the industry is young and deployment experience may be relatively low. Some techniques and practices from the oil and gas industry can be utilised, however, the oil and gas industry is made up of fewer larger standalone units, in contrast, FOW farms are made up of many more smaller units.

50% of the respondents plan on developing large 1+ GW FOW farms with turbine sizes of 15+ MW in a wide range of depths from 50 m to more than 200 m. Ports with a depth of 12 m are required and 86% of the structures being designed will be assembled at the quayside.

FOW developers want platforms that are cost effective, fast to assemble, easy to deploy, and use less materials. 88% of the respondents believe that the semi-submersible platform is the most suitable floater type for Atlantic conditions. O&M requirements and good access are ranked lowest in terms of importance when developing a FOW farm. If O&M requirements are not facilitated at an early stage, it could cause issues in months to come when repairs are necessary, and the access issues were not addressed.

The respondents confirmed that supply chain issues, shortage of skilled personnel, and inadequate port infrastructure are the main risks associated with FOW development. As the FOW industry is in its infancy and large-scale deployment has yet to commence, supply chain routes, practices, and supplies need to be developed and streamlined. Personnel need to be upskilled from other industries and new training practices need to be established to ensure safe working practices are implemented. Port infrastructure was also highlighted as a challenge. It will be up to governments to work with port authorities and FOW farm developers to ensure infrastructure is upgraded to cater for storage and assembly of parts and completed structures.

2.6.2 FOW Technology Developers Survey

This survey was aimed at technology developers working on FOW technologies. The questions were asked in a way that allowed for a better understanding of their level of readiness.

The survey on FOW technology developers' readiness consisted of 32 to 39 questions (depending on the TRL of the FOW technology), grouped into the following categories:

- organisational details,
- technical details,
- maturity – TRL5 or above,
- maturity – TRL4 or below,
- risk and challenges, and
- investability.

2.6.2.1 Respondents to the FOW Technology Developers Survey

For the FOW technology developers survey, 17 responses have been received. Of the 17 responses 47% were multinational corporations with over 250 employees and 53% were SMEs, of which 12% were medium sized, 29% were small, and the remaining 12% were micro companies. None of the responses received came from higher education, non-profit organisations, or research institutes.

The questionnaire was completed by the following type of personnel in the various companies:

- chief technology officer,
- chief executive officer,
- chief commercial officer,
- project director,
- project manager,
- project engineer,
- floating wind manager,
- naval architect,
- business development manager, and
- business development associate.

The profile of the companies and the experience of the respondents is clear. It also gives confidence that their responses are accurate.

81% of the respondents who replied have not tested their FOW technology in an open sea environment, while 19% of the respondents currently have a FOW platform deployed in an open sea environment. Some of the locations include France, Japan, and Gran Canarias, and range in size from 225 kW to 3 MW.

2.6.2.2 Technical Details from the FOW Technology Developers

Barge-type FOW platforms appear to be the most common (36%) platform being developed by the survey respondents, followed by semi-submersibles (29%) and TLPs (14%), as shown in Figure 36. None of the companies surveyed are developing spar-type FOW

Figure 36: Type of FOW platform being developed

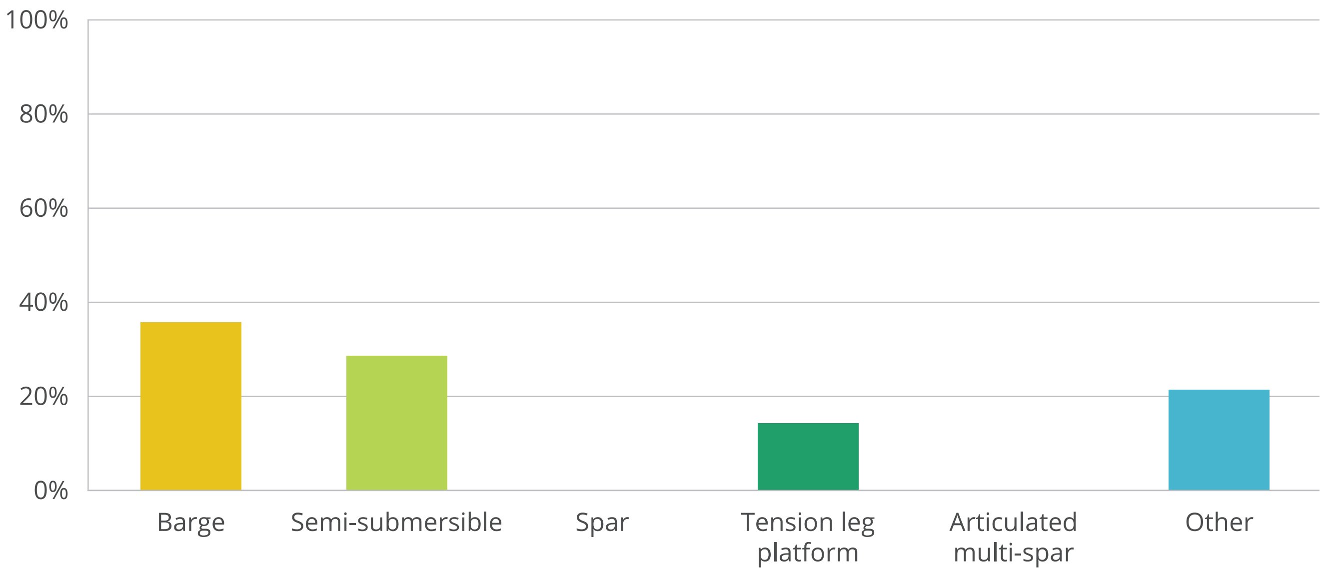
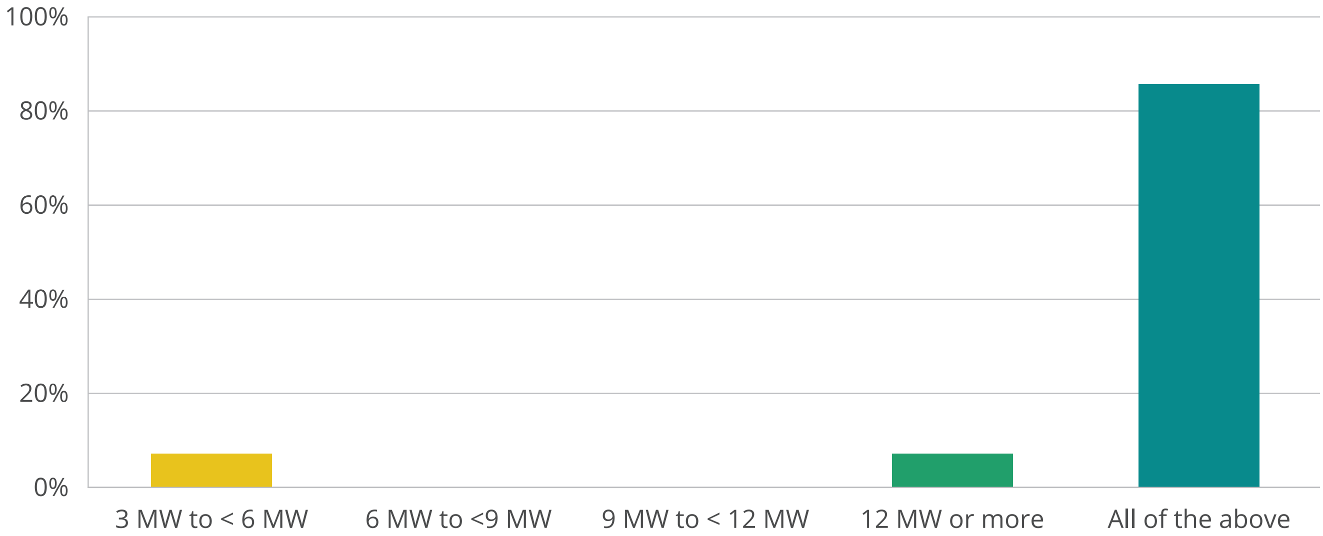


Figure 37: Turbine sizes the FOW platform can support



platforms. However, there was an option to describe alternative platform types. The responses received are as follows:

- *hybrid-spar and semi-submersible;*
- *hybrid semi-submersible; and*
  combination of a semi-submersible and TLP through single point mooring system in a downwind configured design.

Over 86% of the FOW platform designs can be used to support a wide range of turbine sizes from 3 MW to more than 12 MW, as presented in Figure 37. 7% of the responses implied that their design is only suitable for a range of 3 MW to < 6 MW, while another 7% answered 12 MW or more. This shows that technology developers need to design platforms that can carter for a wider market.

In the following, open-text answer are presented, how the respondents describe any unique features about their FOW platform:

- *Concrete as material, hybrid mooring lines (chains and fibre), single-point mooring system.*
- *Modularity and easy construction.*
- *The structure supporting the nacelle is a pyramid instead of a single tower. Thanks to the better distribution of the stresses, the weight of the structure is 40% lower than conventional semi-submersibles.*
- *First motion damping system using oscillating moonpool.*
- *Multi-turbine, inclined towers.*
- *Dynamic mooring system to balance pitch and motions with vertical lines similar to TLPs and loads similar to semi-submersibles.*
- *Single point mooring.*
- *Concrete, stable in transport, manufacture-oriented design.*
- *Fast construction.*

79% of all the platforms being designed can operate in any depth of water (cf. Figure 38). It becomes clear that developers want to design versatile structures for a wide range of locations. One design for multiple applications will drive down LCOE.

Quayside depth is an essential infrastructure in the development of FOW farms. 48% need between 9 and 12 m, 38% need between 6 and 9 m, and 16% need between 3 and 6 m, as presented in Figure 39. Understanding the deployment requirements allow ports to upgrade their infrastructure to cater for the FOW industry.

86% of the structures being designed will be assembled at the quayside, 7% will be assembled at an intermediate safe harbour, and 7% of the assembly processes will be a combination of both (cf. Figure 40).

69% of the platforms will require three mooring lines to secure it to the seabed. 8% will need four mooring lines, while 23% will use six or more, as shown in Figure 41.

Figure 38: Water depth for which the FOW platform is designed to operate in

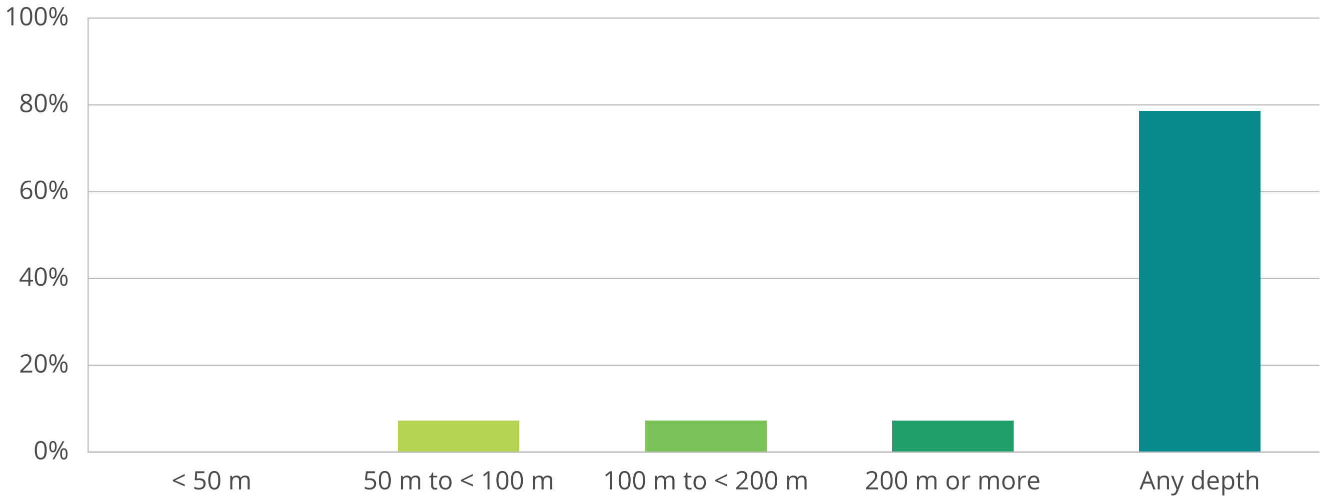


Figure 39: Quayside depth required for assembly and tow out

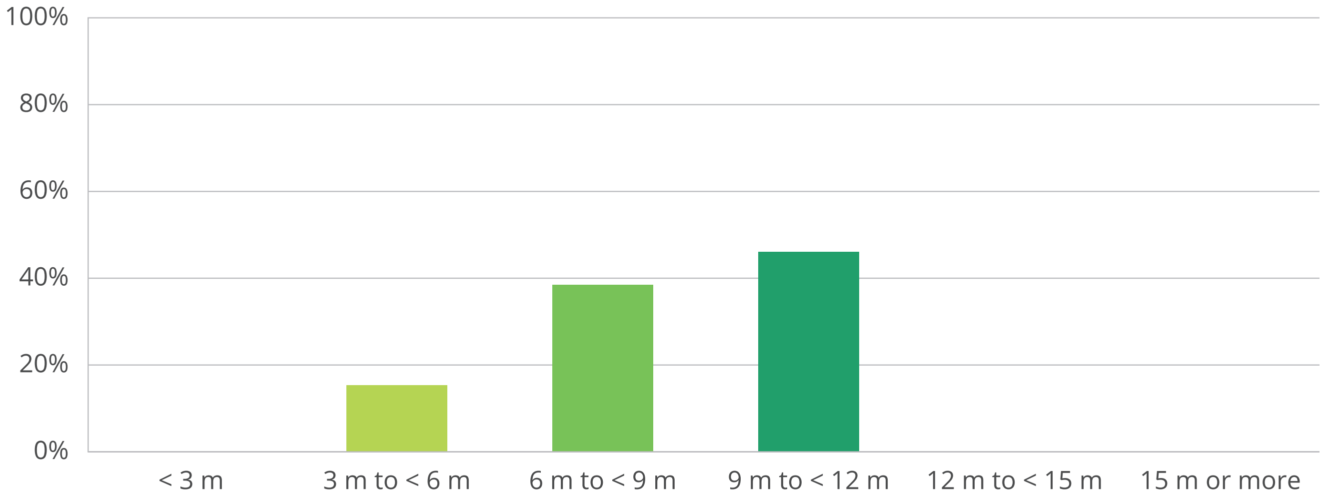


Figure 40: Assembly location

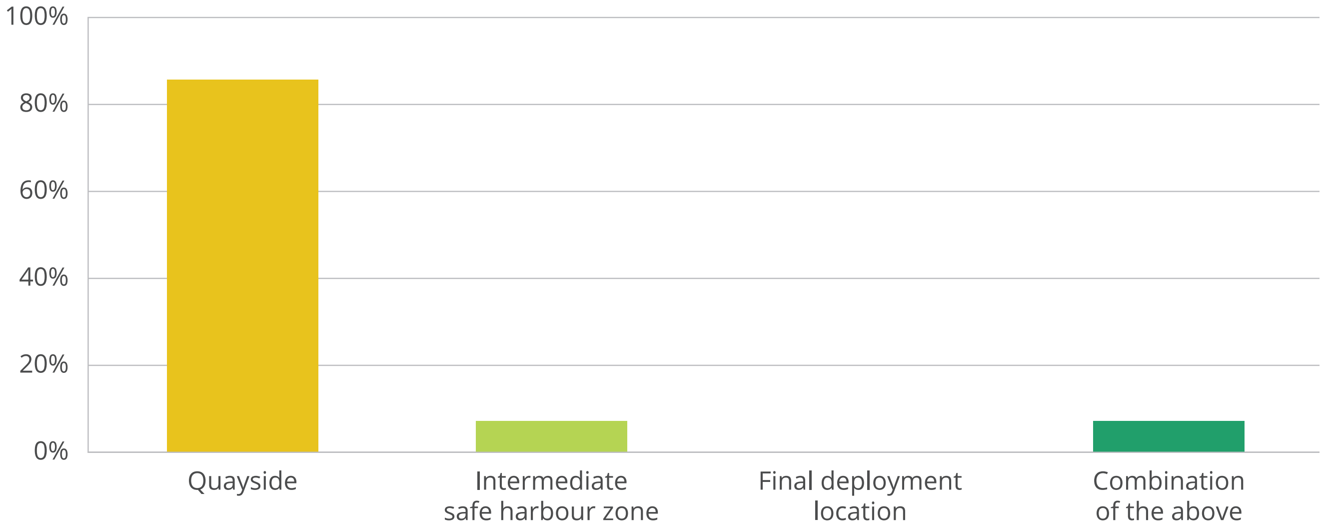


Figure 41: Number of mooring lines required to secure the FOW platform

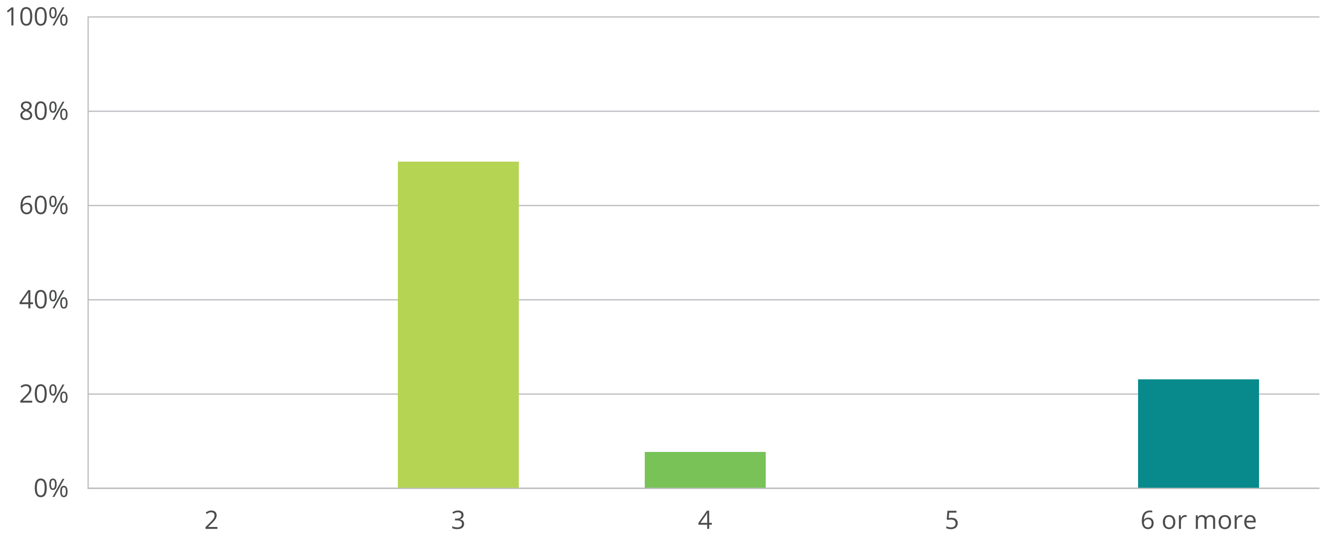


Figure 42: Current TRL

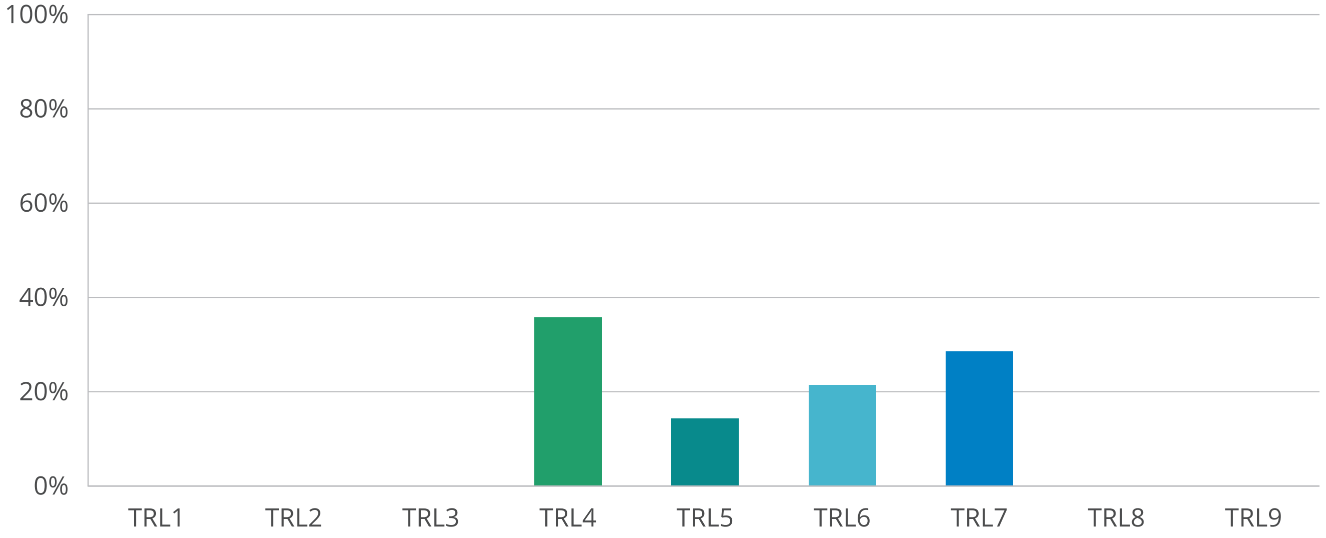


Figure 42 visualises the current TRL of the FOW technology designs developed by the companies represented by the respondents of this survey. For the next two sets of questions it was separated between technologies of or below TRL4 and technologies of and above TRL5.

2.6.2.3 Technology Development Aspects for more Mature Designs (TRL5 or Above)

88% of the respondents with a FOW technology of TRL5 or higher completed numerical modelling, tank testing, and received an engineering certificate (cf. Figure 43). An open sea test was completed by 63% of the respondents with a FOW technology of TRL5 or higher, while 12% completed a scaled open sea test.

80% of the respondents with a FOW technology of TRL5 or higher declared that it had been more than 12 months since their last test, while 20% last tested between six and 12 months ago, as shown in Figure 44.

75% of the tests with a FOW technology of TRL5 or higher were carried out for more than 12 months, and 25% of the tests lasted between three and six months (cf. Figure 45). Usually, 12 months of open sea testing is required to prove a concept.

Figure 43: Types of work and testing that have been carried out

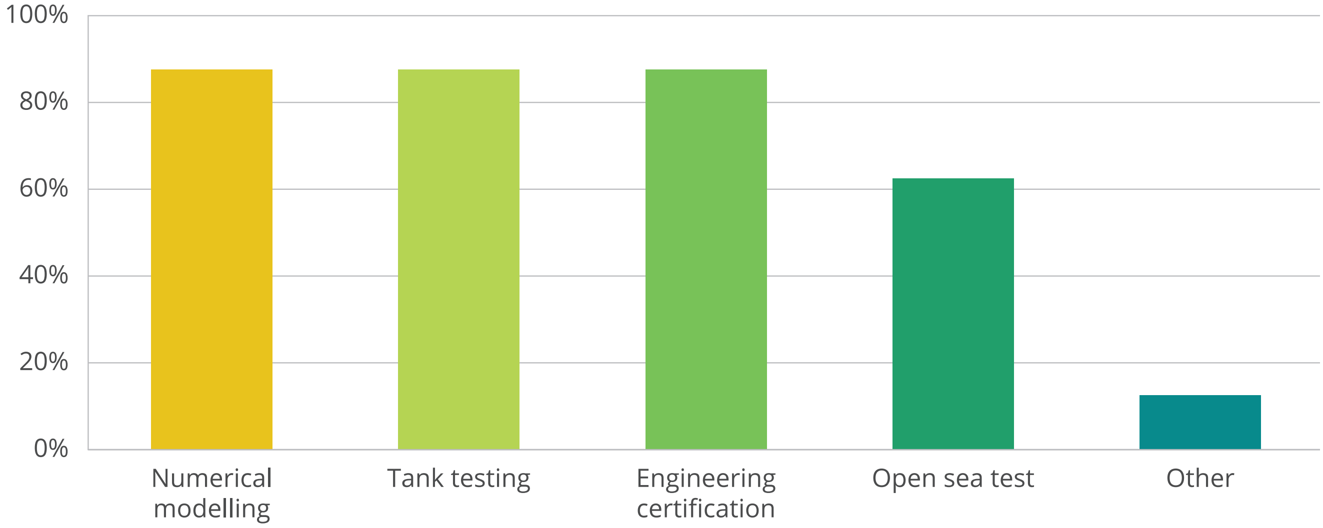


Figure 44: Time since last open sea test

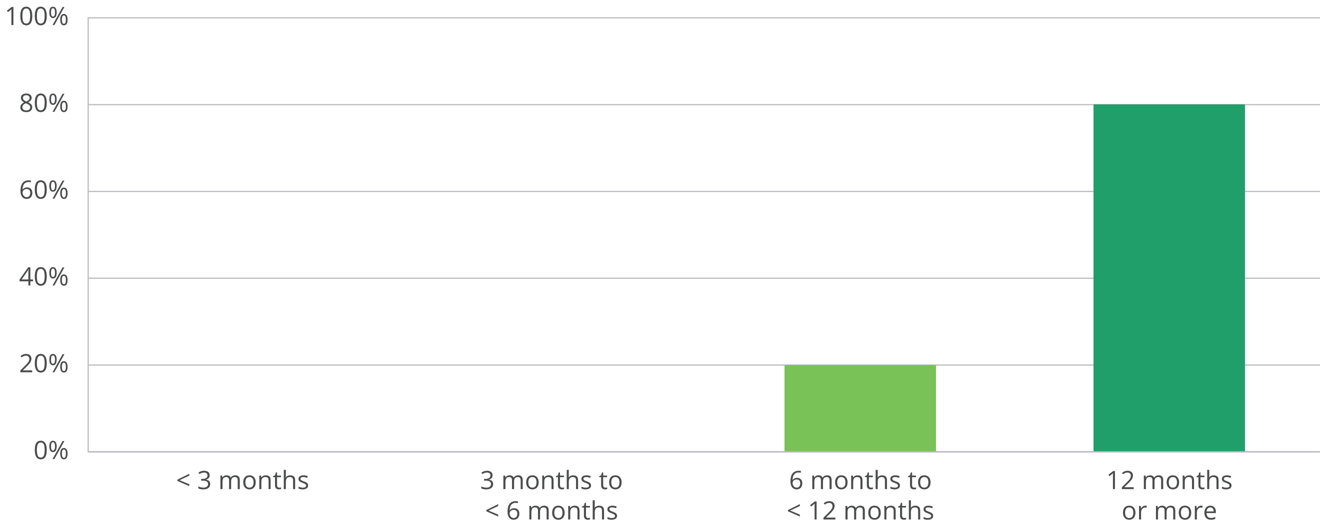
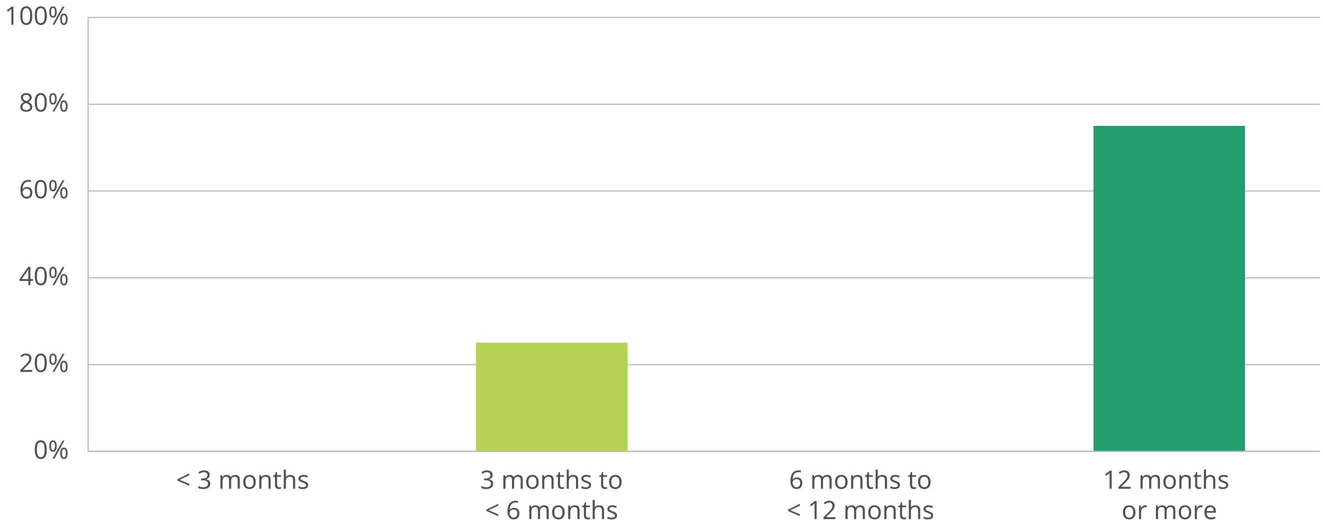


Figure 45: Duration of open sea test



The open sea tests have taken place in Spain (Abra Sardinero and BiMEP), Italy, France, and Japan. Thus, the tests were predominantly carried out in Europe. The reasons for choosing these test sites were the following:

- *regional support;*
- *strong support from local government;*
- *good infrastructure;*
- *grid connection in place;*
- *construction site close to installation site;*
- *proximity to company office; and*
- *suitable metocean conditions for scale of prototype.*

An even split of 25% each experienced highest hourly average wind speed of 5 m/s to < 10 m/s, 15 m/s to < 20 m/s, 20 m/s to < 25 m/s, and 25 m/s to < 30 m/s during deployment (cf. Figure 46). Winds speeds of 25 m/s to < 30 m/s would be considered ocean conditions, whereas highest hourly average wind speed of 5 m/s to < 10 m/s would not be considered as ocean conditions and further testing would be required for commercial deployments in the Atlantic Ocean.

34% of the open sea tests experienced significant wave heights of between 1 and 5 m and 66% of the open sea tests experienced significant wave heights of between 5 and 10 m (cf. Figure 47). Waves with

Figure 46: Highest hourly average wind speed recorded during deployment

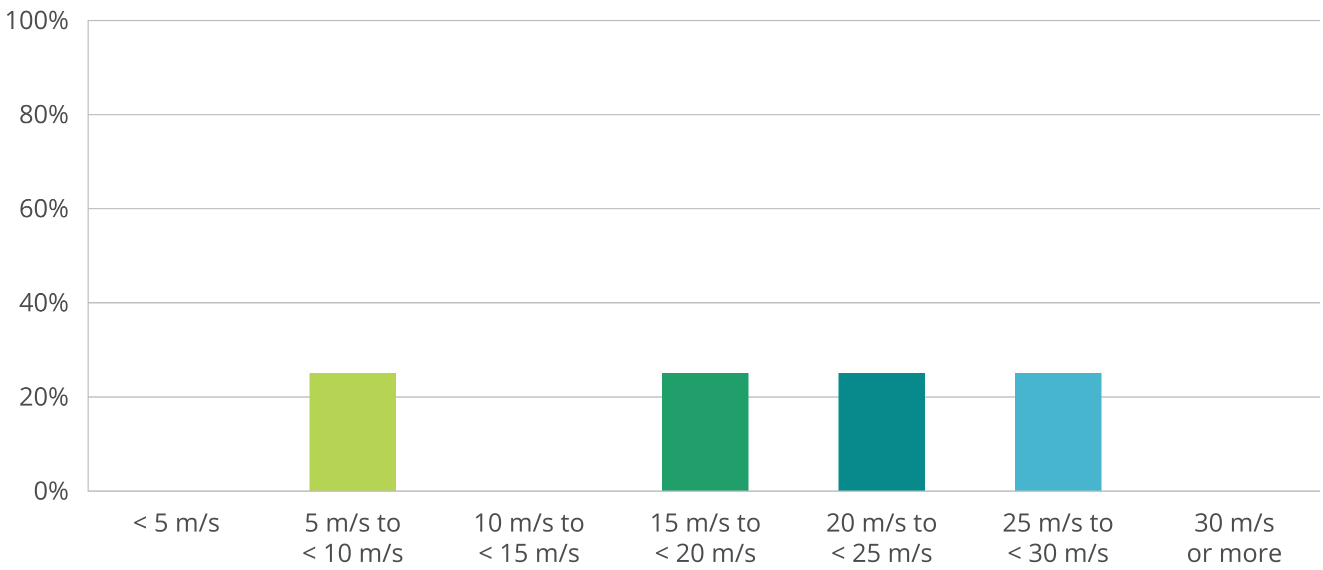
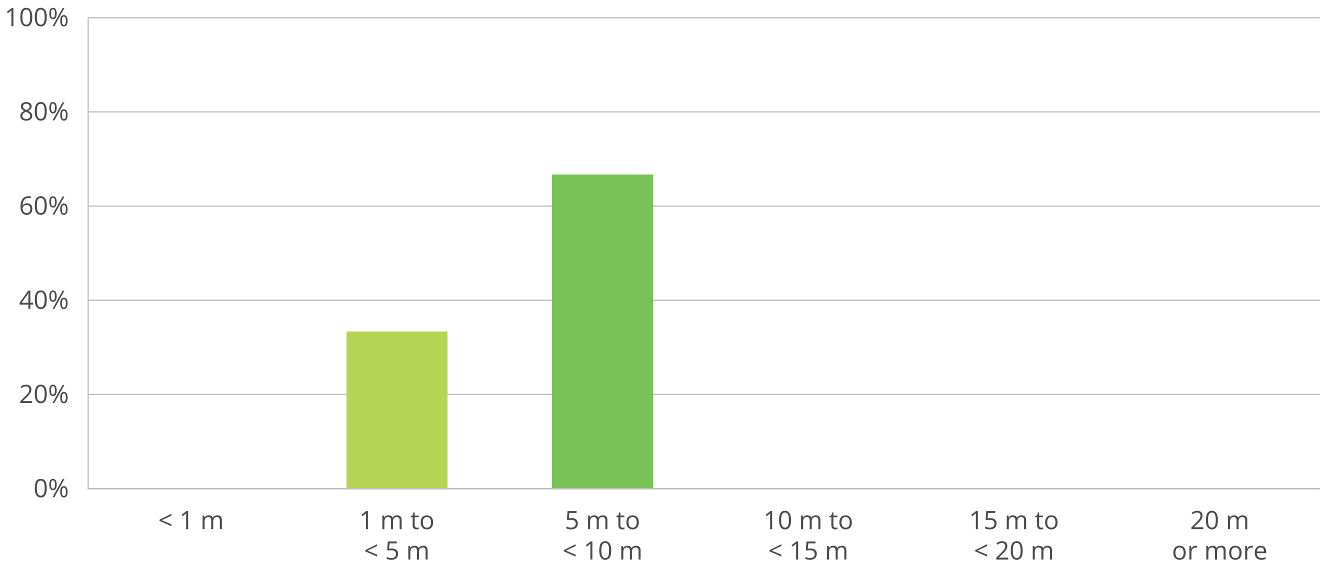


Figure 47: Average significant wave height recorded during deployment



a significant wave height greater than 2.5 m are generally considered large, and those above 6 m are considered very large. Here, respondents probably gave the maximum significant wave height rather than the average one, as values of up to 10 m are not likely.

80% of the technologies with a TRL5 or higher have been assessed by a certification authority, such as:

- Bureau Veritas,
- Lloyd's Register,
- DNV,
- ClassNK, and
- American Bureau of Shipping.

This clearly shows that the technologies are performing well and making progress to commercialisation.

One third of the respondents with a FOW technology of TRL5 or higher acknowledged that all aspects of their technology needed further testing, while one sixth require further testing on both the turbine and the platform (cf. Figure 48). Another sixth of the respondents with a FOW technology of TRL5 or higher do not need any further testing, and as well another sixth mentioned the following other technological aspect to be further tested:

Figure 48: Most critical technological aspect that needs further testing

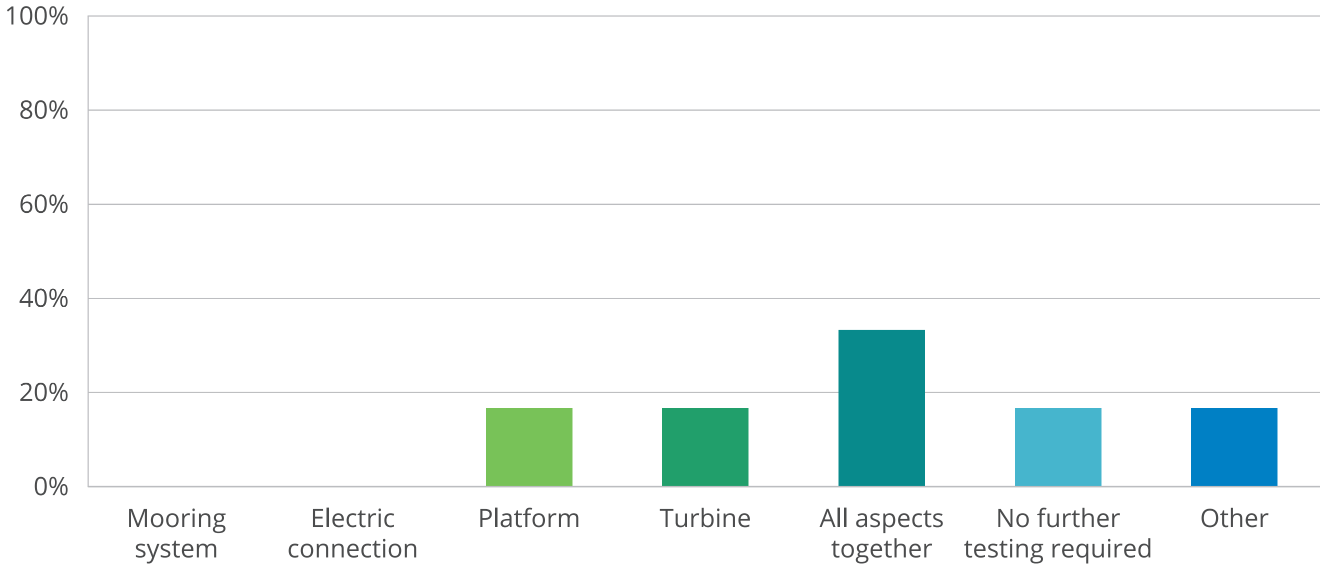
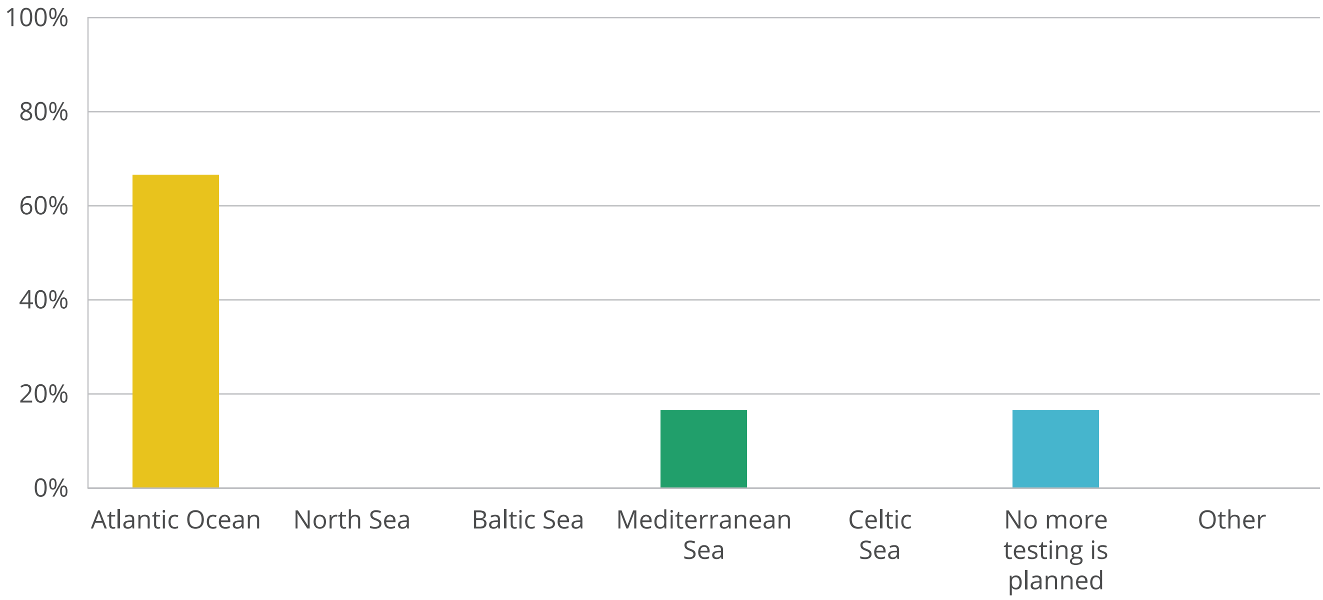


Figure 49: Location of further tests



Intermediate step of pre-commercial wind farms (45-48 MW) for key stakeholders to understand what's a FOW farm, important to engage with fishermen, touristic field, biodiversity, navigation.

Two thirds of the respondents with a FOW technology of TRL5 or higher are planning to carry out further tests in an Atlantic environment, as shown in Figure 49. One sixth will perform more tests in the Mediterranean Sea, while the remainder do not have any further testing planned.

Two thirds of the respondents with a FOW technology of TRL5 or higher believe that their technology should be tested in a site that is exposed to extreme Atlantic weather conditions before commercial deployment, while one third did not think it was required, as already indicated in Figure 49. The following explanations were given:

- *BiMEP already has very strong conditions. It is relevant to have the whole range of scenarios (e.g., low wind speeds with low wave heights, low wind speeds with high wave heights, high wind speeds with low wave heights, high wind speeds with high wave heights, storms). Everything is covered throughout the year at BiMEP.*
- *The purpose is now for us to complete validation of our full numerical integrated modelisation of the technology in its environment.*
- *The benefit of testing at a site exposed to extreme Atlantic weather conditions is that it validates the technology in most of the other locations. It may not be mandatory, but it brings comfort on the suitability of the technology, and it is certainly an advantage when discussing with the client, its lenders, and its technical advisors.*
- *Severe sea-state tests are required, as well as severe day-to-day sea conditions. Tests are already done at SEM-REV.*

2.6.2.4 Technology Development Aspects for less Mature Designs (TRL4 or Below)

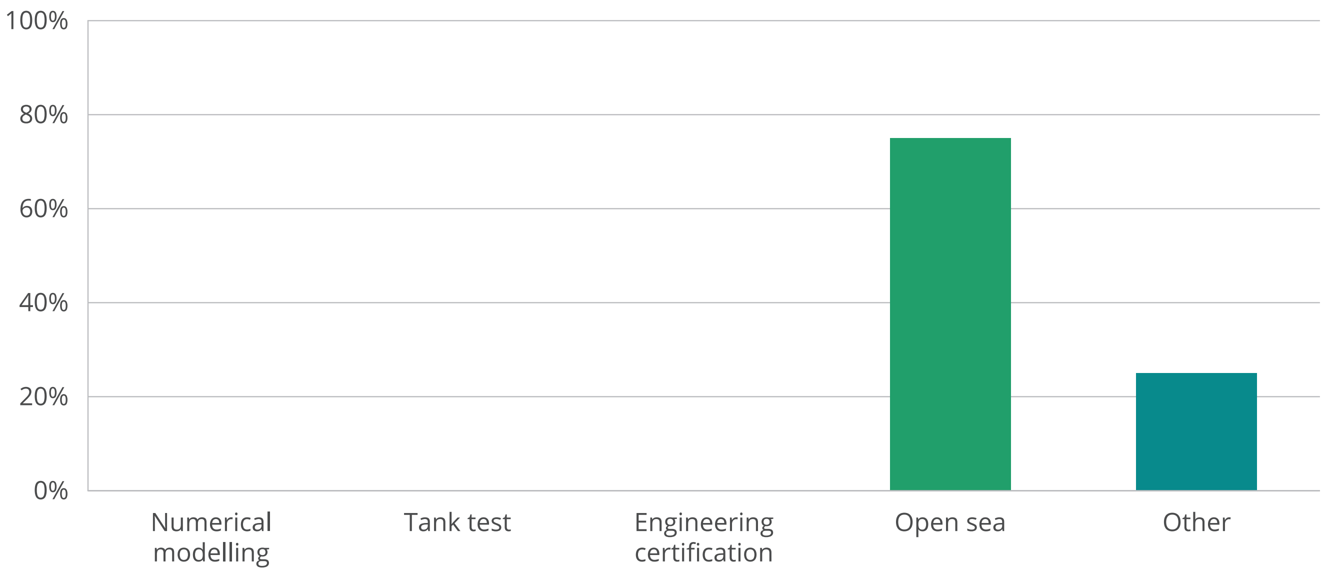
For 75% of the respondents with a FOW technology of TRL4 or lower, the next stage is open sea testing (cf. Figure 50). As other steps, the following information was provided:

- *conceptual engineering;*
- *tank test;*
- *approval in principle;*
- *high power prototype basic engineering; and*
- *high power prototype commercial wind turbine generator compatibility analysis.*

All respondents with a FOW technology of TRL4 or lower think that their technology should be tested at a site that is exposed to extreme weather conditions prior to commercial deployment, suggesting the critical need for test sites when proving technologies. As explanations, the following answers were given:

- *Not because of the extreme conditions but for the demonstration of the technology in real sea conditions, for acquiring deep knowledge of the concept and prepare it for the series production.*

Figure 50: Next stage of development



- *Pre-commercial projects are usually needed to demonstrate technical feasibility and bankability of your technology prior to large investments and commercial deployment.*
- *The mooring system is unique and although proven in basin tests should be demonstrated at pilot scale in open ocean. This is planned for 2024.*
- *Risk mitigation.*

25% of the respondents with a FOW technology of TRL4 or lower will secure funding from third party investors, and the remainder will seek funding from a combination of all options, as presented in Figure 51. All respondents with a FOW technology of TRL4 or lower plan to reach TRL9 between two- and four-years' time, hence between 2025 and 2027.

All respondents with a FOW technology of TRL4 or lower foresee availability of finances as being an obstacle. Furthermore, as shown in Figure 52, half foresee access to open sea test site facilities as an obstacle and a quarter believe supply chain issues will slow progress.

Figure 51: Sources of funding

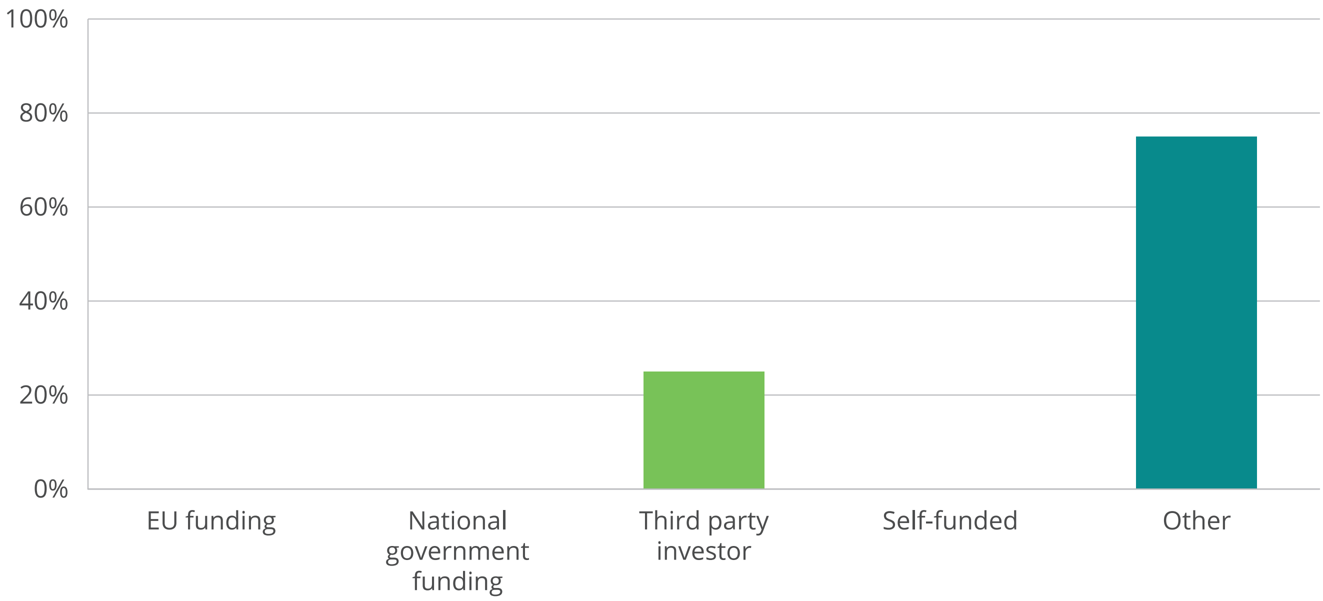
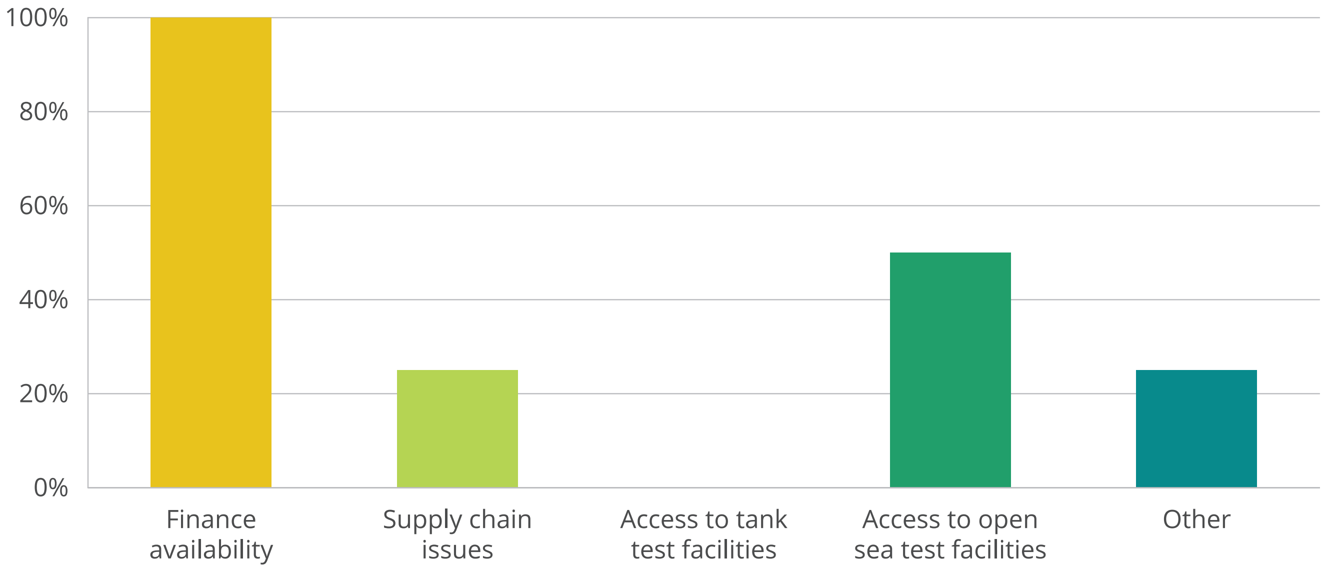


Figure 52: Foreseen obstacles for a smooth and fast progress



2.6.2.5 Risk and Challenges seen by FOW Technology Developers

Table 9 ranks the risks associated with full scale deployment seen by the FOW technology developers answering the survey. Thus, financing, inflation, and costs appear to be the main concern as well as license process complications. Weather windows for O&M and deployment are of a less concern along with shortage of skilled personnel.

Table 9: Ranking of risks associated with full scale deployment

Rank	Risk
1	Financing
2	License process complications
3	Inflation/increased costs
4	Process involved in grid connection
5	Poor availability of deployment vessels and machinery
6	Inadequate port infrastructure
7	Supply chain issues
8	Lack of weather windows for deployment
9	Shortage of skilled personnel
10	Lack of weather windows for O&M

Additionally, the following other risks were identified:

- *Lack of infrastructure in EU is main bottleneck; availability in ports as second risk; local content; civil construction supply chain.*
- *Lack of data for the wind turbine generator characterisation and availability of the wind turbine generator developers for the floating support structure and wind turbine generator compatibility analysis.*
- *Low profitability of turbine manufacturers and competition with bottom-fixed large volume orders. Lack of policy and government subsidies.*
- *Sites for demonstration of scaled technology are difficult to find. The demonstrators are scaled models, but the environmental conditions are not. Therefore, the equivalent ocean conditions at commercial scale do not exist.*
- *The risks are very concept specific.*

In order to mitigate the top three ranked risks the following plans were outlined:

- *Focus investment in Spanish port to have warranty in deliverability; local content via concrete solution.*
- *Anticipation and involvement of local authorities at the earliest stage.*
- *1. Active search for potential investors, application for public aid, and alliances with strategic partners.*
  2. Space reservations in R&D and innovation platforms in marine energies of Spain.
  3. Contacts with suppliers and request for quotation for mean reservation based on planning.
- *1. Long term planning and early engagement with transmission system operators (TSOs).*
  2. Same for port infrastructure, it requires early investment that are only possible with visibility on future programs
  3. Early stakeholders' engagement and simplification of admin processes by governments.
- *1. Supply chain: mainly wind turbine availability; secure turbine prior to starting projects.*
  2. Increased costs: secure long lead items and port infrastructure in stage gate at end of engineering/design certification.
  3. Grid connection: work on secured test sites.
- *1. As a small company, financing can be mitigated by bringing in a large partner and divesting part of the project.*
  2. Clear execution strategies and early project engagement with suppliers to ensure orders are issued on time and are contractually guaranteed.
  3. Lobbying in the public administration, ensuring significant local content and engaging with key marine stakeholders.
- *Working with countries that invested in test sites with facilities required, i.e. easy permitting and grid connection. Government funding access for innovation.*

2.6.2.6 Investability Opinions by FOW Technology Developers

Table 10 presents the distribution of how far, i.e. up to which TRL, investment has already been secured.

Table 10: TRLs up to which investment is secured

Answer Choices	Responses
TRL1 – basic principles observed	0
TRL2 – technology concept formulated	0
TRL3 – experimental proof of concept	0
TRL4 – technology validated in lab	14%
TRL5 – technology validated in relevant environment	14%
TRL6 – technology demonstrated in relevant environment	14%
TRL7 – system prototype demonstrated in operational environment	30%
TRL8 – system complete and qualified	14%
TRL9 – actual system proven in operational environment	14%

14% of the respondents claimed that stability characteristics and another 14% highlighted that low LCOE is their unique selling point (cf. Figure 53). 29% mentioned that their technology is easily mass produced. The remaining 43% left the following comments regarding the unique selling point of their FOW technology:

- *concrete solution (less volatile price – the business case – and low carbon footprint),*
- *high power density, and*
- *all of the above.*

60% of the respondents, as shown in Figure 54, assessed that it is difficult or very difficult to secure funding, while 15% found it very easy and the remaining 15% found it neither easy nor difficult. As process that has been followed to secure investment, the following steps and aspects were outlined:

- *Promising business plan, interesting set of potential partners and parties speaking to.*
- *Financial support from national government, financial support from European Fond (ERDF), and joint venture with other industrials.*
- *Participate with your own and partner funds, apply for public funds, arouse the interest of private investors related to the offshore wind value chain and foreign investors.*
- *Five rounds of combined public/private funding to go to demonstrator.*
- *Failed EU funding submission. Followed private investment funding.*

Figure 53: Unique selling point of the FOW technology

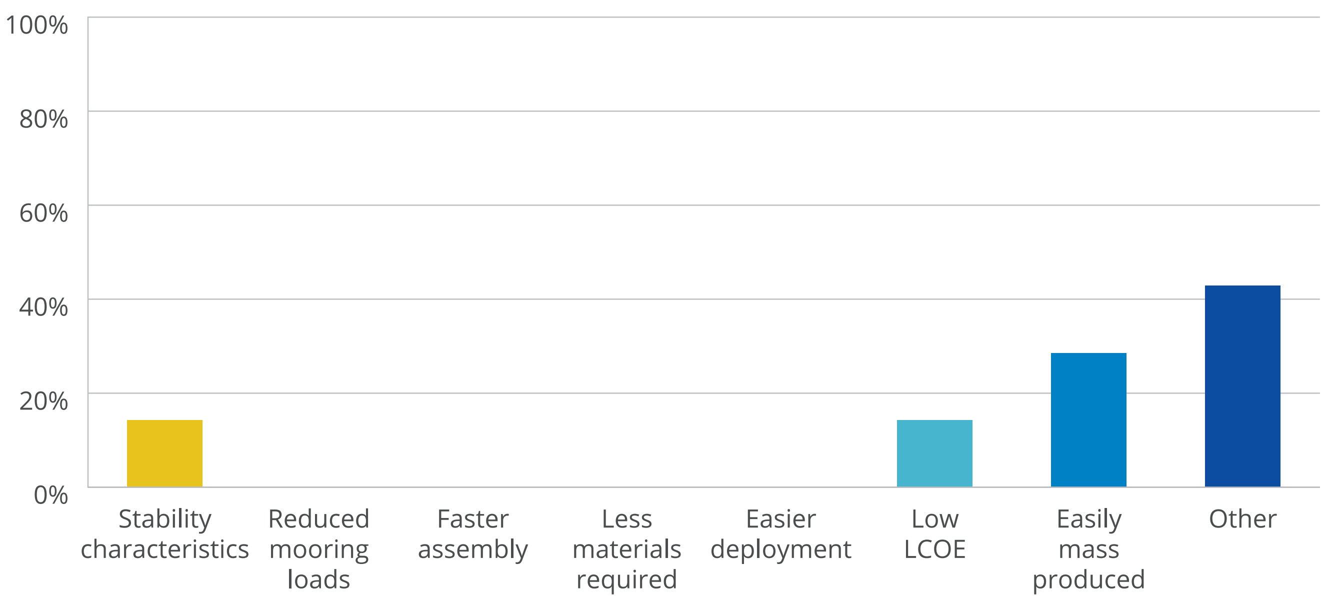
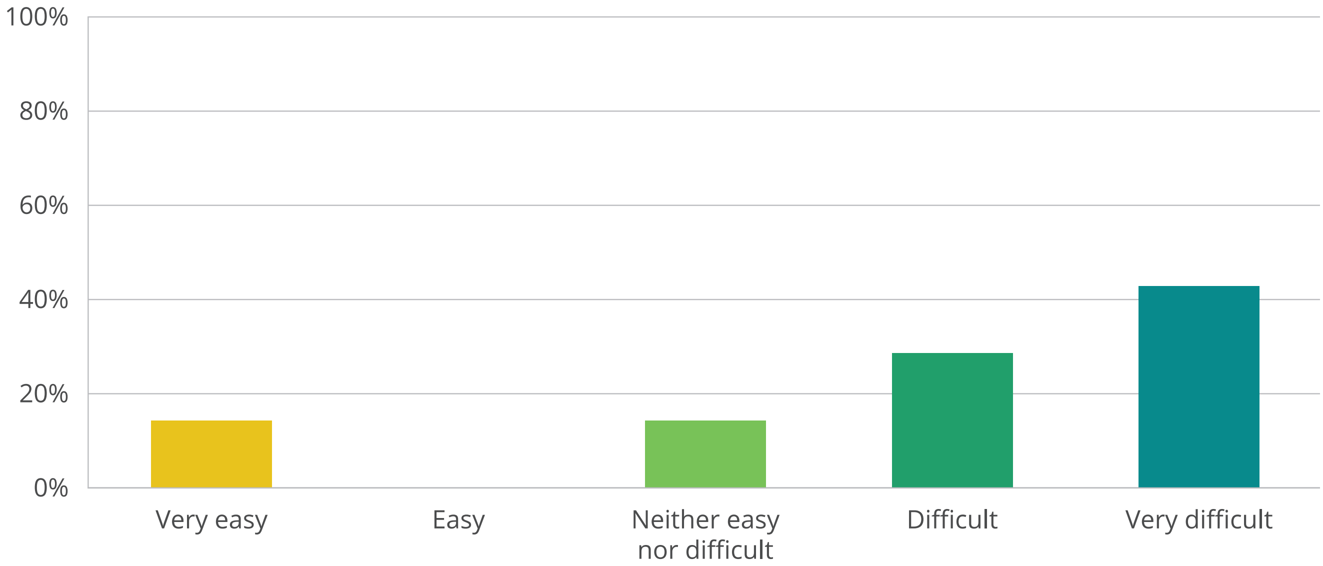


Figure 54: Difficulty in securing funding



To encourage investment through government supports or policies, the following suggestions and requirements were given:

- *Research and development projects and demonstration projects.*
- *Tax deduction proportionally to amount invested.*
- *Clear regulations regarding the planning of maritime space and the auction process. Reconciliation of the stakeholders involved in the territory with the offshore wind energy.*
- *Feed-in tariff supporting innovation. That brings visibility and allows investment.*
- *Test sites funding. Components offshore sea trials (moorings, cables, etc.).*
- *A clear offshore wind capacity target in a reasonable time frame. Subsidies schemes by means of renewable energy certificates, subsidised substations, or direct electricity purchase agreements. Policies to establish right of use of water areas. Fast permitting process with minimum bureaucratic redundancies. Adapting the grid according to additional capacity.*
- *Development of test sites. Grant funding for innovation. Easier permitting and surveys for developed sites. Support to pre-commercial demonstration/insurance and bankability.*

85% of the respondents have demonstrated their technology to FOW farm developers which shows they are moving towards commercialisation. 57% of the respondents have started the initial steps to selling their technology to wind farms developers which is a significant achievement. 72% of the respondents have received a statement of feasibility certified by an international organisation, which is another step closer to commercialisation.

As final comment in relation to the development of FOW platforms the following note was provided: *Among the many different concepts out there, not only one prevail but a handful of them will be more suitable for different markets with different metocean conditions, port infrastructure, or specialised supply chain. Also, we will likely soon will be looking up at China to improve the learning curve of FOW technologies.*

2.6.2.7 FOW Technology Developers Survey Conclusion

A wide range of platform types are being developed. Barge-type FOW platforms appear to be the most popular (36%) platform, followed by semi-submersibles (29%) and TLPs (14%). None of the companies surveyed are developing spar-type FOW platforms at the moment. Spar-type structures were the first designs and TLPs are the newest type. Spars require significant deployment depths which might be the limiting factor in their design. TLPs require less deployment depth but are very unstable until fixed to the anchoring system. Barge and semi-submersible platforms can be deployed from dry docks or assembled alongside the quay. They can then be towed out while remaining stable providing more stable deployment characteristics.

Technology developers are designing versatile platforms that can operate in various depths and carry turbines of different sizes. Designing platforms with this type of flexibility will help to lower costs. However, FOW farm developers are interested in turbine sizes of 15 MW or more.

FOW technology developers have noted that access to test facilities is a challenge. 80% of the respondents claimed that it has been more than 12 months since their last test. This suggests more are required or they need more capacity to provide simultaneous tests. All respondents said there is a critical need for test sites when proving technologies. 75% said the next step is to test in an open sea environment. 66% of the technology developers are planning to carry out further tests in an Atlantic environment.

80% of technologies have been assessed by a certification authority. All respondents were between TRL4 and TRL7. This clearly shows that the technologies are performing well and making progress to commercialisation, however there may be a holder up at the open sea testing stage.

Overall costs, inflation and financial investment appear to be the biggest challenge for FOW technology developers. However, this isn't unique to the FOW industry. There are EU grants that can alleviate this issue. Developers are accessing a range of finance streams, such as EU funding, national government, third party investor, and self-funding to help develop wind farms.

3. Favourable Policy Environment

WG 2 focuses on supporting the policy development with the objective of creating a favourable policy environment. To achieve the WG's targets, the current policy in place is considered in order to encourage and progress FOW in the NWE region. Furthermore, gaps in consenting, funding, and support legislation in NWE are identified and considered. Finally, recommendations are made.

3.1 Current Policy

In this section we will examine at the current FOW policy across NWE.

3.1.1 The Current Context of European Union Targets

The EU has a target of having 300 GW of offshore wind installed by 2050. The European Union's 'Fit for 55' commits to a 55% reduction in emissions by 2030 compared to 1990 levels, and to achieving carbon neutrality by 2050.

The EC has determined that the aim of installing at least 60 GW of offshore wind and at least 1 GW of ocean energy by 2030, and by 2050, continue to install a total of 300 GW and 40 GW respectively, is both practical and attainable. Reaching these goals would result in huge benefits regarding decarbonising electricity production and promote the decarbonisation of hard-to-abate sectors with renewable hydrogen. It will also enhance jobs and growth. Substantial changes are required in this sector to accomplish installed capacities of 300 GW of offshore wind and 40 GW of ocean energy in less than 30 years. By 2050, 30 times more offshore renewable energy technologies will need to be installed requiring an estimated €800bn [58]. The EU will successfully reach climate neutrality and zero pollution, positioning itself as a leader in clean technologies.

Cooperations have been established to develop renewable energy sources and promote integrating energy systems. The North Sea Energy Cooperation (NSEC) is an offshore grid that links the nine countries in the North Sea region. Established in 2016, its aim is to promote renewable energy and boost economic growth. The NSEC supports and facilitates the development of the offshore grid development and the large renewable energy potential in the region. Belgium, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Denmark, Sweden, and the EC are currently members of the NSEC. Since the UK withdrew from the EU in 2020, they are no longer members. The primary purpose of the NSEC is to promote cooperation among the participating countries to develop and expand the use of renewable energy sources, such as wind, solar, and hydrogen, in the North Sea region. This includes the development of offshore wind farms, the creation of cross-border electricity interconnections, and the integration of the North Sea region's energy systems.

A well-established link already exists between the countries involved in the AFLOWT project.

3.1.2 Belgium

Under EU regulations, Belgium has targets to reduce non-ETS (Emission Trading System) GHG emissions by 35% by 2030 relative to 2005 levels. In 2021, the 2030 EU-wide GHG emissions reduction target was increased from 40% to 55% by 2030 (versus the 1990 level). This additional ambition at the European level will likely require Belgium to adopt a non-ETS emissions reduction target for 2030 that is higher than 35%, and to take stronger actions to reduce emissions.

Regarding the installation of offshore wind and raising the proportion of electric vehicles, Belgium has made significant strides. However, fossil fuels continue to predominate the nation's energy mix, and this dependence is only going to grow. To reach Belgium's goals for increasing the share of renewables, reducing energy demand, and cutting emissions, all sectors still have a lot of work to do. [59]

In 2021, Belgium had the sixth-highest offshore wind capacity in the world and is planning for a major expansion of offshore wind deployment. However, as of the 'International Energy Agency Belgium 2022 Energy Policy Review' report, Belgium's ORE policy is focused on BFOW turbine installation as opposed to FOW turbines.

The federal government established a dedicated offshore wind zone covering 225 km². As of 2021, nine BFOW farms with a total capacity of 2.26 GW had been built in the offshore wind zone. Belgium is developing a second offshore wind zone of 281 km² and a planned capacity of up to 3.5 GW. Competitive bidding procedures to drive cost-effective deployment in the second offshore wind zone is being developed by the federal government. Belgium's TSO developed a modular offshore grid to connect offshore wind projects to the onshore grid. This offshore grid will be expanded and upgraded to connect projects developed in the second offshore wind zone. The federal government is examining options to further increase offshore wind generation, including repowering the first offshore wind zone and creation of a third offshore wind zone. [59]

3.1.3 France

France has set targets to be achieved by 2030. These include increasing the share of renewable energy in its final energy consumption to 32%, reducing its GHG emissions by 40% below 1990 levels, and reducing its final energy consumption by 32.5%. These targets are part of France's commitments under the Paris Agreement on climate change. [60]

France has set a target to install 12 GW of offshore wind energy by 2028, and a significant portion of this is expected to come from FOW turbines [61]. This goal was set in the country's Multiannual Energy Programme (Programmation Pluriannuelle de l'Énergie, PPE) in 2019. The PPE also sets targets for other renewable energy sources, such as solar and onshore wind, as well as energy efficiency and carbon emissions reductions.

Under EU state support rules, the EC has authorised a €2.08bn budget to support offshore wind energy production in France. The finance will contribute to France reaching its environmental and energy targets, as well as the objectives relating to the EU's European Green Deal and the ORE strategy. France informed the EC of its intention to support the development and operation of a FOW farm off the coast of the south of Brittany. The aid effort has a budget of €2.08bn and will run for 20 years, starting with the operation of the wind farm in 2028. FOW technology is in an initial phase in France. So far, only small pilot projects have been developed. The FOW farm funded by the programme will be the first commercial project of its kind in France. It is planned to have a 230 to 270 MW capacity and harvest 1 TWh of renewable power per year for 35 years. [62]

3.1.4 The Netherlands

The Dutch part of the North Sea runs from the coast to the outer limit of the Dutch continental shelf and encompasses approximately 58,000 km². The Dutch North Sea Exclusive Economic Zone (EEZ), as shown in Figure 55, has water depths that are largely in the range of 20 to 40 m. There are some areas with depths up to 50 or 60 m in a northerly direction, but these are exceptions, and not part of the spatial planning. The average depth of the Dutch EEZ is 35 m. Currently it is more cost effective to install BFOW than FOW in these depths, and the permits are only for BFOW technology. The Netherlands do not have a specific FOW policy. In fact, the existing roadmaps exclude FOW. [63]

After taking office in January 2022, the current Dutch government committed to ambitious targets for offshore wind development. Compared to 1990 levels, EU countries must meet a goal of reducing CO_2 emissions by 55% by 2030. The government announced acceleration plans that nearly double

Figure 55: The Dutch North Sea EEZ [64]

the country's offshore wind target from the current 11.5 GW to approximately 21 GW by 2030, equivalent to around 75% of the country's current electricity consumption. The corresponding roadmap for wind farms and their capacities are outlined in Table 11 and detailed in Figure 56.

Table 11: Dutch wind farms and their capacities as of November 2022 [65]

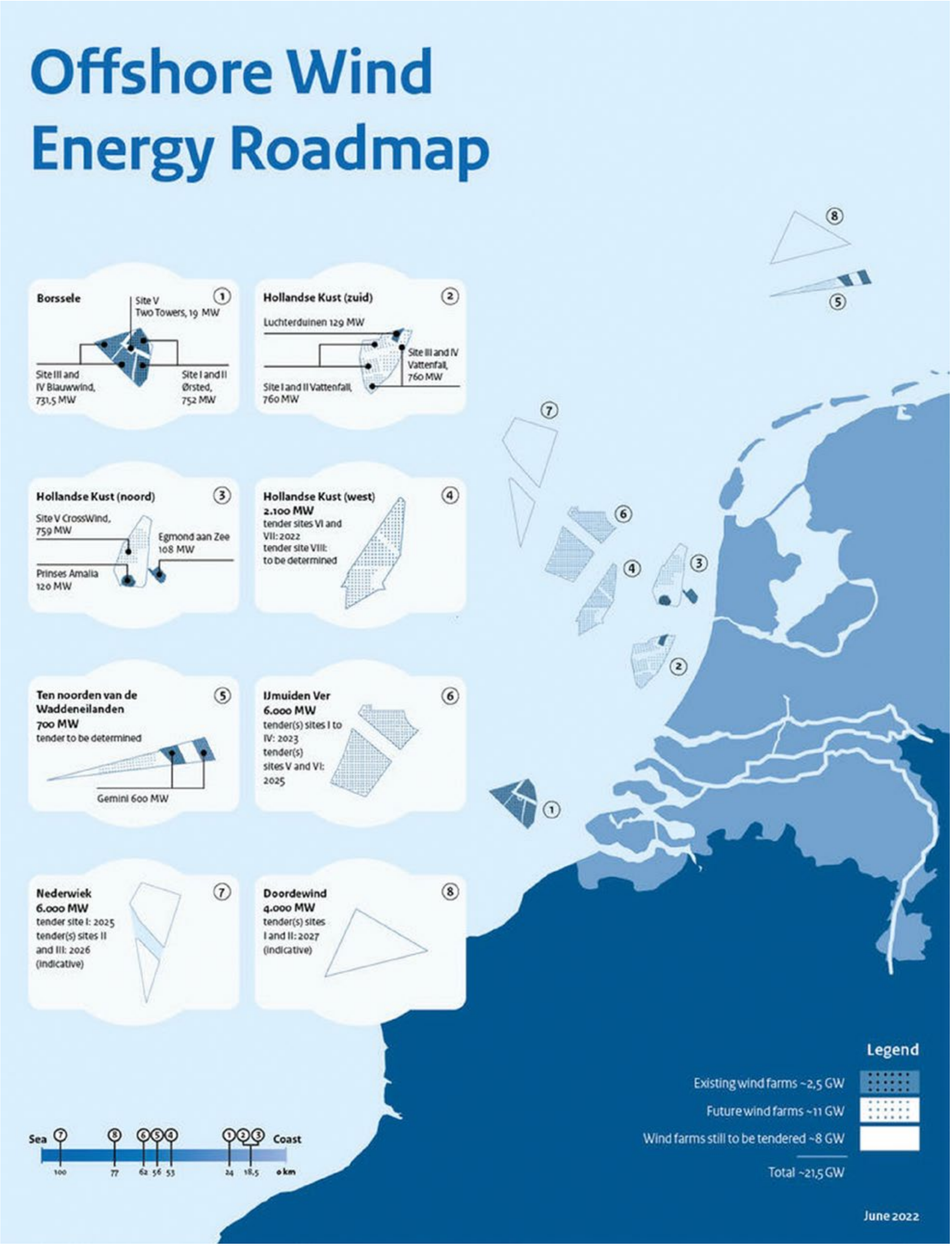
Wind Farms	Capacity
Operational wind farms	2.5 GW
Wind farms under construction	2.3 GW
Wind farms in development	0.7 GW
Planned wind farms	16 GW
Total	**21.5 GW**

In March and June 2022, the government subsequently revealed the additional wind farm zones and site-specific tendering timelines for eight additional offshore wind farms (cf. Table 12 and detailed information in Figure 56) with a total of at least 10.7 GW to be put out to tender before the end of 2027 and to be up and running around 2030. The eight new projects are located to the north and northwest of the Netherlands.

Table 12: The eight additional Dutch offshore wind farm sites

Site	Capacity
Nederwiek (zuid) I	2 GW
Nederwiek (noord) II	2 GW
Nederwiek (noord) III	2 GW
Hollandse Kust (west) VIII	0.7 GW
IJmuiden Ver (noord) V	1 GW
IJmuiden Ver (noord) VI	1 GW
Doordewind I	2 GW
Doordewind II	2 GW

Figure 56: Dutch offshore wind energy roadmap [66, p. 17]



It is expected that the Netherlands will need at least 38 GW of operating offshore wind capacity to reach climate-neutral status by 2050. This implies that the Dutch government plans to develop another 16 GW of offshore wind capacity between 2030 and 2050.

The Dutch government currently view FOW as in a “pre-commercial phase” and still has a “higher LCOE than BFOW turbines”. They see the supply chain and port infrastructure as a challenge. That being said, they are optimistic FOW will be competitive by 2030 and provide lower installation costs. [66]

3.1.5 Germany

In 2022, 46% of the power used in Germany came from renewable energy sources [67]. Germany has set a target to generate at least 65% of its electricity from renewable sources by 2030 and to achieve carbon neutrality before 2050 [68]. As part of this target, offshore wind power is expected to play a major role in Germany’s renewable energy mix. The new area development plan has a target of installing at least 30 GW by 2030, with further aims to install 40 GW by 2035 and 70 GW by 2045 [69].

The German government also provides financial support for the construction of offshore wind farms through various mechanisms, including low-interest loans, loan guarantees, and grants. In addition, the government has established a regulatory framework to ensure the safety and environmental sustainability of offshore wind projects. A key element of Germany’s offshore wind policy is the development of a robust supply chain to support the construction and maintenance of offshore wind farms. The country has made significant investments in research and development and has established centres of excellence for offshore wind technology and innovation.

These targets are part of the country’s ‘Energiewende’ (energy transition) policy, which aims to shift away from fossil fuels and nuclear power towards renewable energy sources. The policy also aims to increase energy efficiency and reduce overall energy consumption. [70]

Due to the relatively shallow waters of the German seas (German North Sea and German Baltic Sea) there currently appears to be no ‘political need’ for FOW technology, especially as BFOW solutions for such water depths are still cheaper. Nevertheless, there are several advantages and reasons why FOW could be also deployed in German waters:

- The impacts of installation on the environment are less for FOW turbines than BFOW turbines. Should this be accounted for in the future in an ecological-based economic analysis, there will be clear advantages with regards to costs.
- Some soil conditions, especially in the Baltic Sea, are quite challenging. Therefore, deploying FOW systems rather than BFOW systems could be easier and more feasible.
- If the offshore wind energy targets (with respect to the installed capacity) are to be further increased, additional sites need to be opened for utilisation of offshore wind energy. Currently all areas of German waters are dedicated to specific use (offshore wind, military, fishery, natural habitats, shipping routes, etc.). This means that more sites may be opened for deployment of offshore wind energy only if co-use of these sites is made possible. FOW turbine systems may open additional opportunities for co-use of offshore sites.

3.1.6 Ireland

Ireland was a forerunner in deploying offshore wind, with a 25 MW BFOW farm generating since 2004. However, due to significant onshore wind potential and a lack of clarity around the planning and consenting process beyond the 12 nautical mile limit, offshore wind did not progress further.

There is a national target of 7 GW offshore wind by 2030, this is likely to be 5 GW of mostly BFOW and 2 GW of FOW ringfenced for green hydrogen production. Post-2030 there is a government target for at least 30 GW of FOW generation capacity in Ireland’s Atlantic water. The offshore wind targets are in the context of an 80% share of renewables in total electricity generated by 2030 and a net zero economy by 2050 target.

The Marine Planning Policy Statement (MPPS) sits at the top of the new marine planning framework in Ireland. The current MPPS was adopted on a non-statutory basis in 2019 and an update is currently under development by the Department of Housing, Local Government, and Heritage. The National Marine Planning Framework published in 2021 was Ireland’s first marine spatial plan in the overarching national policy context, which supports the sustainable spatial planning and management of the ORE sector into the future. This was closely followed by the Maritime Area Planning Act in December 2021, which setup the Maritime Area Consent process. Environmental surveys are required for planning permission and the impact on birds, sea life, seabed, etc. are considered through the planning process.

Most of the potential for BFOW is in the east of the country, with one BFOW farm in the west. While the 2030 target will be met through developer-led projects, the DECC are moving towards a plan-led approach and have identified dedicated marine areas and projects with long term potential.

Phase One of offshore wind development in Ireland included the first offshore wind auction, which took place in Ireland Q2 2023 under the ORESS. The average price of the winning bids was €86/MWh. Four projects were successful with a combined capacity of 3 GW. However, with prospects that some Phase One projects may fail to secure a route to market or development consent, additional offshore projects will be needed to meet 5 GW by the end of this decade.

The DECC has developed the new framework and policy for Phase Two which was approved by the government on 7 March 2023. The following main elements are part of the Phase Two policy:

- Phase Two will see the deployment of offshore wind through an expedited work programme that will concentrate on near-term delivery based on technology that has been demonstrated to be scalable in other jurisdictions. This work programme will also procure the extra offshore wind capacity needed to meet the government's target, i.e. 5 GW by 2030.
- The size, frequency, and urgency of auctions necessary to reach the 5 GW goal will be decided by onshore grid and marine spatial restrictions, as well as the results of Phase One. Phase Two offshore capacity will continue to be bought under the Renewable Electricity Support Scheme (RESS). The first ORESS 2 auction under Phase Two is due in 2024.
- ORESS 2, and any following Phase Two auctions, will only purchase a predetermined amount of offshore wind capacity for construction inside specific ORE defined areas, which will be chosen in accordance with Maritime Area Planning Act rules for Designated Maritime Area Plans. Public engagement and consultation in the development of ORE designated sites will be possible, and legal environmental assessments will be necessary. Geographical alignment with onshore grid capacity will be used to determine where the ORE designated regions for Phase Two will be located. Environmental factors, such as marine protected areas and European sites, will also be taken into account.
- A total of about 700 MW present onshore grid capacity has been identified by EirGrid for additional connectivity of offshore renewables off the south coast of Ireland. The extra offshore wind capacity is supposed to be split into two connections, each of about 350 MW, at various points along the south coast. These onshore connection nodes are supposed to be situated so that they are geographically adjacent to the first two ORE designated zones. Participants in ORESS 2 will compete for funding to build offshore wind projects totalling 350 MW in each of these zones, or a 700 MW project in only one ORE defined area.
- The availability of extra onshore grid capacity – that may arise in the case that Phase One projects fail to obtain a route to market or planning consent – will impact the location of later Phase Two ORE designated areas and Phase Two ORESS auctions. It is anticipated that all Phase Two auctions, including any potential future auctions on the East or West coast should EirGrid identify additional grid capacity after Phase One is complete, will only seek to procure offshore wind capacity situated within ORE designated zones.
- The Irish government additionally committed to creating a new phase – Phase Three – which targets an initial FOW capacity of 2 GW off the south and west coasts, in addition to Phase Two and the 5 GW aim. By 2030, these projects are anticipated to be in development and might include initiatives for the generation of green hydrogen and other off-grid applications.

Post 2030, the government will move to the Future Framework which is Ireland's long-term vision for ORE. By adopting a more strategic, plan-led approach, the state will endeavour to ensure that the economic, environmental, and social benefits of ORE are realised for everyone. This includes

- meeting future energy demands;
- transforming the Irish economy and industry;
- achieving net zero carbon emissions;
- protecting the Irish and global environment;
- sharing use of Irish seas; and
- choosing the right offshore technologies to use in the right places through the ORE development plan.

A component of creating the Future Framework is the Offshore Renewable Energy National Spatial Strategy as well as a hydrogen policy, an economic assessment, and an interconnector policy.

3.1.7 Luxembourg

Luxembourg is committed to increasing the share of renewable power sources in its energy mix and has set ambitious targets to achieve this goal, as outlined in Table 13. The targets are in line with the EU's overall goals for renewable energy and carbon reduction. Luxembourg has set a target of achieving a 25% share of renewable energy in its gross final energy consumption by 2030, consequently reducing GHG emissions by 55% by 2030, compared to 1990 levels. [71]

Despite being a landlocked country, Luxembourg has an indirect offshore wind energy policy. Luxembourg participates in cross-border cooperation projects for the development of offshore wind energy, such as the NSEC initiative, which aims to facilitate the deployment of offshore wind energy in the North Sea region. [71]

3.1.8 The United Kingdom

The Climate Change Committee (CCC) is UK's independent advisor on tackling climate change. To date they have produced six carbon budgets for the UK government ranging from 2008 up until 2037. The carbon budgets map out the plan to reach a net zero future by 2050. The latest budget, Carbon Budget 6, was legislated for in June 2021. The UK has already met and surpassed its first (2008–2012), second (2013–2017), and third (2018–2022) carbon budget targets. The UK is decarbonising faster than any other G7 country. Between 1990 and 2021, the UK's emissions fell by 48% while their economy grew by 65%.

Under the Climate Change Act 2008, the UK is legally obliged to reduce GHG emissions by 100% on 1990 levels by 2050 (preceding this, the target was at least an 80% reduction on 1990 levels). Parliament authorised this act to legislate the UK's framework for setting carbon budgets. In 2019, on the advice of the CCC, the UK committed to reaching net zero emissions by 2050 and the target was modified.

Among other types of renewable energy, FOW will play a part in continuing to achieve UK's targets and features significantly in the UK government's 'Powering Up Britain' blueprint for the future of energy in the UK – which itself brings together the UK's 'Energy Security Plan' and 'Net Zero Growth Plan'. To underline this commitment, the UK government has split the former Department for Business, Energy & Industrial Strategy (BEIS) into three new departments, placing accountability for delivery of the Powering Up Britain plan into the new Department for Energy Security and Net Zero (DESNZ). The DESNZ's responsibilities comprise providing energy supply security, ensuring that energy markets are operating properly, promoting increased energy efficiency, and taking advantage of net zero's chances to pioneer new green industry sectors.

Thus, the DESNZ identifies its priorities for 2023 according to GOV.UK [73] as:

1. Ensure security of energy supply this winter, next winter, and in the longer-term – bringing down energy bills and reducing inflation.
2. Ensure the UK is on track to meet its legally binding Net Zero commitments and support economic growth by significantly speeding up delivery of network infrastructure and domestic energy production.
3. Improve the energy efficiency of UK homes, businesses, and public sector buildings to meet the 15% demand reduction ambition.

Table 13: Luxembourg's 2020 and 2030 renewable energy targets and the 2017 status [72]

Sector	Status – 2017	Target – 2020	Target – 2030
Gross final consumption	6.38%	11%	23-25%
Electricity	8.05%	11.8%	33.6%
Heating and cooling	8.11%	8.5%	30.3%
Transport	6.44%	10%	25.9% (10% from biofuels)

4. Deliver current schemes to support energy consumers with their bills and develop options for long-term reform to improve how the electricity market works for families and businesses.
5. Seize the economic benefits of Net Zero, including the jobs and growth created through investment in new green industries.
6. Pass the Energy Bill to support the emerging carbon capture, utilisation, and storage (CCUS) and hydrogen sectors; to update the governance of the energy system; and to reduce the time taken to consent offshore wind.

Thus, DESNZ aims to encourage 'new green industries' – which includes FOW – and reduce the time taken to consent offshore wind. The new green industries themselves comprise ten low carbon priority areas and are also collected under a Net Zero Innovation Portfolio (NZIP), which supersedes the 2015–2021 BEIS energy innovation programme and provides government funding for low carbon technologies and systems. FOW sits within the 'future offshore wind' category (other categories comprise energy storage, CCUS, direct air capture, etc.), which includes the £60m match-funded FOW demonstration programme and £2m of additional support for the ORE Catapult's FOW Centre of Excellence (CoE) programme. Separately to the NZIP, the UK government also launched the £160m FOW manufacturing investment scheme, which aims to kick-start investment in the port infrastructure projects needed to deploy and service the scale of the FOW pipeline. This will indirectly support carbon emission reductions by de-risking the delivery of offshore wind capacity. [74]

In terms of how fixed and floating offshore wind projects are remunerated for the energy they produce: this is by means of contracts for difference (CfDs). CfDs are the long-term contractual agreements between a low-carbon electricity generator and the low carbon contracts company (LCCC), the government-owned non-profit company that manages the scheme headed by the Secretary of State for Energy Security and Net Zero. The CfD scheme is designed to encourage investment in low-carbon electricity generation by providing long-term contracts that guarantee a fixed price for electricity generated from eligible renewable and low-carbon sources, thereby providing the generator with price certainty over the lifetime of the contract [75].

The LCCC is responsible for managing the financial aspects of the CfD scheme, including administering the contracts, making payments to generators, and collecting payments from electricity suppliers. The organisation is also responsible for monitoring the performance of generators and ensuring that they meet their contractual obligations, such as delivering a minimum level of electricity output. The LCCC plays a critical role in the UK's efforts to transition to a low- carbon energy system by providing financial incentives to encourage investment in renewable and low-carbon electricity generation.

From 2023, the CfD allocation rounds (ARs) will run annually. The first annual auction will be the fifth CfD AR (AR5), which opened in the spring of 2023, and which will declare winning applicants in September 2023. This is the government's main mechanism for supporting low-carbon electricity generating projects in the UK, including within it the goal to deliver up to 50 GW of offshore wind by 2030 and up to 70 GW solar by 2035.

Guidance for applicants for the next allocation round (AR6) is already published and requires all FOW applicants, and all other applicants looking for more than 300 MW, to also provide a statement from the Secretary of State for Energy Security and Net Zero approving the supply chain plan (SCP) submitted for the specific generating station. The SCP questionnaires are specific to the generator type (onshore wind, offshore wind, solar, etc.), and the FOW one is described as 'lighter touch' to reflect the likely size of the projects, and the challenges and maturity of FOW technologies. Nevertheless, the FOW SCP questionnaire is comprehensive and requires the applicant to specify in detail the commitments they intend to make regarding

- engagement with the FOW supply chain;
- collaboration on technology development to help mature the FOW sector;
- adoption of sustainable production, transportation, installation, and construction practices;
- involvement and ambition for inclusion and deployment of innovation, bias to UK sourcing;
- commitment to supporting supply chain infrastructure upgrades; and
- support for skills development, equality, and reducing the disability employment gap.

In addition, the applicants must state an anticipated percentage level of UK content to be delivered over the project lifetime, broken down by development, capital, operational, and decommissioning expenditures and by the project's major components.

Taken altogether this demonstrates that the UK government wants FOW developers to commit to supporting UK-originating innovations and the UK supply chain and encourage developers to align with this 'UK as world leader in FOW' ambition.

3.2 Policy Recommendations that Promote Progress

NWE has a natural potential for FOW energy. Countries are developing policy for FOW projects by building upon years of experience from BFOW turbine infrastructure, grid connection, and a world-leading network of test centres. To ensure that FOW energy can help reach the EU's challenging climate and energy targets for 2030 and 2050, the EC published a dedicated EU strategy on ORE in 2020. It proposes detailed procedures to support the long-term sustainable development of this industry. The strategy targets an installed capacity of at least 60 GW of offshore wind by 2030 and 300 GW by 2050 [76]. Governments should act quickly and effectively to meet these targets and the deadlines they have committed to. Efficient policies that encourage progress and eliminate barriers are critical to the swift installation of FOW turbines.

Similarly, the EU established the Renewable Energy Directive (RED) which is a policy framework created to promote renewable energy sources and reduce GHG emissions in the energy sector. The directive sets binding targets for EU member states to increase the share of renewable energy in their energy consumption.

The first Renewable Energy Directive, RED I, was adopted in 2009 and set a target for the EU to achieve a 20% share of renewable energy in its final energy consumption by 2020. This target was binding for all member states, and they were required to implement national renewable energy action plans outlining their strategies and measures to reach the target.

In 2018, the EU introduced an updated version of the directive known as RED II. The main goal of RED II is to increase the renewable energy share in the EU to at least 32% by 2030. It includes several key provisions and measures to support the deployment of renewable energy sources, such as:

1. Binding national targets: Each EU member state has an individual target for the share of renewable energy in its final energy consumption by 2030. These targets consider national circumstances and consider factors like gross domestic product and renewable energy potential.
2. Renewable energy support schemes: Member states are encouraged to establish support schemes to promote the production and use of renewable energy. These include feed-in tariffs, premiums, auctions, and other market-based mechanisms.
3. Bioenergy sustainability criteria: Specific sustainability criteria are set for the production and use of biofuels and bioliquids to ensure they meet certain environmental standards and do not cause deforestation or other negative impacts.
4. Renewable heating and cooling: The directive aims to promote the use of renewable energy in heating and cooling sectors, encouraging member states to set indicative national targets and implement measures to increase the share of renewables in these areas.
5. Renewable energy in transport: RED II sets a target for the share of renewable energy in transport, aiming for a minimum of 14% by 2030. It encourages the use of renewable fuels and the deployment of electric vehicles and other sustainable transport solutions.

The RED was further updated in March 2023 to RED III. A provisional agreement was reached between the European Parliament and the Council. It raises the target to a minimum of 42.5% by 2030.

The RED plays a crucial role in driving the transition towards a low-carbon economy in the EU by promoting renewable energy sources and reducing dependence on fossil fuels. It provides a framework for member states to set targets, develop policies, and implement measures to accelerate the deployment of renewable energy technologies. A substantial scaling-up and acceleration of renewable energy across all industries will reduce energy prices over time while also decreasing dependence on fossil fuels.

The following policies can be implemented to promote progress in the FOW industry:

- fiscal supports,
- consent process,
- R&D funding programmes,
- international collaboration,
- public awareness,
- infrastructure,
- multi-use of sea space, and
- transparent application process.

3.2.1 Fiscal Supports

Government subsidies or tax credits for companies that invest in the development and installation of FOW turbines would encourage investment in this technology and help reduce the project's overall cost. Providing subsidies similar to the CfD scheme in the UK or EU feed-in tariff scheme provide various financial incentives to develop energy projects.

The CfD scheme provides a guaranteed price for the electricity generated by the developer and is a government's means of supporting low-carbon electricity generation. CfD's incentivise investment in renewable energy by providing developers of projects with long lifetimes and high upfront costs with direct protection from volatile wholesale prices. They also protect customers from paying increased support costs when electricity costs are high [77]. To be eligible for UK CfD subsidies, a project must be classified as a 'less established technology' with a capacity of at least 5 MW.

EU countries offer feed-in tariff schemes which support sustainable energy sources, including FOW energy. To avail of these schemes, certain criteria must be met. These will vary from country to country but may include providing a fixed price for the electricity generated by the project. To be eligible, the project must have a capacity of at least 3 MW and use turbines certified by a recognised certification body.

The development of renewable energy sources and the accomplishment of particular policy goals can be facilitated in EU countries by national support programmes.

3.2.2 Consent Process

Developing FOW farms typically involves a complex consent process that concerns multiple stakeholders, including government bodies, local communities, environmental organisations, and other interested parties. Many countries already have consent processes in place for marine projects. However, streamlining and adjusting the process for FOW developments can help reduce the time and cost required for companies to obtain necessary permits and licenses, making investing more attractive and reducing uncertainty. Identifying the key stakeholders interested in the project and understanding their concerns and priorities, can help streamline the process and ensure their views are considered.

It is highly recommended to engage with the following stakeholders early and continue to communicate throughout the process by hosting public consultations and regular meetings and engaging with stakeholders to discuss project progress and address concerns:

- government bodies responsible for granting permits and approvals,
- local communities, and
- environmental organisations.

Having just one designated government agency involved in the consent process with a clear regulatory framework can reduce uncertainty and ensure developers understand the process and requirements for obtaining the necessary permits and approvals. An online portal with unique private access that displays application progress, clear timelines for review and approval, and provides a single point of contact for developers to coordinate through will allow for transparency and clarity within the system. This technology can help streamline the consent process by automating certain tasks, such as document management and data analysis. This can help reduce the time and cost of obtaining permits and approvals while improving accuracy and efficiency. The portal may also include guidelines for environmental assessments, safety regulations, and other relevant requirements.

Streamlining the consent process for FOW farm development requires a collaborative approach that involves all stakeholders. By working together to establish a clear regulatory framework, standardise the process, engage with stakeholders, and use efficient technology, developers can obtain permits and approvals quicker while ensuring that environmental and community concerns are addressed.

3.2.3 R&D Funding Programmes

R&D funding programmes improve the efficiency and reliability of the technology by allowing for a more thorough analysis of technologies and methods, making it more attractive to investors. Continuing to establish effective R&D funding programmes will accelerate technology development and make it accessible to more people. Programmes that encourage technologies to move through the various TRLs effectively are required because substantially more funding is needed as it progresses. Outlining detailed and clear milestones that the technology must achieve before it progresses to the next TRL allows for better planning and transparency.

There are several R&D funding programs available for FOW technologies. Among the well-known ones are:

- The LIFE Clean Energy Transition sub-programme is a funding instrument of the EU that supports projects in the areas of environment and climate action that can accelerate the transition to a low-carbon and climate-resilient economy. The budget for this programme is €527m between 2021-2024.
- InvestEU Fund provides a range of financial instruments to support sustainable infrastructure projects, including loans, guarantees, and equity investments. With a budget of €26.2bn these instruments can be used to finance different stages of the project lifecycle, from research and development to commercialisation and operation.
- BlueInvest Fund is a venture capital fund created by the EC to support innovation and growth in the blue economy. The fund was launched in 2019 and is set to continue until 2027 with a budget of €500m. The fund invests in companies at different stages of development, from early-stage startups to more established businesses. [78]

These funding programs are highly competitive and require a rigorous application process. Companies interested in applying for funding must comply with the eligibility criteria before submitting a proposal.

3.2.4 International Collaboration

Transferring to renewable energy sources is a global movement, therefore, an international collaboration between governments and other countries and stakeholders to develop common standards and regulations for FOW turbines and farms will allow developers to expand projects across many countries more easily. As energy companies develop their technologies, they will seek customers worldwide. Establishing international best practices, policies, and processes will ensure clarity for the developer as they advance. International collaborative efforts would encourage progression of the FOW industry.

3.2.4.1 United Nations Convention on the Law of the Sea

Currently the United Nations (UN) Convention on the Law of the Sea [79] governs nearly all aspects of international law relating to the sea, namely:

- outlining maritime zones, such as the territorial sea, EEZ, and continental shelf and the high seas;
- assigning sea area uses, such as research, overflight, cable and pipeline laying, shipping, and fishing;
- development and transfer of marine technology;
- marine environment protection;
- seabed mining; and
- settle disputes.

This convention already outlines the legal requirements of maritime activities. By integrating an offshore renewable consent process into this convention would allow countries to follow law abiding guidelines that can be easily implemented into their country.

3.2.4.2 International Renewable Energy Agency (IRENA)

IRENA has developed collaborative frameworks in response to a request from its international membership that serves as an effective platform for increased communication and coordinated action among its 168 members. In order to understand the role of the ocean and offshore renewables in the energy transition and ensure their widespread deployment in the future, countries are coming together under a new collaborative framework on ocean energy/offshore renewables.

Member nations have approved the collaborative framework, which is presently in use. This collaborative platform aims to promote developments in fields related to ORE, such as technological development, research and innovation, market incentives, regulatory frameworks, and sustainability. It demonstrates IRENA's ongoing dedication to serving as a premier global forum for information exchange and government assistance with renewable energy development.

In the following two paragraphs, examples of successful international projects that have benefited their individual sectors are presented. Adopting a similar arrangement for FOW could help accelerate the industry.

3.2.4.2.1 SIDS Lighthouses Initiative
A new phase of the Small Island Developing States (SIDS) Lighthouses Initiative was launched in 2018 to promote all renewable sources and enhance ties between renewables and non-energy sectors. The initiative helps small islands in scaling up renewable energy through collaborations.

3.2.4.2.2 Shipping: Getting to Zero Coalition
IRENA has joined the Getting to Zero Coalition to get commercially viable deep-sea zero-emission vessels into operation by 2030, and is supporting Workstream #1 – Fuels, Technologies & Pathways.

3.2.5 Public Awareness
Governments can increase public awareness of the benefits of FOW technology, such as environmental improvement, energy security, and the creation of new jobs, particularly in coastal communities. Having the support of the public for this type of development enhances investment opportunities. Communicating the benefits and the operation of FOW farms is a crucial first step. Communication may happen through various means, such as informational websites, brochures, videos, and social media campaigns. Reaching out to local communities and stakeholders will help to build trust and support. Engagement may involve public meetings and workshops to answer questions and address concerns. Tangible marketing and promotion through case studies is an effective way to prove the economic and social benefits of FOW.

3.2.6 Infrastructure
FOW uptake relies on the availability of suitable port and grid infrastructure across Europe. The economics of FOW is largely defined by the number of operations that can take place in the ports. A large balance of plant components require extensive facilities and significant investment. Suppliers need scale to thrive, making it a potentially tough market to break into without clear market demand signals. Manufacturing facilities must be relatively large to meet the high production volumes required for offshore wind and benefit from economies of scale [80]. Specific infrastructure is required to develop FOW farms. Governments should invest in port and electricity transmission infrastructure. WindEurope has recently estimated that Europe's ports will need to invest €6.5bn between now and 2030 to support the expansion of offshore wind, with a significant focus on FOW [22].

Designing and investing in port infrastructure to develop FOW farms poses several challenges as Europe's ports are not configured to handle FOW turbines. Converting old industrial harbours to develop FOW requires significant political support at national, regional, and European levels. Crucially, private investors and local authorities would only invest if they had visibility on project volumes and clear pipelines of business opportunities. Building or upgrading port infrastructure requires significant capital investment. Ports would require subsidies and development aid from the government. This can be a barrier to entry for companies looking to develop FOW farms. Additionally, the construction and development of infrastructure often takes several years to complete, meaning that the benefits of the investment may not be realised for some time [81]. Many existing ports are already operating at capacity and have limited space available to accommodate the large and heavy components required for FOW farms. New infrastructure may need to be built, or existing infrastructure may need to be expanded or modified to accommodate the unique needs of the offshore wind industry.

The transportation and logistics of large and heavy components required for FOW farms, including turbine platform materials, blades, towers, and nacelles, can be challenging. These components must be transported to the port, loaded onto specialised vessels, and transported to the offshore site. The logistics of these operations require careful planning and coordination to ensure that they are completed safely and efficiently.

During the development of port infrastructure, environmental concerns need to be considered, including the potential impact on marine life and coastal ecosystems. This may require additional permits and approvals from regulatory bodies, which can increase the time and cost of the project.

The availability of specialised vessels, machinery, equipment, and personnel is also of concern. Often vessels and machinery must be custom-made to assemble the FOW components into complete structures. Personnel also require special training to work offshore. Training centres need to expand or be established to meet the training demands.

Investing in port infrastructure to support the development of FOW farms requires careful planning and consideration of the unique challenges and opportunities of the offshore wind industry. While the initial costs and logistical challenges may be significant, the potential benefits of this infrastructure investment, including increased job opportunities, energy security, and economic growth, make it a worthwhile endeavour for many governments and private companies.

Grid connection is a challenge for the entire offshore wind sector. The distance to shore and the availability of networks at the point of connection are a bottleneck restricting both FOW and BFOW. If the required groundwork was put in place by governments, the cost and risk for developers are reduced, making it more attractive to invest in this technology and providing certainty that the government is committed to advancing the industry.

3.2.7 Multi-Use of Sea Space

In order to reduce the impact the FOW industry could have on existing stakeholders, policy that facilitates the multi-use of sea space is essential. It will reduce pushback or objection if the national maritime spatial plan includes and promotes a multi-use/multipurpose approach. FOW farms can and should coexist with many other activities. Promoting and determining locations for further analysis of multiple-use and recognising that particular economic activities can co-exist in the same area are critical. Depending on what procedure is implemented, fishing inside wind farms can work – the UK, France, and Poland are examples of multi-use cooperation [22]. These multi-use experiences and good practices should be moved to all sea uses, including the defence, fisheries, and security sectors. Policy must allow all stakeholders to operate together without disruption for the FOW industry to progress effectively.

Maritime spatial planning is an essential and well-established tool to anticipate change, prevent and mitigate conflicts between policy priorities while also creating synergies between economic sectors [76].

3.2.8 Transparent Application Process

Article 16 in the RED clearly outlines the organisation structure and provides traceability throughout the permit-granting process. A contact point is established at the beginning of the process. This contact point shall guide the applicant through the entire administrative permit application and granting process in a transparent manner. The applicant will be facilitated right through to the end of the process, provided with all necessary information and, where appropriate, other administrative authorities will be involved. No more than one contact point must be used by the applicant throughout the procedure. Digital documents are permitted when submitting the required information [82]. Clear and transparent policy that developers can easily comprehend is essential to allow projects to commence and progress seamlessly. Developers need assurance that governments will not produce policy that will add delays or cost to the consenting process. Establishing policy that considers every aspect of FOW development ensures clarity, structure, and trust in the process. FOW developers will review a country's FOW policy before committing resources. Having well-thought-out practical guidelines is reassuring for developers when completing risk analysis.

3.3 Gaps in Consent

Accelerating consent in the application process for FOW farms is challenging as it currently has a complex regulatory procedure that includes various steps of considerations. However, there are some potential procedures that may help to speed up the process.

3.3.1 Potential Procedures for Speeding up the Consenting Process

Addressing prevailing gaps in the consent process can help to ensure that FOW farms are developed in a sustainable and responsible manner that maximises their benefits while minimising any potential negative impacts to the environment and public. Accelerating the consent process for FOW farm applications requires a collaborative and well-coordinated approach involving regulators, developers, and local communities. It also requires a commitment to addressing environmental concerns and complying with regulatory requirements. Governments can also consider streamlining regulatory processes to make them more efficient and reduce delays. This can involve setting clear timelines for approvals and reducing duplication in the approval process.

3.3.1.1 Collaborative Relationship

Building a collaborative relationship between stakeholders, including regulators, developers, and environmental groups, can help streamline the approval process. This can involve regular meetings to discuss project plans, environmental concerns, and potential solutions.

3.3.1.2 Engagement

It is advisable to engage with regulators at an early stage to identify potential issues and provide sufficient time for addressing them. This will help avoid any delays in the later stages of the approval process. Developers should also engage with local communities early in the process to address any concerns and build support for the project [22]. There may be a lack of meaningful public consultation during the consent process, which can lead to misunderstandings, mistrust, and opposition from local communities. Effective communication and engagement with stakeholders are crucial to building trust and addressing concerns. This can help avoid delays due to opposition or protests.

3.3.1.3 Environmental Impact Assessment

The environmental impact assessment (EIA) should be comprehensive and thorough, covering all potential environmental effects and proposed mitigation measures. This can help minimise the need for further studies or revisions, which can cause delays. Developers should ensure that they comply with all regulatory requirements, including those related to EIAs, noise limits, and visual impact assessments. As the FOW industry is a relatively new technology, the EIA may not adequately consider the potential impacts of FOW farms on the marine ecosystem, including wildlife and habitats. EIAs should include thorough and scientifically sound assessments of potential impacts, mitigation measures, and monitoring plans. This will help avoid delays due to the need for additional information or revisions.

3.3.1.4 Technical Assistance

The use of technology such as remote sensing, artificial intelligence, and larger data sources can help assess potential impacts and inform decision-making. This can help speed up the approval process and reduce costs. [83]

3.3.1.5 Ships Colliding with FOW Farms

The impact FOW farms have on navigation and shipping safety may not be fully understood or considered during the consent process. Potential issues, such as the risk of collision or interference with and distance from shipping lanes, should be evaluated and addressed. There have already been several collisions between ships and offshore wind structures. Protection methods are currently being established. An incident in 2022 promoted MARIN to test three ‘crash barrier’ type concepts that surround and protect wind farms from ships that are adrift due to loss of propulsion. [84]

On 24 April 2023, another incident occurred when a cargo ship collided with a wind turbine at Orsted’s Gode Wind 1 offshore wind farm. With more wind farms being deployed over the next two decades it indicates the substantial risks involved in safe navigation. In order to protect the environment and personnel it is important to learn from this incident and ensure appropriate practices are in place going forward.

3.3.1.6 Infrastructure Requirements

The infrastructure required for the installation and maintenance of FOW farms, such as ports and supply chains, may not be considered in the consent process. These requirements should be evaluated and planned for to ensure that the necessary infrastructure is in place to future proof operations.

3.3.1.7 Cumulative Impacts

The cumulative impacts of multiple FOW farms in a particular region may not be fully assessed during the consent process. The potential for cumulative impacts on the marine ecosystem, shipping, and other industries should be evaluated. For this reason, careful consideration should be practiced when allocating the sea area uses.

3.3.1.8 Spatial Planning

The potential for conflict with other uses, such as fishing, aquaculture, and recreational activities, may not be fully considered during the consent process. The impact of FOW farms on these activities should be evaluated, and measures to mitigate any negative impacts should be planned. Multi-use cooperative approach is required.

3.3.2 Consent Process

In 2020, Wind Energy Ireland (formerly Irish Wind Energy Association) outlined the consent steps involved in establishing wind projects. The ten-step process begins with early-stage assessment and continues through to construction and commissioning, as listed in Table 14. Timelines for each step are also outlined with some steps being carried out simultaneously.

Table 14: Consent steps involved in establishing wind projects

Step	WP	Elements	Timelines
1	Early-stage assessment	Desktop studies and application for foreshore licence and/or planning interest.	1 to 1.5 years.
2	Site characterisation	High resolution geophysical and geotechnical drilling campaigns, offshore met ocean and wind resource data collection and modelling.	1 to 2 years, post completion of WP 1.
3	Environmental assessments	Baseline data collection including a minimum of two years offshore bird and mammal surveying, seasonal onshore ecological surveys, basic design, and EIA preparation and consultation.	2 to 3 years, can run in parallel to WP 2.
4	Grid connection	Connection method from TSO confirming specifications and costs, cable route planning, substation design, and negotiation of associated landowner agreements.	2 years, can run in parallel with WPs 2 and 3.
5	Consents	Planning application, further consultation, and decision process including likely oral hearing.	1 to 1.5 years, post completion of WPs 2, 3, and 4.
6	Auction preparation	Front end engineering design and supply chain pricing.	1 year, can run in parallel to WP 5.
7	Engineering and procurement	Detailed design for supply chain tendering and contracting.	1 to 2 years, post success in RESS auction.
8	Financing – FID	Debt and equity package negotiation including due diligence.	1 to 2 years, post success in RESS auction, in parallel with WP 7.
9	Fabrication	Main components fabrication, turbines, foundations, high voltage (HV) equipment, cables.	1 to 2 years post FID, depending on supply chain availability.
10	Construction and commissioning	Offshore foundation, turbine, and offshore HV substation installation, onshore cable and HV system construction.	1 to 3 years, depending on construction methodologies and complexity of grid connection.

These timelines allow a proposed FOW farm to pass through all the planning steps to final commissioning in about ten years. Grid development must also happen in parallel which could take up to eight years for a single grid project. [85]

3.4 Sources of Funding

Developers need access to substantial funding in order to carry out successful projects. Dogger Bank offshore wind farm currently being constructed off the east coast of England has a capacity of 3.6 GW, will provide clean electricity to six million homes, and will come at a cost of nearly €3.5bn. Projects of similar financial capacity in the energy industry are not uncommon. However, as the FOW industry is relatively new, securing funding may be more difficult.

3.4.1 Early-Stage Sources of Funding

Start-up grants may allow early-stage progress where novel technologies or improvements can be explored and developed. For example, Enterprise Ireland provides the following grants:

- Feasibility study grant – 50% of the investment or €15,000 whichever is the lesser.
- Priming grant – 50% of investment or €150,000 whichever is the lesser.
- Business expansion grants – 50% of the investment or €150,000 whichever is the lesser.
- Microfinance small business loans – business loans available from €2,000 up to €25,000.

Early-stage finance supports are vital to enable start-ups with novel ideas and technologies to access test sites and laboratories to prove their concept. Once these technologies achieve certain milestones they can progress onto the next stage and thus be viable for successive funding.

To progress the technology further, more capital will be required to progress the various TRL milestones before eventually developing a full scale protype which will be tested in an open water environment. To get to this stage can take considerable resources in time and finance. Companies developing FOW farms or technologies typically seek funding from a variety of sources, including:

- venture capital firms,
- private equity firms,
- government agencies,
- development banks,
- commercial banks, and
- crowdfunding.

The below mentioned funding sources will depend on the size and stage of the project, the location of the project, and the specific financial needs of the company.

3.4.2 Venture Capital Firms

Venture capital firms invest in high-growth companies with innovative technologies and business models. Seeking funding from venture capitalists specialising in renewable energy and clean technology may be beneficial.

3.4.3 Private Equity Firms

Private equity firms invest in established companies that are seeking funding to expand or to finance new projects. Companies developing FOW farms may seek funding from private equity firms specialising in energy and infrastructure investments.

3.4.4 Government Agencies

Government agencies at the national, state, or local level may provide funding for research and development of renewable energy projects. Companies developing FOW farms may seek grants or loans from government agencies to help fund their projects.

A financial initiative called the Connecting Europe Facility (CEF) encourages the creation of trans-European networks in the fields of digital technologies, energy, and transportation. The programme provides financial support for projects related to the development of offshore wind farms, including the construction of offshore transmission infrastructure.

Within CEF is the European Green Deal which is a thorough plan to make the EU's economy more sustainable and climate friendly. The plan includes a target of reaching 60 GW of offshore wind power by 2030, which will require substantial investment in the sector. The European Green Deal will change the EU into a modern, resource-efficient, and competitive economy, ensuring:

- no net emissions of GHGs by 2050,
- economic growth decoupled from resource use, and
- no person and no place are left behind.

The EC has introduced a set of recommendations to make the EU's climate, energy, transport, and taxation policies necessary for reducing net GHG emissions by at least 55% by 2030, compared to levels in 1990. [86]

3.4.5 Development Banks

Development banks, such as the World Bank or the European Investment Bank (EIB), provide financing for sustainable infrastructure projects, including renewable energy projects. Companies developing FOW farms may seek funding from these banks. The EIB is the lending arm of the EU and provides financing for a wide range of projects, including offshore renewables. The bank provides loans, guarantees, and equity investments to support the development of offshore wind farms and other renewable energy projects. The EIB's €50m loan advances the design, development, construction, commissioning, operation, maintenance, and dismantling of a FOW project consisting of three Siemens Gamesa turbines with a total energy capacity of around 25 MW. [87]

3.4.6 Commercial Banks

Commercial banks may provide loans or lines of credit to companies developing FOW farms. The availability and terms of financing from commercial banks may depend on factors, such as the creditworthiness of the company, the size and scope of the project, and the level of risk involved.

3.4.7 Crowdfunding

Crowdfunding platforms allow individuals to invest in projects they believe in. Companies developing FOW farms may use crowdfunding platforms to raise funds from individuals who support renewable energy projects.

Eolmed joined forces with Enerfip, the first French crowdfunding platform dedicated to renewable energy. In 2018, they collected €400,000 in the first investment round. Eolmed offered another possibility to the inhabitants of the Occitanie region, then to all from 10 June 2022, to invest in one of the first European projects of this scale. The project raised €3m in 2022 to become the first floating wind farm to carry out citizen financing in France. [88]

3.4.8 Horizon Europe Support Fund

Horizon Europe aims to solve some of the biggest challenges of our time, such as adapting to climate change, fighting cancer, and helping to achieve the UN's sustainable development goals. Horizon Europe is the EU's research and innovation funding programme for the period 2021-2027, having a budget of €95.5bn. Cluster 5, also known as 'Climate, Energy and Mobility', is one of the six thematic clusters in Horizon Europe. The primary focus of Cluster 5 is to support research and innovation in areas related to the transition to a climate-neutral and green Europe, with a particular emphasis on sustainable energy systems, clean and efficient transport, and the circular economy. Some of the key areas of research and innovation that Cluster 5 aims to support include:

- renewable energy sources, such as solar, wind, and geothermal energy;
- energy storage and conversion technologies, such as batteries and fuel cells;
- smart and efficient energy systems, including smart grids and energy management systems;
- low-emission transport, such as electric and hydrogen-powered vehicles;
- sustainable urban mobility, including public transport and cycling; and
- circular economy, aiming to reduce waste and promote resource efficiency and reuse.

Cluster 5 of Horizon Europe aims to support research and innovation projects that will contribute to a sustainable, climate-neutral, and green Europe, in the areas of energy, transport, and circular economy.

3.4.9 European Green Bonds

The EU is taking steps to implement its strategy on financing sustainable development and the transition to a resource-efficient, climate-neutral economy. Mediators of the Council and the European Parliament reached a provisional arrangement on creating European green bonds (EuGB).

This regulation outlines consistent conditions for issuers of bonds that are interested in using the designated EuGB for their environmentally sustainable bonds that are consistent with the EU taxonomy and made available to investors worldwide. Additionally, it also creates a registration process and structure for oversight for EuGB's external reviewers. The regulation also provides some voluntary disclosure requirements for other environmentally sustainable bonds and sustainability-linked bonds issued in the EU, which aims to eliminate greenwashing in the green bonds market [89]. Environmentally sustainable bonds are one of the main mechanisms for financing investments related to green technologies, energy and resource efficiency, and sustainable transport and research infrastructure.

3.5 Roles and Responsibilities

The main stakeholders investing in the development of the FOW industry are the government and the developers. There are other stakeholders who impact but are not investing financially. The responsibilities of these stakeholders are to work together to promote the development of the FOW industry, ensuring that it is economically viable, environmentally sustainable, and socially responsible.

3.5.1 Responsibility of Government

Governments play a crucial role in promoting the development of the FOW industry by setting policies and regulations that support the growth of the sector. They are responsible for granting permits, licenses, and other regulatory approvals for the development and operation of FOW farms.

3.5.1.1 Regulatory Framework

The government needs to establish a regulatory framework that outlines the guidelines and standards for the development, installation, operation, and decommissioning of FOW farms. This regulatory framework should ensure safety, environmental protection, grid connection, and other considerations, such as fisheries, shipping lanes, and defence.
It should also be a streamlined process with no duplication or unnecessary steps. Ideally the process should be limited to just one agency.

3.5.1.2 Research and Development

The government must invest in R&D to advance the technology and reduce the costs associated with FOW. This includes funding for research institutions, universities, and private companies to conduct research and develop new technologies, as well as the development of test sites.

3.5.1.3 Market Incentives

The government can also provide market incentives to stimulate the development of the FOW industry. This can include feed-in tariffs, tax incentives, and subsidies to encourage the adoption of FOW technology.

3.5.1.4 Infrastructure Development

The government should also support the development of the necessary infrastructure to deploy FOW farms. This includes the construction of ports, storage facilities, and transmission infrastructure.

3.5.1.5 International Cooperation

The government should promote international cooperation to facilitate the deployment of FOW farms in international waters. This includes the development of international standards, sharing of best practices, and the establishment of common regulatory frameworks.

3.5.2 Responsibility of FOW Farm Developers

As the FOW industry is still relatively new and rapidly evolving, developers' responsibilities are significant in shaping the industry's growth and ensuring its long-term success. FOW farm developers are responsible for building the FOW farms. They are also responsible for securing the necessary funding and permits, managing the construction process, and ensuring that the wind farms operate efficiently. The responsibilities of FOW farm developers are significant. Their success in meeting these responsibilities will be critical to the growth and success of the FOW industry.

3.5.2.1 Innovating and Developing New Technologies

FOW farm developers should continue to invest in R&D to improve the efficiency and cost-effectiveness of FOW turbines, as well as to develop new technologies that can help overcome challenges, such as harsh weather conditions, deep water depths, and seabed instability.

3.5.2.2 Demonstrating the Viability of FOW Farms

FOW farm developers must demonstrate that FOW farms can be deployed and operated safely and reliably and generate electricity at a competitive cost with other renewable energy sources.

3.5.2.3 Engaging with Stakeholders

FOW farm developers need to engage with stakeholders, including local communities, governments, environmental organisations, and other industry players, to address concerns and build support for FOW projects. This includes addressing environmental impact, fishing, shipping, and navigation issues.

3.5.2.4 Community Funds

Community funds are agreed annual payments made by the developer to pre-determined local communities during the operating lifetime of an FOW. Funds can be used by the community to support initiatives and projects that directly benefit community groups, such as schools, non-governmental organisations, and local/parish councils. Depending on the agreed model, local groups could apply for funding through an application process. Award decisions are made by either the developer, local authorities, or an independent community panel or trust. Another option is that wind farm developers contribute to pre-existing funds that were not set up for the specific offshore project, such as regional development funds and wildlife/nature trusts.

3.5.2.5 Collaborating with Supply Chain Partners

FOW farm developers should work closely with supply chain partners to ensure that the necessary components, materials, and equipment are available to support the development and construction of FOW farms.

3.5.2.6 Ensuring Project Finance and Risk Management

FOW farm developers must secure the necessary financing and manage the risks associated with developing and operating FOW farms, which can include risks related to technology, weather, construction, and operational performance.

3.5.3 Technology Developers

Technology developers provide the necessary hardware and software for FOW farms, including floating platforms, mooring systems, and turbines. They are responsible for ensuring that the technology is safe and reliable, and they should continue to improve components to maximise efficiency and reduce the LCOE of FOW.

3.5.4 Supply Chain Partners

Supply chain partners include companies that provide materials, equipment, and services necessary for the construction and operation of FOW farms, such as cable manufacturers, vessel operators, and maintenance and repair companies. Regular dialogue between project developers, supply chain companies, and port authorities/companies is required in conjunction with an offshore wind market that is certain and facilitated by government.

3.5.5 Environmental and Social Groups

Environmental and social groups play an important role in ensuring that the development and operation of FOW farms are carried out in an environmentally sustainable and socially responsible manner. They advocate for the protection of wildlife and ecosystems, as well as for the interests of local communities and indigenous peoples.

4. Active Supply Chain

WG 3 aimed to develop an active supply chain.
Thus, the objectives were to

- highlight critical procurement issues within the NWE region;
- define the procurement value of different supply chain segments for the FOW market as well as the opportunities that are available for supply chain companies within the NWE region;
- highlight investments that could help bring down the supply chain costs; and
- engage with key stakeholders on these issues.

The final targeted outcome was to ensure maximum economic benefit for the NWE region.

From these objectives, the following seven steps were deduced as activities:

1. List all commodity codes concerned with FOW development.
2. Screen for high-level actual suppliers in the NWE region.
3. Quantify the value added for procured items in a typical FOW development.
4. List a detailed list of potential suppliers in the NWE region.
5. Refine the list to actually technically capable suppliers in the NWE region.
6. Identify gaps and required investments to compete on international market standards.
7. Engage with key stakeholders on these issues.

By completing the above-mentioned activities, finally, a high-level and refined list of potential suppliers as well as a value chain definition report could be delivered. The following report and results are based on the work conducted by WG 3, which happened in the form of four virtual meetings, individual input, and data processing by the WG lead. WG 3 was led by the AFLOWT project partner SAIPEM. From the AFLOWT project consortium, the following project partners contributed to WG 3 (listed in alphabetical order):

- EMEC from the UK,
- EMEC Ireland from Ireland,
- Febus Optics from France,
- Fraunhofer IWES from Germany,
- Kraken Subsea from France, and
- SEAI from Ireland.

Additionally, the following members of the advisory board actively participated in WG 3 (members that were rather passive but indicated interests in WG 3 are added in square brackets):

- Agence régionale Pays de la Loire from France,
- Atlantic Technological University from Ireland,
- BlueWise Marine from Ireland,
- Highlands and Islands Enterprise from the UK,
- Mainstream Renewable Power from Ireland,
- ORE Catapult from the UK,
- Steel Inspect GmbH from Germany,
- [TKI Wind oop Zee from the Netherlands],
- University of Rostock/Chair for Wind Energy Technology from Germany, and
- WindEurope from Belgium.

This report does not comprise all the seven steps listed above to achieve the overall objective. Due to changes in responsibilities and feasible contributions from partners and the WG lead, the final three steps could not be completed. However, the available results that are presented hereinafter already provide valuable information on the current status of the supply chain in the NWE region and allow for the identification of gaps and the derivation of recommendations.

4.1 List of Commodity Codes Concerned with FOW Development

Based on SAIPEM's offshore experience, a detailed list of categories and corresponding commodity groups was compiled and is presented in Table 15. This is applicable to (floating) offshore systems in a more general sense.

Table 15: Detailed list of categories and corresponding commodity groups

Category	Commodity Group
Means of transport	Sea and river means of transport
Lifting equipment	Cranes
	Hoists and winches
	Ropes and metal wires
Specific machinery for offshore	Propellers and positioning
Subsea robot system, remotely operated vehicle (ROV)	Offshore and floating (production) storage offloading (FSO/FPSO) equipment
	Mooring and manoeuvring
	Navigation equipment
	Mooring materials
Pipes	Structural piles
Structural materials	Metal sheets
	Structural sections
	Nuts and bolts
Lining, coatings, and paintings	Painting and solvents
Instrumentation	Automation
	Gauges
	Detectors
Electrical components and systems	Power distribution switchgear
	Switchgear electric components/electrical equipment
	Uninterruptible power supplies and direct current systems
	Anodes and cathodic protection
	Batteries
	Electrical/instrument/telecom cables
	Cable accessories
	Electrical material for lighting system
	Earthing system materials
Telecommunications	Radio systems

Table 15: Detailed list of categories and corresponding commodity groups (continued)

Category	Commodity Group
Individual safety equipment, clothing, and apparatus	Fire-fighting equipment
Construction of complete plants	Construction of complete plants
Electrical, instrumentation, and mechanical installation	Supply and assembly of structural and mechanical works
	Installation of equipment and packages
Painting, coatings, insulations, and sound proofing	Painting
	Anti-acid coatings
Hire/charter of equipment, vehicles, and vessels	Charter of assistant vessels
	Charter of work barge/vessel
	Charter of transportation barge/vessel
	Hire of ROV
	Hire of specific work site machines
Prefabricated items and yard construction	Yard construction of steel structure
	Shipyard construction
Offshore and onshore activities	Works on the seabed
	Subsea works with divers
	Installation
	Commissioning
	Start-up/shutdowns
Maintenance, repair, and conversion of assets	Maintenance, repair, and conversion of equipment
	Maintenance, repair, and conversion of shipping units
Design/engineering	Conceptual, design feasibility studies and basic design
	Detail design (front end/detail engineering)
	Technical assistance on site
	Specialist activities
Surveys and positioning	Geophysical, geognostical, geotechnical, and geophysics
	Meteo-marine and structural data acquisition services
	Other surveys
Procurement, expediting, inspection, transport, and quality, health, safety, and environment (QHSE) management	Procurement activities
	Maritime technical services
	Transport of goods
	Auxiliary transport services
	Quality activities
	Health, safety, and environment (HSE) activities
	QHSE site activities

Table 15: Detailed list of categories and corresponding commodity groups (continued)

Category	Commodity Group
Tests and analysis	Tests/inspections – welding inspections
	Tests and analyses
Consultancy, training activities, and services for companies	Consultancy services
	Training courses
	Services of the personnel management

As, however, not only offshore systems in general are to be considered but commodity codes concerned with FOW development shall be derived, the provided and previously presented information was further revised and adapted to FOW. In this way, 24 commodity codes (categorised into five groups) and two additional commodity groups were specified that are tailored to FOW development. This final list is presented in Table 16.

Table 16: List of commodity codes concerned with FOW development

Development and project management
Development and consenting services
Environmental survey
Resource and metocean assessment
Geological and hydrological surveys
Engineering and consultancy

Wind turbine
Nacelle
Rotor
Tower

Balance of plant
Cables
Floater/substructure
Offshore substation
Onshore substation

Installation and commissioning
Floater/substructure installation
Offshore substation installation
Onshore substation construction
Onshore export cable installation
Offshore cable installation
Turbine installation
Offshore logistics

Operation, maintenance, and service
Operations
Maintenance and service
Operations and maintenance support
Operations port
Health and safety

Decommissioning

Sector support functions

4.2 Screening for High-Level Actual Suppliers in the NWE Region

The supply chain is a critical and strategic subject for the AFLOWT project's success. For this reason, SAIPEM has planned ahead and identified, already at the beginning of the project, key and potential vendors for different tasks required for the FOW demonstrator, as presented in Table 17 and Table 18, respectively.

A special focus lied on suppliers in the NWE region. Thus, the screening for high-level actual suppliers in the NWE region was based on the Hexafloat FOW demonstrator initially planned to be developed and deployed within the AFLOWT project. The list of key and potential vendors for work and material required for the FOW demonstrator presented in Table 17 and Table 18, respectively, reveals that the majority of potential suppliers identified are located in the NWE region.

Table 17: Key vendors for work required for the FOW demonstrator

Work Description	Supplier in the NWE Region	Supplier Outside the NWE Region
Hexafloat and counterweight fabrication	ABLE Seaton Port (the UK)	ASM (Portugal)
	BiFab (the UK)	Bladt Industries (Denmark)
	Harland & Wolff (Ireland)	CRIST (Poland)
	Smulders (Belgium)	Schwartz Hautmont (Spain)
Wind turbine integration activities	Mammoet (France, the Netherlands)	
	Sarens (Belgium, France, the Netherlands)	
Wind turbine (second hand)	NaRval Solutions (France)	

Table 18: Potential vendors for material required for the FOW demonstrator

Material Description	Supplier in the NWE Region	Supplier Outside the NWE Region
Mooring supply	CARLIER Chaines SAS (France)	Vicinay (Spain)
	MARIT (France)	
Equipment transportation	Boskalis (France, the Netherlands)	
	TPI (France)	
	United Heavy Lift (Germany)	
Dynamic cable	JDR Cable Systems (the Netherlands, the UK)	Hellenic Cables (Greece)
	Oceaneering (the UK, Switzerland)	
	Prysmian Group (France, the UK)	
Counterweight steel structure	ArcelorMittal (the Netherlands)	
	Edgen Murray (France, the UK)	
	EEW Group (Germany)	
	Europe Steel Center (the Netherlands)	

Table 18: Potential vendors for material required for the FOW demonstrator (continued)

Material Description	Supplier in the NWE Region	Supplier Outside the NWE Region
Electrical and instrumentation supply	ABB (France, the Netherlands, the UK)	Sielte (Italy)
	AUTOCHIM (France)	
	Global Valve Center (the Netherlands)	
	MARIN (the Netherlands)	
	SEMCO (France, the UK)	
	Severn Glocon (the UK)	
	VEGA (France, the UK)	
Synthetic tendons	BEXCO (the Netherlands)	
	Bridon-Bekaert (the UK)	
	Cortland (the Netherlands)	
	Royal Lankhorst Euronete Group (the Netherlands, (Portugal,) the UK)	
Ballast system: valves and pumps	Flowserve (France, Germany, the Netherlands, the UK)	
	SACCAP (France)	
	XOMOX® (France, Germany)	

4.3 Quantification of Value Added for Procured Items of a Typical FOW Development

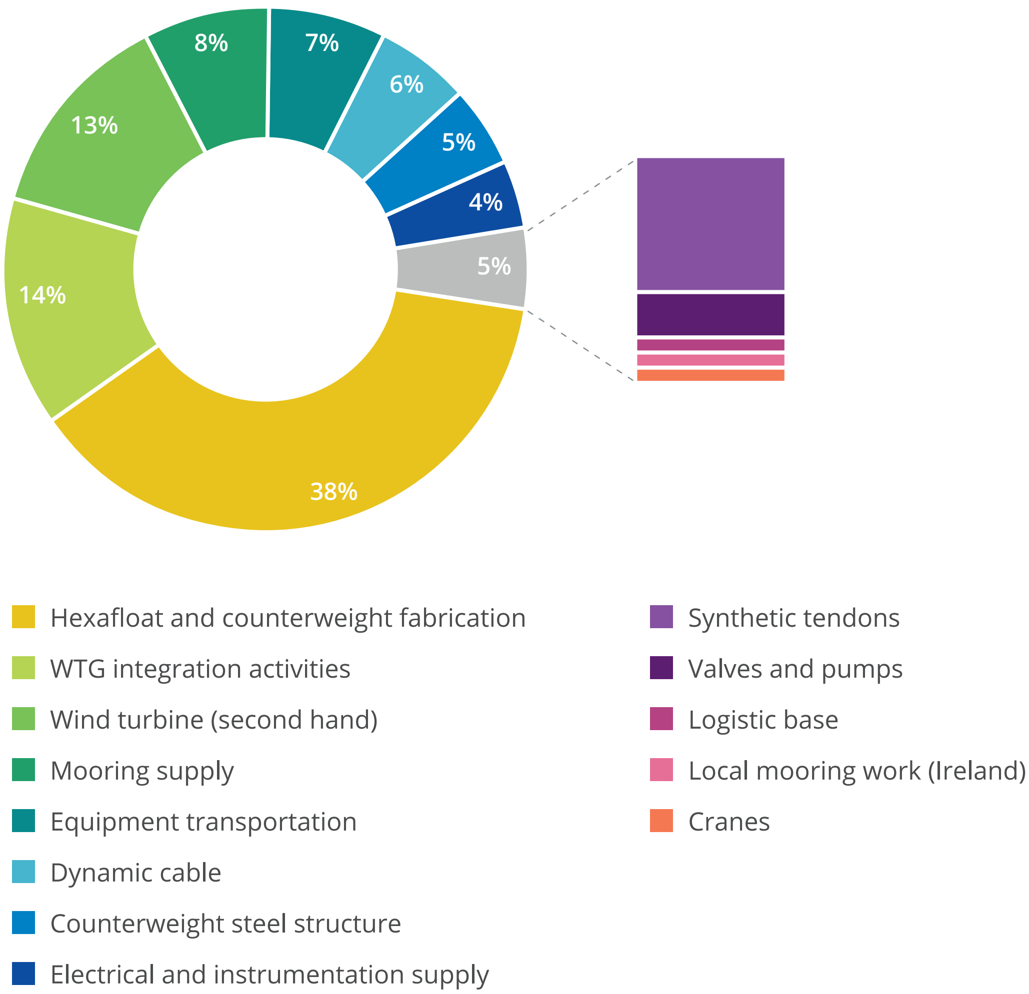
As already mentioned, the supply chain is a critical and strategic subject for the AFLOWT project's success. This is also reflected by the project budget: Not considering any O&M or decommissioning costs, 55% of the project budget was allocated to supply chain activities, while the remaining 45% was accounted for by engineering, management, installation, commissioning, and start-up costs.

The supply chain breakdown reveals fabrication and final assembly work as the main supply chain items. Beyond this, supply chain activities include procurement, integration, and transport. The supply chain activities are broken down in detail as follows:

- 65% are dedicated to
  - fabrication of the Hexafloat and the counterweight,
  - decommissioning of the second-hand turbine[3], including site facilities, heavy lifting equipment and manpower, and
  - final assembly;
- 27% for material supply;
- 7% for transportation activities; and
- 1% for subcontracting activities.

All supply chain items and their shares are presented in Figure 57.

Figure 57: Supply chain items



3 As a second-hand item, the proportion of the turbine in the supply chain (13%) is not typical of an offshore wind farm project.

4.4 Detailed List of Potential Suppliers in the NWE Region

With the help of the AFLOWT advisory board members – comprising both the project partners and the associate partners, and covering representatives from all countries in the NWE region – detailed information on potential suppliers for FOW development was collected. The inputs were gathered in the previously defined commodity codes of the seven respective commodity groups (cf. Table 16) and further refined with respect to the products and/or services provided. Several vendors were identified in each country of the NWE region, namely:

- 11 in Belgium,
- 118 in France,
- 145 in Germany,
- 80 in Ireland,
- 2 in Luxembourg,
- 41 in the Netherlands,
- 6 in Switzerland,
- 108 in the UK, excluding Scotland, and
- 371 in Scotland.

While some vendors could be found in more than one country in the NWE region, there were many vendors that did not offer only one product or service belonging to one commodity code but could be counted in different groups and services. The detailed list of potential suppliers in the NWE region is, hence, very extensive. Thus, the results are summarised in Table 19 in terms of the numbers of vendors offering the various products and services in the different commodity groups.

Table 19: Detailed list of potential suppliers in the NWE region

Commodity Group	Commodity Code	Product or Service	Vendors in NWE
Development and project management	Development and consenting services	Project development, investment	24
		Development and consenting services	5
		Planning services	6
		Financial services	1
		Engineering	1
		Consultancy	1
		Marine project consultant	1
		Construction port services	2
		Recruitment	6
	Environmental survey	Environmental surveys	7
		Environmental impact assessment	12
		Environmental services	1
		Consultancy	1
	Resource and metocean assessment	Metocean and structural data acquisition services	1
		Sensors and measurement technology	10
		Buoys	1
	Geological and hydrological surveys	Geophysical, geognostical, geotechnical, and geophysics	22
		Other surveys	3
		Vessel supply	1

Table 19: Detailed list of potential suppliers in the NWE region (continued)

Commodity Group	Commodity Code	Product or Service	Vendors in NWE
	Engineering and consultancy	Design/engineering	17
		Engineering	8
		Engineering and consultancy	30
		FEED studies	24
		Marine project consultant	1
		Moorings	1
		Survey	2
		Inspection	1
		Software, digital, and IT support	1
		R&D and education	1
Wind turbine		Turbine supplier	12
		Turbines	1
		Transition piece design and construction	4
		Turbine foundation	6
		Manufacturing facility	4
		Machine carrier	1
		Assembly	1
		Wind farm zone	6
	Nacelle	Nacelle	4
		Gearbox	5
		Generator	1
		Frequency converter	1
		Hydraulic system	1
		Main bearings	1
		Azimuth bearings	1
		Break	1
		Spinner	2
		Service lift system	1
		Sliding roof	3
		Air treatment	1
		Programmable logic controller	1
		Control box	1
		Auxiliary systems	7
		Small engineering components	2

Table 19: Detailed list of potential suppliers in the NWE region (continued)

Commodity Group	Commodity Code	Product or Service	Vendors in NWE
	Rotor	Rotor	1
		Blades	6
		Blade bearings	1
		Rotor bearing cover	3
		Pitch systems	1
		Manufacturing facility	1
	Tower	Tower	1
		Tower design	5
		Manufacturing facility	1
Balance of plant	Cables	Array and export cables	6
		Dynamic cable	6
		Cable accessories	3
		Inter-array/export cables manufacturing	4
		Manufacturing facility	5
	Floater/substructure	Fabrication	8
		Fabrication yard	16
		Yard construction of steel structure	4
		Shipyard construction	3
		Construction port infrastructure	1
		Manufacturing facility	28
		Site facilities construction	5
		Assembly	5
		Cranes and heavy lifting	23
		(Heavy) lifting equipment	10
		Hoists and winches	2
		Ropes and metal wires	4
		Flanges	1
		Piles	4
		Piping bulk	4
		Pipes	1
		Platforms	1
		Foundation/steelwork	6
		Foundation design	12
		Engineering	1

Table 19: Detailed list of potential suppliers in the NWE region (continued)

Commodity Group	Commodity Code	Product or Service	Vendors in NWE
	Floater/substructure (continued)	Turbine foundation	8
		Concrete foundation	1
		Secondary steel design and components	2
		Buoys	1
		Ballast system – manual valves	6
		Ballast system – instrumentation on-off valves	3
		Ballast system – pumps	5
		Mooring	15
		Mooring materials	3
		Tendons – synthetic tendons	4
		Anchors	4
		Concrete supply/contractors	7
		Steel structure	2
		Steel fabrication	5
		Fabricated steel components	18
		Structural materials	7
		Structural sections	2
		Central column cover	1
		Metal sheets	1
		Nuts and bolts	5
		Lining, coatings, and paintings	5
		Corrosion protection (chemical and others)	18
		Cathodic protection – anodes	3
		Electrical components and systems	21
		Power distribution switchgear	1
		Switchgear electric components/electrical equipment	1
		Telecommunications	1
		Radio systems	1

Table 19: Detailed list of potential suppliers in the NWE region (continued)

Commodity Group	Commodity Code	Product or Service	Vendors in NWE
	Offshore substation	Fabrication	8
		Fabrication yard	4
		Shipyard construction	3
		Manufacturing facility	2
		Site facilities construction	1
		Assembly	5
		Supply and assembly of structural and mechanical works	3
		Offshore substation	1
		Steel fabrication	5
		Concrete supply/contractors	6
		Substation and electrification engineering, procurement, and construction (EPC)	3
		Electrical supply	7
		Instrumentation (telecom and others)	22
		Radio systems	1
		Heating, ventilation, and air conditioning and fire safety	1
		Safety systems	1
		Monitoring system	7
	Onshore substation	Fabrication	8
		Fabrication yard	4
		Shipyard construction	3
		Construction of complete plants	1
		Manufacturing facility	2
		Assembly	5
		Supply and assembly of structural and mechanical works	3
		Onshore civils work	4
		Steel fabrication	5
		Concrete supply/contractors	6
		Substation and EPC	3
		Electrical supply	7
		Instrumentation (telecom and others)	22
		Radio systems	1

Table 19: Detailed list of potential suppliers in the NWE region (continued)

Commodity Group	Commodity Code	Product or Service	Vendors in NWE
Installation and commissioning		Installation	31
		Assembly (bolting)	2
		Construction port infrastructure	5
		Construction port services	15
		Vessels/vessel supply	6
		Subsea support services	1
	Floater/substructure installation	Foundation installation	2
		Moorings	1
		Mooring and manoeuvring	1
		Mooring monitoring	1
	Offshore substation installation		
	Onshore substation construction	Transformation station	1
	Onshore export cable installation	Onshore cabling	1
		Cable-handling equipment	3
	Offshore cable installation	Cable installation	19
		Inter-array/export cables installation	1
		Subsea systems – cable lay	2
		Trenching/burying cable landing	4
		Cable-handling equipment	3
		Trenching and repair solutions	4
		Grid connection	3
		Electrical design	1
	Turbine installation		
	Offshore logistics	Offshore logistics	1
		Offshore marine services and support	2
		Installation, vessels	1
		Vessel supply	4
		Diving	1
		Navigation equipment	2
		Marine project consultant	1
		Meteo-marine and structural data acquisition services	7
		Survey	3

Table 19: Detailed list of potential suppliers in the NWE region (continued)

Commodity Group	Commodity Code	Product or Service	Vendors in NWE
	Offshore and onshore activities	Installation	3
		Installation of equipment and packages	3
		Commissioning	4
		Works on the seabed	3
		Subsea works with divers	4
Operation, maintenance, and service	Operations	Onshore/offshore logistics	60
		Onshore loadout	1
		Charter of assistant vessel/work barge/vessel	6
		Vessel supply	5
		Offshore cargo carrying units	1
		Access systems	1
		Subsea support services	1
		Tests/inspections – welding inspections	3
		HSE activity	1
	Maintenance and service	O&M base	39
		Monitoring, inspection, and maintenance	29
		Balance of plant maintenance and service	6
		Maintenance, repair, and conversion of equipment	6
		Maintenance, repair, and conversion of shipping units	6
		Non-destructive testing (NDT) inspection services	2
		Training courses	5
	Operations and maintenance support	Specific machinery for offshore	2
		Offshore and FSO/FPSO equipment	1
		ROV/hire of ROV	5
		Unmanned aerial vehicles	1
		Unmanned surface vessel – survey	1
		Subsea systems – camera, lights	1
		Navigation equipment	1
		Maintenance service	1
		Painting and solvents	7
		Anti-acid coatings	1

Table 19: Detailed list of potential suppliers in the NWE region (continued)

Commodity Group	Commodity Code	Product or Service	Vendors in NWE
	Operations and maintenance support (continued)	Tooling, consumables, and specialist equipment	22
		Monitoring software and logistics planning	2
		Action management software	1
		Software, digital, and IT support	15
	Operations port	Port	11
		Operations port infrastructure	6
		Operations port services	1
		Pontoon systems, harbour	1
		Vessel supply	1
		Fabrication	1
	Health and safety	Health and safety equipment	5
		Health and safety inspections	5
		Fire-fighting equipment	1
Decommissioning		Decommissioning	6
		Re-installation services	1
Sector support functions	Consultancy and services for companies	Technical assistance on site	2
		Specialist activities	4
		NDT inspection services	1
		Marine project consultant	1
		Environmental services	1
		Consultancy services	25
		Services of the personnel management	1
		Software, digital, and IT support	1
		Numerical modelling	1
		Certification support	1
		Training courses	1
		R&D and education	3
	Procurement, expediting, inspection, transport and QHSE	Procurement, quality	3

4.5 Supply Chain Analysis

The potential suppliers found in the NWE region and the results presented in summary in Table 19 are analysed in some more detail in the following. Different aspects are considered, in particular the status of the national supply chain in each country of the NWE region as well as the situation of the supply chain throughout NWE.

Figure 58 shows the national supply chains, presenting the share of the commodity groups in each country of the NWE region. This national supply chain analysis reveals a high share of vendors addressing the balance of plant in most countries of NWE (apart from Scotland). Furthermore, vendors addressing operation, maintenance, and service are also well represented in the majority of countries. The national supply chain of Belgium, Luxembourg, and Switzerland, however, lacks any vendor for decommissioning and sector support functions. France and the UK, excluding Scotland, have vendors for all seven commodity groups, however, decommissioning is not well represented in both countries and France also has only a few wind turbine suppliers, while the UK, excluding Scotland, is a bit short of vendors addressing sector support functions. Both Germany and the Netherlands do not have any suppliers for sector support functions and only a few for decommissioning as well as development and project management. Ireland and Scotland, on the other hand, cannot exhibit any vendor addressing decommissioning and demonstrate only small shares of wind turbine suppliers as well as vendors for sector support functions.

The comparison of the supply chains of the countries within NWE, as depicted in Figure 59a, reveals that Belgium, Luxembourg, and Switzerland are the least developed areas in the NWE region, followed by the Netherlands, which, however, are well developed with respect to the balance of plant suppliers. Ireland is – based on the numbers – still rather at the lower end; however, it is already well developed, having almost equal shares of suppliers for balance of plant, development and project management, operation, maintenance, and service, and installation and commissioning. The UK, excluding Scotland, is also well developed with respect to most of the commodity groups (apart from decommissioning and sector support functions). The third highest number of suppliers can be found in France, which, however, is mostly addressing the balance of plant but only rarely decommissioning or the wind turbine itself. Germany is the second-best developed country in NWE, but it is also not well represented in the commodity groups decommissioning as well as development and project management, and not at all in sector support functions. Scotland is by far the most developed country in the NWE region.

The supply chain analysis with respect to the different commodity groups served in the entire NWE region, as presented in Figure 59b, shows that NWE is most developed in terms of vendors serving the balance of plant. Vendors in NWE addressing operation, maintenance, and service are the second-most, followed by development and project management suppliers, to which Scotland contributes the most. The commodity group installation and commissioning is still well represented; however, the number of vendors is only one third of those for the balance of plant. There is still an accountable number of wind turbine suppliers in NWE, whereas most of them are located in Germany. There are only a few vendors serving sector support functions, most of them coming from Scotland or France. Finally, the least and very poorly developed commodity group – being existent only in four countries of NWE – is clearly decommissioning, with only a few vendors at most.

Figure 58: The supply chains in the countries belonging to the NWE region

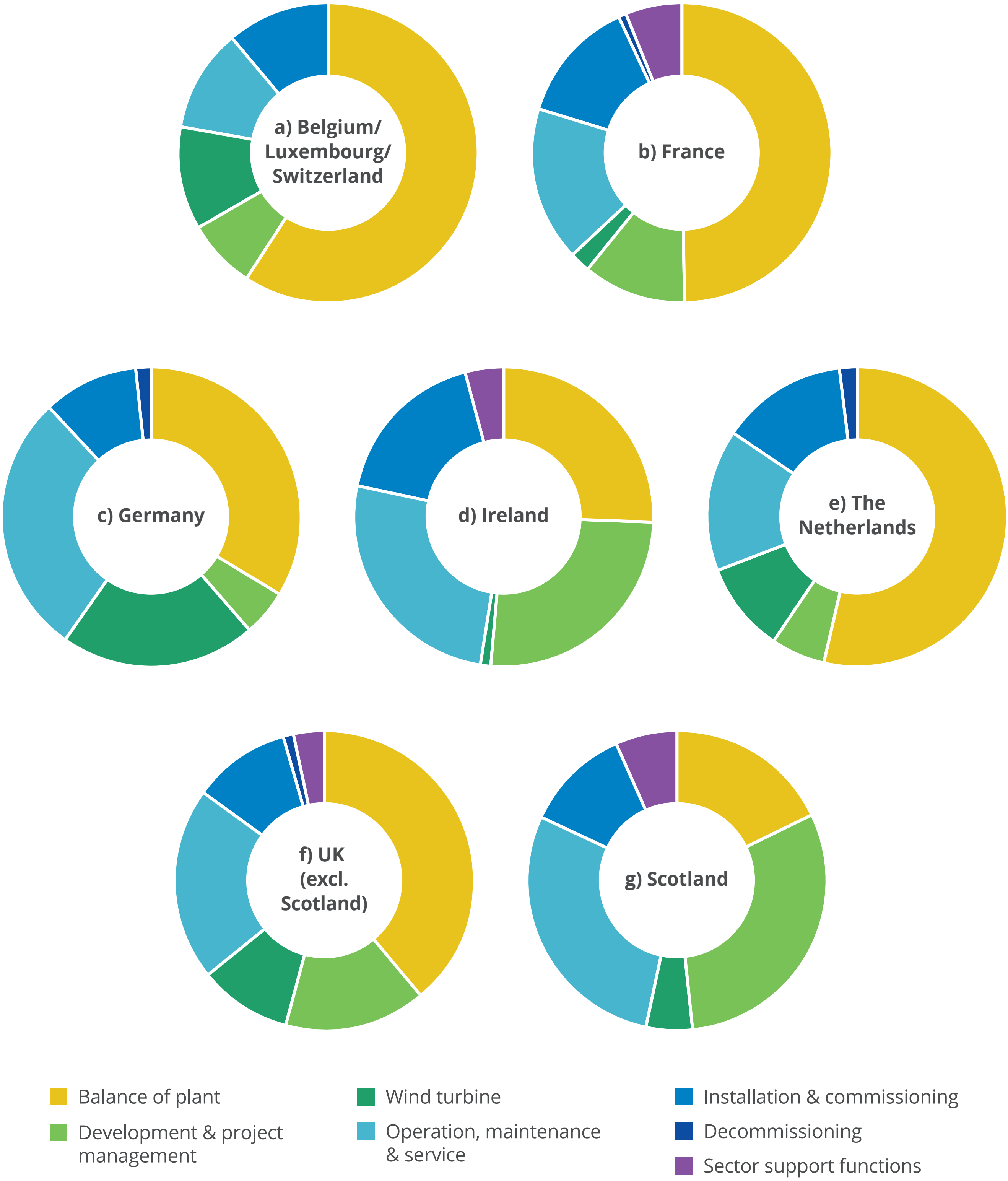
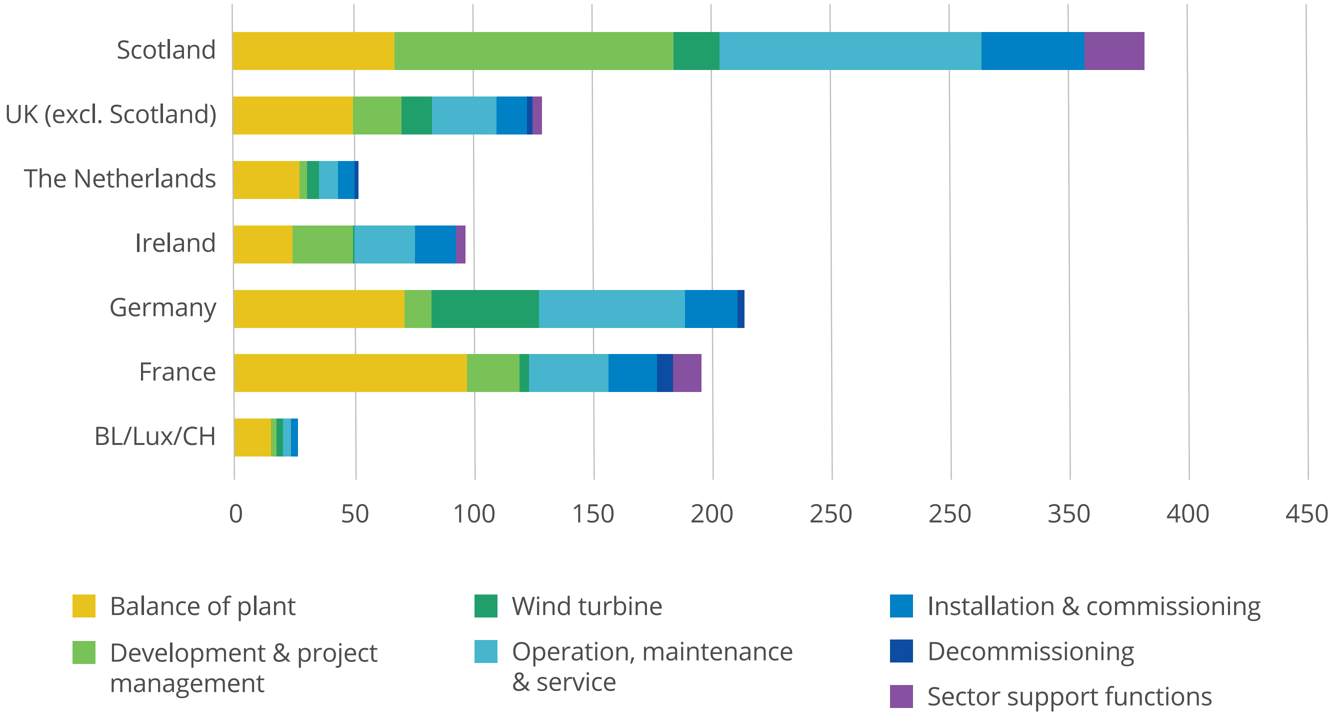
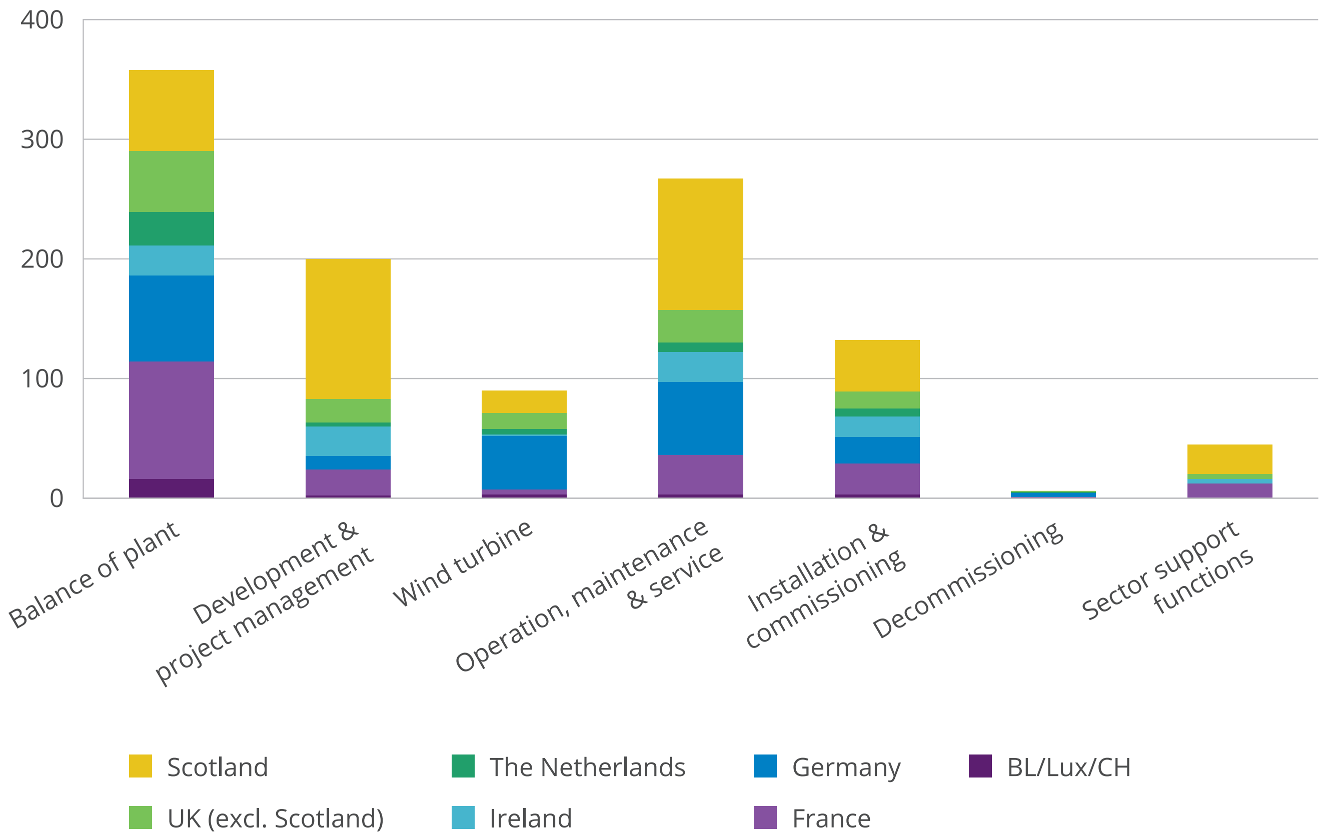


Figure 59: The supply chain in NWE

a) Comparison with respect to the countries



b) Comparison with respect to the commodity groups



4.6 Recommendations for Identifying Gaps and Required Investments to Compete on International Market Standards

The supply chain analysis in Section 4.5 already reveals a clear underrepresentation of vendors addressing decommissioning. However, to identify gaps in the supply chain in the NWE region, the number of vendors is not meaningful by itself. Additionally, it is required to know the vendors' production capacities as well as the needs from the industries or project developers and the resulting requirements on the suppliers. Based on the current situation in Europe and many other parts of the world, which is that many countries have placed high targets for renewable energies until similar deadlines, actually most of the manufacturers and suppliers are heavily booked out. Thus, the following questions need to be investigated to identify the real gaps in NWE's supply chain:

- What is the production capacity (minimum/ maximum) of each vendor in NWE's FOW supply chain?
- What are the vendors' production plans for the next few years?
- Do suppliers have material in stock, and if so, how much?
- What costs do the vendors have?
- What cost development do the suppliers expect for the next few years?
- What are the national targets for (floating) offshore energy in the NWE countries in terms of installed capacity and year of commissioning?

Some information may already be available in a database or be publicly accessible, such as national or international political agreements or legislative proposals. Others, however, might be very complex and difficult to acquire due to the amount and extent as well as confidentiality issues. The most promising approach might be to perform a survey, having a set of prepared questions to be shared with and asked to the vendors, most preferably through an online survey system. Anonymisation and careful formulation of the question may avoid any confidentiality issues. Beyond this, another survey may help identify companies and vendors that are interested in being involved in more depth and are willing to contribute to the supply chain analysis and identification of gaps in further discussions.

The mapping of all information helps identify the gaps in the commodity groups and in the NWE countries. Critical aspects that can be derived from such a holistic mapping are, for example, the following:

- The conformity in timing – Will the required components be manufactured and installed in accordance with the timeline of the FOW park project?
- Bottlenecks in the overall schedule – Some investments and supply chain development can only be made when certain project decisions have come to a decision.
- Limits for a solely local (or NWE) supply chain – Are the required materials and manufacturing capacities available, and is the infrastructure sufficient locally or at least within NWE?
- Hidden costs – Where are dependencies that may affect the overall costs, and how will the (national, European, or global) economy develop?

The final step is then to engage with key stakeholders on the identified issues. Especially, suppliers and stakeholders related to commodity codes that need to get more developed or also certain components within balance of plant should be focused on and engaged with. It needs to be discussed on what is required to bridge the gaps and achieve the overall goal of competing on international market standards.

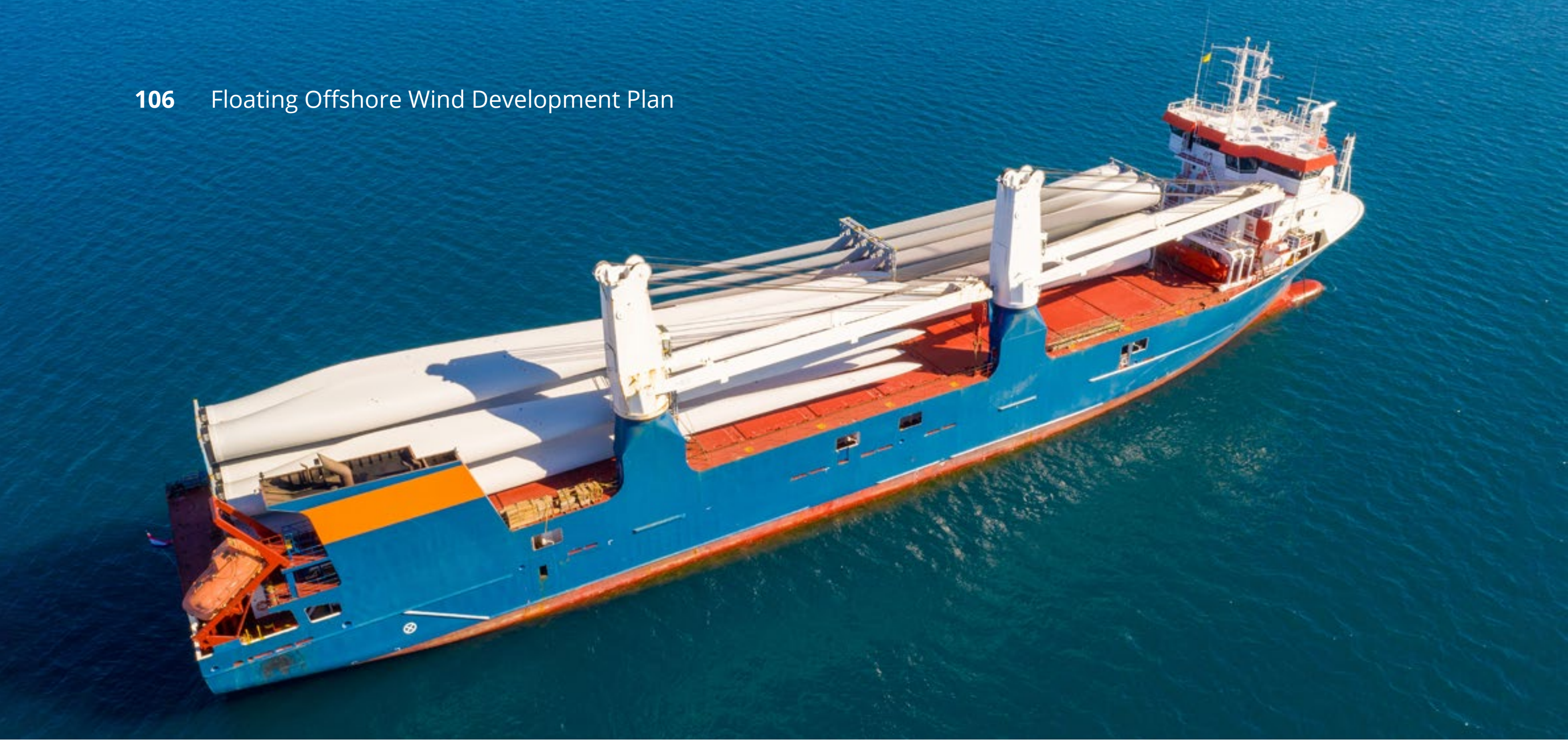
4.7 The Findings of the Work Conducted in WG 3 put into Context with Other Studies on FOW Supply Chain

In the past two years, some other studies on the FOW supply chain have been performed [90, 91, 92, 93]. These differ in the considered area and focus topic and are, hence, addressed and compared to the findings of the work conducted in WG 3 in this separated section.

A quite similar broad focus on the entire supply chain for FOW turbine systems is pursued by the FOW CoE of ORE Catapult [90]. The project aimed at "identify[ing] and quantify[ing] the key infrastructure and supply chain requirements to deliver a pipeline of large[-] scale FOW projects cost effectively across the UK and with a significant share of project activity based in the UK" [90, p. 07]. The work is, thus, only focusing on the UK's supply chain, but is, in return, much more detailed. It covers the requirements for the FOW supply chain, the capability and capacity of the existing infrastructure, and the impacts of developing the FOW infrastructure with a focus on economics. Similar to the approach followed in WG 3, further needs for the FOW supply chain are derived from a comparison of the identified requirements to the capacities of the existing supply chain. The UK's supply chain capacity, especially with respect to manufacturing, assembly, and construction of FOW turbine systems, is currently not sufficient, but there are many facilities with high development potentials. Apart from financial support, there is the need for clear commitment – mostly by the government and through energy policies – to the development and future deployment of FOW technologies in specific regions, implying then as well the associated development of grid and regional infrastructure. The results of the report by the FOW CoE show good agreement with the findings of the work conducted in WG 3, especially that operation, maintenance, and service are well represented in the UK, including Scotland. It is also pointed out that decommissioning might not be fully assessable at this time, as it is not yet clear what the requirements are for FOW turbine system decommissioning. Overall, the FOW CoE points out that an active supply chain is relevant for deploying FOW technology and that it may affect project costs and risks as well as the UK's Gross Value Add positively.

A global supply chain analysis, with the focus on the optimal array voltage level for future wind farms with large MW-class wind turbines, is performed by Carbon Trust [92]. Using a higher array voltage level of 132 kV would allow cost savings. To benefit as much as possible from these, proactive actions by the supply chain are required as soon as possible. For this, a close cooperation between developers and the supply chain is needed, encompassing the engagement with the supply chain regarding the availability and cost of key components and the provision of information on market demand to the suppliers. The Offshore Wind Accelerator programme would be a suitable framework for the continuation of the work and engagement with the suppliers. The overall recommendation by Carbon Trust that "formal commercial engagement with the supply chain should start immediately" [92, p. 18] is not applicable to the optimal array voltage level but to the entire FOW supply chain to avoid any delays in realising the deployment roadmap.

Finally, DNV [91] and Guidehouse and Berenschot [93] both focus on the supply chain for hydrogen in combination with offshore wind energy. While DNV's report was commissioned by the Danish Energy Agency, Guidehouse and Berenschot's study was commissioned by the Netherlands Enterprise Agency. However, the investigated scenarios are not limited to a national level but also comprise the European region and countries along the North Sea. DNV compares different infrastructure concepts, such as centralised or distributed hubs with onshore or offshore hydrogen generation, and assesses their requirements and benefits. As a conclusion, Guidehouse and Berenschot point out that any decisions with respect to offshore wind system integration should be taken as early as possible because different infrastructural approaches are needed for different realisations. This can be directly transferred to any supply chain and, thus, also to the FOW supply chain in general, since "the long lead times for infrastructure projects mean a decision is needed to guarantee that future offshore wind projects are in line with requirements" [93, p. 139] and "connected" [93, p. 16].



5. Conclusion

The FOW industry presents many exciting opportunities and challenges, requiring a comprehensive understanding of several key aspects. Successful engagement in this industry requires a solid knowledge base encompassing the principles of wind energy generation, offshore engineering, and the infrastructure needed for assembly and installation. Transparent development processes that outline the steps involved, from early assessment to construction and commissioning, outline specific departments responsible for each stage and the expected timeline involved, will help developers plan and execute projects more efficiently. Growing energy demands and an increasing focus on renewable energy sources suggests a significant market opportunity for FOW. Despite the drop off in 2021 and 2022 due to economic uncertainty as a result of the pandemic and the war in Ukraine, investments in the sector have been increasing steadily. Creating dedicated test sites for FOW technologies is vital for the growth of this industry. These test sites are invaluable for assessing new concepts and prototypes' performance, reliability, and environmental impact. They provide opportunities to validate technological advancements, optimise designs, and gather essential data to refine deployment strategies. Thorough testing will allow developers to establish practices that help to reduce the LCOE of FOW energy.

There are many ways to develop FOW infrastructure across the NWE region. Numerous reports and documents were reviewed in order to understand the various practices and recommendations from well-established and experienced renewable energy agencies. An overview of the CO_2 emissions and installed FOW capacity targets were determined for each country within the NWE region. These ambitious targets are to be achieved over the next two decades, with a net zero emission target by 2050. As FOW industry is relatively new territory all stakeholders involved must work together to install the required targets. With FOW farms capable of operating at up to 800 m depths, the potential sea area available is extensive, particularly when compared to the limitations of BFOW turbines. Once wind farms are proven in the easily accessible sites the potential energy available in other areas will drive industry to rapidly scale up. At that stage the consenting and planning process, and the grid connection will be the main factors that controls how quickly other sites are developed. In the meantime, port infrastructure could cause bottlenecks for the deployment of the initial FOW farms. Having a clear consent process where the developer can see how their application is progressing at all stages will improve trust in the system and aid developers with their planning process. Also having multiple process occurring at the same time will improve efficiency.

With respect to the active supply chain for floating offshore wind development, working group 3 of the 'Long Term' work package within the AFLOWT project identified a detailed list of potential suppliers in the NWE region. These were assigned to previously defined seven commodity groups (i.e. development and project management, wind turbine, balance of plant, installation and commissioning, operation, maintenance, and service, decommissioning, and sector support functions) and corresponding commodity codes. The supply chain analysis reveals an overall well-developed supply chain across the entire NWE region, with, however, a lack of resources or vendors for decommissioning. A comparison of the countries shows that Scotland is the most established country within NWE with respect to the supply chain for floating offshore wind development, while Belgium, Luxembourg, and Switzerland are the least developed countries. A more sound analysis for identifying the actual gaps in the supply chain is still to be performed and shall consider not only the number of available vendors but also their production capacities and plans, their costs and expenses, and the envisaged targets for floating offshore wind in NWE.

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