

FLOATING OFFSHORE WIND
CENTRE OF EXCELLENCE

Delivered by
CATAPULT
Offshore Renewable Energy

FLOATING OFFSHORE WIND AND FISHING FRAMEWORK FOR CO-EXISTENCE – A FEASIBILITY STUDY

Public Summary Report



Credit: Equinor Hywind
Floating Wind Farm

Authors: Grant Phillips, Luke Eatough

Date: 16/07/2025

In partnership with:



**Crown Estate
Scotland**
Oighreachd a' Chrùin Alba

DISCLAIMER

Whilst the information contained in this report has been prepared and collated in good faith, ORE Catapult makes no representation or warranty (express or implied) as to the accuracy or completeness of the information contained herein nor shall we be liable for any loss or damage resultant from reliance on same.

EXECUTIVE SUMMARY

In February 2025, the Climate Change Committee published its Seventh Carbon Budget, advising the UK Government that 125 GW of offshore wind capacity, a sevenfold increase upon 2025 levels, would be required by 2050 to meet net zero greenhouse emissions targets. According to the latest industry estimates, it is anticipated that floating offshore wind (FOW) technology will account for more than one third of the UK's total offshore wind capacity by 2050. Given the scale of this ambition, it is important that the potential risks and opportunities associated with the coexistence of future large scale FOW farms and other sea users are considered early so that the appropriate measures and enabling actions can be undertaken.

As an established maritime industry, commercial fisheries are considered a key stakeholder in the offshore wind development process. Therefore, in 2021, the Floating Offshore Wind Centre of Excellence (FOW CoE) launched its FOW and Fishing Interaction Roadmap project which facilitated an extensive cross-industry engagement process to identify potential interactions between the FOW and fishing industries. A principal recommendation from the resulting Roadmap was to assess whether the FOW array layout design process could play a role in facilitating coexistence between future large scale FOW farms and commercial fisheries.

The FOW CoE therefore subsequently established the *Floating Offshore Wind and Fishing Framework for Coexistence* project in order to deliver on this recommendation. Although the primacy of marine spatial planning is recognised as a key method for managing the requirements of a range of maritime industries, the objective of this project was to determine the extent to which decisions made during the design of future large-scale FOW farms, post-lease award, might facilitate potential coexistence with commercial fisheries. A UK remit was adopted for this work, with a particular focus on the Scottish North Sea and the Celtic Sea.

The project was developed with the following core aims:

- To undertake targeted engagements with key stakeholders in order to identify and characterise potential opportunities to support coexistence between the FOW and fishing industries, with a focus on the role of FOW farm array layout design.
- To deliver a technical feasibility assessment of the identified opportunities and innovations for maximising coexistence.
- To undertake an economic impact assessment to determine the potential financial implications of the identified opportunities and innovations, both in respect of a FOW project's capital expenditure (CAPEX), operational expenditure (OPEX) and LCoE, as well as the potential considerations for the fishing industry.
- To develop guidance in the form of a coexistence framework for supporting decision making during the development process of commercial scale FOW arrays – both at the project-level and a strategic-level – in respect of maximising coexistence with the fishing industry. This will summarise both the technical and economic considerations, and, where relevant, the potential role of innovations.

Technical workshops were convened to facilitate the cross industry-engagement process. These were conducted regionally, with in-person workshops held in Scotland and Cornwall, and included representatives from the fishing industry (including several with direct experience of working on or captaining commercial fishing vessels) and FOW farm developers (including design engineers, development and consenting specialists, and fisheries engagement managers). The project team also

sought the input of other relevant stakeholders, including seabed leasing authorities, regulators, and maritime navigational and safety bodies.

Following the technical engagement process, the identified opportunities for supporting potential coexistence were assessed by the project team in respect of their technical and economic feasibility. The opportunities were subsequently scored in the coexistence framework.

The principal innovation opportunities for supporting potential future coexistence between large-scale FOW farms and commercial fisheries include: larger turbine capacities, and the increased spacing within arrays that they would enable; taut nylon moorings, and the reduction in mooring footprints that they could facilitate; the appropriate positioning of substations within FOW arrays; the simplification of FOW farm maritime logistics through the adoption of SOV-led logistic strategies and the development of in-situ heavy lift solutions; and the digital mapping of FOW subsea infrastructure. These innovation opportunities exist in addition to the overriding spatial planning strategy of siting offshore wind developments away from high value fishing grounds – a strategy that must be underpinned by early and proactive cross-sector engagement, and the appropriate sharing of information and data regarding respective activities (such as historical fishing vessel data, which is critical to the offshore wind lease area selection process).

Other opportunities that were also reviewed, but were judged by some developers to be less feasible, include: the adjustment of turbine separations (assuming a set turbine capacity), either to reduce the overall size of an array, or increase the space within it for fishing operations; the inclusion of one or a small number of widened lanes within an array for fishing operations; the partial burial of catenary moorings to increase the unobstructed seabed between mooring footprints; and the use of marker buoys to identify FOW anchor locations.

It was noted that the ability to facilitate coexistence will be contingent on a range of challenges being successfully addressed. It is likely that this will depend on multiple opportunities being realised in tandem, rather than any one innovation being pursued in isolation. Continued and proactive cross-sector collaboration will also be vital.

Recommended enabling actions outlined in this report include:

- Continued support for the development of relevant innovations, including larger capacity turbines, nylon mooring systems, and in-situ heavy lift solutions for FOW turbines.
- The use of maritime simulations to further understand the practical risks and opportunities of coexistence. It is proposed that the FOW and fishing industries jointly undertake a series of simulated fishing operations within virtual FOW environments using specialised maritime simulation facilities. The simulated scenarios should consider the opportunities and relevant innovation areas identified in the coexistence framework set out in this report.
- Ongoing proactive cross-sector communication, both at a project-level, where early communication regarding FOW farm development plans is crucial, and at an industry-level, where the status of applicable FOW technology innovations and the development of relevant protocols can also be impactful.
- A continued monitoring of the innovation landscape, particularly in relation to any new opportunities not identified in this coexistence framework.
- Opportunities to support the development of innovations applicable to fishing practices could also play a role. While it was noted that fishing practices are well established and have matured over the course of the industry's long history, there may also be support for an R&D programme dedicated to potential fisheries innovations.

For the purposes of this project, a flexible understanding was adopted for the term coexistence. During the project's cross industry engagements and subsequent analyses, the project team used the term coexistence to refer to the ability of the FOW and fishing industries to exist and operate independently within the same general marine space. As such, coexistence (as applied in this report) refers to a fishing vessel skipper's ability to operate in the vicinity of a FOW farm, including potentially within the interior of the array.

The question of coexistence between FOW and fishing is undoubtedly a challenging topic that evokes a broad range of perspectives across all stakeholder groups. The publication of this coexistence framework is an attempt to advance the current discussion and identify areas of consensus. It is hoped that the work undertaken in this project will allow both industries to concentrate their collaborative efforts on opportunities that have a greater prospect of achieving their shared aims.

CONTENTS

1	Introduction.....	10
1.1	Floating Offshore Wind Centre of Excellence	10
1.2	Environmental Interactions Strategic Programme	11
2	Project Plan and Scope	12
2.1	Project Objectives	12
2.2	Project Structure and Approach.....	12
2.3	Prior Work	13
3	Stakeholder Engagement Approach	16
3.1	Process	16
3.2	Stakeholders.....	17
3.3	Managing Stakeholder Engagement Risks	17
4	Workshop Technical Content	18
4.1	Technical Input	18
4.2	Technical Drawings.....	19
4.3	Array Layout	19
4.4	Components	20
4.4.1	Mooring Profile A.....	20
4.4.2	Mooring Profile B.....	21
4.4.3	Mooring Profile C.....	21
4.4.4	Mooring Profile D	21
4.4.5	Mooring Profile E.....	22
5	Summary of Workshop Outputs.....	23
5.1	Participating Stakeholders	23
5.2	Workshop Outputs.....	23
6	Assessment of Workshop Outcomes	29
6.1	Turbine Spacing.....	29
6.1.1	Constraints on Turbine Separation.....	29
6.1.2	Turbine Capacity	30
6.1.3	Power Density.....	31

6.2	Array Topology	32
6.2.1	Perimeter-Loaded Wind Farms	33
6.2.2	Search & Rescue (SAR) Lanes	33
6.2.3	Assessment of FOW implications, including potential challenges posed by mooring lines and dynamic cables. Wind-Tide Orientation	34
6.2.4	Lanes for Fishing Vessels	34
6.2.5	Aligned vs Staggered Array Configuration.....	35
6.3	Mooring & Anchors	36
6.3.1	Catenary Chain Burial	36
6.3.2	Redundancy in Mooring Systems	37
6.3.3	Synthetic Mooring Lines	37
6.3.4	Decommissioning of Anchors	38
6.3.5	Marking of Anchors	38
6.3.6	Anchor, Seabed and Fishing Method.....	39
6.4	Operations & Maintenance	40
6.4.1	CTV vs SOV	40
6.4.2	Major Component Exchange	40
6.5	Cables	41
6.5.1	Dynamic Cable	41
6.5.2	Static Cable Burial.....	41
6.5.3	Static Cable Rock Armouring	41
6.5.4	Shared Mooring Clusters	42
6.5.5	Substation Location	42
6.6	Communication & Collaboration.....	42
6.6.1	Early Engagement	42
6.6.2	Towing Patterns & AIS Data Sharing.....	42
6.6.3	Modelling Fishing Activities	42
6.6.4	Entanglement Protocols	42
7	Coexistence Framework	44
7.1	Summary	58
8	Conclusions and Recommendations	59
9	References	61

FIGURES

Figure 1 Floating Offshore Wind Centre of Excellence Industrial Partners.....	11
Figure 2 Project Steering Group Members.....	11
Figure 3 Project Structure	12
Figure 4 VMS intensity for the UK fleet operating in the Irish Sea in 2007 [30]	15
Figure 5 VMS intensity for the UK fleet operating in the Irish Sea in 2013 [30]	15
Figure 6 Stakeholder Engagement Structure	16
Figure 7 Mooring Profile A	20
Figure 8 Mooring Profile B	21
Figure 9 Mooring Profile C.....	21
Figure 10 Mooring Profile D	21
Figure 11 Mooring Profile E.....	22
Figure 12 Effect of turbine separation on net AEP & wake losses: North Sea FOW farm case study (for a defined lease area)	30
Figure 13 Aligned Layout.....	36
Figure 14 Staggered Layout.....	36

TABLES

Table 1 Variation of turbine spacing and wind farm power density with turbine capacity (assuming a mean turbine separation of 8-9 rotor diameters).....	32
Table 2 Comparison of soil types with FOW anchor compatibility and fishing methods	39
Table 3 Opportunity Scoring Matrix.....	44
Table 4 Coexistence framework.....	46

NOMENCLATURE

CAPEX	Capital Expenditure
CoE	Centre of Excellence
EISP	Environmental Interactions Strategic Programme
FOW	Floating Offshore Wind
GW	Gigawatt
MW	Megawatt
LCoE	Levelised Cost of Energy
O&M	Operation & Maintenance
OPEX	Operational Expenditure
ORE	Offshore Renewable Energy
TLP	Tension Leg Platform
TRL	Technology Readiness Level
OSW	Offshore Wind
OEM	Original Equipment Manufacturer

1 INTRODUCTION

In February 2025, the Climate Change Committee published its Seventh Carbon Budget, advising the UK Government that 125 GW of offshore wind capacity would be required by 2050 – a sevenfold increase upon 2025 levels – in order to meet net zero greenhouse emissions targets [1]. Given the ability of floating offshore wind (FOW) technology to access the wind resource in water depths beyond the reach of fixed wind foundations, such as those located in the Scottish North Sea and the Celtic Sea, it is anticipated that FOW turbines will account for more than one third of the UK's total offshore wind capacity by 2050 [2].

In light of this ambition, the FOW industry has recognised the importance of proactively managing the risks and opportunities associated with coexistence with other sea users, including the commercial fishing industry. Following its launch, the Floating Offshore Wind Centre of Excellence (FOW CoE) delivered the FOW and Fishing Interaction Roadmap project which facilitated a stakeholder engagement process between the Scottish fishing industry and FOW farm developers in order to identify potential interactions between the two sectors [3]. This work resulted in a Roadmap of further research and activities to mitigate the potential risks and exploit the opportunities associated with these interactions.

One such interaction, which both industries agreed required further attention as a matter of priority, was the potential displacement effect that future commercial FOW development could have on existing fishing activities, either due to the complete obstruction of fishing operations, or unacceptable operational risk. It was further agreed by both industries that in order to assess the extent of the risk associated with this interaction, and to develop potential mitigations, it would be prudent to undertake a review of the array layout design process for commercial scale FOW farms with the objective of maximising the potential for coexistence with commercial fisheries.

The *Floating Offshore Wind and Fishing Framework for Coexistence* project has therefore been established in order to deliver on this recommendation. Through assessing the technical, operational and economic considerations of facilitating coexistence with commercial fisheries, this project is intended to develop a framework for stakeholders to support and inform decision making during the development process for future commercial FOW arrays – both at the project level and a strategic level. This process was informed by the engagements undertaken to date with the fishing industry, as well as targeted follow-up engagements where appropriate and required.

For the purposes of this project, a flexible understanding was adopted for the term *coexistence*. It is recognised that, at the time of writing, a broader discussion was ongoing regarding the distinction between *coexistence* and *colocation*, and their appropriate definitions. During the project's cross industry engagements and subsequent analyses, the project team used the term *coexistence* to refer to the ability of the FOW and fishing industries to exist and operate independently within the same general marine space. As such, *coexistence* (as applied in this report) refers to a fishing vessel skipper's ability to operate in the vicinity of a FOW farm, including potentially within the interior of the array.

1.1 Floating Offshore Wind Centre of Excellence

The Floating Offshore Wind Centre of Excellence was established in 2020 by the Offshore Renewable Energy (ORE) Catapult with the vision:

To establish an internationally recognised centre of excellence in floating offshore wind which will work towards reducing the Levelised Cost of Energy (LCoE) from floating wind to a commercially manageable rate, cut back development time for FOW farms and develop opportunities for the local

supply chain, driving innovation in manufacturing, installation and Operations and Maintenance (O&M) methodologies in floating wind.

The FOW CoE is a collaborative programme with industry, academic and stakeholder partners. At the time of writing, the following organisations are Industry Partners in the FOW CoE Project Partners in the FOW CoE:



Figure 1 Floating Offshore Wind Centre of Excellence Industrial Partners

1.2 Environmental Interactions Strategic Programme

Since its inception, the FOW CoE has established a number of Strategic Programmes in high priority areas. Included among these is the Environmental Interactions Strategic Programme (EISP), which was launched in 2022 with the aim of coordinating and delivering a range of activities to address FOW-specific environmental and consenting knowledge gaps. The FOW and Fishing Framework for Coexistence project will be delivered under the FOW CoE's EISP.

In order to facilitate additional strategic guidance and input during the development and delivery of the EISP's project portfolio, a Steering Group was established including Crown Estate Scotland, Defra, DESNZ, Marine Scotland, Natural Resources Wales and The Crown Estate.



Figure 2 Project Steering Group Members

2 PROJECT PLAN AND SCOPE

2.1 Project Objectives

The FOW and Fishing Framework for Coexistence project was developed with the following objectives:

- To undertake targeted engagements with key stakeholders in order to identify and characterise potential opportunities to support coexistence between the FOW and fishing industries, with a focus on the role of FOW farm array layout design.
- To deliver a technical feasibility assessment of the identified opportunities and innovations for maximising coexistence.
- To undertake an economic impact assessment in order to determine the potential financial implications of the identified opportunities and innovations, both in respect of a FOW project's capital expenditure (CAPEX), operational expenditure (OPEX) and LCoE, as well as the potential considerations for the fishing industry.
- To develop guidance in the form of a Framework for supporting decision making during the development process of commercial scale FOW arrays – both at the project-level and a strategic-level – in respect of maximising coexistence with the fishing industry. This will summarise both the technical and economic considerations, and, where relevant, the potential role of innovations.

2.2 Project Structure and Approach

The project was structured around six core work packages.

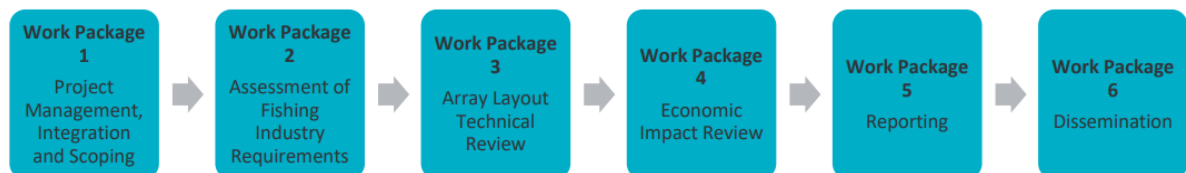


Figure 3 Project Structure

Work Package 1

In addition to overseeing project management function throughout the delivery of the project, Work Package 1 included, at the kick off stage, a review of the project delivery plan and the conformation of key details such as core assumptions, key stakeholders to engage with, the information required from the FOW CoE partners, and other minor details as required.

Work Package 2

Work Package 2 focused on targeted engagements with UK commercial fisheries to understand the conditions that might maximise the potential for coexistence with future commercial-scale FOW developments. A review of relevant literature was undertaken at the outset in order to inform the scope of the engagements. The approach aimed to minimise stakeholder fatigue by building upon existing outputs from relevant prior engagements with the fishing industry (including both FOW CoE-led and external initiatives, such as The Crown Estate's Virtual Floating Offshore Wind Project report)

[4] , and following-up with new engagements only where was required to address remaining knowledge gaps and uncertainties.

Work Package 3

A technical review was then undertaken to determine the engineering considerations and practical feasibility of the FOW array layout options identified and discussed during the stakeholder engagement process. This process drew upon the expertise of relevant subject matter experts, including moorings and dynamic cable engineers, naval architects, and offshore wind array design engineers. The technical review process also considered the possible role of relevant innovations in realising the array layout options.

Work Package 4

Work Package 4 focused on assessing the economic considerations of the reviewed array layout options. It also considered the potential effects on a FOW project's CAPEX, OPEX and LCoE that may result from the proposed adaptations to business-as-usual array layout designs (including, for example, the potential cost of including additional or innovative FOW farm components, the potential effects on FOW farm operational logistic strategies resulting from array layout adaptations, the potential role of inter-array wake effects that may result from changes to turbine spacing and orientation etc.).

Work Package 5

The project's outputs and recommendations were then summarised in the form of a Framework that it is hoped will guide and inform decision making for future FOW developments in respect of fisheries coexistence. It is intended that the Framework will be available as a resource to both the FOW and fishing industries, as well as regulators and other key stakeholders.

Work Package 6

Work Package 6 oversees the dissemination of the project's outputs, which is principally delivered through the publication of the project summary report, and the delivery of additional webinars and presentations at future public conferences as and when relevant opportunities are identified.

2.3 Prior Work

Floating Offshore Wind and Fishing Interaction Roadmap

At the project's outset, a literature review of relevant prior work was undertaken. The project team revisited the FOW CoE's [Floating Offshore Wind and Fishing Interaction Roadmap](#) which was delivered by the Offshore Renewable Energy (ORE) Catapult following an extensive stakeholder engagement process involving workshops and collaborative discussions with fishing and offshore wind industry representatives. The roadmap identified and prioritised potential interactions between floating offshore wind (FOW) and the fishing industry in Scotland, outlining associated challenges and opportunities. A timeline of research activities and mitigation measures to support constructive collaboration between the two sectors over the next decade was also established during this project.

[An Overview of Scottish Fisheries Prepared for the Floating Offshore Wind Industry](#) was commissioned by the FOW CoE in 2021 to inform the early stages of this work. The report, which was delivered by Brown & May Marine Ltd, provides a high-level review of Scottish fishing activities, technologies, and operating patterns relevant to the ScotWind offshore wind leasing areas in the Scottish North Sea. It supported the identification of potential interactions between fishing and offshore wind, and informed the subsequent development of the FOW and Fishing Interaction

Roadmap. To avoid duplication with this earlier publication, a summary of fishing methods and technologies was therefore not included in the scope of the FOW and Fishing Framework for Coexistence project. However, readers are encouraged to access the 2021 report, should this be of interest to them.

Virtual Floating Offshore Wind (FOW) Planning Project

The *Virtual Floating Offshore Wind (FOW) Planning Project*, led by the National Federation of Fishermen's Organisations (NFFO) with support from The Crown Estate, utilised a series of workshops to facilitate dialogue between the fishing and offshore wind industries. Focusing on a hypothetical 100 MW FOW farm case study, the project explored site selection, array design, and operational considerations to minimise conflicts and encourage co-existence. One notable conclusion was that, for a 100 MW FOW farm, turbines should be tightly packed, and the overall site footprint reduced to limit disruption to fisheries. The report also noted that a notional "clear corridor" of 1km-1.5km between FOW turbine mooring footprints would not be sufficient to accommodate commercial fishing methods. The FOW and Fishing Framework for Coexistence project aims to build on this foundation and further explore whether this consensus evolves as wind farm capacities increase to 1 GW and beyond.

SSE Renewables Principles For Co-Existence With Commercial Fisheries

Reports from developers were also reviewed, such as the *SSE Renewables Principles For Co-Existence With Commercial Fisheries* document. This report was built around three pillars: communication, collaboration, and co-existence. The report highlights a commitment to engaging fishers throughout the lifecycle of offshore wind projects—from site selection and consent processes to construction, operations, and decommissioning. It emphasises the importance of minimising disruption, adhering to best practices like Fisheries Liaison and Co-existence Plans (FLCPS), and creating evidence-based co-operation agreements when impacts cannot be avoided. The report also addresses safety concerns related to subsea cables and proposes measures to mitigate risks for the fishing industry, ensuring a positive relationship between the two sectors. These subjects reflect not only areas where progress has been made but also areas where more information is required.

SeaShare: Hywind Static Fishing Gear Trials

Equinor has also led the way with the world's first sea trials for fishing within a FOW farm. Their report *SeaShare: Hywind Static Fishing Gear Trials*, commissioned by Equinor and conducted by the Marine Directorate of the Scottish Government, explored the safety and viability of deploying static commercial fishing gear within the Hywind floating offshore wind farm—the world's first floating wind farm, operational since 2017. The trial, conducted between July and November 2022, tested three types of static gear: fish traps, crab and prawn creels, and electronic jiggers, within designated "fishing trial areas" that maintained safe distances from turbines and subsea infrastructure. The trial successfully demonstrated that, on a practical basis alone, static fishing gear could be deployed and operated safely under suitable sea and weather conditions, with no incidents of gear snagging, loss, or safety issues. However, it should be noted that the fishing methods and type of vessel used during the trial were not common commercial practice within the Hywind Scotland development area. Additionally, the commercial viability of the fishing methods deployed during the study were not assessed, and fishing industry stakeholders have noted that the study's findings should be viewed in this context.

Changes to Fishing Practices as a Result of the Development of Offshore Windfarms

The *Changes to Fishing Practices as a Result of the Development of Offshore Windfarms* report, commissioned by The Crown Estate, examines the impact of offshore wind farms (OWFs) in the

Eastern Irish Sea on commercial fishing activities. The study uses data from Vessel Monitoring Systems (VMS), landings records, and stakeholder consultations to assess changes in fishing behaviour before and after OWF construction. VMS data showed in Figure 4 and Figure 5 reflects the reduced fishing activity within certain wind farm areas, such as Walney 2, where significant declines in trawling were recorded post-construction. Fishing vessel skippers cited risks of gear snagging, seabed obstacles, and safety concerns as key factors limiting fishing activity within OWFs. However, fishing was found to co-exist with OWFs, at least in principle, and a small number of skippers claimed to operate demersal trawl gear in cable-free corridors between the turbines (for example where inter-array cables ran parallel to the trawl tracks). The report also explores opportunities for co-existence, including better mapping of seabed hazards, improved communication between developers and fishers, and fishing-friendly cable protection measures. It recommends fostering collaboration between the fishing and offshore wind sectors to mitigate disruption and promote shared use of marine space effectively.

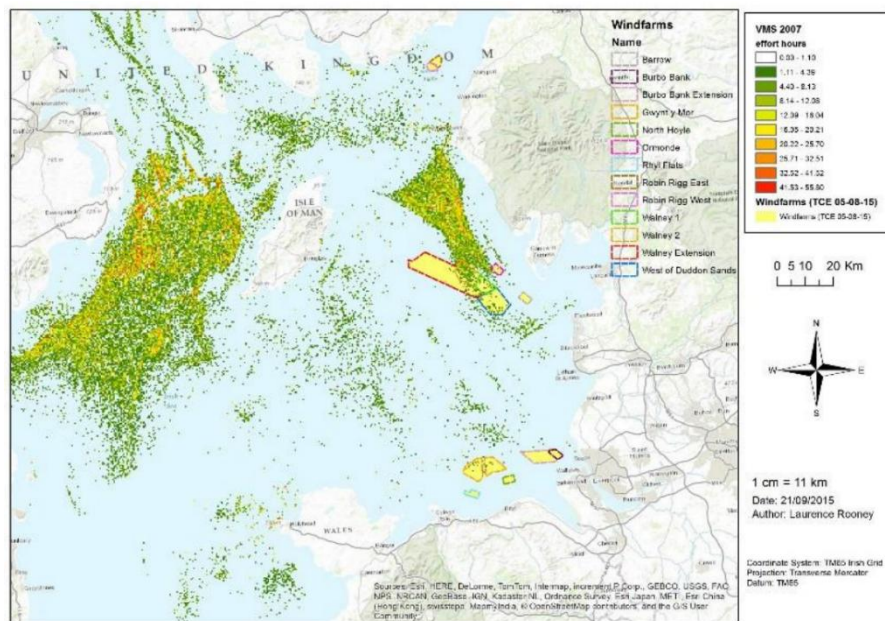


Figure 4 VMS intensity for the UK fleet operating in the Irish Sea in 2007 [9]

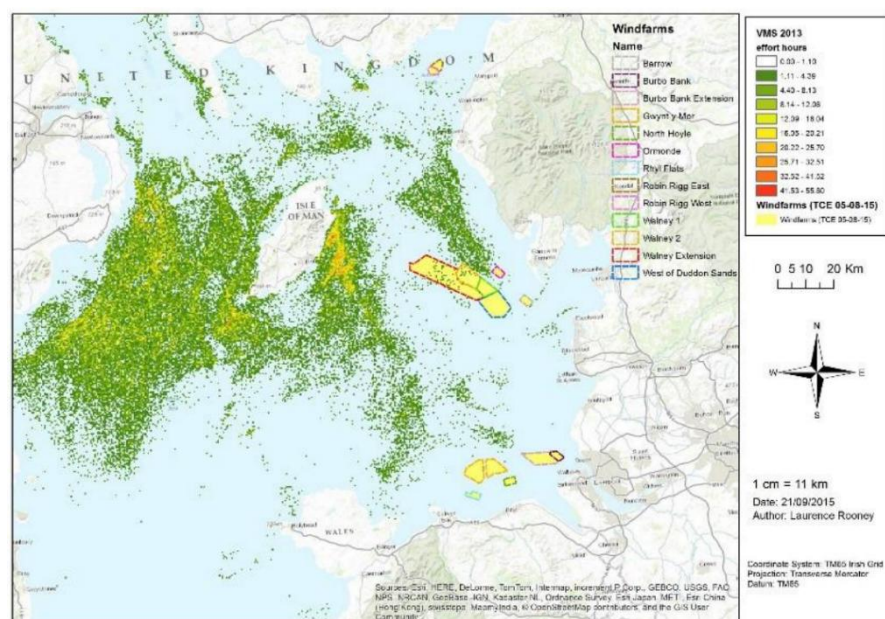


Figure 5 VMS intensity for the UK fleet operating in the Irish Sea in 2013 [9]

3 STAKEHOLDER ENGAGEMENT APPROACH

Key to the success of the FOW and Fishing Framework for Coexistence project was conducting a targeted and effective engagement process with commercial fisheries stakeholders. It was recognised that, while the scope of the project focusses on the UK market, the fishing industry is nevertheless highly regionally specific. As such, the stakeholder engagement approach was developed to reflect this.

Regionally, the North-East of Scotland and the Celtic Sea are considered to represent the principal opportunities for commercial scale FOW development in the short-to-medium term (i.e. present-2035). The project therefore hosted two regionally focussed technical workshops between representatives from the FOW and fishing industries, focused on the Scottish North Sea, and Celtic Sea fisheries. The technical workshops were followed by a summary workshop that provided an opportunity to review the outputs captured during the first two sessions, and also facilitated the input of a broader stakeholder group, including seabed leasing authorities, navigational safety authorities, as well as other relevant public bodies.

3.1 Process

The technical workshops concentrated on the practical and operational considerations of coexistence, and the associated implications of FOW array layout design decisions. The project team developed a number of baselines, or “business-as-usual”, hypothetical FOW array layout scenarios in order to support this process. During the discussions, fisheries stakeholders were then invited to advise on how, if at all, design variations between the presented array layout scenarios might have implications on the potential to undertake fishing operations in the vicinity of a commercial scale FOW farm. Both mobile and static fishing activities were considered. Key FOW design parameters discussed during the workshops included, but were not limited to, turbine spacing and orientation, mooring configuration, dynamic cable configuration, inter-array cable layout etc. The importance of prevailing tide and wind direction in respect of fishing operations and array layout design was also considered.

Following the technical workshops, the outputs were summarised, and a final review session was held with the attendees from technical sessions as well as additional public and regulatory stakeholders. During this summary session, the findings were reviewed and sense-checked, with amendments and updates applied to the outputs where appropriate and required.



Figure 6 Stakeholder Engagement Structure

3.2 Stakeholders

At the outset of the project, the project team contacted key fisheries stakeholders on a provisional basis to notify them that the project was being initiated, and to provide them with an opportunity to comment on and provide feedback on the project's scope and approach. The Fisheries stakeholders who participated in the workshops were:

- Scottish Fishermen's Federation (SFF)
- Scottish Whitefish Producer's Association (SWFPA)
- National Federation of Fishermen's Organisations (NFFO)
- Scottish Pelagic Fishermen's Association (SPFA)
- Cornish Fish Producers Organisation (CFPO)
- Southwestern Fish Producer Organisation (SWFPO)
- Western Fish Producers' Organisation (WFPO)
- Shetland Fish Producers' Organisation (SFPO)
- SeaFish

3.3 Managing Stakeholder Engagement Risks

In order to protect relations between the FOW and fishing industries, and to support continued constructive collaborative engagements between the two sectors going forward, it was critical that during the course of these stakeholder engagements:

- The expectations of all stakeholders were respectfully and appropriately managed by ensuring that all communications and discussions are conducted in as transparent, practical and grounded a manner as possible, particularly where these related to the project's objectives and outcomes.
- The highly regional nature of commercial fisheries was recognised and appropriately reflected in the engagement process.
- The project team were clear throughout the stakeholder engagement process regarding the extent and limits of the project scope (for example, it was essential to communicate that the principal focus of the project is on the role of array layout design, and that the broader marine spatial planning, while a critical consideration, is out with the scope of this work).
- It was made clear that this project is part of a longer-term feedback process, whereby experience from the initial commercial-scale FOW arrays (i.e. those installed between the present and 2035) will be used to update existing guidance and inform the development process of the next generation of commercial scale arrays (i.e. those installed beyond 2035);
- Long-term monitoring and engagement will be key to maximising the impact of this project.

4 WORKSHOP TECHNICAL CONTENT

4.1 Technical Input

To support the cross-industry engagement process, a series of hypothetical FOW array layouts were developed. The aim was to illustrate, in so far as is possible, the FOW technology selections and leading innovations that might feasibly be deployed at future commercial FOW projects within UK waters in the short-to-medium term (i.e. present-2035). The scenarios were developed with the input of moorings, dynamic cables and O&M specialists within the ORE Catapult FOW team and internal technical experts from the FOW CoE's Industry Partners.

The technical scoping exercise was supplemented with a review of the outcomes of the previous leasing rounds for offshore wind projects in the UK to establish the anticipated scales, capacities and geographic distributions of future UK FOW developments. Subsequently, a review of public data was conducted to define the environmental site parameters of the hypothetical FOW arrays.

This process resulted in a series of hypothetical FOW farm scenarios that were defined in accordance with the following parameters:

- Wind farm capacity (MW)
- Number of turbines
- Turbine size (MW)
- Wind farm area (km²)
- Power Density (MW/km²)
- Turbine separation (km, also expressed in terms of number of turbine rotor diameters)
- Mooring configuration (e.g. number of mooring lines, catenary vs taut moorings, mooring line material, anchor design selection)
- Mooring radius (m)
- Inter array cable configuration (e.g. catenary vs lazy wave, cable capacity, dynamic cable section footprint, static cable section length)
- Foundation type (principally steel semi-submersible floating substructures)
- Foundation size (m)
- Number of substations (assuming 450 MW capacity per substation)
- Water depth (m)
- Seabed type
- Prevailing wind direction
- Prevailing tide direction

During the development of the hypothetical scenarios, certain parameters were revised in accordance with industry input. One amendment pertained to the turbine size, where it was noted

that the pursuit of larger capacity (e.g. 20MW) turbines is a current area of innovation and that these could feasibly be deployed by 2035, with significant implications on the power density of future wind farms. Consequently, larger capacity turbines were included in one scenario for both the North Sea and Celtic Sea engagements.

Further, tension leg platforms (TLPs) were initially included in one scenario for each of the regional engagements, as their reduced mooring footprint could help to minimise potential seabed interactions, while their designs could present technical benefits for developers, such as a reduction in material and reduced platform movement [5]. However, following further consideration and feedback, the decision was made to remove this technology from the scope of the workshop discussions. It was noted that, due to their lower technology readiness level (TRL), the commercial deployment timeline for TLPs is not yet understood. Furthermore, through the FOW and Fishing Interaction Roadmap project engagements, it was already understood that the reduced mooring footprint of TLPs would be an important innovation for facilitating potential coexistence, and that there may be more benefit in assessing how variations in higher TRL substructure and mooring assemblies might play a role in facilitating greater coexistence between the two industries.

4.2 Technical Drawings

To facilitate effective communication of wind farm layouts and foster a clear comprehension of the scale and arrangement of infrastructure within a FOW farm, a series of technical drawings were developed for each of the hypothetical array layout scenario. It was noted during the discussions that the sites depicted in the technical drawings did not correspond to any specific geographical location or particular wind farm developments.

Each technical drawing was drafted to scale, thereby ensuring accuracy and precision. These drawings were intended to serve as discussion aids during the stakeholder workshops, allowing participants to analyse the feasibility of various fishing methods within the vicinity of the potential FOW farm configurations.

4.3 Array Layout

Plan view drawings were created to provide a comprehensive understanding of the hypothetical FOW array layouts. Internal discussions and technical input from subject matter experts within the FOW CoE were instrumental in shaping these designs.

Several key assumptions were made during the design process:

- **Substation Capacity:** The substation capacity was restricted to 450MW to align with practical constraints.
- **Dynamic Cable Topology:** A daisy chain cable topology was employed for inter-array connections.
- **Turbine Configuration:** For 66kV cables, strings of turbines were limited to 5 x 15MW turbines or 4 x 20MW turbines; for 132kV cables, a limit of 10 x 15MW turbines was applied.
- **Shared Anchors:** In the scenarios with shared anchors, corridors between turbine clusters have been created to facilitate service and maintenance activities. This assumption aligns with the outputs from the FOW CoE Dynamic Cables Strategic Programme's Gigawatt Scale Cable and Mooring Installation Phase 1 Report. [6]
- **Power density lease agreements:** One factor that differentiates the North Sea and Celtic Sea sites is the minimum power density requirements stipulated in the seabed lease agreements,

with north sea sites to date requiring $>3MW/km^2$ [7] and Celtic Sea sites requiring $>4MW/km^2$. [8]

4.4 Components

Elevation view drawings were created to illustrate the FOW farm components that could be present at and above the water's surface, suspended within the water column, and embedded within the seabed. These drawings were used to communicate the range of profiles that different mooring and dynamic cable configurations would create, and to facilitating discussions on the potential feasibility of various fishing methods in the vicinity of these installations.

The objective was to provide stakeholders with a clear visual representation of the curvature and configuration of mooring lines and dynamic cables. When estimating catenary and semi-taut line curvature, as well as dynamic cable profile, it was important to acknowledge that real-world deployments may vary. Nonetheless, these diagrams were intended to enable stakeholders to comprehend the spatial distribution and potential interactions of these components within the marine environment.

NB The following diagrams are indicative only and are not intended to represent any specific planned wind farm.

4.4.1 Mooring Profile A

A) 15 MW SEMI TAUT - SHARED ANCHORS
9 X DIAMETER SPACING

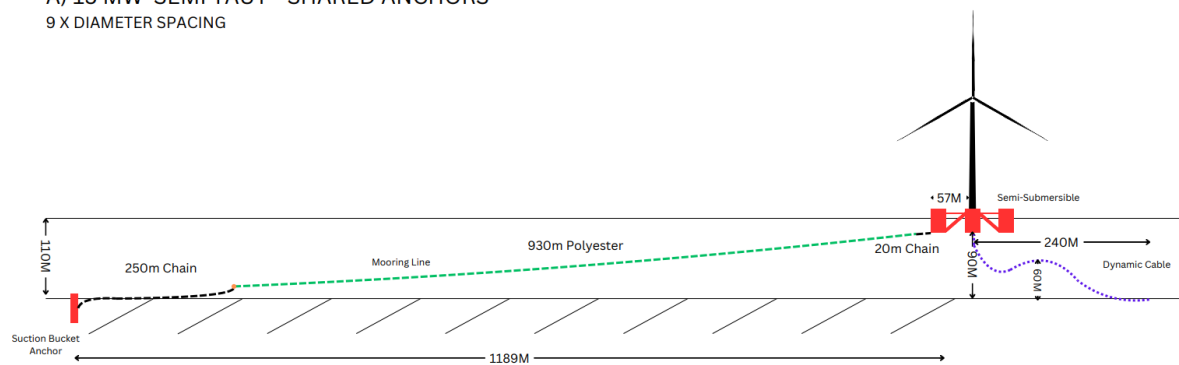


Figure 7 – Mooring Profile A

4.4.2 Mooring Profile B

B) 15 MW CATENARY

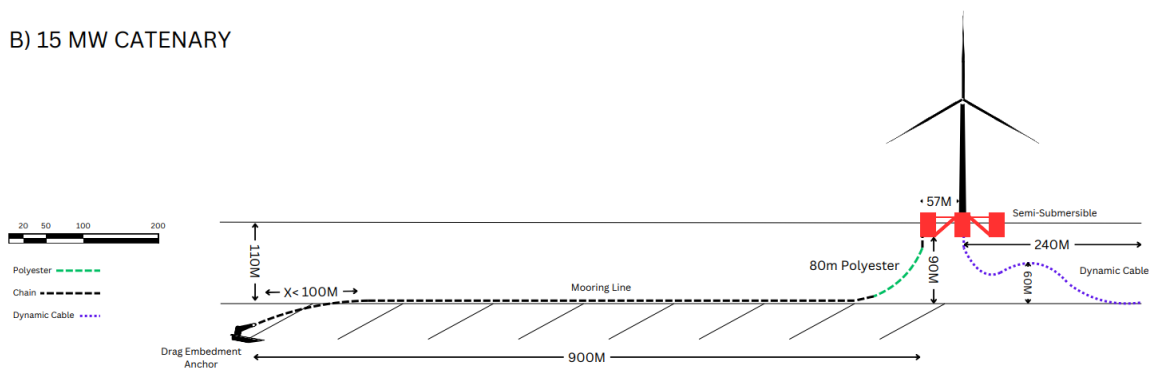


Figure 8 - Mooring Profile B

4.4.3 Mooring Profile C

C) 20 MW CATENARY

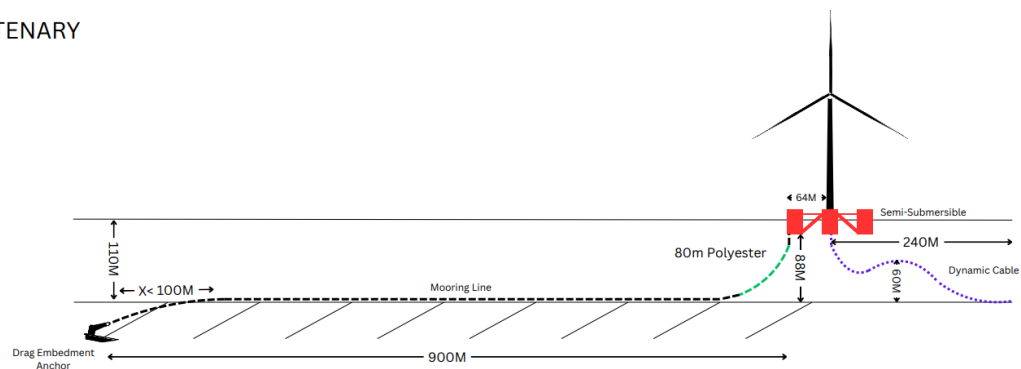


Figure 9 - Mooring Profile C

4.4.4 Mooring Profile D

D) 20 MW NYLON TAUT

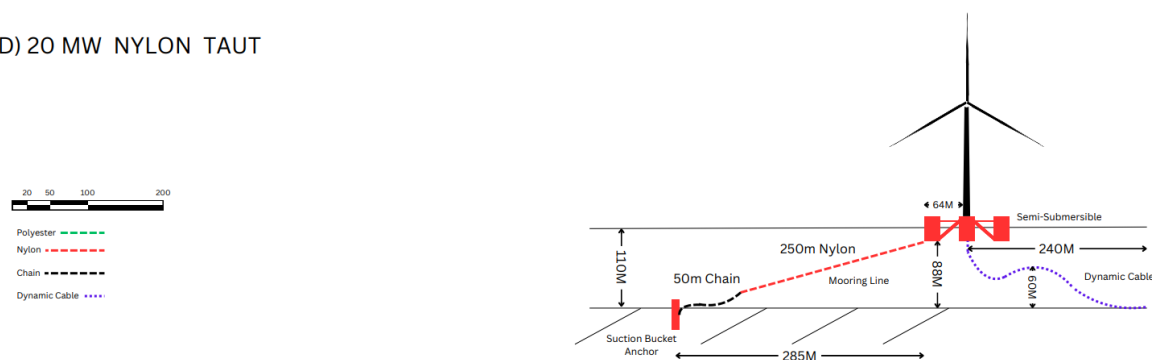


Figure 10 - Mooring Profile D

4.4.5 Mooring Profile E

E) 15 MW SEMI TAUT - SHARED ANCHORS
7 X DIAMETER SPACING

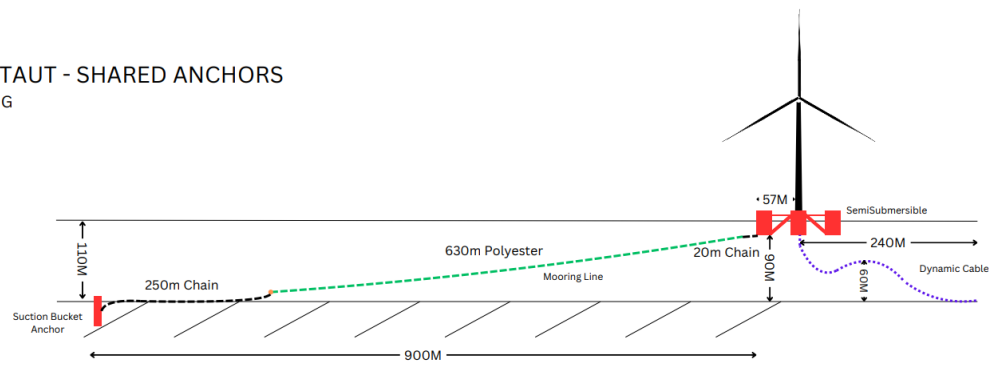


Figure 11 - Mooring Profile E

5 SUMMARY OF WORKSHOP OUTPUTS

5.1 Participating Stakeholders

Collaborative technical discussions were held during full day workshops hosted in Aberdeen at the ORE Catapult's Floating Wind Innovation Centre (FLOWIC) and at ORE Catapult's office in Hayle, Cornwall.

In addition to the workshops, a number of supplementary 1-2-1 discussions were also held. These were principally arranged either to elaborate upon or clarify specific points raised during the workshops, or to offer stakeholders whose availability was limited for the workshops with an opportunity to provide input.

The following organisations participated in the technical discussions:

- Scottish Pelagic Fishermen's Association (SPFA)
- Shetland Fish Producers' Organisation (SFPO)
- Scottish Fishermen's Federation (SFF)
- Scottish Whitefish Producer's Association (SWFPA)
- Western Fish Producers Organisation
- Seafish
- Cornish Fish Producers Organisation
- RWE
- Simply Blue
- EDF
- Ocean Winds
- Floatation Energy
- Celtic Sea Power
- Codling Wind Park
- Offshore Renewable Energy Catapult
- Independent Consultants
 - Colin Warwick
 - Merlin Jackson

5.2 Workshop Outputs

Upon the completion of the technical discussions, the key outputs were reviewed, consolidated and summarised. These are outlined below, grouped into the following technical categories: turbine spacing, mooring footprint, cable routing, wind-tide orientation, decommissioning, seabed, substation placement, and fishing operations.

Turbine Spacing

- There was a general consensus within the participating fishing stakeholders that 3km of clear seabed between anchors would be needed for mobile fishing to be considered safe, with some stating this as an absolute minimum. At sea, the exact conditions would be based on an individual skipper's assessment of the risks on a case-by-case basis.
- It was noted that static fishing could potentially be undertaken within more constricted spaces (i.e. clear corridors of less than 3km in width), although a specific lower limit was not agreed. The fishing industry noted that creel vessels will typically deploy and retrieve lines of creels within a given area multiple times in order to effectively work a fishing ground, and that the

dynamic nature of this process presents potential entanglement risks with FOW infrastructure. FOW developers noted that static fishing activity has been documented in a number of older fixed wind farms where the spacing between turbines is lower than 3km, including Barrow, Robin Rigg, and Walney 1 & 2 [9]. A skipper's assessment of the risks of any particular scenario will be ultimately be key to determining whether static fishing operations will proceed within a given area.

- The continued industry trend towards larger capacity turbines facilitates an increased spacing between turbines without compromising a wind farm's power density. For the purposes of these discussions, it was assumed that that turbine capacities would ultimately level off within the 20-25MW range. It was noted that larger turbines alone would be unlikely to achieve the necessary conditions for fisheries coexistence (i.e. clear corridors of at least 3km in width) and additional innovations, such as reduced FOW mooring footprints, would be required to facilitate the required spacings.
- The potential provision of additional access lanes within FOW arrays was discussed as hypothetical solution for fisheries coexistence. Wind farm developers observed that this has the potential to significantly impact a FOW farm's power density and economic viability, while fishing stakeholders commented that the inclusion of an individual or a small number of access lanes is unlikely to make a material difference to the commercial viability of the wind farm area as a fishing ground. It was however noted that, if fish stocks are present, and they can be safely fished, then it is always possible that skippers may target them.
- The concept of loading the perimeter of the wind farm with turbines and leaving larger spacing inside was discussed. It was noted that the array layout design would be heavily dependent on both the wind resource and economic drivers, and that a developer's ability to maximise spacing within an array would be constrained by these factors.
- The NFFO's Virtual Floating Offshore Wind (FOW) Planning Project, which considered a 100MW FOW farm case study, highlighted the fishing industry's desire to see FOW farm areas minimised as far as possible. During the FOW and Fishing Framework for Coexistence project workshops, it was noted by some stakeholders that at a certain size of FOW farm (e.g. gigawatt-scale), the area occupied could be extensive enough to warrant considering potential means of making the site accessible to fishing (e.g. facilitating 3km spacing between turbines), even if that requires a larger overall footprint.

Mooring Footprint

- The potential viability of fishing within FOW arrays is determined principally by the distance between anchors on the seabed, rather than the spacing between turbines at the water's surface. As such, it is significantly more challenging to achieve the necessary spacing with FOW technology than it is with fixed wind turbines on traditional monopiles, due the difference in their respective seabed footprint sizes.
- It was considered extremely unlikely that skippers would attempt to fish within the catenary mooring footprint due to the risk of entanglement and the uncertainty caused by platform excursion and mooring line movement. For FOW farms utilising shared anchor designs, this would likely eliminate the possibility of fishing from a significant proportion of an array area.
- The development of novel mooring solutions (e.g. taut nylon lines) that could enable a large reduction in FOW mooring footprints, relative to catenary designs, were identified as a potentially key innovation for achieving increased spacing between FOW mooring footprints. It was suggested that the deployment of 20MW turbines in combination with taut nylon mooring

systems could in principle provide sufficient space to enable demersal vessels to operate within the site. It was less clear however if this would provide sufficient space for pelagic vessels to operate.

- Concerns were raised about the durability of nylon mooring lines, should an entanglement scenario occur. While nylon moorings have high tensile strength, they are more easily abraded and susceptible to mechanical damage when compared with chain catenary lines. This was considered particularly significant for mobile fishing operations, although mooring system specialists participating in the workshops suggested that the risk of static fishing gear damaging nylon lines would be lower.
- Shared anchors solutions were considered to present a more complex navigational challenge for fishing vessels.
- The intentional burial of catenary chains between the seabed touchdown point and the anchors was raised as a possible opportunity to increase the amount of unobstructed seabed within FOW arrays. However, mooring engineers encourage caution about this, noting the potential to restrict mooring line movement during severe weather events, and also highlighting that trenching can be considered a potential failure mode for mooring systems. (NB It should be noted that for some FOW anchor designs, the anchor padeye may be submerged, thus requiring the final section of the mooring lines to be embedded within the seabed. This should not be confused with a proactive burial of catenary mooring systems.)
- The potential for FOW anchor positions to be marked via buoys or other physical markers was proposed. However, their potential to create additional surface hazards, as well as the accuracy of their location due to drift, were highlighted as principal concerns. It was agreed by both parties that digital marking systems would be the preferred method.

Cable Routing

- Burial of the static sections of FOW farm inter-array cables was preferred by the fishing stakeholders to reduce the risk of entanglement and avoid the use of rock armouring. This was agreed by the offshore wind stakeholders.
- For FOW farms with shared anchors, it was noted that turbines may be grouped into clusters with shared moorings, with access lanes running between the clusters to provide access to service and maintenance vessels. Should this be the case, fishing stakeholders noted that the burial of static cable sections within turbine clusters may not be a fishing industry requirement, on the understanding that shared anchor configurations are unlikely to be fishable due to their complexity.
- It was noted that whether or not a clear corridor within a FOW farm might be considered fishable would depend in part on the cable topology. Should cable crossings within these clear corridors be necessary, burial would be required to facilitate potential coexistence.
- Fishing stakeholders commented on the current knowledge gaps relating to electromagnetic field (EMF) emissions from FOW inter array cables. The FOW CoE has commissioned a study – delivered concurrently with the FOW and Fishing Framework for Coexistence project – which has reviewed the current state of the science relating to dynamic cable EMFs, both in respect of their technical characteristics and the potential interactions with marine ecology. At the time of writing, the FOW Dynamic Cable EMF Environmental Review project was in the process of concluding, with a summary report – including recommendations for further research –

expected to be published on the FOW CoE website outlining recommendations for further research.

Wind-Tide Orientation

- Fishing operations are often aligned with the tide direction to maximise fuel economy. Deviations from this alignment could reduce operational efficiency and profitability.
- Wind farm designers will seek to orient turbine rows in relation to the prevailing wind direction in order to maximise the site's annual energy production (AEP).
- The orientation of turbine rows and lanes relative to tidal flow is therefore a key consideration for potential fisheries coexistence.
- Static fishing gear, such as gill netting, is typically deployed with the tide rather than across it. The relative orientation of turbine rows would therefore be a key consideration for these operations.
- Fishing gear is often towed 1/3 mile from the vessel and, due to tidal currents, may not be directly aligned behind the vessel. As such, any potentially fishable corridors within a FOW array would need to be wide enough to accommodate this drift. General agreement by fishing stakeholders that 3km should be sufficient in this regard, with some stating this as an absolute minimum.
- Adverse or emergency events, such as a vessel loss of power scenario within a FOW farm, is a key consideration for potential coexistence. The prevailing wind and tide directions should factor into these discussions.

Decommissioning

- An anchor system's ease of removal post-wind farm lease was highlighted as a key consideration by fishing stakeholders.
- Fisheries stakeholders emphasised the importance of ensuring full recovery and a clean seabed post-decommissioning. While FOW could offer advantages in this regard, with some mooring and anchoring systems designed for easier removal, approaches will vary by site and technology, and should be addressed through early planning and engagement.
- While driven pile anchors may play an important role in facilitating smaller mooring footprints (the deployment of taut mooring systems may depend on their ability to tolerate uplift, particularly in areas of hard substrate), it was noted that these designs could be more challenging to remove during decommissioning than other anchor designs.

Seabed

- Substrate type and seabed bathymetry are key to determining an area's viability for fishing. By way of example, the following species are typically associated with specific habitats (noting that this list is neither exhaustive nor definitive, and target species can be found in a variety of seabed conditions):
 - Nephrops are often found in sandy sediment without large boulders.
 - Crabs and lobsters favour rocky substrates.

- Flatfish prefer sandy seabed conditions.
- Herring spawn on the seabed, in specific sediment conditions. However, they are caught in the middle of the water column.
- Accessible lanes (i.e. sufficiently wide corridors that are clear of obstructions) within FOW farms would likely only be targeted if they are positioned over fishable grounds.
- Biodiversity enhancing infrastructure or seeding programmes (e.g. reef cubes, cod pipes, lobster/oyster seeding) may support local fish stocks by providing habitat or promoting species recovery. However, further research is needed to evaluate the effectiveness and long-term ecological outcomes of these approaches.
- While shared mooring configurations were deemed incompatible with fishing due to their complexity, the potential inclusion of clear service lanes between clusters of jointly-anchored turbines could potentially accommodate certain fishing activities, if sufficiently spaced. It should be noted that increasing the width of any service lane would have implications on a FOW farm's power density. The presence of static gear within these areas could also have implications for FOW farm service vessels.
- A site's seabed topography and bathymetry will have direct implications on a FOW farm's design process, likely resulting in deviations from idealised layouts. This will be an important consideration for any coexistence discussions.

Substation Placement

- Where possible, substations should be situated within turbine rows (rather than within any unobstructed corridors between turbine rows) to minimise the impact on potential coexistence with fishing activities.
- The unsuitable placement of substations could exacerbate navigational challenges and operational risks for fishing vessels.

Fishing Operations

- The potential feasibility of fishing within FOW arrays depends on several factors, for example:
 - Risks of gear entanglement with mooring lines, subsea cables, or anchors.
 - Space required for safe gear deployment, e.g., 0.1 nautical mile of free space on either side of nets while towing.
 - Accurate mapping of underwater obstructions.
- Stakeholders noted that wider lanes between turbine rows could increase the feasibility of coexistence, but would have implications on the economic viability of the wind farm.
- Static gear fishing is likely to be more feasible than mobile fishing in a number of FOW array configurations, though it is not without risk.
- The trend towards larger turbines and the development of innovative moorings with smaller footprints could potentially make coexistence with mobile fishing more viable over time.

- Fishing stakeholders expressed concerns about adapting established practices for coexistence, citing the abiding nature of current methods, which have been developed based on centuries of experience. Developers present highlighted their willingness to support gear configuration adaptations to enhance coexistence, if necessary.
- The potential displacement of fishing vessels due to FOW developments could increase fishing pressure on adjacent grounds.
- Funding to support research into the adaptation of fishing methods was identified as having the potential to support co-existence.
- Stakeholders highlighted the importance of understanding the trade-off between the minimum spacing required for fishing to be viable and developers' power density requirements.
- The need for early dialogue between fisheries and developers was stressed as critical in all circumstances.

6 ASSESSMENT OF WORKSHOP OUTCOMES

The following discussions assesses the technical and economic implications of the outcomes identified during the project workshops.

6.1 Turbine Spacing

Turbine spacing is a critical factor in the design of any offshore wind farm, and it is a crucial parameter for determining whether coexistence with commercial fisheries might be feasible. In the case of FOW technology, the complexity of the subsea infrastructure means that, from a coexistence perspective, turbine spacing is not simply a measure of the distance between turbines at the water surface. Instead, the configuration of mooring lines and dynamic cables must also be considered. During the project workshops, the fishing industry were in general agreement that 3km of clear seabed between FOW turbine mooring footprints would be required in order to safely undertake most forms of commercial fishing, with some stating the distance as an absolute minimum. There are several important variables which determine the spacing for a given FOW farm, which must be carefully considered during any discussion pertaining to FOW and fishing coexistence.

6.1.1 Constraints on Turbine Separation

The average spacing between turbines in an array has critical implications on a FOW farm's business case. Turbine-to-turbine separation is typically stated in terms of the number of rotor diameters. While this varies from project to project, spacings often average between 7-9 rotor diameters [10]. As such, a turbine's capacity, and therefore rotor size, will directly influence the spacing within a wind farm and will be relevant to a site's power density.

One of the important challenges discussed during the cross-industry workshops is that, with regards to turbine separation and the implications on coexistence, the two sectors have somewhat contrasting requirements.

Fishing stakeholders noted that for future FOW developments, they would either prefer the turbines densely installed in order to reduce the overall area occupied by the FOW farm¹ (assuming a fixed turbine rating and total farm capacity), or alternatively to see the turbine spacing increased substantially to create larger corridors of unobstructed seabed between mooring footprints.

On the other hand, FOW developers require an intermediate turbine spacing to maintain a project's economic viability.

If turbines are installed too-closely together, inter-array wake effects (where the performance of downstream turbines is reduced due to upstream turbines extracting energy from the wind) increase, which in turn impacts a range of key metrics. Inter-array wake assessments conducted by the project team utilising PyWake² concluded that for a hypothetical FOW farm, a reduction in turbine spacing from 9 to 6 rotor diameters could result in wake losses (assessed as a percentage of AEP) increasing by a factor of 2.4, assuming turbine capacities are unchanged and that the wind farm lease area remains fixed. Figure 12 details the results of this analysis, which was conducted for a

¹ This reflects the position put forward in the Virtual Floating Offshore Wind Project report delivered by the NFFO and The Crown Estate [4].

² A Python-based wind farm simulation tool developed by DTU [19].

hypothetical FOW farm in the North Sea using 15MW turbines within a defined lease area of 336 km².



Figure 12 Effect of turbine separation on net AEP & wake losses: North Sea FOW farm case study (for a defined lease area)

Recent research has also suggested that that these effects could be more pronounced in larger wind farms (with efficiency reductions almost trebling for very large, i.e. multi-GW, projects compared to smaller wind farms) [11]. The implications on a wind farm's LCoE – a cost ultimately borne by the end user – are also significant, with recent analysis concluding that decreasing the turbine spacing from 8 to 4 rotor diameters could lead to a 12% increase in the project's LCoE [10]. Strict economic limits therefore apply to a developer's ability to reduce array sizes by installing turbines more closely together.

Conversely, developers are also constrained in how far apart turbines can be installed. An increase in turbine separation within a defined lease area (assuming again that turbine capacities remain fixed) will lead to a corresponding reduction in the project's AEP and power density. Section 6.1.3 details the minimum requirements that a developer must adhere to in respect of a wind farm's power density.

Although developers must ultimately determine a FOW farm's optimised turbine spacing on a project-by-project basis, given the strict constraints that a developer must consider in respect of turbine spacing – both at the lower and upper limits – it is important to avoid unrealistic expectations about the role that adjustments in turbine separation can play in facilitating coexistence. As such, there should be an emphasis on innovations that could increase the amount of clear seabed between mooring footprints (for a given turbine size and spacing) if ambitions for coexistence are to be realised. Larger turbine capacities and taut nylon mooring lines are examples of relevant potential opportunities (see Sections 6.1.2 and 6.3.3, respectively).

6.1.2 Turbine Capacity

The capacity of a FOW farm is determined by the spacing between turbines and the size of the turbines used. The primary limitation of turbine size and spacing is the trade-off between maximising energy generation while balancing CAPEX allocation – both of which influence a wind farm's power density.

Larger turbines spaced further apart can capture more wind energy per unit turbine. On the other hand, closely spaced turbines will experience higher wake effects. This must be carefully balanced with the OPEX of the project, as fewer turbines with higher performance may reduce O&M costs but limit the overall energy output.

The industry trend is towards larger, fewer turbine, as this typically facilitates O&M cost savings (due to the reduced number of assets to maintain), a higher AEP, and therefore a greater return on investment (ROI) for developers. However, it is anticipated that there will ultimately be a limit to the trend towards larger turbines due to a combination of design and logistical factors. For example, blade tip speed is likely to be limited to a maximum of 90 meters per second in order to avoid erosion effects [12]. As such, as the turbine size increases, the rotor speed must be reduced in order to observe this limit. This has a number of implications, for example:

- A turbine's efficiency is closely related to the blade tip speed.
- To maintain the required power output at lower tip speeds, the blades must therefore be pitched in order to deflect more wind. This in turn produces higher loads.
- Blades can be engineered to withstand increased loading, however the additional material required, coupled with complex manufacturing processes, can drive up CAPEX costs. This must be considered against any gains in energy generation.

Furthermore, the market demand for turbine innovation is placing increasing commercial pressure on turbine OEMs (original equipment manufacturers), who must balance the requirement to remain competitive against the continued research and development (R&D) expenditure in the pursuit of larger turbines. There are also concerns that the rapid rate of the R&D required by OEMs may have implications on the reliability of new turbine technologies [13], which could in turn impact wind farm profitability.

Ultimately, the trend towards larger turbines will halt when they cease to be economically viable, or when the design and manufacturing challenges become prohibitive. At the time of writing, this point has not been reached, and the industry remains confident that 20MW turbines are an achievable minimum target in the medium term.

China is currently dominating the turbine OEM sector with over 80% market share in the first half of 2024 [14]. Notably, in the first half of 2024, orders of 16MW+ turbines with Chinese OEMs more than doubled, rising 57% year-on-year [14]. In August 2024, Mingyang installed the largest single capacity turbine to date with a 20 MW prototype in Hainan, China, although the device subsequently suffered a blade failure in December of that year [15].

To summarise, larger turbines are ultimately expected to be deployed by the FOW industry. They could allow for greater spacing, provided that wake effect modelling permits, although they are not without their design challenges. This increased spacing would be pertinent to discussions concerning potential coexistence between the FOW and fishing industries.

6.1.3 Power Density

Power density refers to the average power capacity of a wind farm per square kilometre. To ensure that the marine space is efficiently utilised, a wind farm's seabed lease agreement will include stipulations for a minimum power density. A wind farm developer is also commercially constrained by a site's power density and will require a minimum value to be met in order to approve a financial investment decision for a project.

Practical considerations will also influence a wind farm’s power density, including seabed constraints and the requirement to manage inter-array wake effects.

Lease Agreement

Lease agreements will stipulate the minimum power density the site is required to achieve. Crown Estate Scotland’s ScotWind leasing process required projects to have a minimum power density of $3\text{MW}/\text{km}^2$ [7], while The Crown Estate’s Round 5 leasing process for the Celtic Sea required $4\text{MW}/\text{km}^2$ [8] for its projects.

These power density requirements ultimately place a limit on how far apart turbines of a given capacity can be spaced. For ScotWind sites this corresponds to 5km^2 per turbine at 15MW capacity turbines, and 6.7km^2 for 20MW turbines (as a proportion of a windfarm’s total area). For the Round 5 Celtic Sea projects, the power density requirements equate to 3.8km^2 per turbine at 15MW capacity turbines and 5km^2 for 20MW turbines. Any discussions regarding potential co-existence will need to consider the spatial restrictions that these requirements impose.

Project Economics

The economic feasibility of a FOW project is partly dependent on its total capacity, and the associated economies of scale that this determines. Wider turbine spacing will lead to lower power densities, reducing the overall AEP of a site, unless the turbine capacity is increased commensurately. A carefully designed layout is therefore required in order to optimise power generation while minimising O&M costs, ensuring that the project remains economically viable over its lifetime. In recent years rising costs have also increased market pressures on developers through supply chain inflation, creating a greater emphasis on maximising power output.

Table 1 outlines indicative power densities and distances between turbines for 15MW and 20MW capacity turbines, assuming a mean turbine separation of 8-9 rotor diameters (equidistant in the upwind and crosswind directions) [16]. While these power densities in certain cases exceed the minimum requirements of the seabed lease agreements, they are nevertheless indicative of what developers may require in order to ensure a project’s economic viability.

Table 1 Variation of turbine spacing and wind farm power density with turbine capacity (assuming a mean turbine separation of 8-9 rotor diameters)

Turbine Capacity (MW)	Turbine Spacing (km)	Wind Farm Power Density (MW/km2)
15	1.9 - 2.1	3.4 - 4.2
20	2.0 - 2.3	3.8 - 5.0

6.2 Array Topology

The topology of a floating offshore wind farm refers to the specific positioning of the infrastructure within the lease area. The choice of topology can have significant implications for both energy capture and the interactions with other maritime industries, including fishing. While turbine spacing and orientation are critical considerations in wind farm layout design, a range of site-specific factors

such as wrecks, archaeological features, and seabed geology will also play a key role in determining what is practically achievable for turbine positioning.

6.2.1 Perimeter-Loaded Wind Farms

A perimeter-loaded wind farm creates a greater concentration of turbines at boundary of the lease area and a comparatively lower density within. This design approach offers potential advantages, including:

- Maximising access for vessels operating within or around the farm, which could be important for fishing operations.
- Creating additional space for maintenance vessels within the array.
- Complex wake analysis with a significant number of turbines and variables can be simplified using the perimeter loaded methodology [17].

However, perimeter-loaded designs can also present challenges. For example:

- They may require longer cable runs, increasing both installation costs and transmission losses.
- The visual impact of turbines placed along the boundary of a lease area may be more significant than for other topologies. (It should be noted that FOW farms will likely be sited further offshore, thereby reducing the significance of this issue.)
- Isolated structures (e.g. turbines positioned on exposed corners of an array) have a higher collision risk than condensed structure layouts.
- Various potential perimeter-loaded topologies are possible, however in most cases there are still a significant number of turbines situated inside the boundary loaded layout, either in rows or randomly sited. This could still provide navigation problems for fishing vessels.
- Perimeter-loaded layouts may simplify the optimisation process for sites with many turbines, where managing numerous variables is challenging. However, with advancements in wake modelling and the trend towards future sites using fewer, larger turbines, these layouts may become less favourable [17].

6.2.2 Search & Rescue (SAR) Lanes

Search and Rescue (SAR) lanes are navigational corridors established within or adjacent to offshore wind farm sites to ensure safe and efficient access for SAR operations, typically coordinated by HM Coastguard. Their primary purpose is to facilitate the rapid deployment of rescue vessels and aircraft in the event of emergency situations, thereby safeguarding both offshore personnel and third-party mariners, including fishing vessel crews.

SAR must remain clear of obstructions such as turbines, moorings, and surface infrastructure. Their placement is determined in coordination with the UK Maritime and Coastguard Agency (MCA), which provides guidance based on site-specific risk assessments, navigational hazards, and operational considerations.

The inclusion of SAR lanes has a direct influence on wind farm layout topology, as they necessitate clear linear corridors through or alongside turbine arrays. This can reduce the effective area available for turbine placement, impact power density, and influence the economic and technical optimisation of the array. As such, SAR requirements must be factored into the early stages of array design to balance navigational safety with project viability. [18]

Key considerations for SAR lanes include:

- Linear corridor alignments that provide clear access for rescue vessels and aircraft.
- Sufficient spacing to allow safe operation of SAR helicopters, rescue boats, and lifeboats in and around turbines. (e.g. 500m for East Anglia TWO & 800m for Hornsea 4).

6.2.3 Assessment of FOW implications, including potential challenges posed by mooring lines and dynamic cables. Wind-Tide Orientation

Tide direction is a key consideration for a number of fishing methods, and it can have important implications on vessel fuel economy. On the other hand, prevailing wind direction is a crucial environmental parameter in the wind farm development process, and turbines positioning will be carefully selected in relation to this, which often results in turbines being installed in rows in order to maximise AEP and minimise inter-array wake effects. The relative orientation of the prevailing wind and tide directions at a given wind farm will therefore be an important consideration for determining the feasibility of potential coexistence.

Wind farm layout optimisation is a complex, multicriterial process that has significant financial implications for developers, and turbine positioning in relation to the prevailing wind direction is key to a project's economic viability.

The potential coexistence of FOW and commercial fishing therefore depends on whether or not, in principle, the wind farm array layout design, which is optimised in relation to the prevailing wind direction, would allow for an optimisation of fishing operations in relation to the prevailing tide direction.

In order to understand this relationship, the project team undertook a series of inter-array wake assessments utilising PyWake, a Python-based wind farm simulation tool developed by DTU [19]. The outputs of these simulations enabled the project team to assess the impact on a wind farm's AEP that would result from the non-optimised positioning of turbines in relation to the prevailing wind direction. Subsequently, utilising the ORE Catapult's in house FOW farm cost model, the economic implications of the resulting AEP losses could be assessed.

Through this analysis it was estimated that, for a hypothetical 1GW FOW farm, the AEP losses resulting from the deployment of non-optimised array layouts, designed to accommodate optimised fishing in relation to the tide, could incur costs of up to £100m+ over the lifetime of the windfarm (depending on the extent of the deviation from the ideal turbine positioning). It is important to note that there are regional differences in relation to the tide with more severe currents around headlands and narrow passages and reduced currents in open water [20]. As a result, the AEP analysis for a specific wind farm would be highly sensitive to the local environmental conditions.

6.2.4 Lanes for Fishing Vessels

Lanes between turbine rows can provide unobstructed pathways for the transit of vessels through a wind farm and could provide opportunities for fishing to take place. These lanes must be carefully designed, however, with navigational risk in mind. It is important to note that a number of practical factors, such as local bathymetric conditions, will influence the exact positioning of FOW turbines and their anchors, therefore the final layout of a FOW farm may not reflect the initial, more idealised, designs discussed at the outset of a wind farm's front end engineering design (FEED) process.

Location of Fishing Grounds

If a FOW farm's turbine spacing and mooring configuration allow for a sufficient distance between mooring footprints for fishing to safely take place, the subsequent commercial viability of that area as a fishing ground will partly depend on the composition of the available seabed. Early consultation with local fisheries would be key to understanding what fisheries might operate within those areas, and whether the available seabed is suitable for those methods. If the available ground is considered unsuitable or unsafe for fishing, then fishing is highly unlikely to take place regardless of the FOW farm's topology.

Therefore, the potential for coexistence would depend on early cross-industry engagement to determine whether the FOW infrastructure is appropriately sited in relation to suitable fishing grounds.

Multiple Vessels

The width of an unobstructed lane will determine the number of fishing vessels that could hypothetically safely operate within that space simultaneously alongside each other. Wider lanes could allow multiple vessels to pass through simultaneously, although increasing the distance between turbines beyond the optimised spacing would impact upon the site's power density for a defined leased area.

The potential feasibility of fishing within a wind farm will depend on the type of gear used and the size of the vessels involved. Smaller vessels using static gear, such as traps or pots, may be able to operate in narrower lanes (approximately 1km+; although the requirement to move gear could require more space), while larger vessels using mobile gear would require wider lanes (approximately 3km+).

6.2.5 Aligned vs Staggered Array Configuration

The exact positioning of a FOW farm's turbines and subsea infrastructure will depend on a range of factors, including the prevailing wind direction, the requirement for search and rescue (SAR) access, inter-array wake effects, seabed leasing constraints, as well as local bathymetric conditions. During the wind farm FEED stage, the wind resource is assessed in order to calculate the AEP and wake losses for a range of array layout scenarios. This is a critical step in the selection of the optimal array design.

One consideration during this process is whether to stagger the turbine rows (see Figure 13) or align them (see Figure 14). While some analyses have indicated that staggered arrays could produce more power and lower wake losses [21], there are hypothetical scenarios where aligned turbines with tighter lateral spacing can produce similar output [22].

With respect to potential coexistence considerations, the decision to stagger turbine rows or align them may influence the orientation of navigable lanes through the FOW array. Of course, other practical considerations relating to the specific lease area mean that deviations from the idealised layouts, such as those illustrated in Figure 13 and Figure 14, are very likely to be required, and no array is likely to consist of perfectly aligned or staggered row in practice.

Aligned Layout

This configuration facilitates several routes that vessels could potentially take through the wind farm, with equal spacing between turbines in the downwind and crosswind directions. These include North-South, East-West, or diagonally (Northeast-Southwest and Northwest-Southeast). However, the diagonal lanes would be approximately 30% narrower than the straight North-South and East-West lanes.

Staggered Layout

By staggering the turbines in an equal downwind and crosswind spacing, the composition of vessel routes is altered. Vessels could navigate through the farm North-South and diagonally (Northeast-Southwest and Northwest-Southeast). With this topology, the diagonal lanes would be approximately 10% narrower than the North-South lanes, although it is worth noting that the East-West routes would be 50% narrower than the North-South lanes.

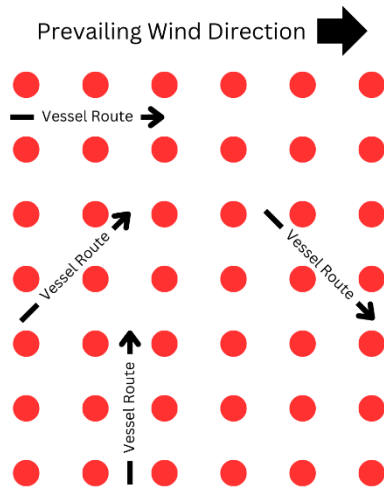


Figure 13 - Aligned Layout

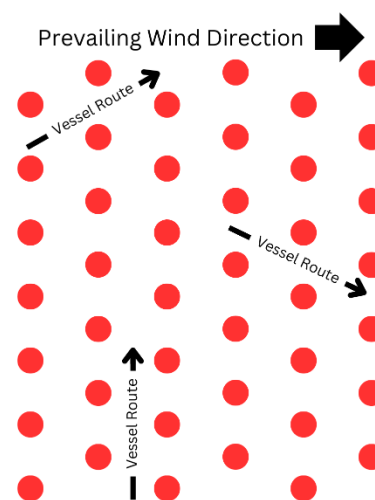


Figure 14 - Staggered Layout

Summary

While the aligned topology provides more directions for vessels to transit through the windfarm, the diagonal lanes see a significant reduction in width compared to those in the staggered layout. The tide orientation of a specific site in relation to the wind will play an important role in determining which of these layouts may be preferable in relation to any coexistence discussions.

6.3 Mooring & Anchors

The selection of a suitable mooring and anchoring system is crucial to the success of a FOW project. The choice of mooring and anchoring system is determined by a number of hard constraints, including the stability and station keeping requirements of the selected FOW substructure design, as well as environmental variables including water depth, metocean conditions, the wind resource, and seabed composition. Additional factors such as material cost, supply chain capabilities, logistics and insurance policy also play an important role in the design decision. These drivers are essential to a project's safety and financial viability; however, mooring system design choices may also have implications on the potential for coexistence with other sea users, including commercial fisheries.

6.3.1 Catenary Chain Burial

During the project workshops, it was questioned whether the amount of unobstructed seabed in between catenary mooring footprints could be increased through the burial of the mooring chain between the anchor and the seabed touch down point.

The moorings engineers participating in the workshops raised concerns that catenary chain movement during severe weather events could undo the work of any burial operation, and could

adversely impact the FOW substructure's dynamics. Furthermore, it was noted that catenary mooring line trenching has traditionally been considered a failure mode in the Oil & Gas (O&G) sector. As such, catenary chain burial is unlikely to present a significant opportunity to facilitate co-existence.

It should be noted that for a number of anchor designs, the padeye is submerged, which requires the final section of a mooring chain to be embedded within the seabed (this is the case for the suction caisson anchors utilised at the Hywind Tampen FOW farm [23], by way of example). This should not be confused with a broader design strategy to proactively bury a catenary mooring chain beyond its seabed touchdown point.

6.3.2 Redundancy in Mooring Systems

Redundancy in mooring systems can provide additional security in the event of a mooring line failure. For example, in place of a 3x1 mooring system consisting of three separate lines per turbine, a developer could opt for a 3x2 design consisting of three pairs of lines (each with a separate anchor) to enable the turbine to maintain its station keeping capacity in the event of a mooring line failure.

In deep water, where environmental forces are more extreme, redundant mooring lines can ensure the stability of the turbine even if one line becomes damaged. However, redundancy comes at the increased cost and complexity of a mooring system, and can also add additional installation time.

While the decision to include redundant lines requires developers to undertake a cost benefit analysis, it may have implications for the potential for coexistence with commercial fisheries and other sea users. For example, on the one hand, redundancy in the mooring system would reduce the likelihood of a FOW turbine loss of station scenario, but on the other, it increases the volume and complexity of the subsea infrastructure within the FOW array. As such, during the development of a FOW farm, it may be prudent to include the topic of mooring redundancy in early cross-industry engagements.

6.3.3 Synthetic Mooring Lines

The FOW industry is increasingly considering the use of synthetic moorings in place of chain designs for future large scale FOW farms. Synthetic mooring lines could offer several advantages over traditional catenary chains, including lighter materials, easier handling and potential cost reductions.

In synthetic mooring systems, the rope's break elongation is a key factor in determining mooring line length. For example, nylon has a higher break elongation than polyester, which allows for shorter mooring lines to be used. This reduction in line length, in turn, reduces the overall mooring footprint around the platform.

The mooring footprint radius of taut nylon configurations is anticipated to be closer to those expected of future TLP platform designs. However, nylon moorings would be compatible with FOW substructure typologies that are of a higher TRL than TLPs, including semi-submersibles, spars and barges, all of which have a proven track record of deployment at full scale. As a result, nylon moorings have the potential to accelerate the reduction of FOW mooring footprints without the reliance of TLP designs, which, at the time of writing, are not commercially available. (It should be noted that TLP platforms are ultimately expected to have the smallest mooring footprint of any FOW substructure designs, once they are commercially available.)

Nylon Technical Qualification

While polyester has a proven track record in O&G, nylon mooring designs still need to undergo a full technology qualification (TQ) process before commercial applications are possible. For certain

designs, the statement of feasibility and endorsement qualification plan have been passed, while knowledge gaps relating to the long term characterisation of key properties must be addressed, and the testing of yarn, sub rope and full rope must be completed in order for the TQ process to be concluded [24]. At the time of writing, it is expected that certain leading designs will complete the qualification process in 2025.

Synthetic Mooring Integrity

It is important to note that synthetic moorings, including nylon lines, are more susceptible to damage from external mechanical impacts than chain systems. Synthetic mooring lines are also more sensitive to the additional mass introduced through biofouling. Unlike catenary chains, which have greater mass, and are therefore less impacted by marine growth, synthetic lines will require more frequent cleaning. This is likely to increase a project's O&M requirements, and could increase the potential for interactions with fisheries. Developers should account for these factors when selecting mooring systems and planning maintenance strategies.

Some fishing stakeholders also raised concerns about the release of microplastics from the abrasion of synthetic mooring lines. It is worth noting that synthetic lines are typically designed to avoid seabed contact in order to manage the risk of abrasion. For example, chain sections may be included at the seabed touchdown point, and lines may be fitted with buoyancy modules to minimise seabed contact.

6.3.4 Decommissioning of Anchors

A FOW farm must be safely decommissioned at the end of its lifecycle – a process that involves the removal of anchors and mooring lines from the seabed. Decommissioning must be planned carefully to minimise the environmental impacts and ensure that the seabed is returned to its natural state. FOW drag embedment and suction caisson anchors are expected to be easier to remove compared to fixed wind monopile foundations. The decommissioning of FOW pile driven anchors is expected to follow a similar strategy to the decommissioning of pinpiles for jacket substructures. This is a more involved process that may require the anchor to be cut below the seabed and buried. Depending on the sand type, it is possible that vibro-installed anchors could be removed through reverse vibro-extraction methods, although further validation is required to approve these technologies for FOW applications. The potential coexistence implications of anchor decommissioning should be considered during the wind farm development process.

6.3.5 Marking of Anchors

The mapping of anchor locations would be crucial to any potential co-existence between the FOW and fishing industries, particularly for managing the risk of entanglement between mooring systems and fishing gear. This would likely be achieved through the use of digital mapping systems, such as KIS-ORCA.

For navigational safety systems to be effective, developers must supply accurate and timely data, while fishers must ensure their onboard systems are regularly updated. Currently, the KIS-ORCA platform is updated on an annual basis, which may not reflect the most recent offshore developments. To address this gap, the SFF has developed the Horizon Watch platform, which includes proposed cable routes and anchor locations in advance of installation, supporting fisheries during this interim period. There is an opportunity for greater collaboration to improve information sharing, either through enhancements to existing platforms, or the development of a more responsive, jointly managed system.

During the project's workshops, the potential use of physical markers, such as buoys, to identify anchor locations was discussed. However, it was agreed that digital marking offers a greater benefit to fisheries, as physical markers may drift, become obscured by waves, or potential even come untethered. Marker buoys could also provide navigational challenges for service vessels working within the farm. As such, it was noted that they would be unlikely to be approved by navigational safety authorities.

6.3.6 Anchor, Seabed and Fishing Method

The type of anchor used in a FOW project must be selected based on the specific conditions of the seabed. The following tables details the overlap between seabed composition, anchor selection, target species and fishery typically associated with those ground types.

Table 2 – Comparison of soil types with FOW anchor compatibility and fishing methods

Soil Type	FOW Anchor Type					Target Species	Fishing Method
	Drag Embedment Anchor (DEA)	Driven Pile	Drilled Pile	Gravity	Suction Pile		
Soft Clay /Mud	Good	Good	Capable	Poor	Good	Demersal Species, Nephrops	Beam Trawling, Otter trawling, Dredging, Demersal Seining
Stiff Clay	Good	Good	Capable	Good	Good	Demersal Species	Beam Trawling, Otter trawling, Dredging, Demersal Seining
Sand / Gravel	Good	Good	Capable	Good	Capable	Demersal Species, Scallops	Beam Trawling, Otter trawling, Dredging, Demersal Seining
Hard / Rock	Poor	Poor	Good	Good	Poor	Lobsters, Crabs	Pots traps and creels

Mid column fishing methods such as pelagic trawling, purse seine or gillnetting are less likely to interact with FOW anchors. However the anchor choice and mooring configuration will have a significant impact on mooring footprint, thus their selection is still an important factor to consider [25].

6.4 Operations & Maintenance

The careful management of the operations and maintenance (O&M) phase of a floating offshore wind farm is critical to the project's economic viability. O&M activities must be carefully planned to minimise downtime, reduce costs, and ensure the safety of personnel. In addition, O&M strategies must take into account the presence of other maritime activities in the area, including commercial fisheries. For effective co-existence, this means the appropriate, accurate and timely communication of maintenance operations.

6.4.1 CTV vs SOV

A wind farm operator will typically opt for either a crew transfer vessels (CTV) or service operation vessels (SOV) led logistic strategy, depending on the size and location of the FOW project.

CTV

CTVs are smaller vessels that transport personnel and equipment to and from the wind farm on a daily basis. They are more cost-effective for smaller projects or those located closer to shore (i.e. within 40km). Typically, turbine access from CTVs is limited to significant wave heights (H_s) of approximately 1.5-2.0 metres [26].

SOV

SOVs are larger vessels that can remain offshore for extended periods, reducing the need for frequent trips to and from shore. This makes them ideal for larger FOW projects located further from shore, i.e. beyond 40nm [26]. SOVs are typically equipped with motion compensated "walk-to-work" systems, enabling technicians to access turbines in conditions up to H_s 3.0-4.0 metres.

From a fisheries coexistence perspective, the two strategies present different considerations. For CTV-led strategies, a wind farm may have multiple smaller vessels transiting to and from the site, particularly during favourable weather windows. A FOW farm with an SOV-led strategy will have fewer maintenance vessels operating in the vicinity of the wind farm perimeter, with less journeys between the wind farm and operations base, although those vessels will be larger and less agile.

For successful co-existence with either of these O&M strategies, clear communications between wind farm and fishing vessels will be critical.

6.4.2 Major Component Exchange

In the event that a major component exchange is required for a FOW turbine, the current conventional O&M strategy is tow-to-port (T2P). This involves disconnecting the floating substructure from its dynamic cables and mooring lines, and towing the platform and turbine to a suitable port. To date, T2P logistics have been required when the water depths at pilot FOW farms exceed the limits of standard jack-up vessels, or if floating-to-floating component exchange has been prohibitively complex.

T2P operations would present an important navigational consideration to other sea users, including fishing vessels. Therefore, clear communication would be an important part of the planning process for these operations.

Technology Development

A number of innovative in-situ methods for exchanging major components are currently being developed and could be applicable to the FOW industry. Although these methods are at a lower TRL

compared to T2P solutions, they could offer cost savings by reducing the number of vessels needed for maintenance. In-situ methods could also support reduced turbine downtime, as they may require narrower weather windows than T2P operations, therefore helping to minimise lost revenue. In-situ component exchange solutions could also reduce the need for space at the O&M port, easing quayside demands.

In-situ repair methods could also support potential coexistence with other maritime industries, including commercial fishing, as they would require fewer vessels and avoid the need to tow turbines back and forth between the wind farm location and the O&M port.

6.5 Cables

Subsea cables are critical components of a floating offshore wind project, and their safe installation and subsequent protection are crucial considerations. Cables must be carefully designed to ensure the efficient transmission of energy from the turbines to the onshore grid, while potential interactions with commercial fisheries and other maritime activities must also be considered.

6.5.1 Dynamic Cable

The dynamic section of the cable, which transmits power from the turbine to the sea floor is a novel element of FOW infrastructure, relative to traditional fixed wind farms. For the cable to remain operational it must be able to conform to the movement of the platform. There are several methods available to achieve this, but the configuration expected to be utilised in UK waters is the lazy wave configuration. This utilises components including buoyancy modules, bend stiffeners and tethers in order to keep the cable within its mechanical limits and functioning safety.

For catenary, semi taut and taut mooring configurations the anchor point will most likely be the furthest subsea obstacle from the FOW turbine platform (i.e., the components that define the width of any potential unobstructed corridors within arrays, between turbine rows). However, in the event that TLP designs are commercialised for FOW applications, the dynamic cable touchdown point could become the outermost point that defines a FOW turbine's seabed footprint (and the unobstructed space between the turbines).

6.5.2 Static Cable Burial

Burial is the most effective method for protecting static subsea cables from damage and reducing the likelihood of fishing gear entanglement. Power cable failure currently accounts for 75% of the cost of all insurance claims associated with offshore wind projects, and faults typically take 100+ days to rectify [27]. Therefore, consented FOW environmental impact assessment (EIA) design envelopes specify a target burial depth of 1.5m for the static sections of inter array cables where possible, dependant on seabed composition. Burial maintains the stability of the cable and thus has beneficial properties for the developer. The burial process for static cables can incur significant vessel costs during the wind farm installation process, therefore a developer must weigh this up against the resulting benefits from a cable protection perspective.

From a fisheries perspective, the burial of any static cables on the seafloor is considered key to the ability to trawl over those grounds.

6.5.3 Static Cable Rock Armouring

Rock armouring involves placing rocks or other protective materials over the cables to protect them from external damage. This method is typically used in areas where burial is not feasible, such as rocky or hard substrate. While rock armouring can provide effective protection from cable

movement, the fishing industry typically objects to its use, as well as that of concrete mattresses, grout bags, rock/sand-bags, as they consider them to pose a significant snagging hazard to fishing gear. Offshore wind developers observed that it could be possible to mitigate these risks through the selection of appropriately graded rock, however further discussion would be required to arrive at a cross-industry consensus on this topic.

6.5.4 Shared Mooring Clusters

For FOW farms with shared mooring designs, fishing stakeholders noted that if cables could be routed within clusters of turbines with shared mooring, cable burial may not be required (as shared mooring configurations were generally considered unfishable due to their complexity). Concerns were noted regarding the implications this may have on cable maintenance, given the increased complexity of completing a cable repair operation within a cluster of jointly-moored turbines. Notwithstanding, the general limited space within FOW arrays with shared moorings remained a concern for fishing stakeholders.

6.5.5 Substation Location

The location of a wind farm's offshore substation(s) is a key design consideration, and it has implications on both the efficiency of energy transmission and the ease of access for maintenance vessels. Placing the substation in line with the turbine rows could reduce the length of electrical cables required, lowering installation costs and reducing transmission losses. The positioning of substations in relation to turbine rows and navigable lanes could be an important consideration for potential fisheries coexistence, particularly if a substation could be located outside any otherwise clear and unobstructed corridors.

6.6 Communication & Collaboration

6.6.1 Early Engagement

Effective communication and liaison between floating offshore wind developers and the fishing industry are essential for minimising conflicts and ensuring the success of both industries. Early engagement – for example in the form of consultations, surveys, stakeholder dialogues – and subsequent ongoing discussion in relation to any offshore development is therefore crucial.

6.6.2 Towing Patterns & AIS Data Sharing

Data pertaining to fishing towing patterns, such as vessel AIS data, can help developers to understand and manage the potential navigational risks associated with coexistence. As such, this information can be an important input during the FOW farm development process.

6.6.3 Modelling Fishing Activities

The ability to accurately model the fishing activities relevant to a particular area or region will be crucial if discussions and efforts relating to the potential coexistence of FOW and fishing industries are to prove fruitful. This includes the fishing methods and types of gear used, the size and number of vessels operating in the area, and the location of important fishing grounds. Only through a thorough understanding of these details can the coexistence question be meaningfully addressed during the FOW farm development phase.

6.6.4 Entanglement Protocols

The development of clear protocols for managing potential entanglement scenarios would benefit the current discussion regarding potential coexistence between FOW and fishing. These should

address a range of possible scenarios, including active mobile and static gear, as well potential interactions with lost gear, and should consider methods for safe disentanglement that minimises the risk of loss or damage to both industries.

7 COEXISTENCE FRAMEWORK

To summarise the analysis of the workshop outcomes, the project team compiled a matrix, or a coexistence framework, scoring each of the identified opportunities relevant to potential coexistence between the FOW and fishing industries.

Each opportunity was assigned scores for technical and economic feasibility (where 1 = low, 2 = medium, and 3 = high), as well as an overall score reflecting its potential impact on efforts to support future coexistence between the two sectors. Table 3 outlines the method for calculating the overall score, based on an opportunity's combined technical and economic feasibility ratings.

Table 3 Opportunity Scoring Matrix

		Economic Feasibility		
		Low	Medium	High
Technical Feasibility	High	3	6	9
	Medium	2	4	6
	Low	1	2	3

The scoring process is intended to support and inform ongoing and subsequent discussions concerning the potential future coexistence of the FOW and fishing industries by providing clarity regarding the opportunities and innovation areas that represent the highest potential for positive impact, and those that are unlikely to facilitate meaningful change. Opportunities and innovations with a high overall score are considered to merit the attention of continued collaborative enabling actions and targeted R&D efforts.

There are some important considerations to note when reviewing the coexistence framework:

- Each opportunity outlined in the coexistence framework is assessed on its own merits and on the basis of all other things being equal. However, no one opportunity or innovation in isolation is expected to solve the question of FOW and fishing coexistence. If the future coexistence of the two industries is to be realised, this will likely be dependent on the success of multiple measures in tandem.
- The development of a FOW farm is a complex, multicriterial decision making process that is subject to numerous technical, financial, practical and environmental constraints. Fisheries coexistence is one such important consideration and is the principal focus of this project and coexistence framework. However, in practice, a FOW farm developer must also consider a range of other factors and constraints (e.g. seabed bathymetry, metocean conditions, SAR requirements, environmental impact assessment mitigation measures, supply chain constraints etc.) which will also directly influence the design decisions made.

- The final design for any FOW farm will be less idealised than early design concepts, and FOW turbine moorings will be micro-sited according to local bathymetric and environmental conditions.

It is also important to note that the question of coexistence between FOW and fishing is a complex and challenging topic that evokes a broad range of perspectives within both industries. The discussion outlined above and summarised below is an attempt to identify areas of general consensus, insofar as is possible, with the aim of progressing this discussion for the collective benefit of both industries.

As with any discussions relating to technical innovation and an evolving commercial landscape, it is possible (and in some cases likely) that unforeseen factors and developments that were not anticipated during the project discussions may subsequently play a significant role in the potential coexistence of FOW and fishing in the future.

Table 4 – Coexistence framework

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
1	Larger turbines	Technology Development	Turbines with increasing capacity would typically be installed further apart, thereby increasing the spacing within FOW arrays.	2	3	6	A key outcome from the project workshops was the importance of sufficient spacing between turbines in order for coexistence to be feasible, particularly for mobile fishing. As a guiding principle, the spacing for turbines within an array is calculated as a multiple of their rotor diameter (often, but not always, within the 7-10 times rotor diameter range). A turbine's rotor diameter generally increases with higher turbine capacities, therefore larger turbines could play an important role in facilitating increased spacing within FOW arrays. From a wind farm developer's perspective, larger turbines are a current innovation priority due to their role in improving a project's return on investment. Therefore, if new turbine designs of higher capacities (e.g. 20MW and above) are successfully commercialised in the medium term, it is likely that developers will utilise them for future large scale FOW farms.
2	Power density requirements	Policy & Lease Agreements	The power density requirements set by seabed leasing authorities place an administrative limit on a wind farm developer's ability to increase the spacing	3	1	3	Seabed leasing authorities (The Crown Estate and Crown Estate Scotland, in the UK) have a duty to maximise the efficient use of the seabed. Therefore, in most cases, a wind farm's seabed lease agreement will stipulate the minimum power density requirement that the project must adhere to. This places an administrative limit on the average distance between turbines in an array, as there is an inverse relationship between a site's power density requirement and the maximum spacing at which

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
			between turbines. Future conversations regarding FOW and fishing coexistence should therefore consider the role of this constraint, and the relevant public stakeholders should be involved in any discussion regarding potential solutions.				turbines of a given capacity can be installed. As such, a developer's ability to increase turbine separation in order to support potential coexistence is restricted on contractual grounds. If coexistence between FOW and fishing is to be considered a shared objective, particularly at a policy level, then the role of power density stipulations must be assessed. It is critical to note, however, that a wind farm's power density has crucial economic implications, irrespective of the requirements of a seabed lease. Reducing a wind farm's power density could negatively impact the project's LCoE and underlying business case. As such, power density is a critical parameter in the wind farm development process, and one which a project's viability is highly dependent upon.
3	Perimeter loaded wind farms	Array Topology	If the positioning of turbines within an array could be concentrated on the boundary of the leased area, resulting in fewer turbines and more open spaces within wind farm's interior, this could increase the practical viability of the wind	2	2	4	In certain scenarios, it may be possible to weight the positioning of turbines towards the wind farm's perimeter and away from the interior. This would depend heavily on the nature wind resource, and the exact array topology would need to be defined through detailed wake analysis studies. A developer's ability to implement a perimeter-loaded array design will be limited by a dual requirement to mitigate inter-array wake effects (a specific concern if turbines are positioned too closely together at the perimeter) and to maintain the requisite average power density for the wind farm (which limits the ability to space turbines significantly within the interior). As such, it is not guaranteed

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
			farm as a fishing ground.				that the implementation of perimeter-loaded designs alone would be sufficient to create the spacing require for colocation with fisheries, without the implementation of additional complementary innovation measures.
4	Positioning turbine rows to align with the tide	Array Topology	During the project workshops, the participants discussed the feasibility of orienting a FOW array's turbine rows to align with the tide in order to increase the potential for coexistence with fishing.	2	1	2	Turbine rows within an array are typically positioned in relation to the prevailing wind direction to maximise AEP, while fishing activities are often conducted in relation to the prevailing tide direction to maximise efficiency. The relative orientation of the prevailing wind and tide for a given location is therefore relevant to the potential for coexistence between FOW and fishing in that any clear corridors between optimised turbine rows may or may not be conducive for fishing vessels seeking to operate with the tide. The specific topology of an optimised FOW array is informed by a range of technical and economic design factors. Array-scale deviations from an optimised topology may result in some otherwise-avoidable technical challenges, however the AEP impact could be significant. A combined wake-analysis and cost modelling exercise undertaken by the project team indicated that, for a hypothetical 1GW FOW farm, this loss of earnings would equate to a loss of up to £102 million in a project's net present value (NPV) for a Celtic Sea development, and up to £96 million NPV for a North Sea farm. The exact impact for an

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
							actual farm would depend on the specifics of that development and the extent of any deviation from an optimised array design.
5	Inclusion of fishing lanes within FOW arrays	Array Topology	The workshops participants considered the potential adjustment of turbine and mooring positioning to allow for the widening of a lane (or select few lanes) between turbine rows in a FOW array for the specific use of fishing vessels.	2	2	4	Large scale FOW arrays are likely to include a number of clear lanes between turbine rows. For example, access is required for maintenance vessels, and developers are required to include SAR lanes within arrays to enable low level flight paths for SAR aircraft. Under a business-as-usual scenario (without the implementation of other innovations or design-based measures), lanes within FOW arrays are unlikely to be sufficiently wide enough to provide the 3km of clear seabed highlighted by the fishing stakeholders during the workshop discussions. Analysis delivered by the project team concluded that, hypothetically, it may be possible to include at least one widened lane (of 3km width) within a FOW array with catenary moorings while still meeting the contractual power density requirements stipulated in the wind farm's seabed lease agreement. It was however noted that the site's power density was highly sensitive to the widening of individual lanes, and therefore the inclusion of multiple widened lanes would be very challenging. It should also be noted that the analysis applied only to the administrative requirements for power density, and that the implications on a project's financial viability would need to be determined on a project-by-project basis by the FOW farm developer.

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
							The inclusion of widened lanes within a defined lease area by increasing turbine separation would most likely reduce a FOW farm's AEP and, in turn, impact a project's business case. Further dialogue between the project team and fishing industry stakeholders concluded that the inclusion of a single (or very limited number) of widened lanes within a large scale FOW farm was unlikely to make a meaningful difference to the viability of the array area as a commercial fishing ground, and that greater freedom to operate within the broader array area would ultimately be required. That said, if commercially exploited fish stocks were present within a widened lane, it was noted that a fishing vessel may nevertheless target them, if the skipper determines it is safe to do so.
7	Burying sections of catenary chain moorings	Mooring & Anchoring	The potential to partially bury catenary mooring chains to increase the amount of unobstructed seabed between FOW mooring footprints was discussed during the cross-industry discussions.	1	2	1	For catenary mooring systems, the section of each mooring line between the seabed touchdown point and anchor rests freely on the seabed. While the burial of this section of the moorings would increase the available seabed between turbine rows (assuming the anchors are of a submerged design), this would not be desirable from a FOW turbine design perspective. Mooring engineers consider mooring chain trenching as a failure mode, and a floating turbine's dynamics would be impeded if the chain was embedded within the seabed, particularly in severe weather conditions. Additionally, the burial of mooring chains would incur additional installation costs.

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
8	Nylon taut mooring systems	Mooring & Anchoring	The commercialisation of nylon FOW moorings would allow developers to significantly reduce the mooring footprint of FOW turbines, thereby increasing the amount of unobstructed seabed within a FOW array.	2	3	6	The future application of taut nylon mooring systems could enable FOW mooring footprint radii to be reduced by as much as two-thirds, relative to current chain catenary and polyester semi-taut designs. Nylon mooring designs are currently undergoing technology qualification processes (a prerequisite for commercial applications), which they are expected to complete in the short term. Once qualified, developers are likely to view nylon moorings favourably because of their lighter weight, easier handling properties, and the potential net cost reductions that they could enable. The expectation that nylon moorings could enable significant reductions in FOW mooring footprints (and thereby meaningfully increase the available seabed within FOW arrays), without the reliance on lower-TRL TLP designs, means that they could therefore be a highly relevant innovation relating to the potential coexistence between FOW and fishing.
9	Marking anchors physically	Mooring & Anchoring	The location of FOW mooring anchors could be potentially be marked at the water surface, for example through the use of marker buoys.	1	3	3	While the use of marker buoys would be a relatively inexpensive method for vessel skippers to visually identify the location of FOW subsea infrastructure, concerns were raised about practical viability. Fishing stakeholders noted that the potential for marker buoys to drift would hinder their accuracy, and that the presence of the buoys themselves would present an additional navigational hazard. Navigational safety bodies also noted that they would be unlikely to approve the use of marker buoys for this application.

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
10	Marking anchors digitally	Mooring & Anchoring	The location of FOW mooring anchors could be marked on digital maps to accurately communicate the location of FOW anchor other sea users, including fishing vessels.	3	3	9	The use of digital mapping services, such as KIS-ORCA, is an established method of communicating the location of subsea infrastructure to vessel skippers. There was cross sector agreement during the project discussions that this approach should be extended to future FOW farms to communicate the location of anchor points. For coexistence ambitions to be realised, these measures would be vital. As discussed in Section 6.3.5, it was also noted that there are opportunities to adopt a more responsive approach to the mapping of new subsea obstacles.
11	SOV logistic strategy	Operation & Maintenance	The selection of an SOV vs CTV logistic strategy for a FOW farm's operations and maintenance will influence the number of wind farm vessels present at the site.	3	3	9	In the UK market, large scale FOW farms will be installed in deeper waters, further from shore. It is expected that, for these locations, an SOV-led logistic strategy will more economically viable than a CTV strategy. As a result, it is probable that FOW farms will have fewer, larger vessels operating in the vicinity of the site, transiting to shore more less frequently, compared to the majority of traditional fixed wind farms, which rely on multiple smaller CTVs to conduct maintenance activities. It was noted during the workshop discussions that reducing the number of maintenance vessels operating within an array mitigates some of the navigational risks facing other sea users in the vicinity, including fishing vessels.
12	In situ maintenance	Operation & Maintenance	The ability to conduct in-situ heavy	2	3	6	Unlike fixed wind turbines, FOW turbines can be towed to back to port to conduct major maintenance or repairs. Indeed, this is

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
			maintenance, including floating-to-floating major component exchange, would reduce the complexity of a FOW farm's marine logistics.				sometimes required where standard solutions (e.g. jack-up or dynamic positioning vessels) cannot be utilised (e.g. because water depth or H_s limits are exceeded). T2P operations could increase a FOW farm's navigational complexity for other sea users, therefore it was agreed during the workshops that if these could be conducted in-situ, without towing the turbine away, this could support efforts to facilitate coexistence between the two industries. While in-situ FOW repair solutions are currently at a lower TRL, important progress has been made in the recent past in advancing capabilities in this space, and it is hoped that leading innovations could become commercially ready in the short to medium term.
13	Static cable burial	Cables	The burial of static sections of FOW inter-array cables would lower the snagging risk that they present to fishing operations.	3	2	6	During the workshop discussions, fishing industry stakeholders reiterated the industry's position that static cables should be buried to reduce the risk of entanglement with fishing gear. FOW engineers participating in the discussions noted that this may also be preferred by developers. Although the burial of static cables would incur additional installation costs, burial could assist with cable integrity by providing stability. The seabed composition at a given site will determine the feasibility of cable burial, however cross-industry discussions regarding this topic early in the FOW Farm development process is recommended.

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
15	Routing cables within shared mooring clusters	Cables	If FOW arrays utilise shared anchors, and clusters of jointly-moored turbines are separated by service lanes, it may be possible to limit the seabed obstructions within the service lanes by routing cables within the shared mooring clusters.	2	2	4	The cross-industry discussions undertaken during the project concluded that due to the complexity of FOW shared mooring configurations, these designs are unlikely to facilitate coexistence with commercial fisheries. Notwithstanding, it was noted that if turbines were to be jointly-moored in clusters, with service lanes separating the turbine clusters, then in principle the service lanes could be utilised for fishing (if they are of sufficient width). Were this to be the case, the likelihood of skippers fishing within service lanes would depend in part on the number of cable crossings present. It was observed that these could be minimised by primarily routing cables through shared mooring clusters. Deviations from an optimised array cable topology would likely incur additional CAPEX costs. The specific seabed composition at a site would also determine the viability of this solution. Further, positioning cables within clusters of jointly-moored turbines may increase the complexity of any future cable repairs required by the developer. It is important to manage expectations regarding the coexistence of fishing with FOW farms utilising shared anchors. While any service lanes within a shared mooring array could in principle be utilised by some fisheries, the likelihood of this was generally deemed to be low.

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
16	Optimised placement of substations	Array Topology	The specific location of a FOW farm's substation(s) could influence the potential for fisheries coexistence.	3	2	6	A large scale FOW farm could have several substations (typically one per 450-500MW of installed capacity). At the time of writing, these are likely to be jacket supported, as floating substation designs are not yet commercialised. The specific placement of substations could be relevant to the potential for coexistence with commercial fisheries. For example, if the unobstructed lanes within a FOW array were deemed to be wide enough to safely fish within, then from a coexistence perspective it would not be desirable for substations to be located within these lanes. It was noted that while the specific positioning of substations would influence a FOW farm's business case (e.g. due to the requirement for additional cable length [with implications on material costs and transmission losses], installation of jacket foundations in deeper waters etc.), in principle it is at least practically possible to select alternative locations for them within the vicinity of an array. Fisheries stakeholders noted during the workshops that if substations could be placed in line with turbine rows, rather than within the clear lanes between turbine rows, this would support efforts to facilitate coexistence between the two industries.
17	Data sharing	Communication & Collaboration	Access to fishing towing patterns and AIS data could allow developers how an	3	3	9	Early engagement with fisheries during the development of a FOW farm is crucial to efforts to support coexistence between the two industries. AIS data and information on towing patterns can enhance these discussions, as they would allow developers to understand the nuances of (and potentially model) how an area is used for fishing,

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
			area is used as a fishing ground.				and in turn how the siting of FOW infrastructure may influence existing activities.
18	Fishing gear innovation	Communication & Collaboration	In principle, the potential for coexistence could be supported by targeted innovation in fishing gear and/or techniques.	2	2	4	During the cross-industry discussions, the question of whether coexistence could be facilitated through fishing innovations was raised. Fishing stakeholders noted that fishing methods and technologies are well established and mature, having been developed and adapted over the course of the industry's history. Therefore, it is important to manage expectations about attempts to adapt these techniques in the short term. Nevertheless, it was noted that if there was a funded programme or mechanism for supporting the targeted R&D for fishing innovations, there could be cross-industry support for this.
19	Development of entanglement protocols	Communication & Collaboration	The development of procedures and protocols to follow in the event of an entanglement scenario could help mitigate the potential risks associated with coexistence.	2	3	6	The potential for entanglement scenarios with fishing gear and FOW infrastructure is one of the principal concerns regarding potential coexistence between the two industries. If protocols outlining the procedure for entanglement scenarios could be developed through collaborative cross-industry discussions, this could be an important mechanism for supporting potential coexistence between the two sectors.

No.	Opportunity	Type	Description	Technical Feasibility	Economic Feasibility	Opportunity Score	Discussion
20	Modified turbine separation	Array Topology	The potential to facilitate coexistence by altering the distance between turbines in a FOW array was discussed during the cross industry discussions.	3	1	3	Fishing stakeholders noted that the turbine separation within a FOW array would influence the potential for coexistence. Either, turbine separation could be significantly lowered in order to reduce the overall area occupied a FOW farm, effectively rendering the array a no-take zone but increasing the surrounding clear seabed for commercial fishing. Or, separation could be increased in order to widen the lanes between turbine rows to facilitate safe fishing. Analysis by the project team and a review of relevant literature have highlighted that strict upper and lower limits apply – both economically and contractually – to the turbine separations which a developer must adhere to. At lower separations, AEP losses due to inter-array wake effects become prohibitive. At greater separations, developers will struggle to achieve the minimum power densities needed to meet the requirements of their seabed lease agreement and to achieve financial viability. Therefore, whilst turbine separations are a relevant consideration for coexistence between FOW and fishing, it is highly unlikely that this parameter alone could be sufficiently adjusted to achieve coexistence.

7.1 Summary

Analysis of the outcomes from the project's cross industry engagements identified a range of opportunities to support potential future coexistence between FOW and commercial fisheries. These are summarised in a coexistence framework, which scores each opportunity on technical and economic grounds in accordance with their potential to facilitate positive relations between the two industries.

Concerning **technology**, the principal opportunities relate to higher capacity turbine innovations (i.e. 20MW and above), and the commercialisation of taut nylon mooring systems with smaller mooring footprints. These two developments in tandem could play a significant role in potentially providing the spatial requirements for fishing to safely occur within future FOW arrays (on the basis that additional conditions are met). It was also noted that the burial of static sections of array cables, particularly where these cross otherwise unobstructed corridors of seabed, would be a necessary condition for fishing to occur. Furthermore, the location of FOW farm substations was also noted as important. A large-scale FOW farm could have several substations, therefore, potential coexistence between FOW and commercial fisheries will depend on the careful selection of substation positioning to ensure that their jacket foundations do not obstruct otherwise fishable grounds.

Regarding **operations and maintenance**, it was recognised that the continued development of in-situ heavy lift innovations that could enable major repairs on FOW turbines to be conducted at the wind farm location would help to reduce the logistical complexity of large scale FOW farms by avoiding the need for FOW turbines to be disconnected from their moorings and dynamic cables and towed back to port. Maritime traffic within future FOW farms could be further reduced through the selection of SOV-led logistics strategies, which are expected to be more economically viable than CTV strategies for developments further offshore. By reducing the volume and complexity of FOW farm maritime operations, the number of potential navigational hazards facing fishing vessels is lowered.

A number of opportunities relating to **cross sector communication** were also highlighted. The FOW CoE's FOW-Fishing Interaction Roadmap previously highlighted the criticality of early engagement with commercial fisheries regarding the development of a commercial FOW farm development, and this project's discussions only reiterated that. The use of digital mapping systems to communicate the location of FOW subsea infrastructure, including anchor positions, was acknowledged as a low cost yet crucial action for supporting potential coexistence. It was also noted that any data that could be shared regarding fishing patterns in the area of a FOW development would inform any discussions relating to coexistence.

8 CONCLUSIONS AND RECOMMENDATIONS

The Floating Offshore Wind and Fishing Framework for Coexistence Project has facilitated an analysis of potential opportunities to support coexistence between future large-scale FOW farms and commercial fisheries. This analysis focussed on opportunities that may be relevant to the FOW farm development phase, following the award of a seabed lease. While the project team recognised the primacy of marine spatial planning in ensuring that the requirements of a broad range of maritime industries are met, the specific aim of this project was to understand the extent to which decisions made during the FEED studies of future large-scale FOW farms might facilitate potential coexistence with commercial fisheries. The project adopted a UK remit, with a particular focus on the Scottish North Sea and the Celtic Sea.

A somewhat flexible understanding of the term *coexistence* was adopted for the purposes of the project. The project team recognised that, at the time of writing, a broader discussion was ongoing regarding the distinction between *coexistence* and *colocation*, and their appropriate definitions. This project did not seek to comment on that discussion. During the project's cross industry engagements and subsequent analyses, the project team used the term *coexistence* to refer to the ability of the FOW and fishing industries to exist and operate independently within the same general marine space. As such, coexistence (as applied in this report) refers to a fishing vessel skipper's ability to operate in the vicinity of a FOW farm, including potentially within the interior of the array.

The project was informed by a series of technical cross-industry engagements. These were conducted regionally, with in-person workshops held in Scotland and Cornwall, and included representatives from the fishing industry (including several with direct experience of working on or captaining commercial fishing vessels) and FOW farm developers (including design engineers, development and consenting specialists, and fisheries engagement managers). The project team also sought the input of other relevant stakeholders, including seabed leasing authorities, regulators, and maritime navigational and safety bodies.

Outcomes captured during the workshops were subsequently reviewed, and the identified opportunities to facilitate cross-sector coexistence were assessed in respect of their technical and economic feasibility. A coexistence framework was then developed, which summarised the opportunities and scored them in accordance with their potential to facilitate future cross-sector coexistence.

The principal opportunities for supporting potential future coexistence between large-scale FOW farms and commercial fisheries include: larger turbine capacities, and the increased spacing within arrays that they would enable; taut nylon moorings, and the reduction in mooring footprints that they could facilitate; the appropriate positioning of substations within FOW arrays; the simplification of FOW farm maritime logistics through the adoption of SOV-led logistic strategies and the development of in-situ heavy lift solutions; the digital mapping of FOW subsea infrastructure; and early and proactive cross-sector engagement, including the appropriate sharing of information and data regarding respective activities, where possible. It should be noted that these opportunities are not believed to guarantee future coexistence, but that coexistence-related efforts and discussions would benefit from a focus on these particular topics. It is also believed that the potential to facilitate coexistence will depend on a number of opportunities being realised in tandem, rather than a concentration on any one opportunity in isolation.

Other opportunities that were also reviewed, but judged to be less feasible, include: the adjustment of turbine separations (assuming a set turbine capacity), either to reduce the overall size of an array, or increase the space within it for fishing operations; the inclusion of one or a small number of widened lanes within an array for fishing operations; the partial burial of catenary moorings to

increase the unobstructed seabed between mooring footprints; and the use of marker buoys to identify FOW anchor locations.

Achieving coexistence between future large-scale FOW farms and commercial fisheries will depend heavily further collaborative cross-sector efforts. Recommended enabling actions include:

- Continued support for the development of relevant innovations, including larger capacity turbines, nylon mooring systems, and in-situ heavy lift solutions for FOW turbines.
- The use of maritime simulations to further understand the practical risks and opportunities of coexistence, are expected to play an important role. It is proposed that the FOW and fishing industries jointly undertake a series of simulated fishing operations within virtual FOW environments using specialised maritime simulation facilities. The simulated scenarios should consider the opportunities and relevant innovation areas identified in the coexistence framework set out in this report. Such work would represent an important progression from the desk-based work that has been undertaken to date.
- Ongoing proactive cross-sector communication will be vital to any coexistence related efforts. This is true both at a project-level, where early communication regarding FOW farm development plans is crucial, and at an industry-level, where the status of applicable FOW technology innovations and the development of relevant protocols can be equally impactful.
- A continued monitoring of the innovation landscape, particularly in relation to new opportunities not identified in this coexistence framework.
- Opportunities to support the development of innovations applicable to fishing practices could also play a role. While it was noted that fishing practices are well established and have matured over the course of the industry's long history, there may also be support for an R&D programme dedicated to potential fisheries innovations.

The question of coexistence between FOW and fishing is undoubtedly a challenging topic that evokes a broad range of perspectives across all stakeholder groups. The publication of this coexistence framework is an attempt to advance the current discussion and identify areas of consensus, insofar as is possible. It is hoped that the work undertaken in this project will allow both industries to concentrate their collaborative efforts on opportunities that have a greater prospect of achieving their shared aims.

The project team would like to take the opportunity to extend their gratitude to the participants of the project, including those who attended the in-person workshops. The expertise and input shared during the project engagements was critical to the project and the development of its conclusions and recommendations.

9 REFERENCES

- [1] Climate Change Committee, “The Seventh Carbon Budget,” Climate Change Committee, London, 2025.
- [2] UK Floating Offshore Wind (FLOW) Task Force, “Floating Wind: Anchoring the next generation offshore,” RenewableUK, London, 2024.
- [3] Offshore Renewable Energy Catapult, “Floating Offshore Wind and Fishing Interaction Roadmap,” ORE Catapult, Glasgow, 2021.
- [4] TCE, NFFO, “Summary report of the Virtual Floating Offshore Wind (FOW) planning project delivered by NFFO with support from The Crown Estate (TCE),” OWEC, 2022.
- [5] D. Kim, “Design strategy for resonance avoidance to improve the performance of tension leg platform-type floating offshore wind turbines,” *Ocean Engineering*, vol. 306, 2024.
- [6] Offshore Renewable Energy Catapult, “GIGAWATT SCALE CABLE AND MOORING INSTALLATION,” ORE Catapult, Glasgow, 2023.
- [7] The Crown Estate, “Introducing Offshore Wind Leasing Round 4,” TCE, 2019.
- [8] The Crown Estate, “Information Memorandum Celtic Sea Floating Offshore Wind,” TCE, 2023.
- [9] NFFO & The Crown Estate, “Changes to Fishing Practices as a Result of the Development of Offshore Windfarms,” The Crown Estate, London, 2016.
- [10] X. C. M. d. D. C. M. G.-G. B. Thomas, “Wake effect impact on the levelized cost of energy in large floating offshore wind farms: A case of study in the northwest of the Iberian Peninsula,” *Energy*, vol. 304, no. 132159, 2024.
- [11] O. a. R. S. Maas, “Wake properties and power output of very large wind farms for different meteorological conditions and turbine spacings: a large-eddy simulation case study for the German Bight,” *Wind Energ. Sci.*, vol. 7, no. 2, p. 715–739, 2022.
- [12] S. Hogg, “Wind turbines are already skyscraper-sized – is there any limit to how big they will get?,” *UKERC*, 2023.
- [13] E. Lico, “Wind turbine technology evolution is diverging quickly between China and the rest of the world,” *Wood Mackenzie*, 2024.
- [14] P. Largue, “China’s wind turbine OEMs advance global dominance shows report,” *Power Engineering International*, 2024.
- [15] Recharge, “‘Two blades break off’ world’s most powerful wind turbine in China,” 12 December 2024. [Online]. Available: https://www.rechargenews.com/wind/two-blades-break-off-worlds-most-powerful-wind-turbine-in-china/2-1-1752939?zephro_sso_ott=fZ3VVm. [Accessed 10 January 2025].

- [16] N. Kirchner-Bossi, "Wind farm power density optimization according to the area size using a novel self-adaptive genetic algorithm," *Renewable Energy*, 2024.
- [17] A. P. J. Stanley, "Massive simplification of the wind farm layout optimization problem," *EAWF*, vol. 4, no. 4, 2019.
- [18] MCA, *Offshore Renewable Energy Installations: Requirements, guidance and operational considerations for SAR and Emergency Response*, 2024.
- [19] D. W. Energy, "Py-Wake," Py-Wake, 2018. [Online]. Available: <https://topfarm.pages.windenergy.dtu.dk/PyWake/>. [Accessed 13 01 2025].
- [20] Marine Scotland, "Scotland Marine Assessment," Marine Scotland , 2020.
- [21] Y.-T. Wu, "Power output efficiency in large wind farms with different hub heights and configurations," *Renewable Energy*, 2019.
- [22] R. V. Rodrigues, "Aligned and Staggered Layouts: What is the Impact on Wind Farms Land-Use?," 2020.
- [23] A. C. U. Palm, "Cruise report Hywind Tampen 13 to 28 March 2023," Nordsjøen, 2023.
- [24] S. A. A. –, "floatingwindsolutions," 5 Feb 2024. [Online]. Available: <https://floatingwindsolutions.com/wp-content/uploads/2024/02/1-FWS-2024-Bekaert-Nylon-Mooring.pdf>. [Accessed 25 Nov 2024].
- [25] Marine Conservation Society, "Fishing methods explained," Marine Conservation Society, 25 Nov 2024. [Online]. Available: <https://www.mcsuk.org/ocean-emergency/sustainable-seafood/from-sea-to-plate/fishing-methods-explained/#introduction>. [Accessed 25 Nov 2024].
- [26] BVG Associates , "Guide to a Floating Offshore Wind Farm," BVG Associates , 2023.
- [27] Y. Sharif, "Characterization of anchor penetration behaviour for Cable burial risk assessment," University of Dundee, Dundee, 2023.
- [28] DNV, "Cluster wakes and their effect on a wind farm annual energy production," DNV , 2024.
- [29] UK Government, *The Electricity Offshore Generating Stations Safety Zones Application Procedures and Control of Access) Regulations*, UK Government, 2007.
- [30] N. Rouxel, *Floating Substations: the next challenge on the path to commercial scale floating*, DNV, 2021.

FLOATING OFFSHORE WIND CENTRE OF EXCELLENCE

ORE Catapult
Inovo
121 George Street
Glasgow, G1 1RD

+44 (0)333 004 1400

Disclaimer

While the information contained in this report has been prepared and collated in good faith, ORE Catapult makes no representation or warranty (express or implied) as to the accuracy or completeness of the information contained herein nor shall be liable for any loss or damage resultant from reliance on same.