FLOATING OFFSHORE WIND
CENTRE OF EXCELLENCE

Delivered by
CATAPULT
Offshore Renewable Energy

FLOATING OFFSHORE WIND
ENVIRONMENTAL INTERACTIONS ROADMAP
Public Summary Report

In Partnership with

XODUS

Author:
ORE Catapult & Xodus Group
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CONTENTS

List of Figures

List of Tables

Nomenclature

BHA	British Helicopter Association
CAA	Civil Aviation Authority
CES	Crown Estate Scotland
CIFA	Community Inshore Fisheries Alliance
CoE	Centre of Excellence
EIA	Environmental Impact Assessment
EMF	Electromagnetic Field
ESCA	European Subsea Cables Association
FOW	Floating Offshore Wind
FOWT	Floating Offshore Wind Turbine
GW	Gigawatt
HRA	Habitats Regulations Assessment
IFCA	Inshore Fisheries Conservation Authority
INTOG	Innovation and Targeted Oil and Gas
JNCC	Joint Nature Conservation Committee
LCOE	Levelised Cost of Energy
MCA	Maritime & Coastguard Agency
MGN	Marine Guidance Note
MMO	Marine Management Organisation
MS-LOT	Marine Scotland - Licensing Operations Team
MSS	Marine Scotland Science
NRA	Navigational Risk Assessment
NRW	Natural Resource Wales
ORE	Offshore Renewable Energy
ORJIP	Offshore Renewables Joint Industry Programme
OWEC	Offshore Wind Evidence and Change
OWEER	Offshore Wind Environmental Evidence Register
O&G	Oil and Gas
O&M	Operations and Maintenance
PINS	Planning Inspectorate
SAR	Search and Rescue
SFF	Scottish Fishermen's Federation
SMRU	Sea Mammal Research Unit
UXO	Unexploded Ordnance

1 BACKGROUND

1.1 Context

The UK Government has set ambitious targets associated with climate change and decarbonisation, including achieving Net Zero by 2050 (with 2045 as a separate specific target in Scotland). One fundamental activity underpinning this target is the decarbonisation of our energy system through the removal of conventional fossil fuel generation and investment in the growth of low carbon, renewable technologies. Offshore wind is critical to the decarbonisation process, and the UK is already positioned as a global leader with an operational capacity of 10.4 Gigawatt (GW) (Renewable UK, 2021).

The latest UK Government targets set out that offshore wind will provide up to 50GW of generation capacity by 2030 and 100 GW by 2050 (CCC, 2019). Alongside conventional, bottom-fixed offshore wind, floating offshore wind (FOW) technology has an important role to play in meeting these targets, and the UK Government's most recent targets aim to deliver 5GW of FOW by 2030. Furthermore, in January 2022, Crown Estate Scotland (CES) announced the results of their first leasing round for offshore wind – Scotwind – totalling 25GW of potential generation capacity in Scotland, of which ~60% is proposed to be provided through FOW.

Within the UK, there are a small number of operational (demonstrator) FOW arrays in Scotland. There are plans for further such projects in Scotland, as well as for projects in Welsh and English waters, notably within the Celtic Sea regions and off the coast of Blyth, Northumberland. As the pace of FOW development increases, it is acknowledged that there will be a range of technical, commercial and consenting challenges; one such challenge is related to the limited understanding of environmental interactions associated with commercial scale FOW.

With this context in mind, the Offshore Renewable Energy (ORE) Catapult's Floating Offshore Wind Centre of Excellence (FOW CoE) launched the Floating Offshore Wind Environmental Interactions initiative in September 2021. Fundamentally, this three-phase project seeks to:

Phase One: Identify potential knowledge gaps and identify activities which may address them; and

Phases Two and Three: Coordinate onward workstreams to address these gaps, including relevant research initiatives and leading the development of innovative solutions.

This public summary report is associated with the first of these three phases. During the delivery of Phase One, a range of potential knowledge gaps associated with FOW environmental interactions were identified across various different topic groups, and a series of further research and activities were proposed in relation to these. A prioritisation exercise was also undertaken during the course of the roadmap's development, and this public summary concentrates on the areas that were considered to represent the most pressing case for industry intervention.

In addition to this public summary report, a full, confidential report was also report delivered to the FOW CoE partners. The full report documents a complete overview of all interactions identified and reviewed during the course of this project

The Floating Offshore Wind Environmental Interactions project forms part of the FOW CoE's Development and Consent workstream, and it is the third project to be delivered within this workstream to date. Publicly available findings from the preceding two projects are available as follows:

- Floating Offshore Wind Development and Consenting Process – Risks and Opportunities
- Floating Offshore Wind and Fishing Interaction Roadmap

Further information on the FOW CoE's broader project portfolio, including its other workstreams, is available here.

1.2 Project Overview

FOW projects are anticipated to grow in scale around the UK from 2020 to 2030 from small demonstrator projects to full scale commercial projects. This growth in scale is consistent with the broader growth in offshore wind development in the UK as part of the UK's efforts to achieve Net Zero by 2050 (and 2045 in Scotland).

Key to ensuring that the FOW industry in the UK can scale up swiftly is having an efficient, timely and transparent development and consenting process. FOW is expected to play a critical role in the UK achieving its Net Zero emissions targets. However, in order for these deployment ambitions to be met, it is vital that FOW developers and stakeholders are able to work together to anticipate, understand, assess and manage potential environmental interactions as part of a timely and efficient consenting process.

A key element of this will be the Environmental Impact Assessment (EIA) process, informed by a relevant, robust and proportionate body of knowledge regarding environmental impacts. It is recognised that conventional offshore wind remains an evolving industry, and that there are evidence gaps associated with the environmental interactions of fixed bottom wind and the marine environment. Nonetheless, owing to the relatively young FOW industry and the rapid pace of planned growth, this report is focused specifically on FOW-related challenges.

The objective of the Floating Offshore Wind Environmental Interactions project is therefore to directly address the environmental interaction challenges facing FOW by identifying the current knowledge gaps and developing a programme of research activities to strengthen the industry's understanding in these areas.

There are three distinctive benefits with this approach:

1. By addressing environmental uncertainties in advance of full-scale commercial deployment, this project will anticipate and mitigate key consenting challenges, thereby reducing the time, cost and risk associated with the development process;
2. By strengthening the understanding of the environmental interactions specific to FOW, this project will enable both the FOW industry and key environmental stakeholders to mitigate the potential impacts of FOW, thereby supporting sustainable development; and
3. The study involves close collaboration with UK marine regulators and a wide range of topic-specific stakeholders. By holding early discussions with key regulatory bodies and working toward agreement on the key FOW issues, the FOW CoE hopes to drive efficiencies in the consenting for FOW going forward.

While the FOW CoE has previously delivered development and consent-focussed project prior to the delivery of this work (namely, the Floating Offshore Wind Development and Consenting Process – Risks and Opportunities project, which reviewed the broader regulatory landscape relevant to FOW development, and the Floating Offshore Wind Fishing Interaction Roadmap, which focussed specifically on the priority issue of fisheries interactions), this project places specific focus on challenges and opportunities specific to the FOW EIA process.

The principal delivery partners of the project are the ORE Catapult and Xodus Group Limited, who together led the development of the roadmap. A project Focus Group of FOW CoE Industry Partners was established at the outset to provide guidance and strategic advice throughout project delivery, ensuring that a balanced approach was adopted.

1.3 Floating Offshore Wind Centre of Excellence

The Floating Offshore Wind Centre of Excellence was established in 2020 by the Offshore Renewable Energy 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 has developed an initial core work programme across four workstreams:

- Technology Development;
- Supply Chain and Operations;
- Development and Consent; and
- Delivering Net Zero.

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.

Figure 1: Floating Offshore Wind Centre of Excellence Industry Partners

2 METHODOLOGY

Phase One of the Floating Offshore Wind Environmental Interactions project was structured around three distinct stages.

During the first stage – the **Environmental Review** – an evaluation of the EIA process applicable to FOW developments was undertaken to establish the necessary context for the subsequent development of the roadmap, and to identify and confirm the environmental receptors (both in respect of ecology, and impacts on other sea users) that would form its key areas of focus. A review of the relevant legislation – both UK wide and applicable to the devolved regions – was also undertaken to ensure that pertinent regulatory considerations were not overlooked. Finally, an analysis of existing evidence in relation to the environmental interactions of FOW was conducted. This encompassed existing consenting and environmental data, peer reviewed literature as well as the emerging research being undertaken in relation to this topic.

The scope of the second stage – **Technical Engagement** – was guided by the outcomes of the Environmental Review. During the Technical Engagement process, key environmental stakeholders and subject matter experts were invited to participate in a series of topic-specific workshops, as well as one-to-one engagements with the project team.

The third stage – the **Roadmap Development** – focussed on formalising the outcomes from the Environmental Review and Technical Engagement, and confirming the priority areas of focus in relation to current knowledge gaps and areas of uncertainty concerning the specific environmental interactions of FOW developments in the UK.

Further detail on the process undertaken during the course of the project is outlined in the following subsections.

Figure 2: Structure of Phase One of the Floating Offshore Wind Environmental Interactions Project

2.1 Environmental Review

The environmental review was divided into two discrete activities; (1) a review of the legislative and consenting process, and; (2) a review of the existing evidence associated with environmental interactions of FOW arrays.

1. A high-level overview of the general EIA process was carried out based on existing legislation, published regulatory guidance, consenting precedent and author experience. The principal objective was to identify FOW-specific considerations relevant to the EIA and broader consenting process. In the case of the broader consenting process, the previous FOW CoE project, FOW – Development and Consenting Process – Risks and Opportunities (ORE Catapult, 2021), had already performed a review UK marine planning and consenting for FOW, hence this preceding report was referred to both for guidance, and to avoid a duplication of previous efforts.

Legislation reviewed in support of the roadmap development
The Crown Estate Act 1961
Section 36 of Electricity Act 1989
Planning Act 2008
Marine and Coastal Access Act 2009
Marine (Scotland) Act 2010
Scotland Act 2016
Wales Act 2017
Scotland Crown Estate Act 2019

Table 1: Legislation Reviewed in Support of the Roadmap Development

2. Following this process, a review of how FOW farms interact with the environment in the UK and how their impacts are assessed was completed. This was informed by a detailed review of existing consenting and environmental data, peer reviewed literature, and – perhaps most significantly – emerging research being undertaken related to this topic.

Literature / ongoing research reviewed in support of the roadmap development	
Hywind Environmental Statement (2015)	Literature / Industry Report
Kincardine Environmental Statement (2016)	
Wave Hub Floating Wind Environmental Statement (2018)	
NERC (2016) - Environmental and Consenting Barriers to Developing Floating Wind Farms Including Innovative Solutions	
Hdidouan, D., Staffel, I., (2018) - The impact of climate change on the levelised cost of wind energy	
Hywind Noise Impact Assessment (2019)	
Copping, A.E. and Hemery, L.G - 2020 State of the Science Report	
Hutchison, Z.L., Secor, D,H., Gill, A,B., (2020) - The Interaction Between Resource Species and Electromagnetic Fields Associated with Electricity Production by Offshore Wind Farms	
Farr, H., Ruttenberg, B., Walter, R., Wang. Y., White, C (2021) - Potential environmental effects of deepwater floating offshore wind energy facilities	
Scottish Government (2021) - Fostering future Scottish-French research and development collaboration in floating wind and green hydrogen	
Floating Offshore Wind Centre of Excellence (2021) - Floating Offshore Wind Development and Consenting Process – Risks and Opportunities	
Floating Offshore Wind Centre of Excellence (2021) - Floating Offshore Wind and Fishing Interaction Roadmap	
FORTUNE: Floating Offshore Wind Turbine Noise	Ongoing Research Initiative
Offshore Renewables Joint Industry Programme (ORJIP) (Stage 2)	
Offshore Wind Evidence and Change (OWEC) Programme	
JNCC Offshore Wind Environmental Evidence Register (OWEER)	
Scottish Marine Energy Research (ScotMER) programme	

Table 2: Literature / Ongoing Research Reviewed in Support of the Roadmap Development

2.2 Technical Engagement

Informed by a detailed stakeholder mapping exercise, as well as the outcomes of the Environmental Review, a series of five topic-specific workshops were planned. With the exception of the first session, the workshops were structured around principal environmental receptor themes so that subject matter experts could attend the workshop(s) most applicable to their area of expertise. The first of the five workshops however focussed on the overarching licensing and consenting context; this session provided an additional opportunity to identify further FOW-specific considerations that may not have been identified during the course of the Environmental Review.

The topic-specific workshops were structured as follows:

- Group 1 – Licensing & Consenting;
- Group 2 – Physical Environment (Including Water Quality, Benthic and Coastal Process);
- Group 3 – Marine Ecology (Including Ornithology & Marine Mammals);
- Group 4 – Fish and Shellfish Ecology; and
- Group 5 – Other Sea Users / Human Environment.

The purpose of the technical engagement process was to confirm, based on input from topic-specific specialists (including regulators, statutory consultees, regulatory advisors and industry organisations), what the current knowledge gaps and areas of uncertainty are in relation to the environmental interactions specific to FOW technology, and where further research, data collection and/or technical innovation would enable these to be addressed.

In order to examine the topics identified during the workshops in closer detail, and to provide an opportunity for discussion with stakeholders who could not attend the workshops, a series of 11 detailed one-to-one interviews were also held. Attendance through the one-to-one interviews included members of the regulatory community, statutory nature conservation bodies, developers and various topic-specific specialists from the advisory and academic setting.

Table 3 outlines the stakeholders that accepted invitations to participate in the technical workshops and/or one-to-one interviews. In addition to these stakeholders, throughout the course of the project an ongoing dialogue was maintained with the Industry Partners of the FOW CoE, thereby ensuring that their input, advice, and technical guidance was also used to inform and support the roadmap development. As a result, the roadmap's findings and recommendations present a balanced reflection of the priorities and concerns of environmental stakeholders, regulators, and the FOW industry.

Attendees of the technical workshops and/or one-to-one interviews	
British Helicopter Association (BHA)	North East Inshore Fisheries Conservation Authority (IFCA)
Civil Aviation Authority (CAA)	Northern Lighthouse Board
Community Inshore Fisheries Alliance (CIFA)	RSPB
Crown Estate Scotland	Scottish Fishermen's Federation (SFF)
European Subsea Cables Association (ESCA)	Scottish Regional Inshore Fisheries Group
Historic England	Sea Mammal Research Unit (SMRU)
Joint Nature Conservation Committee (JNCC)	Simply Blue
Marine Management Organisation (MMO)	St Abbs Marine Station
Marine Scotland - Licensing Operations Team (MS-LOT)	The Crown Estate
Marine Scotland Science (MSS)	The Planning Inspectorate (PINS) / BEIS
Maritime and Coastguard Agency	The Wildlife Trust
Natural England	Trinity House
Natural Resource Wales (NRW)	Wales Marine Fisheries Advisory Group
NatureScot	Welsh Government – Marine Planning & Licensing

Table 3: Stakeholder Overview

3 FLOATING OFFSHORE WIND ENVIRONMENTAL INTERACTIONS ROADMAP

Informed by the outcomes of the Environmental Review and Technical Engagement processes, a Floating Offshore Wind Environmental Interactions Roadmap was developed in order to outline the key knowledge gaps and areas of uncertainty associated with the specific environmental interactions of FOW technology. Additionally, the roadmap presents a series of recommendations for further research and activities specifically intended to address the identified knowledge gaps. This section of the report sets out the public findings and recommendations of the Floating Offshore Wind Environmental Interactions Roadmap.

The outcomes from the Environmental Review and Technical Engagement processes were also used to support a prioritisation exercise for the identified interactions. The prioritisation of an interaction reflects a number of considerations, including:

- The extent to which an interaction is unique to FOW, or has particular nuances that require careful consideration in the case of FOW developments;
- The potential impact of an interaction's occurrence;
- The perceived likelihood of its potential occurrence;
- The ability of key stakeholders to intervene to mitigate the associated challenges or exploit an opportunity.

Recognising the subjective aspects of this rating process, draft ratings were reviewed by the project team and FOW CoE Industry Partners to provide a level of validation or, where applicable, to provide an opportunity for independent challenge. The priority rating scale is defined in Table 4.

Priority	Explanation
Low	Indicates a general consensus that, although the interaction may still require some further work, there is no immediate requirement to investigate further.
Medium	Indicates a broader range of views obtained throughout the project, with at least some stakeholders believing that further investigation is required.
High	Indicates a general consensus that the interaction should be investigated further.

Table 4: Interaction Priority Scale

To ensure that public outcomes from this project are appropriately focused, this public summary report concentrates on the interactions that were deemed to constitute a more pressing case for collective industry attention, as informed by the outcomes of the prioritisation exercise. The full, confidential report delivered to the FOW CoE partners documents a complete overview of all interactions identified and reviewed during the course of the project.

In order to help provide structure to the recommendations within the report, potential actions to help address an evidence gap are categorised as follows:

Recommended Action Category	Explanation
Environmental Science	Addressing knowledge gaps through application of environmental science.
Technical Innovation	Technological solutions, such as advancements in environmental monitoring.
Policy	Broader enabling actions.

Table 5: Recommended Action Categories

With the above considerations in mind, Tables 6 to 15 present a summary of the following key themes that were identified during the development of the Floating Offshore Wind Environmental Interactions Roadmap:

- Aviation Safety
- Colocation and Coexistence
- Cumulative Impacts
- Electromagnetic Fields (EMF)
- Fisheries Access
- Habitats Regulations Assessment
- Navigational Risk
- Ornithology
- Skills Gaps
- Underwater Noise

Theme / Knowledge Gap	Aviation Safety
Receptor	Other Sea Users / Aviators
Background	As is the case with maritime navigational risk, there are potential knowledge gaps associated with the specific implications of FOW technology on aviation safety. Further investigation is required in order to determine the possible impacts of FOW arrays on aviation radar systems, as well as the implications on aviation safety, such as the requirements for Search and Rescue (SAR) access.
Recommendations	Further investigation is required in order to determine the nature and extent of potential radar interference effects generated by FOW arrays. The implications on the radar systems used for air traffic control is an existing consideration for bottom-fixed offshore wind farms, as it is understood that the movement of turbine rotors can act to mimic low-level aircraft activity. However, it is currently unclear whether the specific characteristics of FOW technology, in particular the heave and roll motions of FOW turbines, might alter these impacts to any meaningful extent. An analysis of this issue, factoring in engagement with subject matter experts (recognising the highly technical and specialist nature of this issue), is therefore recommended. Where relevant, modelling and/or simulations may be undertaken to determine more precisely the nature of any anticipated radar and/or aviation navigation issues specific to FOW technology. Potential mitigations, where required, should also be considered and explored. Much like conventional bottom-fixed offshore wind, FOW arrays will be subject to the same requirements for SAR access – or 'safe lanes'. Given the typical distances anticipated between tethered FOW turbines, it is not expected that compliance with the requirement for SAR access will be problematic for FOW projects. Nonetheless, a review of this issue informed by subject matter experts in the field of offshore (rotary) aviation, as well as relevant SAR bodies, would be beneficial in confirming these assumptions. This review should consider (but not be limited to) the specific interactions between O&G and FOW arrays Pending the outcomes of the above actions, opportunities should be explored for updating exiting industry guidance on Aviation Safety for offshore wind to reflect any nuances associated with FOW. This may include recognition of, where applicable, the implications on obstacle notifications and aircraft obstacle lighting, associated with the Air Navigation Order (2021) and wider associated regulations and policy. NB At the time of writing, the FOW CoE is launching a new project investigating the implications of future commercial FOW developments on navigational planning and risk assessment (both maritime and aviation). A summary of the findings and recommendations from this work will be made publicly available in due course.
Summary of Recommended Actions	Policy: • An analysis of the potential effects of FOW on aviation radar systems, supported by engagement with relevant subject matter experts; • Assess opportunities to update / refine industry guidance on aviation safety for offshore wind to reflect the nuances associated with FOW. Technical Innovation: • Completion of modelling and/or simulation activity (informed by aviation subject matter experts) to characterise FOW effects on radar and identify potential mitigation measures.

Table 6: Aviation Safety

Theme / Knowledge Gap	Colocation and Coexistence
Receptor	Other Sea Users / Commercial Fisheries
Background	There is currently a limited general understanding of how FOW projects can be co-located with other industries, including commercial fisheries (see Table 10) and oil and gas (O&G) assets.
Recommendations	At a strategic level, a targeted analysis of recent, current and forthcoming consent applications (UK-wide), as well as the respective responses from consultees and relevant stakeholders, would be beneficial. In relation specifically to O&G colocation, collaboration with industry players with experience in both O&G and emerging FOW would be beneficial to understand this issue further; this could include entities such as the DeepWind (Scotland) Cluster, which is made up in a large part by O&G organisations (Offshore Wind Scotland, 2022). In Scotland, Crown Estate Scotland lease the seabed for the development of offshore wind, among other marine activities. The Innovation and Targeted Oil and Gas (INTOG) leasing round is a process by which developers will be able to apply for the rights to build offshore wind farms specifically for the purpose of providing low carbon electricity to power oil and gas installations and help to decarbonise the sector. Given the water depths found within the areas of the sea under consideration for the INTOG leasing round, FOW technology is expected to be deployed at future INTOG project. A close watching brief on this process is recommended to help understand potential challenges associated with coexistence and colocation. Further specific liaison with Crown Estate Scotland is also encouraged to advance understanding around this topic. One of the key potential evidence gaps in this broad topic is related to coexistence with commercial fisheries (i.e., understanding the implications of commercial-scale FOW for fishers, and how they differ over and above those impacts associated with conventional, fixed bottom offshore wind). Collaborative engagement with key relevant organisations, such as the bodies involved in this roadmap, is therefore recommended. Further discussion regarding fisheries access is included in Table 10.
Summary of Recommended Actions	Environmental Science: • Completion of a strategic analysis of recent, current and forthcoming consent applications (including stakeholder representations). Policy: • Collaboration with key stakeholders (including commercial fisheries and the O&G industry) particularly related to organisations committed to / actively involved in FOW transition work; • Engagement with seabed leasing authorities to further advance understanding of topic-specific coexistence issues.

Table 7: Colocation and Coexistence

Theme / Knowledge Gap	Cumulative Impacts
Receptor	Various
Background	The understanding of cumulative and in-combination impacts is relatively well developed in relation to conventional bottom-fixed offshore wind, and according to the input secured during the stakeholder engagement process, the equivalent effects from FOW are expected to be comparable. However, there is currently a potential lack of data associated with the different cumulative effects of multiple FOW farms on various receptors, and so further work is required to corroborate these assumptions. It is anticipated that distance from shore will be an important factor when determining cumulative and in-combination effects.
Recommendations	A receptor-by-receptor review would support a stronger understanding of whether the discreet differences in FOW technology would lead to a difference in cumulative or in-combination impacts on any key receptor, relative to bottom-fixed wind. A cumulative impact assessment must ensure that scoping takes place with clear boundaries, outlined at the earliest possible opportunity. There is a wealth of evidence associated with this process from Scottish, Welsh and English marine consenting. Effective data sharing would therefore be key to this review, and it should be considered how the outcomes might influence mitigation and monitoring plans for FOW farms. It should also be recognised during the course of the review that receptor-specific considerations will vary in practice from project to project. In addition to the receptor-specific considerations, targeted engagement with key decision makers relevant to FOW development on the subject of cumulative and in-combination associated with FOW is recommended.
Summary of Recommended Actions	Environmental Science: • Targeted assessment of potential FOW cumulative and in-combination impacts on a receptor-by-receptor basis. Policy: • Engagement with key decision makers to understand and strategically address emerging cumulative and in-combination challenges.

Table 8: Cumulative Impacts

Theme / Knowledge Gap	Electromagnetic Fields (EMF)
Receptor	Various
Background	EMF is recognised as a key area of interest, and a potential evidence gap, across the offshore wind and wider power transmission industry. There are however potential evidence gaps concerning how FOW-specific features (such as dynamic cables in the water column, or free and partially buried cables) interact with the marine environment. There is an emerging body of new research within a laboratory setting and, albeit to a lesser extent, the field environment associated with EMF effects arising from electricity transmission. Some of this research indicates measurable effects and responses to EMF on a small number of individual species, however it is not considered appropriate to apply these findings wholesale to advance the wider understanding of potential EMF effects from FOW.
Recommendations	Currently, conclusive evidence is insufficient and additional knowledge about receptor species' (both benthic and pelagic, and at different life stages) exposure to different EMFs (i.e. sources, intensities), and the determination of the EMF environment, is needed. It is anticipated that for FOW arrays, the use of suspended, dynamic inter-array cables (rather than static cables that run solely along the seafloor) may increase the scope of anthropogenic EMFs in the water column and potentially interact with a greater diversity and abundance of marine organisms. However, it is also recognised any effects of EMFs resulting from inter-array cables may be less than those from export cables due to the lower capacities involved. In-situ monitoring of FOW inter-array dynamic cables would be valuable to addressing this knowledge gap and substantiating any current predictions. Owing to the diverse range of commercial entities involved in the suite of forthcoming FOW projects, it is recognised that there may be commercial, governance and coordination challenges; the experience of bodies involved in existing data coordination, such as those involved in the development of this roadmap, would be highly beneficial. In order to deliver maximum value, it would be key that any such monitoring would be developed in conjunction with key specialist advisers, such as those who provided technical input to this roadmap (in particular, SAMS, Cefas, St Abbs Marine Station and MSS). It is also recognised that a number of organisations are currently exploring EMF on an individual technology or sector-specific basis, and there is a range of ongoing laboratory and field studies focused on fisheries and shellfisheries. Further, while this roadmap has a UK focus, it should not be overlooked that there is a body of research emerging on an international level. From a strategic perspective, a detailed review of the latest activities should therefore be performed before any further work is undertaken, as a minimum to avoid duplication, but also to identify potential synergies and collaboration opportunities; there is an opportunity for industry to work together and align existing workstreams in order to address this evidence gap, but this must be delivered in a coordinated manner in order to provide maximum impact.
Summary of Recommended Actions	Environmental Science: • A comprehensive review of current and emerging evidence resulting from the latest research undertaken by regulatory, governmental, non-governmental and commercial research organisations, supported by developers within the FOW industry; • In-situ monitoring within operational FOW arrays, the scope of which would be informed and guided by the outcomes of the review of the latest evidence. Policy: • Collaboration with wider industry actions in the UK, and elsewhere, to ensure maximisation of efficiencies in tackling industry-wide knowledge gaps (recognising the prominence of this topic across industries, including power transmission, interconnectors and conventional offshore wind etc.).

Table 9: Electromagnetic Fields

Theme / Knowledge Gap	Fisheries Access
Receptor	Commercial Fisheries
Background	The more complex subsea infrastructure of FOW farms (relative to bottom-fixed offshore wind) and the ability of FOW technology to access greater areas of the sea with deeper waters (beyond the reach of bottom-fixed wind) raises additional considerations regarding potential interactions with commercial fisheries.
Recommendations	Fundamentally, the question of fisheries interactions applies to both FOW and bottom-fixed wind developments, however further work is required to determine the extent to which this issue varies between the two technologies. At a strategic level, there is a need for Marine Spatial Planning to be cognisant of the forthcoming growth in FOW around the UK, and the implications on fisheries interactions. While this is already in motion in Scotland (notably through the role of the Sectoral Marine Plan for Offshore Wind in informing the ScotWind leasing process), it will need to be applied appropriately throughout the other UK jurisdictions. The body of evidence associated with the consenting of operational pilot FOW farms in Scotland would provide valuable insights in this regard. At a project level, the projected growth of the FOW industry, and the pressures that this will place on the established fishing sector, only increases the importance of early stakeholder engagement. Further, it should be considered whether 'traditional' engagement approach with inshore fisheries bodies and dockside one-to-one engagement would be appropriate for FOW developments; given the greater distances from shore, detailed engagement with the larger fleet (which are more likely to target the fishing grounds potentially impacted by FOW developments) may be required, and strategic guidance on the most appropriate approach to this would be beneficial. NB The FOW CoE has developed a range of further recommendations in relation to the topic of fisheries access. These are summarised in the existing 'Floating Offshore Wind and Fishing Interaction Roadmap' (ORE Catapult, 2021), and its recommendations should be considered in parallel with those set out in this roadmap.
Summary of Recommended Actions	Environmental Science: • A review of existing FOW consenting to help understand potential access and displacement issues for FOW (appreciating the limitations due to differing scales of demonstrator vs commercial scale sites); • Delivery of the environmental research recommendations outlined in the Floating Offshore Wind and Fishing Interaction Roadmap (e.g. a review of current research and support for the development of relevant monitoring studies within early commercial FOW farms to investigate potential impacts on commercial fish stocks). Technical Innovation: • Delivery of the technical investigations / appraisals, outlined in the Floating Offshore Wind and Fishing Interaction Roadmap (e.g. a feasibility assessment of fishing-friendly array layout designs; an entanglement risk assessment of mobile fishing gear and FOW subsea infrastructure etc.). Policy: • Bodies responsible for marine spatial planning to be cognisant of forthcoming growth of FOW, and to ensure this is adequately factored in across jurisdictions; • A sectoral position setting out guidance on robust engagement across the UK jurisdictions would be advantageous.

Table 10: Fisheries Access

Theme / Knowledge Gap	Habitats Regulations Assessment (HRA)
Receptor	Various
Background	Some concerns have been highlighted within the regulatory community around the limited HRA precedent for FOW (largely linked to the greater distances offshore typically associated with commercial scale FOW). As with bottom-fixed offshore wind, a plan-level HRA is required in support of future seabed leasing. This level of HRA must be undertaken to assess the potential impacts from offshore wind on legally protected habitats and species of importance which form part of the UK national site network. This must be undertaken before seabed rights for development are awarded, recognising that there are also project specific HRA requirements in support of individual consents. While the broad process for undertaking HRA is well understood, and there are considered to be limited FOW-specific issues in terms of process, it is possible there may be some additional uncertainties associated with FOW that the plan-level HRA must consider and accommodate.
Recommendations	At a technical receptor level, the increasing distances further offshore may lead to different impacts associated with both the UK national site network, but also further afield (i.e., Mainland and additional European Marine Sites). With this in mind, targeted engagement between respective conservation authorities (i.e., NatureScot, Natural England, NRW and their European counterparts) regarding the HRA considerations of FOW technology would be valuable. Recognising that during the consenting process for commercial FOW farms, the determining authorities will draw on the available data at the time of their decision(s) (consistent with recent precedent, such as ScotWind (Scottish Ministers, 2020)), and that receptor-specific considerations will vary from project to project, it is nevertheless recommended that the emerging body of evidence associated with HRA at a project-level be continually reviewed to help inform the future decision making undertaken by competent authorities on plan-level HRA.
Summary of Recommended Actions	Policy: • Ongoing and targeted engagement between respective conservation authorities regarding FOW-specific HRA considerations; Environmental Science: • Ongoing coordinated review of the emerging body of evidence associated with project-level HRA for commercial FOW developments.

Table 11: Habitats Regulations Assessment

Theme / Knowledge Gap	Navigational Risk
Receptor	Other Sea Users / Shipping and navigation
Background	There are potential knowledge gaps associated with understanding how FOW differs from bottom-fixed offshore wind with regards to navigational risk. Further work is required to determine the implications on marine safety of a number of FOW technology's characteristics, including: the larger seabed footprints of FOW turbines; the more complex subsea infrastructure; inshore wet storage operations; and the potential for tow-to-port operations for heavy maintenance and major repairs.
Recommendations	A review of FOW-specific considerations in respect of the UK Navigational Risk Assessment (NRA) process would support a stronger understanding of the nuances between FOW and bottom-fixed wind technology. This should take into account the existing precedent for consenting conventional bottom-fixed projects alongside the experience from more recent pilot scale FOW developments. This process should also be supplemented by detailed engagement with the relevant navigational bodies around the UK in order to seek a position of consensus. Key considerations would include the impacts on navigational risk of FOW dynamic cable and mooring configurations, as well as anchor technologies, the potential size and location (i.e. increased distance offshore) of future commercial FOW arrays, FOW-specific marine operations including tow-to-port activities and the inshore wet storage of turbines during (both the development and operational phases), and the potential implications on lighting and demarcation requirements for FOW farms. Pending the outcomes of the actions above, opportunities should be explored for updating exiting industry guidance on Navigational Safety for offshore wind to reflect the nuances associated with FOW. This may include formal documents, such as Marine Guidance Note (MGN) 654 (MCA, 2021), MGN 372 (MCA, 2008) and the Maritime & Coastguard Agency (MCA) 'Methodology for Assessing the Marine Navigational Safety Risks & Emergency Response of Offshore Renewable Energy Installations' (MCA, 2021). NB At the time of writing, the FOW CoE is launching a new project investigating the implications of future commercial FOW developments on navigational planning and risk assessment (both maritime and aviation). A summary of the findings and recommendations from this work will be made publicly available in due course.
Summary of Recommended Actions	Policy: • A review of UK NRA precedent for conventional offshore wind alongside more recent pilot scale FOW consenting; • Assess opportunities to update / refine of industry guidance on Navigational Safety for offshore to reflect nuances associated with FOW.

Table 12: Navigational Risk

Theme / Knowledge Gap	Ornithological Considerations
Receptor	Ornithology
Background	Considerations of the effects of offshore wind development on bird ecology are not unique to FOW technology. However, there are certain characteristics of FOW developments that would benefit from further attention in order to address any existing uncertainty. One particular distinction relates to the question of barrier effects, whereby the presence of a wind farm forms a barrier, forcing species around the site and disconnecting ecological units. Typically these effects are considered in respect of roosting or feeding sites, however there is some uncertainty with regards to the installation of FOW technology in deeper waters further offshore, and whether this will have any significant implications on bird migratory routes (rather than potential disruption associated with deployment further inshore). Further, there is uncertainty with regards to the impact of FOW turbine heave and roll motions on the blade tip clearance between a turbine's rotor system and the water level. Offshore wind farms are required to have a minimum blade tip clearance in order to avoid the principal travel corridors for seabirds, but further clarity is required with regards to the design process for FOW farms in this regard. It is also currently unclear whether the increased distance from shore will present increased challenges for establishing ornithological baselines during the EIA process for future commercial FOW farms. The development of ornithological baselines is increasingly achieved using plane-based techniques from a relatively small series of UK suppliers, rather than traditional boat-based spotter techniques. Whilst this is not the default position for all developments, there is a need to understand how – if at all – survey effort is impacted further offshore. For example, where flight logistics mean there is reduced time on target, how does this impact survey quality/confidence? Similarly, are there specific populations, such as migratory birds, which are more challenging to identify and define further offshore? An additional consideration relates to current evidence gaps concerning the potential attraction of birds to floating sub-structures for resting/roosting. It is not currently understood the extent to which this is a factor, and how – if at all – this influences collision risk with turbine blades.
Recommendations	Subject matter experts with relevant ornithological expertise on offshore distribution should be engaged to appraise the questions of barrier effects and attraction in further detail, alongside ornithological specialist advisers to the regulatory community. This process should seek to explore the emerging range of ornithological evidence further offshore from survey effort in other industries (for example, the increasing body of ornithological evidence associated with decommissioning of North Sea O&G assets). Where specific data gaps are identified, it should be considered whether these could be addressed through targeted monitoring studies, potentially undertaken at pilot scale and early commercial FOW farms. Further, subject matter experts with relevant ornithological expertise on offshore bird surveys should be engaged, alongside ornithological specialist advisers to the regulatory community, to identify and assess any challenges related to the development of FOW farms at unprecedented distances from shore. Where innovation needs are identified, these should be addressed through targeted research and development activities.
Summary of Recommended Actions	Environmental Science: • Engagement with subject matter experts and ornithological specialist advisers to the regulatory community to appraise the questions of potential barrier and attraction effects in relation to FOW developments; • Where data gaps are identified, the potential for monitoring studies within pilot and early commercial FOW farms should be explored. Technical innovation: • An assessment of the technical challenges and innovation requirements in respect of ornithology surveys far from shore; • Where innovation requirements are identified, these should be supported with targeted research and development.

Table 13: Ornithological Considerations

Theme / Knowledge Gap	Skills Gaps
Receptor	Socioeconomic
Background	As FOW is a nascent industry, there may be skills gaps in key aspects of FOW development, including the environmental assessment and consenting process. This may be a challenge both within the regulatory community (i.e. in terms of ensuring that regulators are able to secure well-resourced teams with the skills and knowledge required to facilitate the consenting of commercial FOW farms), but potentially also, if not to a lesser extent, for wind farm developers (i.e. ensuring that staff have the relevant environmental and consenting expertise to support development). A key consideration for developers will involve supporting the transition of, and reskilling, personnel from other industries, such as bottom-fixed wind and O&G. It is also recognised that the FOW industry is anticipated to commercialise at an accelerated rate compared to the bottom-fixed wind sector (which matured more gradually over a number of decades), thereby placing greater pressure on regulators and developers.
Recommendations	Proactive engagement with the regulatory community across the key jurisdictions should be undertaken to understand what the key uncertainties and/or skills gaps actually are, thus informing onward actions. Stakeholder feedback highlighted the range of experience across jurisdictions; at the time of writing, Scotland has the experience of consenting two FOW projects, while in England and Wales, there is only emerging equivalent experience. Utilising and enhancing the existing strategic links between regulators could therefore help to share this experience more proactively. The development of guidance and outreach resources would help to capture existing experience from mature consenting processes in order to support an efficient FOW development process, while at the same time advocating the FOW sector's case to regulators and stakeholders. Involvement with the relevant professional bodies throughout this process would enhance the credibility of these materials and help to underpin their impact. Cross-industry professional development opportunities would complement these objectives; examples of this approach include the major infrastructure projects Thames Tideway Tunnel and Sizewell C, as well as the X-Academy transition skills initiative, led by Xodus with support from bp and EnBW. In the longer-term, industry collaboration with the educational system now would support the development of the appropriate skills required to meet the demands of the offshore wind installation targets over the course of the next decade, and beyond. NB The skills gaps issue was highlighted during the FOW CoE's project: FOW Development and Consenting Process – Risks and Opportunities. Further discussion is available in that project's public summary report.
Summary of Recommended Actions	Policy: • Detailed discussions with the regulatory community across the key jurisdictions to help inform onward actions; • Exploitation and enhancement of strategic links between jurisdictions to help share lessons-learned for FOW consenting, now and in the future; • Investment in sectoral training materials (or similar) and drawing on approaches noted above surrounding upskilling to meet FOW-specific challenges; • Collaboration with the educational system to develop the skills of a future workforce.

Table 14: Skills Gaps

Theme / Knowledge Gap	Underwater Noise
Receptor	Marine mammals / fish ecology / commercial fisheries
Background	FOW technology is anticipated to have a different noise profile relative to bottom-fixed wind, during both the construction and operational phases. However, evidence gaps still exist that will need to be addressed in order to confirm both the nature and extent of these differences. Further work is required to understand the installation noise associated with different anchor types, as well as the noise emitted from the mooring and dynamic cable systems of commercial scale FOW arrays. It is also unclear whether Unexploded Ordnance (UXO) may be a greater or lesser risk in the deeper water sites more suited to FOW.
Recommendations	Further investigation is required to address current evidence gaps related to construction and operational underwater noise associated with FOW projects, and also how deeper water deployment may influence impact significance. The level of noise emitted during the installation of a FOW farm will likely be specific to the anchor type selected for the turbine mooring systems, as well as the local conditions. The majority of anchor types are expected to be less noisy to install than bottom-fixed monopile foundations. An analysis of the underwater noise levels associated with the installation of a range of FOW anchor types – and a subsequent comparison against the noise emissions from conventional monopile foundation installations – would be beneficial in confirming these assumptions. This analysis may be informed by underwater noise assessments for pilot-scale deployment, acknowledging that there may be a need to exercise caution when extrapolating conclusions (considering project-specific differences such as seabed conditions, water depth, piling methodologies and array size). It should also be considered whether analogues can be drawn using existing data from other comparable operations, such as the O&G industry, and even other marine renewable energy sectors (e.g. floating wave and tidal). During the operational phase, there is the potential for FOW to have unique distinctive noise sources compared to bottom-fixed wind. These sources may be associated with cable 'thrums' and/or 'snapping' effects resulting from dynamic cables suspended within the water column, and potentially also noise resulting from mooring line dynamics. A more detailed analysis into the nature and extent of these additional noise sources would help to address the current associated knowledge gaps. Where possible, in-situ testing at pilot-scale and early commercial FOW farms – such as the initial investigations carried out by the FORTUNE (Floating Offshore Wind Turbine Noise) project – would accelerate the industry's understanding around this topic. Again, it should be considered whether existing data from other industries would support this exercise. Aside from installation and operational noise, it is currently unclear whether UXO may present a different level of risk in the deeper water sites better suited to FOW deployment. The impact of water depth on sound propagation is largely well understood, and it can generally be expected that UXO may require disposal in deeper waters. However, it is less well understood whether the larger footprints and more complex subsea infrastructure of FOW projects (including the greater level of seabed interactions that is likely to be associated with this), could potentially require a different scale and frequency of UXO disposals compared to conventional wind farms with fixed monopile foundations of smaller footprints. Further investigation exploring this issue, factoring in insights from subject matter experts in UXO and sound propagation, would help to reduce current uncertainty.
Summary of Recommended Actions	Environmental Science: • A review of FOW-specific UXO disposal characteristics and/or potential issues, alongside insights from subject matter experts in UXO and sound propagation; • An analysis underwater noise levels produced during installation and operation of a FOW array. Existing projects in the industry can be used to support this exercise, such as the FORTUNE project which aims to obtain systematic, long-term measurements of underwater noise generated by FOW turbines; where relevant and possible, this analysis would be supported by in-situ monitoring during both construction and operation within pilot scale and early commercial FOW farms.

Table 15: Underwater Noise

4 CONCLUSIONS AND NEXT STEPS

This first phase of the Floating Offshore Wind (FOW) Environmental Interactions project has supported the development of a roadmap that identifies and prioritises a series of knowledge gaps associated with the environmental interactions of FOW technology, and proposes a range of further activities and research to address them.

The development of the FOW Environmental Interactions Roadmap has been informed by a comprehensive literature review, as well as the findings from recent and emerging research, and an extensive stakeholder engagement exercise resulting in a range of specialist technical feedback. The priority knowledge gaps, and corresponding recommendations, identified during the course of this process are outlined in this public summary report.

The UK Government has set ambitious targets associated with climate change and decarbonisation, including achieving Net Zero by 2050; FOW has an important role to play in meeting this target, as reflected by the UK Government's most recent target of up to 5GW of this technology by 2030. Underpinning the marine consenting process is a robust assessment of environmental impacts; on this basis, it is considered vital that the current knowledge gaps associated with FOW environmental interactions be managed proactively, including – where appropriate – through industry actions. Ultimately, the actions identified by the Floating Offshore Wind Environmental Interactions Roadmap can be summarised as follows.

Environmental Science
It will be critical to harness the scientific knowledge from existing (operational) pilot-scale FOW projects, as well as data from other industries where appropriate. Whilst the sector will need to be cognisant of limitations to such resources, this scientific data and knowledge may form an important part of the answer in responding to the evidence gaps identified. Recognising the highly technical nature of some of the key potential knowledge gaps identified, subject matter experts with specialist expertise should be engaged to help provide insight into where limitations lie, and how they can be mitigated.

Technical Innovation
In addition to supporting environmental science initiatives, it is expected that in the case of some interactions, technical innovation will play a role in addressing the current knowledge gaps and areas of uncertainty. In some instances, this may involve supporting the development of innovative environmental monitoring technologies and methodologies, while in other cases technical innovation may have a role to play in developing mitigations to any risks associated with FOW environmental interactions, as well as exploiting potential opportunities.

Policy
Various wider enabling actions are also required which – in many cases – are likely to be optimally delivered alongside the completion of environmental science and technical innovation actions noted above. In several cases, to maximise the value of the actions proposed to address a particular evidence gap, it is anticipated that targeted industry engagement, dissemination or onward discussion will be beneficial.

In order to achieve tangible progress associated with the findings of this report, it will be vital for the FOW industry to take proactive action. In order to support the delivery of the next phases of this project, the FOW CoE is launching an Environmental Interactions Strategic Programme, which will serve as the delivery framework for the further activities and research identified in this roadmap.

From the outset of the FOW Environmental Interactions Roadmap project, efforts have been made to ensure maximum alignment with the multitude of activity ongoing within the offshore wind and wider power sector. As the actions detailed within the roadmap are considered in further detail and taken forward with the direction of ORE Catapult, it will be crucial to continue in a coordinated manner across industry.

Through the timely delivery of actions to address the gaps identified by this report, there is a real opportunity to help reduce the risks associated with the development and consenting process for Floating Offshore Wind development, in turn helping to harness the potential for this sector in the UK. The FOW CoE would like to extend its gratitude to the stakeholders and individuals involved in the project, without whom the development of the roadmap would not be possible.

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CONTACT US

info@ore.catapult.org.uk

ore.catapult.org.uk

ENGAGE WITH US

FLOATING OFFSHORE WIND CENTRE OF EXCELLENCE

ORE Catapult
Inovo
121 George Street
Glasgow
G1 1RD

T +44 (0)333 004 1400