Impacts of Floating Offshore Wind: Planning for a Sustainable Source of Energy

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Cover: Marine biologist performing fish monitoring on the Biohut nature-inclusive design (NID) of the EFG1 WindFloat. Copyright Ecocean/Remy Dubas.

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Acknowledgments

WFO's 100+ members represent the entire offshore wind value chain including but not limited to utility companies, developers, manufacturers, service firms, consultancies and other non-profit organisations.

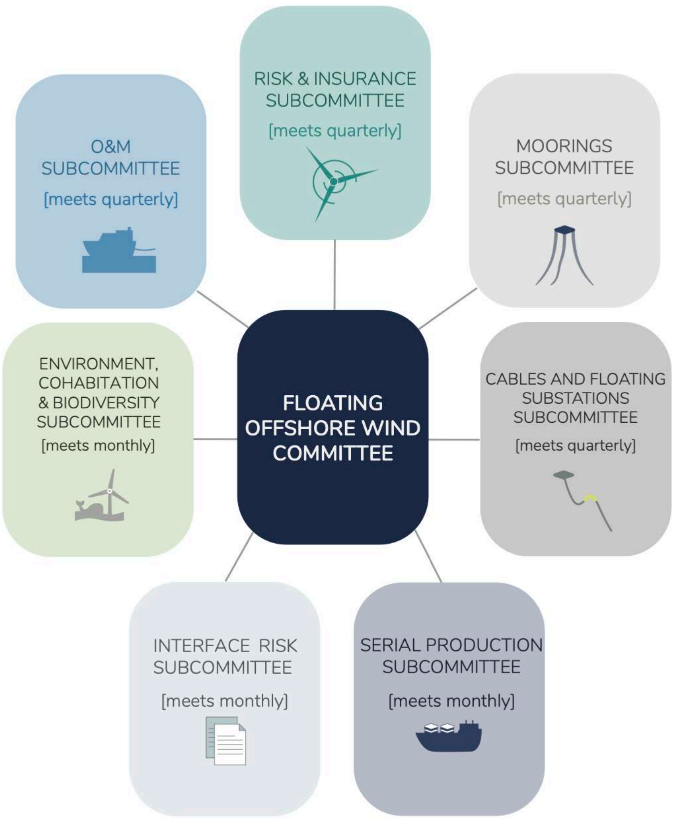
This document is the result of two years' worth of monthly discussions between participating WFO members during meetings of WFO's Floating Offshore Wind Committee on the environmental impact of floating wind. WFO would like to thank everyone who has contributed their time and expertise during the discussions. An internal literature review was run in parallel.

A special thank you to the Chairs of the ECB Subcommittee who have guided these valuable discussions: Roland Teixeira de Mattos, EOPSA; Jean-Philippe Pagot, EDF Power Solutions; Brian McGrellis, Nadara; Tania Moreira, Masdar; Roeland De Rycker, DEME.

Disclaimer

The views in this report do not necessarily represent the views of all WFO members but are based on a synthesis of recorded insights undertaken by the WFO Environment, Cohabitation & Biodiversity Subcommittee over the last couple of years. The findings are also designed to serve as a general account of the status of floating offshore wind's environmental impact, related challenges and opportunities, and therefore are subject to evolve along with the industry.

Structure of the Floating Offshore Wind Committee



Summary

Understanding the environmental impact of floating offshore wind is critical at this stage of the industry's development to ensure that is commercializes sustainably. WFO's Floating Offshore Wind Environment, Biodiversity & Cohabitation Subcommittee has spent the last two years discussing known and expected impacts as well as associated mitigation measures across three main themes: lifecycle carbon emissions, marine biodiversity (various species, habitats, wider ecosystems), and commercial fishing.

With over a hundred floater concepts on the market, it is not straightforward to estimate floating wind's carbon footprint. This is because the fabrication stage is the hotspot for carbon emissions, where material extraction and component fabrication are intrinsic to the floater design. As a result, floater designers are conducting lifecycle assessments (LCA) to provide transparency on their technology's anticipated footprint and enhance their competitiveness. Innovation in materials (concrete, steel, hybrid or other) is an important part of the discussion to improve not only reliability but also environmental performance. Ultimately, the main takeaway is that offshore wind contributes to 8-32 gCO2e/kWh and is one of the lowest carbon emitting sources of energy production. While floating wind is considered to emit in this same range or slightly more than bottom-fixed wind, it is important to weigh these values against our other options for energy production in the context of the climate and biodiversity crises as well as security of supply.

Although FOWTs share similar impacts to bottom-fixed offshore wind (e.g. risks to avifauna, seabed disturbance from export cable installation), the anchors, moorings and dynamic cables create unique interactions at the seabed and in the water column. For example, more compliant FOWTs may have sweeping mooring lines from platform excursion that create a continuous disturbance to benthic habitats in addition to their installation; mooring lines and free-hanging dynamic cables can potentially cause primary or secondary marine mammal entanglement; operational noise from turbine vibrations as well as EMFs from the dynamic cables need to be studied further in comparison to bottom-fixed wind technology. Finally, bio-colonisation and attraction of life at the floater, mooring lines and anchors can have more spatially distributed ecosystem effects, especially in deeper waters.

Continuous, high-resolution and multi-parameter monitoring across longer time frames are needed to confirm the "positive" impact of FOWTs acting as artificial habitats for marine life. Results from the demonstrators and pilots are promising, but these are still preliminary and hence cannot be extrapolated to larger-scale floating wind farms. The initial findings are nonetheless foundational to our understanding of floating wind's impacts and the effectiveness of mitigation measures. Pilot projects are notably valuable testing grounds for novel monitoring methods (e.g. eDNA, AI-supported data analysis) as well as nature-inclusive design approaches (e.g. artificial nurseries, more environmentally friendly materials), which need validation before being widely adopted.

Floating wind's impact on commercial fishing cannot be understated. The spatial footprint of the turbine, station-keeping system and dynamic cables are expected to restrict allowable fishing areas more than in bottom-fixed wind farms. Across the world, the fishing community is concerned with how their activity will be affected. Unfortunately, the early stage of our

industry makes it difficult to quantify and communicate expected impacts, as these depend on the floater and mooring system design, which at the moment are not yet commercially deployed or standardised technologies.

Despite the many unknowns, innovations to improve technology performance and lower cost can also support biodiversity or coexistence with fishing: larger WTGs, smaller mooring footprints and strategic array configurations can increase the allowable area for fishing to continue; taut mooring systems can also minimise seabed contact that damages benthic habitats; innovative installation and O&M activities (e.g. onsite major component replacement) can reduce the number of vessel trips; innovative components can lower carbon footprint or attract marine life. The requirements for engineering robustness and cost competitiveness are thus not at odds with environmental sustainability. A holistic approach is key to ensuring that these issues are all balanced in a project's final design.

Finally, tackling the environmental impact of floating wind is a microcosm of the challenge our human societies face in understanding complex marine ecosystems and managing their services. Therefore, this paper synthesizes the relevant issues on regulation, spatial planning and environmental research to support the sustainable growth of our sector.

There is a unique opportunity at this stage of our industry, where large-scale projects are in early development or waiting to tender, to *avoid* negative impacts as much as possible. This can be achieved with MSP-informed site selection that maximises coexistence with the fishing industry and ecologically sensitive areas, amongst other aspects. It can also be supported by tender requirements that incentivise the incorporation of mitigation measures in project design. As for the projects already in the development phase, there is a chance to take advantage of early-stage design flexibility to *minimise* environmental impacts and consenting risks. Meaningful stakeholder engagement – with the fishing industry, scientists, coastal communities and more – is essential throughout these processes to develop effective, evidence-based mitigation measures.

Acronyms

AI - Artificial Intelligence
BACI - Before–After–Control–Impact
CAPEX - Capital Expenditure
CO_2 - Carbon Dioxide
CO_2e - Carbon Dioxide Equivalent
ECB Subcommittee - Environment, Cohabitation and Biodiversity Subcommittee
eDNA - Environmental DNA
EFGL - Éoliennes Flottantes du Golfe du Lion (floating wind pilot project in France)
EIA - Environmental Impact Assessment
EIS - Environmental Impact Statement
EMF - Electromagnetic Field
EoL - End of Life
ESIA - Environmental and Social Impact Assessment
FOW - Floating Offshore Wind
FOWC - Floating Offshore Wind Committee
FOWT - Floating Offshore Wind Turbine (comprising the floater, turbine, cable and station-keeping system)
GIS - Geographic Information System
LCA - Life Cycle Assessment, LCIA – Life Cycle Impact Assessment
LCI - Life Cycle Inventory
LCoE - Levelised Cost of Energy
MSP - Marine Spatial Planning
NID - Nature-Inclusive Design
O&M - Operations and Maintenance
OCEaN - Offshore Coalition for Energy and Nature
OEM - Original Equipment Manufacturer
OPEX - Operational Expenditure
R&D - Research and Development
ROV - Remotely Operated Vehicle
SDG - Sustainable Development Goal
SEA - Strategic Environmental Assessment
SOV - Service Operation Vessel
WTG - Wind Turbine Generator

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1 Introduction

1.1 Purpose of the White Paper

The expansion of floating offshore wind presents an unprecedented opportunity to accelerate the global transition to renewable energy. As the industry evolves in a world affected by climate change and biodiversity loss, balancing technological advancement with environmental responsibility is crucial to ensuring that floating offshore wind can contribute meaningfully to decarbonisation while minimising its ecological footprint.

This White Paper serves as the first comprehensive report by the Floating Wind Environmental, Cohabitation, and Biodiversity (ECB) Subcommittee. It consolidates key discussions, research findings, and strategic recommendations from the Subcommittee's work, aiming to provide industry stakeholders with an informed perspective on the observed but mainly anticipated environmental impacts of floating offshore wind. Through this document, we seek to:

- Identify critical environmental impacts, both positive and negative, in floating offshore wind deployment.
- Summarise research efforts and innovative strategies to minimise potential environmental impacts.
- Frame these impacts within the current industry context to highlight the challenges and recommendations to realising effective solutions.
- Promote collaboration between policymakers, industry leaders, and marine stakeholders for sustainable offshore wind expansion.

Beyond consolidating current knowledge, this paper aims to support a shift in how floating offshore wind is developed, moving from a model centred on optimised electricity production to one that actively minimises environmental impacts and enables coexistence with marine ecosystems and sea users. In doing so, it positions environmental performance as a core component of long-term project viability and industry credibility.

1.2 Overview of the Environment, Cohabitation and Biodiversity Subcommittee

The ECB Subcommittee was established to address the increasingly complex interface between floating offshore renewable energy development, marine ecosystems, and existing ocean uses. The group brings together experts from industry, academia, and environmental organisations to develop a shared understanding of ecological risks, opportunities, and best practices across the full lifecycle of floating offshore wind projects.

Through structured dialogue and continuous knowledge exchange, the ECB Subcommittee:

- Identifies key environmental indicators[1] and data gaps critical to informed decision-making.
- Facilitates alignment on impact assessment methodologies.
- Promotes the consideration of biodiversity enhancement in engineering and operational design.
- Supports the development of practical, science-based and collaborative solutions for coexistence with other marine sectors.

The Subcommittee also aims to align floating offshore wind projects with the United Nations Sustainable Development Goals (SDGs): SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 14 (Life Below Water). By quantifying the resource use and ecological and/or net climate impacts of a project, developers and policymakers can make informed decisions to optimise environmental outcomes while maintaining energy production efficiency.

Figure 1. Sustainable Development Goals, United Nations

The Subcommittee does not aim to produce regulatory guidance but rather synthesise pathways towards more sustainable floating offshore wind development based on research, innovation, and policy best practice.

1.3 Role of floating offshore wind

Floating offshore wind extends renewable energy generation capacity into deep-water environments previously inaccessible to bottom-fixed systems. This shift not only unlocks vast wind resources but also introduces new spatial and ecological dynamics. Floating wind farms interact with the marine environment through:

[1] *Quantitative or qualitative measures that provide information on the condition of the environment, human pressures, and the effectiveness of mitigation measures. In the context of floating offshore wind, environmental indicators are used to evaluate project impacts and track sustainability performance across the project lifecycle.*

- Surface and sub-surface structures that act as artificial habitats, their dynamic movement influencing habitat conditions.
- Water column and seabed interactions with mooring systems, anchors, and dynamic cables.

These characteristics create both risks and opportunities. On the one hand, floating wind developments may affect marine species distribution, navigational patterns and fishing activity. On the other, they have the potential to function as novel ecological substrates, contributing to habitat complexity and, under the right conditions, enhancing local biodiversity. Finally, the extraction of materials for the FOWTs and wider value chain activities have an impact. As such, projects under development must factor in:

- Minimising ecological disturbance.
- Minimising carbon footprint.
- Incorporating nature-inclusive design (NID) principles to support biodiversity.
- Enabling safe and equitable coexistence with fisheries, shipping, and other sea users.
- Contributing to long-term ecosystem resilience from project site identification to decommissioning.

The first two years of ECB Subcommittee meetings have shown that the industry is actively working to minimise the impact of floating wind on three specific areas: lifecycle carbon emissions, marine biodiversity (various species, habitats, wider ecosystems), and commercial fishing. The scope of this paper will therefore be restricted to these themes. While the relative importance of each impact is highly project-specific, this thematic grouping helps clarify the necessary policy and R&D efforts for the future commercial-scale (+250 MW) projects.

Other important themes like the environmental impacts of decommissioning, which represent a larger research gap in the offshore wind industry, or the socio-economic impacts of floating wind on coastal communities – to list a few – are not addressed in detail in this paper.[2]

[2] *WFO's End-Of-Life Committee chaired by Engineering X was launched in August 2025 to address the growing global need for safe, sustainable, lifecycle design, late-life management and decommissioning in offshore wind: Press release.*

2 Defining environmental impacts

An environmental impact (or just "impact") is a change in the state of ecosystems resulting from human activities or natural events. In this case, the driver is the resource flows (movement of materials, energy, and waste) and activities associated with building a (floating) offshore wind project. Impacts can be positive or negative, affecting marine ecosystems and coastal communities.

2.1 Scale of impacts

Offshore wind environmental impacts must be understood across both spatial and temporal scales. Discussions within the Subcommittee consistently emphasise the need to distinguish when an impact occurs across the project lifecycle and where it occurs: turbine, wind farm (i.e. project level), across wind farms or wider basin.

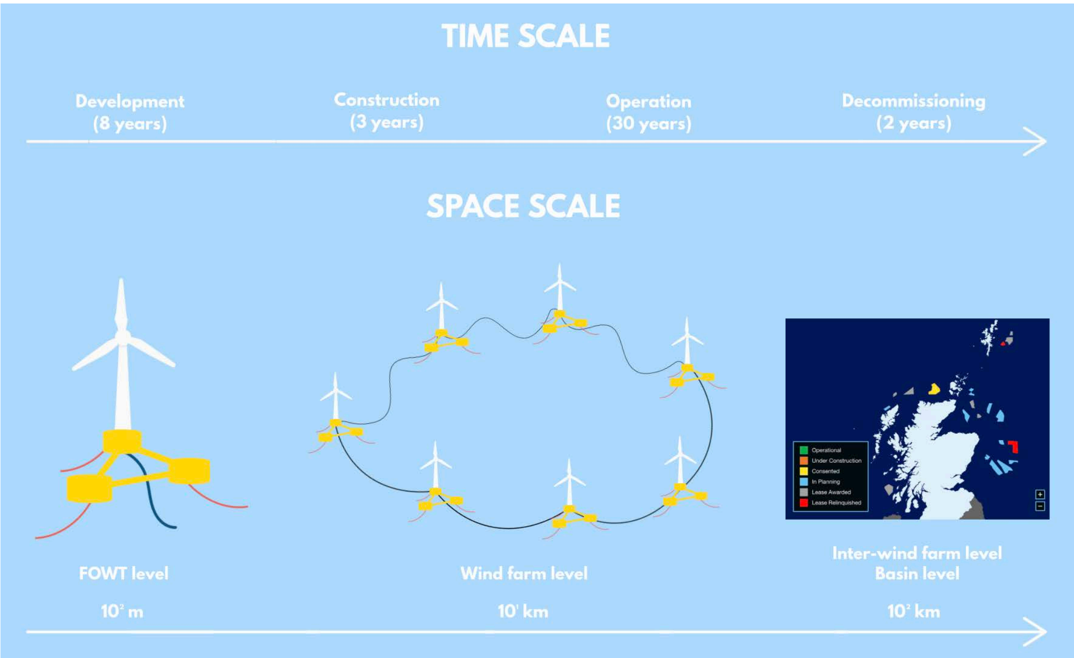

Figure 2. Illustration of the temporal and spatial scales necessary to specify when studying impacts. Temporal and spatial scales illustrative only. Source: WFO (map source from Offshore Wind Scotland).

One can focus on the wind farm's local impacts which are restricted to its site and vary depending on local environmental conditions, project design and operational practices. By contrast, global environmental impacts arise from the resource flows across the wind farm's full lifecycle. These include emissions and resource use associated with raw material extraction, component manufacturing, transport, installation, operation and maintenance, and eventual decommissioning. Global impacts can also include wider ecological changes in and around the project area, often as the result of larger wind farms or neighbouring wind farms together.

The dual perspective of local and global impacts as well as the mitigation hierarchy form the foundation for environmental assessment in floating offshore wind. These concepts underpin the complementary uses of Marine Spatial Planning (MSP), Environmental Impact Assessment (EIA) and Life Cycle Assessment (LCA) methodologies.

2.2 Mitigation hierarchy

The mitigation hierarchy is a widely accepted framework for managing negative environmental impacts.[3] It prioritises actions in the following sequence: avoidance, minimisation, restoration, and offsetting or compensation. For the rest of this paper "mitigation measures" would refer broadly to any or all of the four actions.

Avoidance remains the most effective strategy. This involves careful site selection to prevent development in critical habitats, migration corridors, fishing zones and more. Early-stage environmental assessments and spatial planning are essential to supporting this process. Where impacts cannot be fully avoided, minimisation measures focus on reducing their magnitude, i.e. controlling their duration, intensity and extent.

Restoration efforts aim to support ecosystem recovery following disturbance. These include habitat enhancement initiatives and support for conservation programs, although their effectiveness depends on robust ecological understanding and long-term monitoring. Finally, financial compensation can be provided to fishers and other users whose economic activity or livelihood is negatively impacted.

Adaptive management is a critical part of the mitigation hierarchy. This approach relies on continuous monitoring and the ability to adjust operational practices in response to observed impacts. It enables projects to respond to evolving scientific knowledge and site-specific conditions.

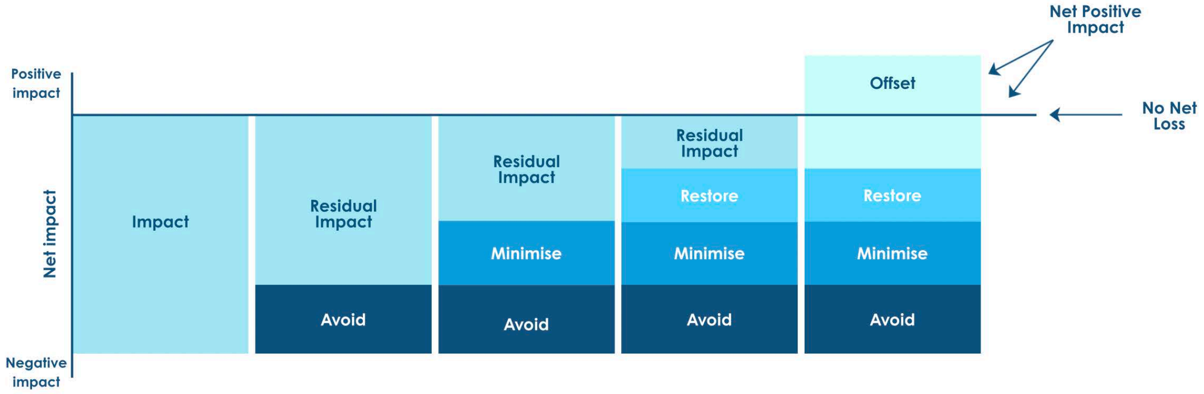

Figure 3. Mitigation hierarchy. Source: The Biodiversity Consultancy 2024.

[3] *Watson et al. 2025; The Biodiversity Consultancy 2024.*

2.3 Influence of regulatory frameworks

High-level marine resource management procedures frame offshore wind development in a given country. Marine Spatial Planning (MSP) is often cited as a primordial coordination exercise to identifying zones for offshore wind that do not overlap with ecologically sensitive and protected areas, fishing grounds, navigation routes, military and other activities. It is the first step to achieving the avoidance goal of the mitigation hierarchy.[4] In the European Union, the 2026 Ocean Act aims to modernize the 2014 MSP Directive and encourage a more organised sea basin approach. For floating wind, MSP-driven siting may be particularly important given the difficulty to coexist with commercial fishing (Section 3). Another high-level planning strategy often mentioned is the Strategic Environmental Assessments (SEA) which evaluates the environmental impacts of policies, programs and plans.[5]

Stakeholder engagement is a key part of the governmental processes involved in offshore wind development. For example, engagement with the fishing industry ideally occurs both during MSP and throughout a specific project's development (e.g. development/EIA, installation and operation) to maximise the wind farm's compatibility with fishing operations. Marine biologists and scientists are consulted to ensure that policies properly support biodiversity protection. Studying how one country or region coordinates stakeholder engagement in its marine and offshore wind regulation can provide valuable lessons learned to other regions looking to improve their process. While each process is country/site-specific, involving national and local bodies, one common takeaway is that transparency and trust in a given offshore wind governance model fosters successful stakeholder engagement.[6]

Finally, governments are involved in collecting environmental data on offshore sites to varying degrees. This in turn affects how involved the developer is in this task for the project's environmental impact assessment.[7] Because this process is not standardised within and/or across countries, a fragmented knowledge on the global marine environment exists.[8] Many international efforts are working to align study methods, widen study scopes and share results

[4] *Dvorak et al. 2024: Survey responses for the IEA Wind Task 49 on floating wind and marine spatial planning also indicated that the most efficient approach to building offshore wind would start with an MSP authority to identify the sites.*

[5] *The following works address the intersection between MSP and offshore wind, covering country descriptions, general challenges and recommendations to improve current and new MSP frameworks: UNESCO-IOC 2025; Dvorak et al. 2024; Watson et al. 2025; Airoldi et al. 2025; OCEaN 2024.*

[6] *A comparative study across 5 South Korean regions presented by the Energy Transition Forum Korea at WindEurope Madrid 2026 concludes that the optimal offshore wind governance model combines state leadership with inclusive local engagement.*

[7] *Watson et al. 2025 describe the difference between centralised, de-centralised and hybrid approaches to the way countries assess the potential impacts of offshore wind projects.*

[8] *Mature offshore wind markets in Northern Europe have more established systems for collecting and using environmental data. For example, the Netherlands' WOZEP (Wind op Zee Ecologisch Programma) coordinates government-led ecological research across Dutch offshore wind projects to improve cumulative impact assessment and standardise monitoring approaches. The United Kingdom's Offshore Wind Evidence and Change Programme (OWEC) and Marine Data Exchange (MDE) platform facilitate the sharing of environmental survey data between developers, regulators, and researchers to support evidence-based consenting and regional-scale assessments. A new offshore wind market like Australia has baseline survey efforts that are siloed between project sites; a national government model is therefore recommended by Przeslawski et al. 2025.*

via open-access portals to reduce the data siloes.[9] However, it is important to acknowledge that the complexity of marine environments will always be a challenge to study even if methods in data collection and analysis are more standardised.

2.4 Environmental Impact Assessment (EIA)

Environmental Impact Assessments (EIAs) are essential tools for evaluating the potential environmental, social, and economic effects of offshore wind developments.[10] EIAs are typically run by the project developer and ensure that the project is designed, implemented, and operated in a manner that minimises harm to the environment.

National governments generally require an offshore wind project to submit an EIA, each the result of a structured methodology to ensure regulatory compliance. Regional and international frameworks shape best practices (e.g. the European Union's EIA Directive). However, the scope and efficiency of EIAs can vary significantly by country due to differences in regulatory stringency, enforcement, and stakeholder engagement.

The key stages of an EIA are:

- **Screening**: Determines the EIA requirements for an offshore wind project based on its scale, location, and potential impacts. Factors such as turbine height, distance from shore, and proximity to sensitive marine areas are considered.
- **Scoping**: Determines what needs to be studied in detail during the EIA. This stage defines the boundaries and focus areas of the assessment, based on potential risks identified during screening. It typically involves input from regulators, scientific experts and other stakeholders to ensure that the most relevant environmental aspects (e.g., sediment movement, noise impacts, emissions, or biodiversity interactions) are prioritised for further analysis.
- **Data collection:** Conducts field studies, also known as baseline studies, to establish existing environmental conditions before construction begins. This includes data on seabed composition, water chemistry, air quality, background noise levels, and marine life/habitats. International experience highlights the importance of collecting 3–5 years of baseline data before construction.[11]
- **Impact assessment and mitigation strategies:** Evaluates the magnitude, significance, and likelihood of both positive and negative environmental impacts across all project phases. This stage quantifies the potential effects, comparing them against baseline conditions. It then proposes specific mitigation or enhancement measures (e.g., noise reduction technologies, alternative installation methods, or habitat restoration plans).

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[9] Global Ocean Observation System (GOOS), European Marine Observation and Data Network (EMODnet), Copernicus Marine Service, EU Digital Twin of the Ocean (whose inputs come from open-source platforms). Other open-source platforms are summarised in this LinkedIn post by Open Science Analytics.

[10] When an EIA includes social impact assessments, it is called an ESIA (Environmental and Social Impact Assessment).

[11] Observation from AMCS 2025 who drafted recommendations to improve decision-making for Australia's nascent offshore wind market. In addition, the MARINEWIND project compiled the most critical aspects to consider in a floating wind EIA after consulting floating wind markets in the EU (Airoldi et al. 2025, p. 15)

- **Reporting and review:** Compiles findings into the Environmental Impact Statement (EIS), which is submitted to regulators. The statement undergoes public consultation and expert review before approval to pursue the project is granted.
- **Monitoring and compliance:** After project approval, continuous monitoring programs ensure compliance with environmental standards. Adjustments are made to operational procedures if unexpected environmental effects arise (= adaptive management).

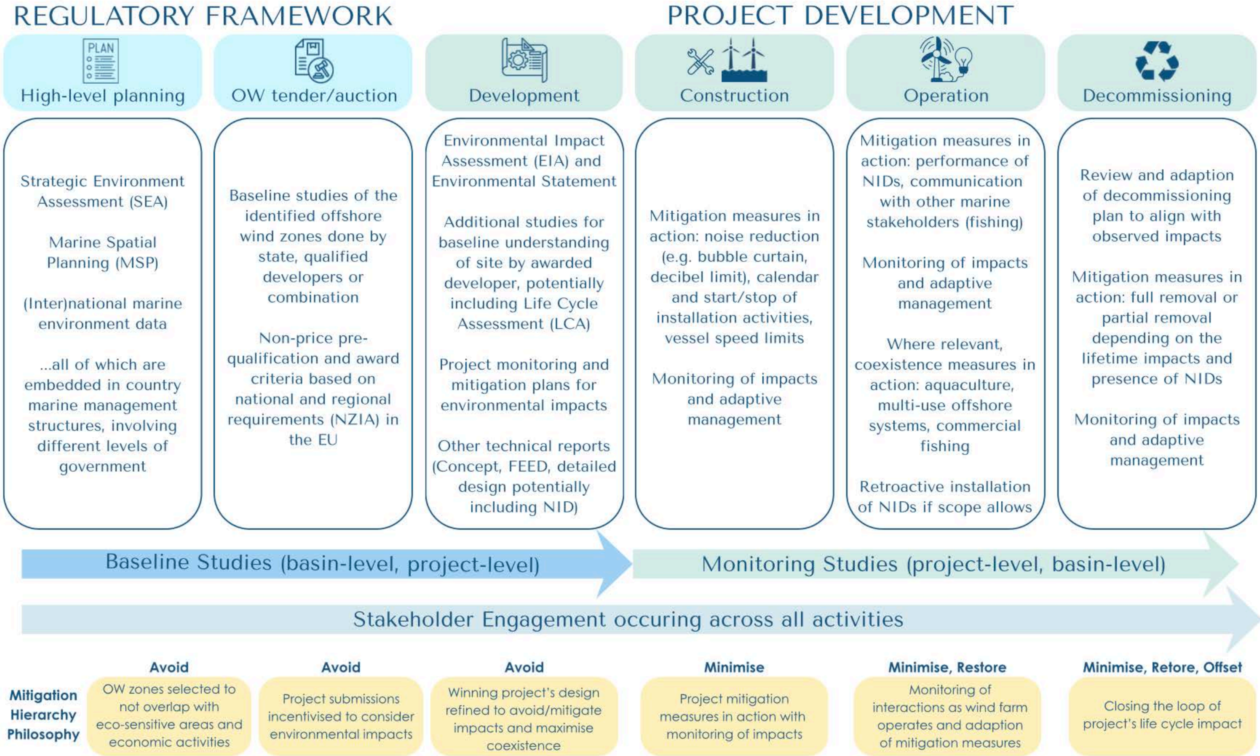

Figure 4. Policy and industry mechanisms that frame the management of floating wind environmental impacts. *NZIA = Net-Zero Industry Act; FEED = Front-End Engineering & Design; NID = Nature-Inclusive Design; OW = offshore wind.* Source: WFO

2.5 Lifecycle Assessment (LCA) – emissions focus

Life Cycle Assessment is a quantitative methodology for evaluating the environmental performance of products or systems across their entire lifecycle. LCA adheres to ISO 14040 and 14044 standards, ensuring methodological consistency and comparability. As opposed to EIAs which are regulatory requirements for a developer to be granted consent to build its project, an LCA is not always mandatory. However, LCA is increasingly recognised as a valuable tool for improving the sustainability of offshore wind projects.

The LCA is typically divided into four key phases:

- **Goal and Scope Definition:** Defines why the LCA is being conducted (e.g., to inform design choices, compare materials, or guide permitting). It specifies the intended audience (regulators, project developers, suppliers) and clarifies what aspects of the project will be assessed. The scope sets the boundaries of the study, i.e. whether the analysis covers specific components or lifecycle stages.

- **Life Cycle Inventory (LCI):** In this phase, data is gathered on the resources and energy used in the study scope. Data may come directly from project developers and suppliers, or from established databases for materials and processes.
- **Life Cycle Impact Assessment (LCIA):** The collected data is analysed to evaluate environmental impacts across categories such as greenhouse gas emissions, water use, land use, resource depletion, and pollution. Results can be broken down by project stage (e.g. construction, operation, decommissioning) or by component (e.g. moorings, cables, turbines) to highlight where the greatest impacts occur.
- **Interpretation:** The results are reviewed to identify key "hotspots" (areas of significant impact) in the lifecycle. These insights then inform decisions on design optimisation, material choices, or mitigation measures that align with sustainability targets.

During the ECB meetings, LCAs were mainly discussed in the context of emissions intensity metrics associated with the project such as CO_2 per kWh of electricity produced in operation. Another area of interest is the CO_2 per unit mass of material/foundation fabricated (upfront emissions).[12] In this context, the key LCA stages of a floating offshore wind project are:

- **Extraction and transportation of raw materials:** The production of floating wind platforms, turbines, mooring lines, anchors, cables rely on steel, aluminium, concrete, fiberglass, and rare earth elements (e.g., neodymium for magnets). This stage contributes significantly to CO_2 emissions due to mining, transportation refining, and material processing.
- **Manufacturing and assembly**: This stage looks at the fabrication, assembly and storing of the FOWT components: turbine (nacelle, tower, blade), floater, station-keeping (moorings, anchor) and dynamic cable. It is an energy-intensive stage with high waste generation from composite material manufacturing.
- **Transportation:** This stage involves moving large components from production sites to the project site offshore, typically using trucks, tugs, heavy-lift vessels, anchor handlers, barges, helicopters, etc. Transportation is used in every phase and plays a large role in total emissions through fuel use.
- **Use phase (including O&M):** Floating offshore wind turbines have a typical lifespan of 20-30 years. In this stage, transportation and manufacturing of new components, crew transfer, may be included.
- **Decommissioning and End-of-Life (EoL) management:** At the end of their lifespan, FOWTs are dismantled and either disposed of, recycled, or repurposed. Components may be reused (e.g., old blades used as bike shelters), recycled (e.g. materials such as steel and aluminium can be reprocessed into new products), or recovered (e.g. waste products used in incineration processes to generate heat or electricity). The environmental benefits of these activities can be reported as credits. Credits quantify the emissions saved from offsetting the need for new material production and improve the carbon footprint result.

The floater or substructure is the main novel element of the industry with over 100 concepts on the market. Conducting LCA early on can most effectively address a concept's carbon footprint (and/or other environmental impacts). At this stage of the industry's development, providing transparency on a floater's anticipated carbon footprint contributes to its

[12] *ECB Subcommittee October 2024: Carbon Trust has created an offshore wind industry product carbon footprinting guidance (linked is the updated 2026 version).*

competitiveness.[13] Indeed, with production lines and operational strategies not yet developed/matured, it is important for regulators, investors and developers to be aware of these dimensions before committing to specific designs or materials.

Ultimately, the main takeaway is that offshore wind contributes to 8-32 gCO2e/kWh[14] and is one of the lowest carbon emitting sources of energy production. Floating wind is considered to emit within the same range or slightly more than bottom-fixed wind. Some points must be considered:

- The fabrication stage is almost always the hotspot for carbon emissions due to the manufacturing of components and associated energy use (mining, transporting, processing). O&M also plays a significant role mainly due to the fabrication of spare components and vessel trips.
- The project's capacity factor and lifespan affect emissions per unit of energy generated. Capacity factors depend on wind speed, turbine model, farm layout and operational strategies. In general, wind turbines operating at sites with higher wind speeds tend to generate more electricity, which can dilute upfront emissions over greater electricity output. Similarly, longer project lifespans can reduce lifecycle emissions per unit of electricity generated by spreading upfront emissions over a greater amount of energy production. However, extending the operational life of a project may increase O&M requirements or component replacement. Finally, larger turbine designs may enable higher capacity factors but potentially require additional materials during manufacturing. As such, lifecycle assessments must consider all these aspects jointly.
- The end-of-life phase plays a crucial role in reducing the overall carbon footprint through life-extension or recycling processes.
- Due to the diversity of concepts on the market, there is a variability in floating wind carbon footprint estimations. Even sensitivity analysis on an individual FOWT or wind farm show that relatively small design changes or other assumptions can have measurable effects.[15]

[13] The "concrete vs. steel" debate is a general term to describe the discussions in the industry on the effectiveness of each material for floater performance, fabrication, installation, local content and carbon footprint. These last two points demonstrate how socio-enviro-economic impacts are actively considered in the wider engineering optimisation exercise. Example: Ocergy comment paper on its steel floater using DNV methodology. Ultimately, both steel and concrete are expected to be used; the term "debate" should rather refer to the competitive nature of our sector's pre-commercial stage as technology providers shape arguments for selecting their concept.

[14] ECB Subcommittee February 2025: Principle Power presentation on LCA of floating wind farms (quoted as being from Mendecka and Lombardi 2019).

[15] ECB Subcommittee October 2025: One study from Politecnico di Milano showed that a large-scale offshore wind project comprising 190 turbines (15 MW each) over a 30-year lifetime yielded a carbon footprint of approximately 31 tCO_2e/GWh, while a smaller project with 35 turbines and a lower capacity factor resulted in a higher footprint of 38 tCO_2e/GWh; ECB Subcommittee February 2025: one floater designer shared how reducing platform weight led to an approximate 10% decrease in carbon footprint.

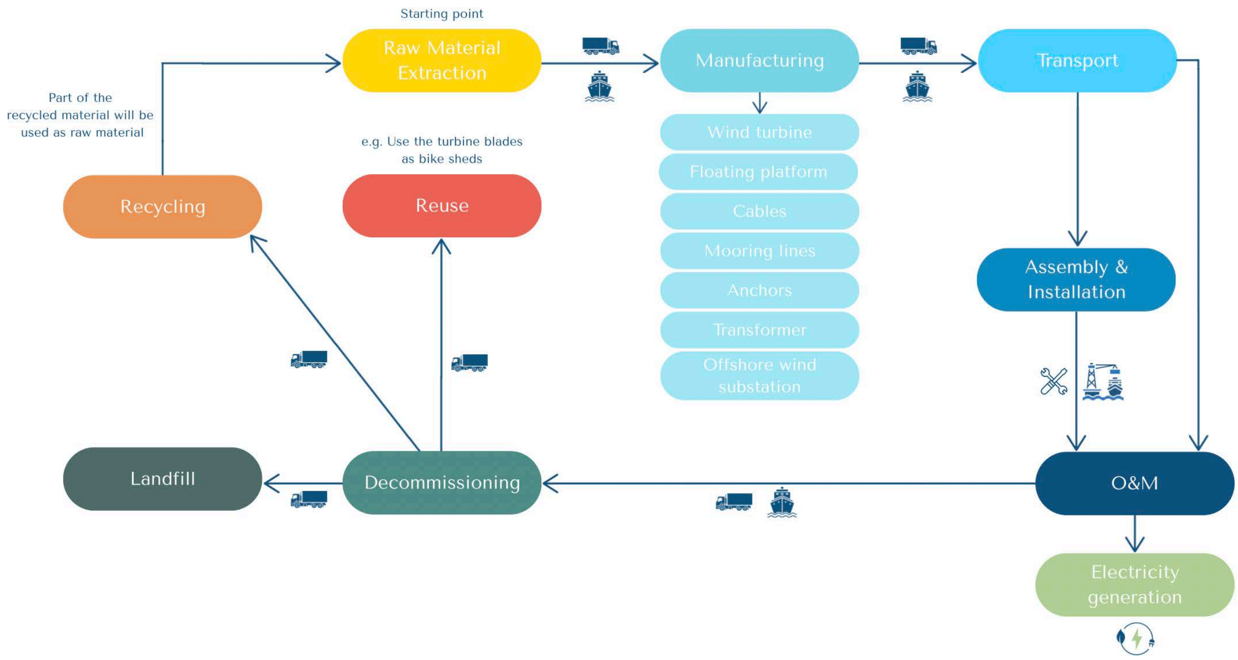

Figure 5. Simplified diagram of the LCA stages of a floating offshore wind farm. Source WFO (adapted from Politecnico di Milano).

2.6 Mitigation measures and innovations to reduce impacts

Mitigation measures to manage negative impacts are either concepts, tested or implemented. Many measures successfully trialled on bottom-fixed winds projects are applicable to floating, e.g. curtailment or shutdown on demand of the turbines during periods of high bird/bat activity, noise thresholds and bubble curtains, vessel trips that limit animal disturbance (speed, route, frequency). These measures are often validated through limited timeframes around the construction, installation and commissioning phases. Restoration efforts would need a longer time frame to be validated. For more information on mitigation measures, the Offshore Coalition for Energy and Nature (OCEaN) has compiled an online database for bottom-fixed offshore wind infrastructure in the North & Baltic Seas with the aim of supporting developers and transmission system operators in avoiding and minimising their own project impacts. Xodus Group and Rich North Sea also developed a Good Practice Library for offshore wind developers in Scotland, shortlisting measures that have already been tried and test in the region.[16]

To improve the lifecycle carbon footprint and wider environmental performance of offshore wind farms, the following industry developments are relevant:

- **Material selection**:
  - Recycled or recyclable materials: Incorporating bio-based composites for blades.[17]

[16] *Crown Estate Scotland 2025: Collaboration for Environmental Mitigation and Nature-Inclusive Design (CEMNID).*

[17] *Siemens Gamesa's RecyclableBlade by Siemens Gamesa has already been deployed on bottom-fixed turbines in the North Sea.*

- Materials with more sustainable production processes: using green steel and/or sourcing concrete locally to lower embodied carbon of the floater.[18] 3D printing is an emerging technique that can potentially localise production processes.
- Material properties with indirect impacts on project carbon footprint: For example, nylon for mooring lines have a higher elongation which allows for significantly shorter rope lengths, thereby reducing the quantity of synthetic fibre required and/or the size of associated steel components (chain, anchor, in-line components). Beyond the material savings, shorter and lighter mooring systems can reduce T&I requirements by lowering deck space demands, potentially allowing for smaller installation vessels or fewer vessel trips.[19]

- **End-of-life management**: Extension of turbine and platform lifetimes through component replacement and digital monitoring. For example, BW Ideol's Floatgen demonstrator (2 MW) has undergone lifetime extension[20] alongside continued operational optimisation, enabling additional energy generation while also providing further opportunities for environmental performance assessment over an extended operational period. Life extension was also recently announced for the grid-connected Zephyros (also known as Hywind Demo, 2 MW) demonstrator. Scheduled decommissioning like the case of the TetraSpar demonstrator is equally important as it represents a rare trial for full-scale removal. The components can also be analysed in detail, revealing how the FOWT was affected by the environment during operation.
- **Electrification and decarbonisation of port and offshore operations:** electrified port infrastructure; more efficient vessel design and speed optimisation/reduction; and the use of low-emission vessels powered by LNG, ammonia, hydrogen, methanol, or batteries.[21]

Mitigation measures for floating offshore wind impacts to commercial fishing and the marine environment are explored in the following sections.

[18] *BW Ideol is launching the Fos3F foundation manufacturing factory to generate local content, prioritise "short" supply chains and recyclability for a reduced environmental footprint.*

[19] *Another example is MADE4WIND, an EU-funded project developing circular, lightweight blade and floater components for FOWTs.*

[20] *BW Ideol press release January 2024*

[21] *The European Onshore Power Supply Association (EOPSA) is advancing the decarbonisation of maritime and offshore operations through the development of low-emission infrastructure for alternative-fuel and electrified vessels; the integration of renewable energy and battery storage in ports…*

3 Coexistence with the fishing industry

The rapid expansion of (floating) offshore wind energy adds another layer of pressure on the marine environment amidst multiple industries already competing for space, each with their own impacts.[22] The increasing introduction of marine protected areas and the management measures often associated with them (i.e. fisheries closures) further contribute to competition for space. However, rather than being seen solely as a source of potential conflict, offshore wind can act as a catalyst for integrated ocean use, fostering new partnerships, shared economic benefits, and enhanced marine stewardship.[23] This ambition is captured by the term "coexistence", which means the ability of (floating) offshore wind and other industries to exist and operate independently within the same general marine space.

3.1 Stakeholder overview

Floating offshore wind projects intersect with a wide range of maritime activities and stakeholders:

- Commercial fisheries, encompassing both mobile and static fishing practices, whose access to fishing grounds are affected.[24]
- Shipping and maritime transport, including commercial navigation routes and port access corridors, which may have to circumvent or pass through offshore wind farms.
- Coastal communities and tourism sectors, influenced by visual impacts, economic opportunities and other changes to their environment.
- Marine conservation, regulated by government and/or advocated for by non-governmental and community organisations.
- Defence and strategic maritime zones, where offshore wind development may not be possible.
- Emerging industries such as aquaculture, other renewables (floating solar, wave and tidal), offshore hydrogen production where co-location with offshore wind is possible.

The rest of this section zooms in on the interaction between floating wind farms and fishing, which is one of the more complex and sensitive dimensions of the industry's development.

3.2 Commercial fishing focus

The complexity of the interaction between floating offshore wind and commercial fishing arises from the physical constraints introduced by FOWTs that either prevent fishing

[22] *Across papers and conference presentations, spatial congestion (actual and estimated) in the North Sea is illustrated to show the need for improved planning approaches. Cross-country agreements like the North Sea Declaration add complexity and urgency to these coordination efforts.*
[23] *Research projects uniting stakeholders from offshore wind, fishing and marine biology like FISHWIND in the Mediterranean are exploring such a forward-looking vision for ocean use.*
[24] *For a general summary of fishing methods, refer to this blog article by the UK Marine Conservation Society; the Appendix A of the Engagement Strategy for the Kincardine floating wind farm for insights on local methods; slide 16 of this Mitsubishi Research Institute report for an illustration of methods in Japan.*

activity altogether or require an adaptation of fishing methods. As such, coexistence in this context is defined as "a fishing vessel skipper's ability to operate in the vicinity of a FOW farm, including potentially within the interior of the array."[25]

The physical constraints introduced by FOWTs differ quite significantly from fixed-bottom systems. Depending on the FOWT design, the mooring lines, anchors, and dynamic cables create a distributed spatial footprint in addition to turbine spacing that may prevent accessibility to fishing grounds or make proximate operations risky. These access limitations can reduce catch efficiency and economic viability, displace fishing efforts to other areas, increase operational costs and fuel consumption, and create secondary pressures on adjacent fishing zones. Specific fishing methods are affected unevenly:

- Mobile fishing techniques like trawling and dredging are highly sensitive to seabed obstructions and spatial restrictions. Safety concerns from the risk of gear entanglement (on catenary mooring lines, free-hanging cables) and allision (complicated by platform excursion) can restrict mobile fishing entirely. Gear entanglement can notably harm marine species (Section 4).
- Static fishing methods like pots and traps may be more adaptable but still face gear entanglement and allision risk, especially in harsh metocean conditions that affect vessel, gear and FOWT positions. Switching from mobile fishing to static methods may not be a long-term solution at a given location for which mobile fishing practices have been shaped by decades of experience.[26]
- Across all methods, export cable routes can further limit allowable fishing areas. Temporary fishing exclusion zones can also occur during the development (to run surveys), construction and installation phases.

Existing pilot projects have engaged with fisheries to varying degrees to favour coexistence.[27] However, it is difficult to quantify on a general level the anticipated spatial footprint of commercial-scale floating wind farms considering the wide variety of floater, mooring and

[25] *Definition used by the ORE Catapult in its Floating Offshore Wind and Fishing Framework for Coexistence report, which was the result of workshops where representatives of the fishing industry, floating wind developers and some government bodies came together to advance the current discussion on the impacts of floating wind on fishing.*

[26] *As stated in The Carbon Trust's 2026 report, "the Hywind floating OWF static fishing gear trial, commissioned by Equinor to the Scottish Marine Directorate, highlighted a proof of concept with static gear successfully operated within the prescribed areas of the OWF with no safety issues, gear snagging, or gear lost. However, as these static gear trials were undertaken on mobile fishing grounds the economic viability as a replacement fishing method is not yet understood." In Japan, granting/changing static fishing licenses can be very difficult due to the way fishing grounds remain within groups/family members for generations, and the challenge in predicting how migratory fish behave and affect the licensed fishing grounds, whether by an offshore wind project or other factors (e.g. management practices that affect fish recovery or climate change).*

[27] *Examples : EFGL's project page states that the wind farm layout was decided together with fisheries; During early development, the Pentland Offshore Wind Farm decreased the array size following stakeholder consultation, which benefits fisheries ; the Goto Demonstration Project in Japan is considered to have had a successful fisheries engagement; The Green Volt floating offshore wind farm boundaries were adjusted during the EIA and stakeholder engagement process to avoid overlap with an important Nephrops fishing ground, thereby reducing potential displacement of established fishing activity and supporting coexistence with commercial fisheries.*

cable designs under development.[28] Shared anchoring or moorings would further complicate the possibility for coexistence. Finally, the ecological impacts of offshore wind infrastructure on fish stocks remains an area of ongoing research (further described in Section 4.1).[29]

Based on these impacts, project siting becomes an extremely important process to maximise the possibility of coexistence between both industries. Governments must promote the collection and sharing of detailed fisheries information (through data portals and consultation processes), whereas developers must be incentivised to understand and minimise the impacts of their projects on fishing activities. Early and continuous engagement with the fishing industry is critical for these processes.[30] For example, the Mitsubishi Research Institute stated that "the *national* government should take the lead in consolidating data on fisheries and sharing it as transparently as possible" in its May 2025 report on Potential Sea Areas for Offshore Wind in Japan, where there is not yet a MSP approach and where coexistence with fishing is a critical topic. While these efforts can reduce specific project consenting risk, technical workshops like those of the ORE Catapult are important efforts outside the project planning process to openly discuss the impacts.[31]

3.3 Best practices for stakeholder engagement

Effective coexistence depends on the ability to integrate stakeholder perspectives into spatial planning frameworks and project design. When involved early, stakeholders can meaningfully influence decisions related to site selection, array configuration, and FOWT design. The framework for engagement must drive respectful and productive dialogue.[32] However, in practice, early engagement can be constrained by inefficient processes, commercial confidentiality, limited transparency and trust-building. These issues are captured in Table 1 below.

[28] TLPs are expected to offer the most constrained spatial footprint but were not considered in ORE Catapult's workshop between industry and the fishing industry because of their relatively lower technology readiness level. In the meantime, mooring innovations like taut nylon lines can be used for other substructure designs to reduce the footprint. Regarding cables, the number of free-hanging cables can be reduced through the use of subsea transformers and hubs, although this is also a relatively early technology development. The first floating wind star configuration system using a subsea power system will be tested at the METCentre in Norway.

[29] The Japan Fisheries Agency (JFA) has a scientifically proven track record of using "floating artificial reefs" to create commercial fishing habitats as part of fish resource management. Their experience could be useful for the offshore wind sector.

[30] ECB Subcommittee May 2024: Brown & May Marine presentation on floating offshore wind and commercial fisheries.

[31] The Renewable Energy Association for Sustainable Power Supply (REASP) in Japan also advocated for regular exchanges of opinions between stakeholders outside of wind area planning processes.

[32] More details on the stakeholder engagement process are captured in a 2022 WFO blog article.

Table 1. Practical issues in an engagement process with fisheries

Initial goal of the engagement	In practice	Best practice
Build trust thanks to the structure of the engagement process	Developer-led engagement is often difficult to foster trust in due to the motives of the developer to build a commercially viable project.	There are many lessons to be taken from comparative work on offshore wind governance and marine spatial planning models. The presence of a credible mediator who is independent from government and private developers can help guarantee procedural fairness.[33]
Save time thanks to the effectiveness of the engagement process	The fishing community can experience consultation burden if multiple developers are approaching them separately with the same questions.	Elect trusted points of contact for project's development (Fisheries Liaison Officer) and the fishing community (Fishing Industry Representative) to streamline communication[34] and, when possible, consolidate consultation events for projects that are adjacent or run by the same developer.
Provide information thanks to scenario-building and data-sharing in the engagement process	On the one hand, unknowns in floating wind make estimating and communicating impacts difficult. On the other hand, lack of or difficulty in sharing fishing data impede the co-designing of solutions.	Visualising FOWTs improve the understanding of technologies involved and their spatial implications. Technical drawings, GIS mapping and scenario modelling tools can aid consultation events.[35] In parallel, centralised fishery data collection processes are needed to support these modelling exercises to best quantify anticipated impacts.
Enact change in policy and/or the project as a result of the engagement process	It is important for the engagement process to have a genuine, tangible impact.	Return on experience from specific engagement efforts show that the relationships improve when progress is tangible, e.g. a policy is updated, the FOWT array is modified etc.
Collaborate to maintain coexistence and trial new solutions together	Need high-level coordination and funding to conduct surveys for additional fishing data or test coexistence solutions.	Government requirements for offshore wind surveys can drive coordinated data collection. Funded research programmes can standardise methods or test new solutions.[36]
Compensate meaningful support to fisheries if their activity is strongly impacted by the floating wind farm	The reality is that a FOW farm will be less idealised in practice than in early design concepts due to the need to balance multiple criteria (technology, cost, social, political, environmental…). Compensation may sometimes be the only way.[37]	Direct financial compensation may work for demonstration projects given their smaller footprint. However, other mechanisms for larger projects must be in place, e.g. nature credit schemes which quantify and reward positive biodiversity outcomes.[38]

[33] "Local mediator" term used by the Energy Transition Forum Korea at WindEurope Madrid 2026. The idea is to ensure a degree of neutrality and fair opportunity in the engagement/negotiation process.

[34] Refer to the Fishing Liaison with Offshore Wind and Wet Renewables (FLOWW) group's 2025 Best Practice Guidance for more details on the stakeholder engagement process in the UK. REASP in Japan also recommends "well-versed personnel in both offshore wind and the fishing industry" to coordinate engagement processes.

[35] DNV's MARCO Project and DHI's Environmental Vulnerability Indicator are examples of tools aimed at modelling and forecasting marine activities and/or environmental pressures to guide decisions for offshore wind area planning. These tools rely heavily on data (availability, quality, resolution) which is not always easy to obtain. To address data limitations, alternative information can be used like in the example of Brown & May Marine sourcing Automatic Identification System (AIS) data to complement knowledge on trawler activity.

[36] In the United States, fisheries data is required for project construction and operations plans, which has facilitated the trial of a new monitoring technique for fisheries data. Australia, on the other hand, does not yet have a national model for surveying that includes fisheries data.

[37] Case of WindFloat Atlantic in Portugal.

[38] In May 2026, the UK government enacted a reform to enable a broader range of ways that developers can compensate for any unavoidable impact their projects have on protected sites like protecting seabird nesting sites, reducing predator numbers near protected colonies, or funding the restoration of native oyster populations. Slide 9 of this European Commission 2026 presentation on nature credits has some examples.

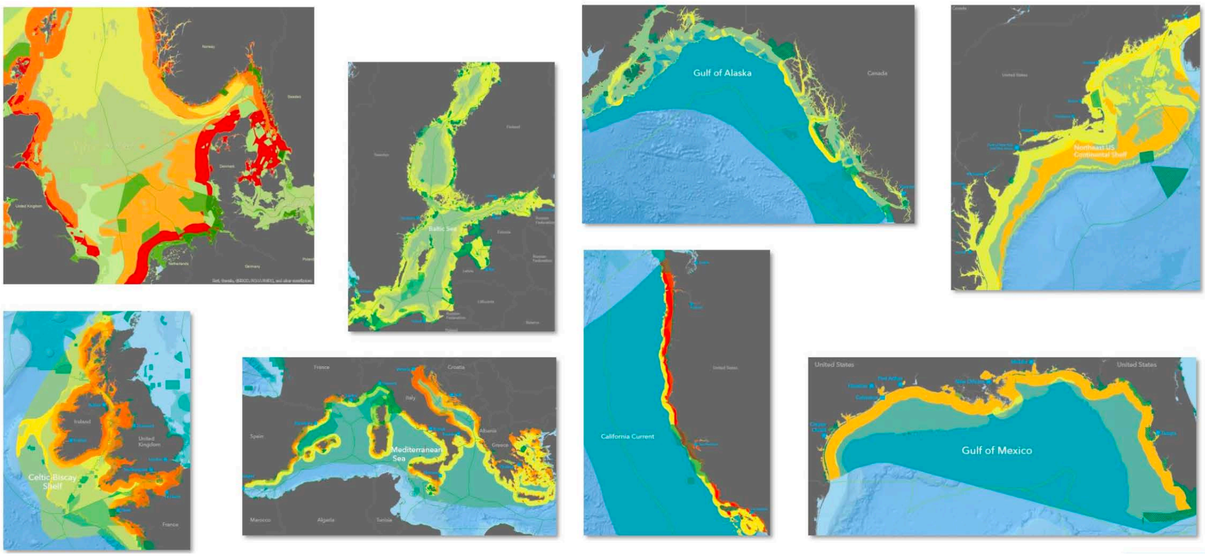

Figure 6. DNV's Spatial Competition Forecast for large marine ecosystems around the world in 2050. Areas in red are the most competitive and those in blue are the least competitive. By combining spatial analysis, modelling, and stakeholder input, DNV aims to develop a decision-support tool that helps balance competing marine uses at regional scales. Such mapping tools are particularly important as offshore wind expands into increasingly crowded marine environments, where cumulative impacts must be carefully managed. Source: DNV MARCO research project.[39]

3.4 Strategies for coexistence with the fishing industry

The fishing industry flags floating offshore wind as a concern given the uncertainty regarding technology design, mooring system footprint, and associated impacts to their activity. When it comes to coexistence, Carbon Trust recorded "scepticism regarding the effectiveness [of solutions]."[40]

Strategies to improve coexistence with fishing remain theoretical in nature and are by-products of the industry's most promising innovations. ORE Catapult[41] cites larger turbine capacities that increase between-turbine spacing and reduces the total amount of turbines in the array; taut nylon mooring lines that reduce mooring footprints; strategic positioning of substations; strategic choice of installation & maintenance methods to reduce vessel traffic (e.g. SOV-led logistics or switching from tow-to-port to onsite major maintenance); and the digital mapping of floating wind subsea infrastructure to guide fishing traffic. As such, many of the industry's ongoing innovation work contain important socio-environmental

[39] ECB Subcommittee February 2025: Resources that describe MARCO in more detail - Offshore wind in the race for ocean space: A forecast to 2050 - IOPscience and Scenarios for offshore wind co-existence opportunities and trade-offs - IOPscience.

[40] Carbon Trust February 2026: Improving the evidence base for coexistence between offshore renewables and commercial fishing.

[41] Refer to the matrix of the ORE Catapult's Floating Offshore Wind and Fishing Framework for Coexistence for a more detailed explanation on these coexistence opportunities and their scoring.

implications, which further underlines the need to maintain a holistic view when interpreting floating wind's technology and commercial progress.[42]

Finally, the development of multi-use offshore systems in which energy production is combined with other uses is an emerging and promising form of coexistence. These systems aim to optimise space utilisation while creating additional environmental and economic value. Several examples include:

- Co-location of floating wind with aquaculture, where the FOWT infrastructure provides physical support for farming systems or creates favourable environmental conditions for certain species.[43]
- Integration with other renewable energy technologies, such as wave energy converters and floating solar to optimise energy generation within the same spatial footprint.[44]
- Offshore hydrogen production, which could reduce reliance on subsea cable infrastructure and enable new offshore energy value chains.[45]
- Oil & gas powered by floating offshore wind to reduce the former installations' carbon footprint. While a debated use case, FOWTs built for this purpose still advance the maturation of the industry (e.g. Hywind Tampen in Norway as world's largest floating wind farm; Culzean Floating Wind under construction as part of the INTOG leasing round).

Most of these applications remain experimental and face several barriers, including technical complexity, economic viability and social acceptance. Site-specific technology evaluation and validation through pilot projects is important to measure the impacts before investing further. Policy frameworks must also be sufficiently advanced to support the unique requirements of these multi-use technologies, which can then incentivise the appropriate supply chain and workforce developments. For example, the INTOG leasing round in Scotland has created a pipeline of floating wind projects specifically aimed at powering oil & gas installations.

[42] *The holistic engineering approach has been promoted across all WFO's Floating Offshore Wind Subcommittees. Floating wind must be designed for robustness, reliability and resilience but also for easy production, installation, operation. With this paper, we can add to this list a minimised to positive environmental impact.*

[43] *Feasibility and policy studies include OFFWOFF 2025 (Scandinavia); IHCantabria 2025 (Spain); SeaTwirl 2025 (Chile). Physical pilot trials include AquaWind 2025 (Spain); Guoneng Sharing 2025 (China); AQUASATH under development (Spain). These examples are relatively recent and specific to floating wind. There are many other studies looking at the application of existing knowledge to future markets (e.g. the United States). Finally, there is already experience on bottom-fixed wind farms: the UNESCO-IOC and UN Global Compact cite pilot studies in section 6.3 (p. 44) of their report (North and Baltic Sea).*

[44] *Cables & Floating Substations Subcommittee March 2025: Offshore wind and solar have a powerful co-location synergy as they are complementary production systems (night/day, seasonality). The solar panels can also make use of the existing offshore wind electrical infrastructure (export cable, substation). Academia is also very involved in combined technologies, e.g. the OMAE 2026 conference had a few papers looking at floating wind and wave energy systems.*

[45] *The Milford Haven Hydrogen Kingdom project in the Celtic Sea is looking at the co-location of green hydrogen, wave and floating wind energy.*

4 Biodiversity and marine ecosystems

The marine environment is a complex, interconnected system where changes affecting one species or habitat can cascade through the ecosystem. The development of floating offshore wind farms introduces large artificial structures and dynamic subsea components that influence species abundance, distribution, behaviour and ecosystem dynamics.

4.1 Pressures and impacts

Although there are shared environmental impacts with bottom-fixed systems, the mooring systems and dynamic cables of FOWTs create additional pathways for interaction at the seabed and in the water column. These interactions can be grouped into several key categories along with their impacts:

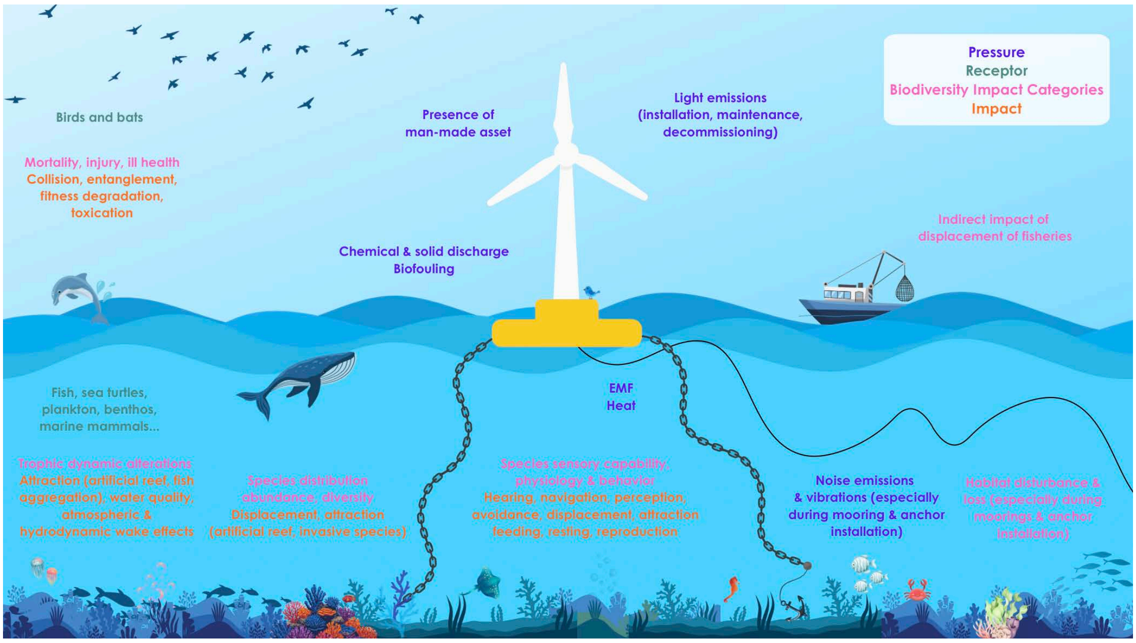

Figure 7. Biodiversity impacts of floating offshore wind. Source: WFO (adapted from Watson et al. 2025, Przeslawski et al. 2025, OCEaN 2024, Farr et al. 2021).

- **Habitat disturbance and loss**: Seabed disturbance and benthic habitat alteration arise primarily from the installation of anchors and mooring systems. During operation, more compliant mooring lines can sweep across the seabed due to platform excursion, creating a continuous seabed disturbance mechanism that affects invertebrate communities and alters sediment structure. Sensitive habitats such as seagrass meadows are particularly vulnerable due to their ecological importance in supporting coastal biodiversity and carbon sequestration.[46]
- **Species behaviour**: Marine mammals, fish, and seabirds may alter their movement patterns in response to the presence of structures and related installation or O&M activity.

[46] *ECB Subcommittee April 2024: WSP presentation on the environmental impacts of FOWTs on Posidonia meadows.*

For migratory species, such changes may lead to increased energy expenditure or reduced access to critical habitats.

  - **Affected by noise emissions and vibrations**: Underwater noise generated during installation, maintenance, and vessel operations can interfere with the acoustic communication and sensory perception of marine mammals and fish. While installation and maintenance related noise is often the most intense, operational noise from the FOWT (vibrations) and snap from the mooring lines can also occur. The extent of these impacts needs to be studied more.[47]
  - **Affected by electromagnetic fields (EMF)**: EMFs emitted by subsea power cables can affect species like elasmobranchs (sharks, rays) and migratory fish species who rely on geomagnetic cues for navigation. This interaction also requires further investigation, especially in floating wind where more free-hanging, high-voltage cable segments are present in the water column.[48]

- **Mortality, injury or ill health:** Birds can collide with the FOWT; based on experiences in fishing and ocean pollution, marine mammals can potentially get entangled on the mooring line through primary or secondary entanglement.[49] Chemical releases from metal corrosion, eutrophication, hydrology and water turbidity may affect species.[50]
- **Species distribution, abundance and diversity:** The anchors provide hard substrate for reef-associated communities while in-line mooring components and floating platform can act as fish aggregation devices. Bio-colonisation of the lines by mussels, barnacles, and other sessile organisms can attract crustaceans and fish, potentially modifying predator-prey relationships, creating new ecological niches or facilitating the transport of invasive species.[51] The **displacement of certain activities** in the wind farm area (shipping, fishing) can create a reserve effect that benefits fish species, although evidence for this remains limited.[52]
- **Trophic dynamics alterations** may occur as a result of habitat modification shaped by the above points.
- **Cumulative impacts** which are applied across all impact categories. Cumulative impacts are the incremental, combined, and interactive impacts that may result from repeated human activities over time and space. It is very challenging to conceive monitoring programmes for cumulative impacts.[53] For example, results from local habitat monitoring (artificial reef, reserve effect) cannot be generalised to net ecological benefits that

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[47] Relevant work: study on Hywind Scotland, study by blueOASIS part of the FLOATFARM project where finite-element modelling and underwater acoustic propagation simulations were used to assess the underwater acoustic footprint of different floaters.

[48] Relevant work: ORE Catapult 2025 Floating Offshore Wind Dynamic Cable EMF Review.

[49] ES Environmental : Primary entanglement is defined as the direct impact from contact between mooring lines/cables and marine animals. Secondary entanglement occurs when debris or fishing gear that was lost or abandoned by another industry becomes attached or caught on the FOWT mooring lines/cables which then affects marine fauna. See footnote 59 for example studies.

[50] Rezaei et al. 2023.

[51] ECB Subcommittee May 2025: Saitec Offshore Technologies observed several invertebrate phyla and macroalgal groups colonise the DemoSATH foundation, supporting additional habitat niches. A recent study on the Floatgen demonstrator using ROVs and visual surveys was able to detail the biofouling composition on two of the six mooring lines (Dubois et al. 2025). Although the study does not directly assess structural or ecological impacts, it underscores the importance of robust and standardised monitoring protocols to assess the phenomenon and quantify long-term trends. Note that the term biofouling is used to refer more specifically to unwanted bio-colonisation that affect the asset's structural integrity.

[52] Przeslawski et al. 2025.

[53] Rezaei et al. 2023.

increase local fish populations, a critical point for coexistence with the fishing industry. On a cumulative level, these effects might be negligible, simply redistribute existing biomass, or even harm ecosystem function. Another example of emerging research interest is the atmospheric and hydrodynamic wake effects on plankton dynamics. The 2026 HORIZON EU call on "Understand and minimise the environmental impacts of offshore wind" seeks to address the knowledge gap on cumulative effects.

Generally, positive impacts relate to increasing biodiversity (species abundance, diversity) due to the FOWT acting as a substrate and altered/reduced human activity at the wind farm site that allow for benthic communities or fish populations to recover. However, even for bottom-fixed wind, more work is needed to validate if the positive impacts are significant and remain as such over time. Negative impacts are those that directly (from collision, entanglement) or indirectly (from avoidance and displacement) harm species and their habitats, with consequent effects on populations and ecosystems.

4.2 Status of offshore wind environmental impacts research

Most offshore wind environmental impact research is on a localised scale (i.e. individual bottom-fixed wind farms), with particular concentration in the North Sea region due to the advanced industry development.[54] Some studies are part of EIA activities (including monitoring of impacts), others are independently carried out by/in collaboration with a developer, or belong to other research and academic programmes.[55] Research consortia play a unique role in achieving basin-scale analysis of impacts to guide regional national and marine spatial planning.[56]

Across the studies, a range of empirical and modelling methods are used. Empirical methods, specifically 'before-after-control-impact' (BACI) studies that assess ecological conditions at the impact and control sites before and after construction, are generally considered the most robust. However, they can be difficult to implement because of insufficient baseline data, difficulty identifying suitable control sites and the cost and logistical demands of long-term monitoring. BACI methods are commonly applied in Northern Europe where robust regulatory frameworks support best-practice ecological monitoring.[57] Emerging offshore wind markets can apply lessons learned to their contexts, and sometimes vice-versa.[58] Scenario modelling helps researchers analyse specific impacts as well as predict long-term ecological impacts (e.g. trophic changes).

[54] *Galparsoro et al. 2022.*

[55] *The following works can be consulted for a comprehensive overview on environmental impacts for offshore wind. They also provide insights on study methodologies, monitoring technologies and mitigation measures: Przeslawski et al. 2025, Watson et al. 2025, OCEaN 2024, Rezaei et al. 2023, Galparsoro et al. 2022, Farr et al. 2021.*

[56] *ECOWind Programme (UK North Sea: Crown Estate / NERC); ORJIP Offshore Wind (UK North Sea: Carbon Trust); NO-REGRETS Programme (Netherlands North Sea: NIOZ), Migralion (French Mediterranean: OFB and FEM)*

[57] *Watson et al. 2025.*

[58] *Przeslawski et al. 2025 and AMCS 2025 frame key recommendations for the Australian market based on other country best practices. Interestingly, the United States, a younger offshore wind market, now has experiences that can serve the more mature European markets, e.g. INSPIRE Environmental's biodiversity monitoring technology; VolturnUS floating wind demo's learnings; BOEM's approach to cumulative impact assessment. All of this demonstrates the global nature of knowledge exchange for offshore wind environmental impacts.*

For floating offshore wind, research is limited to the current demonstrators, which is elaborated further in Section 4.3. As such, modelling and experimental testing are especially important at this stage to predict floating wind's unique impacts, like for the entanglement of marine mammals which has not yet been observed in the floating wind context.[59] In addition, experimental testing is being used to validate new technologies that influence a FOWT's environmental footprint.[60] Relevant species/impacts studied in bottom-fixed wind contexts can also support estimations for floating wind.

4.3 Inspection and monitoring technologies

Environmental data is the foundation of all the policies, methodologies and tools that manage floating wind environmental impacts. Baseline studies inform the wind farm design and initial mitigation measures. Monitoring studies support the implementation of those mitigation measures throughout the project lifecycle. Effective surveying and monitoring rely on the integration of complementary technologies:[61]

- Direct, camera-assisted visual observation techniques through vessel-based, aerial-based or diver-based surveys using ecology experts, Remotely Operated Vehicles (ROV), other. These provide direct insights into species presence, behaviour, and bio-colonisation. Underwater methods can be limited by poor visibility, harsh sea states, dive windows, and the high cost of offshore deployment.
- Acoustic monitoring systems play a central role in detecting marine fauna. Hydrophones enable the identification of vocalising marine mammals, while sonar technologies provide information on fish distribution, abundance and movement patterns around offshore structures.
- More invasive methods like trawling and traps capture and count fauna.
- Tracking (telemetry) and satellite remote sensing technologies to monitor marine mammal or avian activity especially during migration.

New technologies are further expanding monitoring capabilities in a non-invasive manner:

- Environmental DNA (eDNA) where samples of soil, water or air are collected and analyse for genetic material, which can help detect species likely present near offshore infrastructure.
- Unmanned robots (underwater, surface and aerial/drone vehicles) equipped with sensors[62] that reduce the risk to both people and wildlife. Some of these technologies may

[59] WFO Workshop February 2022 on floating wind environmental risks to protected species on the US West Coast where it was shared that BOEM (at the time of the workshop) was developing a model to quantify the secondary entanglement risks based on scenarios in this area. The MoorSEA project has been still looking into this topic with a recent report published May 2026 to inform entanglement modelling efforts for offshore wind energy areas in California.

[60] TAILWIND is an EU-funded project studying FOWTs with smaller mooring footprints and low-noise installation methods, amongst other sustainability factors.

[61] Table 2 of Watson et al. 2025 lists traditional and innovative monitoring innovations in more detail.

[62] Example of the Baited Remote Underwater Video (BRUV) by INSPIRE Environmental – which does not necessarily make use of new technology but suggests a new method for fisheries monitoring versus trawling.

be more cost-effective, providing high-resolution observations and environmental inspections in difficult-to-access offshore areas.

- Autonomous sampling systems (e.g. on a buoy, autonomous platform, robot) with onboard data logging. These systems enable long-term, remotely operated collection of environmental and biological samples with minimal human intervention.
- The integration of multiple monitoring instruments on floating data platforms (camera, hydrophone, radar, meteorological sensors, underwater and airborne DNA sampling).[63]
- Artificial intelligence (AI) and machine learning for automated image, acoustic, and sensor-data processing, species identification, collision-risk assessment, and behavioural pattern recognition.
- Digital twins and predictive ecosystem models integrating environmental and engineering data to simulate offshore wind performance, biodiversity responses, and cumulative impacts under different scenarios. These can be validated with onsite camera or sensor data.

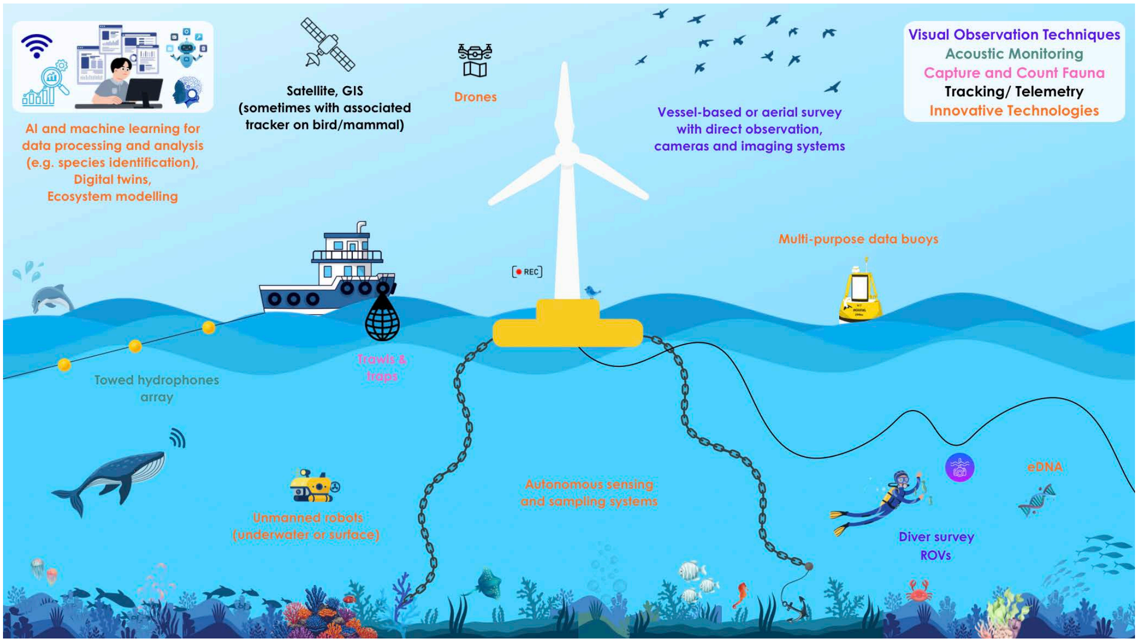

Figure 8. Different types of environmental monitoring technologies. While some of the innovative technologies may have been around for some time, it is their application to floating offshore wind that is new. Source: WFO.

Environmental DNA (eDNA) techniques have advanced significantly in the last years. By analysing genetic material present in water samples, eDNA enables non-invasive detection of a wide range of species.[64] Pairing water sampling opportunistically with routine offshore

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[63] *ECB Subcommittee November 2025: The [Ocergy OCG-Data data acquisition platform] is an example of integrated site assessment and monitoring infrastructure. Installed in the French Mediterranean, the platform enables simultaneous observation of metocean and biodiversity conditions versus traditional methods (i.e. using a metmast for wind, buoys for ocean, and surveys for biodiversity measurements). The Blue Oracle project was an important step in demonstrating its feasibility. A related example is the FLiDAR by Fraunhofer IWES which [recently] received the highest level of commercial acceptance validation under the Carbon Trust OWA roadmap for this technology.*

[64] *ECB Subcommittee April 2025: An eDNA monitoring study conducted by NatureMetrics in and around a UK operational wind farm detected around 70% more species than traditional trawling and netting surveys, while requiring approximately 66% fewer personnel. A key advantage was the ability to sample within the turbine array where conventional survey methods may not.*

operations can reduce the cost and impact of additional survey campaigns. However, there remains uncertainty around eDNA results as sometimes genetic detections do not fully match benchmark data from visual observations.[65] This discrepancy does not invalidate eDNA, but it does mean that eDNA can capture broader or transient genetic signals that are not always directly observable in-situ. Ultimately, this approach needs more calibration before widespread deployment.

Across all these innovations, the trend is toward continuous, high-resolution, and multi-parameter monitoring systems, enabling a more comprehensive understanding of ecological dynamics in (floating) offshore wind environments.

4.4 Insights from first demonstrators and pilot projects

Demonstration and pilot installations are providing the first critical insights into the environmental interactions of floating offshore wind systems. Several projects were highlighted across the Subcommittee meetings, each contributing valuable learnings on biodiversity responses and monitoring methodologies. While some of the following cases illustrate how a specific pressure from Figure 7 is being evaluated, these examples are all part of comprehensive monitoring programmes looking at multiple pressures, species and impacts.

The VELELLA project reinforces the role of the Floatgen demonstrator (2 MW) at the SEM-REV test site (off the coast of Le Croisic, France) in leading next-generation environmental observation and assessment methodologies. It combines mandatory measurements (underwater noise, electromagnetic fields, and benthic habitats) with complementary monitoring of marine mammals and bio-colonisation on submerged structures. Each innovation within the project is uniquely conceived through a lifecycle lens, accounting for environmental impacts and recyclability.[66] There is also a publicly available environmental monitoring report of the demonstrator summarising the observed impacts after 3 first years of operation.[67]

Figure 9. Left photo: European shag (*cormorant huppé*) on the upper mooring chain of Floatgen. Source: Centrale Nantes. Right photo: European lobster beneath a screw anchor of the Floatgen umbilical cable. Source: MNHN-Centrale Nantes.

[65] *ECB Subcommittee September 2025: An eDNA study conducted by ECOCEAN suggested the presence of species that did not align with expected local ecological conditions and parallel sightings from professional divers.*
[66] *ECB Subcommittee December 2024; BW Ideol May 2023 press release.*
[67] *Reynaud et al. 2021 (in French).*

The TetraSpar demonstrator (3.6 MW) at the METCentre test site in Karmøy, Norway worked with a specialised company (SpoorAI) to test the use of AI-based systems for bird monitoring. The experts assessed bird–turbine interactions using autonomous 8K camera systems as well as AI-driven 3D tracking of flight paths and rotor interactions. Over 5,500 hours of video analysis resulted in approximately 21,000 bird detections, with no recorded bird collisions across roughly 2,500 high-risk flight tracks within the rotor sweep zone. The AI system was also reported to perform at a level comparable to expert ornithologists (95%+ accuracy), enabling continuous offshore monitoring that is not feasible through manual observation alone.[68]

The DemoSATH unit (2 MW) operating at the BiMEP open-sea test site in the Cantabrian Sea, Spain has become a "living laboratory" for floating offshore wind under the DemoSATH Lab framework. All of the impacts and tools mentioned in this paper – EIA, biodiversity monitoring, coexistence with fisheries, platform LCA and nature-inclusive design – are captured in the Lab's focus areas. Currently, the Lab is incorporating AI to improve bird detection, recognise ringed individuals and quantify collisions after two years of using manual methods (via field ornithology, automated detection, continuous CCTV).[69]

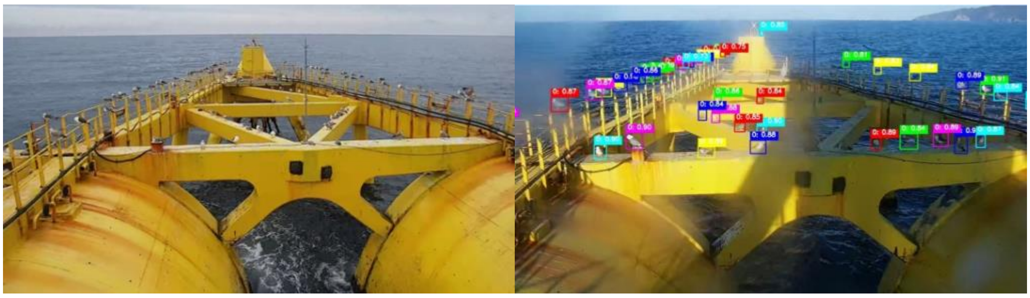

Figure 10. Photos of AI-powered bird monitoring at the DemoSATH floating wind platform. Source: Saitec Offshore Technologies.

Studies at Hywind Scotland on the country's east coast (30 MW, 5 units) and Hywind Tampen in the Norwegian North Sea (94.6 MW, 11 units) show evolving methodologies to assess the comprehensiveness of eDNA in capturing the local fish and plankton communities. The latest technical note for Hywind Tampen concludes no detectable impact (negative or positive) from the construction and operation of the Tampen project itself despite some changes in community composition. The note also underlines the importance of ground-truthing eDNA results versus previous baseline studies based on fish capture, camera, ROV or sediment analysis data.[70]

The BoB (Biodiversity observation Buoys) monitoring programme led by Ecocean and Ocean Winds/EFGL has evaluated, with the involvement of CEFREM-University of Perpignan, the settling of aquatic offshore biodiversity (fish, crustacean, mollusc) on floating structures in the Mediterranean Sea. The project directly contributed to the development of NIDs for the Éoliennes Flottantes du Golfe du Lion (EFGL) floating wind farm in the same geography. After four years of monitoring including 45 scientific dives and 150 survey sessions, researchers documented 47 species, juvenile recruitment as well as the presence of higher trophic species

[68] *ECB Subcommittee May 2025: SpoorAI presentation on environmental monitoring of TetraSpar.*
[69] *ECB Subcommittee May 2025; Saitec Offshore Technologies.*
[70] *Hestetun et al. 2025 ; Related impact assessments can be consulted at this link to Equinor's website.*

such as groupers, sharks, and octopus. Telemetry data further showed repeated movement of fish between coastal habitats and the offshore structures, suggesting ecological connectivity.[71]

The EolBio programme is an ecological monitoring initiative at the EolMed pilot (30 MW, 3 unit) in the French Mediterranean. Led by EPHE University and Qair, the project's central objective is to quantify the effect of the wind farm on marine biomass (specifically fish biomass). It will also identify scenarios for co-use with a sustainable exploitation of fisheries resources. A buoy equipped with various sensors is deployed to observe biofouling, fish, marine mammals and birds. A total of 32 taxa and ecological succession patterns were observed, with mussels dominating biofouling communities. Acoustic monitoring confirmed the presence of marine mammals (bottlenose dolphins and fin whales). The results were then used as inputs into the Ecopath with Ecosim open-source modelling software to simulate various scenarios including one of a 25-turbine configuration. The simulations suggested an increase in total biomass, ecosystem maturity and functional diversity. However, these findings remain site-specific and are based on pilot-scale inputs; longer-term and larger-scale validation is required before conclusions can be drawn on the impacts of commercial floating wind developments.[72]

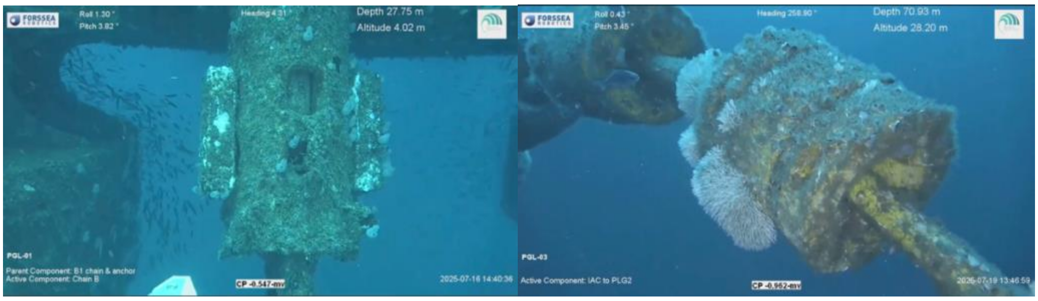

Figure 11. Screenshots from underwater monitoring of the mooring line connector to the floater (left) and dynamic cable buoyancy module (right) at the Provence Grand Large pilot project (25 MW, 3 units) in the French Mediterranean. Source: EDF Power Solutions video on YouTube. PGL is the third of the 3 pilot projects commissioned in the French Mediterranean from 2025-2026. Subsea inspections showed biofouling and other marine life around the FOWT.

In Japan, both the Fukushima FORWARD (14 MW, 3 units – now decommissioned) and Goto Floating Offshore Wind Farm (16.8 MW, 8 units) demonstrators have publicly available environmental monitoring reports, featuring details on methodology and photographs. Similar to the other demonstrators, results from Fukushima FORWARD show interactions between the avian/marine life and the structures with no significant negative impact. However, experts state that more research is needed for future wind farms, especially for assessing the wind farm's role in potentially serving as a protected area-like space that increases fish catch in surrounding waters versus preventing fishing activity at the site.

[71] ECB Subcommittee September 2025: ECOCEAN presentation on BioHuts at the EFGL pilot project.
[72]ECB Subcommittee November 2025; EolBio project description by Marepolis; Ocean Winds Floating Offshore Wind & Biodiversity Coexistence: A Data-Driven Report from WindFloat Atlantic in-person side event during WindEurope Madrid 2026, where a similar conclusion on extrapolating pilot findings to commercial-scale outcomes was made.

4.5 Nature-Inclusive Design (NID)

Nature-Inclusive Designs (NIDs) are "measures which are either integrated into the design of an offshore structure or incorporated as a standalone unit within the wind farm design as a whole, with the specific aim of supporting species or enhancing species richness."[73] In floating offshore wind, NIDs can be structural elements on the floater (and potentially the anchors or mooring cables)[74] or installed separately in the wind farm area.

In bottom-fixed offshore wind, NIDs can be reef-type structures, eco-concrete modules, artificial nurseries, textured surfaces, and adapted scour or cable protection for static components. They promote bio-colonisation, support ecological function (by acting as nursery grounds), increase habitat complexity or restore degraded habitats. Some concepts aim to influence bio-colonisation composition, reducing dominance by a single species and encouraging more diverse ecological communities. Examples of applications can be found at the OCEaN's Energy and Nature Database on nature enhancement and restoration.

NIDs are ideally considered early during the design phase (FEED – Front-End Engineering and Design and detailed design) to account for local ecological conditions, target species, platform stability, hydrodynamic behaviour, consenting implications, maintenance requirements, and eventual decommissioning. There is work to guide the incorporation of NIDs in the design phases to align ecological objectives with technical requirements. Other projects are identifying best practices for NID suitability assessments in offshore wind.[75] Incorporating NIDs retroactively is possible, although it is considered more complex and costly.

One of the world's first examples of NIDs on a full-scale FOWT is ECOCEAN's Biohuts (artificial nurseries) at the EFGL pilot farm (30 MW, 3 units) in the French Mediterranean. The modules are made from steel frames and filled with recycled oyster shells and serve as sheltered microhabitats. Within weeks of installation, a rapid early life stage of fish aggregation was observed. However, it is important to note that more time is needed to be sure of the NID's positive biodiversity impact as EFGL was only installed in summer 2025. To strengthen the conclusions, the ECOFEOL project is now comparing a Biohut-equipped versus non-equipped (control) floater at the EFGL wind farm. Lasting four years, this project will allow scientists to evaluate the net positive gain of the NID.

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[73] *Crown Estate Scotland 2025.*

[74] *A scaled prototype of a FOWT with NID at the anchors has been deployed in the Netherlands in May 2026.*

[75] *The INF4INiTY project is numerically and experimentally (test-tank) testing different nature-inclusive designs for a specific floating wind concept; NiD4OCEAN is assessing knowledge gaps for NIDs in the European Seas and creating tools to measure their performance. They also organised a competition to support nature-inclusive concepts specific to floating wind; The Wageningen Marine Research, Nature Regeneration North Sea developed spatial habitat suitability maps to inform offshore wind NID design in the Southern North Sea.*

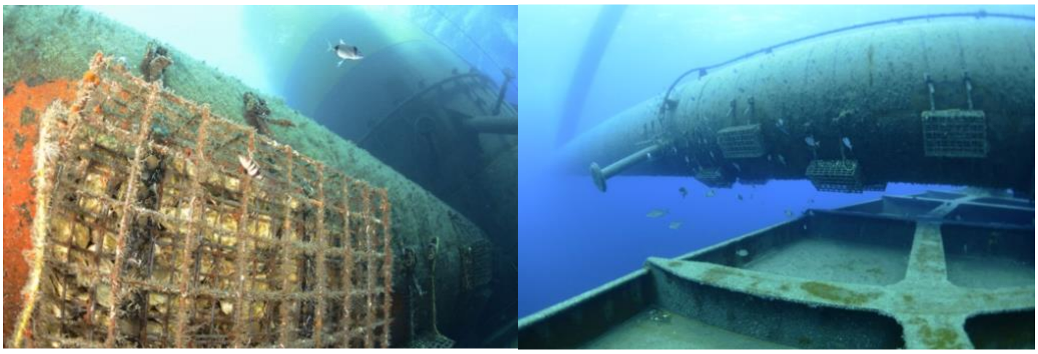

Figure 12. Photos of NIDs. Left photo: Coastal juvenile fish using Biohut as its new home on the EFG1 WindFloat. Right photo: Wider view of coastal fish near Biohuts on the EFG1 WindFloat. Source: Copyright Ecocean/Remy Dubas.

The DemoSATH Lab programme is advancing NID research by looking into the use of decommissioned turbine blades as multifunctional structures for cable protection and habitat enhancement. While not yet demonstrated for either application, preliminary observations on habitat or shelter provision are promising. Further validation is required to assess the long-term performance of the blade materials (resistance to degradation, abrasion, potential fragmentation) and their structural and hydrodynamic suitability as cable-protection elements. The DemoSATH Lab is also looking into platform-integrated aquaculture for mussels, oysters, clams, barnacles and algae.[76]

While these initiatives illustrate the sector's early interest in nature-inclusive design, implementing solutions remains constrained by uncertainties around the biodiversity benefits and the effects on the asset's structural loading. Developers might be reticent to adopt solutions if they are perceived as adding technical complexity, operational uncertainty, or financial risk.[77] There is also the larger industry pressure to lower floating wind's LCoE, and so NID requirements "compete" with other FOWT design priorities illustrated in Figure 13 below. If net gains can be proven thanks to rigorous testing and monitoring, NIDs could help reduce consenting risk by driving stakeholder acceptance of floating wind technology and aligning with wider biodiversity goals (e.g. Target 2 of the 2030 Biodiversity Targets). Tender requirements can incentivise the advancement of NID research and implementation (referring back to Figure 4).

[76] *ECB Subcommittee May 2025.*
[77] *Crown Estate Scotland 2025.*

Figure 13. FOWT design constraints. Projects are under immense pressure to balance all these factors and deliver technologically robust, cost-competitive projects with minimised environmental impacts. Developing NIDs is especially tricky in this period when FOWT concepts and associated production, transport and O&M methods are not yet standardised. *MCR = Major Component Replacement; T&I = Transport & Installation; WTG = Wind Turbine Generator; ILA = Integrated Loads Analysis.* Source: WFO.

5 Real world industry reflections

Uncertainty around the nature and extent of floating offshore wind environmental impacts slows the implementation of solutions. In this context, the industry faces a particular kind of "chicken-and-egg" dilemma: project data is needed to confirm the impacts and develop associated mitigation measures, but that data cannot be obtained without having installed projects. The upcoming commercial-scale floating wind farms must therefore compensate for current unknowns across design, logistics and environmental sustainability. The variability in FOWT concepts with vastly different spatial footprints, carbon footprints etc. further complicate the issue.

In addition, the multi-criteria optimisation exercise for FOW projects is highly complex, and "the final design for any floating wind farm will be less idealised than early design concepts."[78] Cost competitiveness remains the sector's strongest priority. While the LCoE pressure is more specific to floating wind, the industry is also affected by general challenges affecting offshore wind and marine renewable energy. These obstacles, summarised below, occur at the level of policy (marine spatial planning and offshore wind regulation), scientific research and public perception.

5.1 LCoE pressure

In this early-stage commercialization phase, cost competitiveness understandably remains the dominant drivers of decision-making. For developers, delivering a financially viable project is the prerequisite to achieving any broader environmental or social goals. While innovations such as larger turbines, optimised station-keeping systems, and improved logistics (installation, O&M) can reduce environmental impacts, they are primarily adopted based on their contribution to cost reduction. Environmental measures are therefore often treated as secondary unless it aligns directly with economic outcomes.[79]

Furthermore, the race to drive down the LCoE has created a very competitive industry environment with multiple platform designs competing for future projects. Technology selection approaches like competitive FEED can lead to attractive offers for final detailed design and EPCI contracts but these challenge consenting because of the lack of early visibility on the FOWT/project design.[80]

5.2 Policy versus practice

Regulatory frameworks play a critical role in shaping development conditions for floating wind, but many countries do not have established systems. For example, floating wind markets like in the Mediterranean do not have mature MSP frameworks or offshore wind regulatory frameworks.[81] This translates into increased development uncertainty, delays in

[78] *ORE Catapult 2025.*
[79] *ECB Subcommittee meetings; Crown Estate Scotland 2025.*
[80] *Interface Risk Subcommittee October 2024.*
[81] *Airoldi et al. 2025 (MARINEWIND); UNESCO-IOC and UN Global Compact 2025.*

permitting, and higher perceived investment risk where spatial allocation or project award timelines are not clearly defined.

When it comes to offshore wind planning, governments are incorporating non-price criteria, coexistence rules and biodiversity-related requirements for projects. However, these criteria are not fully matured.[82] In the case that the criteria are established, they often carry limited weight compared to economic and technical factors.[83] Finally, baseline and monitoring study requirements are not sufficiently standardised or comprehensive, challenging the creation of evidence-based strategies to reduce environmental impacts.[84]

5.3 Knowledge gaps and data-sharing

Insufficient knowledge on floating wind environmental impacts – from lack of track record, larger marine data gaps[85] and/or competitive project structures that do not fix technology selection early on – act as critical barriers to consenting. Despite progress through pilot projects, key questions remain regarding long-term and cumulative environmental impacts, as well as the scalability of emerging solutions such as nature-inclusive design. To address this uncertainty, the EIA process may factor in conservatism at the risk of overestimating the negative impact of a project. This creates additional time and money spent on associated studies and the planning of mitigation measures which can then delay the overall consenting process.[86]

Another major bottleneck lies in the sharing of data. Environmental and operational datasets are frequently fragmented, project-specific, or commercially sensitive (e.g. fishing grounds data). This limits cross-project comparisons and constrains the development of integrated ecosystem models capable of assessing multiple environmental parameters simultaneously. ECB discussions highlighted growing interest in collaborative digital approaches such as system dynamics modelling frameworks that combine social, environmental, operational, and oceanographic data into more comprehensive decision-making tools.

5.4 Public perception

Finally, concerns with fishing activity displacement, ecosystem impacts, and long-term uncertainty can lead to resistance of floating wind development. The general information gaps on the marine environment plus the variability in FOWT technology makes it difficult to

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[82] *In 2025, WindEurope published recommendations to EU governments on implementing non-price criteria in wind energy auctions under the Net-Zero Industry Act (NZIA). They recommend that the landfill ban be considered as pre-qualification and that wider circularity criteria and biodiversity impact should be considered for award. They do* ***not*** *recommend using LCAs for prequalification or award.*

[83] *Spinergie 2026: The latest AO10 tender in France will attribute 14 points out of 100 to "industrial, environmental and social/territorial value". 6 of those points will specifically go to a "simplified carbon footprint" of the turbine, foundation and station-keeping system.*

[84] *Watson et al. 2025; OCEaN Process Harmonisation for Better Environmental Monitoring Factsheet*

[85] *Galparsoro et al. 2020: There is a general need for more data on species distribution and abundance across larger spatio-temporal scales (annual cycles and on migration routes) to support offshore wind developments.*

[86] *ECB Subcommittee April 2026 where participants discussed the excessive lengths Environmental Impact Statements to address many impacts and uncertainties.*

communicate clearly what the industry's environmental impacts are and as a result delay the consenting process (i.e. failure to address stakeholder concerns).[87] This disconnects between scientific findings and stakeholder perceptions highlights the importance of early engagement and clear, transparent communication of impacts.

5.5 Call to industry and policymakers

Despite these constraints, efforts to improve lifecycle assessments, biodiversity monitoring, and coexistence with other economic activities reflect an early but tangible commitment from the floating wind sector to more sustainable practices. Some recommendations to properly embed and scale the various solutions emerge:

5.5.1 Adapt regulatory frameworks to ensure sustainable FOW development

Governments must ensure that environmental performance is effectively integrated into (floating) offshore wind project development. This includes:

- MSP as the foundation to allocating the most suitable zones to offshore wind, supported by data-driven mapping & modelling tools and early stakeholder engagement.[88]
- Country offshore wind strategies that distinguish between bottom-fixed and floating offshore wind targets, which then helps allocate the right support to each technology's associated impacts. Explicit commitments to multi-use systems (e.g. floating wind and aquaculture) can support related technology development.
- Offshore wind permitting processes that reduce the duration and uncertainties of the development phase: one-stop-shop regulatory body to coordinate permits, standard EIA rules that assess realistic worst cases but are not overly conservative, framework for stakeholder engagement and coexistence, recognition of alternative compensation mechanisms like biodiversity protection and restoration efforts.
- Offshore wind tender/auction designs with weighted environmental requirements (i.e. non-price criteria) that meaningfully influence project selection.
- Clear guidance and standards on site assessment and monitoring methodologies[89] plus access to high-quality environmental data through dedicated portals.
- Support for innovation through targeted funding. This helps allocate resources to innovation and modelling tools that address more than just the LCoE (environmental and

[87] *For example, bird observations at the TetraSpar demonstrator in Norway and the DemoSATH in Spain concluded very little to no collisions. However, both projects highlight that it is not possible to generalise the impact across future developments given how results vary from the monitoring method, local species behaviour and project configuration (pilot versus large scale).*

[88] *OCEaN's official feedback to The Ocean Act in February 2026 lists 4 recommendations for Europe: Strengthen MSP as a central and strategic governance tool ; Strengthen the cross-border and sea-basin perspective; Enable coexistence and multi-use; Improve data sharing. The Mitsubishi Research Institute has 11 recommendations across 4 themes in slide 18 for Japan: MSP and segregation of the two industries; Accumulation, verification and sharing of scientific data; Contribution to the sustainable development of the fishing industry; Development of human resources with a comprehensive perspective. REASP also published recommendations in 2026 to restructure the Japanese offshore area selection process into a data-driven, highly transparent system.*

[89] *The revision of the MSP Directive under the Ocean Act 2026 could benefit from setting clearer quantitative targets or monitoring indicators (OCEaN 2026). The Global Initiative for Nature, Grids and Renewables (GINGR) is an initiative to develop monitoring and reporting systems that are globally aligned and standardised. They published a guidance on biodiversity monitoring for offshore wind.*

socio-economic indicators).[90] High-level coordination can also help expand monitoring programs to cover ecosystem/basin-level impacts.[91]

- Transparent communication of results (both positive and negative) to the wider public to educate and drive support for floating offshore wind.

5.5.2 Adopt the holistic approach to mitigate project-level impacts

A holistic, lifecycle-based approach to design is key to mitigating environmental impacts. Methods like LCA and NID can support early-stage design so that FOWTs intrinsically address emissions, biodiversity, and coexistence with other marine resource activities. In addition, monitoring indicators that are decided from the design phase must contribute to the industry's learning of long-term effects. These indicators can then serve as inputs to system dynamics models, enabling the assessment of multiple and cumulative impacts across operational, environmental and social dimensions. By evaluating trade-offs under different development scenarios, these models can also support evidence-based decision-making for projects. Government plays a role in incentivising these design choices as well as facilitating the sharing of findings (biodiversity monitoring data, LCA inputs…).

5.5.3 Support standardised R&D to track and reduce environmental impacts

National and international standards in baseline and monitoring studies are important to ensure quality results that support comparative assessments and evidence-based decision-making. Validating impacts through observation is the core principle, like for instance through the BACI method. Statistical biases and natural variability in data should also be carefully considered in investigation and interpretation of EIA studies. Harmonised indicators notably support the tracking of cumulative impacts and wider ecosystem dynamics. Finally, methods to study pressures in combination can reveal impacts otherwise not found when looking at them in isolation.[92]

Mitigation measures and new monitoring technologies must also be validated. Experimental testing and full-scale pilot projects are essential to gaining confidence in solutions (NIDs, eDNA, multi-purpose data buoy…), which then facilitates future investment in them. Other mitigation measures implemented for bottom-fixed technology should be assessed for relevance to floating wind.

5.5.4 Promote knowledge-sharing between and across all stakeholders

While floating wind environmental impacts, their mitigation measures and encompassing regulation are extremely context-specific, there is great benefit to international

[90] DNV's MARCO project received a grant under The Research Council of Norway. Another mapping tool from a private company discussed at WindEurope Madrid 2026 has its origins in the HorizonEU programme. The four HorizonEU projects presented in the "Designing the Future of Floating Offshore Wind" side event are all incorporating environmental and socio-ecological parameters.

[91] The ORE Catapult's Regional Ecosystem-based Monitoring Programme (REMP) advocates for regional rather than project-by-project monitoring, summarising recommendations including the appointment of a central, neutral facilitator to oversee the approach (for which the Catapult considers itself suitable given its inter-disciplinary track record and links to industry, government and academia).

[92] GINGR 2024 discussion paper on advancing standardised biodiversity monitoring for nature-positive offshore wind development; OCEaN Process Harmonisation for Better Environmental Monitoring Factsheet; Rezaei et al. 2023; Watson et al. 2025; Galparsoro et al. 2020; DHI at WindEurope Madrid 2026.

knowledge exchanges on lessons learned. These exchanges help markets at earlier stage of offshore wind development adopt best practices in their regulation and stakeholder engagement process early on; they create the necessary partnerships to build large-scale, accurate maps of ecosystem responses to offshore wind; they pool complementary expertise to develop new mitigation or monitoring technologies; they increase public awareness of the world's environmental crises and the role of offshore wind in solving them.

The ECB Subcommittee will continue supporting this effort by hosting knowledge-sharing sessions, documenting emerging practices, and advocating for harmonised guidance to make sustainable best practices a scalable reality for floating offshore wind.

Appendix – Definitions

Acoustic monitoring = Use of acoustic sensors (e.g. hydrophone) to track marine mammal communication, fish movement, and noise impacts from offshore wind activities. Acoustic monitoring is a standard method under the Marine Strategy Framework Directive (2008/56/EC) for assessing underwater noise pollution.

Baseline data collection = Systematic gathering of ecological, physical, and social data before project development to establish reference conditions. Baselines are essential in EIAs and LCAs to enable impact comparison (EU EIA Directive 2014/52/EU).

Carbon footprint or intensity = A measure of greenhouse gas emissions (e.g. CO_2) per unit of energy generated. In offshore wind, this is often expressed as grams of CO_2 equivalent per kilowatt-hour (gCO_2e/kWh). Offshore wind averages 8-32 gCO_2e/kWh, among the lowest of all energy sources. Other estimates can vary around this range, with floating wind expecting to emit more than bottom-fixed wind. Measuring the emissions per mass of material/foundation fabricated is also a parameter of interest.

Coexistence (or cohabitation) = The coexistence of floating offshore wind farms with other marine users, such as fisheries, aquaculture, and shipping. Effective cohabitation relies on spatial planning, stakeholder engagement, and governance models (EU MSP Directive, 2014/89/EU). Regarding coexistence with commercial fishing specifically, coexistence 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.” (ORE Catapult 2025).

Credits = In lifecycle assessment (LCA), “credits” refer to avoided emissions or resource use that result when recycling, reuse, or recovery displaces the need for producing new materials or products. Nature credit is broader term for quantifying and rewarding positive biodiversity outcomes from restoration efforts (e.g. that sequester carbon, support habitat recovery, conservation etc.).

Cumulative impacts = Combined environmental effects from multiple offshore wind farms and other marine activities over time. Often assessed using system dynamics modelling and required under the EU Strategic Environmental Assessment (SEA) Directive (2001/42/EC).

Electromagnetic fields (EMF) = Fields generated by subsea power cables, potentially affecting magneto-sensitive species such as sharks, rays, and eels. EMF impacts are typically mitigated through burial, shielding, or optimised cable routing.

End-of-Life (EoL) management = Processes for dismantling, reusing, refining, or recycling components of floating wind farms after decommissioning. EoL strategies contribute to circularity and emission reduction (ISO 14040, EU Circular Economy Action Plan, 2020).

Environmental impacts or just impact = Change in the state of ecosystems resulting from human activities or natural events. In the context of this paper, the cause of the impacts is the resource flows (movement of materials, energy, and waste) and activities associated with building a (floating) offshore wind project. Impacts can be positive or negative, affecting marine ecosystems and coastal communities. Impacts are identified and managed through EIA and LCA frameworks.

Environmental indicators = Quantitative or qualitative measures that provide information on the condition of the environment, human pressures, and the effectiveness of mitigation measures. In the context of floating offshore wind, environmental indicators are used to evaluate project impacts and track sustainability performance across the lifecycle.

Hotspot analysis = Identification of lifecycle stages or components that contribute most significantly to environmental impacts (e.g., steel production). Central to interpreting LCA results (ISO 14044).

Marine Spatial Planning (MSP) = A governance framework for organising human activities in marine areas to balance economic, social, and environmental objectives. Required under the EU MSP Directive (2014/89/EU).

Nature-Inclusive design (NID) = “Measures which are either integrated into the design of an offshore structure or incorporated as a standalone unit within the wind farm design as a whole, with the specific aim of supporting species or enhancing species richness” (Crown Estate Scotland 2025). In floating offshore wind, NIDs can be structural elements on the floater (and potentially the anchors or mooring cables) or installed separately in the wind farm area.

Noise pollution (underwater) = Sound generated during construction, operation, and decommissioning of offshore wind projects, which can disrupt communication and behaviour of marine mammals and fish. Regulated under the Marine Strategy Framework Directive (2008/56/EC).

Resource flow = The movement of materials, energy, and waste across the lifecycle of floating wind projects. Analysis of resource flows supports circular economy goals and sustainability reporting.

Stakeholder engagement = The process of involving marine users, regulators, and communities in marine spatial or offshore wind project planning to identify conflicts of interest, build trust, and co-design solutions. Best practice frameworks include early engagement and transparent communication (OECD, 2017).

Trophic dynamics = Ecosystem-level changes in predator-prey relationships driven by offshore wind structures acting as artificial reefs. These dynamics may increase local biomass but alter species composition (ICES, 2021).

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