

FLOATING WIND JOINT INDUSTRY PROGRAMME

# Resilience of mooring systems exposed to fishing

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## RESILIENCE OF MOORING SYSTEMS EXPOSED TO FISHING (RMSF)

# Introduction

As floating wind progresses from the pilot stage to the first commercial-scale arrays, the activities and needs of other marine users must be strongly considered from both a marine spatial planning and risk management perspective. Fishing, with its diverse techniques used internationally, represents one of the most significant interacting sectors, with the potential to affect and be affected by floating wind developments. The primary objective of this project was therefore to evaluate the potential risks and impacts associated with fishing activities on the mooring systems and subsea cables of floating offshore wind turbines (FOWTs) in scenarios where fishing activities take place around floating offshore wind farms.

By investigating existing fishing practices worldwide and analysing a range of mooring systems and cable configurations, the study sought to identify potential failure modes and develop effective mitigation and remediation strategies. The project assessed the feasibility of coexistence between floating offshore wind farms and fisheries and explored how such coexistence could be achieved in practice. It also aimed to improve industry understanding of the potential risks and impacts of fishing activities on FOWT mooring systems and subsea cables.

In response to the anticipated increase in interactions between these two industries, the existing fishing methods and floating offshore wind configurations were analysed to identify and assess failure modes and their effects on key components. Hazards were categorised by risk level to determine which fishing activities can be safely conducted in the proximity of floating offshore wind assets. An economic assessment was also performed to evaluate the costs associated with different mitigations and remediation measures, and the financial implication of coexistence for both industries.

## Project objectives

1. Assess the potential damage fishing activities pose to mooring systems, dynamic and static cable systems and critical components of offshore infrastructure.
2. Evaluate fishing-related risks to mooring and subsea cable systems and define both remediation and mitigation strategies, including a cost-comparison between the two.

## Methodology

The study adopted a structured methodology combining a literature review and stakeholder engagement to establish context and gather industry insights, followed by a risk assessment to evaluate potential interactions between fishing activities and floating offshore wind assets. The outcomes of these activities informed the identification of key risks and the development of appropriate mitigation measures.

The methodology and underlying assumptions outlined below, defined the scope and boundary conditions of the analysis and guided the assessment of potential risks and interactions affecting FOWT mooring systems and subsea cables.

### Assumptions

The key assumptions and system definitions for this study were as follows:

- The fishing techniques evaluated are the most commonly used in offshore fishing: surrounding nets and lift nets, trawls, gillnets, pots and traps.
- The floating foundations are categorised based on their general arrangement and how they achieve stability. This resulted in the following substructure types: semi-submersible, spar, barge, tension leg platform (TLP).
- The station-keeping system configurations are categorised into the following types: catenary, semi-taut, taut and TLP systems.
- Cable configurations, considered less critical than station-keeping system configurations in the risk assessment, include lazy-wave, W-shaped, catenary, lazy-S, tethered-wave, steep-wave and Chinese lantern. In addition, the cable array layouts outlined in the report comprise daisy chain, star and fishbone inter-array.

### Literature review

A literature review was conducted to collect relevant scientific literature, industry reports, safety bulletins, and government regulations. It was followed by a detailed review to extract key insights and summarise findings related to mooring and subsea cable systems risks.

### Stakeholder Engagement

Feedback was collected via tailored questionnaires distributed to the following stakeholder groups:

- **Mooring systems:** fishing industry representatives, mooring system designers, rope manufacturers, oil and gas and renewable operators, installation contractors, research and development organizations, and classification societies.
- **Cable systems:** manufacturers, operators, transport and installation (T&I) contractors, consultants, auxiliary components and monitoring.

### Damage mechanisms and failure modes

Damage mechanisms and failure modes affecting mooring systems and subsea cable systems were identified through the literature review and stakeholder engagement. These provided insight into how different fishing practices may impact floating offshore wind mooring systems and subsea cables.

### Scenario definition

The scenario definition considered regions with significant fishing activity and potential for floating wind deployment. These scenarios incorporated variations in water depth, fishing techniques, and mooring configurations, providing examples of potential coexistence between floating offshore wind farms and fishing activities.

### **Risk Assessment**

A qualitative risk assessment was conducted based on mooring system configuration, focusing on how the extent of the mooring system's seabed footprint and makeup influences its compatibility with different fishing techniques.

Additionally, component-level risk assessments were performed through the development of a Failure Modes, Effects, and Criticality Analysis (FMECA). Separate FMECA was developed for mooring-system and subsea cable system components, covering both buried and exposed cables.

Each FMECA outlined identified risks, their potential impact, and helped develop the corresponding mitigation measures. It assessed the likelihood, severity, and detectability of each failure mode and categorised risks into critical, medium-risk and low-risk scenarios. This analysis provided the foundation for identifying the correlation between specific fishing techniques and the most severe failure modes of the mooring components and subsea cables.

The FMECA presented certain limitations. The interactions between the mooring systems and subsea cables with the fishing gear of a specific technique did not account for the position of the mooring line or cable components. Moreover, the severity ratings of failure consequences may be similar across different fishing techniques.

### **Cost Analysis**

A cost analysis was conducted and a probabilistic model was developed to compare various mitigation and remediation strategies with the objective of identifying the most cost-efficient option. For each mitigation measure, a cost label was applied based on expert feedback and cost comparisons from a proprietary database. Each cost label corresponds to a defined cost range, which was subsequently incorporated into the probabilistic model.

Recognising that not all measures would be implemented simultaneously, these were grouped into three realistic scenarios, each representing a strategic combination of mitigation and remediation measures with associated costs, cash flows, and levels of implementation complexity. The analysis considered both Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) perspectives and included cash flow assessments for the fishing and floating offshore wind industries to evaluate the broader economic implications of coexistence.

## 1.1. Key findings

1

**The consequences of fishing interactions are influenced by the mooring configuration and seabed footprint, along with the type of component.**

- Mooring systems with large seabed footprints pose the highest risk of interference with fishing activities, particularly with active fishing methods. In contrast, TLPs and taut systems with near-vertical lines present lower risks of interference.
- The materials used in mooring lines or tendons influence the severity of the consequences in the event of an interaction with fishing activities. While larger seabed footprints may increase vulnerability, using more resistant materials can reduce the severity of impacts.
- The design of mooring systems must satisfy various constraints, meaning their configuration cannot depend only on compatibility with local fishing practices.
- Mooring lines and tendons are the most vulnerable subsystem components of station-keeping systems, particularly synthetic fibre ropes and wire ropes, which are susceptible to cutting and snap loads.
- Exclusion zones ensure safety; however, mooring components may still extend beyond these exclusion zones and remain exposed to fishing activities.

2

**Certain fishing techniques cannot be conducted within floating offshore wind farms.**

- Fishing methods that actively tow gear through the water column, especially those involving dragging across the seabed, are more likely to interfere with station-keeping systems and are associated with high-risk scenarios.
- Fishing techniques that use towed gear are generally incompatible with floating offshore wind farms. However, they may be compatible with TLP configurations under very specific conditions such as favourable metocean conditions, small gear sizes, and adequate spacing within the floating offshore wind farm. A site-specific assessment should be carried out to determine if coexistence is feasible.
- Passive fishing techniques pose a lower risk of interaction provided there is sufficient space, except during deployment and retrieval.

3

**Mitigation and remediation strategies are key to reduce the risk of interactions.**

- Mitigation and remediation strategies include technical design adaptations and definition of operational best practices and collaborative approaches with stakeholders. Their selection and effectiveness depend on the specific technologies, design requirements, and site conditions, with implementation determined by the appropriate parties, either floating offshore wind developers or the fishing industry, based on project-specific studies.
- Mitigation and remediation strategies can be evaluated based on their potential to reduce the likelihood and severity of failure modes, improve detectability, and their implementation complexity.

Cost considerations have major impact on strategy selection and should be integrated in the decision-making process.

- Measures that involve modifications to the technical design typically incur the highest costs.

4

**Coexistence between floating offshore wind farms and fishing activities is highly site-specific.**

- The analysis of multiple case studies, supported by risk assessments and incidents reviews, shows that coexistence between floating offshore wind farms and fishing activities is highly site-specific. This is mainly driven by differences in fishing techniques, fleet characteristics, target species, metocean conditions, and floating offshore wind infrastructure.
- The risk assessments showed that the technical compatibility between both industries is governed by a combination of site and project-specific factors. In particular, the type of fishing activity, seabed footprint, materials, mooring system configuration, including the location of its components along the mooring line, were found to strongly influence the criticality of interactions. These findings underscore the importance of project-based risk assessments to support the design of mitigation and remediation measures.

5

**Subsea cable systems generally face lower risk of interaction than station-keeping systems.**

- Unlike mooring systems, the risks associated with subsea cables evaluated through an FMECA indicate no high-risk scenarios. This is due to the likelihood of detecting the cause of the most severe and probable failures through the implementation of mitigation measures.
- Several medium-risk scenarios can be detected through a risk assessment and should be considered for the development of mitigation and remediation measures. Examples of medium-risks arising from interactions with different fishing techniques include wear and abrasion of bend stiffeners, as well as torsion and bending of the subsea connectors and joints, among others.
- Dynamic cables within floating offshore wind arrays are exposed to higher risks as multiple cables and mooring lines, which may include several ancillary components, are present in the water column.

## 1.2. Innovation/technology needs

1

**Innovative approaches are required to improve safety and enable coexistence.**

- While safety zones are mandatory in some countries, regulatory approaches and their implementation vary and may not be sufficient to prevent interactions between floating offshore wind farms and fishing activities. Improved regulatory consistency and spatial planning frameworks, supported by advanced monitoring approaches, enhanced asset marking, and interoperable regulatory standards, are needed to ensure safety and enable coexistence.
- Adapting wind farm layouts, establishing designated fishing zones and transit corridors, and improving the visibility and marking of floating offshore wind assets can reduce the likelihood of interactions between the two industries. Further innovation in spatial planning and marking technologies could significantly enhance safe coexistence.
- Given the complexity of floating offshore wind cable layouts, new approaches to system redundancy and integrated design are required to ensure continuity of power production. In particular, the interdependence between subsea cable systems and station-keeping systems should be better addressed through co-design, system-level risk assessment, and advanced modelling tools when defining mitigation strategies.
- The development and deployment of enhanced materials for station keeping systems and subsea cable systems, represents an important area for research and development. In parallel, innovation in fishing gear design and adaptation can play a key role in reducing the likelihood and severity of interactions between floating offshore wind assets and fishing activities.

2

**Data sharing and engagement approaches are needed to strengthen early-stage planning.**

- Fisheries studies conducted at an early-stage of project development are essential to identify the local fishing techniques, their spatial distribution and traffic density. There is a need for data sharing to maintain updated information and support spatial planning decisions.
- Early engagement with the fishing community during the planning process helps identify the most suitable mitigation measures. In some regions, spatial planning approval may depend on the agreement of fisher's representatives. Therefore, new consistent communication approaches and collaborative frameworks are needed to facilitate dialogue and build trust among stakeholders.

3

**There is a need to implement and maintain up-to-date databases and accurate nautical charts to reduce risks and enable coexistence of floating offshore wind and fishing activities.**

- Maintaining up-to-date databases and nautical charts, integrating the locations of station-keeping systems and subsea cables, is essential to ensure that the information is accurate and accessible to fishers and maritime authorities.

- Communication tools play a key role ensuring compliance with designated exclusion zones, thereby reducing the likelihood of interference. It is essential that these tools are reliable and widely adopted, as adherence to safety zones is critical for maintaining safe operations, particularly during construction and operations phases.

4

**Improving safety response and conflict resolution mechanisms is essential for incident management and compensation.**

- Emergency response plans for entangled gear need to be developed and clearly communicated to fishers, as fishing gear retrieval can compromise personnel safety. Other incidents (e.g., impact damage, wear & abrasion, or anchor displacement), while not posing immediate risks to personnel safety, also require clear guidance on how to implement remediation measures and prevent further damage to assets.
- Compensation mechanisms for demonstrable economic losses to fishers, along with insurance liability frameworks, remain a knowledge gap and require further development to ensure fair and transparent conflict resolution.

## ABOUT THE FLOATING WIND JIP

The Floating Wind Joint Industry Project (Floating Wind JIP) is a collaborative research and development (R&D) initiative between the Carbon Trust and 17 leading international offshore wind developers: bp, EDF Renouvelables, EnBW, Equinor, Kyuden Mirai Energy, Ørsted, Ocean Winds, Parkwind, RWE Renewables, ScottishPower Renewables, Shell, Skyborn Renewables, SSE Renewables, TEPCO, Tohoku Electric Power Company, Total Energies and Vattenfall.



The primary objective of the Floating Wind JIP is to overcome technical challenges and advance opportunities for commercial scale floating wind. Since its formation in 2016, the programme scope has evolved from feasibility studies to specific challenges focusing on:

- Large scale deployment
- De-risking technology challenges
- Identifying innovative solutions
- Cost reduction

Stage 3 of the Floating Wind JIP commenced in 2022 and projects are expected to run until early 2027. With several commercial scale floating offshore wind farm projects in design phase and having the ambition to be commissioned by 2030, the industry needs to address several challenges. The 17 Floating Wind JIP partners agreed on six research areas where further understanding and advancement is required to reach full commercialisation of floating offshore wind projects.

Electrical systems	Mooring systems	Logistics	Windfarm optimisation	Foundations	Asset Integrity and monitoring

This Resilience of mooring systems exposed to fishing (RMSF) project addresses the ambitions of the Mooring Systems research area:

## Mooring systems

1	Define optimal mooring layout and anchoring for different challenging environments and model subsea interactions.
2	Better understand the integrity of mooring lines through improved monitoring techniques.

The Stage 3 summary reports can be found here: [Phase I](#), [Phase II](#).

## ABOUT THE CARBON TRUST

### Who we are

Our mission is to accelerate the move to a decarbonised future. We are your expert guide to turn your climate ambition into impact.

We have been climate pioneers for more than 20 years, partnering with leading businesses, governments and financial institutions to drive positive climate action. To date, our 400 experts globally have helped set 200+ science-based targets and guided 3,000+ organisations and cities across five continents on their route to Net Zero.

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