Offshore Wind Evidence + Change Programme

FLOWERS – Floating Offshore Wind Environmental Response to Stressors

Overview of Work Packages (WP 1, 2 and 3)

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1. Introduction

The FLOWERS project forms part of the Offshore Wind Evidence and Change programme, led by The Crown Estate in partnership with the Department for Energy Security and Net Zero and Department for Environment, Food & Rural Affairs. The Offshore Wind Evidence and Change programme is an ambitious strategic research and data-led programme. Its aim is to facilitate the sustainable and coordinated expansion of offshore wind to help meet the UK's commitments to low carbon energy transition whilst supporting clean, healthy, productive and biologically diverse seas.

There is uncertainty regarding the potential impacts of floating offshore wind (FLOW) structures on the marine environment. This uncertainty raises concern among stakeholders and regulators, which could increase the potential for delays with FLOW developments in order to address stakeholder concerns or the potential for barriers to consent to arise.

The FLOWERS project was commissioned to improve knowledge of poorly understood stressors identified during the assessment of environmental impacts for floating offshore wind (FLOW). The outputs from the FLOWERS project will support the environmental knowledge base towards the future transition towards floating offshore wind technology to meet the UK's low carbon energy transition ambition. FLOWERS also address the OWEC Programme theme of: Improving the understanding of environmental impacts and benefits.

The project looked at three topics that have a relatively poor knowledge base with the aim to improve the level of confidence in addressing EIA requirements based on evaluation of the scientific evidence supported by modelling (where possible) for each of the topics in the context of floating offshore wind.

The project consisted of three Work Packages (WP):

1. **Scour of mooring lines -** which modelled the physical consequences of the hydrodynamic changes associated with the scour from FLOW mooring lines. The scour modelling identified localised changes in the seabed (scour pits and a coarsening of sediment distribution) as well as broader changes in the distribution of suspended sediment in a shelf-wide case study of a small windfarm in the Celtic Sea. The WP considered the potential pathways for the impact of scour on the seabed and the thereby the loss of habitat to benthic communities and associated marine life at the local and regional scales. Further

work is needed to validate such modelling with field observations, and to investigate the effect of seasonal variations and extreme weather events.

2. **Electromagnetic fields (EMFs)** – which modelled and measured EMFs and developed an approach to assess the likelihood of encounter between receptor species and EMFs emitted by subsea power cables. The likelihood of encounter approach will assist during the scoping stage of the environmental assessment of whether EMFs from FLOW infrastructure (in particular the dynamic cables) will potentially impact receptors that are of conservation, commercial or ecological importance. This work built on a previous OWEC-funded EMF workshop.
3. **Multiple Stressor Framework** - which investigated how separate pressure-receptor interactions described in environmental impact assessments can be integrated into a multi-stressor framework. This work aligns with the need for cumulative environmental assessment methods throughout the FLOW project lifecycle.

A summary of each work package and recommendations is provided in the subsequent sections of this overview, while full details of the outputs are provided in the corresponding technical report for each work package.

The FLOWERS project was focused on UK waters, however the outputs of all the WPs are generally applicable: the modelling and the frameworks produced could be applied in any region where floating offshore wind is being developed. We anticipate these outputs will help inform decision-making processes and support the deployment of floating offshore wind from demonstration level to full commercial scale.

2. WP1 – Modelling seabed impacts of floating offshore wind

WP1 of the FLOWERS project aimed to understand the potential impacts of floating wind turbines on the marine environment, with a focus on the effects on the seabed. Mooring lines are used to keep floating wind turbines in place but the motion of the structure can cause mooring lines to abrade the seabed and generate local scour. Here we developed a suite of models to assess impacts from the scale of individual mooring lines and floating structures up to wind farms and shelf-wide impacts. This methodology can then be used to assess how seabed disturbance may impact benthic habitats and communities.

The Celtic Sea was chosen for this case study as it has been identified as a site for future floating wind farm development. To assess the impact of wind, waves, and tidal currents on mooring lines at this site, the OpenFAST model was used. This engineering model simulates the movement a structure under different environmental conditions, with resulting changes in the Touch Down Zone (TDZ), as illustrated in Figure 1. The results from these simulations showed that tidal currents generated the largest change in TDZ, hereby impacting the seabed on the greatest extent. The inferred relationship between tidal current magnitude and absolute change in TDZ was then chosen to parameterise the increased disturbance on the seabed in further model development.

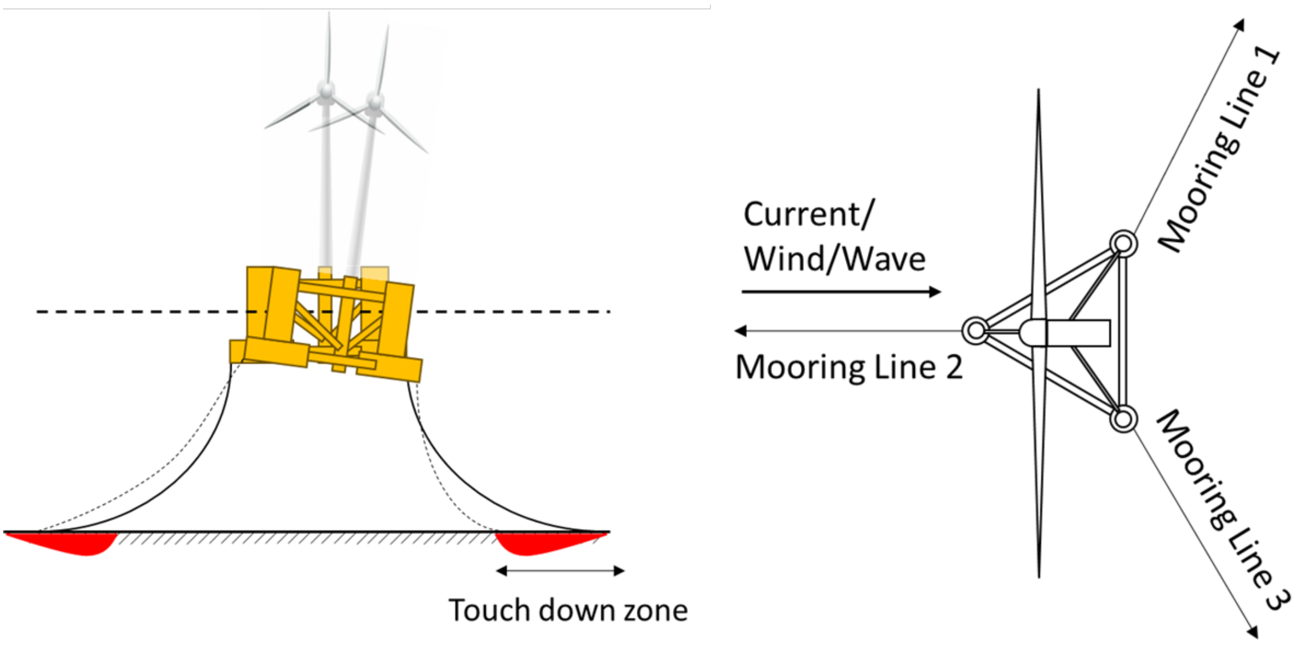

Figure 1. Schematic illustrating movement of floating wind turbine and resulting change in touch down zone (TDZ) for mooring lines on seabed. Structure considered here is OC4-DeepCWind semi-submersible floating wind platform and mooring system.

The TELEMAC-3D hydrodynamic model was used to explore the impacts on sediment distribution within the scale of a wind farm development. This high-resolution case study examined the combined physical effects of floating wind turbines, such as reduction in wind speed, hydrodynamic drag of the structures, increase in turbulence, weight of the structures, and increase in bed shear stress over the TDZ. All these factors have potential to contribute to the overall environmental impact. An idealised model of a small-scale floating wind farm was initially used to demonstrate model performance. The same methodology was then used to simulate impacts on known sediment distribution in the Celtic Sea. The results from both configurations suggest that seabed impacts may be highly localised within the wind farm area. Within the footprint of each wind turbine, a scour pit forms (Figure 2), with a coarsening of sediment remaining in the area. However, as these simulations only considered impacts over a relatively short period (up to 28 days), the final depth of scour and fate of suspended material is uncertain.

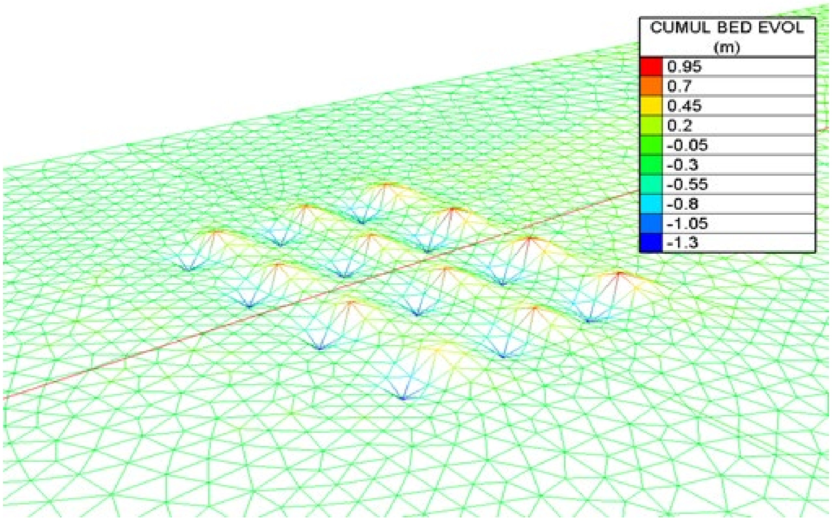

Figure 2. Cumulative bed evolution after 28-days shown in TELEMAC-3D idealised test case simulation. Scour developed under each of the 12 floating turbine structures.

To assess impacts on longer timescales and wider areas, the NEMO hydrodynamic model was used, coupled to a suspended particulate model (IOW-SPM). This model again considered impacts from a single wind farm within the Celtic Sea. However, the lower resolution of the model (approximately 7 km grid spacing) enables us to explore wider impacts on sediment distribution across UK shelf seas, over a longer, 1-year simulation. Results here demonstrate potential loss of fine sediment from the wind farm area, with settling distributed around the surrounding regions (Figure 3). As the model considered only fine sediment, it was not possible to assess how size fractions may evolve within the wind farm area. However, the model was able to demonstrate how increased suspended sediment in the water column could also have wider impacts for marine ecosystems and productivity. The year-long simulation showed there was considerable seasonal variability in both the seabed and the water column as well as a longer-term trend. Therefore, further work is needed to assess how these changes may evolve over longer timescales, to determine whether the wind farm may reach an equilibrium state in the region.

This study provides a methodology to assess the environmental impacts of floating wind turbines, ranging from the scale of individual mooring line movements to potential wider shelf seas impacts. This approach could inform future offshore development planning and policy decisions. The initial simulations show potential localised impacts on the seabed as well as broader changes in sediment distribution. Additionally, the shelf-wide study demonstrates how seasonal variations and extreme weather events could potentially influence impacts for both benthic habitats and suspended sediment within the water column. However, to enable these models to be used effectively for decision making, there is a need to validate their results with observations. No observations were available at the time of this study. We therefore strongly recommend that future in-situ observations needed, to understand the variability in sediment distribution around floating wind turbine structures as well as the suspended sediment throughout the water column.

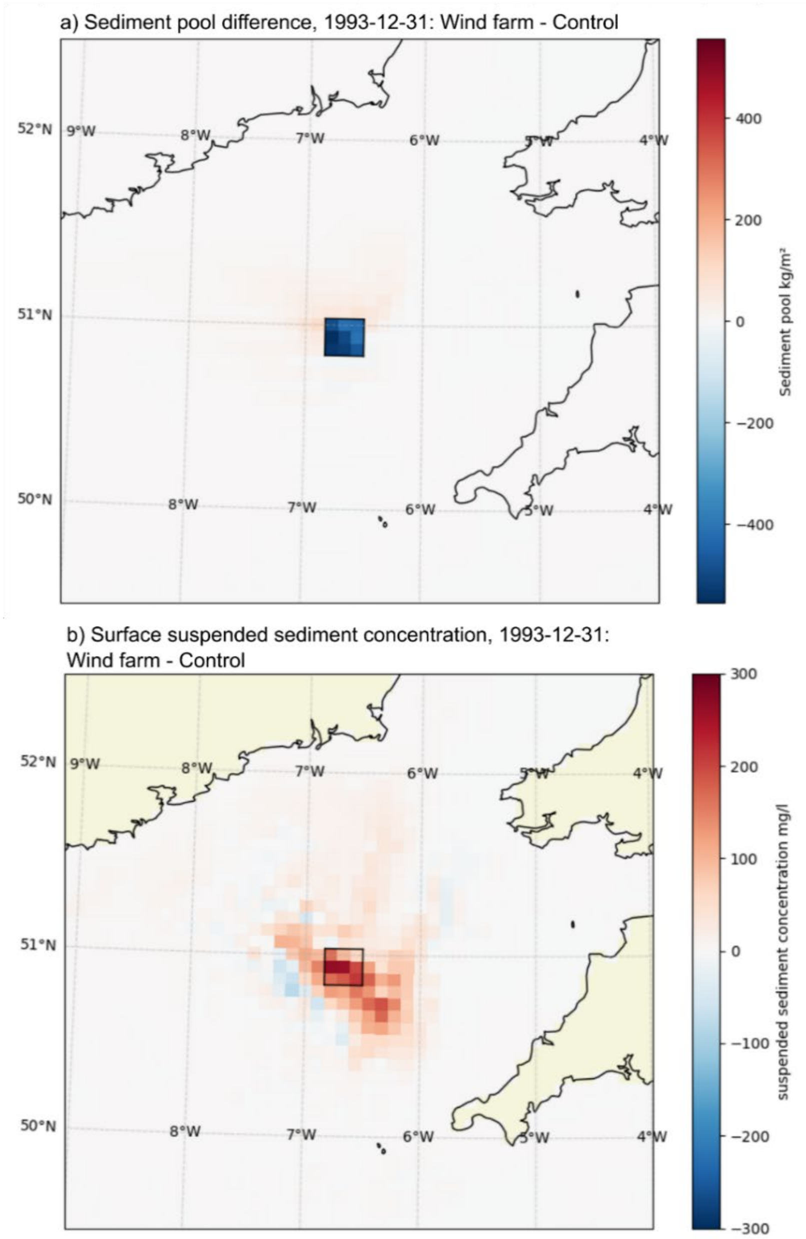

Figure 3. Difference in daily-mean sediment distribution between the wind farm minus control simulations at the end of the 1-year NEMO shelf-wide simulation, for a) bed sediment pool (kg/m^2); b) suspended sediment concentration at the sea surface. Black box shows the limit of region where wind farm impacts are applied.

Key Recommendations:

1. **Refine Simulations:**
    a. The work highlights significant differences in mooring line dynamics depending on turbine size, emphasising the need to keep pace with increasing power in future wind farm developments, and variations in dynamics will need to be validated.
    b. A longer Telemac run would assess the impact over a full tidal cycle, providing better confidence in simulation outputs.
    c. Including a comprehensive sediment distribution in NEMO will enhance the understanding of the transport of various sediment types, facilitating the reproduction of coarsening and fining processes.
2. **Validate Model Outputs:**
    a. The model outputs currently lack comparable seabed observations to validate the physical processes included in the model.
    b. While our model provides useful indications of potential impacts on seabed erosion and changes in sediment distribution over the water column and at the seabed, these simulations have only been conducted at the selected Celtic Sea site. Further work is needed to assess impacts at other locations.
3. **Monitoring Plan for Future Turbines:**
    a. We recommend that future planned floating turbines include a monitoring plan to acquire baseline information before construction, and continue monitoring throughout the construction, exploitation and decommissioning phases.
4. **Reproducibility of Methodology:**
    a. Upon successful validation (see second bullet), the methodology developed here can be reproduced at different sites where future wind farms may be planned.

3. WP2 – Likelihood of receptor encounter with floating offshore wind dynamic cable electromagnetic fields (EMFs)

This work package aimed to determine the likelihood of encounter between focal species and electromagnetic fields (EMFs) generated by floating offshore wind (FLOW) power cables. Since the magnetic fields around electricity cables are similar regardless of whether they are buried, on the seabed, in the water column or in the air, we were able to apply existing knowledge from fixed OSW to the FLOW case.

WP2 addressed the following objectives:

Objective 1) Define the key attributes of the magnetic field associated with subsea cables (both on the seabed and in the water column) by building on simple EMF emission models.

Objective 2) Verify modelled magnetic field related parameters through field data collection.

Objective 3) Estimate the temporal and spatial overlap between selected sensitive species and cabling routes.

Objective 4) Develop an initial approach to estimate the likelihood of species encounter with EMF to inform the potential risk to target species.

Objective 5) Provide guidance based on the outputs from the other Objectives. above.

For Objective 1, the minimum parameters required for basic modelling of the magnetic field used within existing permitting/licensing considerations were split into the cable EMF (i.e. the energy emission only) and the cable within the environment. These parameters were obtained for typical offshore wind export cables (with a balanced phase-current) and the outputs were an extended bell distribution of magnetic field intensity, with propagation of the field is predicted as $1/r^2$ where r is the distance from the cable centre (***Figure 4***).

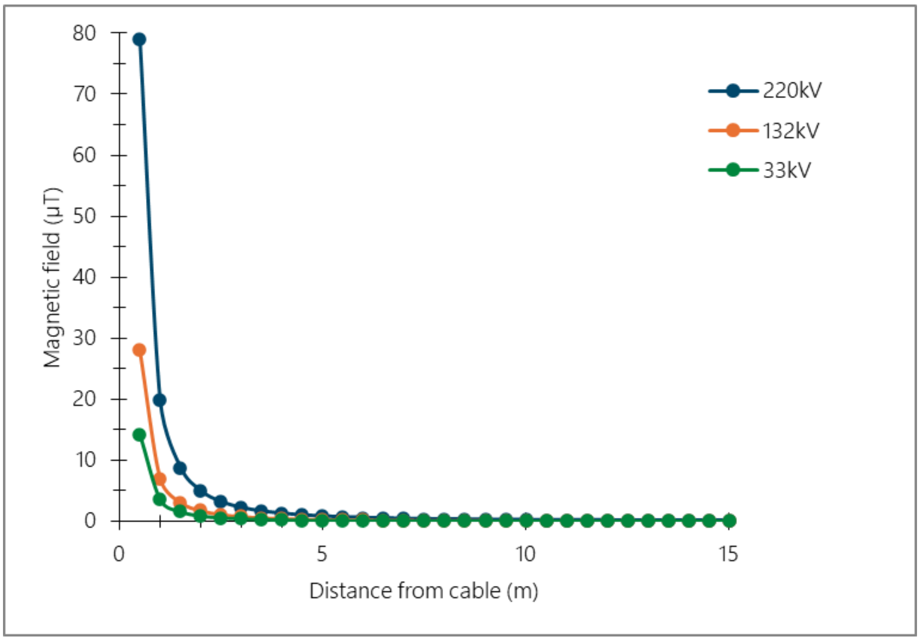

Figure 4. Typical plot of the magnetic field intensity and propagation with distance from cable axis for three types of subsea power cable installed at UK offshore wind farm sites.

To verify the modelling for objective 2, 12 offshore wind HVAC export cable sites within four geographic areas around the U.K. coast were surveyed using paired magnetometers and a standardised transect method perpendicular to the cable route at landfall in the intertidal zone. The measurements confirmed the maximum magnetic field intensity was found above the cable axis and that the intensity dropped off with distance (Figure 5). However, the intensity of the magnetic field remained at a higher level than predicted by the models and this was consistent for all sites visited (where data were available to conduct the comparison). Furthermore, most sites had more than one export cable, which means that the EMFs extent in the water column is over a greater distance than predicted by modelling of one cable. In Figure 5 two cables are clearly discernible and their combined EMF extends over approximately 50m, where it is within the range of detection by receptors (shown by the light blue zone in Figure 6).

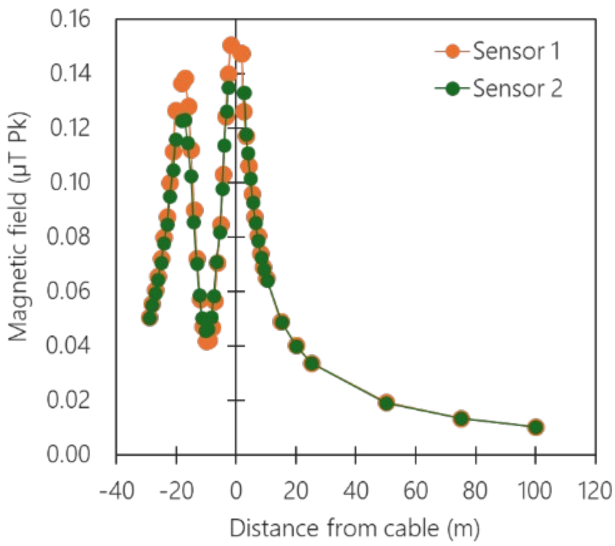

Figure 5. Field measurements for a 132kV sites (with two cables) showing the magnetic field intensity for Sensor 1 (orange) and 2 (green) in relation to distance from the cable (at 0m).

Objective 3 focussed on determining focal species occurrence and distribution in areas where offshore wind developments and cables routes are present. We used predictive species distribution models (based on habitat suitability assessment) within UK waters to produce spatial data to be overlaid on cable location data in the regions where we conducted the EMF field surveys. The species chosen were: the basking shark (*Cetorhinus maximus*), European seabass (*Dicentrarchus labrax*), and the thornback ray (*Raja clavata*). These species represent a range of life histories, they inhabit different habitats, they may use either electric or magnetic field cues in the environment and include those that have conservation interest and/or important from a fishing perspective within UK waters. A stepwise approach was used to determine the spatial overlap between the three species and the existing and planned offshore wind developments, adding a footprint representing an EMF zone associated with each development. The spatial outputs (Figure 6) can be generally applied and could be useful for the scoping stages prior to a formal Environmental Impact Assessment (EIA) for FLOW.

The spatial overlap assessment in Figure 6 provided a two-dimensional assessment of the likelihood of encounter between a species and the EMFs associated with subsea power cables. Therefore, the third dimension was added to better reflect the environment that receptors inhabit. Furthermore, some species of interest have strong temporal occurrence, therefore the time of year and life history stage when the species may occur within an area should be included. Atlantic salmon smolts data were used to illustrate this extended approach to determining likelihood of encounter.

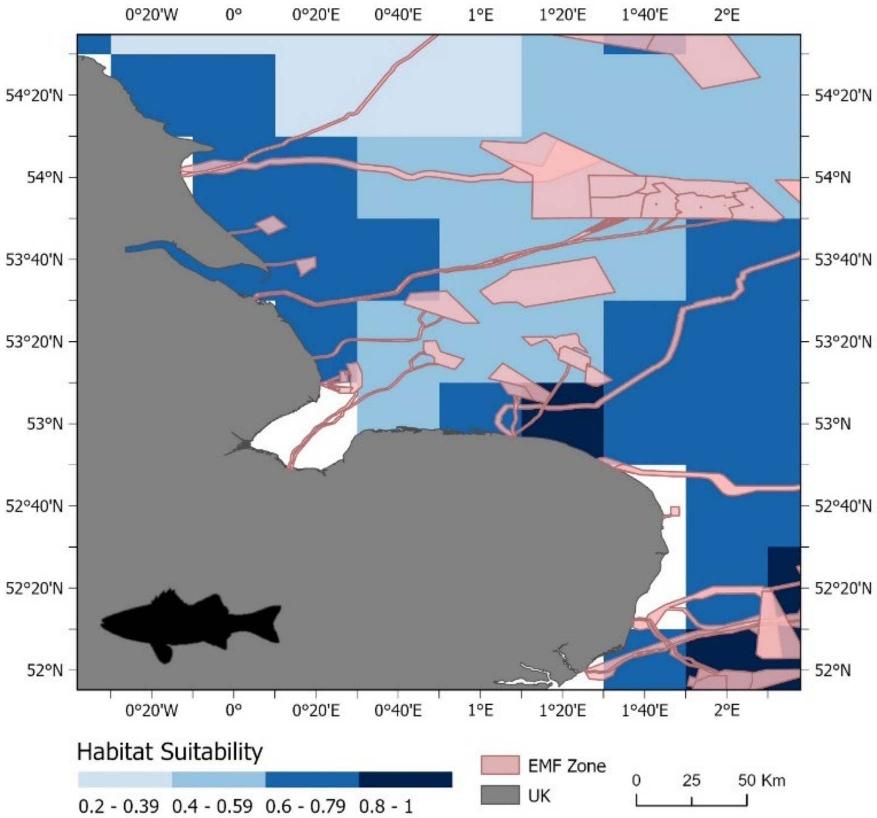

Figure 6. Overlay of seabass habitat suitability and fixed offshore wind farm EMF footprints (including the export cable route) in the western North Sea.

The fourth objective of the FLOWERS WP2 was the development of a first version approach to determine the likelihood of encounter between EM-receptive species and dynamic cable EMF. The outputs from Objectives 1, 2 and 3 were drawn together and a stepwise framework was developed (Figure 7). The framework was then applied to an example of FLOW development in the Celtic Sea.

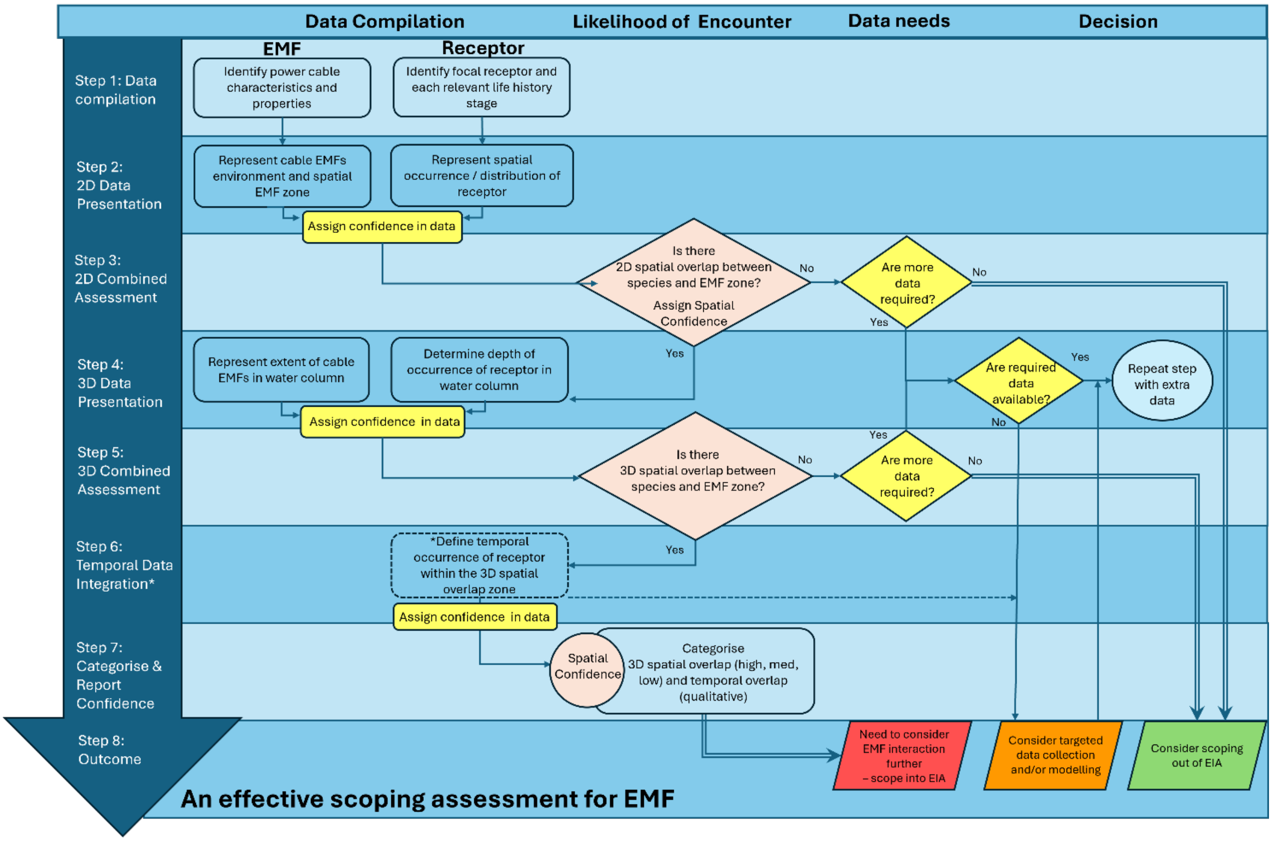

Figure 7. The stepwise framework for determining the likelihood of encounter between a focal receptor and EMFs associated with subsea power cable areas.

Key Recommendations

1. Basic modelling of EMFs provides a reasonable estimate of the intensity and spatial extent although to ensure the models represent the EMF environment encountered by receptors, EMF measurements are required to validate models and improve them in future. The spatial extent of EMFs has been demonstrated to be greater than the predictions by models, by several to tens of metres.
2. Modelling and measurements of EMFs should be expanded to include electric fields in future and methods developed for direct applicability to the dynamic cabling scenario of floating offshore wind developments.
3. In the early stages of scoping the potential impacts of EMF on a receptor, in the environmental impact process, use the framework in Section 5 and guidance in Section 6 of WP2 to assess the likelihood of encounter for focal receptors, and report the categorisation together with the data confidence.
4. A 2D spatial assessment is the first assessment that provides a basic understanding of the potential encounter, and a more robust assessment will be in 3D taking account of vertical distribution of the receptor as well as temporal occurrence. Data deficiency will result in low confidence in the assessments.
5. Where the outcome of the likelihood of encounter assessment is to consider a receptor further and scope in to impact prediction process, the initial likelihood of encounter assessment and framework can be used as a basis to build upon to understand the encounter rate and potential response to EMFs.
6. The framework should be considered modular and can be built upon as new evidence becomes available (e.g. improved burial data, better magnetic field estimations, electric field estimations, improved receptor occurrence resolution).

4. WP3 – A framework for multiple pressures within Environmental Impact Assessment for floating offshore wind farms.

Floating offshore wind farms create a series of environmental impacts throughout their lifecycle. These impacts are not uniformly distributed but instead grouped depending on when in their lifecycle they occur. During the construction and decommissioning phases many activities, pressures and subsequent impacts are likely to overlap in time and space. During the operational phase, these impacts are likely to be more spread out in time and become more routine. WP3 defined a conceptual framework for considering the impacts of multiple pressures within an environmental impact assessment (EIA).

EIAs consider pressures in isolation from each other, but this does not reflect the multi-stressor world that receptors are exposed to. EIAs also tend to scope out impacts deemed to be of low level or where there is limited knowledge of the impact. This approach risks overlooking the potential for multiple small impacts to cumulatively create a larger impact. In addition, most EIAs tend to use categories of impact scoring e.g. minor, moderate or major. This makes it challenging to consider multiple pressures together. For example, what is the cumulative impact of two moderate impacts – moderate, major or somewhere in between? In contrast most research-based cumulative impact assessment methodologies use numerical metrics for scoring impact. This has the advantage as it allows multiple impact scores to be combined giving an overall cumulative impact score.

How to combine individual impacts into a cumulative impact assessment is an area that requires further research. However, the impact and subsequent recovery period are affected by whether the receptor is recovering from other overlapping impacts. We defined conceptual equations to cover scenarios where impacts do not overlap (additive), where impacts overlap (synergistic) where the impact is increased, where the first pressure/impact displaces the receptor away from other impacts (antagonistic) leading to a reduction in the cumulative impact and finally, where the receptor becomes habituated to multiple exposures to the same pressure leading to a gradual decrease in cumulative impact *(Figure 8)*.

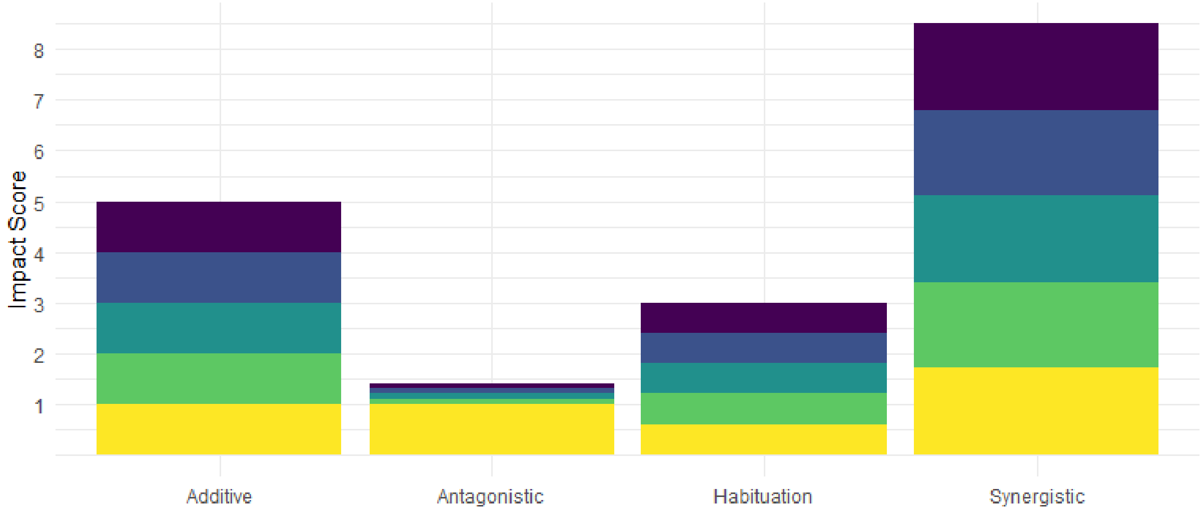

Figure 8. Example showing the total impact score of five different pressures on a receptor depending on the interaction type. Each colour represents a separate impact. The Additive bar shows the individual impact scores without any interaction weighting.

The framework considers the following three key points. Smaller impacts are not scoped out but instead retained to ensure a more realistic assessment. Numerical impact scores are used to allow the combining of individual impacts into a cumulative impact assessment. Finally, an approach for considering the interactions is presented based on the lifecycle of a floating wind farm (Figure 9).

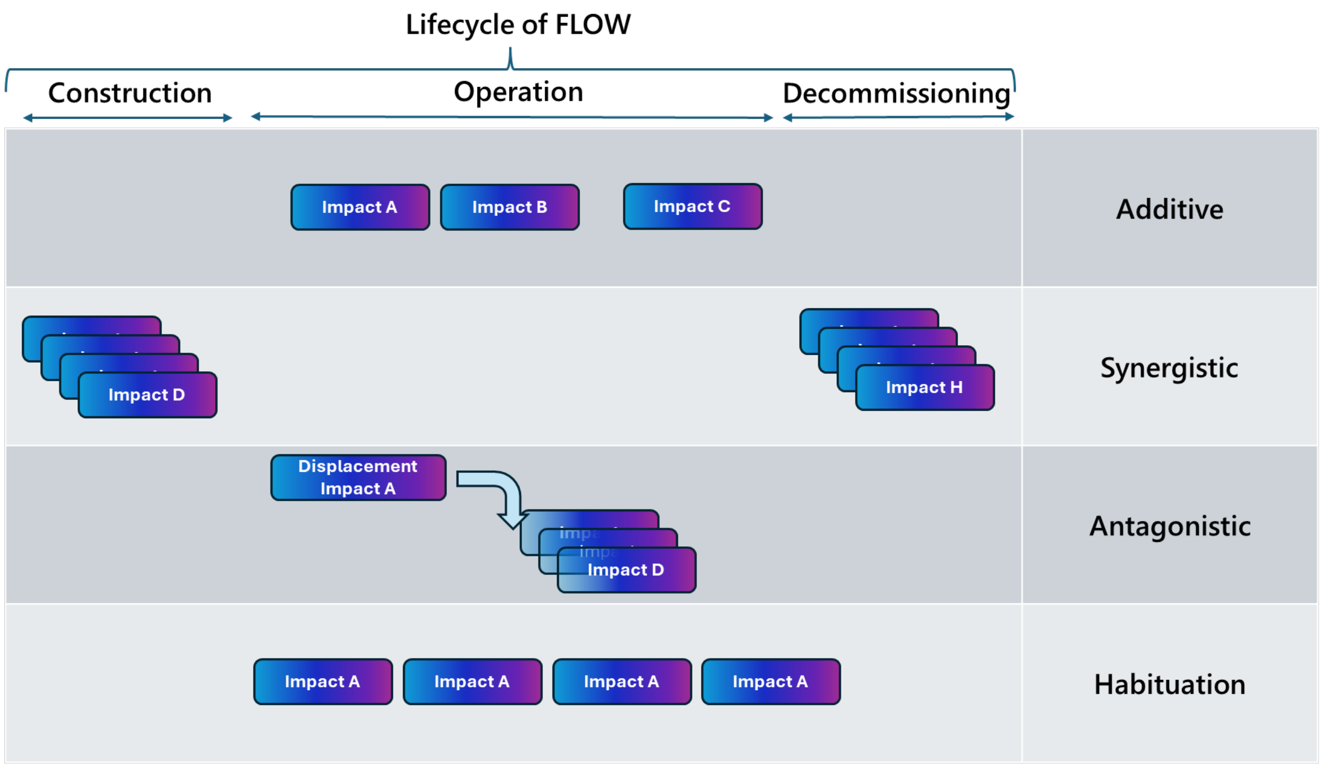

Figure 9. Different types of interaction depending on how individual impacts from pressures overlap in time.

Key Recommendations

1. The next step is to apply this framework to a commercial EIA for a floating wind farm to see in practice how it affects the overall assessment. We anticipate that the outputs would be a more realistic assessment of the impacts, both negative and positive. The benefits are a more proportional assessment where effort can be focused on effective mitigation of negative impacts and greater confidence in the success of management measures.