Offshore Wind Evidence + Change Programme

WP 3. A framework for multiple pressures within EIA for floating offshore wind farms.

Bringing CIA Into EIA

July 2025

THE CROWN ESTATE

Contents

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.

Document Control

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Executive Summary

Floating offshore wind farms create a series of environmental impacts throughout their Lifecyle. 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. This report defines a conceptual framework for considering the impacts of multiple pressures within an environmental impact assessment (EIA).

EIAs effectively consider pressures in isolation from each other and therefore the real world that receptors such as protected species or habitats 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 ignores 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 scores 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 1).

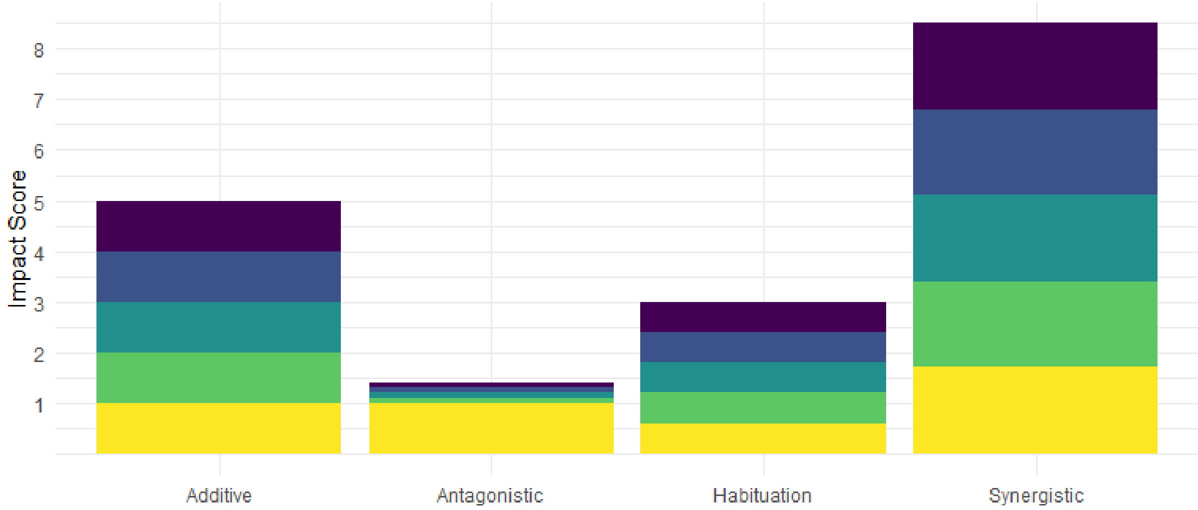

Figure 1. Example showing the total impact score of five different pressures on a receptor depending on the interaction type. Each colour represents a separate impact. The Additive bar shows the individual impact scores without any interaction weighting.

The framework considers the three key points. Smaller impacts are not scoped out but instead kept in 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 2).

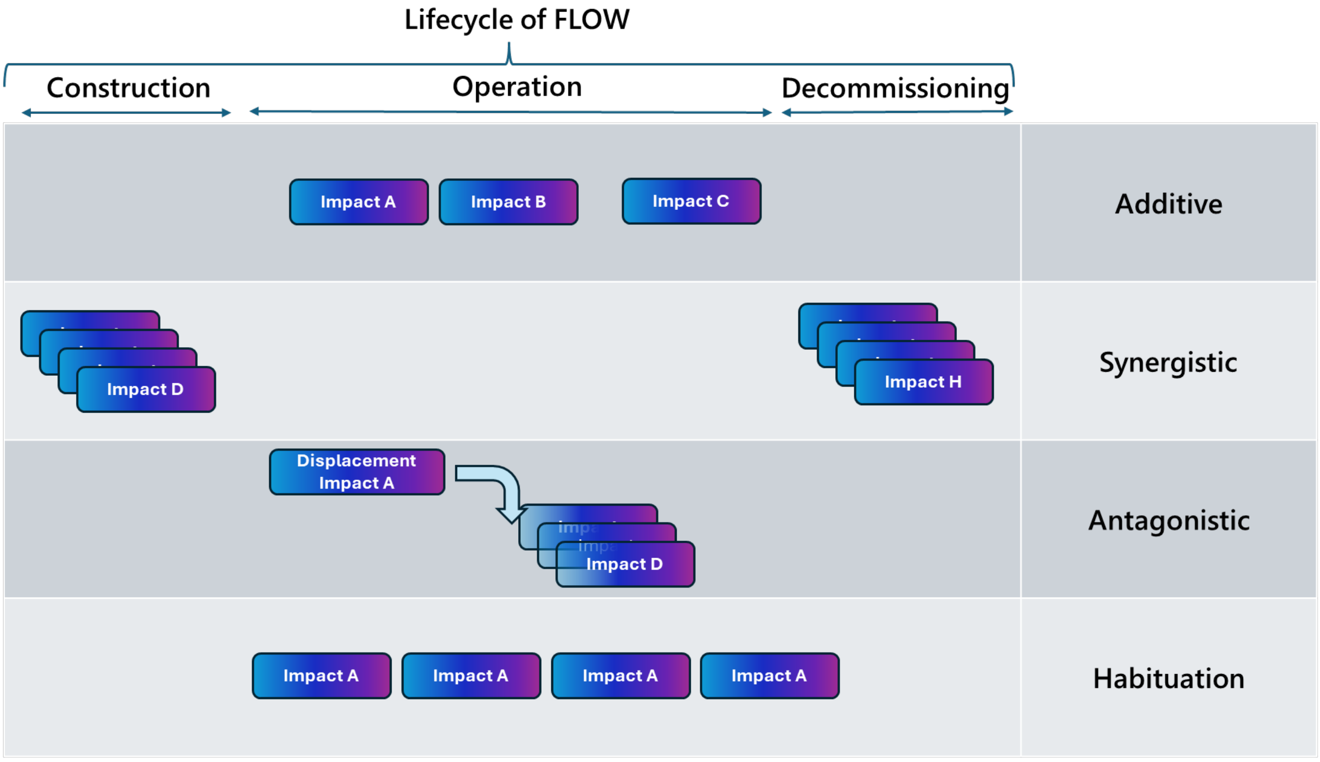

Figure 2. Different types of interaction depending on how individual impacts from pressures overlap in time.

Recommendation

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 so 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. The EIA for White Cross wind farm appears to be a suitable candidate.

1. Scope

The FLOWERS project considered different pressures for floating offshore wind development; WP3 focussed on what would be needed to draw environmental pressures together and fit into the concept of assessment of multiple stressors. An introduction to the topic and an approach applicable to the Environmental Impact Assessment (EIA) process is described here.

2. Introduction

2.1 Lifecycle of a floating wind farm

Floating wind farms (FLOW), as with fixed offshore wind farms (OWF), and indeed any other structure installed in the marine environment, have several distinct phases in their lifecycle. Typically, following approval of the deemed Marine Licence (dML), there will be a period of pre-construction work where the site is surveyed to determine suitability and understand any issues or obstructions that need to be overcome or removed. Next there will be a period of intensive construction where the turbines are installed. During this phase there will be considerable activity with vessel movements, seabed preparation, foundation and cable installation. Given the infancy of the FLOW industry there is very little data on how long the construction phase lasts for, but as an estimate this could be up to two years based on the installation of fixed offshore wind farms (Paterson *et al.*, 2018). The main proportion of a FLOW lifecycle is the operation phase, estimated at 25-35 years. Here the presence of the wind turbines remains constant, the rotation of the blades largely constant with routine periods of maintenance. Finally, there will be a period of decommissioning. To date no fully commercial FLOW have been decommissioned and indeed very few fixed OWF have been either, however, this is expected to be a similar duration as the construction phase. Throughout each of these phases there are a series of activities and subsequent pressures on the marine environment. Within the EIA process the individual combinations of activity-pressure-impact on receptors such as a species or habitat are treated as separate events. However, in the real world a receptor will be exposed to multiple pressures at the same time which can interact with each other creating a combined impact.

Work Packages 1 and 2 of FLOWERS follow the traditional approach with a focus on addressing two poorly understood abiotic pressures (physical scour and energy emissions in the form of Electromagnetic Fields (EMF)). However, when considering environmental impact and risk to receptors, drawing together the different identified pressures and considering them as a set of potential impacts early in the EIA process (scoping stage) could ensure better consideration and improve confidence in the assessment of the different impacts.

By setting up a framework which draws different pressures together, the Environmental Impact Assessment (EIA) process can be assisted in terms of identifying where there may be combined, additive, synergistic, cumulative, or perhaps subtractive effects, which brings more efficiency compared to the consideration of all the different pressures individually. Taking account of multiple pressures and focussing on the combined effect on receptors is considered in the published academic literature as the next step in the evidence base towards more confident and integrated environmental assessment process, which will assist in the decision-making process. The aim of this project is to develop a framework that can be used to start to understand what the overall cumulative impact of multiple pressures on a receptor is.

2.2 Defining impact

The concept of an environmental impact, both negative and positive has been generally defined (CIEEM, 2018) with ranges of impact being commonly described in EIA's (e.g. RPS, 2023). However, defining impact in a way that can be used to consider the impacts of multiple pressures on a receptor requires an understanding on the mechanisms of impact.

Piet *et al.* (2023) describes the risk of impact as having two key factors: Likelihood of Exposure i.e. the likelihood of an overlap in space and time between the pressure and the receptor and the Effect Potential (Figure 1). The effect potential is made up of two components: the ability of the receptor to resist/avoid the pressure (e.g. can a bird avoid the turbine blades) and the ability of the receptor to recover from an impact. At a population level we often consider the viability of the population, which is determined by how resistant the population is to the activity and how well the population recovers, following impact, such as through reproduction, reduced mortality or migration (Lotze *et al.*, 2006, 2011).

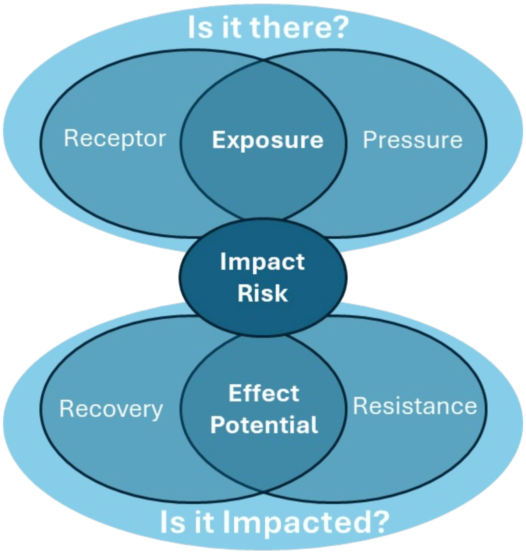

Figure 1. Concept of determining Impact Risk adapted from Piet el., 2023.

Gunderson *et al.,* 2016 describes the process of impact followed by the time required for recovery as a compensatory physiological response. The rate of recovery is reduced if the receptor is already recovering from other impacts (Lotze *et al.*, 2011; Gunderson *et al.*, 2016). The baseline status of the receptor and the timeline over which the receptor experiences the pressures therefore becomes critical. It is worth noting that the time taken for recovery is often largely excluded from EIA's (Willsteed *et al.*, 2018). Gunderson *et al.* observed that the time required for recovery from an exposure to multiple pressures varied depending on when in time the exposures occurred and how the pressures interacted (Figure 2 - left). For simplicity's sake, we refer to this period of exposure to pressure, impact and subsequent recovery as Impact.

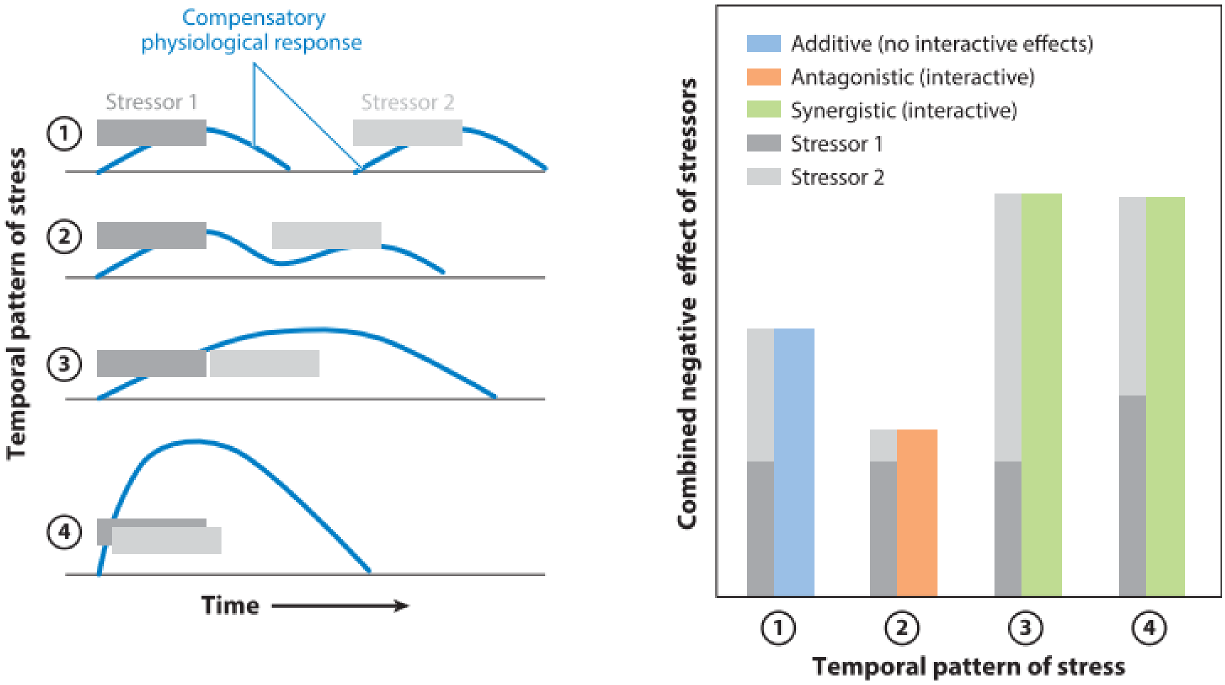

Figure 2. From Gunderson et al., 2016. Note that the term stressor refers to the activity and pressure. Compensatory physiological response is the period of impact and subsequent recovery.

Based on Gunderson *et al.,* (2016) we consider three possible scenarios for how individual impacts could interact, affecting recovery, and creating a cumulative impact: additive, antagonistic and synergistic (Figure 2). We define these as:

- Additive – the impact and subsequent recovery of multiple pressure exposure events do not interact or overlap in time. The total impact risk is the sum of the individual impacts.
- Antagonistic - the impact and subsequent recovery of multiple pressure exposure events interact and/or overlap in time. The total impact risk is **less than** the sum of the individual impacts.
- Synergistic – the impact and subsequent recovery of multiple pressure exposure events interact and or overlap in time. The total impact risk is **greater than** the sum of the individual impacts.

In addition, we also considered the aspect of Habituation to the same pressure. Here the receptor becomes resilient to the repeated exposures to the same pressure. Therefore, the total impact risk is less than the sum of the individual impact risks. Note, that this is not explicitly considering multiple different pressures, it is more related to cumulative exposure, however, habituation to one or more pressures could reduce the overall impact (risk score), therefore it is worth including.

2.3 Multiple pressures within Environmental Impact Assessments.

The current EIA process follows a series of well-defined steps (Figure 3). A key step is the scoping phase where agreement is made between the developer and the regulator on what pressures and receptors are included in the EIA. As part of the scoping phase, most, if not all EIA's carry out a standard process of mapping linkages (also referred to as cause-effect pathways) between the activity, pressure, receptor and impact. The receptor may be an individual species, group of animals (e.g. seals or prey fish) or type of habitat.

Figure 3. Overview of the EIA process.

The likelihood of impact on the receptor resulting from exposure to the pressure is estimated for each linkage (Figure 4). Typically, pressures and receptors are included in the assessment if it is determined that there is likely to be a significant impact. Pressures and receptors are logically excluded if they are unlikely to overlap in time and or space within the development (see WP2 Likelihood of Encounter). However, pressures and receptors may also be excluded if there is a lack of information about the distribution of the receptor or impact potential of a pressure, or if the potential for impact is deemed to be very low. For example, the impacts of heat and electromagnetic fields from cabling are often excluded from EIAs due to a lack of information (Boehlert and Gill, 2010; Hutchison *et al.*, 2021). The decision-making process in the scoping phase is usually based on expert judgement of the assessor. The approach has some logic as it is difficult (but certainly not impossible) to assess things that one knows very little about. However, it also means that the cumulative impacts of multiple small impacts are largely ignored by the assessment process.

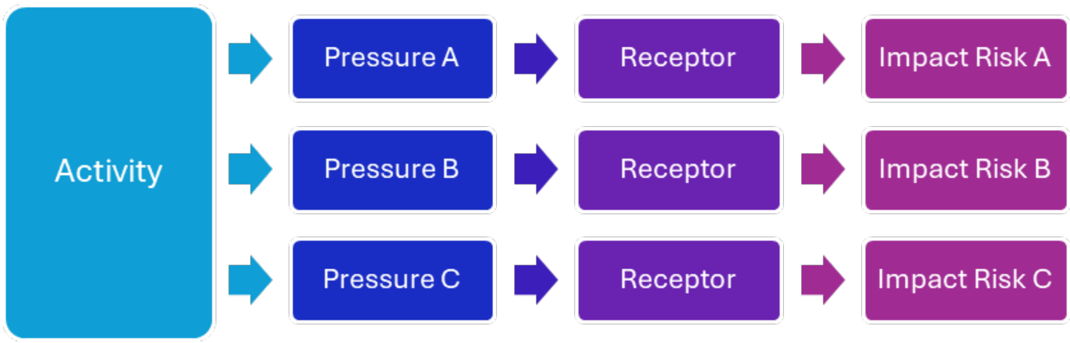

Figure 4. Example of EIA cause-effect linkages. An Activity produces a variety of Pressures which overlap with a Receptor creating a series of Impacts. Note that different pressures all come from same activity in this example.

The second key point to note with the existing EIA process is how impact is scored. We refer to this as the Impact Risk Score. Typically, within a commercial offshore wind development, impact is given a qualitative categorical score ranging from no change to major impact. The scoring is based on the magnitude of the impact and the sensitivity of the receptor to that relevant pressure/impact (Table 1).

Table 1. Example of Impact Risk Scoring used in a typical commercial EIA (RPS, 2023).

Sensitivity of receptor	**Magnitude of impact**				
	No Change	**Negligible**	**Low**	**Medium**	**High**

Negligible	No change	Negligible	Negligible or Minor	Negligible or Minor	Minor
Low	No change	Negligible or Minor	Negligible or Minor	Minor	Minor or Moderate
Medium	No change	Negligible or Minor	Minor	Moderate	Moderate or Major
High	No change	Minor	Minor or Moderate	Moderate or Major	Major
Very High	No change	Minor	Moderate or Major	Major	Major

The use of qualitative impact risk scoring is arguably suitable for assessing single linkages but becomes restrictive when one considers the impact of two or more pressures on the same receptor. For example, if a fish is exposed to three pressures, each with an impact risk score of "moderate" what is the cumulative impact risk score? Does moderate + moderate + moderate equal moderate, major or somewhere in-between? The use of quantitative categories therefore makes it very difficult to consider the impacts of multiple pressures on a receptor in the current EIA process (Figure 5). It also makes it challenging to include the effect of positive impacts. A positive impact could reduce the overall cumulative impact, but again the use of qualitative categories makes it difficult to calculate the level of reduction.

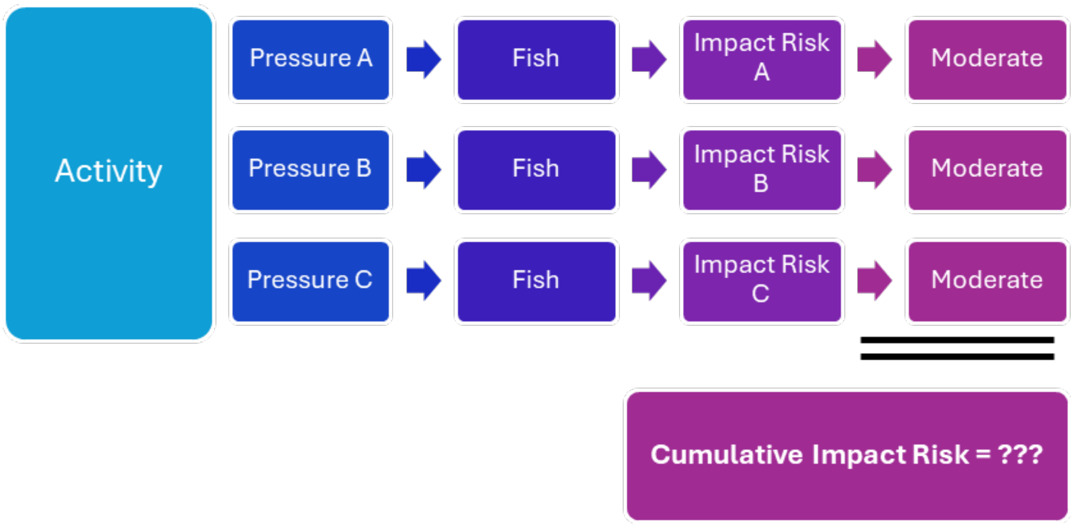

Figure 5. Application of category-based impact risk scores.

2.4 Multiple pressures within cumulative impact assessments

In reality, it is unlikely that an ecological receptor only experiences a single pressure at any one time. Most human activities create multiple pressures at the same time. For example, the installation of a monopile creates underwater noise and vibration from the piling and also the noise, light and chemical emissions of the vessel activity. In addition, the receptor is likely to face pressures from all the other human activities taking place in the area at the same time (Holsman *et al.*, 2017; ICES, 2019). Therefore, for an assessment of an activity to be realistic we must consider the timing, the duration, the extent and the cumulative impacts on the receptor. [Note that the terminology used to describe impacts can vary depending on the source. Commercial EIA's often use the term "cumulative impact" to describe the impacts from other activities or developments in the local area, while the term "inter-related impacts" may be used to describe multiple impacts from the same activity on a single receptor (RPS, 2023). For the purposes of simplicity, we use the term cumulative impact to describe the impact of more than one pressure on a receptor regardless of the source.]

While guidance on how to carry out cumulative impact assessments for commercial EIAs exists (RenewablesUK, 2013; CIEEM, 2018; UK Government, 2024), they are lacking methodological detail, reflecting the developmental state of the science underpinning such assessments. There are, however, several research-based methods that have been developed (Halpern *et al.*, 2012; Stelzenmüller *et al.*, 2018; Borgwardt *et al.*, 2019; Piet *et al.*, 2023). These approaches differ from commercial EIAs as they apply a numerical score to the impact risk rather using categories such minor, moderate or major. The key advantage of using numerical scores is that it makes it easier to combine the impacts from multiple activities/pressures in a cumulative assessment of impact.

The individual impact risk numerical scores are usually standardised to make the scores comparable to each other and then added together to create a Cumulative Impact Risk score (Halpern *et al.*, 2012; Borgwardt *et al.*, 2019; Piet *et al.*, 2021). The approach of simply adding the scores together is called the Additive approach (see section 2.2 above). The output is a single score that represents the cumulative impact risk of all the individual exposures to pressures (Figure 6). In practice however, the cumulative impact risk is unlikely to be as simple as this.

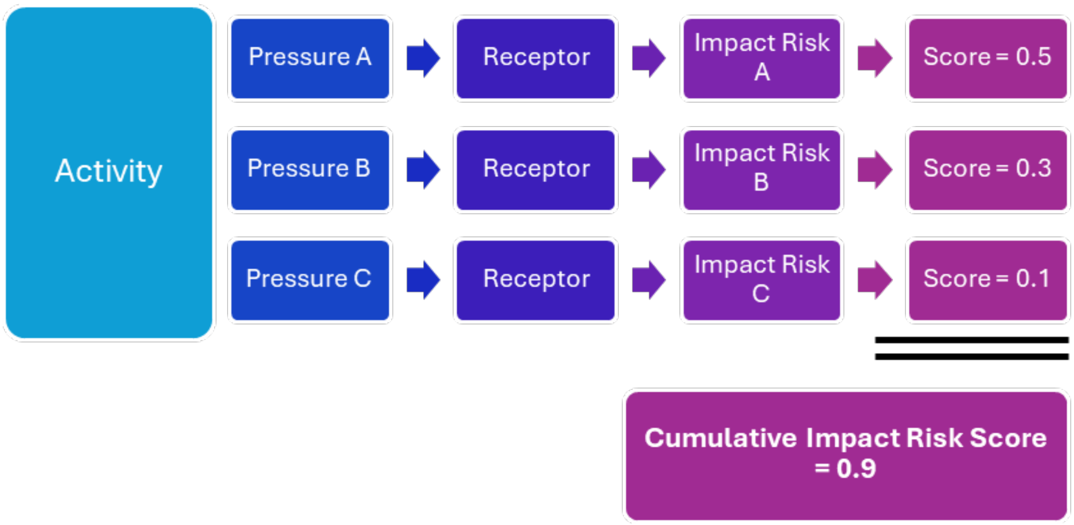

Figure 6. Concept of combining individual numerical impact risk scores from a single activity into a Cumulative Impact Risk Score by simple addition.

3. Framework

In summary there are three key aspects that would need to be included within the EIA process in order better consider the effects of multiple pressures on receptors.

- The scoping-out of pressure-receptor linkages deemed to have a low impact or a low evidence base means that the cumulative effect of multiple small impacts is currently excluded from assessment.

- The use of numerical impact risk scores vs category-based scores, allowing the impacts of multiple pressures to be combined into a single score.
- The interactions between multiple impacts on the same receptor may affect the cumulative impact score.

To include these factors into the EIA process a stepwise framework is proposed (Figure 7). The framework builds on the existing EIA process but brings in aspects from research-based cumulative impact assessments that have, so far, not been used in licensing applications.

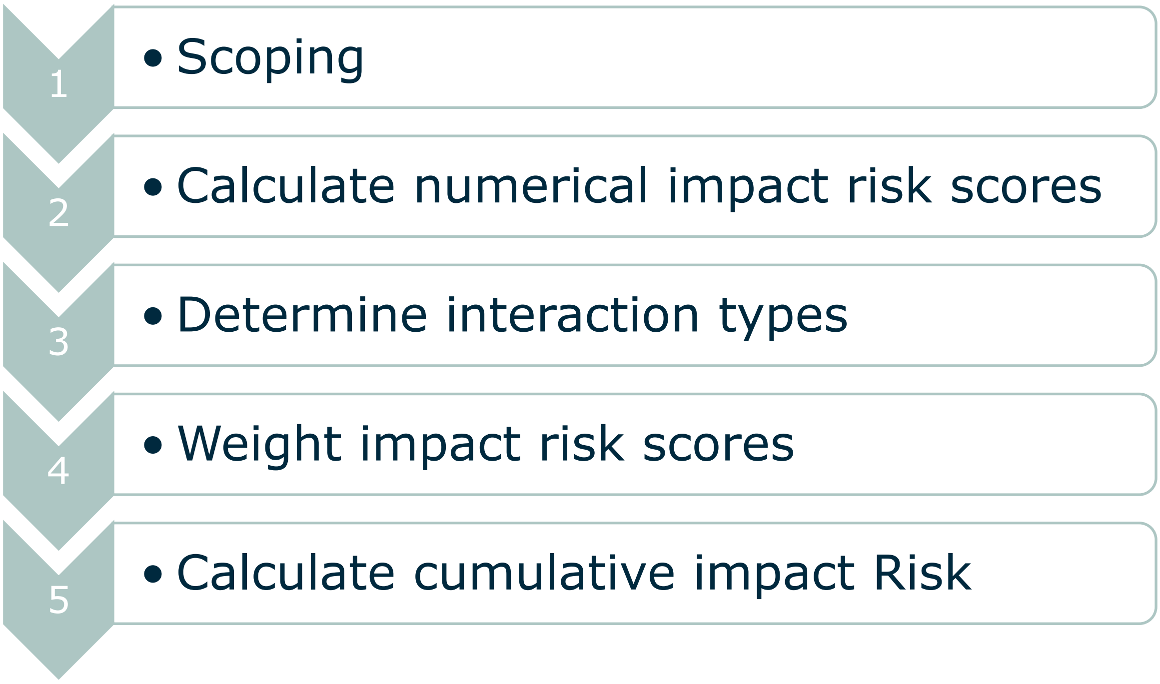

Figure 7. Framework for considering multiple pressures and impacts within an EIA.

3.1 Scoping phase

The scoping stage (Figure 3) is carried out as normal. Firstly, the theoretical linkages between the individual activity – pressure – receptor – impact are determined. Linkages where there is no overlap in space and or time between the pressure and receptor are excluded as there is no exposure to the pressure (Figure 1). However, and crucially, all linkages where there is an overlap between the pressure and receptor (i.e. exposure) are included, no matter how small the perceived impact is. Doing so helps to ensure that the EIA is relevant to the real world. Note, that a commonsense approach should still be applied to the requirements for fieldwork and sampling. For example, it is unlikely to be sensible to spend disproportionate amounts of effort sampling a species that is near impossible to find. In these situations, we propose that these components of the assessment are desk-based, still ensuring the impact is considered, but keeping the assessment proportionate.

3.2 Individual Impact Risk Scoring

The next step is to define impact risk scoring. Again, this is the same process as in a standard EIA except that numerical scores are used rather than categories. There are multiple options for doing so, such as the Halpern method (Halpern *et al.*, 2012), Symphony (Hammar *et al.*, 2020) or SCAIRM (Piet *et al.*, 2023). These methods add more detail to how the impact risk is calculated compared to a commercial EIA where magnitude of the impact versus sensitivity of the receptor to that relevant pressure/impact is typically used (Table 1). An interim approach could be simply applying a numerical scale over an existing category-based score as in Table 2. Applying numerical scoring in this way allows for simple addition of individual impact scores to a single cumulative impact risk score (Figure 6).

Table 2. Example of category-based scoring converted to number-based impact scoring to enable cumulative impact assessments (adapted from Borgwardt et al., 2019).

Traditional EIA Impact Scoring	Numerical Impact Scoring (0-1)
No Change	0.01
Negligible	0.1
Minor	0.37
Moderate	0.67
Major	1

3.3 Determine Interaction Types

Throughout the lifecycle of a FLOW, a collection of activities, pressures and subsequent impacts take place (Section 2.1). To determine how the individual impacts interact, the timeline of impacts, including any subsequent recovery, is mapped out. Doing so requires firstly an estimation of when in the lifecycle of a FLOW the impact is likely to occur. Secondly, an estimation of how long recovery from the impact might take. Determining recovery can be challenging, particularly at the level of individuals, however, estimates for populations and habitats have been developed (Tyler-Walters *et al.*, 2018; Piet *et al.*, 2021).

When the timeline of impact and the type of pressure are examined together, we are able to determine the type of interaction between the pressures and subsequent impacts that might take place. As defined in Section 2.2, four scenarios can be defined based on how the impacts interact over time – additive, synergistic, antagonistic and habituation (Figure 8).

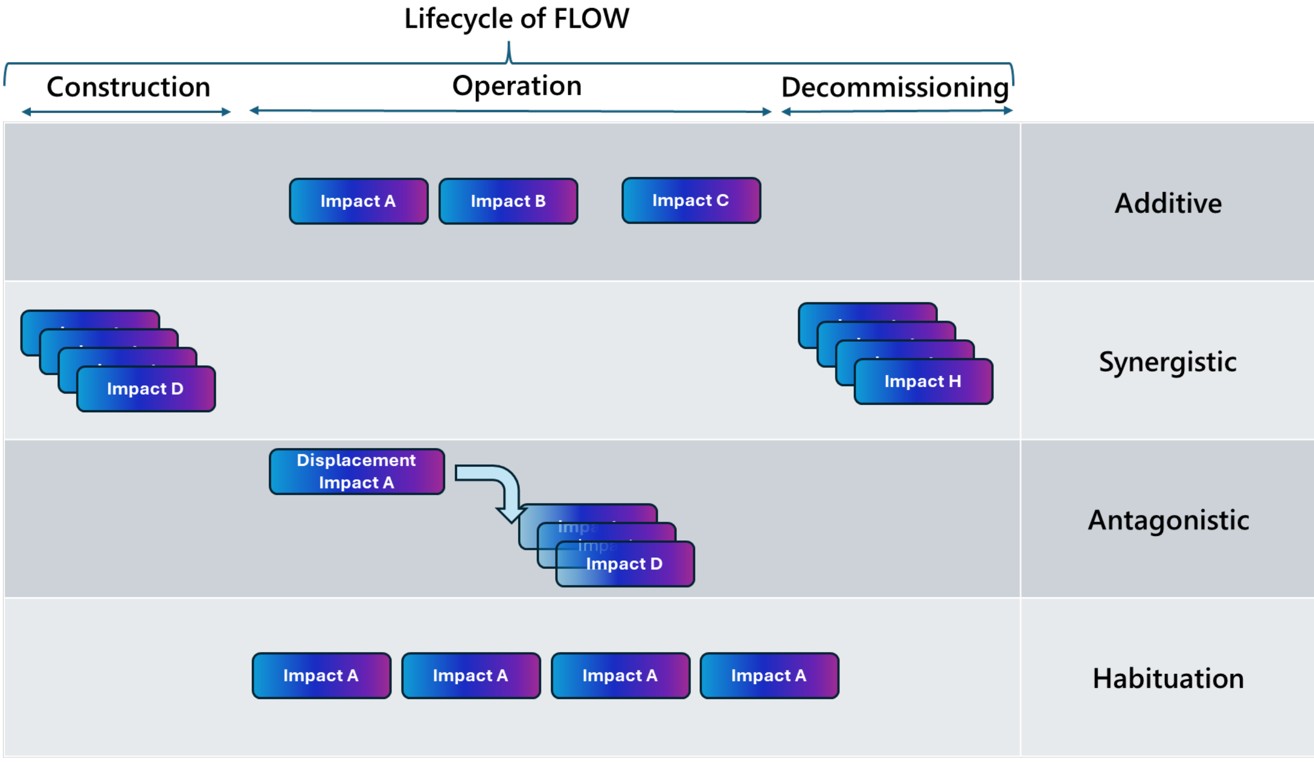

Figure 8. Different types of interaction depending on how individual impacts from pressures overlap in time.

Additive: the impacts from different pressures do not overlap in time allowing for the receptor to recover from each impact in turn. In effect, the receptor is not experiencing multiple pressures, rather it is experiencing pressures one at a time.

Synergistic: the impacts from multiple pressures overlap in time. In this scenario the receptor faces recovering from multiple impacts at the same time. Therefore, the overall recovery period is likely extended and therefore the total impact risk increases. For FLOW this type of interaction is likely to particularly relevant to construction and decommissioning phases due to many different activities and subsequent pressures all overlapping at the same time. During the operational phase some activities are still likely to overlap in time. For example, if the scour effect of moorings increases turbidity in the water column, then visual predators, such as sharks, will have to switch to other foraging modes and therefore may be more sensitive to other pressures such as noise and EMF. In these scenarios the time taken to recover from one impact and adapt to the other pressures becomes important (and complex). Overall, it is thought that synergistic interactions between impacts is likely to be the most common type of interaction.

Antagonistic: Here, the effect of a single pressure deters the receptor away from exposure to other pressures. For example, red throated diver are known to be displaced by the presence of wind farms (Dierschke *et al.*, 2017). While the effect of displacement may have a negative effect in terms of additional energy spent avoiding the wind farm or displacement from feeding sites, it decreases the likelihood of exposure to the pressure of collision with the rotor blades. Antagonistic interactions are thought to be applicable to all phases of a FLOW lifecycle, but only to specific receptors. Further work would be required to determine how often antagonistic interactions are likely to occur.

Habituation: A further antagonistic scenario can be created when one considers habituation. If an ecological receptor experiences the same pressure multiple times (e.g. collision risk), then depending on the nature of the impact, the impact of subsequent exposures may be reduced. For example, a bird species may learn to avoid the blades, therefore subsequent encounters with the wind farm may lead to a reduced collision likelihood. We believe that habituation interactions are likely to be restricted to the operational phase of the FLOW when activities such as blades spinning or routine maintenance visits become a regular and predictable occurrence.

It is important to consider the movements of the receptors being assessed if an overly precautionary output is to be avoided. Many mobile receptors, such as birds and marine mammals, show seasonal variation in their distribution. Fish such as salmon may only be present in the FLOW for a short period of time (see salmon smolt example WP2). Therefore, while pressures may overlap in time, we are only interested in them if the receptor is also present.

3.4 Accounting for interactions between impacts

To account for the effect of interactions between multiple impacts from multiple pressures we have included a step to weight the impact risk scores. [Note that this step is theoretical as to date there is very few data on which to base this step (Pirotta *et al.*, 2022). It is instead based on logical assumptions on how receptors may respond to multiple pressures under different scenarios.]

In this step the impact risk scores from the individual impacts are modified to consider the type of interaction between multiple impacts. Interactions between multiple impacts can only be considered if numerical impact risk scores are used for the individual impacts – see section 3.2. The way the individual impact risk scores are modified depends on the type of interaction.

Additive: Where the impact periods of multiple impacts do not overlap in time (Figure 10) the individual impact risk scores are not modified and are simply added together.

Equation 1: $Impact\ Risk\ a + Impact\ Risk\ b + Impact\ Risk\ c\ \ldots..$

Synergistic: The effect of multiple overlapping pressures increases the impact risk. The more pressures the receptor experiences at the same time, the greater the effect on total impact risk. Here, we apply a common logarithmic increase for each additional impact the receptor is exposed to in the same time period. [Note that there are currently no data that we are aware of to support a logarithmic increase versus another type. It is simply a function that produces a logical transformation.]

Equation 2: $Impact\ Risk + log_{10}(Pressures)$

Where Impact Risk = the impact risk score of the individual linkage, and Pressures = the total number of overlapping pressures impacting on the receptor.

Antagonistic: Because the receptor responds to one pressure by moving away from it i.e. displacement or avoidance, the effect of the other pressures is reduced. Here we apply a formula that reduces additional impact risk scores to only 10%. This continues to increase the total impact risk score above the initial impact score, but at a much lesser rate. Here, we are reflecting that the impact of displacement is thought unlikely to completely remove the other impacts but is expected to reduce them e.g. not all members of a receptor population will move away from the other pressures. In practice, the value of 10% is an estimate and may vary considerably between species. Further research would be needed to define this reduction value (see also behavioural factoring in Piet et al., (2023).

Equation 3: *Impact Risk a + (Impact Risk B * 0.1) + (Impact Risk C * 0.1)……*

Where Pressures = the total number of overlapping pressures impacting on the receptor.

Habituation: Here, the Impact Risk scores of subsequent exposures to the same impact are gradually reduced, reflecting the habituation to the pressure. The effect of the reduction is less than for an antagonistic interaction as the receptor still experiences the additional impacts, but the response is less than the original impact.

Equation 4: *Impact Risk - (Pressures - 1) * 0.1*

The greater the number of impacts the receptor experiences at the same time, the greater the effect of the interaction. The other two impact risk scores are modified in the same way.

Table 3 shows effect of the different interactions on the individual impact risk scores based on the number of pressures the receptor experiences during the study period. For simplicity, each individual impact is shown to have an original score of 1. In practice, this number would be specific for each individual impact and the impact risk score would be specific for each individual impact. For example, in one scenario, a fish experiences three separate impacts from EMF, each being scored 1. None of these impacts overlap in time therefore the interaction is considered additive. The individual impact risk score remains 1. In a different scenario, the fish experiences three impacts all at the same time. Each of the individual impacts is valued at 1. The interaction is considered to be synergistic because of the overlap in time. The impact risk score is therefore modified to become 1.47. The equation would be:

$Impact\ Risk + log_{10}(Pressures)$

$1 + log_{10}(3) = 1.47$

The other two impact risk scores are modified in the same way.

Table 3. Effect of applying the adjustment on the original impact risk scores based on the interaction type. [Note that no adjustment is made to the impact risk scores in additive interactions.]

No. of Impacts	Original Impact Risk Score	Additive	Synergistic	Antagonistic	Habituation
1	1	1	1	1	1
2	1	1	1.30	0.1	0.9
3	1	1	1.48	0.1	0.8
4	1	1	1.60	0.1	0.7
5	1	1	1.70	0.1	0.6
6	1	1	1.79	0.1	0.5
7	1	1	1.85	0.1	0.4
8	1	1	1.90	0.1	0.3
9	1	1	1.95	0.1	0.2

The effect of the interaction adjustment on the total impact score can be visualised in a graph (Figure 9). Synergistic interactions, where impacts overlap in time, create the greatest cumulative impact, while antagonistic interactions result in the smallest cumulative impact because the receptor has been displaced from the majority of the other impacts. Through considering the multiple stressor scenario, the impact assessment is more realistic in that it is not simply additive of each stressor. It also provides a basis on which to consider not just the most acute negative impacts in the short term, but longer-term impacts that may indicate positive or less negative outcomes or highlight where management should focus.

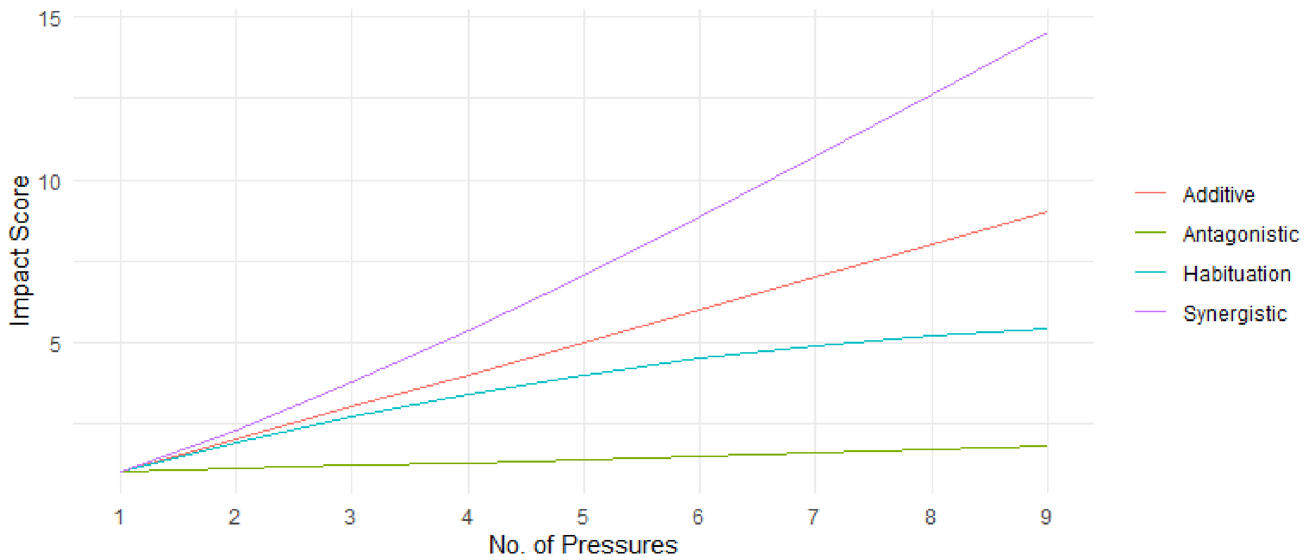

Figure 9. Effect of different types of impact interaction from multiple pressures on ecological receptors. Additive impacts do not overlap in time, Antagonistic = the first impact displaces the receptor away from the other impacts, Habituation = the receptor starts to habituate to the same pressure and Synergistic = the impacts overlap in time.

3.5 Calculate Cumulative Impact Risk

The final step is to sum all the individual modified impact scores to create a Cumulative Impact Risk score. In most cases it is likely to be difficult to determine the exact order the pressures occurred in. Therefore, rather than trying to adjust each individual score based on the number of other pressures the receptor has already experienced, all the individual scores in the study period are adjusted by the same value.

Example: A receptor experiences five different impacts during the same time period, none of which displace the receptor. The interaction is therefore Synergistic. Each individual impact risk score is weighted by equation 2, using 5 as the number of pressures:

Impact Risk + $\log_{10}(5)$.

The effect of this weighting versus the individual impact risk scores are shown in Figure 10. If a traditional additive approach is taken, where each impact score of 1 is summed, then the total impact risk score is 5. However, if weighting for the synergistic interaction between the five pressures is applied, then the total impact risk score is much higher, at almost 8.5. The effects of antagonistic and habitation interactions are also shown for comparison.

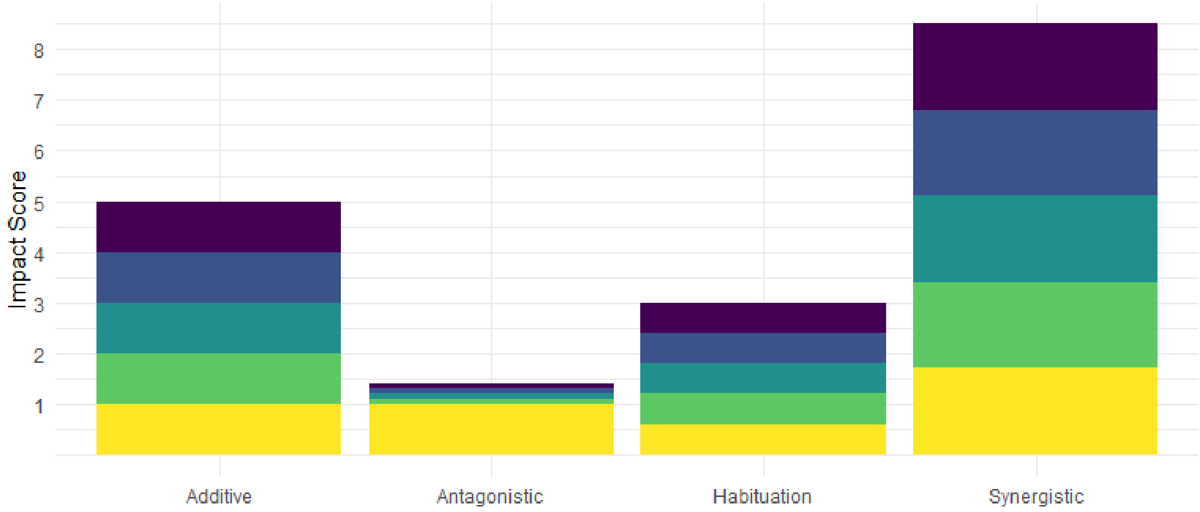

Figure 10. Example showing the total impact score of five different pressures on a receptor depending on the interaction type. Each colour represents a separate impact. The Additive bar shows the individual impact scores without any interaction weighting.

The lifecycle of a floating wind farm is made up of several distinct phases and the impacts created during these phases will vary. There is likely to be a considerable amount of some activities and associated impacts created during the construction and decommissioning phases and a more routine series of impacts during the operational phase. Impacts are therefore not evenly distributed across the lifecycle of the wind farm. As such there will likely be periods where impacts are best considered synergistically and other periods where impacts should be considered as additive (Figure 11). It may therefore be appropriate to carry out a separate impact assessment for distinct phases of the wind farm lifecycle. Once these sub-assessments with the appropriate interaction adjustments have been made, the cumulative impact risk scores for each sub-assessment can be combined to create an overall assessment of impact for the life cycle of the wind farm.

Construction	Operation	Decommissioning
Impact D	Impact E, Impact F, Impact G, Impact H	Impact K
Synergistic Interactions	Additive Interactions	Synergistic Interactions
Subtotal Impact Risk Score	Subtotal Impact Risk Score	Subtotal Impact Risk Score

Figure 11. Concept of subdividing the overall lifecycle of a floating wind farm to better examine the interactions at different phases.

4. Discussion

The framework presented here considers the three main limitations of the current EIA process and suggests improvements to the assessment of multiple pressures on key environmental pressures:

- Exclusion of Cumulative Small Impacts: Current practice often scopes out pressure–receptor linkages considered to have low impact or minimal supporting evidence. This approach results in the cumulative effects of multiple minor impacts being omitted from assessment, potentially underestimating or overestimating total risk.
- Lack of Numerical Scoring System: The reliance on category-based (qualitative) impact risk scores, rather than quantitative measures, limits the ability to combine impacts from multiple pressures into a single, comprehensive score. This constrains meaningful cumulative assessment and reduces transparency.
- Inadequate Consideration of Interaction Effects: Existing methodologies may not sufficiently account for the ways in which multiple impacts interact on the same receptor. As a result, cumulative impact scores may not accurately reflect the synergistic or antagonistic relationships between pressures.

The approach applied in WP3 allows all impacts (including those currently deemed minor and therefore scoped out) to be considered in a more ecologically realistic EIA process. The objective here is not to increase the size of the EIA undertaken but provide a science-led and pragmatic approach to justify how much effort is put into assessing the minor impacts. This will not only ensure more realism in the environmental assessment process but facilitates a cumulative-based approach, which is lacking at present. Furthermore, a multiple stressor approach can be used to demonstrate to stakeholders and decision-makers that impacts have been effectively scoped and assessed, which should contribute towards greater confidence in the EIA process.

A change is needed from category-based impact risk scores to numerical based scoring if the cumulative impact of multiple pressures is to be meaningfully assessed. The current process of assessing each separate impact in isolation means the overall picture is missed. This could lead to the effectiveness of mitigation measures being undermined because previously excluded impacts are excluded, or increased effort by developers if impacts are over estimated.

Using numerical scoring to assess impact also allows greater consideration of positive impacts. Positive impacts could form a second antagonistic scenario, and one that is rarely considered in EIA is if one pressure has a positive impact which counters some of the negative impacts of other pressures. For example, cormorants are attracted to OWF as a source of resting points and possibly food sources despite the risk of collision with the rotor blades (Dierschke *et al.*, 2016). The net impact risk of all the pressures may be less than sum of the individual impact risks. We did not explore positive impacts within this project, but believe the framework presented here could certainly be used to include them.

The equations presented here, for considering the interactions between multiple impacts, are theoretical. To our knowledge, there has been no attempt to apply such approaches with empirical data (Pirotta *et al.*, 2022).

In order to test this framework, we propose that it is applied to an existing EIA to determine how a revised approach affects the outcome. Ideally this would be using an existing FLOW EIA, however, there are only three that we are aware of in the world (two in Scotland, one in England). Alternatively, the framework could equally be applied to a fixed OWF. 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.

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