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DELIVERABLE 8.3
REPORT ON ENVIRONMENTAL ASSESSMENT AND VALIDATION

Work Package 8
Assessment and Validation

December 31st, 2023

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Abstract

As part of work package 8 of the Horizon 2020 European project UNITED, this deliverable reports on the environmental impact assessment of the ocean multi-use combinations that were tested in the five pilots of the project. The marine uses combined in these pilots are the following: offshore wind energy production, fish and low-trophic aquaculture (oysters, mussels and seaweed), tourism in the form of boat and diving tours, oyster reef restoration and offshore solar energy production.

To predict environmental risk reduction, an Environmental Impact Risk Assessment (EIRA) method was applied, adapted from a SCAIRM (Spatial Cumulative Assessment of Impact Risk for Management) method developed by Wageningen University and Research a partner of the project. The predicted impact risks for the upscaled scenarios of the project, foresee a reduction of environmental impact for ocean multi-use when compared to single-uses for the five pilots. Highest reductions were of approximately 40% for fish and mammals in the installation phase of the Belgian and Dutch pilots, approximately 15% for fish and mammals in the operation phase of the Dutch pilot and approximately 20% for seabed habitats in the decommissioning phase of the Belgian pilot. In addition, an optimal scenario was designed, in which current technological and regulatory challenges would have been resolved, and the combination of activities in a multi-use context enhanced. The application of the EIRA to evaluate this scenario indicates that multi-use projects could provide substantial reductions in environmental impact risk (potentially a factor 2 improvement) in a future that enables them fully.

In addition to the prediction of environmental impact risk reduction, the potential for ocean multi-use to generate positive environmental impact is described. These potential benefits were identified based on expert knowledge and information gathered through reviewing the scientific literature. The following potential added-value for the marine environment was identified:

- The possibility to incorporate habitat restoration (specifically biogenic reefs in the North Sea) in OWF-LTA multi-use combinations.
- Biodiversity increase thanks to strong fisheries exclusions and artificial reef effect in the multi-use area, although not identical to a natural reef.
- A potential increase in commercial fish species if the project is well designed and well protected.
- Increased nutrient cycling and carbon sequestration in the case of multi-use including LTA.
- Sustainable food production and increased social acceptance of offshore wind production and aquaculture.
- More space for conservation and reduction of conflicts over space use at sea.

Additionally, the potential for ocean multi-use as a mean for achieving or maintaining Good Environmental Status (GES) as defined by the Marine Strategy Framework Directive (MSFD), and as a tool for achieving other European environmental goals and strategies, was developed in the second part of the document. For most descriptors of GES by the MSFD, and for all goals and strategies considered, ocean multi-use was found to be a useful tool. For a few descriptors, multi-use may be a risk and close monitoring must be undertaken.

The strongest potential synergies from an environmental perspective have been attributed to the combination of low-trophic aquaculture (LTA) and offshore windfarms (OWF). This combination provides many benefits for the marine ecosystem, including: an increase in biodiversity thanks to the artificial reef effect; a stronger protection of the seafloor thanks to prohibition of bottom trawling within wind

	farms; the potential for implementing restoration measures such as flat oyster reefs restoration in the North Sea; an increased carbon sink thanks to more organic matter ending up as sediment on the seafloor; a potential for mitigation of eutrophication effects thanks to an increase in suspension feeding organisms (oysters and mussels); a potential for spill-over effect from the shelter and nursery offered by the multi-use area; and a reduction of overall underwater noise and carbon footprint due to combined boat uses. Because of all these potential positive environmental synergies, the combination of OWF and LTA might fit in the Other Effective area-based Conservation Measures (OECM) category, support conservation efforts and help State Members to achieve the 2030 Biodiversity goals. Another potential for ocean multi-use as a tool for achieving environmental strategies, is that they can help solve space allocation uses in the maritime spatial plan and may free space to be allocated for conservation purposes as marine protected area. Combining wind farms and low-trophic aquaculture, both being space-demanding activities, would reduce conflicts with other sectors and increase their acceptability to the general public and to other users of marine space and resources. Based on the pilots developed in UNITED, ocean multi-use shows potential to be used as part of ecosystem-based marine spatial planning for achieving restoration of habitats and species, 2030 biodiversity goals and the Green Deal (renewable energy production, sustainable blue economy, farm-to-fork, sustainable carbon cycle and potential of algae).
Keywords	Ocean multi-use, environmental impact, environmental policies

HISTORY OF CHANGES

VERSION 2.0	December 2023	D8.3 required information from D4.4. This information was not yet available at the time of the original submission because D4.4 had a later due date. This version (2.0) has incorporated the required information from D4.4.
VERSION 3.0	June 2024	Revisions made to cover and introduction pages

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ACRONYMS

CBD	Convention on Biodiversity
CCT	Coordination Committee Team
CSET	Core Services Exploitation Team
CT	Consortium Coordination Team
EC	European Commission
EIRA	Environmental Impact Risk Assessment
IPR	Intellectual Property Right
IR	Impact Risk
LTA	Low-Trophic Aquaculture
MPA	Marine Protected Area
MUCL	Multi-use and co-location
OECM	Other Effective area-based Conservation Measures
OWF	Offshore Windfarm
PA	Partner Assembly
PM	Project Management
RSM	Restorative Shellfish Mariculture
SAB	Stakeholder Advisory Board
SCAIRM	Spatial Cumulative Assessment of Impact Risk for Management
UAF	United Assessment Framework
WP	Work package

EXECUTIVE SUMMARY

As part of work package 8 of the Horizon 2020 European project UNITED, this deliverable reports on the environmental impact assessment of the ocean multi-use combinations that were tested in the five pilots of the project. The marine uses combined in these pilots are the following: offshore wind energy production, fish and low-trophic aquaculture (oysters, mussels and seaweed), tourism in the form of boat and diving tours, oyster reef restoration and offshore solar energy production.

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Another potential for ocean multi-use as a tool for achieving environmental strategies, is that they can help solve space allocation uses in the maritime spatial plan and may free space to be allocated for conservation purposes as marine protected area. Combining wind farms and low-trophic aquaculture, both being space-demanding

activities, would reduce conflicts with other sectors and increase their acceptability to the general public and to other users of marine space and resources.

Based on the pilots developed in UNITED, ocean multi-use shows potential to be used as part of ecosystem-based marine spatial planning for achieving restoration of habitats and species, 2030 biodiversity goals and the Green Deal (renewable energy production, sustainable blue economy, farm-to-fork, sustainable carbon cycle and potential of algae).

1. INTRODUCTION

The marine environment has gained attention in the last years, and is increasingly subjected to conflicting uses of its space and resources. Traditional activities, such as fishing and shipping, now have to share the scene with newly arising activities such as offshore wind farms and aquaculture. With current European objectives (Blue Growth Strategy, Green Deal, Sustainable Blue Economy), these new sectors are bound to increase in the future and may trigger conflicts over space availability and compromise the achievement of environmental goals. Offshore wind farms (OWFs) appear to be a necessity to achieve the climate and energy targets, demanding large quantities of space. However, space is also needed for other users and sectors.

Maritime spatial planning (MSP) was created to address space issues in the oceans. It allocates areas for specific uses and forbids some uses in specific zones such as protected areas. Yet, given the large amount of space required for windfarms, and the intensive use of European seas, space at sea has become a scarce resource. As a solution for resolving use conflicts, multi-use (MU) of ocean space has risen in the last two decades. The concept refers to using, and allocating, a single area to conduct several compatible activities, with the objective of maximizing spatial efficiency and productivity (Schupp et al., 2019).

Following Schupp et al. (2019), four types of ocean multi-use can be differentiated:

- Type 1 – Multi-purpose/multi-functional: activities take place in the same area, at the same time, with shared services and core infrastructure.
- Type 2 – Symbiotic use: activities take place in the same area, at the same time, and peripheral infrastructure or services on sea or on land are shared.
- Type 3 – Co-existence/co-location: activities take place in the same place and at the same time.
- Type 4 – Subsequent use/repurposing: activities take place in the same ocean space but subsequently.

In addition to offering a solution to space allocation issues, multi-use projects constitute opportunities for fruitful collaborations. Multi-use can create synergies in terms of costs, infrastructure use, human resources, etc., but also opens the door to innovations, learning opportunities, technological advancement and sustainability. Combination of activities within a single marine area may lead to positive or negative environmental impact and/or environmental benefits and/or costs when compared to a situation where each maritime use is conducted independently.

This deliverable concludes on the environmental impact assessment for the five multi-use projects developed within UNITED, and further develops how multi-use might benefit European countries as tools for achieving European environmental goals and strategies.

1.1. Description of UNITED

The H2020 programme UNITED provides pilot results and research for the EU topic of interest "BG-05-2019 Multi-use of the marine space, offshore and near-shore: pilot demonstrators"[1]. The objective of the H2020 UNITED project is to encourage multi-use of marine areas by developing guidelines, tools and experience through five pilots. These pilots combine renewable energy, aquaculture, nature restoration and tourism activities, with the aim to provide evidence for the viability of marine multi-use. UNITED will provide solutions to improve operation, planning, and management of multiple marine offshore activities, as well as reducing costs and space demand of offshore operations.

The project is deployed across five pillars, presenting challenges and opportunities:

- Technological;
- Economic;
- Environmental;
- Societal;
- Legal/Policy/Governance.

[1] BG-05-2019: Multi-use of the marine space, offshore and near-shore: pilot demonstrators | Atlantic Action Plan | Atlantic Strategy (europa.eu)

The five developed pilots combine the following activities:

- German pilot: offshore wind research and aquaculture (mussels and seaweed);
- Dutch pilot: offshore wind, solar and aquaculture (seaweed);
- Belgian pilot: offshore wind, aquaculture (European flat oysters and seaweed) and oyster reef restoration;
- Danish pilot: offshore wind and tourism;
- Greek pilot: aquaculture (finfish) and tourism.

Within UNITED, most pilots can be categorized as 'Symbiotic use' or 'Co-existence/co-location'.

1.2. Work package 8 and current deliverable

1.2.1. Work package 8

Work package (WP) 8 is an umbrella work package, that brings a conclusion to other work packages of UNITED by validating and assessing the proposed solutions' acceptability across the economic, social and environmental dimensions. In the United Assessment Framework, Figure 1, work package 8 corresponds to the third and fifth boxes: respectively 'Assessment reporting' and 'Audit and post-decision monitoring'.

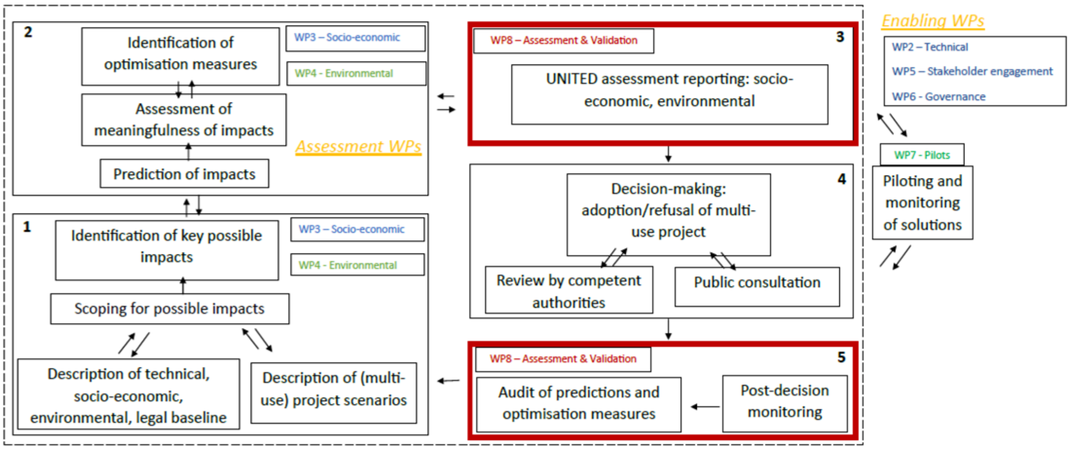

Figure 1. The UNITED Assessment Framework, with steps 3 and 5 - indicated by the red rectangles - as the ones corresponding to WP8.

The following graph (Figure 2) gives an overview of the WP8 deliverables and their link to the United Assessment Framework (UAF). Tasks 8.1 'Technical assessment and validation', 8.2 'Socio-economic assessment and validation' and 8.3 'Environmental assessment and validation' correspond to the third step of the UAF 'Assessment reporting: technical, socio-economic and environmental', while task 8.4 'Auditing procedures and TRL assessment' partially corresponds to part of the fifth step of the UAF 'Audit of predictions and optimization measures'.

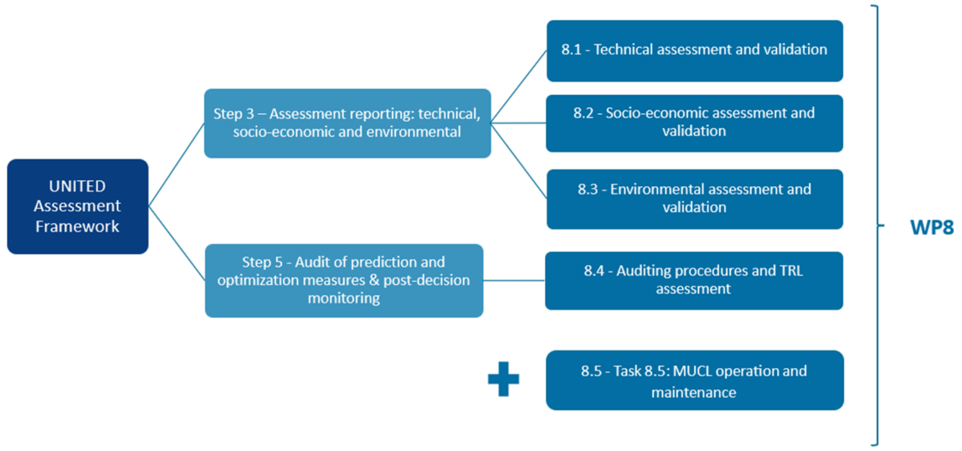

Figure 2. Link between the UNITED Assessment framework and WP8.

1.2.2. Task 8.3 and links to other WPs

This report falls under task 8.3 within the H2020 UNITED project and corresponds to the 'Environmental assessment and validation', step 5 of the UNITED Assessment Framework. The described results and conclusions drawn in this report are based on the environmental impact analysis put together by work package 4 (WP4), 'Environmental added-value of multi-use of marine space and infrastructure. Within WP 4, the environmental impact of single uses versus multi-use of the pilots' activities in upscaled commercialized scenarios, are predicted and compared. Task 8.3 synthetizes these results and assesses their meaningfulness for each considered ecosystem component and for each pilot. Then, the potential for ocean multi-use as a tool for achieving European environmental strategies and goals, is highlighted. A specific focus is given to the Marine Strategy Framework Directive (MSFD) and its descriptors of Good Environmental Status (GES).

1.2.3. Method and plan of the document

The first section of the document synthetizes the results and lessons learned of the environmental impact prediction conducted in deliverables 4.3 and 4.4. Impacts were predicted for each use of the UNITED pilots in a single-use setting, then for each use in a multi-use setting, informed by the experience of the five pilots of UNITED during the four years of the project. Impacts were predicted following an Environmental Impact Risk Assessment (EIRA) method. In addition, a literature review was conducted to identify potential beneficial environmental impacts that may come out of ocean multi-use project, if properly designed and managed.

The second section compares the predicted impact between single-use and multi-use scenarios, for each of the five pilots. It provides an assessment for each pilot as to whether multi-use if preferable to single-use, based on the activities tested by the pilots during the duration of the project. That section also links the previously identified potential environmental benefits to each pilot, multi-use combinations and to European environmental strategies it might help achieve.

The last section investigates European environmental goals and strategies, and the potential for ocean multi-use to be used as a tool for their achievement. The MSFD is first considered, by going through its proposed descriptors for reaching GES. In the second part of this section, the following goals and strategies are considered: oyster reef restoration, maritime spatial planning, 2030 biodiversity goals and parts of the Green Deal, such as sustainable blue economy, renewable energy production, farm-to-fork strategy, potential of algae, and sustainable carbon cycle.

2. PREDICTION OF ENVIRONMENTAL IMPACT OF OCEAN MULTI-USE

2.1. Method for environmental impact prediction

The method used to predict direct impacts of multi-use versus single-use in the five pilots of UNITED is an Environmental Impact Risk Assessment (EIRA). The EIRA is an adaptation of the SCAIRM (Spatial Cumulative Assessment of Impact Risk for Management) method developed by Wageningen University and Research a partner in the project, but which now focusses only on the sectoral activities included in the multi-use project. This method was applied to upscaled scenarios of the multi-use combinations tested in the five pilots of UNITED.

Activities in the upscaled projections of the pilots were described based on three phases: installation, operation and decommissioning. All activities were decomposed into actions causing pressures which may impact ecosystem components. This analysis was done for a generic baseline scenario, and for a single-use (SU) scenario and a multi-use (MU) scenario for each pilot, allowing for a comparison of impact risk (IR) between SU and MU for each phase of each pilot.

A systematic procedure was applied to identify and assess environmental impacts caused by multiple sources or activities, through a linkage framework. This procedure enables the identification and evaluation of environmental impacts caused by multiple sources or activities through a risk-based approach. For each impact chain, an 'Impact Risk' (IR) score is attributed. It is calculated as the product of Exposure and the Effect Potential and is expressed as the proportional (%) change in the abundance or biomass of a particular ecosystem component due to a particular activity-pressure combination. The pressures and ecosystem components used in this methodology are derived from the Marine Strategy Framework Directive (MSFD). The result is an overview of the cumulative impact risk of the considered activities on the selected ecosystem components. This impact risk thus provides a way to compare different scenarios, select the best option, and guide the implementation of efficient management measures.

The analysis of the causes (source of pressures and effects), pathways, and consequences of the effects on ecosystem components is an essential and integral part of the process (Judd et al., 2015, Piet et al. 2017). The main principles are:

- The effect of a pressure on an ecosystem component results in a potential impact or Impact Risk (IR). IR represents a potential change in the state expressed as a relative change in equilibrium abundance of the ecosystem component (e.g., species or in the case of habitats the associated biota) compared to an undisturbed situation (Piet et al., 2023). As an impact can only be negative, the proportional change ranges from - 0 (no impact) to +100% IR (maximum impact).
- The cumulative impact assessment provides the sum of all the impact risk per ecosystem component and then aggregated into an ecosystem assessment as the average across the components (thus assuming equal importance).

A more detailed explanation of the approach can be found in deliverable 4.2 (Rozemeijer et al., 2021), deliverable 4.3 (Rozemeijer et al., 2022) and deliverable 4.4 (Van Gerven et al., 2023) of the UNITED project. A description of the pilots and the activities considered in them can be found in Annex 1. Additionally, for a more detailed description of the ecological situation of the pilots, refer to Deliverable 4.1 of UNITED, "Revision of the current environmental assessment and status of the pilots" (Lukic et al., 2020).

The output of the EIRA:

- Is especially informative on relative values, i.e., the differences between the reference situation and the alternative/future situation (baseline scenario and the other scenarios of single-use and multi-use).
- Provides ranking orders of the main stressors.
- Can be used to provide an integrative view of the ecological effects of activities and their pressures on the ecological components of the study area.
- Provides Impact Risk as a measure of potential impact on the biota. This does not reflect the expected actual abundance as can be obtained from monitoring programmes.
- Gives directions for thinking and rough prioritization.

2.2. Results summary

2.2.1. Prediction of environmental impact of activities in a single-use setting

Deliverable 4.3 of UNITED synthesizes the results of the first analysis that was conducted to assess and predict the environmental impact of the activities when happening on their own, hereafter referred to as 'single-use activities', as opposed to activities happening simultaneously in a same area (multi-use activities). The ecosystem components that were evaluated in deliverable 4.3 were the following: 'Sublittoral sediment', 'Pelagic water column', 'Circalittoral rock and other hard substrate', 'Fish & Cephalopods', 'Birds', 'Mammals'. Only first order impacts are assessed with the EIRA method.

The pilots of UNITED are trying out different combination of activities in five different regional seas and are all at different levels of technological readiness. The Danish and Greek pilots' activities are already implemented and functioning, so their impacts were calculated according to the actual situations. The Belgian, German and Dutch pilots, however, are only at experimental stages and therefore required to design up-scaled scenarios on which environmental impacts could be predicted. These up-scaled scenarios are used across all work packages of UNITED, to ensure homogeneity. For more information about the scenarios used to conduct the environmental impact analysis, please refer to Annex 2 or deliverable 4.3.

Figure 3 displays the results of the rough analysis conducted in deliverable 4.3, following the EIRA methodology. Each activity tested in the UNITED pilots for a potential multi-use combination is attributed an IR score, for its 'installation/removal' and its 'operational' phases, on each ecosystem components considered by the present analysis. These IR score have been standardized for a fixed surface unit, so the displayed result in Figure 3 assume that each activity occupies the exact same amount of space.

When the IR has a positive value, the population or habitat is reduced. When it has a negative value, the population or habitat increases. An ecological reference surface around the pilot was defined in which the population was set at 100% for 22 km^2. When an IR is more than 100%, it means that the ecosystem component is diminished including new born and immigrating specimens.

From the graph, the following conclusions can be made. On the condition that the same amount of surface is exploited by the single-use activities considered by the UNITED pilots:

- Reptiles are only impacted by Finfish aquaculture and Diving because these are the two activities combined in the Greek pilot, the only location where reptiles (sea turtles) are present. Finfish culture has the highest negative impact on reptiles for both its operational phase and its installation/removal phase, and its operational phase is the most impactful of the two.
- Mammals are the most negatively impacted by Windfarms during their installation/removal phase, then by Finfish aquaculture during its operational phase. Cable, Solar and Diving also have a potentially significant impact on Mammals during their operational phase.
- Birds are largely more negatively impacted by Windfarms than by any other activity, both for the installation/removal phase and the operational phase.
- Fish & Cephalopods are strongly negatively impacted by the installation/removal phases of Windfarms, as well as by the Finfish aquaculture operational phase. Additionally, the operational phase of Cable and Solar seem to also have a strong impact on this ecosystem component.
- Circalittoral rock and other hard substrate is negatively impacted by the operational phases of Finish and Seaweed culture, but strongly positively impacted by the installation/removal phase of Restoration activities.
- Pelagic water column is moderately negatively impacted by Solar installation/removal, as well as by Finfish operational and installation/removal phases, and by Seaweed aquaculture installation/removal.
- Sublittoral sediment is the most negatively impacted by Finfish operational phase and by Restoration installation/removal phase. It is also, but more moderately, impacted by the installation/removal phase of Cable, and by the operational phase of Shellfish culture.

Overall, when activities are compared as if using the same amount of surface, Wind had the highest IR in the Installation phase and Finfish culturing had the higher IRs on most Ecosystem Components in the Operational phase. The high impact of attributed to finfish aquaculture on mammals is mainly due to shipping activities (alike diving). Otherwise, the release of synthetic substances (e.g., anti-parasitic substances) is a major cause of impact for finfish aquaculture.

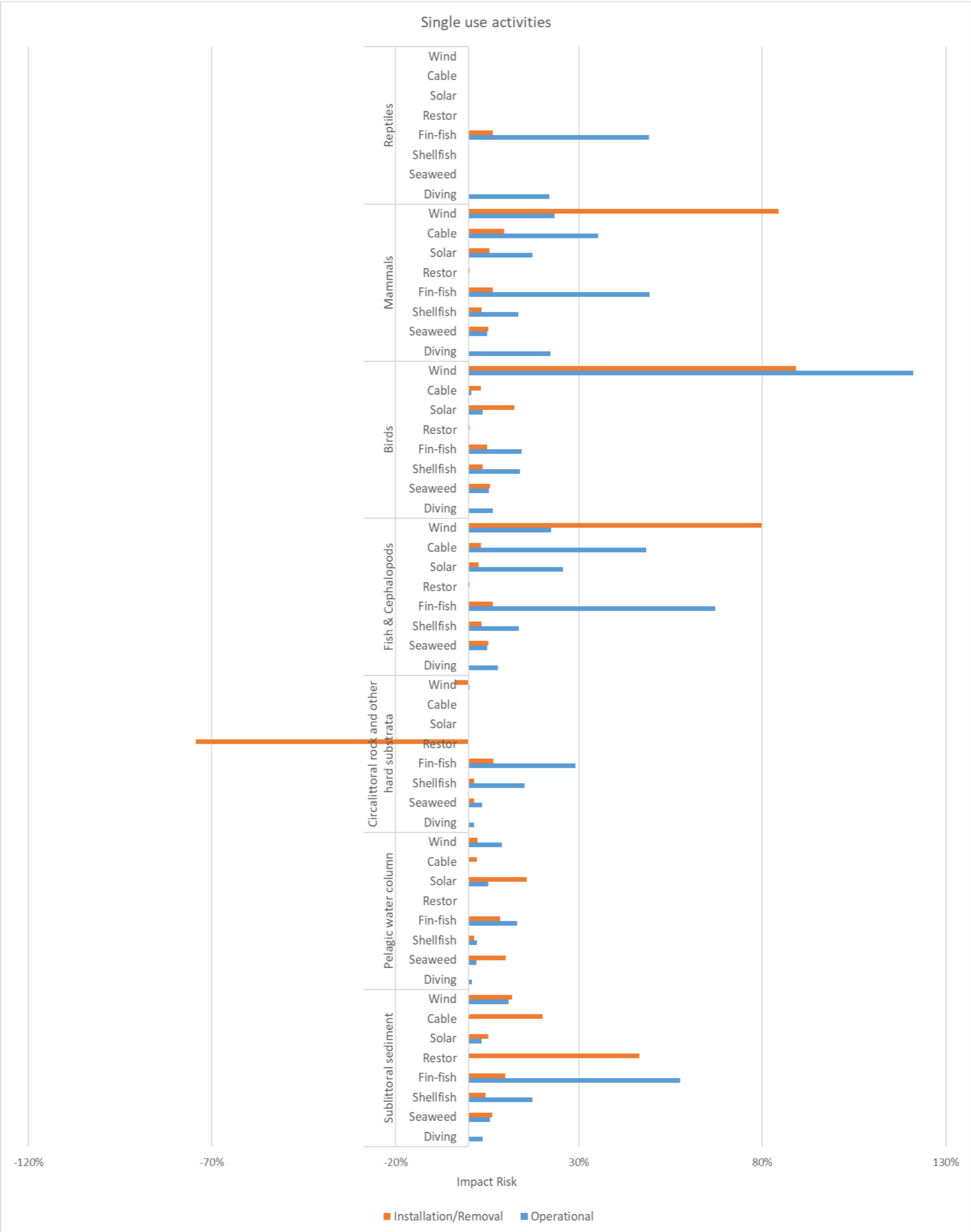

Figure 3. Impact risk (reduction in population) of the different activities on the ecosystem components per surface unit. See other figures for more detailing. On the standing axis the different Ecosystem components are given (outer division, most left). On the standing axis itself the different activities are given, that have an impact risk on the ecosystem components (inner division, rights side). The laying axis is the % Impact Risk.

The two following graphs, Figure 4 and Figure 5, show impacts per activity, summed per pilot, on each ecosystem component, taking into account the surface estimated for the upscaled scenarios (e.g., 17km^2 for a windfarm and 4.2 km^2 for seaweed aquaculture), for more detail about the methodology, refer to deliverable 4.3 of the UNITED project deliverables.

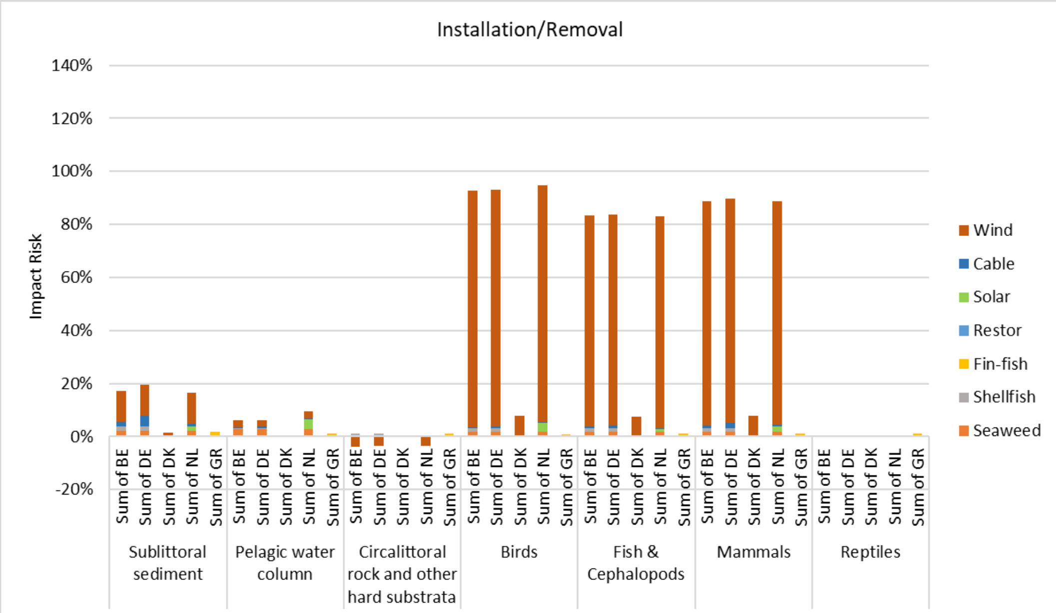

Figure 4. Impact risks of the different summed activities in the Installation/removal phase. On the X-axis the summed pilots (against the axis) per Ecosystem Component (lower level). BE Belgium; DE: Germany (Deutschland); DK: Denmark; NL: Netherlands; GR: Greece. On the Y-axis the calculated Impact Risk.

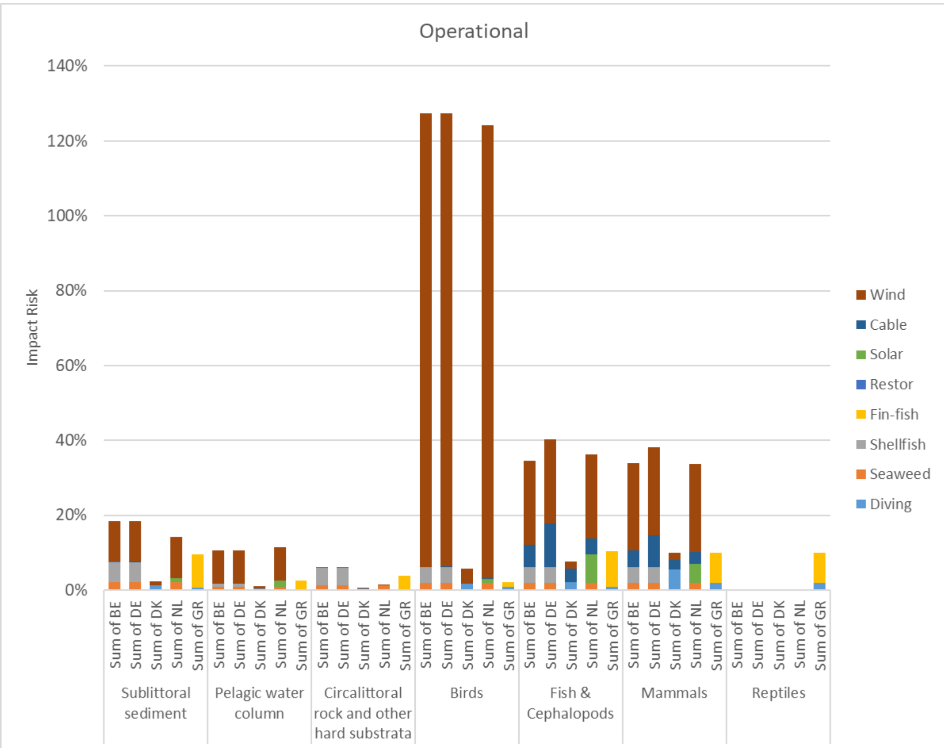

Figure 5. Impact risks of the different summed activities in the Operational phase. On the X-axis the summed pilots (against the axis) per Ecosystem Component (lower level). BE: Belgium; DE: Germany (Deutschland); DK: Denmark; NL: Netherlands; GR: Greece. On the Y-axis the calculated Impact Risk.

Across most ecosystem components considered, the windfarms have the strongest impact during the operational phase, as they also occupy the biggest surface. The only exception is Circalittoral rock and other hard substrate, for which the impacts seem to be caused by other activities than windfarms.

When it comes to Mammals and Fish & Cephalopods, the installation and removal of windfarms have a higher impact than the operational activities (predominantly caused by the pressure Impulsive Noise). For Birds, on the other hand, the impact of installation and removal is high, but the operational phase has an even higher impact risk (predominantly caused by the pressure Death by collision).

The second highest activity is Finfish culturing, with high impact risks on almost all ecosystem components. Finfish culturing is also the only activity with IRs on reptiles, due to the fact that this is the only activity taking place in an ecosystem where this component is present (sea turtles in Greece).

Regarding positive impacts, windfarms have so far been the only activity identified as causing positive impacts, which can be seen in Figure 4 on the ‘Circalittoral rock and other hard substrata’ component, during the installation phase of wind farms. The benefits for the ecosystem would come from the turbine foundations and scour protection layer providing new (artificial) hard substrates for species to colonize. The extent to these benefits to the environment may be subject to debate, given that adding any type of artificial structure could have unforeseen impacts, not all positive. This evaluation being very context-dependent, the potential positive benefits from having artificial hard substrate added to the North Sea specifically will be investigated in deliverable 4.4.

The graphs below, Sankey maps of the installation phase (Figure 6) and operational phase (Figure 7), provide more details about the type of pressure that is exerted on each considered ecosystem component, by each activity.

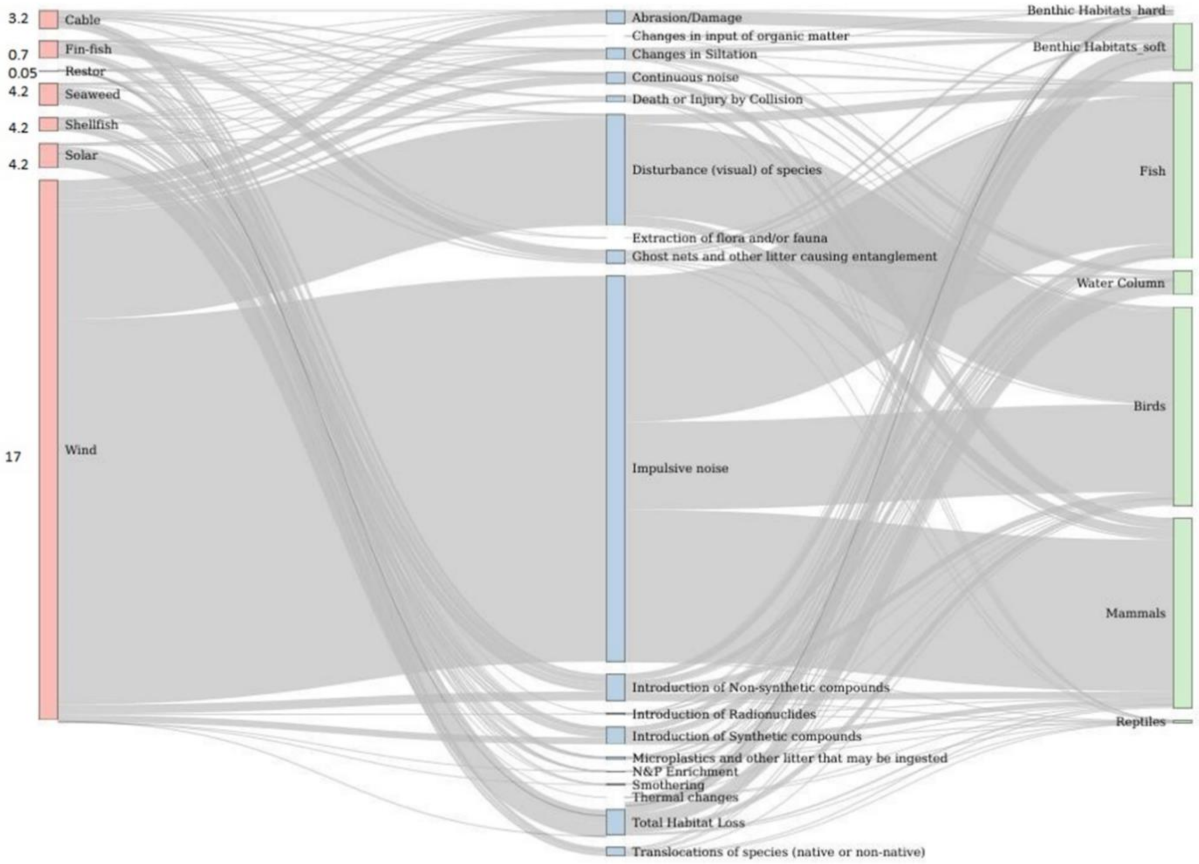

Figure 6. Sankey map of Installation phase. The areas covered by each activity are displayed in the left side; the maximum surface of each activity was used (Wind, 17 km2; Solar, Shellfish and Seaweed: each 4.2 km2; Export cables: 3.2 km2; Finfish: 0.7 km2; Nature restoration: 0.049 km2). The sum of the bars left represents 100% Impact Risk. The length of each bar represents its percentage contribution to the 100%. The same is valid for the bars in the middle and the right. Also the thickness of the flows left represents the percentage contribution to the total of flows, as is valid for the right as well. Diving was not integrated since it has no installation phase.

During the installation phase, impulsive noise is by far the heaviest pressure on biodiversity, followed by visual disturbance, and wind is the biggest cause of these two pressures. This result is not surprising, given that wind-farms also cover the biggest surface (17 km^2) and that their construction is heavy work.

Looking at the operational phase, Figure 7, results are a bit more surprising with a heavy impact on fish and mammal coming from windfarms through the pressure 'Electromagnetic change'. This result is mostly due to the fact that elasmobranchs are included in the 'Fish' category and that no finer distinction could be made between different types of fish. The same applies to mammals and birds. Although it is well known that several bird species suffer from windfarms, some species on the other hand, have been reported to thrive in windfarms (successful crossing, feeding and nesting).

In addition, secondary impacts, such as the artificial reef effect resulting from added hard substrate in windfarms, or the effect of fishing exclusion in the windfarms could not be integrated in the analysis so far.

Finally, positive impact does not appear as differentiated from negative impacts in these flows. The flow will only account for the result of the difference between the two.

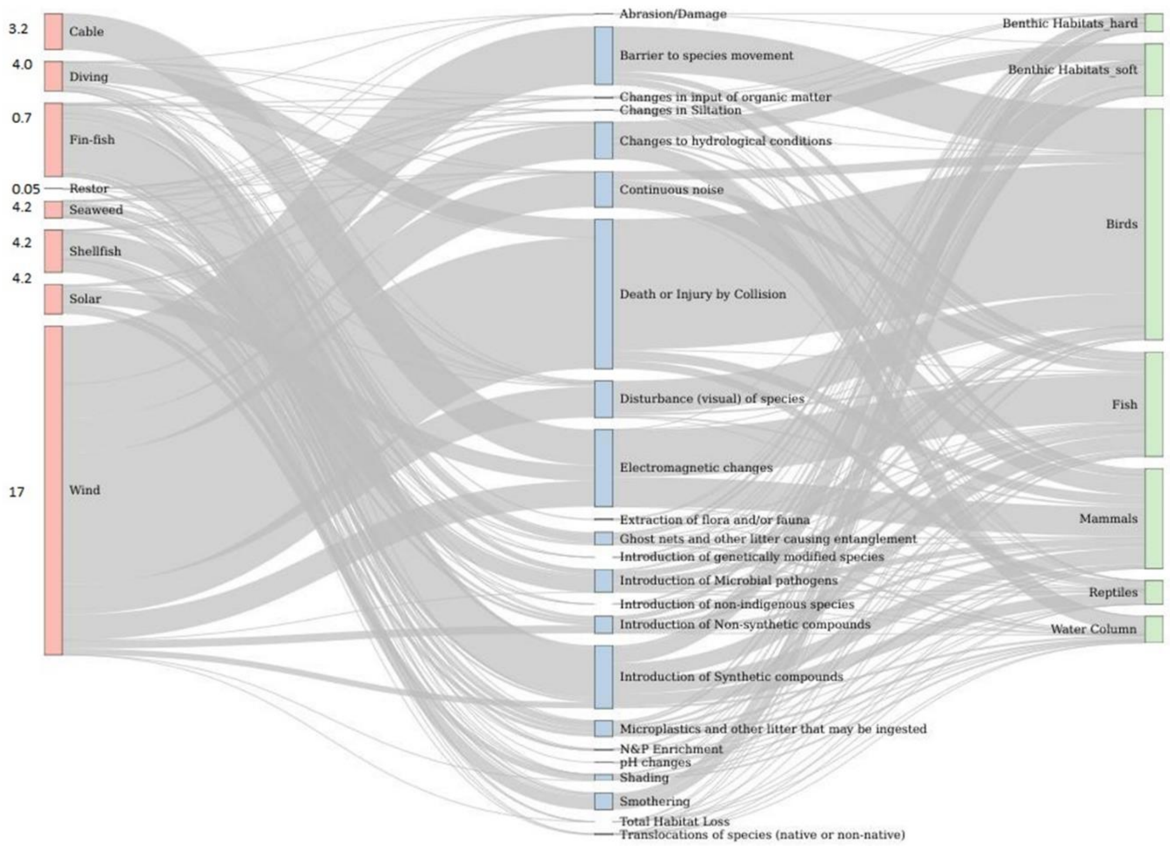

Figure 7. Sankey map of the operational phase. The areas covered by each activity is displayed in the left side; the maximum surface of each activity was used (Wind, 17 km2; Solar, Shellfish and Seaweed: each 4.2 km2; Export cables: 3.2 km2; Finfish: 0.7 km2; Nature restoration: 0.049 km2). The sum of the bars left represents 100% Impact Risk. The length of each bar represents its percentage contribution to the 100%. The same is valid for the bars in the middle and the right. Also the thickness of the flows left represents the percentage contribution to the total of flows, as is valid for the right as well.

Funded by the European Union (H2020 Grant Agreement no 862915). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them

2.2.2. Prediction of environmental impact of activities in a multi-use setting

Deliverable 4.4 extended the impact risk prediction to upscaled multi-use scenarios based on the experience of the pilots of UNITED. Impact risk was predicted for each ecosystem component, then these impact risks were compared between the activities in a single-use setting and the activities in a multi-use setting. The results of the impact risk prediction per ecosystem component are displayed in Figure 8.

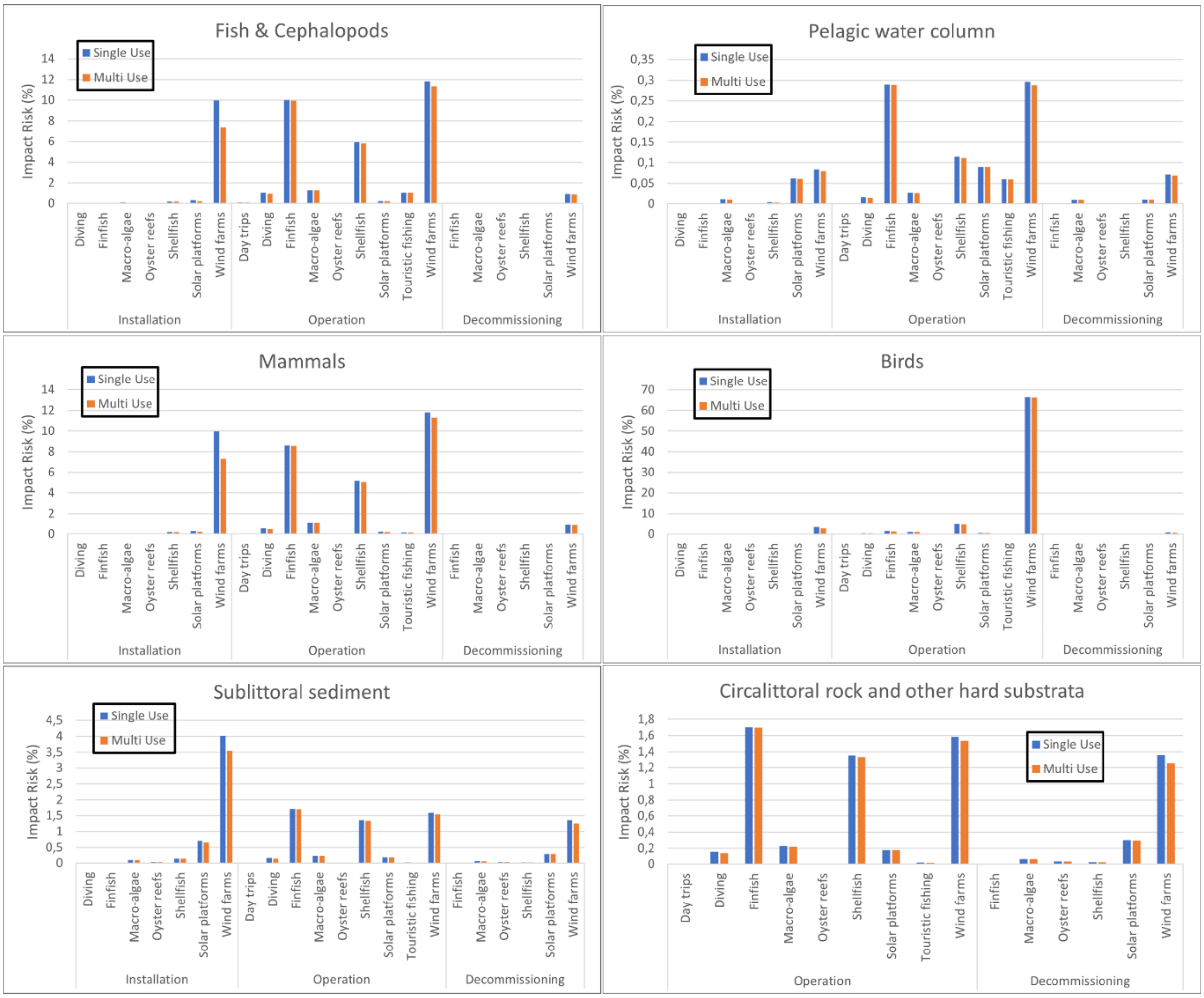

Figure 8. Prediction of impact risk reduction between single-use and multi-use setting per UNITED activity, for each considered ecosystem component.

The following conclusions can be drawn from these predictions:

- For the Fish and Cephalopods category, the highest impact reductions are expected for wind farms in multi-use settings, especially during installation but also during the operation phase. Shellfish aquaculture and diving activities also appear to have a reduced environmental impact on fish and cephalopods during their operation phase if conducted in multi-use settings.
- Impact risk on the Pelagic Water Column category is expected to occur from wind farms during installation but mostly during operation in a multi-use setting. The impact risk reduction magnitude is lower, however, than for the Fish and Cephalopods category, as can be seen from the difference in the y-axis of the graphs that displays much lower values.
- Mammals are expected to experience less impact risk during the installation and operation of wind farms in a multi-use setting, as well as during the operation phase of shellfish aquaculture in multi-use, although to a lesser extent.

- Impact risk on Birds does not appear to change much between single-use and multi-use activities, expect for some impact risk reduction during the installation phase of wind farms in a multi-use context.
- The biggest impact risk reduction for the Sublittoral Sediment ecosystem component is expected to happen during the installation phase of wind farms in multi-use. Some impact reduction is also expected for wind farms and shellfish aquaculture in multi-use settings, and also some reduction during the decommissioning phase of wind farms in multi-use.
- Sublittoral Rocks and other Hard Substrate would experience most impact risk reduction during the decommissioning of offshore wind farms in a multi-use context, although the impact risk magnitude is again quite low.

2.2.3. Looking further: identification of wider potential environmental benefits of multi-use

While a reduction in negative impact certainly is a major argument to implement multi-use projects instead of single-use ones, the potential of generating positive environmental impacts is equally essential. Positive impacts occur when restoring threatened habitats, providing protection for biodiversity, enhancing ecosystem functions, or offering a more eco-friendly food production system for example. These types of wider impacts are discussed in the following section. They are meant to support decision-making as to what type of multi-use to implement, based on contextual priorities (restoring habitat vs raising social awareness on environmental issues for example). They can also support applications by informing on what ecosystem services are provided or what European environmental strategies would benefit from ocean multi-use. This analysis participates in the assessment of the meaningfulness of impacts, as envisioned by step 2 of the UAF.

Wider positive impacts of ocean multi-use were gathered through literature review and expert judgement. The following were identified as major impacts:

- Habitat restoration

The North Sea's seabed primarily consists of soft sediments like sand and silt, with some gravel bed patches. Before 1900, hard substrates, such as biogenic reefs of European flat oysters and remnants of trees and vegetation, were present but were largely destroyed by human activities (Lengkeek et al., 2017). This led to a significant loss of biodiversity and keystone species. Restoring European flat oyster reefs was historically challenging due to ongoing disturbances on the seafloor. However, the exclusion of fishing activities in offshore wind farms and the presence of scour protections, made of natural rocks, now offer opportunities for habitat restoration. The ideal scenario involves locating historical oyster reef habitats near multi-use projects, allowing for the rebuilding of reefs through the introduction of oysters. In cases where historical habitats are absent, careful research and planning are necessary to justify habitat creation, considering potential consequences and ensuring the preservation of natural features in the area.

- Biodiversity increase thanks to fisheries exclusion and artificial reef effect in OWF-LTA multi-use

In the future, extensive protection measures against high-impact activities in the North Sea, such as offshore wind farms, have the potential to significantly benefit the marine ecosystem. Wind farms restrict bottom trawling fisheries and often prohibit fishing activities within their boundaries, providing protection for sensitive and slow-growing macrofaunal species. After just three years of fishing exclusion, these species show higher abundance (Coates et al., 2016). This protection also extends to higher trophic levels, potentially compensating, at least partially, for the loss of fishing grounds (Halouni et al., 2020). Integrating low-trophic aquaculture practices within wind farms, using lines suspended between turbines, further enhances fishing exclusion.

Wind farms exhibit a positive influence on biodiversity through the artificial reef effect, facilitated by scour protection and monopiles, creating solid substrate habitats. This effect attracts sessile fauna, pelagic and demersal fish, and increases the density of large decapods (Dannheim et al., 2020). While artificial reefs do not present the same species diversity and community composition as natural reefs (Degraer et al., 2020), they can still contribute to biodiversity, connectivity, and ecosystem health, especially when complementing well-protected natural habitats (van der Molen et al., 2018; Tidbury et al., 2019; Degraer et al., 2020; Glarou et al., 2020). The combination of offshore wind farms and low-trophic aquaculture presents a promising approach for sustainable marine ecosystem management.

- Increase in commercial fish species in OWF-LTA multi-use

The previously described biodiversity increase may lead to a spill-over effect (Halouni et al., 2020). This spill-over effect could benefit commercial fish stocks, as a consequence of a protected area where fish can thrive and potentially contribute to increased populations beyond the boundaries of the OWF-LTA combination. Overall, ocean multi-use presents a promising strategy for not only enhancing biodiversity but also positively impacting the abundance of commercially valuable fish species.

- Increased nutrient cycling and carbon sequestration in the case of multi-use including LTA

Organisms like mussels, barnacles, and anemones, forming benthic fauna on artificial hard substrate, contribute to water quality by removing excess nutrients, aiding in nutrient cycling. Shellfish aquaculture, such as mussel farming, plays a crucial role in regulating nutrient levels. Seaweed further enhances nutrient cycling, effectively removing nutrients and mitigating overload from sources like fed aquaculture. Cultivated without fertilizers, seaweeds, as photosynthetic organisms, produce oxygen, prevent coastal hypoxia, and absorb carbon dioxide, participating in carbon sequestration, potentially reducing ocean acidification (Buck et al., 2017).

Both seaweed and shellfish aquaculture promote increased sedimentation, through the transfer of fecal pallets and dead organic material (leaves and shells) to marine sediments. In the long term and if the seafloor remains undisturbed, this accumulation of organic matter on the seafloor may become a significant carbon sink (De Borger et al., 2021; Jones et al., 2022).

Seaweed, both wild and cultivated, is crucial for removing carbon dioxide from the atmosphere. Highly autotrophic seaweed communities globally capture a substantial amount of carbon. Seaweed communities contribute more organic matter through photosynthesis than consumed through respiration, playing a vital role in capturing carbon dioxide in marine vegetated habitats. Carbon sequestration from seaweed aquaculture occurs locally, underneath the farm, with a potential for larger-scale sequestration through the lateral transportation of seaweed detritus to carbon sinks (Ross et al., 2023).

- Sustainable food production

Cultivating shellfish and seaweed in low-trophic aquaculture has a smaller ecological footprint, preserving land and resources (Buck et al., 2017; Jones et al., 2022). These organisms grow naturally at sea, reducing environmental and economic costs. Mussels, for example, attach themselves to longlines without the need for land-based hatcheries. This sustainable practice contributes to marine ecosystem preservation, acting as a habitat and mitigating eutrophication.

While finfish aquaculture has a higher ecological footprint (Jones et al., 2022), local production supports sustainability compared to importing. With the growing demand for protein, integrating fish farms with tourism activities enhances visibility and generates income for coastal communities. This multi-use approach promotes sustainable aquaculture practices, increasing public awareness and acceptance for a reliable supply of high-quality seafood.

- Raising awareness towards offshore wind production and sustainable aquaculture

Ocean multi-use, combining offshore wind farms and lower-trophic aquaculture, addresses historical public concerns by increasing social acceptance through several mechanisms. It enhances the attractiveness of regions by creating economic opportunities, promoting sustainability, and fostering collaboration. The integration of activities such as offshore wind energy, aquaculture, tourism, and marine research attracts industries, investors, and skilled professionals, leading to job creation, economic growth, and sustainable development. Multi-use concepts drive innovation, establish regions as hubs for marine technologies, and diversify economic bases, reducing dependence on a single industry. Additionally, collaborative initiatives enhance the quality of life for residents, offering diverse activities, services, and cultural experiences. By promoting transparency and dispelling misconceptions, ocean multi-use contributes to informed public understanding and acceptance of activities like wind farms and aquaculture, fostering an innovative, diverse, and environmentally responsible destination.

- More space for conservation and reduction of conflicts over space use at sea

Ocean multi-use optimizes space by combining activities like wind farms and aquaculture, addressing conflicts and creating room for conservation. As new commercial activities, particularly offshore wind farms, increase, careful spatial planning becomes crucial. Combining activities in designated areas resolves conflicts over space use, with Maritime Spatial Planning playing a key role. This innovative practice fosters cooperation among sea users, offering a chance to reconcile historically conflicting activities and promote sustainable development.

3. ENVIRONMENTAL ASSESSMENT AND VALIDATION

3.1. Is multi-use better for the marine environment?

The main findings of this application of the extended CIA in a multi-use EIA context were that considerable negative impact reductions compared to single-use can be achieved through multi-use. Highest reductions of approximately 40% for fish and mammals in the installation phase of the Belgian and Dutch pilots, approximately 15% for fish and mammals in the operation phase of the Dutch pilot and approximately 20% for seabed habitats in the decommissioning phase of the Belgian pilot.

The CIA revealed that multi-use always has a lower IR in the case of multi-use when compared to single-use, for each pilot. A reduction of environmental impact can thus be expected when implementing the envisaged combined activities, in a sustainable way. The most IR reduction is found in the operation phase, which is also the longest phase in terms of time.

3.1.1. Single-use versus multi-use

The IR on Ecosystem Components (ECs) from activities in SU and MU is shown for each pilot in the installation, production, and decommissioning phase (Figure 9). It reveals that the highest IR is expected for the operation phase. In many cases, the IR in MU is lower than the IR in SU. The IR in MU is never higher than the IR in SU. Differences between IR of SU and IR of MU are most pronounced for the Dutch and Belgian pilots.

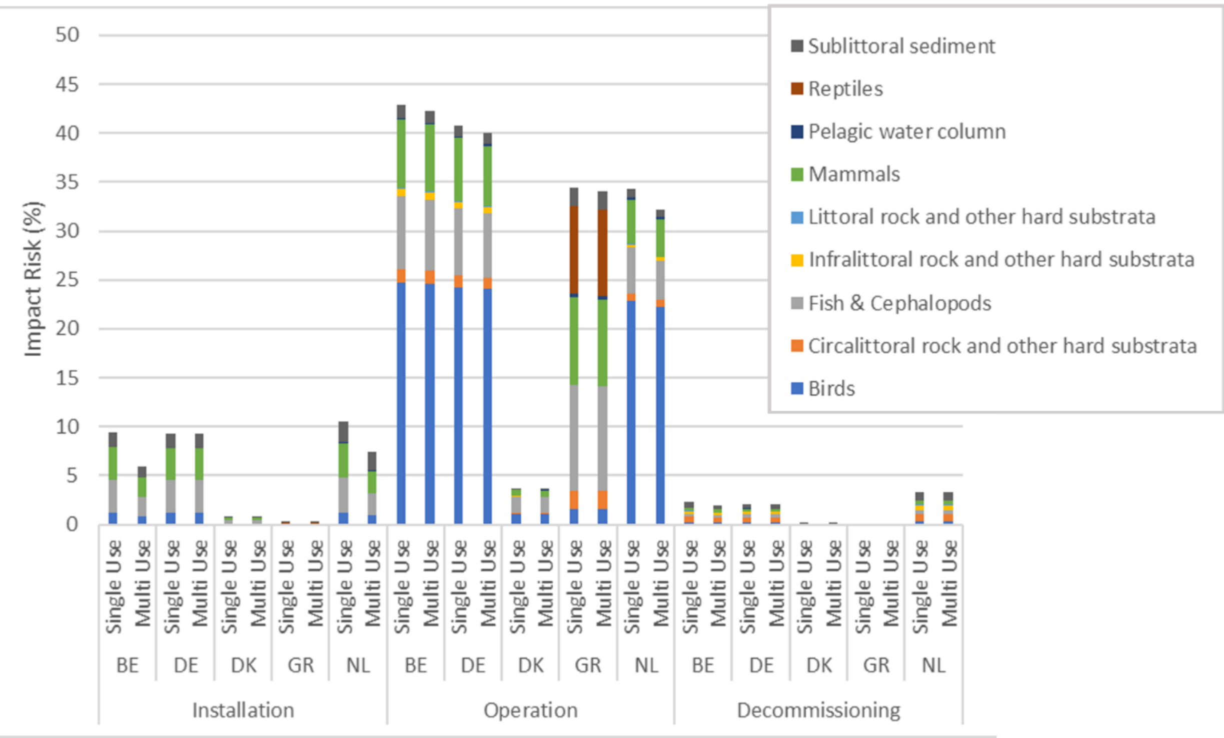

Figure 9. Impact Risk on ecosystem components in the Belgian (BE), German (DE), Danish (DK), Greek (GR) and Dutch (NL) pilot by activities in SU and MU for the Installation phase (left), Operation phase (middle) and Decommissioning phase (right).

For all pilots, IR is expected to reduce in MU compared to SU. Relative IR reductions are most pronounced for ecosystem components in the installation phase, followed by the decommissioning phase (both just occasionally). Small yearly reductions are expected in the operational phase (but lasting the full operational lifespan of the initiative, an anticipated 15 years or more).

Installation phase: IR reduction in the installation phase is highest for the ecosystem components: fish, mammals, birds, and sublittoral sediment. The highest relative reduction (ca. 40% for fish and mammals) is estimated for the Belgian pilot in the installation phase. Also, for the Netherlands, a relatively high reduction of IR is estimated for the installation phase. For other pilots, the installation phase shows no or very little reduction. This is because for these pilots the extent and duration of actions are either identical or similar in MU compared to SU.

Operational phase: During operations, all pilots show reductions of IR in MU compared to SU. Highest reduction is shown for the Netherlands which is estimated to reach ca 14% for fish and mammals mainly related to lines or nets in the water column. Also, in Denmark a relatively high reduction is expected, with a max of ca. 12% for (littoral and infralittoral) rock and other hard substrate mainly related to diving. For Belgium and Germany, the highest reduction is estimated for fish at nearly 3% and 5%, respectively mainly related to species culturing. In Greece, impact reduction is only expected for the operational phase, with a maximum of ca 2.5% for birds which is also mainly related to species culturing. Note that reductions are relative and hence are not a measure of absolute reduction of IR. The absolute reduction in IR is very minor. Because reported reductions are annual, they may accumulate during the operational phase to higher numbers than the incidental high reductions in the installation and decommissioning phase.

Decommissioning phase: IR reduction in the decommissioning phase varies considerably over the pilots with relatively high reduction for Belgium (ca 20% benthic habitats), very little reduction (<1%) for Germany and the Netherlands and no reduction for Denmark and Greece. As was also noted for the installation phase, for the decommissioning phase of these pilots the extent and duration of actions are either similar or identical in MU compared to SU.

3.1.2. Prediction of impact reduction in an optimal multi-use scenario

While multi-use was predicted to have a reduced impact risk than single use for all pilots and stages, this impact reduction remains quite small. This is partially due to current technological and regulatory challenges that would be realistically encountered by multi-use projects in the current system.

In the evaluation of UNITED pilots, realistic assumptions were made regarding the potential integration of activities in upcoming commercial multi-use (MU) projects. These assumptions were grounded in the current capabilities of technology, existing knowledge, and regulatory frameworks. Obstacles preventing the combination of actions in a MU context can be categorized as follows: a) actions solely pertinent to one activity, thus not applicable to MU, or b) actions involving structures, installations, or facilities that cannot be shared among different activities due to practical constraints such as safety regulations, insurance policies, and permit conditions.

While actions in category a) are expected to remain non-shareable in the near future, those in category b) may become feasible with future adaptations in regulations and the development of new tools (insurances, permits) and technology (infrastructure designed specifically to facilitate MU projects). To anticipate this potential evolution where MU could advance to a higher level, a hypothetical scenario, termed the 'Potential Optimal' scenario, was formulated. This scenario envisions a future state where actions falling under category b) become viable through regulatory adjustments and the introduction of innovative tools and technologies supporting MU projects.

Figure 10 displays the expected IR reduction during the operation phase of the Belgian pilot in the potential optimal scenario (hypothetical, blue bars) and in the realistic scenario (pilot, orange bars), on each considered ecosystem component. This predictive analysis indicate that MU projects could provide substantial impact risk reduction (potentially a factor 2 improvement) in a future that enables them fully.

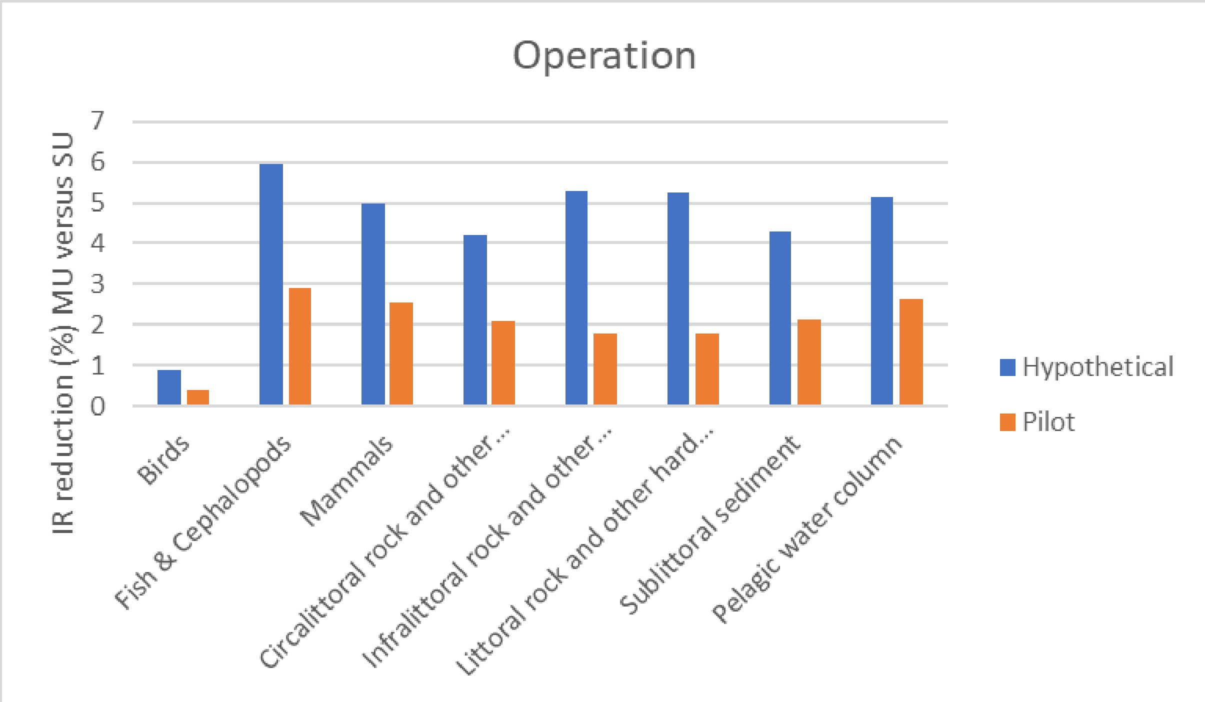

Figure 10. Reduction (%) in Impact Risk for each Ecosystem Component by activities in multi-use compared to single-use for the Belgian pilot (operational phase). Two different assumptions are used: pilot scenario assuming no sharing of structures (used for all results in this study) and hypothetical (potential optimal) scenario assuming sharing of structures is allowed and feasible.

3.1.3. Potential environmental benefits of ocean multi-use in the five pilots of UNITED

The previously identified environmental benefits that may come out of multi-use projects were the following: habitat restoration, biodiversity increase, commercial fish species increase, increased nutrient cycling and carbon sequestration, sustainable food production, raising awareness towards offshore wind farms and sustainable aquaculture, more space for conservation and reduction of conflicts over space use at sea.

Table 1 crosses these potential benefits with the pilots whose activities make these benefits possible, the multi-use combinations that make these positive impacts possible, and the European Environmental strategies that would benefit from these positive impacts.

The reduction of conflict over space-use and the awareness raising towards offshore windfarms and aquaculture are environmental benefits expected for all five pilots of the project. Sustainable food production is expected for all of them expect for the Danish pilot that does not include an activity producing food. Biodiversity increase, commercial fish species increase, nutrient cycling, carbon sequestration and more space for conservation are expected from the Belgian, Dutch and German pilots. This is because all these benefits are expected to come out of the cultivation of low-trophic organisms, the colonization of wind turbines by these same types of organisms, and the sheltering function provided by two space-demanding but low impacting activities, at least during their operation stage. In some cases, other activities might free up space for conservation, but it was not assessed appropriate for the Greek and Danish pilot, as tourism and conservation are not necessarily activities that exclude conservation, at least not in the case of boat and diving tours. Therefore displacing them in a wind farm or around a fin fish farm does not necessarily increase the availability for conservation space. Finally, only the Belgian pilot could pretend to trigger oyster reef restoration, as it is the only pilot in which specific actions were taken for that purpose.

Table 1. Analysis of potential environmental benefits of UNITED's pilots

Impacts	Pilots	Mu scenarios	EU policies
Oyster reef restoration	BE	Rest. & OWF Rest., OWF & Aqua	Green Deal Nature Restoration Law MSFD GES D1
Biodiversity increase	BE NL DE	OWF & Rest. OWF & LTA OWF, Rest. & Aqua	MSFD GES D1
Commercial fish species increase	BE NL DE	OWF & Rest. OWF & Aqua OWF, Rest. & Aqua	MSFD GES D3
Nutrient cycling	BE NL DE	OWF & Rest. OWF & Aqua OWF, Rest. & Aqua	MSFD GES D5
Carbon sequestration	BE NL DE	OWF & Aqua OWF, Rest. & Aqua	Green Deal Sustainable Carbon Cycles
Sustainable food production	BE NL DE GR	Aqua & OWF Aqua & Tourism	Green Deal Farm-to-Fork Strategy Sustainable Blue Economy
Increased social acceptance of OWF and/or aquaculture	BE NL DE DK GR	Aqua & Tourism OWF & Tourism OWF & Rest. OWF & Aqua OWF, Rest. & Aqua	Green Deal in general
More space for conservation	BE NL DE	OWF & Rest. OWF & Aqua OWF, Rest & Aqua	Green Deal Biodiversity Goals
Reduction of conflicts over space use	BE NL DE DK GR	OWF & Rest. OWF & Aqua OWF, Rest. & Aqua OWF & Tourism Aqua & Tourism	MSP Directive

***Aqua**: Aquaculture; **BE**: Belgium; **D**: Descriptor; **DE**: Germany; **DK**: Denmark; **GES**: Good Environmental Status; **GR**: Greece; **MSFD**: Marine Strategy Framework; **NL**: Netherlands; **OWF**: Offshore Wind Farm; **Rest.**: Restoration*

3.2. How can ocean multi-use help achieve the Marine Strategy Framework Directive (MSFD) goals?

Ocean multi-use can result in having less environmental impacts than if these same activities were conducted simultaneously but in different place. In these cases, multi-use could be used as a tool for achieving better environmental status in European seas, as defined by the Marine Strategy Framework Directive (EC, 2008).

The Marine Strategy Framework Directive is a European directive in force since 2008, that requires from Member to "(…) set up national marine strategies to achieve, or maintain where it exists, 'good environmental status' by 2020"(EC, 2020a). 'Good environmental status' is defined as a such: "(…) *the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations […]."*(EC, 2020a).

Eleven descriptors are defined by the MSFD to define the concept of Good Environmental Status (GES)[2]:

- Descriptor 1: The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions
- Descriptor 2: Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems
- Descriptor 3: Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock
- Descriptor 4: All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity
- Descriptor 5: Human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters
- Descriptor 6: Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected
- Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems
- Descriptor 8: Contaminants are at a level not giving rise to pollution effects
- Descriptor 9: Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards
- Descriptor 10: Properties and quantities of marine litter do not cause harm to the coastal and marine environment
- Descriptor 11: Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment

While multi-use might be instrumental in the achievement of some, it may also have adverse impacts on others and should therefore be closely monitored. The following section reviews each descriptor and evaluates how ocean-multi use might have positive or negative effects on it.

3.2.1. Does MU not compromise, or can it even help achieving Good Environmental Status (GES)?

Descriptor 1 – Biodiversity is maintained

Descriptor 1 'The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions' could benefit from multi-use in several ways. One of the simplest ways multi-use can help reducing human impact on the marine environment, is by reducing the amount of space used. This is especially relevant when considering activities that (1) require a large amount of space and (2) conflict with other uses. Such is the case of windfarms, that require large areas and usually do not

[2] https://ec.europa.eu/environment/marine/good-environmental-status/index_en.htm

allow fishing, shipping or gas extraction for safety reasons. Aquaculture also falls in that category, although the size of farms can greatly vary.

While these static types of activities at sea conflict with many other uses of the marine environment, they can be combined into a single area, therefore reducing the total amount of space used. The consequence is twofold: either the 'freed' space is used for other anthropogenic activities, or it is used for conservation purpose as marine protected area. Obviously, only the second option may contribute to biodiversity conservation. Protected areas are efficient tools to protect and enhance biodiversity, when correctly designed and enforced.

Another way multi-use can contribute to conserving biodiversity is by combining specific uses. Looking again at the combination of windfarms and low-trophic aquaculture (LTA), both activities are incompatible with heavily impacting activities such as bottom-trawling. Fishing in the windfarms is either fully forbidden or strongly regulated, for safety reasons. Small-scale fisheries (lines, pots, etc.) are allowed in the Netherlands and the UK, but beam trawling is, to our knowledge, forbidden in all windfarms in European countries. As LTA involves lines and nets spread just underneath the surface to a few meters down, depending on the type of plant or animal cultivated, neither fishing nor shipping can be allowed within a farm and a reasonable safety zone should be implemented around it.

By combining of LTA farm and an offshore windfarm, crossing the area would have to be strictly regulated, and fishing forbidden altogether. As a result, the area could become a sort of protected zone and might fall under the category of Other Effective area-based Conservation Measures (OECMs). OECMs are defined as such by the Convention on Biodiversity (CBD): "*A geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in-situ conservation of biodiversity with associated ecosystem functions and services and where applicable, cultural, spiritual, socio–economic, and other locally relevant values*" (CBD, 2018). In contrast with the IUCN definition of a protected area, as defined by the IUCN: "*A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*" (IUCN, 2019), OECMs do not have conservation as their primary objective but conservation happens within them regardless of their initial objective.

The scour protection and monopiles of wind farms constitute an artificial hard substrate comparable to an artificial reef and create an intertidal zone in an area where it would otherwise not exist. Offshore energy devices have been found to be extensively colonized by sessile fauna, to attract pelagic and demersal fish and to cause an increase in density of large decapods on the scour protection (Dannheim et al., 2020). In turn, this can benefit higher trophic levels by providing additional food sources. When combined with activities that do not heavily impact biodiversity, wind farms could become harbours of biodiversity.

This artificial reef effect might be enhanced by the presence of an aquaculture farm. Seaweed farming, for example, has been found to provide shelter to a variety of species, although farmed seaweed present lower taxa abundance than natural algae forests (Bekkby et al., 2023). While this function is temporary until the seaweed is harvested, the cumulative effect of the shelter provided by the seaweed (Jansen et al., 2018) and the one provided by the wind turbines (Degraer et al., 2020), that remains untouched for years, could have a cumulated positive effect on biodiversity development.

The following fish species have been reported to be attracted to the windfarms (non-exclusive list): European seabass (*Dicentrarchus labrax)*, black sea bass (*Centropristis striata*), Atlantic cod (*Gadus morhua*), pouting (*Trisopterus lusculus*), goldsinny wrasse (*Ctenolabrus rupetris*), plaice (*Pleuronectes platessa*), Arctic sculpin (*Myoxocephalus scorpioides),* Atlantic horse mackerel *(Scomber scombrus),* Atlantic mackerel (*Scomber scombrus*). (Bergström et al., 2013; De Broger et al., 2021; Degraer et al., 2020; Degraer et al., 2021; Makravi, 2020; Reubens et al., 2014; Wilber et al., 2020).

Three major reasons have been defined as to why they visit the turbines and their surroundings: long-term predation on the biofouling community, occasional predation on the biofouling community and non-trophic reasons such as seeking shelter or encounter with other individuals of the same species (Degraer et al., 2020). All three of them would be reinforced by having low-trophic aquaculture in a windfarm: additional biomass on which to feed and additional shelter, nursery and meeting areas.

Marine mammals, in the North Sea mostly harbor porpoises and seals, might benefit from the synergy between windfarms and low-trophic aquaculture. Negative interactions between mussel lines and marine mammals have been found rare (Price et al., 2017; Roycroft et al., 2004), especially for mammals using echo-location (such as porpoises), that easily distinguish non-moving human-made structures at sea. As a general rule, marine mammals will avoid getting too close to the lines, although they have been reported crossing the farms and feeding nearby. Fish are attracted to both low-trophic aquaculture farms and wind turbines, because of the artificial reef effect, and in turn attract marine mammals to feed on them: seals have been seen specifically hunting between wind turbines (Russel and al., 2014) and dolphins have been reported feeding close to mussel farms (Price et al., 2017). To ensure that no negative interactions happen between multi-use projects and marine mammals, it must be ensured that the activities do not overlap with their breeding, migrating and feeding habitats. Additionally, keeping lines tensed further reduces the risk of entanglement. Known incidents involving marine mammals getting entangled in mussel longlines are few, and reported in Price et al. (2017).

In the German Pilot FINO3 the cultivation of mussels and algae at a far remote offshore location in the German North Sea next to wind parks is studied. The final goal is the first step towards the implementation of multi-use of marine space by wind-, algae- and mussel farms. During the testing time the German pilot was able to combine maintenance visits to the monopile and monitoring visits to the aquaculture site. Thereby reducing the environmental impact by half of the traveling to the site. Also, a harbor porpoise monitoring system was installed, recording the echolocation sounds emitted by harbor porpoises, allowing to estimate if harbor porpoises visit the aquaculture area. Data show that harbor porpoises readily visit the area and are not disturbed by the presence of the aquaculture structure. Under water videos also showed the presence of fish swimming around and in the aquaculture system. This could be also the reason that the harbor porpoises are detected in the vicinity of the system, as they might well hunt for food. Hence the presence of the aquaculture system seems not to disturb the present fauna, and might even enhance the living space of marine mammals and allow for fish to use it as a sheltered area. All these observations are still preliminary as the final data collected from the different sensors and monitoring equipment will be available only after the retrieval of the equipment and reviewing the collected data in mid to end 2023.

The impact on multi-use on birds is more complex and is species dependent. The collision risk for birds crossing windfarms is well known, although it does not affect all species equally. Some seabird species are very good at avoiding windfarms altogether, e.g., guillemots (*Uria aalge*) and northern gannets (*Morus bassanus*) (Skov et al., 2018). Others, like seagulls, are attracted to the turbines where they have been seen feeding and nesting, hence are more at risk of collision (Vanermen et al., 2020). The situation with mussel farms appears to be equally species and context dependent (Price et al., 2017; Roycroft et al., 2004; Roycroft et al., 2007). Adding a habitat and source of feeding in the sea may not be an overall positive impact on bird population, as it may influence their migrating habits and their health – feeding on seafood may not be appropriate for all bird species. Impacts per species must be further investigated and carefully monitored to come to a conclusion on this topic.

Finally, multi-use can specifically combine an economic activity with conservation or restoration. The conservation or restoration then becomes one of the ‘use’ of multi-use. Often, conservation measures will be taken to include biodiversity protections in a marine area dedicated to a specific use, nature-inclusive design is a good example of it. However, more is needed to consider it a multi-use combination. Active restoration of a habitat e.g., could be considered as a ‘use’ of a marine area, hence qualifying as multi-use when combined with another activity. Offshore windfarms or areas used for non-invasive touristic activities could be well-suited for this purpose.

In the Belgian pilot, European flat oyster reef restoration was tested as a combined use within an offshore windfarm. Oyster cages filled with mature adult European flat oysters (*Ostrea edulis*) and scour protection stones suited for settlement were installed upstream of other cages with scour protection materials only, in the hope that their offspring might colonize the turbines and scour protection of the own cages (self-fertilization) or the ones downstream, and initiate the restoration of flat oyster reefs. The species of oysters (*Ostrea edulis*) is an indigenous species of the area, from which it has locally disappeared because of overfishing and diseases (Lengkeek et al., 2017). Restoration of oyster reefs in a windfarm, in combination with low-trophic aquaculture (such as oyster aquaculture), could be beneficial in two ways: for one, the windfarm in itself would act as a protection for the oysters since bottom-trawling is strictly forbidden; secondly, restored oyster reefs would provide spat that could naturally settle on the aquaculture lines foreseen for oyster cultivation and be harvested in a non-invasive way.

Descriptor 2 – Non-indigenous species do not adversely alter the ecosystem

The second descriptor of GES is to not have the ecosystem adversely altered by non-indigenous species. Anthropogenic activities at sea are often at risk of bringing nonnative, potentially invasive species, into marine habitats and ecosystems. Having these activities combined in one space may enhance this risk, but little is known about it and further research should be conducted.

Aquaculture is an activity at risk of spreading or transporting non-indigenous species. In the North-east Atlantic, aquaculture, and more specifically oyster culture, has been estimated responsible for over 30% of marine introductions (EC, 2020b) and seaweed cultivation has been identified at risk of introducing invasive species, bio-invasions (Bindu and Levine, 2011), and potential species translocations (Beveridge et al., 1997).

There might a higher risk of non-native species introductions from aquaculture activities if it happens close to the artificial reefs created by the windfarm boulders and scour protection. The turbines' poles provide an intertidal habitat (Dannheim et al., 2020), by crossing the entire water column, that may not have existed there before, hence additional space for native and nonnative species to settle. As non-native species are often found invasive, they might use this space to develop and smother all other life forms. The potential for this to be enhanced by the presence of low trophic aquaculture or the risk for the cultivation devices to be colonized by nonnative invasive species is likely higher than if the aquaculture were to be conducted in another area.

Nevertheless, close monitoring should allow to conduct these activities in combination all the while preventing the development of non-native species, diseases and pathogens. Additionally, given that the risk would still exist if these activities were to happen as single uses, having them combined in a single area would facilitate the monitoring and reduce its costs, both financial and environmental. A single boat and team can be sent to monitor and maintain both the wind farm and the aquaculture installation.

Descriptor 3 - The population of commercial fish species is healthy

Regarding descriptor 3 'P*opulations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock*', the combination of offshore windfarms with low-impact activities, such as low-trophic aquaculture, might be beneficial. The following commercial fish species have been found to be attracted to the windfarms (non-exclusive list): Atlantic cod (*Gadus morhua*), European seabass (*Dicentrarchus labrax*), black seabass (*Centropristis striata*), Atlantic mackerel (*Scomber scombrus*), Atlantic horse mackerel (*Trachurus trachurus*) and plaice (*Pleuronectes platessa*) (Bergström et al., 2013; De Broger et al., 2021; Degraer et al., 2020; Degraer et al., 2021; Reubens et al., 2014; Wilber et al., 2020). With exclusion of fishing in the windfarms, which would be reinforced by the presence of low-trophic aquaculture, a spill-over effect could benefit commercial fish stocks. However, having areas closed to fishing might cause a reallocation of the fishing pressure and impacts elsewhere. This should be investigated in the future.

Descriptor 4 - Elements of food webs ensure long-term abundance and reproduction

The potential of multi-use for participating in the achievement of descriptor 4 '*Elements of food webs ensure long-term abundance and reproduction*' of the GES, could not be developed here. It is a complex and under-documented (EC, 2020b) descriptor, and the potential of multi-use regarding this has yet to be investigated.

Descriptor 5 – Eutrophication is minimized

Considering the fifth descriptor of GES, '*Human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters*', some combination of multi-use might play in favour of reducing eutrophication effects.

Organisms colonizing turbines and scour protection in wind farms are mostly filter feeders, that will absorb food particles in the water column, including phytoplankton, zooplankton and detritus (Degraer et al., 2020). This biofiltering results in a transfer of organic matter from the water column to the seabed, causing an organic enrichment of the surrounding sediments and cleaner water, meaning lower turbidity and increased light penetration (Dannheim et al., 2020; Degraer et al., 2020).

A study led by a team of Belgian researchers has concluded that the colonizing organisms found on wind turbines, mostly suspension feeders, are estimated to reduce the local producer standing stock by approximately 1.3% in the Belgian part of the North Sea (Mavraki et al., 2020). Another study by Slavik et al. (2018) modelized filtration from blue mussels attached to wind turbines and concluded that the decrease in primary production could be up to 8% of the windfarm's footprint. Since an increase in primary producers is a direct effect of eutrophication (European Environmental Agency, 2019), adding mussels, and potentially other suspension feeders, to the environment might mitigate the overall effect of eutrophication of European seas.

With low-trophic aquaculture (mussels, oysters, seaweed), a similar process is likely to occur, with organic waste gathering on the seafloor via sedimentation (Chua Thia Eng et al., 1989; Buschmann et al., 1996; Zhang et al., 2009; Jones et al., 2022). It should be noted, however, that excessive sedimentation can be harmful for both the environment and the aquaculture activities. While some organic enrichment has been found to stimulate the growth of the cultivated species (Chua Thia Eng et al., 1989), excessive sedimentation can increase water turbidity, decrease primary production and cause anaerobic and anoxic conditions (Chua Thia Eng et al., 1989; Zhang et al., 2009; Buschmann et al., 1996). To prevent aquaculture activities to have this type of negative impact, low or medium-intensity production should be favoured. If well designed and located, a low-trophic farm may participate in reducing eutrophication in marine waters. Oysters and mussels, as suspension feeders, feed on microalgae and other suspended organic particles in the water (Zhang et al., 2009), removing nutrients from the water column and from the marine environment entirely as they are harvested. Combining seaweed with oysters or mussel culture might also lead to interesting synergies, with the shellfish cleaning the water and the seaweed benefiting from additional light. In addition, the oxygen consumption of the shellfish could be compensated by the seaweed's photosynthesis (Buck et al., 2017), while the increase of organic matter sedimented from shellfish fecal pellets and dead bodies would increase the mineralization process, leading to higher concentration of inorganic nutrient available for seaweed to consume (Buck et al., 2017; De Borger et al., 2021).

A successful combination of OWF and LTA must take into account the specificity of the site, and more specifically the natural nutrient availability. Offshore environments tend to be poorer in nutrient than coastal environments (Buck et al., 2018), which may limit the growth of the cultivated species. For a successful offshore aquaculture farm, offshore locations where predominant horizontal and vertical currents might carry nutrients and particles beyond where they can be accessed by extractive species should be avoided in the favour of sites characterized by (1) eutrophication induced by human activities, particularly through increased river inputs, (2) atmospheric depositions, (3) upwelling, and (4) areas experiencing natural eutrophication (Buck et al., 2018).

Low trophic aquaculture holds a potential to reduce eutrophication of European seas in some specific contexts. Yet, it is a space-demanding activity that cannot be combined with most other marine use, therefore ocean multi-use might bring the right opportunities for this emerging sector. Offshore wind farms appear especially suited, however nutrient availability in the sites of the offshore wind farms should be evaluated to ensure that it is well-suited for shellfish and seaweed growth.

Descriptor 6 - The sea floor integrity ensures functioning of the ecosystem

Descriptor 6 of a GES states that the Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected. Wind farms strongly impact the seafloor during their installation phase, but then mainly leave it undisturbed during their operational phase, which should be over 15 years. The decommissioning of the windfarms is still under development, and the impact of it is yet unknown. By combining offshore windfarms with non-impactful activities such as low trophic aquaculture or touristic activities, the sea floor would remain untouched and protected from invasive activities such as bottom-trawling or sand extraction. In such context, multi-use could help achieve this aspect of GES.

Nevertheless, aquaculture, both fish and low-trophic, causes an increase in sedimentation, making the sediment both richer in organic matter and finer (De Borger et al., 2021). While this may constitute an interesting carbon sink and transfer nutrients and organic matter from the water column to the seafloor (Degraer et al., 2020), it does compromise sea floor integrity. An increase of organic matter on the seafloor will modify the benthic community, potentially attracting species that would not naturally occur (at all or in such magnitude) in that specific area (Zhang et al., 2009; Degraer et al., 2020).

Descriptor 7 - Permanent alteration of hydrographical conditions does not adversely affect the ecosystem

Descriptor 7 requires that permanent alteration of hydrographical conditions does not adversely affect marine ecosystems. Structures at sea do affect the local hydrodynamics and consequentially also erosion-deposition dynamics and vertical mixing of the water column. Three types of interactions can be discerned: (1) interactions with locally wind-generated waves, (2) interactions with the swell and (3) interactions with (tidal) currents. The effect of co-locating activities requiring offshore infrastructure relates differently to each of these types.

Offshore structures and particularly large grounded infrastructure that touch the water surface like wind turbine foundations or floating infrastructure such as aquaculture long lines, significantly dampen waves and disturb waves coherence. For example, the reduction of the wind speed in the wake of the offshore windmills park may locally decrease the energy contained by locally wind-generated waves up to 15%, while the presence of the aquaculture long lines may dampen wave energy by 25% (both swell and locally wind-generated waves). In general, the higher the density (= size x number) of such structures, the larger the local wave dampening and disturbance effect. It however has to be stressed that the absolute effect size of a particular structure on locally wind-generated wave energy decreases with lower locally wind-generated wave energy, which means that the total effect size of co-located activities is expected to be lower than the sum of the effect size of a single-use design of the same activities.

The same type of offshore structures and particularly those touching the water surface may also affect ocean swell, i.e. local waves generated by distant weather systems. The effect size is positively correlated with the size of the structure close to the water surface. As such, offshore wind turbine foundations with only some tens of m^2 at the sea surface, are expected to have a negligible effect on ocean swell. Offshore aquaculture infrastructure often occupying large stretches of sea surface, on the other hand, may substantially dampen swell energy. The effect on ocean swell dampening by offshore wind farms and aquaculture in a co-location scenario hence is expected not to differ from the single-use scenario. If however several activities with infrastructure occupying large sea surface areas (e.g. offshore aquaculture and (some) photovoltaic installations) would be co-located, a similar pressure reduction as the one described for locally wind-generated waves is to be expected.

Offshore wind turbines affect tidal currents and hence alter the local erosion-sedimentation dynamics at the seafloor, which is why scour protection is often applied to larger offshore structures like offshore wind farm monopile foundations. Larger structures stretching the water column are also known to create turbulences throughout the water column. These are at the basis of the sediment plumes which are often observed in the wake of e.g. offshore wind turbines. These turbulences increase the level of mixing of the water column in the wake of the structure. Near-surface structures like the ones used for floating offshore photovoltaic installations or for mussel and seaweed aquaculture in contrary affect ocean currents mainly at the upper layers of the water column, where current speeds are decreased. As a consequence, current speeds increase lower down the water column. Different structures hence affect ocean currents in different ways and it is as yet unknown how these effects may interact in a co-location scenario.

Descriptors 8 - 'Concentrations of contaminants give no effects' and 9 – 'Contaminants in seafood are below safe levels'

Descriptors 8 and 9 of a Good Environmental Status as described by the MSFD, address contaminants concentration in water and in seafood (fish and others). With a multi-use project, the need for clean waters is enhanced, therefore there is a stronger incentive to ensure that these descriptors are met.

For aquaculture products to be fit for selling and consumption, contaminants concentrations must be closely monitored. In the Belgian pilot, several contaminants like Hg, Pb, Zn and Cu were measured in the mussel tissue from mussels cultured offshore within the Edulis project (project ran from 2017 to 2019). The levels remained below legally maximum allowed levels, hence why this area within the Belgian part of the North Sea, namely the Westdiep area, is considered to result in high quality mollusks and why it is further being explored as a commercial site for mussel and oyster cultivation.

For the Greek pilot, which combines aquaculture with tourism and more specifically with diving activities, parameters that are of importance to visitors – and which can come into conflict with aquaculture - include access, safety, water quality, no litter and scenery. Water quality, which is one of the most important aspects, refers to visual aspects such as the colour of water, absence of algae, absence of litter etc. Eutrophication is a main concern in this context as it can cause algal blooms which not only cause visual pollution, but can also be toxic. Swimming is mostly dependent on good water quality, as are diving and snorkelling; the latter additionally benefitting from the presence of biodiversity. Water quality and biodiversity are therefore interdependent factors that actively support some forms of maritime tourism. More specifically, in the Greek pilot, a monitoring system exists through which all the important environmental parameters are being monitored. These parameters are Temperature, pH, Salinity, Current, Dissolved oxygen, Turbidity, Chlorophyll, Nitrate, Ammonium and Meteorological data. This monitoring takes place continuously in real time, leading to a controlled combination of activities as all the parameters affecting pollution and water quality do not exceed the relevant standards levels and that is also a reason that these multiuse activities offer benefits such as clear water for divers and good quality fish for customers. Except for that, once per year the Ministry of Environment makes environmental inspections in the area and takes measurements concerning the water quality and contaminants in order for the parameters to be at desired levels.

Descriptor 10 – Marine litter does not cause harm

Following descriptor 10, a Good Environmental Status requires for marine litter to not cause any harm to the environment. Marine litter is a major concern to be dealt with in all marine operations. By increasing the use of an area, the risk of creating marine litter is also increased. Therefore, by combining the use of material, workforce and transportation multi use will reduce marine litter, as uses are combined and fewer visits to the sites are necessary. Still the occurrence of marine litter has to be closely monitored. In aquaculture sources of litter can be structures such as ropes, nets and tubing that can get lost. Hence the proper selection of materials according to offshore standards is crucial to minimize this risk.

Descriptor 11 – Introduction of energy does not adversely affect the ecosystem

Finally, descriptor 11 requires that introduction of energy (including underwater noise), does not adversely affect the ecosystem. Maintenance and operation of activities at sea require a lot of boat use. This is the case for windfarms, solar installation, touristic activities and aquaculture (both fish and shellfish). By combining these activities with each other, maintenance and operation teams may share vessel use, resulting in fewer boat trips hence less noise disturbance of the marine environment. The Greek pilot has been able to set this synergy in place, with divers and fish farmers sharing boat trips and use. Moreover, by containing activities in one area, that would otherwise be spread into two areas, the noise disturbance is contained. This allows for mobile marine fauna (mammals, sharks, fish and turtles) to avoid this area altogether. Of course, special attention should be given in the selection of the area, so as to not overlap with key habitats of threatened species.

3.2.2. Conclusions on ocean multi-use as tool for reaching or maintaining GES as defined by the MSFD

Combinations of wind farms with low-trophic aquaculture have the most obvious potential for positive environmental synergies. This does not mean, however, that other combinations should be discarded, for they might have strong potential social or economic positive synergies, or have environmental benefits on aspects not covered by these descriptors, such as carbon footprint.

Regarding the points to monitor to ensure that no negative impacts is caused by OWF-LTA multi-use on these descriptors, the following should be closely monitored: invasive species, eutrophication, contaminants, hydrographical conditions and marine litter.

3.3. How can MU help achieve other EU environmental strategies and ambitions

3.3.1. Maritime Spatial Planning

Marine Spatial Planning (MSP) has a long history in EU waters. Most Member States have a formal MSP since this is an obligation under the European MSP Directive. However, the main driver for planning initiatives are new developments of commercial activities at sea. One sector that clearly increased the need for spatial management is renewable energy production, and more specifically offshore wind farms. Energy transition ambitions have increased the use of European seas for energy production dramatically. These long-lasting fixed installations have caused tensions and even conflicts with other -often traditional- uses, such as shipping and fisheries. As the wind sector became more and more established, new uses, such as sustainable food production, have been claiming space, also inside wind farm zones. The need for multiple use of space at sea is apparent in most European seas, which is often reflected in the objectives of the national MSPs. However, the application of multi-use at sea is still in full development and it is likely that MSP will have to play a role to make this happen. This is either done by designating areas for different functions, either by explicitly allow for all (non-priority) activities in zones that are designated for a specific (priority) activity. Most countries have an MSP authority, however, the different activities at sea are competences that belong to different administrations that often have little experience with cooperating amongst each other.

Possibly, well designed MSP processes can stimulate collaboration between different authorities, stakeholders and the public and can strive for the integration of different economic activities at sea in a multi-use context. It seems to be a very slow integration process that may cause delay in the development of blue economies. Lastly, environmental concerns are an important driver for planning at sea for many countries. MSP in the EU has proven to be able to implement different ecosystem related directives (Marine Strategy Framework Directive, Habitats Directive, Birds Directive) in national waters. Moreover, permits based on environmental considerations are an important requirement for the development of sustainable economic activities and will become more important as cumulative impacts will need to be addressed in a multi-use context.

MSP can help facilitate ocean multi-use by ensuring that different uses are compatible with each other and the environment also taking account of other types of use not part of the multi-use. The Ocean Multi-Use Action Plan (Schultz-Zehden et al., 2018), addresses the relationship between ocean multi-use and MSP by recognising the need for a coordinated approach to planning and management. The action plan outlines the importance of incorporating ocean multi-use into MSP processes and identifying areas where multi-use could be beneficial. It also promotes the use of new technologies and innovative solutions to support ocean multi-use and provides guidance for stakeholders to ensure that multi-use activities are carried out sustainably. By addressing this topic, the Plan aims to facilitate the development of sustainable and integrated approaches to ocean management.

3.3.2. Green Deal

- Biodiversity goals (2030-30-10)

The biodiversity strategy for the European Union aims at having 30% of European seas protected, including 10% strictly protected (EC, 2020c). For most European seas, assigning effective Marine Protected Areas, especially strictly protected ones will prove to be a challenge. European seas are intensively used, therefore finding areas that are both of ecological importance and that can be ‘spared’ by other sectors will not be an easy task for the Member States. By implementing multi-use areas and combining space demanding activities, more space can be freed elsewhere to implement (strictly) protected areas.

In the North Sea, a significant portion of it is set as Marine Protected Area (MPA) under the NATURA 2000 network, but most of these MPAs have weak management plans with little (if any) enforcement, and no evaluation criteria and success assessment. Moving from paper to effective and efficient MPAs is one of the major challenges in the achievement of the 2030-30-10 goal. A strictly protected MPA is one where no impactful activities happen, including commercial fishing (especially bottom-trawling), sand or gas extraction, wind farms, solar panels, aquaculture, intense tourist activities, etc. To achieve such a level of protection, uses of marine space and resources must be concentrated in other areas, hence the importance of ocean multi-use.

In addition, as developed previously, some types of multi-use such as the combination of low-trophic aquaculture and offshore windfarms, or the combination of offshore wind farms with habitat restoration, may have a MPA effect and therefore be acknowledged as OECMs (ICES, 2021). This provides another opportunity for Member States to reach the Biodiversity goals by 2030. For OECMs to be fit for claiming participation in the 30% protected marine areas, they must go a little further than what the definition implies. For efficient protection, a management plan must be implemented, as well as conservation goals and a monitoring plan to assess both the impact of the human activities happening in the area, and the conservation goals’ success.

It should be mentioned that effective protection of the marine environment requires to apply an ecosystem-based approach, hence to give protection priority to areas that hold potential for the entire ecosystem, and not to areas that are conveniently of no use for industrial sectors. Ocean multi-use might have positive side-effects for biodiversity and habitats protection but this should be seen as a support to the original existing nursery, habitats and shelter, and not as an replacement of these naturally occurring key-areas.

- Nature restoration law

The European Commission has recently (2022) proposed a new law for the restoration of ecosystems across the continent, called the Nature Restoration Law. This law is a key aspect of the EU Biodiversity Strategy, which aims to set binding targets for the restoration of degraded ecosystems, particularly those that have the most potential for carbon capture and storage and for reducing the impact of natural disasters. The proposal aims to restore marine ecosystems, and the species they host in order to increase biodiversity, secure the benefits that nature provides us for free (such as water and air purification, pollination, and flood protection), limit global warming to 1.5°C, and build up Europe's resilience and strategic autonomy. One important aspect of the Nature Restoration Law is the specific targets it sets for the restoration of different habitats and species, covering at least 20% of the EU's land and sea areas by 2030 and ultimately all ecosystems in need of restoration by 2050.

In the case of marine ecosystems, the proposal aims to restore habitats such as seagrass beds and sediment bottoms, which deliver significant benefits for climate change mitigation, and to restore the habitats of iconic marine species such as dolphins, porpoises, sharks, and seabirds. The restoration of marine ecosystems has particular relevance for the concept of ocean multi-use, as it can facilitate the co-location of different activities within offshore wind farms, such as the restoration of flat oyster beds. Flat oysters are an ecologically and economically important species, providing important ecosystem services such as water filtration and habitat creation, as well as supporting local fisheries. However, flat oyster populations in many areas have been severely depleted due to overfishing, habitat destruction, and disease.

The restoration of flat oyster beds within offshore wind farms can be a win-win situation, as it can provide a habitat for the oysters while also increasing the biodiversity of the wind farm area and potentially providing a source of income for local communities.

However, the success of such restoration efforts depends on careful planning and management, as well as the implementation of measures to address potential conflicts with other uses of the wind farm area, such as fishing or shipping. Overall, the Nature Restoration Law[3] proposed by the European Commission represents an important step towards the restoration of degraded ecosystems and the preservation of biodiversity in Europe.

The implementation of this law can have important implications for the sustainable development of the ocean multi-use concept, particularly in the context of the restoration of key species such as flat oysters within offshore wind farms.

- Ocean multi-use as a driver for marine restoration

Ocean multi-use, which involves the co-location of multiple activities in a given area of the ocean, presents a unique opportunity for marine restoration. Specifically, the restoration of flat oyster populations within an offshore wind farm, as in the Belgian pilot of UNITED, presents a promising approach for simultaneously achieving conservation and sustainable development goals. Flat oysters, which are important ecosystem engineers, have the potential to provide a range of ecosystem services including water filtration, wave attenuation, and habitat provision for other species. However, their populations have been severely impacted by overfishing, habitat destruction, and disease. Restoration of flat oyster populations can therefore contribute to enhancing biodiversity, improving water quality, and supporting fisheries.

Offshore wind farms offer a promising opportunity for flat oyster restoration due to their potential to provide a hard substrate for oyster larvae settlement and growth. By strategically placing artificial structures within wind farms, it may be possible to create suitable habitat for flat oysters to recolonize, while also avoiding conflicts with other marine activities. The co-location of wind farms and flat oyster restoration can also provide synergistic benefits for other ocean uses, such as carbon sequestration, fishing, and recreation.

For example, the addition of artificial structures within wind farms can enhance the growth of marine flora and fauna, which can contribute to carbon sequestration and support fisheries. Furthermore, the incorporation of flat oyster reefs within wind farms can create new opportunities for ecotourism and recreational activities such as diving and snorkelling, thereby supporting local economies and promoting the conservation of marine biodiversity.

[3] https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

In summary, ocean multi-use presents a unique opportunity for marine restoration by combining the conservation of important species and habitats with sustainable development goals. The co-location of offshore wind farms and flat oyster restoration offers a promising approach to achieve these goals while also providing synergistic benefits for other ocean uses.

- Relevant initiatives and examples outside of UNITED

Offshore wind farms have become an increasingly common feature in many coastal regions around the EU, due to their potential to generate renewable energy. The farms have also been recognized as a potential platform for nature restoration and conservation – in particular, the restoration of flat oyster beds has emerged as a promising strategy. Several initiatives have been put in place to promote the restoration of flat oyster beds within offshore wind farms.

For instance, in the Netherlands "The Rich North Sea program" aims to enhance nature in the North Sea through the installation of artificial reefs and releasing oysters to help marine life thrive. The program plans to establish nature development as a permanent component in the construction of offshore wind farms and is working on creating a 'toolbox' for nature development that can be applied to all offshore wind farms in the North Sea. The program's approach involves building artificial reefs for self-sustaining species such as oysters, tube worms, and Northern horse mussels to create a sheltered nursery at the North Sea seafloor and lay the foundation for an ecosystem that can flourish again. The program also seeks to lobby policymakers to ensure the implementation of policies that support nature development in wind farms at sea. Also, for example, the Dutch company Van Oord has developed a technique for placing old oyster shells on the seabed, creating a substrate for oyster larvae to settle and grow. The technique has been implemented in several pilot projects in the Dutch North Sea, with positive results in terms of oyster survival and growth.

Similarly, the Danish company Ørsted has launched a research project to explore the potential for oyster restoration within its offshore wind farms in the UK. The project involves collaborating with research institutions and stakeholders to investigate the feasibility and ecological benefits of restoring oyster beds within the wind farms.

In the US, the offshore wind farm developer Deepwater Wind has established a partnership with the Nature Conservancy to explore the potential for oyster restoration within the company's offshore wind farms along the US east coast. The partnership aims to develop a scalable approach for restoring oyster beds within the wind farms, with the potential to provide a range of ecological benefits.

These initiatives and examples demonstrate the potential for offshore wind farms to serve as a platform for marine restoration, and in particular for the restoration of flat oyster beds. The continued development and implementation of such initiatives can contribute to achieving the goals of the EU's Nature Restoration Law, by promoting the restoration of degraded marine ecosystems and increasing the biodiversity and resilience of these ecosystems.

- Renewable energy production

As part of the Green Deal, the European Commission has set a goal of a net greenhouse gas emissions reduction of at least 55% by 2030 (compared to 1990's levels). This goal is to be achieved through a set of targets, one of them being an increase of renewable sources of energy to 40% of the EU's energy mix[4]. Additionally, since Russia's invasion of Ukraine, the renewable energy target is to be increased from a target of 40% by 2030, to a target of 45% of EU's energy mix for 2030[5]. This latest measure is part of the RePowerEU Plan.

Because many European countries are densely populated, renewable energy production on land often conflicts with other land uses, such as agriculture, protected areas and habitations. As a consequence, the marine environment presents itself to absorb the large areas necessary for renewable energy production, especially wind energy production. Yet, many European seas already are intensively used, the North Sea being the most industrialized

[4] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[5] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

one. With Norway, Denmark, Germany, the Netherlands, Belgium and France sharing it, plus the UK, conflict for space occurs and will only worsen within the North Sea.

To reach the European goals for renewable energy production for 2030, and the ones that will follow for the next century, multi-use or marine areas is necessary. Mobile and fixed activities should be distinguished when considering multi-use, as they abide by different rules. Wind energy production is a fixed location, that occupies a lot of space and that strongly conflict with many other uses, especially mobile ones. To make the most efficient use of the marine environment, and ensure that some areas remain available for conservation, other activities must be combined with windfarms.

With the UNITED projects, several multi-use projects are tested but when it comes to environmental benefits and optimal use of space, the combination of OWF and LTA is a winner. Both activities are extensive, in the sense that they require a lot of space, and both exclude most other uses. Yet, they can work together and as such represent a great tool to make the most of the space used, reduce conflict with other uses and even enhance conservation of habitats and biodiversity. When properly managed, conservation can happen within an OWF-LTA combination, and the freed space elsewhere can be allocated to fully no-take zones, maximizing the positive impact on marine ecosystems.

- Sustainable blue economy

Developing a sustainable blue economy[6] is part of the Green Deal strategy for the European Union. Most activities considered in UNITED (aquaculture, windfarms and tourism) are listed as sectors of the blue economy, which is defined as: "A sustainable blue economy promotes economic growth, social inclusion and improved livelihoods while ensuring the environmental sustainability of the natural capital of the oceans and seas (…)." (European Commission, European Climate, Infrastructure and Environment Executive Agency, 2021).

Out of the five pilots of UNITED, three were identified as holding strong potential for positive environmental impact: the ones combining offshore windfarms and aquaculture. The two remaining pilots combine windfarms with tourism, and aquaculture with tourism. While environmental synergies are less obvious in these two scenarios, they both promote visibility of activities at sea that would increase their acceptance of the general public. This is an important point to make blue economy more sustainable, as increased acceptance and public support will greatly facilitate future development of these sectors and guide political decisions. In addition, visibility goes with increased transparency, which is an incentive for marine economic sector to conduct their activities in the most sustainable way possible.

More specifically, regarding the Greek pilot, where aquaculture is combined with tourism, another potential positive environmental synergy that can be observed is the joint logistics of both sectors. The diving company has a boat and ROV. In this way, supply and maintenance trips are combined with trips for diving under planning and this synergy results in reduced fuel consumption and noise in the area, which leads to cost saving and reduced environmental footprint.

- Farm to Fork Strategy

The Farm to Fork Strategy[7] was adopted to reach the European Green Deal's aim to make food systems fair, healthy and environmentally-friendly. The objective it to transit to a sustainable food system with a neutral or positive impact on the environment, helps mitigating climate change, reverses biodiversity loss, ensures food security and preserved affordability of food.

The development of LTA in Europe fits in this goal to have sustainable food production. Low-trophic aquaculture, of shellfish and seaweed, has a low environmental impact (Jones et al., 2022; Bekkby et al., 2023). It can participate to the good functioning and conservation of marine's ecosystems by providing shelter for certain species thus enhancing biodiversity and by removing excessive organic matter from the water column, mitigating the effect of eutrophication. Low-trophic organisms are, by definition, those that do not require to consume much energy to

[6] https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/sustainable-blue-economy_en

[7] https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

grow. They tend to be prolific organisms, reproducing fast, easily and in great numbers, which makes them more abundant and less likely to go extinct. When a higher trophic level organism, such as tuna, is consumed, it incorporates years of growing and feeding. Therefore, it is a high-energy consumption, that has an impact on the ecosystem, especially when consuming as much as we do currently. In contrast, shellfish are much faster-growing and only eat organic particles in the water. As such they represent a much lower energetic consumption with a negligible impact on the ecosystem, as long as their extraction remains within reasonable amounts of course.

Seaweed and shellfish do not require any feeding during their growing phase at sea (Zhang et al., 2009), reducing the environmental and economic costs associated with feeding farmed plants and animals. Mussels might even be able to settle on their own to the longlines, from the natural stock, and therefore would not require any hatching time on land. Another positive point for seaweed and shellfish farming is that fecal pellets and dead bodies (leaves, shells, etc.) bring carbon down to be sedimented, which participates in the sinking of carbon in marine sediments (Jones et al., 2022). Yet that only works if the seafloor remains undisturbed, which tends to be the case when aquaculture lines are spread at the surface or in the water column.

However, LTA is a space demanding activity and space is scarce in the North Sea. The solution tested by UNITED is to combine this activity with offshore windfarms, therefore using a single area for two space-demanding activities, that conflict with most of the other uses in the North Sea. With this perspective, multi-use of marine space may be an efficient tool for achieving the Farm to Fork strategy and the Green Deal's objectives.

Finfish aquaculture does not present as many environmental advantages, they must be fed and have a higher environmental footprint (Jones et al., 2022). Nevertheless, local food production is an essential part of a sustainable food system. Coastal finfish aquaculture, if locally consumed is likely to have a lower environmental impact than imported farmed fish. With a current demand for animal protein on the rise, wild fish stocks are unable to follow and fish aquaculture offers a solution for feeding current and future generations. Combining fish farms with touristic activities promotes visibility and trust in aquaculture, that often suffers from a bad reputation. A prolific combination can also bring additional income for local population, allowing them to develop sustainable practices regarding their use of the marine environment and the way its resources are used. Moreover, the aquaculture products gain added value and acceptance as they are better recognized by consumers and local residents. Thus, the multi-use contributes to raising public awareness of sustainable aquaculture practices and increase acceptance by the public, thus promoting the wellbeing of rural and coastal communities and providing a reliable supply of high-quality seafood.

- Remove, recycle and sustainably store carbon

As part of Green Deal, the Commission adopted a Communication on Sustainable Carbon Cycles[8] in December 2021, in which Blue Carbon is specifically mentioned (EC, 2021). While no goal is explicitly mentioned, uses of the marine environment that act as carbon sinks can certainly be a tool for reaching sustainable carbon cycles. Sedimentation of organic matter on the seafloor acts as a carbon sink (European Marine Board, 2023), so long as the seafloor remains undisturbed. Some types of multi-use combinations can both increase carbon sinking in marine sediments, and work as a protection for seafloor-disturbing activities (bottom-trawling, sand extraction, anchoring, etc.).

As discussed previously, combining offshore windfarms and low-trophic aquaculture would increase the sedimentation of organic matter. In the sediments, carbon and nitrogen are mineralized through microbial and faunal activity, with degraded carbon getting buried in sediment layers. As such, the suspension feeders living on the turbines increase the sinking of carbon into the sediments layers by cycling organic matter present in the water column to the seabed (Degraer et al., 2020). Some of this organic matter may feed benthic fauna, while some may be stored for a longer period of time. If the seafloor remains undisturbed, the sediments can constitute a considerable carbon sink (De Borger et al., 2021).

[8] https://climate.ec.europa.eu/system/files/2021-12/com_2021_800_en_0.pdf

- Fully harness the potential of algae

Very recently, in November 2022, a communication and a staff working document were adopted by the Commission, to fully harness the potential of algae[9]. Identified benefits of algae production are the following (EC, 2022):

- Sustainable food and feed source;
- No need of land conversion or freshwater use;
- Potential for bioremediation (eutrophication reduction) through the capacity of algae to take up nitrogen and phosphorus and to capture CO_2;
- Restoration of biodiversity by providing habitat, nursery ground and shelter;
- Reduction of hypoxia caused by eutrophication, by increase of oxygen;
- Reduction of ocean acidification by increase of water pH through CO_2 removal;
- Increased carbon sequestration by sinking of detached seaweed fragments.

Farming algae requires marine space though, which may cause conflict with other sectors at sea. By farming seaweed in windfarms, the conflict over space would be greatly reduced.

[9] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6899

4. CONCLUSIONS

High hopes are set on ocean multi-use to have a reduced environmental impact, in comparison to the traditional single and exclusive use of marine space for specific single anthropogenic activities. To answer this expectation, upscaled scenarios of the five pilots of UNITED were designed, in which the combination of marine uses envisioned by the pilots happen at a larger, commercial scale, and taking into account identified technological and regulatory challenges. These upscaled projections were made for multi-use and single-use scenarios, with the purpose of being able to compare the environmental impacts of one with the other, as recommended by the UNITED Assessment Framework.

To predict environmental risk reduction, an Environmental Impact Risk Assessment (EIRA) method was applied, adapted from a SCAIRM (Spatial Cumulative Assessment of Impact Risk for Management) method developed by Wageningen University and Research a partner of the project. The predicted impact risks for the upscaled scenarios of the project, foresee a reduction of environmental impact for ocean multi-use when compared to single-uses for the five pilots. Highest reductions were of approximately 40% for fish and mammals in the installation phase of the Belgian and Dutch pilots, approximately 15% for fish and mammals in the operation phase of the Dutch pilot and approximately 20% for seabed habitats in the decommissioning phase of the Belgian pilot.

In addition, an optimal scenario was designed, in which current technological and regulatory obstacles would have been resolved, and the combination of activities in a multi-use context enhanced. The application of the EIRA to evaluate this scenario indicates that multi-use projects could provide substantial reductions in environmental impact risk (potentially a factor 2 improvement) in a future that enables them fully.

Besides the potential environmental impact risk reduction, the potential for ocean multi-use to generate positive environmental impact is also described. These potential benefits were identified based on expert knowledge and information gathered through reviewing the scientific literature. The following potential added-value for the marine environment was identified:

- The possibility to incorporate habitat restoration (specifically biogenic reefs in the North Sea) in OWF-LTA multi-use combinations.
- Biodiversity increase thanks to fisheries exclusions and artificial reef effect in the multi-use area, although not equivalent to a natural reef.
- A potential increase in commercial fish species if the project is well designed and well protected.
- Increased nutrient cycling and carbon sequestration in the case of multi-use including LTA.
- Sustainable food production and increased social acceptance of offshore wind production and aquaculture.
- More space for conservation and reduction of conflicts over space use at sea.

From the expected impact risk reduction and environmental benefits, it appears that ocean multi-use holds a potential to help achieve some achieving European environmental goals and strategies. The Marine Strategy Framework (MSFD) may benefit from ocean multi-use projects to achieve Good Environmental Status (GES) in European waters, through the following descriptors: D1 'Biodiversity is maintained', D3 'Population of commercial fish species is healthy', D5 'Eutrophication is minimized', D6 'The seafloor integrity ensures functioning of the ecosystem', D11 'Introduction of energy does not adversely affect the ecosystem'.

Another potential for ocean multi-use as a tool for achieving environmental targets, is that they can help solve space allocation uses in maritime spatial plan and may free space to be allocated for conservation purposes as marine protected area. Wind farms and low-trophic aquaculture being space-demanding activities, combining them would reduce conflicts with other sectors and increase their acceptability from the general public and from other users of marine space and resources. The last point is essential, when taking into considerations European plans of increasing renewable energy production and sustainable, local food production, as foreseen in the Green Deal.

The strongest potential benefits from an environmental perspective have been attributed to the combination of low-trophic aquaculture and offshore windfarms. Because of this, the combination of OWF and LTA might pretend to fit in the OECM category, support conservation efforts and help State Members to achieve the 2030 Biodiversity goals. However, this should not be understood as a potential for multi-use areas to replace Marine Protected

Areas. Added structures to the sea provide interesting opportunities for biodiversity to use as hard substrate, shelter, nursery, meeting points, etc. but (1) not all materials are equal and (2) they should be used a complementary to natural reefs and not as replacements. First, when designing artificial structures, natural materials (stones, boulders, etc.) are better than man-made materials (metal, concrete, etc.). Natural materials will attract different species and react differently to harsh marine conditions. Second, natural long-existing habitats should not be replaced by artificial substrate in the same or in another area. Natural ecosystems are the results of thousands of years of natural evolution, they cannot be easily, or at all, restored to their natural complexity with man-made or man-added structures.

While the two UNITED pilots that combine other activities, respectively windfarms and tourism (boat tours) in the Danish pilot, and finfish aquaculture with tourism (diving) in the Greek pilot, have less obvious benefits for the environment, they have interesting social and economic benefits. Transparency and acceptability are crucial for developing sustainable project, that may always be well understood and accepted by the general public.

Windfarms are often perceived as a landscape disturbance and as bad for biodiversity, especially regarding collision with birds. By allowing boat tours, their use in a transition to sustainable systems might be better appreciated, and their full impact on the environment, with context and species specificities, better communicated. Similarly, finfish aquaculture often has a bad reputation, with fish perceived as diseased and more subjects to contaminants than wild stocks. Having diving tours around the farms increases transparency about its practices, and acts as an additional incentive to apply the best monitoring and management measures possible.

From an environmental perspective, all forms of ocean multi-use considered in the UNITED project, present interesting potential positive synergies, if correctly implemented and managed.

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ANNEX – DESCRIPTION OF THE PILOTS

Pilot 1: FINO3 (FUE, Germany)

Description:

The offshore research platform FINO3 in the North Sea is now operated by FuE-Zentrum. The basic fundament of the platform follows the same characteristics as has been constructed for the offshore wind farm turbines in the area. The experiences from its operation and the results of the numerous scientific research projects carried out so far on and at the platform have helped the wind farm operators and wind turbine manufacturers in the planning, building, and future operation of offshore wind farms. As such FINO3 is well placed to take up an offshore wind and aquaculture demonstration project and will be able to enhance the development from pilot scale to a possible commercial application.

Objectives:

- The first objective of a possible demonstration project at FINO3 is to reduce the **technological, financial, health and safety, and environmental risks** of multi stakeholder undertakings and to accelerate the acceptance of multi-use concepts by North Sea industries. To address the risks, the data management system would be developed, including expanded modus of automatization of data collection and transmission. Furthermore, the knowledge on interactions between target culture species with other natural biota and the effects of such on aquaculture farms on the offshore environment need to be investigated. Since the data for future regulations and permissions of large scale farms is scarce, the available information base must be improved to allow investors, bankers and insurance policies to fully engage in this new industry.
- The second objective **is to demonstrate the societal acceptance of such developments and its benefits**. There is a need to develop possible business models and explore local cooperative ownership opportunities while also creating a positive "climate" in the public at large particularly because offshore facilities are in needof strong support from land based stations.
- Moreover, such joint (multi-stakeholder) activity can also **benefit both development in regards to shared costs,better social/environmental image of involved businesses, and overall increased financial yield for investors**. An opportunity for certain eco label/small spatial footprint certification can also be explored, both for marketing the aquaculture products as well as for the renewable energy derived from the multi-use site.
- The demonstrator project will provide small and medium-size companies or EU institutions with an opportunity to build up reference guidelines and demonstrate their performance capability under realistic conditions.

Stakeholders:

- Offshore wind sector
- Aquaculture suppliers
- Commercial aquaculture producer
- Government
- Insurance companies

Pilot 2: North Sea Innovation Lab (Den Haag, The Netherlands)

Description:

North Sea Innovation Lab is an independent test site for research, pilots and the upscaling of innovations in thefield of seaweed cultivation, floating solar and other renewable energy innovations, and co-use of wind farms. North Sea Innovation Lab is located 12 kilometres off the coast ofThe Hague – Scheveningen with the following technical specifications:

- 600ha/ 6km^2
- 12 km offshore (harbour Scheveningen)
- Water depth approx. 18-20m
- Officially demarcated (cardinal buoys & registered in hydrographic cards)
- Known area by stakeholders

Objectives:

Demonstration of offshore solar integration in offshore wind farms

- Demonstrate the economic feasibility of integrating floating solar at existing/to-be-developed offshore wind farms at power station/turbinelevel
- Reduce technical risks of integrating floating solar at existing/to-be- developed offshore wind turbines by means of demonstration
- Define legal and contractual framework for applying the combination in a commercial setting

Demonstration of a safe operational plan for the commercial roll-out of integrated aquaculture in offshore wind farms

- Demonstrate the economic feasibility of integrating aquaculture at existing/to-be-developed offshore wind farms
- Develop and demonstrate a safe operational plan for commercial roll-out of seaweed activities (seeding, growing, harvesting, processing) in wind farms by means of simulation and demonstration
- Define legal/contractual framework for applying the combination in a commercial setting

Demonstrate and quantify the wave dampening of floating solar array

- Demonstrate the existence and extent of the wave dampening effect of floating solar infrastructure at sea bymeans of a multi-scale approach (field measurements and numerical modelling)
- Define the most efficient configuration of an (up-scaled) floating solar field in relation to an aquaculture field (at NSIL location) to optimally benefit from the wave dampening effect

Demonstrate Remote Monitoring

- Demonstrate the technical feasibility of an energy and communications connection between aquaculture andfloating solar power production systems
- Demonstrate the operational feasibility of using the solar power production system as an energy and communication hub for aquaculture
- Demonstrate the impact on the aquaculture business case by combining it with solar power

Stakeholders:

- Stichting Noordzeeboerderij/North Sea Farm Foundation: non-profit organization aimed at realizing seaweed industry in The Netherlands
- The Seaweed Company (TSC): commercial seaweed company cultivating certified seaweed at open sea
- Oceans of Energy BV (OOE): first company to design, develop and build floating solar systems

that canwithstand robust, offshore conditions
- Ventolines BV: service provider of onshore wind and solar and offshore wind projects
- TNO: supports with research on floating solar energy offshore.
- Vattenfall: Wind farm operator that is interested in impacts of logistics, governance and insurance in multi-use activities in offshore wind farms.
- Government.
- Search & rescue.
- Commercial shipping.
- Fishing.
- Recreation.
- Offshore wind. etc.

Pilot 3: Integration of native flat oyster production, flat oyster restoration and seaweed cultivation in an offshore wind farm (Belgium)

Description:

The project is being carried out in two locations: offshore in the wind farm of Belwind, with Parkwind as concession holder. This wind farm is located at 50 km from the coast (average depth 25-30 m). Secondly, there has been a nearshore site (Westdiep) at 5 km from the coast in front of Nieuwpoort (average depth 15 m) in which the most suited systems and techniques have been assessed to be implemented offshore.

Today, 399 offshore wind turbines are operational in the Belgian part of the North Sea, with a total installed capacity of 2260 MW. The present turbines are located in eight offshore wind farms, amongst which C-Power nv (www.c-power.be) and Belwind nv (one of the farms of Parkwind (www.parkwind.eu/en/projects). Within these two wind farms, an offshore mussel aquaculture pilot project Edulis had been running from September 2016 to 2019. As such, the wind farms have extensive experience with offshore longline systems and bivalve aquaculture.

Operational challenges.

Parkwind as a 360 degrees' company develops, finances, builds and operates offshore wind farms in the North Sea since 2009. The vast experience of the Parkwind team builds on the success of the wind farms Belwind (55 wind turbines), Nobelwind (50 wind turbines) and Northwind (72 wind turbines). Parkwind today operates 552 MW in the Belgian territorial waters and will have a pipeline of 554 MW offshore in Belgium and Ireland. Its latest project is the Northwester 2 (start 2019) which will supply 219 MW (23 wind turbines).

The nearshore site of Westdiep had several longlines since April 2017, being part of the Belgian project Value@Sea and privately owned by Brevisco (partner). The lines were used for test productions of flat oysters, blue mussels and seaweed.

In this pilot, the nearshore site has been used for testing oyster growing equipment, nature-inclusive matrasses and for seaweed techniques. Only the systems that proved to work nearshore, have been implemented in the offshore pilot site of Belwind.

Objectives:

The primary objective of the pilot is to evaluate wind farms as location for restoring native flat oyster reefs in combination with culturing flat oysters for human consumption.

- To identify appropriate areas for oyster reef restoration in offshore wind farms where trawling activities are not allowed.
- To demonstrate the possibility to develop scour protection that fulfils the technical requirements but at thesame time supports the formation of small oyster reefs, which eventually can form a network of small islands of oysters spread over several square kilometres. Choice of filling material is a crucial parameter.
- To design a longline that supports flat oyster production in offshore conditions (based on previous experience).
- To identify appropriate seed collectors and grow-out systems for flat oysters offshore.
- To develop remote monitoring to follow-up oyster growth in function of the environmental parameters.
- To optimize the communication and time schedules between the different activities in order to improve the efficiency of installation and data collection.
- To identify the synergy between oyster reef restoration, aquaculture and the production

of wind energy.

The secondary objective of the pilot is to compare the growth of seaweed grown offshore and nearshore

For that purpose the longlines that hold the oysters, will be used to attach seeded ropes with different seaweed species. Morphological and nutritional characteristics are known to be influenced by the dynamics of the environment and may offer opportunities to culture seaweed for specific purposes.

Stakeholders:

- 4SEA (4 environmental NGOs: WWF, Natuurpunt, Greenpeace, Bond Beter Leefmilieu)
- Fishery sector (including fish auction)
- Port authorities
- Regional and local authorities
- Local recreational companies, e.g. sailing clubs.

Pilot 4: Tourism at Middelgrunden Wind (Denmark)

Description:

The pilot in Denmark considers multi-use of tourism and offshore wind farms (OWF) that result from shared sea space, joint on and offshore infrastructure and operational activities. These include OWF sight-seeing boat tours and shared onshore facilities such as OWF related information centres and museums. The cooperative owned OWF Middelgrunden Wind outside the harbour of Copenhagen is sporadically used for visits by students from abroad, companies and other people interested in offshore wind. Every two years the cooperative have an open house for the share owners consisting of a boat trip and climbing the wind turbine.

Objectives:

- This pilot is expected to increase the TRL level (Level 7 or higher) of the multi-use solution and to expand tourism activities related to OWF (boat tours, leisure fishing and diving) in such a way that it can be a part of the general tourism offer in Copenhagen and the region.
- The pilot is to serve as a demonstrator of the improved multi-use information technology (boat scheduling system) and physical technology (facilities for divers on the platform) and advise the H&S practices, regulation - safety zone measures, and demonstrate operability and profitability of the multi-use solution.
- Synergies that can be potentially established between OWF and tourism at the site include:
  - Sightseeing boat tours combined with angling
  - Specially designed platforms around the turbines serving as designated facilities for divers, local artisanal fishers and offshore restaurants in the vicinity of OWF;
  - Boat tour operators can be engaged in OWF related monitoring activities;
  - On land visits to OWF information centres and museums, and platforms for observing
  - The farms with telescopes from the Round Tower Museum;
  - Helicopter flights around OWF or use of VR (virtual reality) googles to simulate the flight around the turbines or the VR 360 view from the nacelle which can be used when the weather conditions do not allow for climbing up;
  - Educational tours can increase local knowledge about the importance of green energy.

Additional objectives to be considered:

- Support the development of viable business models and capacity building for local tourism oper-ators
- Mainstream such solutions in local development policies, cohesion policies, and as part of broader project development guidance for OWFdevelopers (esp. with regards to consultation and mitigation processes).
- Explore transferability of such multi-use solution to other regions/Member States. Where in the EU is this multi-use relevant – transferability of Danish pilot to which countries/OWF. This Danish pilot will develop general business models from existing examples to support financial viability of future developments in other areas. Suchmodel will include guidance for cost-benefit analysis.

Stakeholders:

- Engagement of local intermediaries and clusters such as tourist boards and local councils will be crucial asthese can have a strong role in initiating and supporting the long-term functioning of this multi-use, mainly by identifying opportunities, facilitating cooperation and promoting MUCL concepts.
- Boat and diving tour operators - one of the aims of this pilot is to empower the sector by gathering relevant tourism stakeholders and maintaining a network of local tour operators.
- Angling and diving associations.
- Local museums, exhibition and information centres.
- Other intermediaries incl. State of Green.
- Organizing visits for professionals.

Pilot 5: Aquaculture/Tourism (Greece)

Description:

KASTELORIZO AQUACULTURE SA operates a fish-farming unit, on floating facilities in the marine area near islet "Patroklos" (the islet is located near the coast, 850 meters away). The aquaculture total annual production of marine Mediterranean fish in that area is 230 tones. There is great touristic interest in the area, as many tourists visit the coasts of Patroklos islet mostly with private boats on the summer. The seabed is also of great touristic value, as the area has many attractions such as an underwater stolen cars cemetery close to the mainland coast. Another significant attraction are the many shipwrecks that have taken place in that area as well as ancient artefacts, making Scuba-diving activities quite popular in that area.

Objectives:

Based on existing activities of the aquaculture and tourism sector in the shared marine space, prospective activities and functions are described below:

- Applied technologies to establish more effective production in terms ofaquaculture (monitoring parameters such as salinity, water quality, fishbehaviour and stress levels);
- Monitoring and management technologies to facilitate the need for synchronization of multiple operations oftouristic diving boats and recreational activities with operational vessels to the aquaculture site;
- Support in management and planning decisions for new developments, such as extension of the aquacultureunit, in order not to intervene to current touristic activities;
- Business development and minimizing costs by combining activities from both sectors. Scenarios for these combined activities could be a) diving expeditions to the aquaculture units as a new recreational attraction for divers, b) diving expeditions and use of special equipment (ROVs) from the diving centre to facilitate aquaculture operational activities in cases of emergency or for risky procedures
- Time management by multi-sharing of infrastructure such as use of existing platform for aquaculture, divingor third party vessels
- Monitoring parameters such as water quality to timely track any pollution threat to marine area;
- To facilitate touristic growth of the area in combination with social acceptance of the aquaculture activities already taking place in the area, these prospective activities could take place.

Expected impacts:

- Aquaculture unit will gain acceptance and continue developing and producing better quality food;
- Important touristic attractions in place that are merely exploited today, will now contribute to growth of thewider area and to local business expansion;
- Trained and certified offshore staff with permissions and insurance in place;
- Benefit from exploiting same marine space;
- Co-use of transportation;
- Co-use of offshore experience.

Stakeholders:

- Kastelorizo SA Aquaculture.
- Planet Blue diving center.
- Local ministry office.
- Local community.
- Tourists – scuba-divers.
- Local chamber of commerce or offices of tourism.