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Facilitating an integrated assessment of impacts in marine multi-use: The Ocean Multi-use Assessment Framework (OMAF)

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ABSTRACT

In the era of blue growth, ocean multi-use is gaining popularity for its potential environmental, economic and societal synergies. Expectations are high for multi-use applications to alleviate marine spatial allocation conflicts amongst users of the sea, and to stimulate innovative ways of sustainably exploiting marine resources. However, a potential barrier to implementing multi-use and co-location is the lack of a well-defined framework to evaluate the impacts of ocean multi-use projects. This paper introduces the Ocean Multi-Use Assessment Framework (OMAF), which builds upon traditional environmental impact assessments but expands to include societal and economic dimensions. In addition to these three pillars of sustainable development, the framework incorporates two critical conditions: technological feasibility and regulatory appropriateness (legal, policy, and governance). The framework promotes the use of scenarios to compare single-use and multi-use approaches in an integrated manner. This approach allows for a comprehensive, holistic evaluation of multi-use projects compared to single-use alternatives, supporting decision-making. Strong stakeholder engagement throughout the process is emphasized. The OMAF has been developed and tested under the EU-funded Horizon 2020 UNITED project, where it was applied to five multi-use pilot projects. Despite challenges related to data availability for emerging marine activities, the framework has proven applicable and effective for most projects.

1. Introduction

With the United Nation's Decade on the Oceans, the seas on our planet are being put in the spotlight [1]. Next to traditional marine activities such as fisheries and shipping, an increasing number of new activities are coming to the foreground, all claiming space at sea [2]. With both old and new sectors growing and potentially competing, marine space has become a limited and conflictual resource [3]. Complicating this matter is a drive for Blue Growth to support the European economy, bolster Europe's Green Deal initiatives, provision food and renewable energy to enhance security, and provide access to wealth of minerals and extractable resources; a strong increase in demand for space and utility of marine systems is close on the horizon [4].

A key method in organizing and integrating developments is Maritime Spatial Planning (MSP), a political and social management process informed by both the natural and social sciences for the distribution of human activities in space and time to achieve ecological, economic and social objectives [5]. In the European Union, the MSP Directive [6] sets the legal framework, and is translated and implemented into each Member State's national legislation. Originally, MSP was approached as a mainly exclusive spatial distribution of marine sectors and activities to support current and future uses of marine space. In an increasingly

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crowded ocean, however, the exclusive allocation of space to a specific sector or activity is becoming untenable. A solution to the conflicts in user needs is to combine activities at sea, i.e. ocean multi-use, a process which can be facilitated by MSP planning [7].

Marine, or ocean, multi-use is defined as the intentional combination of two or more marine activities, with the purpose of sharing space, infrastructure, resources and/or operations [8]. When properly implemented, it can aid in realizing environmental goals and public strategies regarding the sustainable exploitation of marine resources. Benefits from ocean multi-use may fit into one or more pillars of sustainable development: environmental responsibilities, social progress and economic development [8].

The need for assessment frameworks to assess the added value of multi-use has been recently highlighted [9]. Accounting for the impacts of any project, particularly those which involve multiple steps and a combination of pressures, is a complex task. In the case of multi-use projects this is even more pronounced as the activities combined may bring different synergies and opportunities, but also involve various conflicts and exert different pressures, possess different temporalities, and combine into unexpected positive or negative effects.

There is currently no tool specifically designed to evaluate multi-use activities in the marine environment. To address this knowledge gap, we developed the Ocean Multi-use Assessment Framework (OMAF). The OMAF serves as a versatile tool for various stakeholders, including policymakers, enabling them to assess the added value of multi-use and decide whether implementing such projects is justified.

2. The Ocean Multi-use Assessment Framework (OMAF) concept

2.1. An integrated assessment

To account for the potential added value of activities combined in multi-use projects, the three pillars of sustainable development were taken as perspectives for impact assessment: the economy, society and the environment; they are referred to as 'assessed pillars'. In addition, two categories of necessary conditions to enable multi-use projects to exist are considered by the framework: the technological feasibility and regulatory appropriateness (legal, policy and governance). These will be later referred to as 'enabling conditions'.

Assessed pillars refer to those on which the impact is immediately apparent. Impacts of multi-use may be positive or negative, and the overall added-value or drawback of multi-use differs from one pillar to another. Pillar-specific tools and criteria are to be used to assess each type of impact. Intuitively, the multi-use scenarios can be expected to have an added-value, advantages or reduced negative impacts over the single-use scenario, in at least one of the three assessed pillars.

2.1.1. Environmental pillar

As much as possible, a multi-use project should aim at generating positive impact. When considering environmental impacts, the concentration of activities within a restricted spatial area allows for the growth of blue economy sectors while retaining or expanding areas of conservation. On the other hand, if poorly designed and managed, a multi-use project may end up into an intensive use of the area, resulting in environmental degradation of the zone, with cascading effects on the ecosystem. Therefore, activities to be combined must be chosen for their compatibility and their capacity to alleviate environmental impact through sharing of infrastructures and operations. This may be achieved by sharing boat use for maintenance operations for example, minimizing disturbance from sound and presence of vessels. In addition to impact reduction, environmental benefits may be generated by combining an economic activity with conservation or habitat restoration. An example would be taking advantage of the exclusion of bottom-disturbing activities in offshore wind farms [10], to implement artificial reefs. Finally, the combination of some activities may provide synergistic environmental benefits, such as in the case of offshore wind farms and low-trophic aquaculture. Both uses generally exclude other marine activities in the area for safety reasons, therefore providing a relatively undisturbed environment. In addition, both uses encourage the growth of filter feeding organisms, through grown cultivated organisms for aquaculture and colonization of scour protections for offshore wind farms, that may provide additional ecosystem services such as nutrient cycling [11-13], carbon sequestration [12,14,15], and habitat for marine biodiversity [13,16].

2.1.2. Economic pillar

Given the novelty of ocean multi-use, and depending on the type of activities to be combined, financial and economic benefits may require more or less time to be realized. Increased economic efficiency [8,17] and lower financial costs (lower CAPEX and OPEX) [18], may be achieved, making multi-use more profitable from a business viewpoint compared to simultaneous single-use activities located in different marine areas. In addition, multi-use may provide an opportunity for some activities to take place that could not exist in single-use scenarios [19]. This is the case when considering touristic activities that exist only because of the presence of another activity (e.g. boat tours in wind farms for example), or that gain a substantial added value from the other activity (e.g. diving tours around fish farms, which attract marine life, including emblematic species such as marine mammals). Distance to shore is an aspect to consider in assessing the added value of multi-use operations against alternative single uses [17]. Near-shore activities for which there is already a demand for services would make economic benefits of multi-use more likely, such as combining tourism with another activity, in an area where tourism already is an installed sector. On the other hand, when considering low-trophic aquaculture in offshore wind farms, the cost of implementation and the distance from shore may challenge the financial feasibility of the project. Designing wind farms that accommodate aquaculture from the start may reduce implementation costs, while sharing infrastructures, staff and operations could reduce operation costs. In addition, assessing the market to ensure that a demand exist for the cultivated products, is necessary to ensure sufficient return on investment [20].

2.1.3. Social pillar

Reaching social benefits while mitigating potential risks is the third objective of a multi-use project. Societal benefits from multi-use can be, for example, cultural benefits, social equity and community empowerment [9], in the form of job creation, innovation, knowledge sharing and increased attractivity of the locality [21]. Societal benefits vary greatly in their nature depending on the context and the type of multi-use envisaged. Because multi-use specifically aims for sustainable development and is an innovative concept, it can empower coastal populations, and foster cross-sectoral collaboration and innovation. Multi-use can also be implemented with the purpose of allowing a traditional or cultural use of the sea, such as a certain form of fishing, or a specific recreative activity. On the other hand, multi-use may generate new risks for workers and is likely to require new skills and training, excluding certain categories of workers. Offshore work is inherently high-risk for employees. The intricate nature of multi-use installations, coupled with diverse teams and professions sharing the same environment, introduces new safety challenges. This leads to the necessity of upskilling or reskilling part of the workforce of the platforms, creating potential opportunities for individual growth (as a more specific expertise is required), but also uncertainty and potential exclusion. Early impact identification brings the opportunity to prevent and mitigate these risks as much as possible.

2.1.4. Regulatory conditions

The regulatory landscape is a condition that either enables or limits multi-use projects. A maritime spatial plan that already enables, or requires, some dedicated zones to implement multi-use is a great incentive and facilitator for multi-use projects to emerge. However, as multi-use is still a relatively new way of approaching activities in the marine environment, shifting away from the exclusive spatial right, policies, governance and legal frameworks are often not adapted for it. Yet, these aspects are essential for multi-use projects to come into existence. This is why an assessment of the situation at the stage of conception of the project is necessary, to evaluate 1) what is currently possible regarding legal aspects and policies, and 2) what needs to be changed for the project to be implemented and to achieve its maximum benefits potential.

2.1.5. Technological conditions

As with the previous pillar, the technical capacity is a necessary condition for a multi-use project to exist, from the core design elements of structure and systems placed at sea to the supporting infrastructures which enable automation and monitoring. This category is centered on practical considerations and structural design elements. The manner in which ships could be optimized or redesigned to allow for more flexibility in serving different needs versus specialized craft now available. Optimizing site layout for integrating different activities in a manner which allows for the most efficient use of resources and a balanced deployed system. Additionally, the application of modelling to optimize system design for harsh environments and forecast storms and maintenance and site automations are all critical to the technological capacity of integrating offshore activities. Further developments are still required on many aspects, from including what infrastructure and gear is suitable for maximizing the intended use and minimizing environmental impact, how to best choose sites and utilize space available, and balancing use with environmental considerations choices in design and operations. All these aspects, and more, must be analyzed and best solutions put forth to provide the most complete scenarios assessment and support decision making.

2.2. Working with scenarios

A key aspect of the OMAF is its capacity to work with diverse scenarios, allowing for their comparison to determine the most suitable course of action. The primary objective is to assess the (positive and/or negative) impacts of multi-use scenarios in relation to alternative scenarios using predefined assessment criteria specific to each assessed pillar. Consequently, changes in impact (ΔImpact) are gauged against a shared baseline scenario (Fig. 1) across all considered pillars. The ultimate goal of a comparative assessment between scenarios is the qualitative and quantitative evaluation of potential gains and losses of multi-use relative to single-use. This comparative analysis establishes the foundation for making an unbiased, all-encompassing, and well-reasoned decision regarding which scenario is preferable and for what reasons.

Importantly, to be able to assess the added value, the multi-use scenario has to be compared with scenarios that are composed of simultaneous single-use activities. That is, the traditional exclusive right of a certain activity in a certain marine area; e.g. an offshore wind farm area is closed for any other activity and a second activity takes place at the same time yet in a different area. Both activities are thus taking place simultaneously, but at different locations. This scenario, further dubbed as the single-use scenario, is being compared with a multi-use scenario combining both activities (see also Table 1).

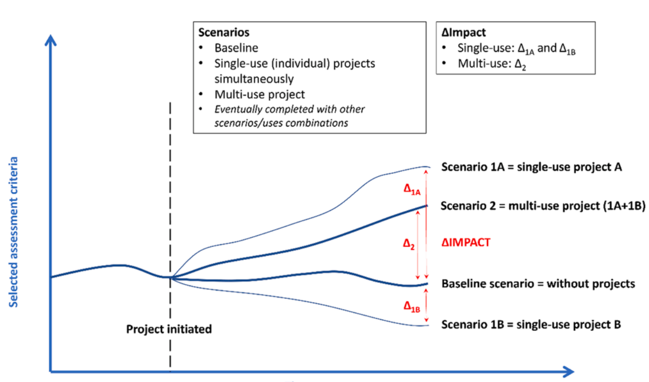

Fig. 1. Changes in impact (ΔImpact) over time between different scenarios, according to a selected assessment criteria (adapted from Glasson et al. [22]).

3. Description of the framework

Developed in the European Horizon 2020 project UNITED, the OMAF offers a method, inspired and adapted from a classic Environmental Impact Assessment (EIA) [22], following a similar stepwise procedure, and the Drivers, Pressures, State, Impact and Response (DPSIR) model [25,26], to evaluate the impact of marine multi-use. The generic framework comprises five key steps (Fig. 2).

3.1. Step 1 – early stages: setting context and selecting priorities

During the early stages, the context of the assessment is set, be it from a technical, economic, environmental, social or regulatory perspective; and priority elements for further assessment are selected. The different scenarios are described, including the different single-use scenarios and the multi-use scenario(s). Additionally, the baseline situation - to which the different scenarios are assessed against- is to be defined. Alternatively, a no-use scenario can serve as a baseline, but in areas with a long history of anthropogenic activities, this will be less feasible and/or relevant.

When the context is set, an exhaustive scoping for possible impacts is undertaken. It is important to note that possible impacts can be positive or negative; they are changes in state compared to the baseline (Fig. 1). From this list, the key possible impacts are selected. These are those impacts that are considered priority elements, and which will form the targets in the prediction stages. The selection is based on expert knowledge, stakeholder consultation and project experience.

3.2. Step 2 – prediction stages

During the prediction stages, the key possible impacts are predicted, and the meaningfulness of these impacts is assessed. Comparison between the alternative scenarios will inform on the added value of multi-use.

The first step is the prediction of impacts. To identify and predict possible impacts, each pillar applies different assessment tools, such as life-cycle analysis, cost-benefit analysis and environmental impact analysis. Once impacts are predicted, an assessment of their meaningfulness is undertaken. Not all impacts are relevant or meaningful. A (statistically) significant increase in revenue may for example not outweigh the costs of the project and thus not be meaningful, or a (statistically) significant decrease in water turbidity may be within the range of natural variability and thus also not be meaningful. This step wants to discern between meaningful impacts, and thus relevant to take further into account, and impacts that may be not so informative.

Finally, if relevant, optimization measures are identified to mitigate undesirable impacts or to maximize the developed solutions. For some pillars, mitigation measures to reduce negative impacts are explicitly stated (e.g. environmental pillar), other pillars might consider mitigation measures already during the development of best practices (e.g. economic pillar).

3.3. Step 3 – reporting stages

Step 3 summarizes the outcomes of the assessments. Depending on the data availability, results may be qualitative, quantitative or a combination of both. While step 1 and 2 are pillar-specific, step 3 integrates

Table 1
Uses of marine space – relevant scenarios.

No use/no activities scenario: This scenario represents an undisturbed marine environment. Being aware that this situation is likely not present anymore in European Seas and accepting the phenomenon of shifting baselines [23], this represents a scenario that can probably only be achieved using a proxy situation. The no-use scenario could be regarded as an alternative baseline scenario.
Example: Marine Protected Areas might serve as a proxy.
Baseline/business-as-usual scenario: This is the scenario before blue growth started prevailing, and before projects at sea occupying space became apparent. This is a somewhat arbitrarily point, and may vary between regions, but its advantage over choosing a baseline from the present condition is that it prevents continually changing reference points [24]. This scenario encompasses (only) the presence of traditional marine uses.
Example: Activities such as fishing, shipping, etc.
Single-use scenario: Projects that occupy marine space and/or a resource, while excluding other activities and projects.
Example: Offshore wind farm, aquaculture farm.
Multi-use scenario: Projects that share marine space and/or resources. Several combinations of activities and projects are possible.
Example: Offshore wind farm and aquaculture installations, aquaculture installations and tourism activities.

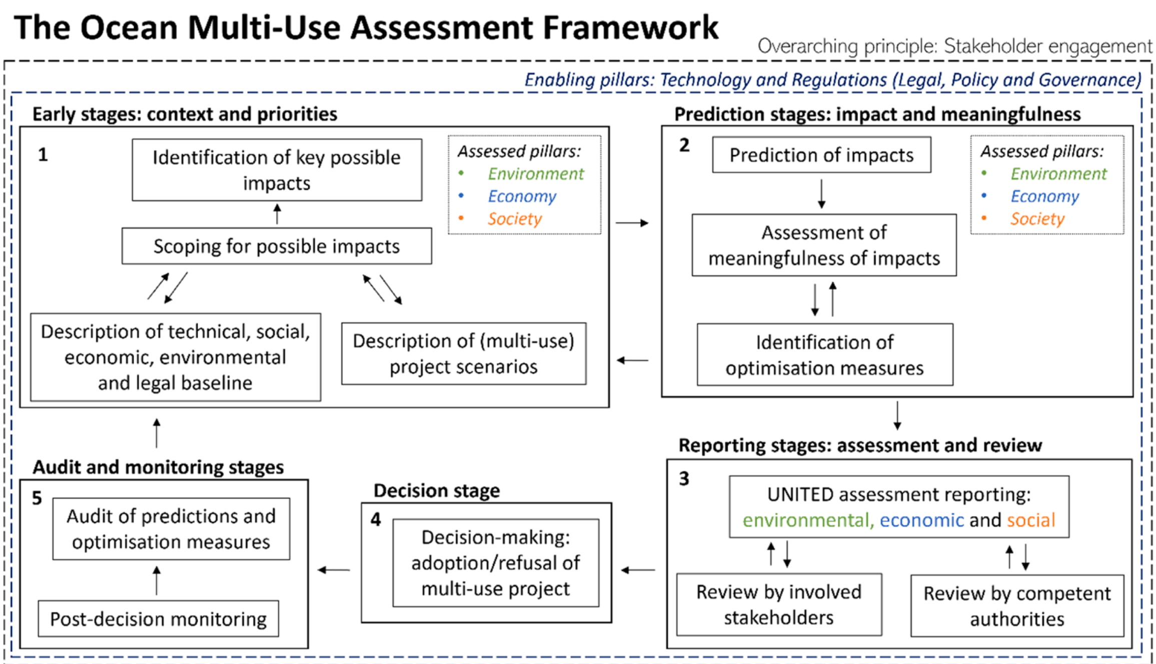

Fig. 2. The ocean multi-use assessment framework, adapted from Glasson et al. [22].

the information across pillars to present a complete and holistic view on the different scenarios. It may indeed be the case that a multi-use scenario scores lower than the separate single-use scenarios for example from an environmental perspective, but scores higher on social and economic indicators. Additionally, this step presents the lessons learned, identifies knowledge gaps and presents advice on licensing for policy makers. The outcomes of the different analyses are reported and analyzed in a holistic way, with the inclusion of a comparative evaluation of the different scenarios.

The produced report should then be available for public consultation, which already is a legally binding obligation in all European Member States for environmental impacts, following the Environmental Impact Assessment Directive [27]. To ensure its accuracy, review and input from competent authorities and relevant stakeholders are required. In the reporting stages, they will be encouraged to deliver input and comments on the analysis of the outcomes. Although a balance between pillars is envisaged in the framework, stakeholder input is ideally suited to safeguard this balance. Additionally, since competent authorities will make the final decision on the adoption of the project (step 4), they can give a first indication if all conditions for licensing are met or if some elements of the analysis should be adapted.

3.4. *Step 4 – decision stage*

Eventually, based on the reviewed assessment report, the competent authorities will make a decision on the (multi-use) project. Increasingly, the licensing procedure advocates or even requires the facilitation of multi-use activities, so the outcome of the assessment will aid in deciding which activities have the most added value across all pillars.

3.5. *Step 5 – monitoring stages*

Once a project is accepted, a monitoring scheme must be designed. The variables chosen for monitoring should match the key impacts assessed in step 2 of the framework.

Additionally, audit procedures are to be made, to assess if predicted impacts are indeed observed after the implementation and operation of the project, and to evaluate the effectiveness of the optimization measures taken. The results of the audit procedures can lead to an adaptation of the optimization measures and improve future assessments and operation.

3.6. *Overarching principle: stakeholder engagement*

To attain a comprehensive and well-rounded perspective on a multi-use project, encompassing both positive and negative impacts, it is crucial that local stakeholders are engaged from the beginning of the design and impact assessments of the project [28]. Engaging stakeholders during the conception of the project serves to discern local priorities, thereby informing the identification of key impacts within the

OMAF process. Additionally, it aids in recognizing potential challenges, barriers and opportunities for implementing the necessary combinations that ensure future synergies. Furthermore, it facilitates an understanding of the existing dynamics among the local marine sectors and stakeholders.

The stakeholder engagement strategy will depend on the specific project and on the targeted stakeholders. Suggested approaches are workshops and focus groups for engaging experts and highly involved stakeholders, or surveys and questionnaires to reach a broader audience. Impact mapping and scenarios analysis were found to be efficient methods during workshops in the application of the OMAF.

4. Application of the OMAF in UNITED

The European Union's Horizon 2020 project UNITED (Multi-Use offshore platforms demoNstrators for boostIng cost-effecTive and Eco-friendly proDuction in sustainable marine activities) was launched to develop multi-use in European seas. Five pilots of ocean multi-use were implemented as part of the project, with the following combination of activities: offshore wind energy production and low-trophic aquaculture (of mussels and seaweed) in Germany; offshore wind energy production, offshore solar energy production and low-trophic aquaculture of seaweed in the Netherlands; offshore wind energy production, low trophic aquaculture (flat oysters and seaweed) and habitat restoration (oyster reefs) in Belgium; offshore wind energy production and tourism (boat tours) in Denmark; high-trophic aquaculture (finfish) and tourism (diving) in Greece.

The OMAF was created as part of UNITED, to assess under what circumstances multi-use projects are better than single-use activities and what kind of benefits could be expected. The manner in which the framework was applied to the pilots of the project is described hereafter.

4.1. Environmental assessment

The environmental assessment of UNITED was achieved using what is essentially a Cumulative Impact Assessment (CIA) approach, adapted from the Spatial Cumulative Assessment of Impact Risk for Management (SCAIRM) method [29-31]. The method is based on a linkage framework, that links activities to actions, actions to pressures and pressures to ecosystem components. The relative importance of each link is determined using a risk-based approach that includes the magnitude of the considered pressures and the sensitivity of the ecosystem components, and estimates the potential impact of those activities and their pressures on ecosystem components. This allows the identification of key potential impacts and their contribution to the ecological footprint.

Assessing cumulative environmental impacts has long been a challenge in the marine environment. The OMAF in itself does not provide a solution to that complex exercise, but a method accounting for cumulative impacts can be applied in the OMAF. In UNITED, the CIA attempts this exercise, providing an idea of the relative decrease or increase in environmental impact of combined activities, regarding specific ecosystems components [30].

To complement the environmental assessment approach in predicting and assessing impact meaningfulness, a literature review was conducted to highlight broader potential impacts in the context of the pilots and the environmental policies that may be facilitated by the envisaged multi-use combination [31]. Finally, optimization measures to enhance potential positive impacts of ocean multi-use were proposed, based on a literature review, results of workshops and suggestions from stakeholders of the pilots [31].

4.2. Economic assessment

Decision makers must consider economic impacts when weighing up the relative social value of different multi-use related options [17]. To ensure that all important impacts are accounted for, a structured, sequential approach was conceived and implemented in close cooperation with pilot leads and other consortium partners directly involved in the pilots. Impacts were scoped for and identified through literature review for each pilot. Workshops with stakeholders were then organized to predict and assess the meaningfulness of the previously identified impacts, by asking participants to evaluate the scale and importance of each impact [20]. The most relevant and important impacts where then further analyzed and predicted as much as possible given the scarcity of quantitative data and assessed through literature review and interviews with partners involved in the activities of the pilots [20].

4.3. Societal assessment

Social impacts were identified, predicted and their meaningfulness assessed with pilot-specific workshops. Each pilot followed a slightly different approach, the workshop of the Belgian pilot will be described hereafter for it was the most complete application.

Stakeholders from a variety of sectors were invited to take part in a full day in-person event. Twenty-three participants from the following sectors attended: research, business, public organization, fisheries and tourism. The participants were placed in four groups, each with a different multi-use scenario to discuss. After being introduced to what social impacts were, and given some categories and illustrations of possible impacts, the participants were asked to (1) identify all social impacts for their scenarios, (2) select the most meaningful ones, (3) identify mitigation and/or optimization measures for the impacts selected as most relevant.

4.4. Enabling conditions

Technical applicability was assessed with a review of the technology developed by and implemented in the five pilots of UNITED. Each implemented design was described and assessed according to the following criteria: costs, avoided damage and loss, environmental benefits, uncertainty, robustness, flexibility and policy cohesion [32]. In addition, a list of required support for the adoption of technological innovation is described, including the following aspects: financial support, research and development, policy and regulatory frameworks, knowledge sharing and capacity building, stakeholder engagement, infrastructure and technical support, marketing development and marketing support [32]. An analysis of the monitoring and modelling capacities of the various pilots was conducted, with recommendations and guides for enhancing monitoring strategies and utilizing process-based models to support planning and operations.

The legal, policy and governance context was analyzed per pilot, to highlight the major barriers for the implementation of commercial multi-use projects. This was done by making an inventory of all potential issues in each country, as identified by each pilot. The identified issues were then reported in a table, classified per implementation phase of a multi-use project: 'pre-operational', 'operational', 'post-operational' [33]. Additionally, the legal framework and governance was assessed for the five countries hosting a pilot of UNITED, highlighting opportunities and barriers in each of them [34].

4.5. Assessment reporting, monitoring and audit procedures

An assessment report, concluding on all steps of the OMAF for each pillar, category and pilot of UNITED was made as one of the final outputs of the project (Deliverable 1.4 "UNITED Framework Design", in the making). Regarding monitoring and audit procedures, these processes are dependent on the predicted impacts and chosen optimization measures. The monitoring procedures should ensure that the impacts were correctly predicted and that they are well managed, mitigated and avoided as foreseen. The audit procedures should ensure that the broader environmental, economic and societal benefits are achieved or that the project is still on track to achieve them. In the scope of UNITED, audit procedures were designed for multi-use projects, based on the predicted environmental, economic and social objectives of the five pilots [35].

4.6. Illustrative application of the OMAF

To support decision making, the application of the OMAF should provide decision makers with the answer to the following question: "*Is multi-use a better option than single-use?*". To illustrate how the identification of environmental, economic and societal impacts may support decision making, the results of the application of the OMAF to the Belgian scenario of UNITED, a combination of offshore wind energy production, offshore low-trophic aquaculture of seaweed and oysters, and active restoration of oyster reefs, is presented hereafter.

Regarding environmental impacts, the Belgian multi-use scenario resulted in an overall impact risk reduction during the installation, operation and decommissioning phases, in comparison to the single-use scenario [36]. Overall, marine mammals, fish and cephalopods and benthic habitats are the ecosystem components that would benefits most from the multi-use scenario instead of the single-use scenario [36]. Impact reductions are expected to be higher for the installation phase than in the operation and decommissioning phases, but the operation phase is expected to last much longer (about 15 years). The impact risk reduction predictions are relatively small in a realistic scenario, due to several technical and regulatory barriers. An additional scenario was therefore conceived, in which more operations and infrastructures are made shareable by both sectors thanks to technical innovations and regulatory adjustments. In this optimal scenario, multi-use is estimated to provide substantial impact risk reduction, up to twice more than in a realistic scenario [36].

Other potential environmental benefits were investigated, although they could not be quantified, to predict how the Belgian multi-use scenario might bring an added-value if implemented at a large scale. These positive impacts were [36]: the potential to include active oyster reef restoration in the area, more diverse species assemblages thanks to an artificial reef effect, a commercial fish species increase, increased nutrient cycling and carbon sequestration from organic matter accumulating on the seafloor if the seafloor remains undisturbed, sustainable food production, more space for conservation elsewhere thanks to the combination of space-demanding activities, a reduction of conflicts over space use and an increased social acceptance of offshore wind farms and aquaculture.

The application of the framework on the economic pillar was considerably limited due to a lack of publicly available economic data about real life operations of the wind farms and aquaculture sectors. As this was mainly due to confidentiality issues, the applicability of the framework would increase as more data becomes available. Potential economic impacts of multi-use were identified during meetings with stakeholders, however the scale of significant impacts was only possible to be qualitatively assessed. These economic impacts were [20]: provision of renewable energy reducing the country's dependency to non-renewable and imported sources of energy, reduction of greenhouse gas emissions, production of local and sustainable food products, fish stock and marine habitat improvement. The scale of the provision of renewable energy and greenhouse gas emissions reduction were estimated to be low, whereas the scale local and sustainable food production was considered to be medium and the scale of habitat and fish stock improvement was estimated to be high. Regarding the financial analysis, to make a multi-use scenario financially viable, it is recommended that offshore wind farms be designed from the beginning, to accommodate low-trophic aquaculture, thereby reducing implementation costs [20].

Social impacts were identified by local stakeholders during a workshop. Foreseen medium/high importance positive impacts for the Belgian pilot were an increase in employment in several sectors, creation of local jobs to remedy the high unemployment rate in Belgian coastal cities, new food source, reduction of conflicts over space use and knowledge development [21]. Foreseen medium/high importance negative impacts were high products selling prices and current lack of capacity in bringing the current research project to a bigger commercial scale [21].

Based on the three pillars assessments, it appears that the combination of offshore wind energy production with low-trophic aquaculture and active oyster reef restoration has the potential to bring environmental, economic and social benefits, in comparison to a single-use scenario. However, the current technical and regulatory context still stands in the way of achieving these benefits fully. Lifting these barriers would be recommended before considering full commercial scale.

5. Discussion

The OMAF is conceptualized as a decision-making tool when faced with a series of alternative uses of a given marine space. The final assessment resulting from the OMAF procedure considers impacts on the three pillars of sustainable development: environment, economy and society, alongside the identification necessary requirements from the enabling conditions: the technological capacity and regulatory framework. Three major strong points of the OMAF are to be highlighted: the comparison of scenarios, the integrated approach, and the flexibility in the choice of methods applied.

Comparing different scenarios provides a strong basis for decision making. A minimum of two scenarios must be envisaged: the multi-use scenario and the single-use scenario. The single-use scenario is the situation where the envisaged uses take place simultaneously but independently of each other, meaning that no area nor activities are shared. The multi-use scenario is one in which the users share space with the option to combine some actions. In addition, a baseline scenario may be envisaged, if deemed useful in the context of the project. That baseline scenario could be one where none of the new activities takes place, or it can be the scenario currently in place. The latest option being of interest is the case of multi-use projects that consider adding a use to one already in place, such as in the case of combining activities with existing offshore wind farms.

In order to provide decision makers with a comprehensive overview, additional scenarios can be formulated and examined. This can be particularly valuable when faced with decisions involving various multi-use combinations, such as the choice between combining offshore wind farms with aquaculture or offshore wind farms with tourism. It also holds significance in determining the number of uses to incorporate into a project, whether it is offshore wind farms with aquaculture alone or with the addition of tourism. Evaluating diverse scenarios offers a broad perspective on the situation and establishes a robust foundation for making informed decisions regarding the feasibility of multi-use applications in the marine environment.

The second major highlight of the OMAF are the three pillars the assessment is based upon. Assessing impacts on the three pillars of sustainable development allows the making of decisions tailored to the needs of the concerned area. In some parts of the world, ecosystem health may be the priority, and combination of uses that promote conservation and restoration of the ecosystem will be favored. In other parts of the world, economic benefits are the priority, and projects that offer an economic added value will be chosen. In other areas, social and cultural benefits will be prioritized, by providing space for traditional or locally valorized uses of the sea. It should be noted, however, that the OMAF aims to promote sustainable development and while trade-offs may be considered, the combination of the three pillars should strive to have minimal negative impacts, and optimal positive impacts.

Beside the impacts of these direct pillars, the OMAF incorporates the need to set the technical, legal, policies and governance requirements necessary for the implementation of the envisaged scenarios. If these aspects are yet to be improved (some technology to create and/or put on the market, a legal possibility for multi-use to take place, subsidies offered to support innovative sustainable solutions, etc.), it should be highlighted, described and whenever possible incorporate recommendations for the necessary progress in the description of the scenarios (step 1 of the OMAF) and in the assessment reporting (step 3 of the OMAF).

Finally, the flexibility of the OMAF in the choice of method applied to identify and assess impacts across all considered pillars, is a key feature that allows it to adapt to various situations. This adaptability makes the OMAF a valuable tool for any context where ocean multi-use is being considered. It means that the OMAF can be utilized effectively in diverse geographic locations and in relation to a wide range of uses scenarios. Because the OMAF can be applied in a consistent manner regardless of the specific context, it becomes possible to make meaningful comparisons between the impacts of multi-use projects in various parts of the world. This standardized approach to assessment and evaluation is valuable for decision-makers, researchers, and stakeholders, as it facilitates the exchange of knowledge and experiences on a global scale, ultimately leading to informed and comprehensive decision-making in the field of ocean multi-use.

6. Conclusion

The OMAF offers a comprehensive and adaptable concept for evaluating the potential of ocean multi-use projects. The framework addresses the increasing demand for marine space allocation amidst growing traditional and emerging marine activities. By considering three key pillars of assessment – economic, social and environmental – the OMAF provides a holistic view of the impacts and benefits associated with multi-use scenarios.

One of the significant strengths of the OMAF is its ability to compare different scenarios, including multi-use and single-use alternatives, thereby enabling decision-makers to make informed choices based on a thorough understanding of potential outcomes. Moreover, the integrated approach ensures that impacts across various dimensions of sustainability are considered, allowing for tailored decisions that balance environmental conservation, economic viability, and social equity.

Furthermore, the flexibility inherent in the OMAF allows for its application in diverse contexts, making it a valuable tool for stakeholders involved in marine spatial planning and policy development worldwide. By incorporating stakeholder engagement throughout the assessment process and emphasizing the importance of monitoring and adaptation, the framework promotes transparency, accountability, and continual improvement in decision-making related to ocean multi-use projects. Stakeholder engagement is particularly crucial in multi-use because, to bring together sectors that may not usually interact much, creating new needs for coordination and cooperation. The OMAF provides stakeholders with a methodology and an arena to cooperate on an impact assessment level.

Overall, the OMAF represents a significant advancement in the field of marine resource management, offering a systematic and inclusive approach to maximizing the benefits of multi-use scenarios while minimizing potential negative impacts. As efforts to harness the potential of our oceans continue to evolve, the OMAF stands ready to support sustainable and equitable development in marine environments around the globe.

CRediT authorship contribution statement

Manuel Lago: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Steven Degraer:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Thomas R.H. Kerkhove:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Marcel J.C. Rozemeijer:** Writing – review & editing, Formal analysis. **Annaïk Van Gerven:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Gerjan Piet:** Writing – review & editing, Formal analysis. **Ruud Jongbloed:** Writing – review & editing, Formal analysis. **Jacqueline Tamis:** Writing – review & editing, Formal analysis. **Ghada El Serafy:** Writing – review & editing. **Alex Ziemba:** Writing – review & editing. **Olga Mashkina:** Writing – review & editing. **Manon Berge:** Writing – review & editing, Writing – original draft, Formal analysis. **Ariel Araujo:** Writing – review & editing, Formal analysis.

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Data availability

No data was used for the research described in the article.

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