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DELIVERABLE 1.4

UNITED FRAMEWORK DESIGN

Work Package 1
Framework and Facilitation

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Abstract	This deliverable covers the UNITED Framework Design, emphasizing its application across project pilots and pillars. The process involves a two-step approach: a bottom-up customization for each pilot to enhance multi-use site management and a top-down cross-comparison to create a holistic solution. The deliverable also introduces the UNITED Assessment Framework (UAF) for impact assessment, with five key steps. This report focuses on assessing technical solutions within the UAF for the project's pilots.

	Comprehensive coverage ensures the project's effectiveness and adaptability for future multi-use endeavours.
Keywords	Framework, Multi-Use
Change Log	Cover page and introduction page revised. Layout and quality of figures enhanced for better legibility Reduction of references to other deliverables and direct citation of supporting deliverables rather than duplication of information in this report. Other deliverables must now be read to obtain similar insight as present in version 1

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ACRONYMS

CCT	Coordination Committee Team
CSET	Core Services Exploitation Team
CT	Consortium Coordination Team
EC	European Commission
H&S	Health and Safety
IPR	Intellectual Property Right
OWF	Off-shore Wind Farms
PA	Partner Assembly
PM	Project Management
SAB	Stakeholder Advisory Board
UAF	United Assessment Framework
WP	Work package

EXECUTIVE SUMMARY

This project deliverable provides an overview of the development and application of the UNITED Framework Design, a pivotal component of our project. It details how this framework has been integrated across the project's pilots and how the pillars have each played a role in the steps of the UNITED Assessment Framework. The primary ambition of this deliverable is to summarize the framework applied within the project, the active pilots, and the results from the various pillars, summarised in the workflow and steps of the assessment framework. It provides an overview of the achievements and efforts undertaken throughout the project and the pilots and cites the relevant supporting deliverables for extensive further information and details. It guides the reader through the application of the UNTIED project and summarises some of the key finding, acting as a consolidator deliverable.

Through this deliverable, the major findings, summation of baselines, projections, assessments, and major impacts each of the pilots has had through the execution of their work can be found. Therefore, we have addressed the full array of specific activities, legal requirements, structural infrastructure needs, and strategic decision-making considerations, TRL developments, and final conclusions for each of the pilots and summarised the benefits and drawbacks to applying such an assessment framework to pilot projects undertaking multi-use development with considerations and recommendations for the benefits in doing so at deployment scale and commercialisation scale. This approach not only enhances the management and monitoring of the multi-use site but also assesses the framework's versatility in accommodating various multi-use applications within the pilots. Employing a top-down approach, we address the successes and pitfalls of the individual framework designs developed for each pilot, with a focus on covering key project pillars. This comparison reveals commonalities and distinctive elements, allowing us to create a holistic solution that bridges any gaps. The results from the applied UNITED framework design, derived from the synthesis of individual pilot designs moves from the outline of the UNITED Assessment Framework (UAF), a versatile tool for assessing the impact of ocean multi-use projects and shows to what extent this framework has been used to and able to evaluate environmental, economic, and social impacts, as well as the effectiveness of enabling pillars like legal and technical aspects. In this report, we specifically assess the effectiveness of technical solutions for the UNITED project's pilots within the UAF. Deliverable 8.1, along with deliverables 8.2 and 8.3, constitutes the third step of the UAF, focusing on assessment reporting. The earlier steps of the framework were addressed in WPs 2 to 6, with impacts and mitigation measures identified for each pillar of the UNITED project.

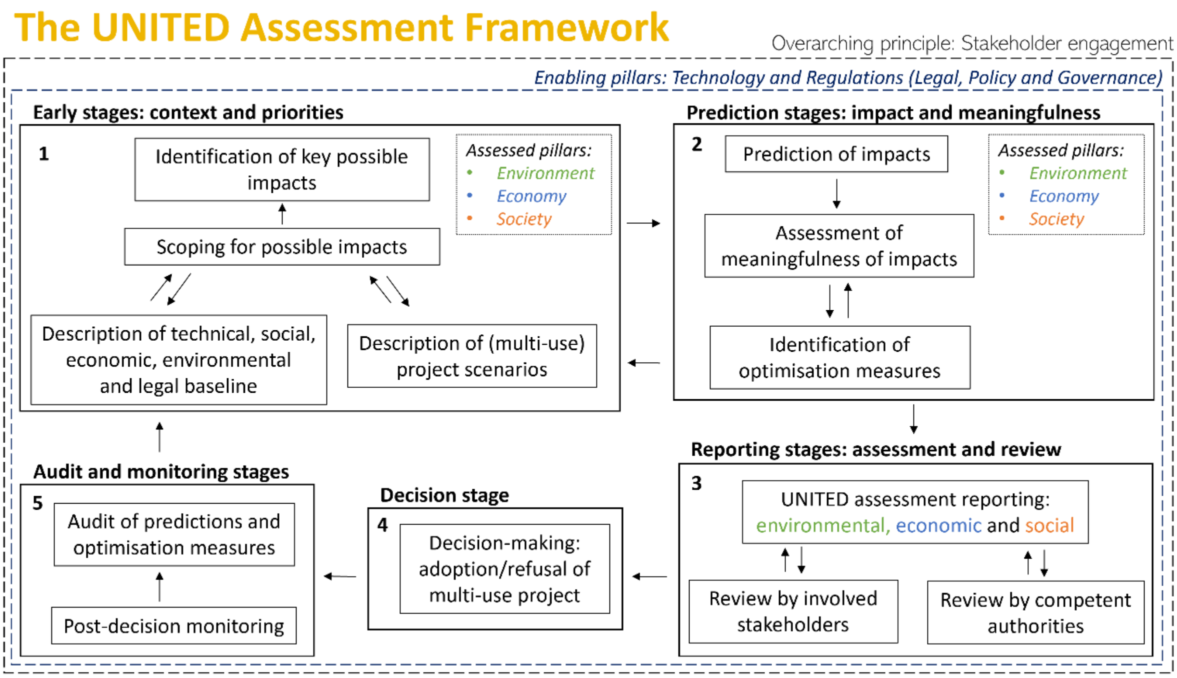
1. INTRODUCTION

1.1. Scope / Objective

This project deliverable is dedicated summarising the development and resulting application of the UNITED Framework Design, a central component of our project. It describes the processes itself in brief, citing other deliverables whom have more expansively covered the topic, and summarises how it has been applied across the project pilots via the project pillars. Employing a systematic approach, we evaluate the achievements and challenges encountered in the development of individual framework designs for each pilot, emphasizing the coverage of key project foundations. This analysis uncovers shared characteristics and unique elements, enabling us to formulate an encompassing solution that bridges any existing gaps. The outcomes stemming from the applied UNITED framework design, synthesized from the individual pilot designs, transition from the delineation of the UNITED Assessment Framework (UAF). This versatile tool serves the purpose of assessing the impact of multi-use projects in ocean environments. It gauges the extent to which this framework has been employed to evaluate environmental, economic, social, and technical impacts, as well as the effectiveness of enabling factors such as legal aspects. Within this report, we address the solutions implemented in the UNITED project's pilots within the context of the UAF. This report aggregates and summarises the various applications of the UAF in a succinct manner, together with Deliverables 8.1, 8.2 and 8.3, and centres on summarising main achievements and areas for improvement. The detailed step-by-step application of framework components were addressed in Work Packages 2 to 6 and are crystalized here in overall view of core outcomes, where impacts and mitigation measures were identified for each foundational aspect of the UNITED project.

1.2. The UNITED Assessment Framework (UAF)

The United Assessment Framework (UAF) is a generic framework to assess impact of ocean multi-use projects. It can be applied to different type of impact and as such offers a comprehensive and multidisciplinary impact assessment. Five steps are proposed in the framework, as represented in the figure below.



The first step of the assessment is to describe the baseline and the scenarios with which to work, then scope for impacts and identify the key impacts. The second step elaborates on the key impacts with prediction of their effect, assessment of their meaningfulness and identification of mitigation measures. The third step of the UAF is the reporting of the previously achieved assessment, accompanied by a review by relevant stakeholders and authorities. The fourth step is the decision making: adopt or refuse the project based on the impact assessment. The fifth and last step of the UAF post-decision monitoring and auditing of the predictions and mitigation measures.

The UAF can be applied to assess environmental, economic and social impacts, but can also serve to evaluate the effectiveness of enabling pillars such as the legal and technical aspects. In the context of this report, the effectiveness of technical solutions for the pilots of UNITED is assessed. Within the UAF, deliverable 8.1, in parallel with deliverables 8.2 and 8.3, constitutes the third step of the framework: assessment reporting. The two first steps of the framework were addressed in WPs 2 to 6, with impacts and mitigation measures identified for each pillar of UNITED.

1.3. Activities in Pilots

1.3.1. German Pilot

Description:

The offshore research platform FINO3 in the North Sea is now operated by FuE-Zentrum. The basic fundament of the platform (windmill monopile construction) follows the same characteristics as has been constructed for the offshore wind farm turbines in the area. The experiences from its operation as reference platform and reference tower (120 m height) without a turbine and the results of the numerous scientific research projects carried out so far on and around t 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 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 need of strong support from land-based stations.
- Moreover, such joint (multi-stakeholder) activity can also benefit both development in regard 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 foot-print 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.

Primary Stakeholders:

The primary stakeholder groups whom have been engaged with through the work completed in the UNITED project German pilot include those listed below. These actors have been brought into contact with the pilot either through workshops, through permitting and legal requirements, or discussions and collaboration on joint deigns and operation of activities.

- Offshore wind sector

- Aquaculture suppliers
- Commercial aquaculture producer
- Insurance companies

Final achievements:

The German pilot started with individual components at TRL 9, however the integration of the various elements into a seamlessly functioning whole was evaluated at a TRL of 5 after extensive testing in the preliminary phases. TRL 5 indicates advanced technology development with components validated in a near-real-world environment, and the pilot project aimed to achieve TRL 7 by its conclusion. The key achievements of this pilot are:

- Functionality: A functional and robust mussel and algae cultivation system withstanding harsh offshore conditions abreast a functioning offshore windfarm within exposed North Sea conditions was realised. Algae was successfully grown and could be harvested in May 2023 from the location; mussels were also grown at the same location and could be harvested in June 2023. A reduction in expected costs were realised through shared boat and helicopter trips for maintenance, validating the idealised synergies of combining multiple uses at sea.
- Administration: Securing of necessary permits for installation and operation of algae and mussel aquaculture offshore and established connections with legal authorities, ensuring compliance and building an open communication channel to share and discuss results of activities
- Investment & Sales: Conducted business plans, market analyses, engaged stakeholders, and deepened ties with regional sellers to establish the market potential for mussels and algae.
- Standardized Infrastructure: Trained offshore staff, optimized logistics, established remote monitoring, and documented management procedures.
- Technological Development: Demonstrated robustness of the technology in the challenging offshore environment, surviving harsh weather conditions, advancement of combined design and operations for both mussel and seaweed aquaculture to a TRL of 7 for the implemented designs and monitoring schemes.
- Environmental Impact: Collection of key environmental data using buoys and sensors to inform on the local conditions; finding no significant negative impacts attributed to the multi-use system at the scale implemented.

The German pilot site at FINO3 successfully reached TRL 7 for the mussel and algae aquaculture multi-use system, was able to bring the topic of multi-use specifically for low trophic aquaculture to a number of permitting and operational points within the German North Sea region, and successfully grew and harvested both mussels and seaweed in a highly dynamic and harsh environment.

1.3.2. Dutch Pilot

Description:

North Sea Innovation Lab is an independent test site for research, pilots and the upscaling of innovations in the field of seaweed cultivation, floating solar and other renewable energy innovations, and co-use of wind farms. Within the UNITED project, 2 parcels within this test location has been used in order to deploy seaweed cultivation lines by The Seaweed Company and floating solar panel arrays by Oceans of Energy. These pilot deployments were set in conditions similar to offshore wind farms located in the same region and are used as proof of concept for the designs and operations to further integrate these activities within offshore wind installations in the near future. North Sea Farmers Offshore Test Site is located 12 kilometers off the coast of The Hague – Scheveningen with the following technical specifications:

- 600 ha/ 6 km^2
- 12 km offshore (Harbor Scheveningen)
- Water depth approx. 18-20 meters
- Officially demarcated (cardinal buoys & registered in hydrographic cards)

Objectives:

The Dutch pilot encompasses 4 key demonstration objectives to showcase the combined functionality of offshore wind developments, floating solar energy production, and seaweed farming in different combinations. While not located within an offshore wind-farm installation, the pretext, designs, and data gathered from the multi-year deployment of both seaweed and floating solar panels in this exposed North Sea testing site has provided data and validity to proposed future combination and showcased the synergies that would bring a benefit to all three activities if combined within one operational site. Of particular relevance are the Dutch activities' demonstrated benefits and considerations for strategic co-design planning of the expanding North Sea offshore wind capacity. The testing of the float solar panel arrays were aimed to:

- Demonstrate the economic feasibility of integrating floating solar at existing/to-be-developed offshore wind farms at power station/turbine level
- 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 off-shore wind farms
- Demonstrate the existence and extent of the wave dampening effect of floating solar infra-structure at sea by means 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 (Dutch pilot test location) to optimally benefit from the wave dampening effect

The deployment of monitoring buoys and seaweed grow-out systems were aimed to demonstrate the economic feasibility of integrating aquaculture at existing as well as to-be-developed offshore wind farms including:

- Development and demonstration of a safe operational plan for commercial roll-out of seaweed activities (seeding, growing, harvesting, processing) in wind farms by means of simulation and demonstration
- Definition of legal/contractual framework for applying the combination in a commercial setting

The combination of floating solar and seaweed aquaculture in a co-location setting also aimed to highlight and the conceived synergies between these sectors and explore additional aspects such as:

- Demonstrate the technical feasibility of an energy and communications connection between aquaculture and floating 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

<u>Primary Stakeholders:</u>

The core participants in the Dutch pilot activities and considerations included the project members participating in the project listed below (

- Stichting Noordzeeboerderij/North Sea Farm Foundation: non-profit organization aimed at realizing sea-weed industry in The Netherlands
- The Seaweed Company (TSC): commercial seaweed company cultivating certified seaweed
- Oceans of Energy BV (OOE): first company to design, develop and build floating solar systems that can withstand robust, offshore conditions
- TNO: supports with research on floating solar energy offshore and provides modelling outputs
- Ventolines BV: service provider of onshore wind and solar and offshore wind projects
- Vattenfall: Wind farm operator that is interested in impacts of logistics, governance and insurance in multi-use activities in offshore wind farms.
- Governmental permitting and planning agencies related to offshore energy and aquaculture
- Search & rescue, Commercial shipping, Fishing

<u>Final achievements:</u>

In this pilot, a floating solar installation and two seaweed cultivation systems were tested in real offshore conditions of the North Sea. The seaweed cultivation systems were tested for two growing seasons, and two different systems designs were improved, installed, and validated in a real offshore environment during the UNITED project. The results of these activities are being used as the basis of a commercial seaweed farm within a wind farm that is planned to be installed in The Netherlands in 2023: North Sea Farm #1. The industrial process of seeding and harvesting of seaweed was further developed by the project members which has moved forward a potentially innovative step towards automated seeding and harvesting. This industrial process was taken from TRL 4 to TRL 6 with the development of pilot tests with a machine that can perform both the seeding and the harvesting, where all aspects of this operation have been tested within the project on full scale.

1.3.3. Belgian Pilot

Description:

The activities in the Belgian pilot of UNITED focused on Low-Trophic Aquaculture deployment within active offshore wind farms and the restoration of native flat oyster reefs as well as their cultivation for human consumption. Within the activities of the pilot two different locations were used, the primary being offshore within the wind farm of Belwind, with Parkwind as concession holder. This wind farm is located 46 km from the coast with an average depth of 25-30 meters and activities were carried out inside of this active offshore wind park. Secondly, a nearshore site, Westdiep, located at a distance of 5 km off the coast in front of Nieuwpoort, Belgium, with an average depth of 15 meters, was utilized as a near-shore testing site at which systems and techniques have been trialed and assessed prior to being implemented offshore. The work carried out within UNITED was built upon an offshore mussel aquaculture pilot project, EDULIS, which had been running from September 2016 to 2019. As such, the wind farm of Belwind had previous experience with offshore longline systems and bivalve aquaculture.

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. In order to achieve this goal, a number of specific questions are required to be answered falling under the following sub-objectives:

- Identification of appropriate areas for oyster reef restoration in offshore wind farms where trawling activities are not allowed.
- Demonstration of the possibility to develop scour protection that fulfils technical requirements while supporting the formation of small oyster reefs, which eventually can form a network of small islands of oysters spread over several square kilometers; the choice of filling material is a crucial parameter.
- Validation of implemented designs for longlines 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

A secondary objective of the pilot is to compare the growth of seaweed grown offshore and nearshore to determine suitability and growth potential for different varieties. For that purpose, the longlines utilized in exploring the objectives of oyster restoration and aquaculture oysters are 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.

Primary Stakeholders:

- 4SEA consisting of 4 environmental NGOs: WWF, Natuurpunt, Greenpeace, Bond Beter Leefmilieu
- Fishery Industry Sector - including fishing and auctioneers
- Regional and local authorities, including permitting and licensing
- Port authorities
- Local recreational companies, e.g. sailing clubs
- Wind farm operators

Final achievements:

The Belgian pilot yields innovations aimed to develop an industrial process for the cultivation and restoration of European flat oysters (*Ostrea edulis*) and seaweed (sugar kelp, *Saccharina latissima*) in the Belgian part of the North Sea. The project represents a significant step towards the implementation of sustainable offshore aquaculture systems, addressing biological constrains, technical solutions for natural development of oysters and solutions required for seaweed and oyster farming. Three key results have resulted from this work in achieving these goals:

- Oyster restoration tables have been successfully installed in the offshore environment, serving as an essential proof of concept in a real-life setting for restoration capacity
- Oyster cultivation systems have been installed in a harsh off-shore environment, laying the foundation for future up-scaling of such designs for commercially viable oyster cultivation
- Seaweed (*Saccharina latissima*) has been cultivated on commercially available nets, demonstrating the potential for large-scale seaweed cultivation in offshore environments within active wind energy parks.

The Belgian pilot project has made significant progress in showcasing the viability of the industrial process, with continuous operation of the pilot plant/unit during a relevant timeframe successfully demonstrated. The project started at TRL 5 and reached TRL 7 for the technical solutions described above.

1.3.4. Danish Pilot

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 centers and museums. The cooperative owned OWF Middelgrunden Wind outside the harbor 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:

The Danish pilot aimed to primarily expand and improve upon the existing multi-use concept that was existing at the on-set of the project, namely tourism to OWF. In order enhance the existing activity, 2 primary objectives were identified, and through the work, a number of hoped for and novel synergies have been realized for this multi-use combination:

- 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 Health and Safety (H & S) practices, regulation - safety zone measures, and demonstrate operability and profitability of the multi-use solution.

As the operation of the tours to the wind turbine were further developed within UNITED, synergies that can be established between OWF and tourism at the site have been expanded or the potential validated for a number of activities. These include sightseeing boat tours combined with angling, expanding the offer of the combination and the breadth of the activities withing the region. Furthermore, special designs for platforms around the turbines serving as designated facilities for divers, local artisanal fishers and offshore restaurants in the vicinity of OWF have been explored. A number of benefits beyond the tourism industry have also been identified and realized including:

- Boat tour operators can be engaged in OWF related monitoring activities;

- On land visits to OWF information centers and museums, and platforms for observing, bringing the offshore experience to museums and increasing the potential interest
- Increasing attention and information surrounding OWF via the installation of 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 increasing local knowledge about the importance of green energy and the technical and scientific components behind it.

Beyond the project objectives, this pilot was additionally able to support:

- Support the development of viable business models and capacity building for local tourism operators
- Mainstream such solutions in local development policies, cohesion policies, and as part of broader project development guidance for OWF developers (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. Such model will include guidance for cost-benefit analysis.

Primary Stakeholders:

- Engagement of local intermediaries and clusters such as tourist boards and local councils will be crucial as these 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 centers.
- Other intermediaries incl. State of Green.
- Organizing visits for professionals.
- All the visitors participating in the guided tours

Final achievements:

The Danish pilot project started at TRL 6 and reached TRL 9 during the UNITED project. The project aimed to organize visits for shareholders and tourists to the Wind turbine cooperative. During the UNITED project, two boat owners were convinced to add the tours to their overall program for trips on the local sea, and one is investing into a new boat that will increase the possible number of visitors. Insurance and legal rules were established, and the overall security and risk assessment has been improved by the operations. Two more guides were trained, and a manual for guides has been produced. Two videos were produced about a virtual visit in order to make it possible during the COVID period to have a visit. Fishing and diving activities were included in the project proposal but were found to be too time consuming and not technically feasible.

1.3.5. Greek Pilot

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 of aquaculture (monitoring parameters such as salinity, water quality, fish behaviour and stress levels);
- Monitoring and management technologies to facilitate the need for synchronization of multiple operations of touristic 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 aquaculture unit, 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 activities in cases of emergency or for risky procedures
- Time management by multi-sharing of infrastructure such as use of existing platform for aquaculture, diving or 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 aqua-culture activities already taking place in the area, these prospective activities could take place.

Primary Stakeholders:

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

Final achievements:

The Greek pilot project has made significant progress from its initial TRL of 5 to its current TRL of 7-8. The pilot site was initially in the advanced development stage, with a focus on establishing the aquaculture unit on floating facilities near the Greek coast. Scuba diving activities were introduced to enhance the understanding of the underwater environment and the operations of the aquaculture farm. Building on this initial progress, plans were made to organize boat tours, enabling visitors to witness the functioning of the aquaculture farm. Professional scuba diving activities were integrated into the pilot's operations, leveraging the expertise and skills of experienced divers. These professional divers contributed to operational tasks such as underwater inspections, infrastructure maintenance, and waste management. ROVs were also used for infrastructure maintenance of the aquaculture farm. Infrastructure improvements were implemented to enhance connectivity and data collection, including internet connectivity through a 4-G access point with Wi-Fi and Ethernet access and photovoltaic panels installed in the floating warehouse.

1.4. Project Scenarios Considered

One of the tasks in the first step of the UAF is the description of the (multi-use) project scenarios. The economic impact assessment, performed under WP3, considered two scenarios, while the environmental impact assessment, performed under WP4 considered three scenarios. Descriptions of the assessment tools, methods and results are discussed at exhaustive lengths in UNITED Deliverables 3.2, D3.3, D4.2, D4.3 and D4.4. A short summary of the scenarios is provided below.

Economic impact assessment:

For each of the pilots, two scenarios have been used to assess the added value of multi-use. Although there are two scenarios for each of the pilots, these scenarios are not all the same. In short, these are the scenarios [Reference UNITED Deliverable 3.3 for extensive details] are summarised as follows. In the case of the German pilot, the baseline scenario represented a situation where an offshore wind farm, a mussel aquaculture farm and a seaweed aquaculture farm operate individually, without sharing space, activities, or infrastructure, in the site of the DanTysk wind park, which is located next to the site of the pilot. When addressing the potential impacts of upscaled multi-use, a situation where mussel and seaweed aquaculture are combined (with a 50-50 ratio) inside a wind park, the size of the Belwind wind park but at the location of the DanTysk wind park was used. Besides the shared use of the location, there is also sharing of operational activities.

For the application in the Dutch was represented within the Princess Amalia Windpark off the coast of North Holland, where floating solar energy production, seaweed production, and offshore wind all had an exclusive right to 1/3 of the wind park area and considerations of the exclusion zones were introduced. This wind park is comparable in size to that of Belwind used in the other two analyses. For addressing the benefits in multi-use, an ideal situation where three marine activities are combined within area of the Princess Amalia Wind Farm, in a redeveloped and co-designed manner in the Netherlands. Here, offshore wind energy production, floating solar energy production and seaweed cultivation were envisioned to be integrated with one another and the cost benefits and increase in potential use is denoted in rough estimates for a park of this size beginning with construction, going through operational benefits, and considering the differences in decommissioning times and requirements. Like the German and Dutch pilots, the baseline scenario for the Belgian case were each of the sectors (oyster restoration, seaweed production, and wind operating independently, so in isolation from one another without exploring synergies, and for an integrated case, the activities are operated in a coordinated manner and the synergies between them are explored. These the scenarios for these three cases were developed together which is why they reflect one another so well as the cases focused on aquaculture production and integration of multiple production (mussel, oyster, seaweed, or additional energy) via infrastructure within offshore wind farms and faced similar challenges and potential synergies.

In the case of the Danish pilot and the Greek pilot, the benefits and scenarios discussed relate more to the tourism and potential synergies from incorporating such activities. The baseline scenario for the Danish pilot represents the current status of the Danish pilot, tourism activities co-existing with an offshore wind farm, with both activities continuing at their current levels without significant changes. The enhancement scenario considered represents the same multi-use situation as the baseline scenario but with an increase in the tourism activities and diversity of offerings. For the Greek pilot, the baseline scenario represented a situation with only an aquaculture farm at the location of the Greek pilot, so without any tourism activities, the case of the pilot prior to the UNITED project. The consideration of multi-use is the scenario explored within UNITED, a multi-use situation where the aquaculture farm is combined with tourism activities.

Environmental impact assessment:

The following three scenarios have been used [Reference UNITED D4.3]:

- A baseline scenario. The scenario represents the situation before the multi-use project was considered.
- A single-uses scenario. This scenario represents the situation where the marine activities are independently implemented at two separate locations. In this scenario, the activities do not share space nor actions nor infrastructure.
- A multi-use scenario. This scenario represents the situation in which the multi-use combination of marine activities is implemented. The activities share space and/or actions.

Because three of the five UNITED pilots (i.e. the German, Dutch and Belgian pilot) are still at an experimental level instead of a commercial level, it was decided to use a hypothetical large-scale scenario for the assessment of those three pilots. The hypothetical scenarios are described in more detail in UNITED Deliverable 4.4, but these are the key highlights:

- One standardised offshore wind farm was used for all three pilots. The wind farm of the Belgian pilot (Belwind) was used for this. The surface area of this wind park (17 km^2) was used as a basis for the surface estimate of the activities.
- The locations that were used are:
    - German pilot: DanTysk wind farm (located next to the FINO3 platform)
    - Dutch pilot: Princess Amalia Wind Park
    - Belgian pilot: Belwind (the actual location of the Belgian pilot

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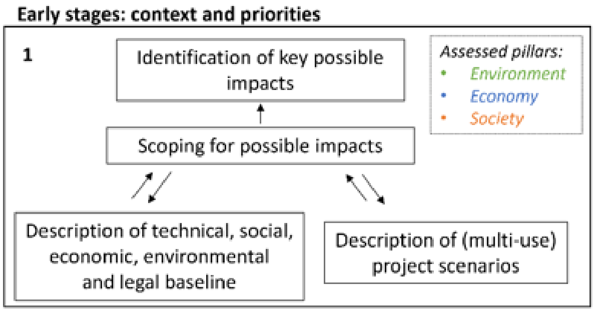
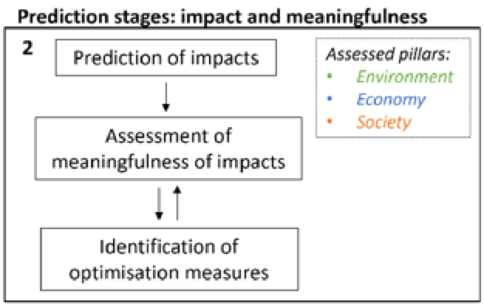
2. APPLICATION OF THE UNITED ASSESSMENT FRAMEWORK

In addressing the applicability and utility of the generalised UAF within the project and how it has been applied to pilot level studies, below, a description of the steps as they were applied and implemented within each of the pilots and associated activities is reviewed. This provides insight into potential limitations of the assessment framework when operating on a pilot level basis with considerations for differences when being applied to commercialisation scale developments. A key limitation found was the assessment of impacts, as these had to be predicted within the context of scaled scenarios. This is due to the small nature of the pilot applications, and the assumptions that negligible environmental impacts would result from the implements test lines. This is in accordance with the project objectives as a project cornerstone was proving the feasibility of the solutions in conjunction with other activities and in real environmental and harsh weather conditions. The 5 steps of the UAF are applied across all pilots in the subsection below, the main outcomes and rational for the phases are detailed below, with considerations for the limitations within pilot sites explained.

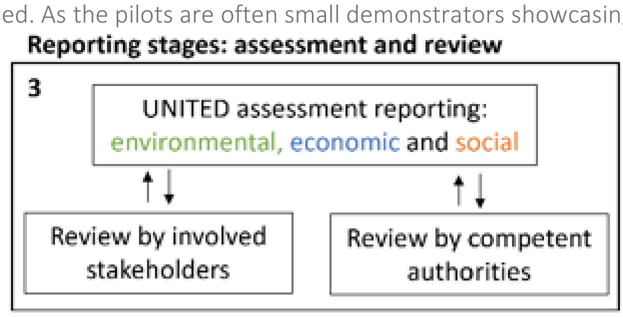
The first step of the processes is a description of baseline conditions and the identification of potential impacts as seen in the general United Assessment Framework (UAF). This step engaged with all of the various pillars, identified in WPs in the figure below, to determine the starting point of developments, potential impacts form deployment and operations, and determination of critical monitoring elements from all key pillars. This included the scoping of potential impacts, not only at the demonstrator level, but consideration for what would be the economic, social, and environmental implication the multi-use combinations considered when scaling to a large deployment and implementation.



In the secondary step across the pilots, the scoped impacts identified in phase one are predicted, the degree of impact, potential negative or positive implications, and the degree to which said impacts would have a meaning or significance across the core pillars being addressed. When addressing the significance of impacts, potential mitigation or optimisation measures for the planned deployment and operations are considered in order to adjust planned execution and design activities to best align them with the objectives of the pilots and the desired outcomes.



Through continued monitoring and assessments of the design, deployment, operations, and decommissioning of the pilot demonstrators within the UNITED project, the impacts, effectiveness of design and operations, and the overall impact on technological readiness, environmental impacts, economic results and influences, and social acceptance or benefits are then addressed and assessed. As the pilots are often small demonstrators showcasing the potential benefits and viability of the configurations considered and deployed within the UNITED project, the overall impacts of these demonstrators on a practical level are often small, as seen in the deployment of longlines and Low Trophic Aquaculture activities. Within UNITED these are confined to demonstration scales and are not economically or commercially producing oysters, mussels, or seaweed. For the objective of the UNITED project, the potential to scale and considerations for what the impacts of such operations at a larger scale would be are the



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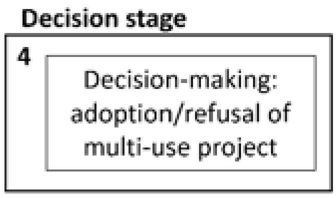
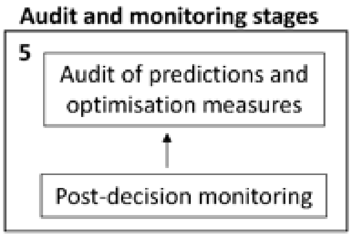
critical evaluation metrics within this phase, alongside building a body of evidence that demonstrates their potential to provide the services that are demonstrated through this work, and capacity to be scaled.

In the fourth phase described for each of the pilot, the decision to adopt and implement such projects is addressed. In the conception of the UNITED project, permitting for demonstration was achieved and the projects executed, but the results of the demonstrators, capacity to function over the timespan of multiple years, and successes of implementation provides decision making bodies critical data points and information, for which future decisions can be based on, namely, further exploration into the scaling and implementation of the multi-use activities demonstrated and the required scoping and prediction of impacts which is required prior to such scaled deployments. Within the scope of UNITED, only the body of evidence and communication of achievements was planned and undertaken in the execution of the project, but it is the hope that the results presented across the compendium of project deliverables will serve to inform and aid decisions into the future state and exploitation of multi-use constructs.



Lastly, an auditing of the pilots take place to addresses enhancements in the TRL levels achieved, determine the success of the implementation and operation of the demonstrators in achieving the targets set forth, and to what degree the social, technological, economic, and environmental considerations and predicted impacts were achieved, either in practice through practical deployment of the pilot, or within the theoretical framework of scenarios and research that was undertaken. Consideration should be given to the fact that, again, the demonstrators were deployed to showcase the viability of the solutions from a technical and practical standpoint and the full extent, impacts, or benefits resulting from scaled deployment of such solutions and activities are addressed through the scenarios described in section 1.4 and considered with the inputs from multiple stakeholders, discussion in workshops, interviews, and desk research.



2.1. German Pilot

As noted in section 1.3.1, the primary activities of the German pilot included demonstration and coupling activities for monitoring and growth systems for algae and seaweed lines in the German North Sea. This was achieved by demonstrating in harsh offshore conditions the resilience of the grow-system and several monitoring components. The final integrated design has reached RL 7. In the course of the UNITED project's German pilot, various stakeholder groups have been actively involved. These stakeholders, including the offshore wind sector, aquaculture suppliers, commercial aquaculture producers, government entities, and insurance companies, have been engaged through workshops, permitting processes, legal requirements, and collaborative discussions on joint designs and operational activities.

2.1.1. Step 1: Description of baseline and identification of impacts

Technical baseline: TRL overview and transition

The TRL 5 of the German Pilot is defined under Horizon2020 as "Technology validated in a relevant environment." The US Department of Energy (USDOE) further details TRL5 as lab-scale testing with a system that's almost prototypical, differing mainly from TRL4 due to its increased fidelity to the actual application.

The technical applications and solutions, infrastructure and logistics (e.g. transportation of personnel and equipment) of the offshore research platform FINO3 have been revised, adapted and improved since 2005. The research platform has been constructed according to wind turbine standards using the monopile approach, making good use of advancements in technology and operating in a real life environment. This platform, along with other offshore installations at the same site, has provided insights that inform future pilot adaptations.

Seaweed and mussels cultivation, the second activity of the ocean multi-use system of the German pilot, was already established in the nearshore site at the Kieler MeeresFarm (KMF). The nearshore site was used to test materials such as particular anchors, longlines, collector lines, shackles, and chain materials. Additionally, buoys designed for FINO3 were tested and the required logistics (installation, service and maintenance trips as well as harvesting) could be tested for their feasibility at the nearshore site, increasing capacity and knowledge in a more controlled environment and reducing the very costly (tens of thousands of Euros) trips to the offshore site in a less prepared manner. Also, training in handling equipment and try out installation techniques were possible in the nearshore site. The results of these tests are used for the design and adaptation of the planned aquaculture system. The technical components for the aquaculture system, used in UNITED, were bought off the shelf and combined and adjusted for the environment at the final location. Some components e.g. longlines used as backbones for the systems or buoys to mark the test side in the German pilot are off the shelf materials. Those materials have been tested in similar use but in different locations, which can be stated as simulated environments. Furthermore, the material itself can even be rated as TRL9, as one of Europe's largest seaweed cultivation farm (in Frøya) applies comparable equipment and technology, that has been classified as TRL 9 for seaweed cultivation Dalton (2019). The sensor equipment for seaweed and mussel monitoring passed several tests, meeting the USDOE (2009)'s TRL5 requirements.

The Scottish Aquaculture Innovation Centre references the Nuclear Decommissioning Authority (NDA)'s definition of TRL5 as an "off the shelf item needing minor modification." This definition perfectly describes the German pilot's status at the start of implementation. The main challenge for the German pilot (Pilot1) is adapting and implementing existing technologies in a new high-energy environment where increased resilience and reliability is required due to the high lag-time and costs of making site visits to adjust and affect repairs. This entails developing new business models and research processes to move from TRL 5 to TRL 7.

Environmental baseline

At the FINO3 location, an array of long-term monitoring projects has been conducted, with some still ongoing. This description of abiotic factors is derived from the comprehensive datasets compiled in the COSYNA (Coastal Observing System for Northern and Arctic Seas) database by the Helmholtz Centre for Materials and Coastal Research Geesthacht (2017), as well as the FINO database maintained by the Federal Maritime and Hydrographic Agency (2017). To depict the environmental conditions, all available data for key parameters such as dissolved oxygen, oxygen saturation, temperature, salinity, turbidity, chlorophyll-a, nitrate, nitrite, maximum swell, and currents were utilized. These parameter datasets were analysed through time series analysis and descriptive statistical frequency analysis techniques. A full and detailed description can be found in the project deliverables pertaining to the environmental baselines and assessments. Within these a detailed analysis of the seabed, sea water, atmosphere and climate, fauna and flora, and a wide array of other important and determining factors for the environmental analysis and baseline can be found.

Identified Gaps

Regarding flora and fauna, uncertainties remain in several areas, particularly concerning mussels and seaweed, as well as fish, birds, and mammals. For mussels and seaweed, the influence of environmental interactions between their cultivation and the surrounding environment needs examination. Factors like water temperature, oxygen, pH, turbidity, and phytoplankton availability are variable and will be monitored. The timing and concentration of blue mussel spat fall at FINO3 are yet to be studied, crucial for planning offshore mussel aquaculture expansion. Additionally, the occurrence and extent of toxic algae blooms in the area are largely unknown and require close monitoring. A key issue in aquaculture is its potential negative impact on existing eutrophication. Although nitrogen input from mussels is expected to be negligible and quickly diluted by strong currents, NO_3 production will be measured to test this hypothesis. For fish, birds, and mammals, the effect of newly introduced substrates like long lines and gravity anchors on fish species diversity is unclear. This may impact the attraction of seabirds and other predators, such as seals and porpoises, leading to changing biological interactions. While this topic is well discussed, the extent of offshore installations' impact on the environment remains unknown.

Scoping of impacts

Potential environmental impacts

This section presents some of the known impacts for the given type of multi-use that may be applicable at the pilot site. Mussel and seaweed cultivation can have impacts on water quality, due to their filtering activities. The seabed may be affected during the installation phase, and mussel excrements during the cultivation can have an impact on the sediment. The construction and operation of the plants can have effects on the local climate, on vegetation and on fauna (benthic community, fish, birds, marine mammals).

Four additional ship cruises and helicopter rides are necessary for installation, maintenance and decommissioning of the aquaculture farm. This additional traffic can have an effect on the number of accidents and pollution. The construction and operation of the plant can have impacts on cultural assets and human activities, as well as impacts related to the increased traffic/transportation for installation, maintenance and decommissioning of the aquaculture farm.

To feed the prediction of impacts that is the second step of the UAF, height ecosystem components (EC) were chosen, on which impact of the multi-use project would be evaluated. These six ECs are: Fish and Cephalopods, Mammals, Birds, Pelagic Water Column, Sublittoral Sediment, Infralittoral Rocks and other hard substrates, littoral Rock and other hard substrates, and Circalittoral Rock and other hard substrates.

Potential social impacts

The initial phase of the German pilot project involved the categorization of social impacts through collaboration with a diverse group of stakeholders during an online socioeconomic workshop held in November 2022. This workshop comprised representatives from various sectors, including offshore wind energy, the regional Agriculture office, the DG for Maritime Affairs and Fisheries European Commission, and experts from multiple disciplines, such as marine ecology, food technology, and engineering. Following this initial discussion on social impacts, a subsequent refinement process took place during the consortium's General Assembly in February 2023, where partners met in person to further analyze and assess these impacts. Through these collaborative efforts, several significant social impacts were identified. Foremost among these is the impact of employment, training, and re-skilling initiatives in the region, which has direct implications for the local population residing within a radius of up to 20 kilometers from the landing port. Additionally, there is a heightened concern regarding the increased risk of offshore accidents stemming from the concurrent operations of multiple teams, primarily affecting offshore workers, and ranking as of medium to high importance. Medium-importance impacts include the establishment of new processing facilities, which create new local job opportunities and thus affect potential employees in the local workforce. Furthermore, the expansion of training and education facilities, currently numbering three, brings more individuals (trainers and employees) to the area, impacting both local residents and professionals. The automation of shipping operations offshore necessitates upskilling of existing workers and attracts new professionals, thereby influencing the existing offshore professional community and students pursuing relevant fields. Another notable impact is the potential exclusion of other uses within the wind farm area, which could hinder activities related to shipping and fishing. Finally, the provision of alternative income sources for fishers transitioning out of the industry ranks as a medium to low level of importance in the assessment of social impacts.

2.1.2. Step 2: Prediction of impacts

Given the above as the baseline conditions within the site where the German Pilot was deployed offshore, the potential impacts for the defined projects scenarios found in section 1.4 was undertaken. Following step 2 of the UAF. This includes the prediction of what impacts the installation and operation of the mussel and seaweed mariculture would have within the area, and denoting if the degree of speculated impact would have a meaningful or significant effect on the area. Given the degree of impact, mitigation or enhancement measures for design and operation can be proposed in order to achieve a best-case scenario for the operations to be deployed and the potential negative or altering effects of said activities to be minimised.

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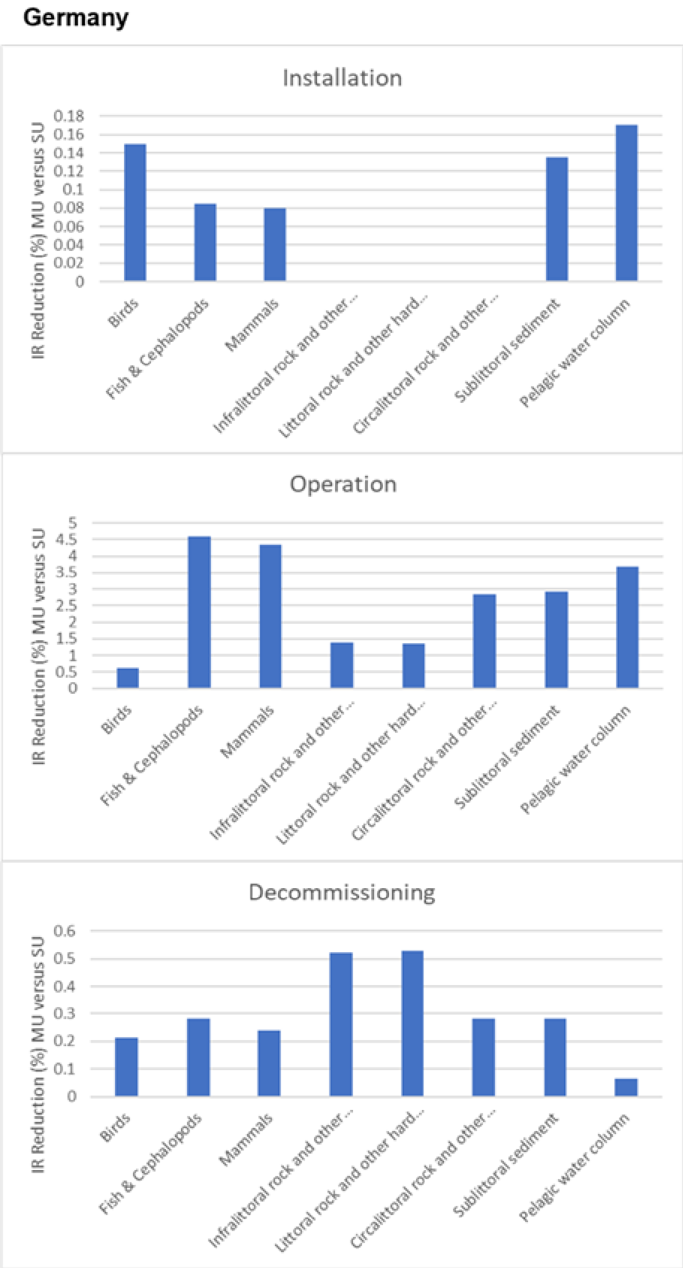

Figure 1 - Reduction (%) in Impact Risk for each Ecosystem Component by activities in multi-use design as compared to single-use design for the German pilot for all three phases.

Environmental Impact prediction

Impact on the ecosystem components were predicted for a baseline scenario, one where the area is not dedicated to a specific activity, for a single use scenario, in which the activities happen simultaneously but independently from each other, and a multi-use scenario in which offshore wind energy production and low-trophic aquaculture of mussels and seaweed are combined. For the single use and multi-use scenarios, impacts were predicted for the three stages of a project: installation, operation and decommissioning.

The method used to predict environmental impact of each scenario is an Environmental Impact Risk Assessment method developed by Wageningen University and Research a partner of the project. A 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.

For the German pilot (Figure 1), little impact reduction (< 1%) is expected in the installation phase and decommissioning phase. The pre-installation activities are not expected to change in MU compared to SU for the German pilot. However, during the operational phase reduction in IR is estimated to reach a maximum of ca 5% for fish. This is primarily due to the degree of impact reduction realised when having all activities not interconnected or utilising the same supporting infrastructure. The primary savings are then from the operational phase as combined monitoring and sea missions can serve to reduce incursions into the area.

In addition to the prediction of environmental impact risk reduction, the potential for the German pilot to build positive environmental synergies was predicted based on expert judgment and literature review. They are the following: biodiversity increase in the area of the project, commercial fish species increase with potential spill-over in the surroundings of the project, nutrient cycling thanks to shellfish filter-feeding with a removal of nutrient through harvesting and the deposit of nutrient and organic matter on the seafloor, carbon sequestration over the long term if the seafloor remains undisturbed, sustainable and local food production, increased social acceptance of OWF and LTA, more space freed for conservation elsewhere in German waters, a reduction of conflict over space-use thanks to the combination of two space-demanding activities.

Assessment of meaningfulness of environmental impacts

The biggest environmental impact risk reductions in the German upscaled multi-use scenario are predicted for the operation phase of the project. Given that this project would include offshore wind farms, it can be expected that these reductions will last for at least 15 years, which could make a major difference for threatened benthic, fish and mammal species mentioned above in the chapter "environmental baseline".

In addition, based on the environmental synergies that can be expected from the German scenario, the following European environmental goals and strategies can be expected to benefit from it:

- Achievement of a Good Environmental Status (GES) as required by the Marine Strategy Framework Directive (MSFD) through Descriptor 1 'Biodiversity is maintained', Descriptor 3 'Population of commercial fish species is healthy', Descriptor 5 'Eutrophication is minimized', and Descriptor 6 'The seafloor integrity ensures functioning of the ecosystem'.
- Achievement of the Green Deal by supporting the following goals: increased blue carbon sequestration (Sustainable Carbon Cycles), sustainable food production (Farm-to-Fork Strategy and Sustainable Blue Economy), renewable energy production, Biodiversity Goals by allowing for more space for conservation, the implementation of the Maritime Spatial Planning Directive thanks to the reduction of conflict over space-use.

For more detail on the assessment of meaningfulness of the predicted environmental impact of the German pilot, refer to Deliverable 8.3 'Report on environmental assessment and validation' (Van Gerven et al., 2023b).

Social impacts

The German pilot and the group of stakeholders assessed the level of acceptability of each social impact identified in Step 1. Among impacts with high level of acceptability, that is having a positive impact and are a desired outcome, are the alternative income for fishers, the new processing facilities and thus new local jobs, the additional employment, training and re-skilling in the region, and the additional training and education facilities, and the automated shipping for operations offshore. Among the negative impacts, with undesired outcome, are the exclusion of other uses in the wind farm, which could be impeded by aquaculture, and the increased risk of accidents offshore due to multiple teams operating in parallel.

2.1.3. Step 3: Assessment reporting

After executing the pilot activities and monitoring of the realised synergies and benefits from the pilot level application, the benefits and realised impacts are summarised and the stakeholders and related authorities are communicated with and the insights and obstacles shared in order to have a betterment and well informed report for decision making generated in step 4.

Environmental synergy effects

One of the positive effects realised through the execution of this work was the reduction of CO2-emissions by combining UNITED and FINO3 maintenance trips. This reduced the number of individual trips required and allowed for an economic as well as environmental (in terms of CO2 reduction) benefit. An abridged version of the potential synergies and benefits identified through the increase in activities, namely the introduction of seaweed and mollusc aquaculture. As we delve into the potential synergies and benefits arising from our increased activities, specifically the introduction of seaweed and mollusc aquaculture, we uncover several key advantages.

Firstly, the aquaculture facilities themselves emerged as vital contributors to the ecosystem. They functioned as crucial fish nurseries and feeding habitats, potentially leading to an increase in fish abundance within the surrounding area. This surge in fish population, however, attracted the attention of natural predators such as seals and harbour porpoises, introducing a complex interplay within the ecosystem. Additionally, the mooring equipment used, particularly anchor stones, played a dual role, serving as artificial reefs. Their rarity as hard structures led to intriguing discussions regarding the benefits they brought and potential alterations to the existing ecosystem. Furthermore, the aquaculture activities had a notable impact on water quality. Algae and mussel cultivation, characterized by their low-trophic filter-feeding and nutrient-absorbing capabilities, proved to be effective in mitigating eutrophication issues stemming from various sources, including agriculture and industry. It is worth noting that the success of these activities hinged on their ability to harmonize with the ecosystem's carrying capacity, ensuring that they did not disrupt the nutrient requirements of naturally occurring species. In instances where this balance was maintained, the scaling of such operations beyond a pilot scale, as seen through the small scale applications, is expected to lead to a reduction in excess nutrients was a significant boon to water quality. Lastly, the spirit of close exchange and cooperation among the UNITED pilots within the aquaculture network yielded a remarkable reduction in the overall consumption of materials. This cooperative manner of working allowed for the sourcing of source anchors, weights, nets, and other essential equipment in used or refurbished conditions, significantly reducing the demand for new raw materials. Moreover, the collaboration facilitated the shift of near-shore activities to offshore conditions, further diminishing the need for newly fabricated elements and the associated raw material and energy consumption in production processes.

The multi-use offshore aquaculture systems offered environmental advantages, as supported by the results of the German Pilot in the UNITED project. One notable benefit was the capacity to promote marine biodiversity by effectively creating artificial reefs and substrates and additional feeding grounds. The overall impacts of such must be considered in the context of changing local ecology and ecosystem dynamics, and while there is an increase in biodiversity, the shifts caused by introducing species which would not necessarily be in this zone in a naturally occurring system taken under advisement and critically evaluated. Furthermore, these aquaculture structures, particularly when cultivating mussels and seaweed, play a pivotal role in environmental and food chain influences. While these low-trophic species require no external feeding or fertilizers, effectively eliminating the risk of nutrient pollution, and in some cases removing excess nutrients which have come from land-based sources, they are an external influence and when implemented at scale and density can have impacts on local and mid field ecological processes. Mussels, when deployed in large-scale systems, contribute to wave and current reduction, which, in turn, aids other offshore operations like seaweed farming, but do change the natural dynamics of the local area. They also enhance water clarity, creating a conducive environment for seaweed growth which is a synergy between the two activities taking place at scale alongside one another. The symbiotic relationship between seaweed and shellfish is noteworthy, as seaweed photosynthesis balances the oxygen consumption of shellfish, thereby maintaining oxygen levels in the surrounding water. Moreover, multi-use offshore aquaculture systems exhibit space efficiency, optimizing the utilization of marine areas. This efficiency opens up opportunities for conservation efforts or sustainable tourism initiatives. By incorporating aquaculture within wind farms, these systems effectively mitigate harmful sea-floor activities such as bottom-trawling, ultimately preserving marine ecosystems by excluding the potential for these other, often damaging activities to take place; in essence making an exclusionary zone which is more readily adhered to. Additionally, the shared use of vessels within these systems contributes to a reduction in boat trips and associated carbon emissions, aligning with sustainability goals. These aquaculture structures also serve as shelter and feeding areas for fish, thereby potentially enhancing the overall biodiversity, however the influence must be better studied to understand if these structures attract organisms already present in the area and as a refuge from fishing or indeed act as a catalyst for increasing numbers. The degree to which such activities change the local biodiversity and ecosystem functionality is critical to ensure that such potential benefits are not used as greenwashing and the introduction of shifts in local ecology results in detrimental impacts on the system. The rapid growth potential of seaweed and shellfish, without the need for external inputs, can be seen as a sustainable source of food for human populations. Furthermore, these species play a crucial role in mitigating the effects of eutrophication, leading to improved water quality, a fact acknowledged by various official maritime and environmental bodies. Therefore, there are a number well-documented environmental impacts which can be seen as advantageous, including biodiversity conservation, water quality enhancement, and space optimization, however these need to be considered in a holistic manner addressing the scaled impact on marine ecosystems. These benefits, substantiated by both pilot projects and scientific research, underscore the potential of these systems to address environmental challenges sustainably while meeting the diverse demands for food, energy, and tourism.

The importance of collecting environmental data to assess the impact of multi-use on the environment was also a key element in the execution and final assessment of the work. This assessment was crucial to understand any potential negative impacts before scaling up the project and to inform mitigation measures. Our environmental data collection efforts included the deployment of data-retrieving buoys and sensors on the net and seabed. Additionally, we gathered weather and environmental data from the FINO 3 platforms and conducted a specialized environmental monitoring collection focusing on harbour porpoise activities. Importantly, no significant detrimental impacts were measured or attributed to the multi-use system established at FINO3. The collected data was documented in various deliverables and made accessible through the HiSea platform for other researchers or commercial entities to reference and use in further developments. In conclusion, the work not only resulted in the reduction of CO2 emissions through the consolidation of maintenance trips but also revealed a multitude of benefits associated with the expansion of our activities, particularly the introduction of seaweed and mollusc aquaculture. These findings underscore the importance of sustainable practices and collaborative efforts in the realm of aquaculture, where economic and environmental gains go hand in hand.

Economic synergy effect

Close collaboration with the FINO3 team yielded several economic synergy effects within the German Pilot. These advantages were realized through a series of coordinated actions. The consolidation of flights to FINO3 emerged as a cost-effective strategy, especially in the face of escalating energy costs. This approach involved combining various tasks, encompassing general FINO3 maintenance activities such as corrosion protection work and server maintenance, alongside the transportation of UNITED spare parts, including server equipment, cables, and cameras. Additionally, it extended to the installation of UNITED landers, which involved connecting power and server equipment, as well as the sea cable. Moreover, to further optimize cost-efficiency, material transport onshore was systematically combined whenever feasible. This encompassed the transportation of harvested materials and the conveyance of items essential for maintenance. These materials were shuttled between the operational harbour in Cuxhaven and the FuE office in Kiel, benefiting both the FINO and UNITED teams. In retrospect, the coordinated efforts and synergistic measures undertaken in collaboration with the FINO3 team proved instrumental in maintaining manageable costs, particularly in light of the rising energy costs. This strategic approach exemplified the commitment to cost-effective operations and resource optimization within the project. Should such activities be scaled, a barrier to doing so is the need for optimum siting of aquaculture activities, these can often overlap with the existing stock of wind turbine parks or those already planned or envisioned through the green energy transformation initiatives across Europe. Many of these sites, and competition for space from other sections such as maritime traffic and fishing area, results in a need for sharing space and combining activities where possible, otherwise, as many of the European member states have saturated maritime space with various competing interests. Therefore, through the combination of activities, in general, this results in a larger potential spatial coverage of such activities which could not otherwise be realised.

Social synergy effects

The outreach efforts undertaken by the German Pilot team have resulted in several social synergy effects, with implications that extend to future multi-use projects, acceptance, and interest within the general public. Online workshops, including topics such as Safety & Logistics and Technology Transfer, have played an important role in raising the interest of both the attending audiences and external experts. These workshops not only generated attention for the project but also brought forth valuable input from external experts, enriching the German Pilot's insights and contributing to the broader goals of the UNITED project. The complex nature of tasks within the German Pilot has also sparked interest in educational settings, particularly in school projects. A notable collaboration has been initiated between the German Pilot team and a local Club of Rome school, yielding mutual benefits. Students are provided with the opportunity to engage in hands-on scientific practices related to a this highly relevant and quickly topic of multi-use in the marine sector. The FuE team also gained fresh perspectives and insights into potential enhancements for algae cultivation at the nearshore site, encompassing aspects such as grow-out substrates, seeding techniques, and yield optimization. Furthermore, engagements with politicians and key stakeholders have uncovered additional social synergies. These discussions with policy makers have laid the groundwork for key outcomes, including the potential for job creation within the aquaculture sector, to be realised within German waters. Additionally, there is an ongoing exploration to restructure the maritime spatial plan in order to elevate the concept of multi-use to a higher level, reflecting a commitment to optimizing resource allocation and foster sustainable practices in the aquatic environment. While these are not the result of only the German pilots activities, the progress shown, data generated, and body of evidence produced through the execution of the pilot's activities has garnered additional interest from the authorities with whom they have worked and also aided in furthering multi-use in German, which has a great need for proof-of-concept applications and data supporting the benefits and feasibility of these activities.

Optimization of scheduling

Scheduling within the context of our offshore endeavours involves a comprehensive consideration of the myriad needs and requirements of the various parties engaged in installation, operation, and maintenance activities. For offshore projects, particularly in the challenging offshore environment of the German pilot, weather conditions are often a determinant factor. Weather conditions hold high significance in scheduling efforts, as many offshore activities can only proceed safely when wave heights remain below the 1-meter threshold, a difficult condition to realise in offshore waters. Consequently, careful planning and monitoring of the weather conditions was required, drawing insights from diverse sources, including Windfinder, Danish weather reports, and data from the FINO3 research platform. A continuous assessment of these weather reports was conducted, enhanced with input from experienced offshore experts who analysed the data to discern the most favourable windows for installations. Effective coordination with vessel companies played a pivotal role in properly scheduling operational visit. This coordination encompassed direct and ongoing communication regarding vessel availability and installation procedures. Commencing with initial project presentations, this communication evolved into daily interactions conducted through various channels, including online meetings, phone calls, and email exchanges. To streamline operations and minimize offshore working time and mitigate unsuccessful trips, the practice of pre-assembly proved to be essential in making the most use of time on site as possible. Certain components of the systems were assembled onshore, a strategy that not only ensures accurate installation but also reduces the risk of errors from mistakes made in a time squeezed and dynamic environment. Predicted periods of adverse weather conditions are utilized to conduct equipment testing nearshore, where the nearshore conditions are most sever, so as to best mimic the more extreme offshore conditions and provide a more realistic testing ground which is closer to shore and has fewer risks involved. These periods of downtime offer invaluable opportunities to gather data and accumulate experience, contributing to our overall project knowledge. In the realm of scheduling tools, Excel was used for data tracking and predicting time windows until the development of a shared data platform. Within these tools, we highlighted critical events, especially concerning seaweed installation, to ensure their prioritization and successful execution. Throughout the UNITED project, essential lessons related to scheduling have been learnt, including using the advanced HiSea data platform with weather and storm condition predictions alongside monitored data. The schedules are influenced by biological cycles, water temperatures, and equipment delivery timelines. Early licensing, transparent partner communication, personalized planning approaches, and alignment of seedling preparation with weather conditions all emerge as critical factors. Furthermore, it is acknowledged that coordination between the nearshore and offshore sites was critical, with particular challenges noted in terms of accessibility at the nearshore KMF site.

Optimizations of operations

In the pursuit of executing a successful multi-use offshore pilot, careful preparation, collaboration, and flexible scheduling proved to be key elements for success. A notable example of the need for adaptability arose during the seeding of seaweed, where the survival of young seedlings was jeopardized by extended storage in the Cuxhaven harbour due to unfavourable weather conditions. This experience prompted a refinement of the seeding process, resulting in a number of improvements to the process. Firstly, efficient application of seedlings onto a rolled net, coupled with the use of wet blankets to maintain moisture was instituted in order to ensure survival if adverse conditions rose and delays were realised in deployment. The adoption of moist sheets, as opposed to seawater spraying, for twine seeding helped survival and quality of deployment. The installation of the mussel system also benefitted from a series of strategic measures such as regular communication and ongoing meetings with stakeholders to ensure clarity and alignment of timing on deliveries and requirements in the deployment process. A steadfast commitment to safety protocols and the efficient utilization of time at sea made for a better use of financial resources and small windows of opportunity in the field. An adaptation to site-specific requirements as they emerged, facilitating a responsive approach to overcome challenges on the spot allowed for overcoming last minute and unexpected issues. In our pursuit of operational optimization, the German pilot employed several tools and methodologies such as the creation of comprehensive installation manuals served as a foundation for discussions during meetings and as a definitive guide for executing operations, ensuring that tasks were clearly defined and potential misunderstandings were minimized. Also, the facilitation of multiple user workshops and online meetings, with the possibility of daily interactions if necessary, fostered close collaboration among all involved parties. These sessions allowed for thorough discussions of each operation, including decisions such as the selection of an appropriate vessel. A meticulous delineation of operations was conducted during in-person meetings, serving as user workshops held directly at the harbour, vessel, or pre-assembled system. These workshops served multiple purposes, including feasibility assessments, identification of potential challenges, hands-on experience, and the testing of various components and procedures.

Lessons Learnt

In retrospect, our experience during this project has yielded valuable lessons that underscore the importance of careful planning and adaptability in offshore operations. These lessons serve as a guide for future endeavours in similar situations. When considering the reliability of weather forecasts, one crucial lesson gleaned is the inherent uncertainty in weather forecasts. While these forecasts are essential for planning, they should be treated as predictions rather than absolutes. For instance, a situation was encountered where the forecast indicated a maximum significant wave height of 1 meter. However, upon reaching the FINO3 site, personnel were met with actual significant wave heights of approximately 1.5 meters, pushing the limits of safe operations and therefore not allowing for the required activities not to be executed. While a difference of .5 meters may seem small, due to safety thresholds and H&S requirements, this can lead to incurred costs of travel and preparation which do not result in the work being executed. This experience emphasized the wisdom of setting more conservative limits for operations, allowing for a small buffer to accommodate the unpredictability of prevailing conditions. Relying solely on the predicted limits can prove costly and frustrating, as starting an operation at the edge of the forecasted limit may necessitate a last-minute cancellation due to safety concerns.

Additionally the validation of methods and ideas for installation is another significant lesson relates to the need for hands-on verification of installation procedures. While ideas for new installation steps are valuable, they must undergo practical validation in the harbour, on the vessel, or within pre-assembled systems. Relying solely on theoretical additions to the installation manual can lead to unforeseen challenges and complications in the field. Therefore, the maximisation of onshore preparations if another critical takeaway is the importance of prioritizing onshore preparations. Every possible step that can be accomplished onshore should be completed before venturing offshore. This approach minimizes the time spent in offshore conditions and, in turn, reduces potential risks. Efficient onshore preparations proved to be a crucial factor in the overall success and safety of our operations. In conclusion, the lessons we've learned from this project underscore the need for adaptability, cautious planning, and hands-on verification in offshore operations. These insights will undoubtedly inform our future endeavours, ensuring smoother and safer project executions.

Optimizations of maintenance

In the pursuit of operational efficiency and effectiveness, certain challenges were encountered during maintenance activities, primarily stemming from the protracted permission procedure and the unpredictable impact of weather delays. However, several strategies were implemented to maximize the use of available resources and streamline our maintenance efforts. One notable approach was the identification and utilization of synergies whenever feasible, particularly in addressing equipment malfunctions. To minimize disruptions and conserve resources, we adopted a proactive approach. During scheduled maintenance trips, we took the opportunity to address malfunctioning equipment. For instance, a malfunctioning webcam was promptly attended to during these planned visits. This strategy allowed us to rectify issues without the need for dedicated trips, ensuring optimal resource allocation. Through implementing collaborative monitoring and communications, an effective monitoring and communication regiment was developed which played a pivotal role in optimizing repair processes. Through collaborative efforts, a streamlined system for monitoring various aspects of our equipment and systems was established. This approach facilitated swift responses to emergent issues, such as the drift of a buoy. By leveraging timely communication and cooperation among team members, we minimized downtime and repair times, ultimately enhancing the efficiency of our maintenance operations.

In retrospect, these optimization strategies not only helped navigate the challenges posed by the extended permission procedures and weather delays but also underscored the importance of proactive planning and collaboration in ensuring the continued reliability of our equipment and systems. These lessons learned will continue to inform our approach to maintenance activities in future projects.

Technical assessment and validation

Costs

The feasibility study for the German pilot (Geissler et al. 2018) examined costs associated with large-scale multi-use offshore aquaculture systems. It covered infrastructure, equipment, operations, maintenance, and revenue projections to ensure economic viability.

Avoided damages or loss

The integrated system, including aquaculture and monitoring instruments, underwent extensive validation. Simulations from external companies and the University of Ghent analysed design and performance. Physical tests, real-world deployments, and continuous monitoring provided insights into system efficiency, mussel and algae growth patterns, and marine ecosystem interactions.

Uncertainty

The German multi-use pilot highlighted uncertainties transferable to all pilots:

- Environmental impacts need further study to ensure sustainability.
- A standardized regulatory framework is crucial.
- Public perception and trust-building are essential for acceptance.

Robustness

The German offshore aquaculture systems showed resilience in adverse conditions, with the mussel and algae systems enduring winter storms and rough seas in the open ocean. The achievement of offshore-grown algae and mussels from the German pilot project in May 2023 further validates the viability and resilience of these systems. The successful cultivation of these organisms in the open ocean demonstrates the potential for large-scale production and commercial viability.

Flexibility

These systems combine environmental benefits with efficient marine space use. Their modular nature allows adaptability, scalability, and continuous improvements, balancing economic productivity with environmental conservation.

Policy cohesion

While multi-use in wind farm zones varies among EU member states, the German solution requires evaluation for broader application. Current plans don't address sea multi-use, leading to uncertainties, especially regarding wind farm decommissioning. These un-resolved issues pose financial feasibility challenges for projects within wind farms. All stakeholders in the pilot project have obtained relevant insurances to cover all aspects. However, insuring loss of aquaculture products, such as mussels, at a reasonable cost is not feasible. Therefore, when conducting financial feasibility studies, the potential loss of mussels should be taken into consideration.

2.1.4. Step 4: Decision-making

As the application of multi-use in the German case, as with all of the seaweed and shellfish applications, was on a pilot scale, the feasibility and applicability of the designs at scale are considered and presented in the finalisation of the work carried out. This information is shared with the permitting authorities and decision makers in order to increase the body of evidence on the suitability of such application at off-shore locations as well as the success or limitation of the applied designs.

At the culmination of the UNITED project, the results obtained and success made in the deployment of the pilot test site have been aggregated and summarised for the relevant authorities. At the current standing, from the work carried out under the UNITED project, no scaled or commercial application are yet envisioned, however, the preliminary results from the deployment of pilot level seaweed and mollusc mariculture has been positively received and is adding to the body of examples which underpins the success of such application and approaches as well as methods and proven solutions which can be utilised in future upscaling and commercial deployments. As the pilot has focused on proof of concept, this step in the Assessment framework did not have an extensive or iterative nature, however, the key data on installation, operations, designs, and collaboration potentials between the wind and aquaculture sector has been effectively communicated through reports and dissemination through presentations and discussions with the relevant authorities. The results of such can already be seen as positive as the successor project of UNITED, ULTFARMS, has already realised a more positive receptions given the results that have come from the UNTIED project.

2.1.5. Step 5: Audit of predictions and optimisation measures

Within the UNITED Deliverable 8.4, an extensive assessment of the TRL levels and assessment methodologies is undertaken. The key and relevant highlights are reproduced here in a summarised way in order to provide a succinct overview of the assessment framework procedures regarding each of the pilots.

The German pilot's overarching objective was to establish an open aquaculture system capable of simultaneously nurturing both mussels and algae. As it was strategically positioned in a dynamic offshore setting approximately 80 kilometers north of Helgoland in shared proximity with the Windpark DanTysc, certain components of the system were already in commercial use, demonstrating their high level of technological readiness, classified as Technology Readiness Level 9 (TRL 9). However, it's worth noting that the overall system, despite individual components being at TRL 9, was assessed to be at TRL 5 after undergoing a series of comprehensive tests to evaluate its baseline state (for further details, refer to Deliverable 3.2, as detailed in Araujo et al., 2021). TRL 5 represents a significant milestone in technology development, involving the integration of components and their validation within an environment closely resembling the intended application. In essence, our system had progressed to an advanced prototype stage.

For the work executed within UNITED, an ambitious goal to attain TRL 7 by the conclusion of the project was set and to achieve this milestone, we identified several action points were required for the combined functioning of the system parts and an overall integration of the aquaculture system into the existing elements. Firstly, demonstrating multi-use functionality was a pivotal goal; to demonstrate the effectiveness of multi-use capabilities while minimizing implementation and operational risks at reasonable costs. The system's functionality and its ability to perform as intended in a relevant environment were of paramount importance. In this regard, the project successfully established a functional mussel cultivation and algae cultivation system. Algae harvesting was achieved in May 2023, followed by mussel harvesting in June 2023, albeit in sample quantities. Nevertheless, this accomplishment validated the system's functionality in its prototype stage. Furthermore, costs were reduced by employing readily available parts commonly used in offshore operations. Additionally, transportation logistics, such as boat and helicopter trips, were optimized by combining maintenance visits to both the aquaculture site and the FINO 3 Platform during the same trips. This approach not only reduced costs but also minimized the carbon footprint associated with our operations.

The importance of finding solutions for governance, encompassing the acquisition of necessary permissions and licenses that conformed to legal standards was also of great importance. It was essential to address regulatory and administrative aspects to ensure compliance with applicable laws and regulations. Consequently, we obtained the required permits and established connections with relevant legal authorities. Comprehensive reports were submitted, and the knowledge gleaned was recorded in various deliverables, serving as valuable resources for future multi-use stakeholders. As noted as the primary results of step 4 in this deliverable.

Simplifying the decision-making process for potential investors was another key objective in order to enhance investor engagement and aid in developing sales strategies. To achieve this, we provided specialized and reliable financing models and business plans, thereby reducing overall economic risks. Additionally, we developed effective marketing strategies to ensure a stable turnover of products, particularly mussels and seaweed. We established a well-defined go-to-market strategy for these products, deepening connections with regional mussel sellers such as Kiel-er Meeresfarm, conducting market assessments, and forging partnerships with resellers to maximize the potential for the utilization of algae and mussels. In reaching a higher TRL level, the standardization of infrastructure was critical for the professional operation of our multi-use project. This encompassed training certified offshore staff, optimizing logistics scheduling, transportation, and maintenance work, and reducing energy consumption. Our efforts in this regard included staff training at the nearshore site, hosting online training workshops, and close collaboration with ship crews responsible for maintaining the pilot during its operation. This standardisation took advantage of the technological advancements that the pilot project showcased. The technology applied in a fully exposed offshore location, subject to harsh conditions was a novel element in the execution of the work and application of system elements. This necessitated the adjustment and optimization of technical components typically used in onshore or near-shore settings for specific offshore conditions. The successful demonstration of the technology in the actual environment was evident as the mussel system remained operational throughout the entire production season, enduring multiple heavy weather events. Similarly, the algae system thrived during the offshore production period from winter to spring/early summer until the harvesting season.

In conclusion, TRL of 7 was successfully achieved for the mussel and algae aquaculture multi-use system at the German pilot site (pilot1) at FINO3. This accomplishment is a testament to the dedication and collaborative efforts of our team, paving the way for future advancements in multi-use systems and sustainable offshore practices.

2.2. Dutch Pilot

2.2.1. Step 1: Description of baseline and identification of impacts

Technical baseline

In our evaluation of the technology readiness level (TRL) within the context of single and multi-use applications, we initiated our assessment at a baseline TRL of 5-6 for the seaweed and floating solar applications applied in the UNITED project. This initial entry point evaluation was conducted through a self-assessment process, guided by the definitions provided in the European Commission (EC) guidelines on TRL using the rubrics and definitions provided. The Dutch pilot project encompassed seaweed aquaculture and floating solar energy generation facilities situated within two separate plots, specifically Plot 2 and Plot 3, at the North Sea Farmers test site off the coast of Den Haag in the Netherlands. At the conclusion of the UNTIED project, both activities have reached a TRL of 7 for their respective components: the seaweed Pilot and the solar farm Pilot. This signifies the successful demonstration of system prototypes in an operational environment, representing a significant advancement in technology development and the systems applied in the two use cases. However, it is important to clarify that the TRL level of the solar farm component is not directly relevant to the United project's primary objectives. The solar farm itself was not developed as part of the United project; instead, it was utilized solely to conduct relevant enabling research associated with multi-use installations, such as solar farms. Furthermore, it is worth noting that the seaweed prototype comprises various elements that hold a slightly lower TRL6. These components have undergone substantial development and validation, positioning them at a stage just prior to full-scale demonstration. In summary, the current assessment places the seaweed Pilot and the solar farm Pilot at TRL7, symbolizing the successful prototype demonstration in operational environments. This achievement reflects our commitment to advancing the technology readiness level within the context of multi-use applications while aligning with the project's overarching objectives. The future development of the systems applied within the UNITED project are envisioned to be tested and deployed within multi-use settings now that the individual components have been tested and validated in real world off-shore conditions, thereby lowering the risk and potential aversions of co-location and integration of these elements into other offshore activities.

Environmental baseline

This section provides the description of the location with regard to its environmental characteristics. It explains what species and habitats are present at the given site, and what are the non-living natural characteristics such as type of habitats, and what human activities are historically taking place in the relative proximity to the site. The description of the baseline environmental account in the pilot site of the Dutch pilot is mainly based on the Maritime Strategy for the Netherlands part of the North Sea 2012-2020 and the Environmental Impact Study of the Hollandse Kust (zuid) Wind Farm Sites III and IV (PONDERA Consult, 2016) (Netherlands Enterprise Agency, 2018). The study was conducted in 2016 by a consultancy PONDERA Consult on behalf of the Dutch Enterprise Agency. These wind farm sites are located approximately 5km from the UNITED pilot, and given the proximity the assumption is that these sites have the same environment as the Dutch pilot site. There have been no environ-mental studies to date referring specifically to the location of the Dutch pilot site. A full and detailed description can be found in the project deliverables pertaining to the environmental baselines and assessments. Within these a detailed analysis of the seabed, sea water, atmosphere and climate, fauna and flora, and a wide array of other important and determining factors for the environmental analysis and baseline can be found.

Identified Gaps

The environmental impact study conducted during the project highlighted several areas where our understanding of animal species and their behaviors in the offshore environment needs supplementation. Specifically, the study identified key knowledge gaps that require further investigation. Our knowledge of the distribution of seabirds in both space and time at sea remains incomplete. Similarly, there is a lack of understanding regarding the duration and spatial extent of bird migration, largely due to challenging habitat accessibility and the absence of standardized counting methods. While various migration routes in the North Sea area have been indicated, quantitative data detailing the extent of these routes in relation to overall migration, as well as local densities in different North Sea areas, remain elusive. Knowledge gaps also persist regarding the presence of bats at sea and their behavior within wind farms, along with insufficient information on the number of collision casualties involving bats. Predicting the consequences of abiotic changes, particularly sediment alterations near wind farms, on benthic organisms is another area with significant gaps, as is understanding the effects of electromagnetic fields along cables. For marine mammals, several knowledge gaps exist, including their distribution, migration patterns, threshold values for Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS), and avoidance behaviors in response to underwater sound. While model calculations and threshold values derived from various studies predict the potential occurrence of avoidance, TTS, and PTS in marine mammals, further research is necessary. This includes field monitoring, additional laboratory research, and the continued development of models. Specific gaps in knowledge regarding fish pertain to the effects of wind farms on fish species, particularly the extent of changes in fish fauna over the long term due to fishery restrictions and the presence of hard substrates. Notably, the actual economic impact of tourist activities following the construction of visible wind farms has not been previously investigated in the Netherlands. Despite these knowledge gaps, informed decisions regarding wind farm sites are still possible. It is crucial to acknowledge the uncertainties that play a role in impact predictions within the decision-making process. The Environmental Impact Assessment (EIA) effectively provides an understanding of these uncertainties, playing a vital role in informing the decision-making process.

Scoping of impacts

Potential environmental impacts

The study by van den Burg SWK et al. (2020) identified key environmental risks associated with seaweed cultivation at offshore wind farms in the Dutch North Sea. These risks were determined through literature review and stakeholder consultation. The main risks include ecosystem change due to increased sedimentation, decreased primary production, effects on biodiversity (including invasive species and bioinvasions), impacts on animals (including birds, marine mammals, and bats), and pollution. Increased sedimentation is a noted risk of aquaculture, with fall-off seaweeds potentially leading to organic enrichment, which can become a food source for other species. The combined effect of wind turbine foundations and seaweed cultivation may exacerbate this sedimentation but could also result in rapid dilution of organic matter. The disturbance caused by wind turbines and seaweed growth may negatively affect primary production and impact the ecosystem, particularly in areas where seaweeds grow naturally. Competition for nutrients can also arise, although seaweed cultivation might benefit areas with nutrient surpluses by removing excess nutrients.

Seaweed cultivation poses risks to biodiversity, including the introduction of invasive species and bio-invasions, with offshore wind turbines potentially serving as stepping stones for these species. The combined presence of wind turbines and seaweed farms can multiply the risk of species translocation and further distribution of exotic species, amplifying potential impacts on habitat and species composition. Offshore wind farms and seaweed cultivation can impact flora and fauna by providing new settlement areas and creating sheltered zones due to activity restrictions like fishing. While these areas can stimulate local biodiversity, they also pose risks such as increased bird and bat mortality due to collisions with turbines, and potential barrier effects for marine mammals. The presence of seaweed farms might further attract avian predators, compounding these risks. Pollution is another significant risk, with seaweeds potentially accumulating heavy metals and other pollutants, rendering them unsafe for food and feed applications. The substances used to protect offshore wind energy infrastructure against corrosion and biofouling might pollute the seaweed, and vice versa, seaweed farms might increase corrosion and biofouling of these structures. To predict the impacts of the multi-use project, eight Ecosystem Components (EC) were chosen: Fish and Cephalopods, Mammals, Birds, Pelagic Water Column, Sublittoral Sediment, Infralittoral Rocks and other hard substrates, Littoral Rock and other hard substrates, and Circalittoral Rock and other hard substrates.

Potential social impacts

The Dutch pilot embarked on an examination of its social impacts during a working group meeting held in person as part of the consortium's General Assembly in February 2023. Subsequently, the pilot undertook the task of completing and validating the results in collaboration with its community of practice throughout the spring of 2023. The preliminary findings from this assessment revealed several notable impacts. These included the potential for job creation as the activities undertaken within the UNITED project generated new employment opportunities across various levels, including direct roles within the pilot activities and those within the supply chain. This was realised at only a smaller pilot level scaled and such opportunities are expected to scale accordingly with the development and roll-out of commercially viable developments. This development presented significant economic prospects for both the fisheries sector and the local community, contributing to increased local wealth. Additionally, energy security is envisioned as the integration of solar energy with wind energy contributed to a more balanced and secure energy production system, enhancing energy security within the region and increasing the total green energy production portfolio potential of the region. Furthermore, food security was enhanced and the carbon footprint therefrom decreased as the multi-use approach led to an increase in food security and the production of nutritious and healthy food resources, notably from lower trophic levels. Also, as space is always a premium, particularly in developed countries and particularly in light of conservation targets and goals such as the European 30% by 2030 objectives. Therefore the increase in land use efficiency is notable; by combining multiple activities, the project successfully reduced the occupation of land space, thereby avoiding the utilization of nature-sensitive areas, including those designated under Natura 2000.

Political stability is also considered as the project's multi-use approach had the added benefit of alleviating political pressures by bolstering local energy and food production security. This reduced dependency on other countries for energy and food stuffs, thereby enhancing political stability. Also, by leveraging the same electricity grid for both solar and wind energy, maximizing its capacity utilization would reduce the need for additional constructions. This efficiency translated into cost savings that could be directed towards other projects, further enhancing the acceptability of the multi-use option when compared to single-use wind farms. The development of offshore activities also contributed to an increase in education and awareness about offshore environments and the sea, fostering a more informed and engaged community. However, it is worth noting that the presence of the wind farm restricted the navigation of fishers and sailors through the area, which led to reduced acceptance of the project among these stakeholders. Overall, the preliminary assessment of social impacts underscored the project's potential to generate positive economic, environmental, and educational outcomes, while also highlighting the challenges posed by restrictions on navigation within the wind farm area.

2.2.2. Step 2: Prediction of impacts

Given the above as the baseline conditions within the site where the Dutch Pilot was deployed offshore, the potential impacts for the defined projects scenarios found in section 1.4 was undertaken. Following step 2 of the UAF. This includes the prediction of what impacts the installation and operation of the seaweed mariculture would have within the area, alongside that of deployed floating solar potential, and denoting if the degree of speculated impact would have a meaningful or significant effect on the area. Given the degree of impact, mitigation or enhancement measures for design and operation can be proposed in order to achieve a best-case scenario for the operations to be deployed and the potential negative or altering effects of said activities to be minimised.

Environmental impacts prediction

Impact on the ecosystem components were predicted for a baseline scenario, one where the area is not dedicated to a specific activity, for a single use scenario, in which the activities happen simultaneously but independently from each other, and a multi-use scenario in which offshore wind energy production, offshore solar energy production and low-trophic aquaculture of seaweed are combined. For the single use and multi-use scenarios, impacts were predicted for the three stages of a project: installation, operation and decommissioning.

The method used to predict environmental impact of each scenario is an Environmental Impact Risk Assessment method developed by Wageningen University and Research a partner of the project. A 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. For the Dutch pilot, as seen in Figure 3, highest reduction in Impact Risk (ca 35% for fish and mammals) is achieved in the installation phase, most by sharing the infield and export cables. The decommissioning phase shows however very little impact reduction (< 1%). During the operational phase reduction in IR is estimated to reach a maximum of ca 14% for fish and mammals.

In addition to the prediction of environmental impact risk reduction, the potential for the Dutch pilot to build positive environmental synergies was predicted based on expert judgment and literature review. They are the following: biodiversity increase in the area of the project, commercial fish species increase with potential spill-over in the surroundings of the project, nutrient cycling thanks to shellfish filter-feeding with a removal of nutrient through harvesting and the deposit of nutrient and organic matter on the seafloor, carbon sequestration over the long term if the seafloor remains undisturbed, sustainable and local food production, increased social acceptance of OWF and LTA, more space freed for conservation elsewhere in Dutch waters, a reduction of conflict over space-use thanks to the combination of two space-demanding activities.

In the Dutch case, big impact risk reductions between single use and multi-use scenarios can be expected during the installation and operation stages. The difference with the previously presented German case is the combination of floating solar panels with offshore wind production, that present strong synergies during the installation of infrastructures, such as cables, for both activities. Since the installation of energy-producing activities is a very impactful step of that sector, a big impact reduction by having them coupled is an important result and incentive to implement this type of multi-use.

In addition, based on the environmental synergies that can be expected from the Dutch scenario, the following European environmental goals and strategies can be expected to benefit from it:

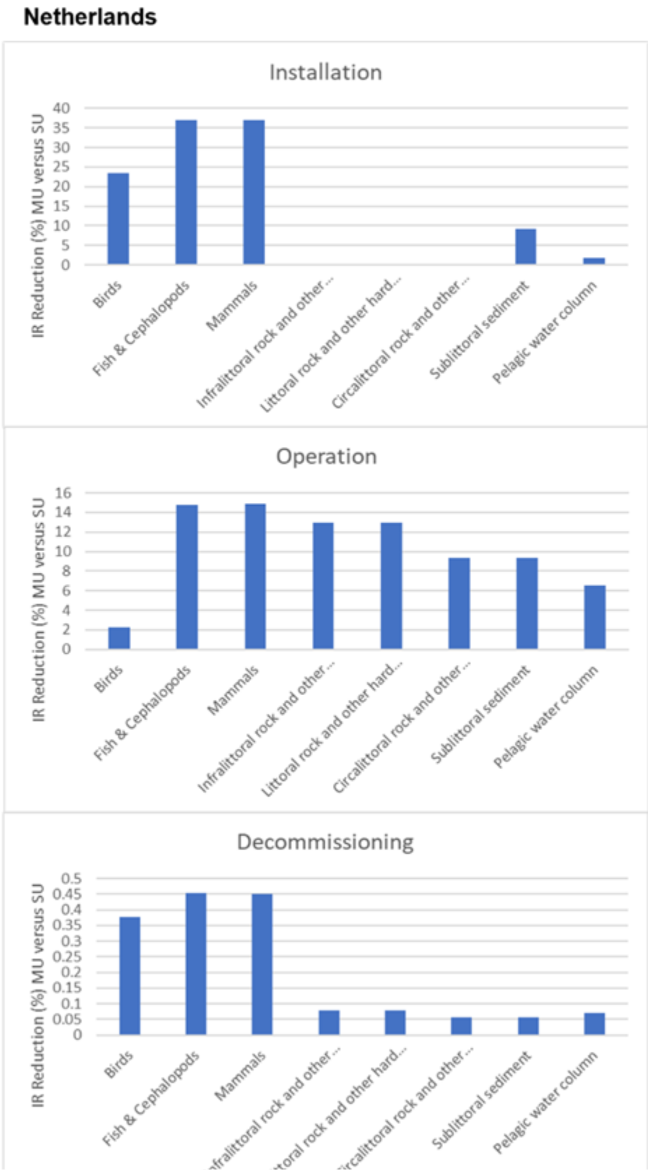

Figure 2 - Reduction (%) in Impact Risk for each Ecosystem Component by activities in multi-use design as compared to single-use design for the Dutch pilot (right) for all three phases.

- Achievement of a Good Environmental Status (GES) as required by the Marine Strategy Framework Directive (MSFD) through Descriptor 1 'Biodiversity is maintained', Descriptor 3 'Population of commmercial fish species is healthy', Descriptor 5 'Eutrophication is minimized', and Descriptor 6 'The seafloor integrity ensures functioning of the ecosystem'.
- Achievement of the Green Deal by supporting the following goals: increased blue carbon sequestration (Sustainable Carbon Cycles), sustainable food production (Farm-to-Fork Strategy and Sustainable Blue Economy), renewable energy production, Biodiversity Goals by allowing for more space for conservation, the implementation of the Maritime Spatial Planning Directive thanks to the reduction of conflict over space-use.

For more detail on the assessment of meaningfulness of the predicted environmental impact of the Dutch pilot, refer to Deliverable 8.3 'Report on environmental assessment and validation' (Van Gerven et al., 2023b). Additionally we had identified that, within the framework of the European-funded project, Intelligent Management System for Integrated Multi-trophic Aquaculture (IMPAQT), an Integrated Multi-Trophic Aquaculture (IMTA) model was meticulously crafted to furnish spatially explicit insights into the intricate interplay between multi-trophic aquaculture practices and the surrounding environment. Spatial Implementation in the NSF and Future Potential Farming Areas was executed as a study and extended its scope to evaluate the spatial implementation of IMTA within the NSF and its applicability in prospective farming areas, particularly those designated for planned wind-farm installations. The results of this comprehensive analysis yielded valuable insights namely in terms of increased production. The study identified a notable research gap. No prior studies had explored the combined impacts of offshore solar panels with seaweed aquaculture and/or offshore wind energy, either at the project site or in comparable environments. This gap in understanding was identified as an area warranting further investigation within the scope of the project, further corroborated by the analysis of UNITED.

Social impacts

The Dutch pilot and the working group of partners assessed the level of acceptability of the social impacts identified in Step 1. The level of acceptability for most of the identified impacts is high, meaning that most of them are expected to have a positive and desirable outcome. This includes new jobs, energy and food security, production of healthy food, reduction of occupied space, relief of political stress due to increased energy and food security, efficiency of using the same electricity grid for both solar and wind energy, education and awareness about the offshore and the sea. However, a negative impact is identified in the inability of fishers and sailor to navigate through the windfarm, which decreases its acceptance among those stakeholders. A better design of the pilot could mitigate this impact.

2.2.3. Step 3: Assessment reporting

After executing the pilot activities and monitoring of the realised synergies and benefits from the pilot level application, the benefits and realised impacts are summarised and the stakeholders and related authorities are communicated with and the insights and obstacles shared in order to have a betterment and well informed report for decision making generated in step 4.

Environmental synergy effects

Throughout the course of the Dutch pilot project, several noteworthy synergistic opportunities emerged, enhancing the overall efficiency and effectiveness of the endeavor. These synergies encompassed various aspects of project implementation and collaboration including unified vessel utilization, a prominent synergy involved the utilization of identical vessel types for offshore operations. Whenever feasible, efforts were made to consolidate multiple activities into a single offshore trip, optimizing resource allocation and reducing operational complexities. Another key synergy revolved around the adoption of consistent anchor types for offshore installations. Collaboration extended to the sharing of insights and experiences related to anchor procurement, installation processes, and the associated calculations. This in turn reduced the negative impacts on the local area by enhancing the effectiveness of anchoring systems and additionally allowing for critical measurement elements to be shared across activities rather than installing redundant elements. In a similar vein, the knowledge exchange on monitoring equipment allow the project participants to actively engage in knowledge sharing regarding monitoring equipment and the dissemination of acquired data. This collaborative approach facilitated a more comprehensive understanding of the project's environmental impact and performance metrics as well as increased the total amount and breadth of information collected. The potential integration of solar panels, while not yet implemented in this particular pilot, has been explored in so far as the concept of utilizing floating solar panels to power monitoring equipment for the seaweed farm was considered as a potential avenue for further synergies. Beyond the synergies encountered within the Offshore Test Site pilot, additional synergies emerged from the integration of seaweed cultivation and floating solar panels with offshore wind energy. These synergies held promise on economic and social fronts. A few illustrative examples of the potential benefits included wind turbine protection; wind turbines served as protective barriers, shielding the seaweed and floating solar farms from potential vessel intrusions, thus safeguarding the infrastructure. Also the potential for electrical integration as the co-location of the floating solar farm allowed for shared electrical connections with the wind turbines, leading to enhanced overall energy efficiency and a reduction in additional infrastructure (and associated environmental impacts and costs). Additionally, the enhancement of biodiversity was realised from cultivating seaweed within a wind farm environment. The potential to boost biodiversity within the wind farm, aligning with the imperative for nature-based solutions within such installations was a key synergistic factor realised in the scoping for future integration of activities within wind energy parks. Moreover, the incorporation of multiple types of multi-use practices, if executed thoughtfully, helped prevent the formation of monocultures and mitigated potential adverse effects. These synergistic approaches underscored the value of collaboration and integration in optimizing the multi-use potential of the project, with an eye toward enhancing both economic outcomes and environmental sustainability.

Economic synergy effects

The Dutch pilot project foresaw a substantial realm of economic synergies that held the promise of enhancing overall project viability and efficiency. While an in-depth exploration of these economic synergies was slated for discussion and assessment in Work Package 3 (WP3) of the project, a preliminary overview sheds light on the potential economic advantages. These include the significant economic synergy arising from the integration of floating solar panels within the project. By sharing the same offshore electricity cable infrastructure, the project aimed to optimize the utilization of this critical resource. This collaborative approach not only reduced redundancy but also bolstered the overall efficiency of the cable network. The implications of this synergy on cost savings and resource optimization were anticipated to be a focal point of discussion. The cultivation of seaweed within the project presented another avenue for economic synergies. Specifically, the project explored the possibility of combining monitoring trips with the offshore crew vessels responsible for the wind farm operations. This collaborative endeavor held the potential to streamline operational logistics and reduce the associated costs. While these economic synergies held great promise, the comprehensive exploration of their impact and potential benefits was reserved for the subsequent stages when these activities would be integrated into an existing or planned wind park. The insights and assessments generated were anticipated to provide a detailed understanding of how these synergies could contribute to the economic sustainability of the Dutch pilot initiative.

Social synergy effects

The Dutch pilot project brought to light several pivotal social synergies, each contributing to the overall success of the multi-use approach. These synergies were instrumental in fostering a more sustainable coexistence within the North Sea environment. One of the foremost social synergies entailed the efficient utilization of space within the North Sea. By identifying core synergies and generating an optimal integration plan for various activities in a multi-use framework, the project minimized the spatial footprint required for each individual activity. This strategic space-saving approach ensured that a larger portion of the North Sea remained available for other stakeholders and uses, thus promoting equitable access and utilization of this valuable resource. The collaborative integration of activities held the potential to engender increased social acceptance and awareness within the community. The multi-use model not only showcased the feasibility of coexistence but also demonstrated a commitment to sustainable practices. This, in turn, fostered a more favourable perception of the project among stakeholders and the broader public. Furthering such co-creation and design and recognizing the strength in unified visions and ownership of design, the project emphasized the importance of collective outreach and communication efforts. By joining forces, the pilot initiatives were able to amplify their messaging and engage in shared communication activities. This collaborative approach ensured that the project's objectives and benefits were effectively conveyed to a wider audience, enhancing the overall impact and reach of the initiatives. These social synergies not only optimized resource utilization and promoted environmental sustainability but also underscored the importance of community engagement and awareness-building in the successful implementation of multi-use practices within the North Sea.

Optimization of scheduling

Throughout the Dutch pilot project, a dedicated focus on optimizations was paramount to ensure safety and effective coordination among the diverse users of the Offshore Test Site (OTS). This commitment to improvement aimed to foster better communication, streamline operations, and enhance overall project efficiency. Primarily the largest optimisation for scheduling between the various pilot partners came from direct and frequent communication on needs, planning, operations, and scheduling of activities. In this manner, though the different activities were focusing on activity specific goals, when opportunities or needs arose in terms of checking on equipment, taking advantage of trips to sea, or any other potential benefit from having additional persons on site or in the area, these needs were swiftly and promptly communicated. The implementation of a permit-to-work system was instrumental in regulating and authorizing offshore activities. This system helped ensure that all operations were conducted safely and in compliance with established protocols. A central registration system was introduced to meticulously record and track all offshore activities at the OTS. This comprehensive database provided valuable insights into project progress and resource allocation. Efforts were underway to refine and expand the OTS Safety Management System, further fortifying safety protocols and procedures.

The project's experience with scheduling optimization revealed that combining activities between co-located initiatives posed inherent challenges. Each party involved sought to maximize the use of vessels for their specific operations, making coordination complex. However, the project emphasized that effective communication was pivotal to achieving scheduling optimization. Clear and frequent communication among stakeholders emerged as the key to overcoming scheduling hurdles and ensuring the successful execution of offshore activities.

Optimization of operations

In the pursuit of operational optimization within the Dutch pilot project, the focus primarily revolved around the collaborative synergy of efforts, as previously highlighted. However, the intricacies of offshore activities often introduced challenges in achieving seamless coordination. A notable approach that emerged as effective involved the sequential combination of larger maintenance and installation activities utilizing the same vessel. In practice, this meant that Party A would utilize the vessel on a specific day (X), followed by Party B on the subsequent day (X+1). This sequential arrangement enabled the sharing of mobilization and demobilization costs, thereby promoting cost efficiency. Additionally, it allowed for a buffer in case of delays experienced by either party. This approach was particularly feasible for substantial activities that extended beyond a single day. While the sequential combination worked well for larger endeavors, it presented challenges for smaller, single-day activities. These activities were typically meticulously planned and executed by a single party, making it more challenging to integrate them into the collaborative optimization framework.

Looking ahead, the Dutch pilot project recognized the potential for further optimizations, especially as the scale of multi-use operations expanded and similarities between different multi-use operations became more apparent. One notable avenue for optimization lay in the shared use of certain resources, such as anchoring systems. In scenarios where multiple multi-use operations employed similar anchoring infrastructure, it was conceivable that a single marine contractor could undertake activities like cleaning the anchoring infrastructure for both a seaweed farm and a solar farm. This approach held the promise of not only reducing mobilization and demobilization costs, as previously mentioned but also optimizing the cleaning operation itself. With a single contractor responsible for both operations, efficiencies could be realized, resulting in faster and more cost-effective cleaning procedures for the farm operators. These considerations underscored the ongoing commitment of the Dutch pilot project to explore and implement optimization strategies that would enhance the overall effectiveness and sustainability of multi-use initiatives in offshore environments.

Optimization of Maintenance

The TRL-levels of the pilot systems are still quite low. Therefore, optimization of maintenance is not yet relevant. The pilots are in prototype stage and as a consequence, the maintenance involved is primarily reactive maintenance and emergency response (contrary to planned maintenance). By its nature, this type of maintenance cannot be planned, hence is difficult to optimize. In general, it can be stated that **the design should improve such that the only maintenance required would be preventative/planned maintenance**. This level of maturity has not yet been achieved in the Dutch pilot."

Technological assessment and validation

Costs

The Dutch pilot installations, maintenance and decommissioning for the separate elements as described above have been carried out within the budget of UNITED. Challenges with increased prices of materials, fuel and equipment have been overcome. Within work package 3 an assessment is done on the business cases for multi-use. In the Netherlands, both for seaweed cultivation (in 2023) and for floating solar (in 2025) the next steps are made to install the systems within a wind farm. The first years are expected to be an innovation phase, which will be followed by the commercial phase. With support of subsidy innovation projects, investors and subsidy programs for the gap between the costs and revenues in the beginning of the development, it is expected that both multi-use sectors will become commercially interesting.

Avoided Damages or Loss

The North Sea is one of the most challenging offshore environments for offshore installations. Therefore, it is important to think carefully about a convenient approach in advance. For the Dutch pilot this was done in three stages: 1) in the design; 2) in remote monitoring; 3) in the operation & maintenance. For the design it was important to use element in the installation that can handle the rough North Sea conditions. In addition, the installations of the seaweed cultivation system and the floating solar were designed in such a way that there is no single point of failure. During the operational phase, both the environmental conditions (wave, wind, etc.) were closely monitored as well as the installations themselves. Think of GPS, load sensors and cameras. In case there would be an incident where for example part the structure would come loose, this could be measured by a shift in the GPS coordinates, a drop in the load measured by the load sensor or visually on the camera. By doing this, it was immediately known via this remote monitoring data on an online dashboard when something was not right. This allowed immediate action to be taken when necessary and avoid further damages or loss.

Finally, during the operational phase regularly inspections took place to check the installations to avoid damages or loss in an early stage. Next, after severe storms, additional inspection trips were made. By using this approach, the installations survive several storms: “Ciara”, “Dennis” and “Bella” in 2020 with wind speeds up to 62 knots and waves up to 9-10 m; “Evert” in 2021 and “Corrie”, “Dudley”, “Eunice” and “Franklin” in 2022 with Eunice being in the top 5 heaviest storms of the past 52 years.

Uncertainty

As mentioned for the German pilot, these uncertainties can be discussed for the Dutch pilot as well. And of course, offshore operations in general come with uncertainties on the operation as it is quite weather de-pendent. This holds for all the pilots as well. Pilots like the ones in UNITED help to tackle these uncertainties together and learn from one another.

Robustness

The Dutch pilot installations with seaweed cultivation and floating solar have demonstrated a great robust-ness in the rough weather conditions of the North Sea. The installations have survived the storms mentioned in paragraph 4.2.3, with is a huge achievement. This offers great prospects for both sectors: successful offshore seaweed cultivation and floating solar panels. The robustness of the installations during the whole lifetime (~25 years) needs to be further studied during the coming years with long-term pilots. With these studies, for example the effect of corrosion on the strength of the systems can be investigated.

Flexibility

The flexibility of the multi-use activities in the Dutch pilot can be discussed in different ways. First of all, the structures themselves: both the seaweed cultivation installation as well as the floating solar installation need to be flexible to resist the rough offshore conditions. Especially the currents and high waves. The seaweed installation is completely flexible with flexible anchor chains, flexible floaters and a flexible net structure. The whole installation can move in the water with the waves and currents. The float-ing solar installation consist of flexible anchor chains and rigid floaters with solar panels. These floaters are connected to each other in a flexible way. Thereby the whole installation can move along with the waves. Next, within the operation flexibility is necessary as well. Due to the offshore location, the work needs to be planned when the weather conditions are acceptable to go offshore. Therefore, the staff and organisation need to be flexible to adjust the activities based on the weather when needed. Last, it is interesting to mention that the market for seaweed cultivation is flexible as well. When seaweed is produced, there are several markets that can buy the seaweed for their products. Amongst others: food, feed, bio-stimulants and biomaterials. When one market is not going well, the seaweed farmer can sell his seaweed to another market. This makes the seaweed industry flexible at the market side as well.

Policy Cohesion

The Dutch pilot is located at the “North Sea Farmers” Offshore Test Site. For this location, the “North Sea Farmers” have a permit for testing innovations in the field of seaweed cultivation and other forms of multi-use. Therefore, there was no need for an addition permit for the activities within the Dutch pilot. They took place within the current permit of “North Sea Farmers”. For the offshore wind farms (OWF) in the Netherlands, the current policy is that every new OWF needs to open up for multi-use. The “old” first windfarms are closed for other activities, but with Borssele as a start and followed by Hollandse Kust Zuid in October 2023, in every new windfarm multi-use will be possible. The construction phase of a OWF first needs to be finished. Then the operational phase starts. At that moment, the OWF “opens up” for multi-use, including an area passport. This area passport is a map of the

OWF with indicated at which location, what type of multi-use can take place. This approach is part of the North Sea Agreement. Together with all the partners involved in the North Sea Agreement and new users, like for example the seaweed industry and floating solar parties, there is a North Sea Consultation every month to discuss the implementation of the North Sea Agreement. Within connected working group "multi-use" this policy is discussed as well. In addition, one of the latest tenders for a new OWF included floating solar as part of the tender criteria. There are two OWF coming up including one with an installation of Oceans of Energy. For the seaweed cultivation, a permit application for the first farm is submitted for installation Q3-Q4 2023. Deliverables D6.1 and D6.2 include additional elements on the policy cohesion in the Netherlands.

2.2.4. Step 4: Decision-making

The Dutch pilot and its partners have actively shared their work with relevant authorities through participation in the Dutch North Sea Community of Practice and collaboration with Dutch ministries on expert panels and sector advocacy groups. They have secured funding and permission for future larger-scale projects, notably developing North Sea Farm 1, a commercial-scale seaweed farm off the Dutch coast with significant funding from Amazon. Project partner North Sea Farmers (NSF), a non-profit organization for the European seaweed industry, has collaborated with pioneering start-ups, research institutes, NGOs, and other stakeholders to facilitate this deployment within an offshore wind park. The work conducted within the UNITED project and similar initiatives provides a robust body of evidence supporting the execution of such projects. These successful activities demonstrate the potential for upscaling and deployment, offering reference points for industry actors, including the insurance sector, to gather sufficient evidence and information to support these activities.

2.2.5. Step 5: Audit of predictions and optimisation measures

Within the UNITED Deliverable 8.4, an extensive assessment of the TRL levels and assessment methodologies is undertaken. The key and relevant highlights are reproduced here in a summarised way in order to provide a succinct overview of the assessment framework procedures regarding each of the pilots.

Progress in the TRL (Technology Readiness Level) was achieved in both product development and the industrial process throughout the UNITED project. Initially, the seaweed cultivation system was assessed at TRL 5-6 using the TRL self-assessment tool (BRIDGE2HE, 2022). However, significant advancements occurred during the project. Two seaweed cultivation systems were enhanced, installed, and rigorously tested in a real offshore environment, encompassing all operational procedures related to offshore testing. These successful tests served as the foundation for the initial steps toward establishing a commercial seaweed farm within a wind farm, scheduled for installation in October 2023 in the Netherlands, known as North Sea Farm #1. As a result, the seaweed cultivation system progressed to TRL 7-8.

Additionally, the industrial process of seeding and harvesting seaweed saw significant development. Initially reliant on manual labour for seeding and harvesting on the cultivation nets, the UNITED project facilitated a transition towards automation. A machine capable of performing both seeding and harvesting processes was developed and tested as part of pilot tests. This development elevated the industrial process from TRL 4 to TRL 6. These tests covered all aspects of the operation, including on-land seeding and both on-land and on-deck vessel harvesting in the harbour of Scheveningen. The floating solar installation made the step from TRL 5 towards TRL 6 during the UNITED project, where a functional version of the solar farm installation was installed and tested in a realistic offshore environment. This made it possible to draw conclusions on the technical and operational capabilities of the product. These insights from the UNITED project will be used for a follow-up solar farm by Oceans of Energy within the Dutch windfarm Hollandse Kust Noord (operated by CrossWind), where the solar farm will be connected, installed and operated from 2025 onwards.[1]

[1] https://oceansofenergy.blue/2023/04/24/crosswind-and-oceans-of-energy-add-offshore-solar-to-the-hkn-offshore-wind-park/

2.3. Belgian Pilot

2.3.1. Step 1: Description of baseline and identification of impacts

Technical Baseline

In assessing the technology readiness levels (TRL) of the Belgian pilot within the UNITED project, we observed distinct phases of development and transition. For the elements implements, the various components in a single use in the operational phase as commercial wind park (TRL9) are for multi-use in pre-operational phase near-shore demonstrated in the intended environment (TRL5-6).

During the pre-operational phase nearshore, the Belgian pilot demonstrated a TRL of 5. This classification aligns with the general definition outlined in the Horizon2020 program, which describes TRL 5 as technology that has been validated and demonstrated in a relevant environment, particularly in the case of key enabling technologies. At this stage, the pilot focused on the cultivation and restoration of flat oysters, as well as seaweed cultivation, in the nearshore site of Westdiep, situated 5 kilometers off the coast of Nieuwpoort. Comprehensive testing encompassed various elements, including anchors, longlines, frames, nets, shackles, chains, buoys, and logistical operations such as installation, service, maintenance trips, and harvesting procedures.

The insights gained from these tests played a crucial role in designing and adapting the aquaculture system intended for the operational phase offshore at the Belwind site, located approximately 50 kilometers off the coast of Ostend. In this phase, off-the-shelf technical components, as used in the UNITED project, were acquired and combined, with necessary adjustments made to suit the specific environmental conditions at the final location. Some components, such as the longlines serving as backbones for the systems and buoys for marking the test site in the Belgian pilot, consisted of off-the-shelf materials. These materials had previously undergone testing in similar applications but in different locations, representing simulated environments. Installation activities were executed in collaboration with a specialized company with a track record of installing anchors and longlines in various locations worldwide, including for commercial purposes. Therefore, in accordance with the "Top Level Questions for Determining Anticipated TRL5" outlined by the US Department of Energy (USDOE) in 2009, which inquire whether "the bench-scale equipment/process testing has been demonstrated in a relevant environment," the Belgian pilot can affirmatively respond with a "yes." The USDOE's table of relevant aspects for TRL 5-6, as applicable to the Belgian pilot, was consulted to ensure alignment with the project's objectives and progress. The table of the USDOE (2009) was used to check for all relevant aspects of TRL5-6 that are applicable in the case of the Belgian pilot (for the Table: see higher with the German pilot in section 2.1).

Environmental baseline

The water depth in the area of the Parkwind wind farms is generally between 15 (at the sand banks) and 37 m (at the gullies). Bligh Bank and surrounding gullies, which may most probably be the best location for the offshore pilot, are part of a system of tidal banks and belong to the Hinderbanks. Both banks and gullies are characterised by the presence of mobile sand dunes. Bligh Bank has a steep eastern side and a more gentle-sloping western side. Sand is the predominant sediment here, with a grain size of 300-350 µm and a maximum of only 1 % clay. Since the installation of the wind turbines and the accompanied erosion protection layers, hard substrates have been introduced in the otherwise sandy area. The hard substrates are colonised by a number of pioneer species, but the climax community is mainly characterised by the presence of the tube-dwelling amphipod and blue mussels. A full and detailed description can be found in the project deliverables pertaining to the environmental baselines and assessments. Within these a detailed analysis of the seabed, sea water, atmosphere and climate, fauna and flora, and a wide array of other important and determining factors for the environmental analysis and baseline can be found.

Identified gaps

Within the context of this assessment, several knowledge gaps require attention. First, there is a lack of data concerning bats' presence and behavior at sea, as well as the extent of bat collisions within wind farms. Additionally, the offshore areas of the Belgian Part of the North Sea (BPNS) have yet to be studied for the presence of parasites, bacteria, or viruses, which holds relevance in terms of biosecurity considerations. Biological interactions within these ecosystems present another area of uncertainty; changes in food webs due to the predation of phyto- and zooplankton by oysters, as well as the attraction of species to aquaculture installations and modifications in benthic habitats, could potentially lead to shifts in biological interactions. However, the scale of these impacts in relation to wind turbines and scour protection remains unknown. The impact of oysters' (pseudo) feces production in the pilot location is not well-understood, although the strong currents in the area may facilitate rapid dilution of these substances. Lastly, the effects of fouling fauna predation on oyster larvae, impacting both aquaculture installations and wind turbines, remain uncertain. These dynamics could potentially affect the success of oyster restoration efforts.

Scoping of impacts

Potential environmental impacts

The Belgian pilot project encompasses the restoration of flat oyster reefs within the Belgian Part of the North Sea (BPNS). These oyster reefs, once prevalent in the North Sea, had dwindled due to overfishing in the early 20th century. The restoration of this habitat, classified under Habitat 1170 in the EU Habitat Directive as biogenic reefs, is a central environmental objective of the project. Furthermore, the combination of aquaculture practices involving flat oysters and the cultivation of sugar kelp seaweed represents a form of extractive aquaculture. These two species potentially impact each other's food resources, and their growth can influence the concentration of waste products in the surrounding marine environment. Offshore wind farms can serve as potential attractors for bird species like the common gull, European herring gull, greater and lesser black-backed gull, black-legged kittiwake, and great cormorant. Similarly, various fish species are drawn to wind turbine foundations due to the artificial reef effect. Additionally, the introduction of aquaculture within an offshore wind farm introduces additional hard substrates such as anchors, buoys, and aquaculture lines. These structural additions are expected to have effects on the hard substrate fauna. Additionally, the presence of aquaculture species may introduce associated pathogens into the ecosystem. The heightened activity at the multi-use pilot site, driven by wind turbine and aquaculture maintenance, harvesting activities, and scientific research, increases the risk of accidents such as collisions and potential spills of substances like oil and chemicals as well as an overall increase in maritime traffic, human presence, and human interventions. This is not inherently a negative consequence as the proposed multi-use approach may impact the generation of new scientific knowledge and could have implications for the tourism sector.

Potential social impacts

In order to explore and identify a hierarchy of social impacts to be addressed in the scaling and deployment of such combined systems in Belgian waters, the Belgian Pilot carried out a one-day workshop specifically organized to discuss the socioeconomics of multiuse with local stakeholders at De Cierk Ostende (Belgium). The workshop gathered 23 participants, from diverse fields and institutions including research institutes, aquaculture, fisheries, and food sectors, commercial actors from general blue economy to wind, aquaculture, and engineering sectors, public organisation and also tourism offices and companies.

Four scenarios were discussed and the relevance and potential impacts discussed with these stakeholder groups, those considered were: combining windfarms with seaweed culture; combining windfarms with oyster aquaculture; combining windfarms with oysters' restoration; and combining all three activities in the windfarms. In the context of the windfarm and seaweed scenario, various social impacts were identified, each assessed for its level of importance. High importance was attributed to impacts related to research and knowledge building, job creation, sustainable food production, concerns about unfair competition (especially between small and large players and at both national and international levels), and the optimization of offshore wind farms (OWF). Additionally, the development of a new culinary experience, maintenance costs, and job-related risks were considered to have medium importance. On the other hand, the impact on nature and biodiversity restoration was deemed to have low importance within this scenario. In the second scenario involving windfarm and oyster culture, certain social impacts were also assessed for their significance. High importance was attached to the fact that local oysters are considered a luxury product, the potential negative perception of wind parks due to increased offshore activities and boat traffic, and the associated increase in costs for both windfarm and aquaculture operations within wind parks. Impacts of medium importance included the sense of pride in sourcing food locally and maintaining a short supply chain, the potential for cultural heritage to attract tourism, and concerns about the impact of aquaculture activities on small fisheries. Other impacts, such as the revalorization of old/traditional activities, the resurgence of historical jobs/crafts, increased visibility of offshore activities at sea, heightened activities in the harbor, and the potential negative public perception of aquaculture, were considered to have low importance within this scenario.

In the context of the third scenario involving windfarms and oyster reef restoration, several impacts were identified, each assessed for its level of importance. Impacts of high importance included the potential for increased social acceptance of wind parks due to their combination with nature restoration efforts, enhanced resilience to climate change through oyster reef restoration, concerns about the introduction of harmful materials into the environment stemming from structural aspects, maintenance, decommissioning, and uncertainties regarding the allocation of additional costs (whether public or private funding). When integrating all activities, the idealised scenario sought by the project, impacts of high importance included the reduction of conflicts of use, particularly the availability of sailing areas when activities like aquaculture occur within windfarms, and the development of knowledge through the integration of activities that could yield international benefits. This was identified as the highest importance with those discussed in the dual use scenarios above had a trickle down effects and were included in the ranking but could not compete with the importance and benefits of increase utility of the marine zone and co-ownership of applications at sea.

2.3.2. Step 2: Prediction of impacts

The predictions of impacts was not confined to the pilot level deployment of the project but the considerations of impacts for the defined projects scenarios found in section 1.4 were undertaken. In this case, the Belgian scenario considers wind production, oyster and seaweed aquaculture, and oyster restoration activities following step 2 of the UAF. This includes the prediction of what impacts the installation and operation of the seaweed mariculture would have within the area, alongside that of culturing and restoring oyster beds, and denoting if the degree of speculated impact would have a meaningful or significant effect on the area. Given the degree of impact, mitigation or enhancement measures for design and operation can be proposed in order to achieve a best-case scenario for the operations to be deployed and the potential negative or altering effects of said activities to be minimised.

Environmental Impact prediction

Impact on the ecosystem components were predicted for a baseline scenario, one where the area is not dedicated to a specific activity, for a single use scenario, in which the activities happen simultaneously but independently from each other, and a multi-use scenario in which offshore wind production, low-trophic aquaculture of oysters and seaweed, and oyster reefs restoration are combined. For the single use and multi-use scenarios, impacts were predicted for the three stages of a project: installation, operation and decommissioning. The method used to predict environmental impact of each scenario is an Environmental Impact Risk Assessment method developed by Wageningen University and Research a partner of the project. A 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. For the Belgian multi-use scenario, the highest reduction in impact risk (ca 40% for fish and mammals) is achieved in the installation phase. This reduction is related to the pre-installation activities. Also, for

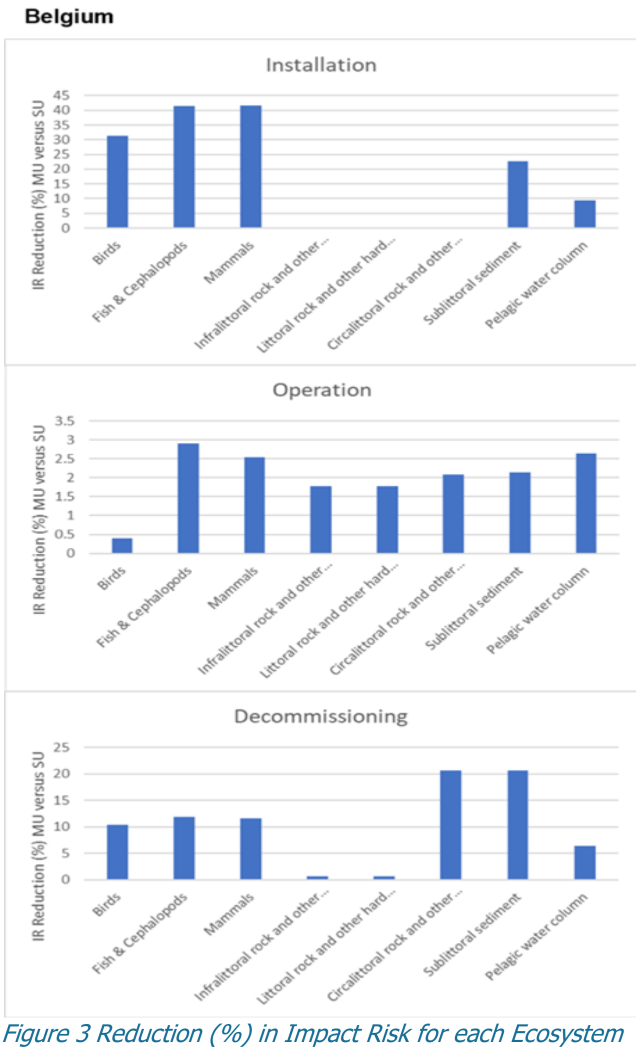

Figure 3 Reduction (%) in Impact Risk for each Ecosystem Component by activities in multi-use design as compared to single-use design for the Belgian pilot for all three phases.

decommissioning considerable reduction in impact risk is shown, with the highest reduction (ca 20%) for circalittoral rock and other hard substrate and sublittoral sediment. The operational phase shows considerably less reduction compared to installation, with nearly 3% at most for fish. This reduction is an annual value (3% reduction each year, not only on one occasion), hence it represents an important relative change. In addition to the prediction of environmental impact risk reduction, the potential for the Belgian pilot to build positive environmental synergies was predicted based on expert judgment and literature review. They are the following: oyster reef restoration, biodiversity increase in the area of the project, commercial fish species increase with potential spill-over in the surroundings of the project, nutrient cycling thanks to shellfish filter-feeding with a removal of nutrient through harvesting and the deposit of nutrient and organic matter on the seafloor, carbon sequestration over the long term if the seafloor remains undisturbed, sustainable and local food production, increased social acceptance of OWF and LTA, more space freed for conservation elsewhere in Belgian waters, a reduction of conflict over space-use thanks to the combination of two space-demanding activities.

The largest potential impact reduction in the Belgian multi-use scenario is expected during the installation and decommissioning phases. As the installation and decommissioning of offshore wind farms often have the highest and most pronounced impact on the marine environment, these reductions are notable and meaningful. The Belgian pilot is the only pilot of UNITED that investigated the potential to add active habitat restoration to a multi-use project. For that purpose, actions were taken to restore biogenic reefs of European flat oysters. These formations are historically naturally occurring but have been mostly destroyed or purposely removed by and for human activities (Lengkeek et al., 2017). In addition, scour protections offer ready-to-use habitat, made of natural rocks, to be colonized by European flat oysters and on which a reef can develop. Also, the strategic integration with wind farms offers safeguarding measures for these reefs against potential fishing activities. Oyster reefs offer an array of ecosystem services, including the enhancement of water quality, heightened fish production, improved sediment stability, and potentially carbon sequestration. Additionally, they serve as vital habitats for a multitude of fish and invertebrate species, encompassing roles as breeding grounds, feeding areas, and sanctuaries.

For more detail on the assessment of meaningfulness of the predicted environmental impact of the Belgian pilot, refer to Deliverable 8.3 'Report on environmental assessment and validation' (Van Gerven et al., 2023b).

Social impacts

Following the scoping for potential social impacts, the workshop participants assessed the acceptability level of each impact, categorizing them as either low (indicating a negative impact and an undesirable outcome), high (indicating a positive impact and a desirable outcome), or ambiguous (indicating a mixture of both positive and negative impacts). In the scenario involving the coexistence of a wind farm and seaweed culture, several impacts garnered high acceptability. These impacts are viewed as positive and desirable outcomes for the project. They include nature and biodiversity restoration, the development of a novel culinary experience, research and knowledge building, job creation, sustainable food production, and the optimization of offshore wind farm operations. Conversely, there are impacts with low acceptability, signifying negative and undesirable outcomes. These include the associated maintenance costs, job-related risks, and concerns regarding unfair competition, particularly between small and large players, as well as on both national and international levels. In the wind farm and oyster aquaculture scenario, several outcomes were deemed highly acceptable. These positive impacts include the revitalization of old/traditional activities, enhanced visibility of offshore activities, increased harbour activities, instilling pride in local food production, and the creation of cultural heritage that can attract tourism. However, several impacts exhibited low acceptability due to their negative and undesirable nature. These impacts encompass the potential negative public perception of aquaculture, adverse effects on small fisheries, increased boat traffic within wind parks, elevated costs for both wind farm and aquaculture activities, and the risk of portraying a negative image of the wind park.

An impact with ambiguous acceptability, pertaining to the transformation of local oysters into luxury products. This impact can be perceived in both positive and negative lights. On one hand, it could be seen as positive, acknowledging that local oyster culture is a costly endeavour deserving suitable compensation. On the other hand, it may be regarded as negative, particularly if it results in limited accessibility or high pricing, rendering it unaffordable for certain segments of the population. When considering a fully integrates multi-use scenario of all three activities in the windfarm, most of the impacts are highly acceptable: attracting or developing new forms of tourism, increasing employment in several sectors, creating local new jobs with good working conditions, providing a new food source, reducing conflict of uses, and developing knowledge from the combination of activities. Some impacts with negative and undesired outcomes are privatising part of the sea, selling products at high prices, and lacking capacities to scale up the project.

2.3.3. Step 3: Assessment reporting

Environmental synergy effects

During the implementation of multi-use activities, environmental synergy effects were observed, enhancing operational efficiency and cost-effectiveness. These synergies included shared crew vessel usage, combined installation and sampling missions, and the utilization of shared scientific diving teams and vessels. Crew vessels were used not only for transporting personnel but also for visually monitoring buoys on longlines, ensuring their condition and adjusting as needed, thus reducing fuel consumption and promoting cost-efficiency. For seaweed and oyster activities, line and anchor installation missions were merged, optimizing resource allocation. Sampling missions initially designated for seaweed monitoring were also used for inspecting oyster longlines and cleaning structures during seaweed harvesting, minimizing trips and resource utilization. Scientific diving teams often used dedicated scientific vessels, such as RV Simon Stevin or the Belgica, sharing these vessels across tasks like aquaculture and wind farm maintenance, which resulted in significant fuel cost reductions and a smaller environmental footprint. Additional optimization potential exists through seasonal complementarity between oyster and seaweed activities, ensuring year-round utilization of vessels and technicians and limiting downtime. Oyster harvesting occurs mainly in the summer, while seaweed harvesting takes place in the winter. With ongoing wind park maintenance requirements throughout the year, resources can be efficiently utilized. In the future, oyster restorations may provide spats to colonize lines dedicated to oyster cultivation. This cyclic relationship between restoration and cultivation activities could further enhance the sustainability and productivity of multi-use initiatives.

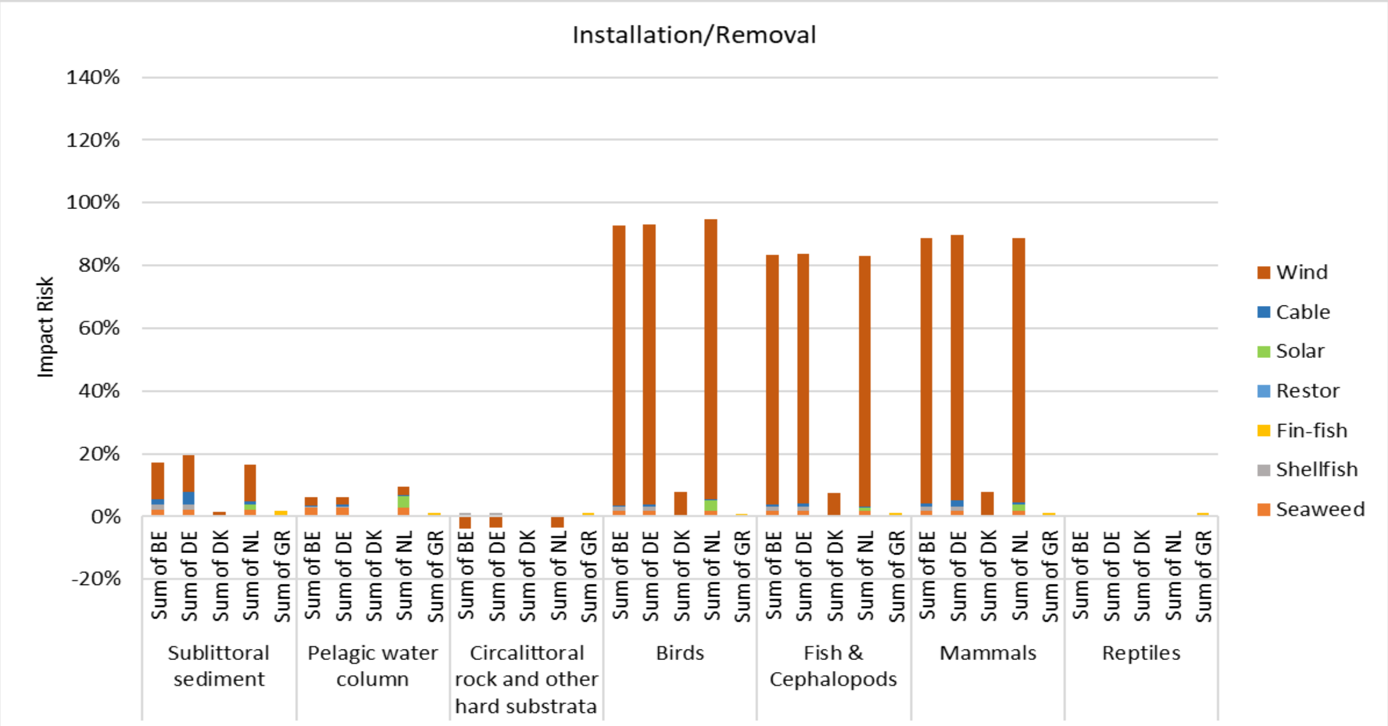

Figure 4 - Impact risks of the different summed activities in the Installation/removal phase. On the X-axis the summed pilots (against the axis) per Ecosystem Component (lower level). Be: Belgium; De: Germany (Deutschland); DK: Denmark; Nl: Netherlands; Gr: Greece. On the Y-axis the calculated Impact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

For the testing of European flat oyster reef restoration as part of the multifaceted offshore wind farm utilization, specialized oyster cages containing mature adult European flat oysters (Ostrea edulis) were strategically deployed. These cages were supplemented with scour protection stones to encourage settlement. The primary goal was to promote the colonization of oyster offspring on the turbines and scour protection systems within the cages (selffertilization) or downstream installations. This effort aimed to revive flat oyster reefs, particularly focusing on the native Ostrea edulis species, which had significantly declined due to overfishing and disease outbreaks.

Integrating oyster reef restoration into a wind farm environment, alongside low-trophic aquaculture like oyster farming, provided dual benefits. The wind farm served as a protective barrier for the oysters by prohibiting bottom-trawling activities. Additionally, the restored oyster reefs had the potential to produce spat, which could naturally settle on the designated aquaculture lines for oyster cultivation. This natural settlement process enabled the use of non-invasive harvesting methods, aligning with the project's sustainability goals. Oyster cultivation in the area has shown potential positive impacts on restoration activities, particularly when scaled up. Oysters lost due to storms and dislodging can complement the hard substrates introduced in the reef restoration initiative. There is a synergistic effect where the colonies on the restorative reefs can supply naturally occurring spat to aid in seeding the cultivation efforts.

Across most ecosystem components considered, the windfarms have the strongest impact during the operational phase, as they also occupy the biggest surface area of all component considered. In the context of Mammals, Fish, and Cephalopods, the installation and removal of windfarms have a higher impact than the operational activities, which operations' impact is predominantly caused by 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). There are additionally positive, 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.

Economic synergy effects

In the realm of economic synergies, the primary cost-saving measure we have witnessed is the optimization of vessel time allocation, resulting in substantial reductions in operational expenses. In contemplating potential synergies for expanded scenarios and commercialisation, several opportunities emerge. The development of Premium Sustainable Products is one of note, though it has scored a potential negative impact or result in the social and societal facet of impacts. There is potential for the creation of distinctive, high-quality products bearing a multi-use designation. These could include seaweed harvested from wind farms or oysters cultivated within wind farm zones. These premium offerings could cater to environmentally-conscious consumers seeking sustainable options. Also, the expansion of multi-use activities opens doors to the development of novel economic sectors within Belgium. These prospects encompass a range of possibilities, such as the production of algae-based bioplastics, the emergence of Belgian sushi brands, the cultivation of Belgian oysters, and the formulation of cosmetic products using locally-sourced algae. These ventures have the potential to contribute to economic diversification and growth but require a diversification and expansion of the down-stream value chain and higher value products resulting from the growth and increase availability of fresh and high quality seaweed in within Belgium and nearby localities. Scoring highest on the relevance and importance is the integration of sustainable aquaculture with restoration endeavours within offshore wind farms, resulting in an overall increase of potential marine space to be used; substantial expanses of marine areas can be effectively utilized for various purposes. This utilization extends beyond aquaculture and wind energy production, offering opportunities for recreation, conservation efforts, and aligning with EU targets aimed at protecting marine ecosystems (e.g., the 2030 30% 10% targets). Due to the limited EEZ of Belgium in the North Sea, this is a boon to marine sectors and operators.

Social synergy effects

In contemplating potential synergies within an upscale scenario, several noteworthy opportunities arise. Integrating aquaculture activities within wind farms frees considerable space within the Belgian sector of the North Sea for alternative uses. This surplus space could accommodate various activities, including professional and recreational fishing, leisurely navigation, and sailing. The allocation of space often sparks conflict, as aquaculture projects tend to prefer nearshore areas due to easier maintenance and protection from the elements. The coexistence of aquaculture within wind farms could alleviate these space-use conflicts, benefiting the local population and fishermen. Additionally, the expansion of multi-use activities would necessitate the recruitment of additional personnel, including technicians, engineers, and marine technicians/biologists. These professionals would be essential for the year-round maintenance and monitoring of the multi-use project. Not only do employment prospects increase by the emergence of new, locally-sourced products offers opportunities to bolster tourism, a significant source of income and activity during the summer along the Belgian coast. These factors combined with a development of a community identity centered around local and sustainable seafood production can ensue. This provides a fresh source of local and sustainable protein, aligning with the region's sustainability objectives.

Additionally, the coast's overall attractiveness stands to benefit from the multi-use initiatives. Effective communication and heightened visibility regarding the Belgian coast and the North Sea can be anticipated. Increased job opportunities will attract an active population, fostering economic growth and community vitality. Residents of the region can take pride in living in an area where sustainability is genuinely prioritized. Witnessing innovation and the development of sustainable activities within wind farms reflects a commitment to environmentally responsible practices. This can underpin a shift as traditional activities often clash with conservation efforts, necessitating a transition to alternative practices. The ability to witness and be part of this transformative shift can instil a sense of pride and progress within the community as well as sharing ownership o the new manner of operation.

Optimization of scheduling

Several valuable lessons have emerged from our project's scheduling endeavours. These insights shed light on critical aspects to consider when planning and executing offshore activities, particularly when doing so at scale. The importance for the substantial demand for screw anchors in the current market, with rapid expansion in the offshore sector occurring and supply chain hurdles repeatedly arising. Smaller-scale projects with limited screw anchor requirements may garner less interest from subcontractors, making short-notice installations challenging. Deployments at scale and with larger contract demands may circumvent such issues. In a similar vein as this, a comprehensive evaluation of alternative subcontractors capable of various activities is key in effective scheduling and execution of activities, an overreliance on internal project partner estimates and capacities can result in overspending and knock-on delays. Such an approach helps identify areas of price variability within the quotations, such as vessel supply, procurement, and installation methods and timing.

Companies offering screw anchor installation services in Europe, especially those qualified for offshore work, are scarce. Consequently, mobilization and demobilization expenses can account for a substantial portion (up to 20%) of installation costs; this cost factor often arises due to procurement of far-off subcontractors. Again, when deploying activities at scale, due to a larger demand for longer period, such considerations are still valid, in terms of the limited supply of specialist versed in such applications. Also, intellectual property concerns may surface during the drafting phase causing delays, particularly in innovation projects and disseminating elements under development; to mitigate risks, these concerns should be identified and communicated in advance when collaborating with external entities is anticipated.

Particularly for combined and multi-functional or unique applications and requirements in multi-use applications, subcontractors can often lack vessels suitable for specific or combined activity offshore work, necessitating adjustments to accommodate a different type of vessel with which they lack prior experience. If such adjustments are not carefully considered, significant operational risks are knowingly introduced. To minimize risks, particularly when innovating offshore, a prudent approach involves thorough planning, evaluation, and, if necessary, near-shore testing of new techniques and equipment.

Optimization of operations

The operational phase of the Belgian pilot has yielded valuable lessons focused on optimizing project performance. These lessons are crucial for refining future operational efforts. A primary issue confronting the project was manual control of installation ropes. Introducing a quick-release system, for instance, proves to be significantly more efficient than manual disconnection of the bollard. Alternatively, employing Remotely Operated Vehicles (ROVs) for installation eliminates the need for installation ropes entirely, enhancing precision and accuracy. Cost-effectiveness should be a key consideration in the evaluation of these alternatives, particularly for scaled or scaling operations. It is essential to acknowledge that working with divers in offshore wind parks is subject to severe limitations, primarily reserved for specific purposes like environmental research and monitoring. When formulating research plans and budgeting, potential diving activities should be explicitly addressed, especially if anticipated at any project stage, including sampling, decommissioning, or handling incidents. Notably, operational ROVs serve as a costlier yet prevalent alternative for sampling in offshore wind parks. Furthermore, a growing number of wind farms adhere to a zero-diving operations policy, necessitating equipment designs capable of functioning without divers or alternative approaches. Nevertheless, certain activities, such as specific environmental monitoring or research tasks, may demand diving operations, which inherently entail risks and should be minimized whenever feasible. Although they are the most common current alternative, ROV operations incur a higher costs than diving, particularly for brief interventions. To mitigate potential budgetary challenges, it is advisable to allocate sufficient funds for these operations upfront or secure funding through insurance, particularly when incident-related ROV operations become necessary. In situations where a substantial number of structures require installation, an ROV-assisted approach may prove economically advantageous compared to scenarios necessitating only a few interventions.

Operational challenges related to structures located beyond the scour protection layer should also be considered. These are susceptible to sand coverage influenced by high current speeds. Additionally, the risk of sand dune migration is elevated in areas beyond this (slightly elevated) scour protection layer. To prevent such occurrences in the future, a more precise installation method should be implemented to ensure structures are placed atop the scour protection layer. The scouring phenomenon and migrating sand dunes pose a risk of burial or loss of structures. Continuous monitoring of these structures is imperative to detect signs necessitating intervention, thereby averting potential losses. However, underwater visibility challenges make it difficult to distinguish between installed structures during diving operations. To mitigate this issue, it is recommended enhanced labelling or identification measures or exploring the use of acoustic releases for specific steps in structure installation or retrieval may also offer a solution, potentially requiring structural modifications to accommodate this approach. These key operational insights provide essential guidance for optimizing future project applications, ensuring smoother execution and minimizing risks associated with offshore operations

2.3.4. Step 4: Decision-making

Upon the culmination of the UNITED project, a comprehensive summary of the results and achievements in deploying the pilot test site has been compiled and presented to the pertinent regulatory bodies. As of the current status, the activities undertaken within the UNITED project have not yet led to scaled or commercial applications. Nonetheless, the initial findings stemming from the pilot-level implementation of seaweed and bivalve mariculture, along with oyster reef restoration, have been favourably received. These outcomes contribute to the growing body of exemplars supporting the viability of such applications, methodologies, and proven solutions. These can serve as valuable assets for future application involving upscaling and commercial deployments. The Belgian pilot and their activities have been showcased at a number of conferences and blue cluster events, even winning a number of awards for integration, collaboration, and innovation in their approaches. This has placed them in a favourable position to showcase this approach and to become engaged in discussions with regional and national authorities as well as blue cluster groups in discussing the potential and requirements for such applications. Furthermore, a number of scientific publications and policy briefs have been developed in order to highlight the needs of such activities in terms of existing barriers to deployment and scaling.

Since the pilot primarily focused on establishing proof of concept, this particular phase within the Assessment framework did not involve extensive iterations or refinements. Nevertheless, crucial data pertaining to installation procedures, operational activities, design considerations, and collaboration opportunities between the wind energy and aquaculture sectors have been effectively communicated. This dissemination was accomplished through detailed reports and engagements in presentations and discussions with relevant regulatory authorities. The initial results of these efforts are already exhibiting positive indications, as evidenced by the favourable reception of the successor project, ULTFARMS and the continued deployment and further enhancement of the UNITED activities in a larger and more complex project, undertaken with the UNITED partners and an expanded group of Belgian entities.

2.3.5. Step 5: Audit of predictions and optimisation measures

The Belgian pilot innovation project developed a sustainable offshore aquaculture system within the Belwind offshore windfarm in the North Sea with key components including the installation of oyster restoration tables, a foundation for future expansion, and the cultivation of sugar kelp seaweed on commercially available nets, showcasing potential for large-scale seaweed farming. While full-scale oyster cultivation is pending, the project marks significant progress towards sustainable offshore aquaculture. In consideration of the Technology Readiness Level (TRL) matrix, the Belgian pilot project has made significant progress in showcasing the viability of the industrial process. The continuous operation of the pilot plant/unit during a relevant timeframe has been successfully demonstrated, starting from a TRL of 5 leading to a TRL of 7. Furthermore, the seaweed cultivation component has been operated continuously during the cultivation period moving towards TRL 8. Further validation is required to accomplish TRL 8 for reliable offshore cultivation and requires efficient low-cost monitoring strategies, even during harsh winter conditions. While the industrial process has reached its final form, it is important to note that further sampling methods, certifications and permits are required before the project can be ready for mass operation. These steps are essential for ensuring compliance with regulatory frameworks and upscaling the cultivation methods legally.

2.4. Danish Pilot

2.4.1. Step 1: Description of baseline and identification of impacts

Baseline TRL and transition

Offshore wind energy has reached a level of maturity classified as TRL9, exemplified by the operational success of the Middelgrunden Offshore Wind Farm. This wind farm has been consistently generating electricity, contributing approximately 3% of Copenhagen's total electricity production since its establishment in 2001. Its long-standing track record and sustained output demonstrate the maturity and reliability of offshore wind energy as a commercially viable source of electricity. Furthermore, when combined with tourism, this synergy can be classified as TRL6. The integration of wind energy and tourism has been tested and demonstrated in relevant environments, such as the provision of on-demand guided tours within the wind farm. These tours not only showcase the operational aspects of the wind farm but also offer visitors a unique and educational experience. The success of these initiatives has prompted plans for expansion, indicating the potential for further growth in the intersection of wind energy and tourism. As both of these activities were successfully operational prior to the onset of the UNITED project, enhancements to the synergies and increased capacity and efficiency were the targeted developments resulting form their participation and activities within the project. A full and detailed description can be found in the project deliverables pertaining to the environmental baselines and assessments. Within these a detailed analysis of the seabed, sea water, atmosphere and climate, fauna and flora, and a wide array of other important and determining factors for the environmental analysis and baseline can be found.

Environmental baseline

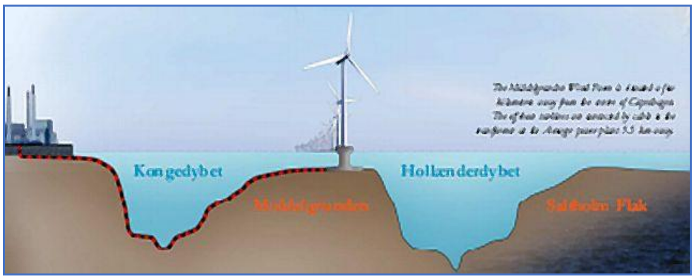

Figure 5 - The Middelgrunden Reef between the sailing rout to Copenhagen: Kongedybet 11-16 meter deep and the south/south sailing route Holænderdybet 19 meter deep

Middelgrunden, situated as a natural reef, falls within the depth range of up to 6 meters, as illustrated in Figure 5. Beneath the water's surface, the seabed composition varies, featuring sandy terrain in the southern region, limestone formations in the central area, and glacial deposits in the northern sector. This natural reef, with a history dating back approximately 7,500 years, owes its existence to the collapse of a post-glacial barrier in the Baltic Sea, an event visualized in Figure 8. Over the past two centuries, extending until 1990, Middelgrunden served as a disposal site for various wastes. Consequently, remnants of sludge containing heavy metals like copper (Cu), lead (Pb), calcium (Ca), zinc (Zn), and mercury (Hg) can still be detected in specific locations, roughly equivalent to the volume of materials discarded over the years. Considering the ever-changing seabed conditions driven by waves and currents, authorities have advised against sailing activities within this area, deeming it unsuitable for navigation. Notwithstanding these recommendations, leisure boats do not consistently adhere to these guidelines. An underwater survey along the turbine line uncovered the presence of 17 shipwrecks, primarily newer vessels measuring 17 to 23 feet in length. This underscores the challenges associated with ensuring compliance with safety and navigation advisories in this dynamic marine environment.

Scoping of impacts

Potential environmental impacts

While the activities at the Danish site had been operational prior to the onset of the UNITED project, an assessment of the expansion and increase in frequency and offering of touristic elements within the area of the offshore wind park were considered. Among the foreseen risks of this multi-use are that an increase in litter from tourism due to higher intensity of boat traffic, environmental impacts linked to introduction of scuba diving, possible looting of wooden shipwrecks. Supporting these potentialities are studies conducted in Denmark and various other countries which offer valuable insights and potential recommendations for this pilot project, particularly regarding its possible impacts. The focal point of such multi-use applications typically lies in the Baltic and North seas; ie. coastal regions in Denmark, Belgium, Sweden, Germany, and the UK have already taken deliberate steps to integrate offshore wind farms with regional tourism aspirations and set forth preliminary guidelines. In light of a MUSES project case study conducted in Denmark, particularly on Lolland, the wind park's sheltering effect and the emergence of a new underwater environment have opened doors to innovative forms of water-based tourism. This includes the potential establishment of activities such as diving excursions and marine nature education programs. Leveraging shared human resources, opportunities for activities such as surveillance, data collection, and information dissemination as integral parts of these tours. The MUSES case study in Denmark has identified several environmental impacts associated with this particular form of multi-use in the Danish context. These include, limited information concerning Environmental Impact Assessments (EIAs) for multi-use initiatives, the potential introduction of habitats that may inadvertently support invasive species, and possible instances of biofouling. Though not conclusive it was also posed that elevated levels of bacteria in the water, attributed to the increased presence of birds and tourists, as well as their excrement pose a risk to the local ecology and pollution of the area due to various factors, including spillage from transportation vehicles, maintenance equipment used for offshore wind farms, lubricants, paints, and other chemicals can also have detrimental effects which scale similarly with increased use. To facilitate the prediction of impacts, a critical phase of the assessment involves selecting specific ecosystem components (ECs) to evaluate the multi-use project's effects, as done in the case of the Belgian pilot described in section 2.3. These components will serve as focal points for evaluating the project's influence on the marine ecosystem and its sustainability in the context of multi-use initiatives.

Potential social impacts

Five social impacts were identified by the project partners and key stakeholders, all are considered as having a high level of importance. The first impact is related to job creation for guides and boat operators, which has a high level of importance locally but low at the national scale. Additionally, the potential to raise awareness about wind energy among the public, locally for those whom reside in the area, but also regionally and wider is a key element. The tourism activities at the Danish site, prior to UNITED, had offered educative tours to school groups and business groups from outside of Denmark whom were interested in having a chance to learn more and view the offshore facilities. Also the inclusion of an educational programme and online tours and guiding elements through the work of UNITED would further expand engagement, education, and acceptance potential by a wide range of communities and offer examples for other wind developments to employ in their localities. In order to visit the turbines, there is an implicit decrease in energy production due to the turbine being stopped for 1 hour for each group of 18 people.

2.4.2. Step 2: Prediction of impacts

Environmental impacts prediction

The impact on the ecosystem components were predicted for a baseline scenario, one where the area is not dedicated to a specific activity, for a single use scenario, in which the activities happen simultaneously but independently from each other, and a multi-use scenario in which offshore wind energy production and touristic activities (boat tour and climbing of a turbine) are combined. For the single use and multi-use scenarios, impacts were predicted for the three stages of a project: installation, operation and decommissioning. The method used to predict environmental impact of each scenario is an Environmental Impact Risk Assessment method developed by Wageningen University and Research a partner of the project. A 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.

In the Danish case (Figure 6), impact reduction in the installation phase is minor (ca. 1% at most). In the decommissioning phase there is no reduction expected. The operational phase, however, shows a relatively high impact reduction (compared to Belgium, Germany, and Greece), with ca. 12% at most for (littoral and infralittoral) rock and other hard substrate. In addition to the prediction of environmental impact risk reduction, the potential for the Danish pilot to build positive environmental synergies was predicted based on expert judgment and literature review. They are the following: increased social acceptance of offshore wind farms and reduction of conflict over space use, although to a lesser extent than the three previously assessed pilots.

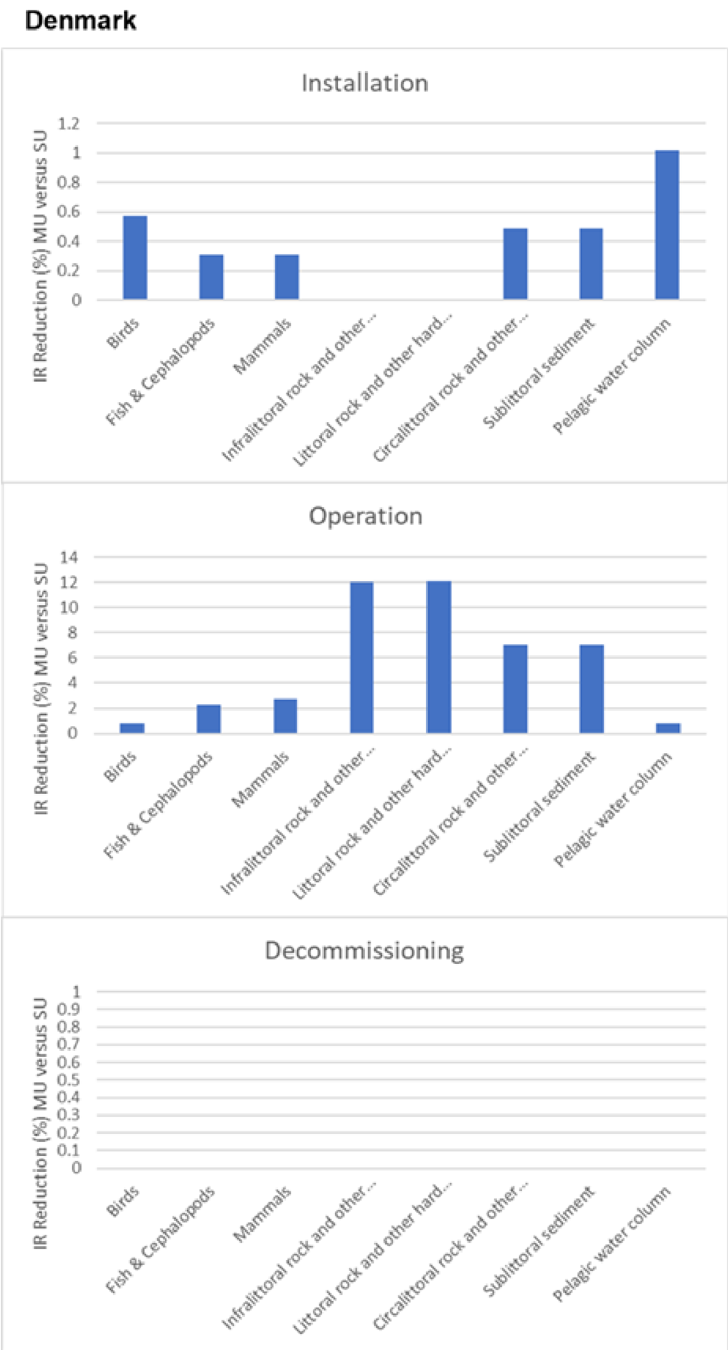

Figure 6 - Reduction (%) in Impact Risk for each Ecosystem Component by activities in multi-use design as compared to single-use design for the Danish pilot for the installation and operation phases.

One of the possible environmental impacts was the higher intensity of boat traffic and the resulting spread of litter from tourism. However, the Middelgrunden pilot is already heavily influenced by intense boat traffic in the area. Thus, the risk of introducing tourism boat tours in the area was considered marginal. The introduction of scuba diving is not believed to increase the environmental impacts as plans to open such activities would be done in collaboration with an organization experienced with leading commercial diving in sensitive areas. Additionally there are multiple examples where sensitive environments are frequented by visitors, however, an overabundance of this type of activity would result in pressured and negative influences, and therefore should be responsibly managed. Consultations and investigations have noted that the reef does not include other shipwrecks than modern wrecks. The National Museum of archaeology is concerned for possible looting of wooden shipwrecks which all diver organizations are aware of. Moreover, the EIA investigations have shown that the reef does not include wooden shipwrecks thereby negativing such a negative outcome.

The water-based tourism in Denmark is expected to increase considerably in the future, and the related environmental pressures from such activities also proportionally increasing. For example, Lolland Municipality together with Business Lolland-Falster has made a “Plan of Potentials 2030” for tourism development on the south coast of Lolland, including the increase of coastal tourism as part of its strategy . In terms of commercialization, the distance from shore usually drives up the marginal costs of wind farm tours (due to fuel and staff cost increases; it is arguable in how far this multi-use increases spatial efficiency as it re-directs tourists from locations, such as beaches, to the open sea and increases activity / traffic there. This multi-use combination, however, seems more relevant from the perspective of easing pressure at touristic hotspots by diversifying the offer or strengthening the local economy.

Social impacts

In Denmark, the acceptability of offshore wind farms within society is generally high, and these developments enjoy widespread support. Consequently, the perspective of offshore wind developers and operators in Denmark is not driven by societal acceptability concerns. However, it's worth noting that the commercial development of this multi-use concept on a large scale could introduce complexities for offshore wind developers. Potential interference with ongoing operations and maintenance activities raises safety and operational concerns. Therefore, from the standpoint of offshore wind developers, the commercialization of this multi-use concept may entail more challenges than advantages.

Among the positive impacts viewed with high acceptability were two specific outcomes. First and foremost, there was the prospect of job creation, particularly for guides and boat operators. This aspect of the initiative held substantial promise, particularly at the local level. Additionally, the objectives aimed to raise awareness about wind energy, particularly targeting new and diverse audiences, including foreign tourists, professionals, and students. This heightened awareness was seen as a valuable outcome of the project. Alternatively, the other three impacts were cast in a less positive light, all categorized as negative impacts with undesirable outcomes. Despite their high level of importance, these impacts garnered low acceptability among the stakeholders involved. The third impact revolved around a decrease in energy production resulting from the temporary halting of turbines for one hour to accommodate each group of 18 visitors. This reduction in energy output directly affected the wind park's operations. There are also additional risk factors in the equation, particularly for boat company operators who navigate in close proximity to the turbine. This increased risk had implications for boat drivers and their crew members, and the prevalence or reporting of such accidents can result in a negative shift in the social opinion of either o both activities. While such events are not expected to be commonplace, any injuries resulting form operations, particularly in the case of novel and unique combinations such as offshore wind turbine tourism, are posed for a high likelihood of notice and potential impact. In such an event, the absence of emergency medical care facilities both on board the boat and within the turbine structure pose complicating factors which may cause negative reactions. This safety concern affected visitors and boat drivers alike, adding an element of vulnerability to their experiences.

2.4.3. Step 3: Assessment reporting

Social synergy effects

Overall, there has been a positive reception to the physical visit to the wind turbines and a resoundingly positive reception to the online and virtual tours developed through the project. The reception to the project's outreach and activities, both in terms of physical visits to the wind turbines and the online virtual tours developed as part of the initiative have garnered significant attention and appreciation from a diverse range of stakeholders. One notable outcome has been a substantial increase in the number of visitors opting for boat tours and turbine-climbing experiences. This surge in interest can be attributed to heightened project visibility and strategic partnerships with various stakeholders, including local museums and blue growth initiatives. These collaborations have played a pivotal role in expanding the project's reach and impact. As a result of these efforts, a broad spectrum of visitors has been attracted, hailing from different backgrounds and origins. This diverse audience encompasses businesses, educational institutions, schools, and general tourists. The operators of the wind turbines have warmly welcomed this diversity, viewing it as a positive development. The pronounced uptick in the volume of individuals and groups seeking tours and benefiting from the digital and physical educational resources offered by the project can be seen as positive for both the tourism and wind energy sectors. Notably, several developer groups have proactively scheduled tours for their employees and stakeholder cohorts, recognizing the value of firsthand exposure to offshore wind operations. On a more practical and societal level, the interest and acceptance of offshore wind energy have received explicit endorsement and validation from participants engaging with the virtual tours and media content created as part of the pilot application. These interactive experiences have effectively conveyed the significance and benefits of harnessing offshore wind energy, contributing to the broader discourse on sustainable energy solutions. The project's multifaceted approach to outreach and education has not only generated enthusiasm among visitors but has also amplified the positive reception of offshore wind energy as a viable and impactful renewable energy source.

Optimization of scheduling

The development of Virtual Tours within the framework of the Danish Pilot[2] project serves a multifaceted purpose, one of which is to expand the accessibility of wind turbine visits to a wider audience, especially during periods when scheduling physical visits becomes challenging, as is the case during the winter months. Doing so allows for outreach efforts to occur when a physical site visit is not possible and accommodate visitors throughout more extended timeframes. While the benefits of virtual tours are evident, there are logistical considerations that necessitate careful planning and coordination for the physical visit as well. The safety concerns associated with offshore wind platform visits dictate that such excursions must occur within a specific operational window, primarily contingent upon wave height and oceanic conditions. Venturing into the offshore environment outside of these established conditions can pose significant risks to tourists, especially during the transition from a vessel to the offshore wind platform. To ensure the efficacy and safety of these tours, it becomes useful to use monitoring and forecasting services, such as the HiSea Platform. These services provide valuable insights into the suitability windows for conducting tours. By aligning the tour schedules with these suitability windows, operators can proactively mitigate potential risks and offer a seamless and secure experience for visitors. The use of forecast and reanalysis information into the planning and execution of these tours enhances the overall coordination between tour operators and wind turbine operators. It aids the operators to make informed choices regarding the timing and frequency of excursions, minimizing the likelihood of embarking on a tour only to encounter adverse weather conditions. This foresight not only safeguards the well-being of tourists but also optimizes the operational efficiency of wind turbine facilities.

Optimization of operations and maintenance

As this pilot is centrally focused on tourism to the offshore wind turbine and the industry and support there-of, the scheduling as described above was keyed to be the critical improvement and boon to the operations. Additionally, the Danish Pilot experienced a lack of boat availability due to the maintenance of the vessels used. This is usually carried out in winter months, however a lapse was realised in the spring and summer months due limited availability of vessels with the appropriate equipment to facilitate boarding the platforms. As vessels are hired on demand when tours are scheduled, scaling such activities so that they posses their own vessels would eliminate such issues.

Technical assessment and validation

Costs

The expenses for making tourism possible has been carried by the boat operators and the minimal losses incurred form the shutdown of the smaller wind turbines have been borne by he cooperative, though seen as an acceptable costs in increase offshore renewable literacy and engaging with a winder audience to increase awareness and acceptance.

Avoided Damages or Loss

There are two potential issues that have been identified during the turbine visits:

1)Loss from wrong treatment of the control system: This occurs when the control board is not re-turned to "remote control" from "local control." As a result, technical service providers need to physically access the turbine and reset the control system, so it can be used in "remote" mode again. To mitigate this issue, strict adherence to the "Training Manual" is crucial. Proper training ensures that the control system is handled correctly during visits, reducing the likelihood of unnecessary technical interventions.

2)Twisting of guests' foot by climbing the ladders in the turbine: Climbing the ladders in the turbine can sometimes lead to accidents, causing injuries like twisted feet. To prevent such incidents, visitors are required to strictly adhere to safety guidelines, which include wearing appropriate footwear. High heels

[2] https://www.h2020united.eu/pilots-denmark

and slippers are not allowed during visits to ensure proper foot protection. Additionally, the guides carry extra water to keep visitors hydrated, especially during warm weather conditions.

Furthermore, weather conditions can impact the feasibility of turbine visits. If the weather does not permit safe access to the turbines, the boat owners and guides may experience lost revenue due to cancelled visits. Therefore, careful consideration of weather conditions is essential to optimize revenue and ensure the safe-ty of visitors. In summary, following the "Training Manual," strictly controlling footwear, and ensuring that the guests are hydrated are effective measures to mitigate the identified issues during turbine visits. Moreover, diligent weather monitoring helps avoid potential revenue losses for boat owners and guides by ensuring safe and enjoyable experiences for visitors.

Uncertainty

Weather conditions are a significant source of uncertainty for turbine visits. Thunder within 70 km, high wind speeds, and large waves can make trips impossible. Boats require maintenance during non-visit periods and may sometimes be unavailable due to other tasks or breakdowns. Using Rigid Inflatable Boats (RIBs) that require climbing up from water level is more uncertain than boats equipped with landing stairs.

Robustness and Flexibility

The successful organization of turbine visits relies on the owner's willingness to temporarily close turbines for 1-2 hours, with compensation for power loss. Fortunately, the cooperative owner of 10 turbines promotes wind energy, reducing interruption risks by considering visits as promotional activities. Long-term continuity requires a 25-year seabed lease extension from the Danish Energy Authority; otherwise, activities must cease by 2025. Accessing the turbine foundation via Zodiacs is challenging due to the ladder's location and problematic wave and current movements at wind speeds over 8-10 m/sec. Improvements to the landing installation in summer 2023 aim to reduce visit cancellations. Using a larger boat with a special stair allows entry from four directions, providing better access in winds up to about 15 m/sec, though boat operations are suspended at higher wind speeds. The availability of only one suitable boat could lead to scheduling conflicts or cancellations if it is occupied or faces technical issues. A potential bottleneck is the availability of skilled guides. The number of trips may not justify full-time positions, leading to a possible shortage of qualified guides. Currently, three guides manage visits alongside their regular jobs, but two of them are retirees over 70 years old, raising concerns about the physical demands of climbing. Visiting activities must be coordinated with the technical service team's daily work, as visits cannot occur during servicing. Addressing these challenges ensures a smoother and more sustainable turbine visit experience.

2.4.4. Step 4: Decision-making

In the case of the Danish pilot, as the activities were already operational prior to the UNITED project, only enhanced and increased in offerings and scope of the activities, there were no needs to change the standings for decision making. However, as the visibility of these activities did increase, there were requests from other countries and operators on what the legal and operational frameworks and guidelines were in the case of visiting the turbines for touristic purposes. Enhancements in the health and safety measures of the operation also took place and were provided to relevant authorities, alongside manuals and operational guidance so as to enable other actor to also conduct such activities. Overall, the popularity and impact of the Danish pilot is continually well received from local and regional authorities and is gaining attention from international actors as well.

2.4.5. Step 5: Audit of predictions and optimisation measures

The Danish pilot was at TRL 6 at the start of the project. Visits were organised as an add to the visits organised every two years for the shareholders. Visits were organised having one board member from the Wind turbine cooperative joining a group of visitors and one specific boat from one operator was used as it was the only boat able to get into the shallow water.

During the UNITED project, two boat owners were convinced to add the tours to their overall program for trips on the local sea. Insurance and legal rules were established and the overall security and risk assessment has been improved by the operations. Three more guides were trained and, as part of this, a manual for guides has been produced. Two videos – about a virtual visit – were produced in order to make it possible during the COVID period to have a visit.

The development can be summarized as: starting at an ad hoc level the Danish pilot is now at a full commercial level: TRL 9, as is described in Figure 7.

The turnover during the period is illustrated in Table 5; note the figures for 2023 is only half year, and thereby represents a market uptick in the tours undertaken at the site and the number of guests whom are engaged with the combined activities. The marked downturn is of course due to the Covid-19 Pandemic and crash in both tourism and inability to conduct such activities. However, with this proof of profitability and operational success, such a combination can be clearly marked as fully mature and ripe for replication in other areas and site which are suitable for such.

Table 5: Number of trips, number of guests and turnover for the period 2017-2023. Note: the figures for 2023 are only for a half year.

Business	2017	2018	2019	2020	2021	2022	2023
Trips	31	35	48	4	13	75	67
Guests	676	930	1117	130	246	1687	1569
1.000 €	38,9	44,3	55,6	4,4	19,5	102,1	111,7

In the project proposal the Danish pilot also included fishing and diver activity. However, the project has shown the fishing activity does not fit with the visit as it takes several hours extra. The fishing activity is handled by one of the boat operators but on a separate tour. During some tours, fishing is done when two groups of people are waiting for each other. Maximum 15-18 people can enter the turbine at the same time. During the period waiting for the first group some of the guests are using the opportunity for fishing. The diving activity turned out to be too complicated. Furthermore, it was based on the wrong assumption: that you need power from the turbine during the diving. In fact, a diving boat all the time need for safety reasons to have a transportable generator in order to be sure that the compressed air can get to the diver. Therefore the synergy was non existing.

2.5. Greek Pilot

2.5.1. Step 1: Description of baseline and identification of impacts

Technical baseline: TRL overview and transition

The ongoing aquaculture and tourism activities in a shared marine environment utilised known and proven elements already deployed and realised in the individual activities. The ambitions was to find synergies and a method to have the two independently operating activities find a manner through which they could benefit from one another and increase the societal acceptance of aquaculture in the region. At the outset of the project, the TRL stood at approximately level 5, signifying its early-stage development in unifying the activities, although the use of individual components was well understood and already in operation. During this initial phase, a selection of the necessary technology components, including sensors and cameras was completed alongside a focused refining of communication systems. As the project has advanced, there was a noteworthy increase in the TRL. This elevation is attributed to the successful deployment of functional installations at the pilot site, which have effectively validated the performance of our technological devices and the associated communication network. These enhancements have been made to ensure seamless data transmission, and we are now on the cusp of reaching the desired TRL7 status. The last step is vital to bridge the remaining gap, ensuring that our multi-use solution, integrating scuba diving and fish aquaculture, reaches an advanced level of maturity and readiness for broader implementation, namely the scalability and ease of replication.

Environmental baseline

Patrokos islet where the scuba diving activities occur is located opposite to the aquaculture site, and has a long history. In ancient times, the island was known as Patroklou Charax ("Camp of Patroclus") or Patroklou Nesos ("Island of Patroclus"), and has experienced and posses a cultural heritage element to the local communities. The pilot site is a typical Mediterranean landscape consisting of three ecosystems, which represent all three species of

Mediterranean ecosystems in Greece, namely pine forests, maquis plants ecosystem (continental and coastal) and phrygana, in various successive stages. The site has been actively engaged in operating a fish farming unit, utilizing floating structures situated in the marine area adjacent to the "Patroklos" islet, located approximately 850 meters from the coastline. In this area, they achieve an annual aquaculture production of around 230 tons of marine Mediterranean fish. Scuba-diving is also very popular in that area, as there are many underwater attractions in site, one of them is a shipwreck, as well as ancient artefacts that can be traced in the seabed of the area. to explore the area's exceptional natural beauty. Other interesting underwater sites that exist in the area, is an underwater car cemetery next to the aquaculture site, as well as a shipwreck on the opposite side, near islet Patroklos. The above sites frequently attract scuba-diving activities.

Scoping of impacts

Potential environmental impacts

The location of the aquaculture unit is located opposite the land area of zone A ' mountainous volume of Lavreotiki, which is governed by the from 24.01.2003 p.d. (D '121). Zone A is a zone of absolute protection, that could be used for recreational uses, outdoor cultural events, outdoor small-scale sports and environmental education facilities. It is assumed that the fish farm could become a refuge for numerous fish and other marine organisms, performing a function similar to artificial underwater reefs or wrecks, an impact realised by other projects as summarised by MUSES. Another potential impact in promoting this multi-use is the possible increase in touristic pressure in already overcrowded areas, with possible increases in coastal cumulative impacts. Certain environmental concerns also arise with the involvement of recreational fishing activity next to aquaculture plants. There is the possibility of fish stock overexploitation if multi-use activities involving fishing are not well monitored. Additionally, finfish culture is expected to have a large environmental impact, particularly with the introduction of external feed stock to support the finfish. This is an environmental impact which is well known and documented across the industry when implemented in a singular context and not combined with other activities such as low-trophic aquaculture or integrate multi-trophic aquaculture. To feed the prediction of impacts that is the second step of the UAF, height ecosystem components (EC) were chosen, on which impact of the multi-use project would be evaluated. These six ECs are: Fish and Cephalopods, Mammals, Birds, Reptiles, Pelagic Water Column, Sublittoral Sediment, and Circalittoral Rock and other hard substrates.

Potential social impacts

The Greek Pilot, through the inclusion of local stakeholder through discussions and workshops, had identified six relevant social impacts, which can be grouped into three categories based on their level of importance. Among high importance impacts are improved diving experience (affecting divers and clients of the diving company) and the production of aquaculture fish (which affects Greek consumers). Among potential impacts of medium importance, there are higher revenues for the local population, increased education and awareness of environmental protection (impacting the tourists), and increased transparency about fish farming conditions (impacting divers, tourists, and the local population). The increase of local tourism, while important for increase revenues and potential employment, did not rank highly among the local stakeholders. This is due in part to the existing degree of tourism and opportunities related to this sector in the region. As the UNITED project looks at the integration of tourism with the existing aquaculture and adaptation of both activities to accommodate for this, though with the assumption on the existence of standard format fin-fish aquaculture, these impacts are primarily related to the integration of tourism, namely diving.

2.5.2. Step 2: Prediction of impacts

Environmental impacts prediction

Impact on the ecosystem components were predicted for a baseline scenario, one where the area is not dedicated to a specific activity, for a single use scenario, in which the activities happen simultaneously but independently from each other, and a multi-use scenario in which fin fish aquaculture and tourism in the form of diving tours are combined. For the single use and multi-use scenarios, impacts were predicted for the three stages of a project: installation, operation and decommissioning. The method used to predict environmental impact of each scenario is an Environmental Impact Risk Assessment method developed by Wageningen University and Research a partner of the project. A 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. In addition to the prediction of environmental impact risk reduction, the potential for the Greek scenario to build positive environmental synergies was predicted based on expert judgment and literature review. They are the following: increased social acceptance of small-scale sustainable fin aquaculture for local consumption, sustainable food production and reduction of conflict over space use, although to a lesser extent than the three firstly assessed pilots.

While predicted impact risk prediction is quite low, the Greek scenario still holds potential for positive environmental impact through the production of sustainable food and the awareness raising towards sustainable aquaculture practices, therefore participating in the Farm to Fork strategy of the Green Deal. 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, that fuels local consumption 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, 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.

According to the MUSES Ocean Multi-Use Action Plan the Aquaculture and Tourism multi-use activities provide various environmental opportunities and benefits. Such solution may raise public awareness of sustainable aquaculture practices and increase commercialisation of local fish products. This way the local aquaculture products gain added value and acceptance as they are better recognised by consumers and local residents. This relieves dependence on imported fish products. A common concern in promoting this multi-use is the possible increase in touristic pressure in already overcrowd-ed areas, with possible increases in coastal cumulative impacts. Certain environmental concerns also arise with the involvement of recreational fishing activity next to aquaculture plants. There is the possibility of fish stock overexploitation if multi-use activities involving fishing are not well monitored.

Assessment of meaningfulness of social impacts

The Greek pilot and other partners assessed the level of acceptability of each social impact identified in Step 1. The impacts with high level of acceptability are the higher revenues for the local population: aquaculture attracts dolphins, which attract visitors. This results in the development of diving activities, restaurants, hotels, etc. which create more revenue for the local population and helps increasing the quality of life locally without the negative impact of a mass tourism activity (16 visitors maximum per day at the aquaculture). Also, other positive outcomes are increased education and awareness of the environmental protection of the area, increased transparency about the fish farming conditions (because of videos, testimonies…), and improved diving experience. Among the negative impacts, with undesired outcome, are the production of aquaculture fish, which are not favoured by the Greek consumers (negative attitude towards aquaculture, preference for wild caught fish over aquaculture fish), and the increased tourism locally, which is not always appreciated by the local population.

2.5.3. Step 3: Assessment reporting

Environmental synergy effects:

The scheduling system facilitates the coordination of multi-use activities involving the aquaculture unit and touristic expeditions, along with related interactions. Both Planet Blue and KASTELORIZO can access the calendar to check the availability of the aquaculture unit and reserve co-use activities. This prevents duplication of activities and offers several advantages. Within this system, stress is minimized as it replaces manual fish sampling with camera-based monitoring, avoiding potential harm to the fish. The system calculates average weight efficiently. Early detection of diseases is made possible through continuous monitoring, allowing for swift preventive measures to contain outbreaks. The presence of the aquaculture unit can attract a variety of marine species, creating additional ecological niches and enhancing the overall marine ecosystem. Operators can optimize feeding schedules by closely observing fish behaviour through the system, leading to more efficient aquaculture practices.

Social synergy effects

In the context of our multi-use project, tourists visiting the area experience several notable benefits. Firstly, they become more attuned to ongoing environmental preservation initiatives within the region, gaining valuable insights into the importance of safeguarding the marine ecosystem. Furthermore, tourists have the opportunity to acquaint themselves with the intricacies of fish farming activities. This engagement serves as an educational platform, dispelling myths and misconceptions surrounding the potential harm caused by fish farming. It allows visitors to appreciate the role of responsible aquaculture in addressing overfishing concerns. Lastly, tourists derive enjoyment from engaging in scuba diving adventures within our biodiverse marine environment. This not only provides them with an immersive experience but also fosters a deeper connection with the rich aquatic life thriving in the area.

Optimization of scheduling

For the Greek pilot a scheduling system has been implemented in order to plan the multi-use activities between the aquaculture unit, the touristic expeditions (and all the linked activities and scenarios between the two). Planet Blue, or KASTELORIZO can have access to the calendar and are able to check availability of the aquaculture and book a co-use activity. This scheduling tool has been created by WINGS as part of the software platform that is connected to the sensors and camera in the aquaculture site. Apart from that, communication through calls is being implemented as part of the scheduling of different activities among the different stakeholders. Individually, the diving centre organizes the touristic diving expeditions after appointments with customers either through social media or through calls. The diving activities are taking place mainly from spring to autumn when the weather conditions are appropriate.

Optimization of operations

The AQUAWINGS platform plays a pivotal role in our operations by providing comprehensive monitoring of our aquaculture site. This monitoring encompasses advanced tracking of environmental factors crucial for the farm's productivity and long-term sustainability. Collected data is systematically processed in order to develop Predictive Analytics for various critical aspects of our operations. This includes closely observing fish behaviour, diagnosing diseases, estimating and forecasting biomass levels, and conducting in-depth analyses of water quality. Our Decision Support System is a vital component of our platform. It not only generates early warnings and alerts but also provides valuable recommendations to optimize our operations. These recommendations cover a wide range of areas, including achieving optimal feeding practices, ensuring the efficiency of harvesting and seeding activities, implementing strategies for disease prevention and mitigation, and streamlining our overall planning processes. In the context of Farm Performance and Assessment, we maintain meticulous records that offer valuable insights into our farm's performance. These records encompass key metrics such as the average weight of biomass, the Feed Conversion Ratio (FCR), fish volume, and stocking density. Maintenance activities within the Greek pilot project primarily revolve around the technical infrastructure at our aquaculture site. This includes the regular upkeep of essential components such as sensors, cameras, and smart gateways. In our commitment to sustainability, we have introduced solar panels to provide a reliable and eco-friendly power supply for our operations. Additionally, we have restructured the WINGS smart gateway to establish wireless internet connectivity. This enhancement allows for seamless data transmission from sensors and cameras positioned throughout each cage, ensuring the efficient functioning of our monitoring system.

Technical assessment and validation

The pilot project aimed to enhance its data collection and validation activities in manners related to equipment deployment, logistics, and data processing through the integration of the scuba-diving and aquaculture activities; resulting in a TRL of 7 in the end. By conducting tests under diverse environmental conditions, a broad spectrum of factors affecting fish behaviour and aquaculture activities was captured; the establishment of uniform data collection protocols, enhancing the reliability and credibility of the collected information. Furthermore, the inclusion of data from these additional sites provided essential baseline data and comparative insights, contributing to a more comprehensive understanding of the aquaculture environment. To address disruptions to farming operations and enhance robustness, the pilot has implemented measures aimed at minimizing disturbances in aquaculture, sea transportation, and diving activities. By monitoring individual diver positions and having mechanisms in place to handle unexpected surface events, the pilot aims to maintain undisturbed and safer diving activities. Real-time data management and decision support systems further enhance operational robustness by providing timely information for effective decision-making.

The pilot project sought flexibility through the co-use of transportation and offshore experiences, optimizing resource utilization and increasing operational adaptability within the shared marine space. Improvements in aquaculture equipment, infrastructure, management, and monitoring systems demonstrate a commitment to adapting to evolving needs and demands. Additionally, the Greek pilot has displayed flexibility in response to economic challenges, adjusting operations to accommodate increased fuel charges and the necessity to reduce diving fees for local divers. This flexibility allows the pilot to optimize operations and cater to changing preferences and financial considerations of divers, lending the final TRL of 7 and robust and flexible nature of the combination of activities resulted in a readily adaptable multi-use scenario.

Policy Cohesion

Spatial planning in Greece primarily follows a sector-focused approach rather than a comprehensive area-based strategy, leading to fragmented maritime spatial planning (MSP). The country has several Special Frameworks for Spatial Planning at the national level, each providing specific guidelines for sectors like aquaculture, renewable energy, industry, and tourism. However, there lacks an overarching, integrated policy framework for marine areas, resulting in a fragmented approach to MSP. This fragmented approach to MSP poses challenges for implementing certain technological solutions. The absence of a holistic, area-based strategy makes it difficult to accommodate multiple activities and interests within a single marine space. Sector-specific spatial plans, such as those for aquaculture, often prioritize preventing interference with other activities rather than embracing multi-use (MU) concepts. This sectorial focus can impede the seamless integration of technical solutions that necessitate coordination and collaboration among various stakeholders.

Furthermore, the decentralized decision-making process regarding MU in Greece means that permissions for MU can vary from one site to another. While MU initiatives exist in Greece, such as fishing tourism activities and the Greek pilot project involving fish farming and tourist diving, the feasibility of implementing the same technical solution in different locations is uncertain. The decision to allow or disallow MU may differ depending on specific site-specific circumstances and considerations. Involving multiple authorities in the establishment and operation of fish farms, including agencies responsible for spatial planning, environmental protection, health, tourism, and nature conservation, as well as local authorities, can introduce challenges and potential delays in implementing specific technical solutions. The necessity to engage in consultations and secure approvals from various agencies adds complexity and may hinder the efficiency of the implementation process.

2.5.4. Step 4: Decision-making

The activities of the Greek pilot were already in operation before the UNITED project, but they functioned individually and were located in separate areas. Through the UNITED project, the pilot introduced a novel approach by allowing divers to engage with the aquaculture site and providing additional monitoring services to the fin-fish facilities while also assessing the conditions in the immediate surroundings. This integration resulted in a mutually beneficial synergy between these activities. As the visibility of these integrated activities increased, other operators expressed interest in understanding the legal and operational frameworks and guidelines for conducting touristic visits to the turbines. To meet this demand, the pilot improved its health and safety measures and collaborated with relevant authorities to establish manuals and operational guidance. These efforts enabled other stakeholders to conduct similar activities. One of the significant advantages of this collaboration was the potential increase in public acceptance of fin-fish farms. Moreover, it contributed to enhancing the understanding of individuals who visited the facilities, as most of them had limited to no prior knowledge of commercial fish farming. This newfound understanding proved crucial and has been shared with local and regional policymakers. Addressing acceptance challenges is essential for the development of such activities, and the pilot's experience offers valuable insights in this regard.

2.5.5. Step 5: Audit of predictions and optimisation measures

The Greek pilot has undergone substantial development, progressing from an initial Technology Readiness Level (TRL) of 5 to its current TRL of 7-8. This advancement reflects the significant improvements and activities carried out at the pilot site to enhance its maturity and readiness. During the TRL 5 stage, the pilot site was in the advanced development phase, with a primary focus on establishing the aquaculture unit on floating facilities near the Greek coast. Its strategic location within the NATURA 2000 protected area, along with its unique attributes, laid a strong foundation for further growth. To gain a deeper understanding of the underwater environment and the functioning of the aquaculture farm, scuba diving activities were introduced. These activities involved exploring, collecting data, and observing the ecosystem and aquaculture operations within the NATURA 2000 private island "Patroklos" and the aquaculture site itself. Building upon these initial steps, plans were formulated to organize boat tours that would allow visitors to witness the aquaculture farm in action. These tours aimed to raise public awareness, showcase sustainable aquaculture practices, and educate visitors about the industry. Additionally, the pilot integrated professional scuba diving activities into its operations, leveraging the expertise of experienced divers. These professionals actively participated in various operational tasks, including underwater inspections, infrastructure maintenance, and waste management. Their involvement significantly improved the efficiency and effectiveness of the aquaculture operations. Furthermore, Remotely Operated Vehicles (ROVs) were employed for infrastructure maintenance within the aquaculture farm.

To enhance connectivity and streamline data collection, the pilot site implemented several infrastructure improvements. It established reliable internet connectivity using a 4G access point equipped with WiFi and Ethernet access, ensuring seamless communication and data transmission. Additionally, the installation of photovoltaic panels in the floating warehouse provided sustainable and renewable power sources, contributing to the overall sustainability of the pilot's operations. In addition to the developments mentioned earlier, sensor devices played a crucial role in enhancing the monitoring and management of aquaculture operations at the Patroklos pilot site. Aquaread and Valeport Model 106 sensors were strategically deployed to measure essential parameters critical for aquaculture monitoring. These sensors were designed to monitor salinity, temperature, dissolved oxygen, pH, turbidity, chlorophyll, and P redox-current accurately. Their strategic placement, coupled with camera and current sensor devices, enabled comprehensive data collection and monitoring. To ensure seamless data transmission and power supply for these sensor devices, a combination of power over Ethernet (PoE) cables and wireless connections was employed. This approach facilitated efficient data gathering and real-time monitoring of aquaculture conditions. The collective progress made in scuba diving activities, the use of ROVs, the introduction of boat tours, the integration of professional diving, improved internet connectivity, sustainable power supply solutions, and the deployment of advanced sensor systems has significantly elevated the pilot site's TRL level to a range of 7-8. This advancement signifies that the pilot site is now much closer to achieving a production-ready state. It has successfully integrated various elements, technologies, and activities, resulting in optimized operations and an enhanced understanding of aquaculture farming practices. This higher TRL level firmly establishes the Patroklos pilot as a mature and promising solution within the aquaculture industry, poised for further growth and implementation.

3. DISCUSSIONS

In the context of the UNTIED project, it is essential to evaluate the suitability and adaptability of the proposed framework. This framework is designed to serve as a universally applicable approach for assessing various activities, whether conducted individually or in combination, within the realm of multi-use scenarios. Our objective here is to assess how effectively this framework can be applied across the diverse range of multi-use cases presented by the pilot sites involved in the project.

In Section 2 of this report, we delve into the practical application of the UNITED Assessment framework (UAF) across each of the pilot sites. This analysis aims to gauge the framework's capacity to address the specific needs and challenges encountered at the pilot level, as compared to the requirements that may arise in larger-scale or commercial implementations. Upon reviewing the outcomes of applying the UAF, a consistent theme emerges: given the relatively small and scaled-down nature of these pilot sites, the expected impacts on ecology, economy, and society are generally minimal to non-significant. This observation aligns with the characteristics of smaller pilot initiatives, which typically do not yield widespread or highly noticeable consequences. However, it is crucial to recognize that, in all pilot cases, there have been discernible impacts, albeit at a relatively modest scale. Importantly, we believe that these impacts have the potential to escalate significantly with the expansion of these initiatives.

This finding underscores the necessity of carefully considering the scalability of actions undertaken within the pilot sites. While immediate impacts may be limited, a well-structured framework should account for the potential amplification of these impacts as projects transition from the pilot phase to broader implementation. As we proceed to examine the specific assessments of each pilot site in Section 2, we will explore in greater detail how the framework addresses the intricacies and implications of multi-use activities, taking into account both the pilot and scalable levels of implementation.

3.1. Applicability by Pillar

To gauge the effectiveness and advantages of implementing marine multi-use scenarios, a comprehensive evaluation from various perspectives becomes imperative. Within the context of the UNITED project, we have identified five fundamental pillars, each representing a distinct facet of assessment: environment, society, economy, legal/policy/governance, and technology. These pillars can be broadly categorized into two groups: direct and indirect. The direct pillars encompass aspects where the impact is immediately discernible. These include the environmental, economic, and social dimensions. On the other hand, the indirect pillars encompass boundary conditions and impacts that are not directly observable but are implicitly assumed. These encompass the legal, policy, governance, and technological dimensions. Each of the direct pillars serves as a focal point for evaluating the impact of marine activities, employing specialized assessment tools and criteria tailored to the unique attributes of each pillar. The underlying premise is that multi-use scenarios should ideally exhibit added value or advantages over single-use scenarios, particularly within at least one of the three direct pillars: environmental, economic, or social.

The assessment of potential environmental impacts, while relevant for permitting and licensure of all of the activities and particularly of note for scaling of operations had one of the most interesting potentials to benefit in a number of ways as realised through the work. The integration of various activities within a single marine area holds the potential to significantly reduce the spatial footprint of human disturbances on ecosystem components. By consolidating construction and maintenance efforts within a specific zone, the impact on other areas can be minimized, preserving their natural state. Moreover, strategic planning of combined activities can also facilitate habitat conservation or restoration. An illustrative example involves the synergy between low-impact activities like low-trophic aquaculture and offshore wind farms where one of the most likely benefits had been realised across the pilots related to said activities. Wind farms, for safety reasons, already prohibit bottom-disturbing activities. By introducing low-trophic aquaculture into this mix, the protective measures for the seabed are optimized. Furthermore, the cultivated organisms can offer additional ecological benefits, including water filtration, carbon storage, and the potential for reintroducing threatened species like European flat oysters.

While generalisations and predictions could be relative well concluded in the environmental aspect of the assessment framework, the important specifics on scaled impacts could not be fully addressed. The reliance of such an approach on specific design plans and carrying loads does not lend itself well to the scaling of pilot results.

Comprehensive studies would be required in order to have a realistic and detailed quantification of the impacts at larger scales, and would be strongly recommended. The framework could address the concerns from the environmental standpoint, the issue therein laid more so with the fact that the scale of application in pilot projects and expected impacts on the environment were so small that the impacts were often expected to be non existent.

The integration of diverse activities within a multi-use framework offers the potential to generate substantial economic advantages while simultaneously managing societal costs. This integration not only enhances overall economic efficiency but also frequently leads to reduced financial expenditures. From a business standpoint, multi-use settings can prove to be more financially rewarding in comparison to concurrent single-use activities situated in separate marine regions. Moreover, multi-use arrangements may open doors to activities that would be financially unviable in single-use scenarios. For instance, certain touristic activities thrive within multi-use environments, relying on the presence of other coexisting activities for their viability. Examples include boat tours in wind farms or diving tours around fish farms, which derive significant added value from the diverse marine life attracted to these combined settings, including iconic species like marine mammals.

In the decision-making process, it is imperative for policymakers and stakeholders to take into account the economic impacts when evaluating the relative societal value of various multi-use options (Araujo et al., 2021). To ensure comprehensive consideration of all relevant impacts, a structured and sequential approach was devised and implemented in close collaboration with pilot leads and other consortium partners directly engaged in the pilot projects. This approach involved the development of application guidelines and scoping for potential impacts, conducted through a thorough literature review for each pilot. Subsequently, workshops involving stakeholders were organized to assess the significance and scale of the previously identified impacts (Araujo et al., 2023). The most pertinent and critical impacts were then subjected to further analysis and prediction, utilizing available quantitative data and insights gathered from literature reviews and interviews with partners involved in the project's pilot activities.

Multi-use scenarios, when compared to single-use approaches, can deliver net societal benefits. These benefits can manifest in various forms, including cultural enrichment, social equity, and community empowerment. Job creation, knowledge sharing, increased attractiveness of localities, and direct or indirect advantages for the recreational sector are among the potential societal gains. The nature of these benefits varies depending on the context and the type of multi-use envisaged. Multi-use, as a concept deeply rooted in sustainable development, has the potential to empower coastal populations, foster cross-sectoral collaboration and innovation, and accommodate traditional or cultural uses of the sea, such as specific forms of fishing or recreational activities. Additionally, the degree to which multi-use can outperform or provide additional benefits as opposed to single use activities is not always evident, particularly in the offshore setting as the societal benefits and gain are realised on land in regional municipalities whereas the tangible differences in co-location versus single use are evident at sea. A key defining factor here was the potentiality to increase overall activities within a certain domain. The framework proved robust and capable of considering pilot level and scaled social benefit and considerations. As key inputs are often taken from stakeholder workshops and wider queries, a consensus on the scaled multi-use features is considered and not at the scale of pilots but future developments and deployments.

Multi-use represents a departure from the traditional exclusive spatial rights approach in the marine environment. Consequently, existing legal frameworks, policies, and governance structures are often ill-suited to accommodate this innovative concept. Therefore, a thorough assessment of the legal, policy, and governance landscape at the project's inception is crucial. This evaluation serves two essential purposes: firstly, to determine the current legal possibilities, policies, and existing insurance mechanisms, and secondly, to identify necessary changes that must be implemented for the project to realize its maximum potential benefits. Adapting the regulatory and governance framework to embrace multi-use is a fundamental step in its successful implementation. The realised roadblocks at a pilot level are also to be realised when scaling to commercial application and to enlarge to complete barriers to implementation. For this reason, the communication of issue and fostering of discussion with stakeholders and policy makes is critical to future multi-use. In the UNITED application the key asset delivered in this regard was the assessment of policy inconsistencies within Europe, notably the North and Baltic sea legislation, and highlighting the issues in replicability and transferability this will pose to innovative multi-use solutions. The framework was robust and can be applied within multiple scaled of development from pilot to envisioned scenarios f commercial applications.

Policy and decision makers play a critical role in the uptake and rollout of multi-use, as seen across the assessment of the UNITED pilots. Marine spatial planning is a tool and requirement in determining the feasibility and implementation of multi-use activities within a given marine area. The applicability of multi-use in different countries is contingent upon the status of MSP within their legal frameworks. In Greece, where no national MSP exists, multi-use is neither expressly permitted nor explicitly prohibited. The absence of specific prohibitions allows for some forms of commercial multi-use to be implemented without a formal permit, as exemplified by activities like diving tours around fish farms. However, certain areas, such as shipping lanes, are designated for exclusive single-use purposes (Maes et al., 2023). In contrast, the Netherlands has a well-defined Maritime Spatial Plan (MSP) that actively promotes and regulates multi-use. Multi-use is permitted in designated areas where priority activities like sand extraction, renewable energy production, oil and gas development, shipping, and military operations are ongoing. These specific zones enable the coexistence of various activities as long as they do not conflict with the priority activity. Furthermore, new wind farms delineate zones within which additional activities can apply for permits and integrate themselves without requiring the formal approval of the wind farm operator(s) (Maes et al., 2023). Conversely, Germany's national MSP lacks provisions for facilitating multi-use. Here, each activity is allocated an exclusive area, with no established procedure for combining multiple activities within the same zone. As a result, initiating a multi-use project in Germany necessitates a specialized permit application, which often involves a protracted and intricate process (Maes et al., 2023). The governance analysis of these three countries yields distinct models of control from a stringent top-down approach characterized by rigorous planning and regulations to a flexible and adaptive management model, emphasizing a bottom-up and innovation-driven approach. With shifting demands and trialing innovative solutions, the more flexible and adaptive management model, as evaluated via the policy and specification requirements, proved most conducive to facilitating multi-use initiatives. The UAF proved flexible and detailed enough to touch on the major considerations and key elements across all the five different countries involved in the assessment to yield such an output when considering the legal, policy, and governance frameworks of the multi-use applications. This was possible regardless of scale and the analysis is believe to be reflective of pilot, small, or large commercial applications.

Technical capacity is a fundamental requirement for the viability of multi-use projects, yet it remains deficient in many cases. This pillar in the assessment framework dealt with practical considerations that must be carefully addressed. Questions about shared boat usage, efficient and safe protocols, coping with offshore installations, managing adverse weather conditions, seasonal variations, and high-energy marine environments all demanded careful analysis and creative solutions. Furthermore, the selection of infrastructure and equipment to optimize intended use while minimizing environmental impact is a critical aspect of this technical dimension. Comprehensive scenario assessments and decision-making support rely on addressing these multifaceted technical challenges effectively. However, the UAF proved to be able to take the requirements of the technical specifications of the different applications, particularly the compliance with regional or national regulations an requirements and forms a cohesive assessment. This would hold true across scales from pilot to commercial applicability, as the demonstration of a technically sound solution, whether it be on or hundreds of implementations, requires conformity to the same hard coded requirements and a degree of flexibility in the scaling and operational sense.

3.2. Conclusions

The UNITED Assessment Framework (UAF) serves as a comprehensive decision-making tool when confronted with multiple potential uses of a given marine area. It delivers a final assessment that encompasses the three fundamental pillars of sustainable development: environment, economy, and society, while also addressing the essential prerequisites outlined in the enabling pillars: technology and regulatory frameworks (governance, legislation, and insurance) necessary for project implementation. Three significant strengths of the UAF warrant special emphasis: the comparative analysis of scenarios, its integrated approach, and the flexibility in method selection. Comparing different scenarios serves as a robust foundation for decision-making processes. At a minimum, two scenarios are considered: the multi-use scenario and the single-uses scenario. In the single-uses scenario, envisioned activities occur concurrently but independently, with no shared areas or interactions. Conversely, the multi-use scenario involves shared spaces and the potential combination of certain actions, such as shared boat use, infrastructure, and monitoring. Additionally, a baseline scenario may be included, either where none of the proposed uses are enacted or as a representation of the existing scenario. This latter option proves especially relevant in multi-use projects seeking to incorporate new activities alongside existing offshore installations, such as wind farms.

To provide decision-makers with a comprehensive understanding, additional scenarios can be formulated and assessed. This becomes particularly valuable when evaluating decisions that encompass various multi-use combinations, such as choosing between combining offshore wind farms with aquaculture or tourism. It also holds significance in determining the optimal number of uses to incorporate into a project, whether it involves offshore wind farms with aquaculture alone or with the addition of tourism. Examining diverse scenarios offers a holistic perspective on the situation and establishes a strong foundation for informed decisions concerning the feasibility of multi-use applications in the marine environment. The second noteworthy aspect of the UAF is its consideration of the five pillars within the UNITED project. Assessing impacts on the three direct pillars of sustainable development enables tailored decision-making based on the specific needs of the area in question. In certain regions, prioritizing ecosystem health may take precedence, leading to a preference for multi-use combinations that promote conservation and ecosystem restoration. In contrast, economic benefits may be the primary focus elsewhere, resulting in the selection of projects that offer substantial economic added value. In some areas, social and cultural benefits may be the top priority, creating space for traditional or locally valued uses of the sea. However, it is essential to note that the UAF's overarching goal is to promote sustainable development. While trade-offs may be considered, all three pillars should ideally experience minimal negative impacts and, ideally, maximum positive impacts.

In addition to assessing the impacts on these direct pillars, the UAF incorporates the need to specify the technical, legal, governance, and insurance requirements essential for implementing the envisioned scenarios. If these aspects require improvement, such as the development of new technology or legal provisions for multi-use, or the availability of affordable insurance options for projects with limited precedents, they should be prominently highlighted, described, and, wherever possible, accompanied by recommendations for necessary advancements. These considerations are integrated into the scenario descriptions (Step 1 of the UAF) and the assessment reporting (Step 3 of the UAF). Lastly, the UAF's flexibility in choosing methods for identifying and assessing impacts across all considered pillars is a key attribute that makes it adaptable to various situations. This adaptability renders the UAF a valuable tool for any context where ocean multi-use is under consideration. It signifies that the UAF can be effectively utilized in diverse geographic locations and in relation to a wide range of use scenarios.

The versatility of the UAF confers a significant advantage, allowing it to generate comparable results across different countries and projects. In essence, because the UAF can be applied consistently 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 proves invaluable for decision-makers, researchers, and stakeholders, facilitating the exchange of knowledge and experiences on a global scale. Ultimately, this contributes to more informed and comprehensive decision-making within the realm of ocean multi-use.