Ref. Ares(2024)4508848 - 21/06/2024

DELIVERABLE 4.5

CONTRIBUTE TO GENERIC ROADMAP

Work Package 4

Environmental gain of multi-use of marine space and infrastructure

June 21st, 2024

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

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

Grant Agreement number	**862915**
Project title	**UNITED: multi-Use platforms and co-locatioN pilots boostIng cost-effecTive, and Eco-friendly and sustainable proDuction in marine environments**
Deliverable title	Contribute to Generic Roadmap
Deliverable number	4.5
Deliverable version	Resubmission
Contractual date of delivery	December 31st, 2023
Actual date of delivery	December 31st, 2023 (Version 1.0) June 21st, 2024 (Version 2.0)
Document status	Final version
Document version	Version 2.0
Online access	Yes
Diffusion	Public
Nature of deliverable	Report
Work Package	WP4 – Environmental gain of multi-use of marine space and infrastructure
Partner responsible	Deltares
Contributing Partners	Deltares, FuE FH Kiel, KMF, UGent, WINGS, NSF, OOE, SPOK
Author(s)	Emma Huijben, Roderik Hoekstra, Tim Staufenberger, Evangelia Lamprakopoulou, Annelies Declercq, Brigitte Vlaswinkel
Editor	Annaïk Van Gerven
Approved by	Ghada El Serafy
Abstract	This deliverable reports on the final task of the environmental work package of the UNITED project. The objective of this task is to summarize the lessons learned from the pilots on approaches to maximize the environmental gain of the

	multi-use of marine space and infrastructure while minimizing the negative environmental impact. The first half of this report presents the approaches of the five individual UNITED pilots and discusses the commonalities that were identified, i.e., choice of material and methods, vessel usage, raising public awareness of sustainable activities, and the consequences of the pilot scale. The second half of the report highlights the key results and lessons learned regarding the environmental pillar that have been documented in other UNITED deliverables but fit the scope of Task 4.5. The following aspects are considered: environmental risk reduction of multi-use (MU), added value of MU through environmental benefits, design of offshore wind farms for MU, commercial benefits and environmental impact, and conservation benefits. The lessons learned from the environmental pillar feed into the Catalogue of multi-use blueprints (Deliverable 1.5), a key output of the UNITED project that can provide guidance for future MU developments.
Keywords	Ocean multi-use, environmental impact, pilots, lessons learned

HISTORY OF CHANGES

VERSION 2.0	June 2024	Updated cover page and information table pages 1-2. Strengthened the link between the current deliverable and the UNITED roadmap (Deliverable 1.5, the catalogue of multi-use blueprints) by: I) changing the formatting of chapter 2 to highlight the practical approaches taken by each of the individual pilots to provide guidance for others implementing similar multi-use combinations II) expanding section 3 to include more consideration into future development and discussion on temporal and spatial scales.

TABLE OF CONTENTS

ACRONYMS

ADCP	Acoustic Doppler Current Profiler
D	Deliverable
DO	Dissolved oxygen
EIRA	Environmental Impact Risk Assessment
GES	Good Environmental Status
MSFD	Marine Strategy Framework Directive
MU	Multi-use
NH_4	Ammonium
NO_3	Nitrates
PV	Photovoltaic
TDS	Total dissolved solids
WP	Work package

EXECUTIVE SUMMARY

This deliverable reports on the final task of the environmental work package of the UNITED project. The objective of this task is to summarize the lessons learned from the pilots on approaches to maximize the environmental gain of the multi-use of marine space and infrastructure while minimizing the negative environmental impact. The first half of this report presents the approaches of the five individual UNITED pilots and discusses the commonalities that were identified, i.e., choice of material and methods, vessel usage, raising public awareness of sustainable activities, and the consequences of the pilot scale. The second half of the report highlights the key results and lessons learned regarding the environmental pillar that have been documented in other UNITED deliverables but fit the scope of Task 4.5. The following aspects are considered: environmental risk reduction of multi-use (MU), added value of MU through environmental benefits, design of offshore wind farms for MU, commercial benefits and environmental impact, and conservation benefits. The lessons learned from the environmental pillar feed into the Catalogue of multi-use blueprints (Deliverable 1.5), a key output of the UNITED project that can provide guidance for future MU developments.

1. INTRODUCTION

1.1. UNITED project

The UNITED project has developed five demonstration pilots in three European seas with the aim to provide evidence of the viability (economic, social, and environmental) of ocean multi-use (MU). These pilots are located in five European countries and combine different marine activities at one location:

- German pilot: Offshore wind energy & Aquaculture (Blue mussels and Seaweed)
- Dutch pilot: Offshore floating solar energy & Aquaculture (Seaweed)
- Belgian pilot: Offshore wind energy & Flat oyster aquaculture and restoration & Seaweed cultivation
- Danish pilot: Offshore wind energy & Tourism (boat tours)
- Greek pilot: Aquaculture (finfish) & Tourism (diving)

The project focuses on five different pillars: technology, economy, legal/governance/policy, society, and environment. There is a dedicated work package (WP) for each of those pillars.

1.2. The environmental pillar and scope of this deliverable

The work package that is centred around the environmental pillar is WP4 – Environmental gain of multi-use of marine space and infrastructure – which has a key focus on environmental monitoring, the development of an assessment framework and the application thereof. The output of this work package is presented in five deliverables:

- D4.1 – Revision of the current environmental assessment and status of the pilots
- D4.2 – Assessment framework to determine ecological feasibility of multi-use platforms
- D4.3 – Application of assessment framework within pilots
- D4.4 – Environmental impact assessment model for the commercial rollout of multi-use platforms
- D4.5 – Contribute to generic roadmap.

UNITED D4.1 (2020) serves as state-of-the art baseline for the succeeding tasks of WP4 and is centred around the baseline environmental account of the pilots and the regulatory requirements for the environmental impact assessment and environmental monitoring of the pilots. UNITED D4.2 (2021) focusses on the approach to assess the environmental impacts of multi-use versus single-use and provides a manual for the implementation of the assessment (UNITED D4.2 Annex 9, 2021). The application of the assessment method – an Environmental Impact Risk Assessment (EIRA) – for upscaled versions of the UNITED pilots is presented in UNITED D4.3 (2022) for the single-use scenarios and in UNITED D4.4 (2023) for the multi-use scenarios.

The outputs of the environmental pillar are not only presented in WP4, but also throughout other work packages. For example, UNITED D8.3 (2023) – Report on environmental assessment and validation – synthesizes results from the environmental impact predictions performed in UNITED D4.3 (2022) and UNITED D4.4 (2023) and assesses the meaningfulness of these results for the different ecosystems components. That report also discusses the potential of marine multi-use as a tool within environmental strategies to achieve goals set by the European Commission. Another example of a deliverable with links to the environmental pillar is UNITED D8.4 (2023) – Auditing procedures and TRL assessment manual – which proposes an environmental audit guide for internal audits of multi-use projects.

The current report (D4.5) highlights the approaches taken by each of the pilots to maximize the environmental gain and minimize the negative environmental impact and describes their commonalities. In addition, it calls attention to work and results fitting within the objective of Task 4.5 but already performed and reported in other UNITED tasks and deliverables.

The lessons learned from the environmental pillar and WP4 can provide guidance to future multi-use project developers and will therefore feed into the Catalogue of multi-use blueprints (D1.5) that is created under WP1.

2. UNITED PILOTS' APPROACHES REGARDING ENVIRONMENTAL IMPACT

2.1. German pilot

Short pilot description

The German pilot has installed aquaculture systems for mussel and algae cultivation near the offshore research platform FINO3 (Figure 1), operated by FuE-Zentrum, situated 80 kilometres north of Helgoland in a highly exposed marine environment within the German North Sea. Two parallel 40 metres long lines, one assigned to algae cultivation and one to mussel cultivation, were installed within the 500 meters radius safety zone that surrounds the FINO3 platform. A monitoring system with different sensors was positioned between these two parallel lines. This lander was equipped with a multibeam echosounder, an Acoustic Doppler Current Profiler (ADCP) and sensors to measure oxygen, algae density, and nitrogen compounds.

Figure 1: FINO3 tower

Approaches to maximize environmental gain and minimize negative environmental impact

In the German offshore pilot FINO3, maximizing environmental gains while minimizing negative impact was of greatest importance. Situated 80 kilometres offshore within a high-energy environment, the challenges were abundant: expensive travel logistics, costly shipping times, and the inherent ecological sensitivity of the marine realm.

To tackle these hurdles, a strategic approach was employed. Task bundling emerged as a cornerstone strategy, synergizing activities like the simultaneous installation of sensors, algae- and mussel lines. This not only curtailed costs but also mitigated environmental strain by reducing fuel consumption.

Sustainability was paramount during all phases of the project. Every aspect, from installation to decommissioning, was meticulously planned to curtail environmental footprints. Rather than resorting to ramming or drilling techniques, only weight and drag anchors were utilized, ensuring minimal disturbance to marine mammals (sound). Additionally, installations remained in place for extended durations, fostering longer growth seasons for mussels and algae while serving as substrates for natural organisms to settle and thrive and doubling as substrate and hiding places for e.g., fish, otherwise missing in the area (nature friendly and inclusive design).

The careful selection of non-toxic anti-fouling agents not only safeguarded against the leakage of toxins into the ecosystem but also ensured the safety and purity of the harvested mussels and algae, aligning with the project's commitment to producing clean and sustainable resources.

Furthermore, the consolidation of tasks not only streamlined operations but also significantly reduced carbon dioxide emissions, amplifying the positive environmental impact of the project.

2.2. Dutch pilot

Short Pilot description

The Dutch pilot was situated at the North Sea Farmers Offshore Test Site, which is an independent test site for research, pilots, and upscaling of innovations, located 12 kilometres off the coast The Hague. UNITED partners The Seaweed Company and North Sea Farmers installed two seaweed cultivation systems, and the UNITED partner Oceans of Energy installed an offshore floating solar installation. In addition, measurement systems were installed as well. Given the location of the pilot, all installations were subjected to the rough conditions of the North Sea.

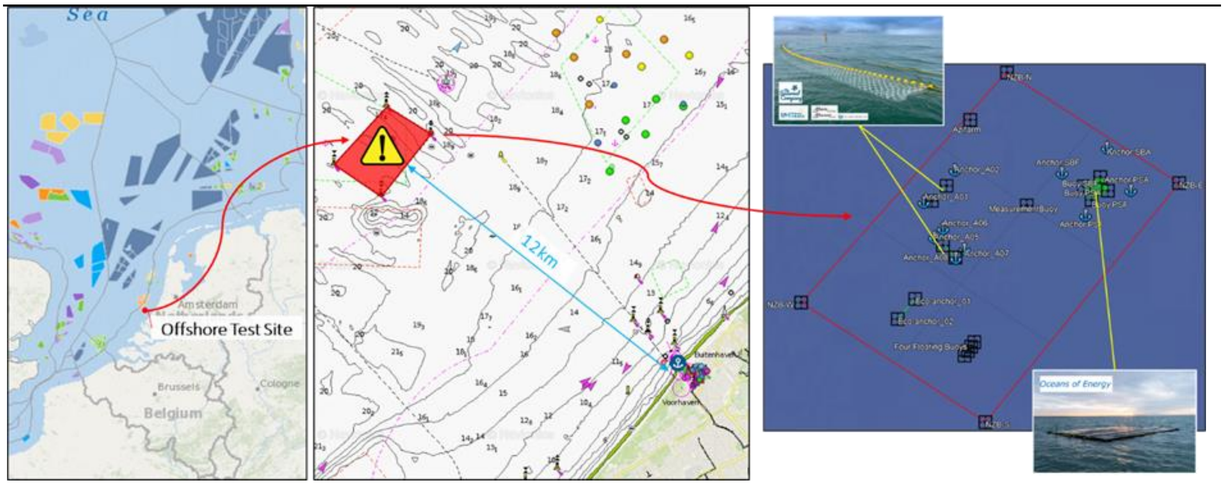

Figure 2: The location of the Dutch pilot at the Nort Sea Farmers Offshore Test Site, situated 12 kilometres off the coast.

Approaches to maximize environmental gain and minimize negative environmental impact

The Dutch pilot has applied several measures to maximize the environmental gains and minimizing the adverse environmental impacts. It is noted that the scale of the current pilots is still too small to be able to measure the effectiveness of these measures and are therefore considered conceptual in this stage. However, the conceptual value of these measures on the environment is considered to be potentially high and will for sure be further investigated in upscaled experiments.

- Seaweed nets were made of relatively small mesh size to minimize the risks of sea animals getting stuck in the nets.
- The application of eco-anchors to mount the floating seaweed installation to the seabed was chosen instead of the application of a traditional anchor. Traditional anchors are an unfavourable option in a windfarm because it gives substantial reworking of the seabed which risks the present infrastructure and can harm benthic biodiversity. The concept of the eco-anchor is to install a semi-permanent pile with a certain elevation above the seabed which can be used as a mounting point for floating structures. First this means that there will only be regular activity on the water surface level and much less potentially harmful activity on seabed level. Second, this pile will be drilled instead of piled, which reduces the marine environmental impact. Third, due to the long-term presence of the pile, it will not only serve as an anchor, but also as an artificial reef. More background information of the eco-anchor can be found on this website: [https://www.northseafarmers.org/news/220211-installation-eco-anchor]
- During offshore installation, inspection and maintenance operations, vessels were shared as much as possible to reduce costs and minimize environmental impact. Multiple experiments in one area allows sharing vessels (and other equipment). On a longer-term it is planned to also employ electrically driven vessels.
- The North Sea Farmers offshore test-site has employed a multi-functional monitoring buoy hosting a range of different sensors. The recorded measurements are available to all the owners of the offshore experiments. Since multiple experiments are carried out in one area, one monitoring buoy can collect data which is representative for all running experiments. A separate buoy for each individual experiment is not needed. This reduces the number of equipment, chains, anchor system used, therefore also reducing the impact on the seabed.
- In 2020, Deltares carried out experimental research in its hydraulic facilities in collaboration with Oceans of Energy. This research investigated the potential of offshore floating photovoltaic (PV) panels to mitigate the incoming offshore waves in the leeside of the floating PV field, which could create favourable conditions for (e.g.) aquaculture. The results of this research are reported in Van Dongen (2021) and demonstrated that there is potential for offshore floating PV fields to mitigate incoming wave energy for relatively small wave lengths with respect to the scales of the floating panels.

- The offshore solar farm is designed in such a way that seals can easily, and without getting hurt, move in between the individual floaters. The individual floaters are separated from each other by a stiff interconnector, making the gap between the floaters (at the long and short end) large enough to have light pass through as well as safe passage for seals (in case they want to pop their heads up between the floaters, they are not in danger).
- Through many still cameras on the farm, the number and behaviour of birds has been monitored. Birds seem to be happy to rest at the farm when the waves are low, so when the floaters are not getting washed over. Once the wind picks up, the birds fly off. They do not seem to be bothered by the floating and moving platforms.
- The platforms do not have anti-fouling to stimulate marine growth on the underside of the platforms. The community is being monitored (with samples being taking by divers) by Wageningen Marine Research. The marine growth (mostly mussels and algae) seems to attract more life, that is many types of invertebrates, some sponges, hydrozoa, crabs, shrimp and also more fish underneath the farm.

2.3. Belgian pilot

Short pilot description

The Belgian pilot was situated at two test locations in the Southern North Sea. The nearshore test site, 5 km off the coast at Nieuwpoort (Westdiep), facilitated optimizing cultivation techniques of the European flat oyster (*Ostrea edulis*) and sugar kelp (*Saccharina latissima*) as well as improving restoration procedures. The best performing methods were then implemented at the offshore test site within the operating wind farm Belwind (operated by Parkwind), 46 km off the Belgian coastline (Figure 3), with a total capacity of 165 MW, powering up to 175 000 households.

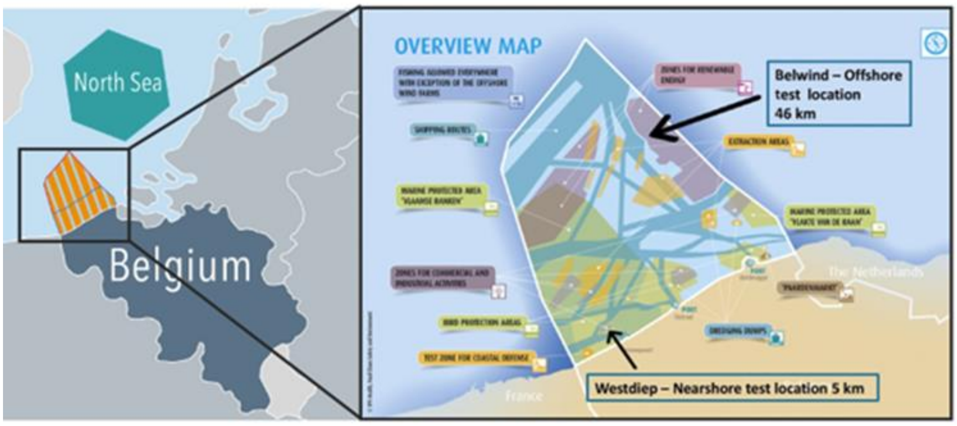

Figure 3: Belgian pilot test locations of the Westdiep (nearshore test site) and Belwind (offshore test site) and marine spatial plan of the Belgian part of the North Sea

The Belwind offshore wind farm is located at the Bligh Bank and its surrounding gullies, where the sea depth varies between 15 and 37 meters. The area is characterized by sandbanks and gullies that are formed and sustained by the tidal currents. The pilot multi-use combines seaweed and European flat oyster (Ostrea edulis) aquaculture, and oyster reef restoration within an offshore wind farm.

Approaches to maximize environmental gain and minimize negative environmental impact

In the following section, we provide a brief overview of key decisions that have influenced the environmental strategy employed in the Belgian pilot of the UNITED project. These decisions encompass critical aspects such as the selection of materials, methods employed, management of vessel time, and monitoring procedures. For a more in-depth understanding of the knowledge base and procedural details, additional information can be referenced in UNITED D4.3 (2022), UNITED D8.1 (2023), and UNITED D8.3 (2023) within the Belgian pilot sections.

Choice of Materials:

The selection of materials for the UNITED project has been meticulously considered to ensure both operational effectiveness and environmental sustainability. Noteworthy choices include the utilization of screw anchors for the backbone offshore, minimizing bottom disturbance compared to other anchor types. The restoration tables are constructed from galvanized stainless steel, with sacrificial zinc anodes strategically attached to mitigate corrosion risks. This material selection reflects a commitment to durability, reduced environmental impact, and long-term effectiveness in the marine environment.

Methods:

The methods employed in the Belgian pilot of the UNITED project demonstrate a comprehensive approach to multi-use marine space. Careful consideration has been given to the placement of backbones and restoration tables, aligning with the biological requirements of flat oysters and seaweed. Furthermore, the project integrates sustainable practices such as the reduction of corrosion through sacrificial anodes, contributing to the longevity of the structures. The combined cultivation of seaweed and European flat oysters in conjunction with offshore wind farms showcases an innovative method that promotes biodiversity, ecosystem health, and potential positive environmental synergies.

Vessel Time:

The management of vessel time in the Belgian pilot reflects a commitment to efficiency and environmental responsibility. By strategically placing the backbones and restoration tables at the outskirts of the wind farm, the need for frequent vessel charters is minimized. Regular monitoring of the surface buoys by passing wind farm vessels and research vessels ensures updates on system functioning without unnecessary boat trips, resulting in reduced fuel consumption and minimized carbon emissions. This approach aligns with sustainability goals and exemplifies a conscientious use of vessel time.

Monitoring:

The monitoring strategy implemented in the Belgian pilot of the UNITED project is designed for both effectiveness and environmental stewardship. The presence of wind farm vessels and research vessels passing through the area contributes to the ongoing surveillance of surface buoys, providing frequent updates on system functionality. This approach not only ensures the reliability of the multi-use platform but also minimizes the need for dedicated vessel charters, thereby reducing overall boat trips and lowering the carbon footprint. The monitoring practices underscore the project's commitment to real-time assessment and environmental sustainability.

2.4. Danish pilot

Short pilot description

The Danish pilot combined production of wind energy with tourism activities. One or two of the twenty existing wind turbines of the Middelgrunden Wind Farm, located 3.5 kilometres off the coast of Copenhagen, were used for visiting. The first visits started already 20 years ago for the 8500 shareholders of the Middelgrunden Wind Turbine Cooperative, following an Old Danish tradition at the annual Wind Day (the 3rd Sunday of June). Afterwards, the opportunity of visiting the inside of a wind turbine also became known by developers and universities and the number of visitors increased since the year 2012. As part of the UNITED project the visits have been professionalized. There are now two boat operators that have visits to the wind farm on their tour program and there are three guides. Two types of trips are organised: a trip with a lecture around 50 metres from the wind turbines and a trip that includes climbing to the nacelle of the wind turbine.

Figure 4: Students and developers visiting Middelgrunden wind farm.

Approaches to maximize environmental gain and minimize negative environmental impact

Contrary to the German, Dutch and Belgian pilot, the Danish pilot did not install additional infrastructure at their pilot site. The Middelgrunden Wind Farm was already built in the year 2000. Given that no additional systems were installed there was also no need to come up with an approach to optimize the effect of such extra installations.

The Danish pilot explored whether it would be feasible to have shared vessel use between the two sectors and thereby reduce the number of boat trips. In the early phase of the pilot, a few of the tours made use of the boat of the service operator. However, it became apparent that this was not a long-term solution.

During a part of the UNITED project the Danish pilot experienced a lack of visitors caused by the COVID-19 restrictions. Both to cope with this lack of visitors and to expand the audience of the guided tours, a set of virtual tours was developed. These tours are available in two languages, both English and Danish, and can be accessed by scanning one of the QR codes that have been placed at several landmarks in the city of Copenhagen. These **virtual tours allow more people to get familiar with the wind farm without an increase in vessel usage**.

The Danish pilot might have an indirect positive effect on the environment through an increase in the social acceptability of wind energy production, a renewable source of energy.

2.5. Greek pilot

Short pilot description

The Greek Pilot, denoted as the PATROKLOS Pilot site, was situated in the 59th km of Athens-Sounio Ave., Palaia Fokaia, Attiki, Greece, in the wider area of Cape Sounio (Figure 5). It includes an aquaculture unit situated in the Mediterranean Sea at the Greek coast. KASTELLORIZO operates a fish-farming unit on floating facilities in the marine area near island “Patroklos” (the island is located 850 metres from the coast). The wider area is protected under NATURA 2000 and the Treaty of Barcelona, due to a number of significant characteristics that this pilot site has. The full area of the Greek UNITED pilot is the whole area between the island and the mainland, and a part of this wider area contains the aquaculture unit (see Figure 5). The multi-use activities taking place during the operational phase are the combined activities of the aquaculture unit with scuba diving tourist expeditions (Planet Blue diving center) facilitated by WINGS ICT Solutions monitoring system, namely AQUAWINGS.

Figure 5: Left and Middle: Proposed Pilot space, the yellow square depicts aquaculture unit (source: Google Earth). Right: Aquaculture unit and islet Patroklos on the opposite - Mediterranean Sea, Greece

Approaches to maximize environmental gain and minimize negative environmental impact

The integration of aquaculture and tourism, as exemplified in the Greek PATROKLOS Pilot, holds great promise for economic and environmental synergies. However, as with any human activity in delicate ecosystems, careful consideration must be given to potential environmental impacts. **Within this pilot, real-time monitoring extends beyond conventional aquaculture parameters to include salinity, water quality, temperature, dissolved oxygen (DO), pH, electrical conductivity, total dissolved solids (TDS), turbidity, Chlorophyll-a, nitrates (NO3), and ammonium (NH4).** AQUAWINGS employs underwater sensors, fish sensors, water quality sensors, meteorological sensors, and underwater cameras for comprehensive monitoring.

The co-location of aquaculture and scuba diving tourist expeditions, facilitated by Planet Blue diving center, introduces a dynamic multi-use dimension. AQUAWINGS is dedicated to aquaculture activities, providing monitoring and planning services for both diving and aquaculture activities. Its technical capabilities extend to diverse functionalities, incorporating AI-driven algorithms for optimal feeding, production planning, grading, breeding, disease prevention, infrastructure maintenance, and environmental sustainability. Predictive analytics are applied to analyse average fish weight, water quality trends, identify irregularities, and generate alerts for potential issues. The coexistence of tourism and aquaculture raises concerns about increased touristic pressure in already populated areas. Coastal cumulative impacts and potential environmental stress due to recreational fishing activities need careful monitoring. The challenge is to strike a balance between promoting sustainable aquaculture practices, increasing the commercialization of local fish products, and avoiding overexploitation of fish stocks.

In light of the PATROKLOS Pilot site falling under the protection of NATURA 2000 and the Treaty of Barcelona, the aquaculture unit operates within a zone of absolute protection, emphasizing the need for responsible practices. To address concerns related to eutrophication and the introduction of non-natural substances, specific measures are implemented. For managing eutrophication, controlled feeding practices are employed to minimize excess nutrient release into the water. An advanced monitoring system is in place to regularly assess water quality, detect nutrient levels, and ensure compliance with environmental standards. Simultaneously, efforts are made to minimize the introduction of non-natural substances. Responsible aquaculture practices aim to decrease the reliance on medications. The cleaning of infrastructure is carried out using innovative methods that minimize the use of chemicals, ensuring a reduced impact on the marine environment. Adherence to strict regulations and guidelines governs the use of any substances, emphasizing proper disposal methods to minimize environmental impact.

In the Greek pilot, the Aquaculture and Tourism multi-use activities have the potential to enhance public awareness of sustainable aquaculture practices, increase the marketability of local fish products, and contribute to the economic viability of the region. The monitoring and decision support capabilities of AQUAWINGS minimize adverse impacts by providing real-time data on critical parameters such as water quality, aquaculture activities, and environmental conditions. This enables prompt identification of potential issues allowing for immediate and targeted interventions. For example, if the system detects a deviation in water quality parameters, aquaculture operators can take corrective actions, such as adjusting feeding practices or implementing preventive measures against diseases. This proactive approach ensures that adverse impacts are mitigated swiftly, contributing to the overall health and sustainability of the aquaculture environment. Continuous evaluation and adaptive management are essential to ensure the long-term environmental sustainability of these multi-use activities.

The Greek pilot has implemented several measures to enhance environmental benefits and mitigate adverse environmental impacts. The current scale of the pilot is relatively small, making it challenging to quantify the effectiveness of these measures at this stage. Nevertheless, the conceptual significance of these measures for the environment is deemed potentially substantial, prompting a commitment to further exploration in larger-scale experiments.

3. LESSONS LEARNED FROM UNITED (PILOTS)

The lessons learned from the pilots on approaches to maximize the environmental gain and minimize negative environmental impact of multi-use of marine space can be looked at from different perspectives. Section 3.1 considers the commonalties of the five individual pilot approaches described in Chapter 2. Section 3.2 to 3.6 highlight key items from other lessons learned regarding the environmental pillar; outputs of work performed and reported in other UNITED tasks and deliverables but fitting the scope of Task 4.5.

3.1. Commonalities of the pilot approaches

There are several commonalities between the individual approaches:

Choice of materials and methods

Environmental impact was considered during the selection of materials and methods. Two examples are the choice to avoid piling, sometimes even drilling, when anchoring the installations and the selection of a small mesh size for a seaweed cultivation system. These approaches taken by the pilots relate to several environmental pressures that were described by Borgwardt et al. (2019) or MacDiarmid et al. (2011) and were raised in UNITED D4.2 (2021) and UNITED D4.3 (2022): (I) abrasion/damage; the physical interaction of anthropogenic activities with the seafloor and with the benthic fauna/flora causing physical damage and/or mortality (II) noise; the introduction of noises beyond regular background levels for example produced by pile driving (III) entangling in net-type structures; the entanglement of megafauna in subsurface equipment including e.g. nets. Avoiding such activities and the choice of materials, while posing relatively small impact reductions at a pilot scale, would have large implications and impacts should such activities be deployed at commercial scale and high densities within OWF or in general at sea. With the installation of pilings at the scale of an entire OWF, the impact of such activities to support Low Trophic Aquaculture in an offshore scenario would be considerable. Similarly, the interaction with benthic fauna and flora and the negative impact that would result form higher density of installation and could be considerable and has the potential to negate or severely reduce positive benefits realised from the restoration of ecosystems through nature inclusive design or active restoration. Therefore, when put in the context of upscaling and commercial exploitation, the benefits of the choices made in the UNITED pilots would stand to be considerable. Furthermore, the attraction potential of small pilot deployment for short periods of time on megafauna are not as considerable as a long-term commercial activity and exploitation of a region if such activities are scaled and deployed over decades, as would be the case in commercial aquaculture activities. There is the potential, which is continually being investigated, that large areas where new potential food sources for megafauna are introduced and maintained through aquaculture activities could have a larger attractive effect on these species. The benefits from choosing proper design elements to negate such potential impacts is critical for scale spatial deployment and also temporal operations of these activities.

Vessel usage

Vessel time has been minimized, for example by consolidating installation tasks, sharing vessels for installation, inspection, and maintenance operations, placing the additional infrastructure at a strategic location in the site, and making use of the vessel movements that occur anyway. Reduced vessel time does not only reduce the fuel usage and thus carbon dioxide emissions, but it also relates to two of the environmental pressures noted in UNITED D4.3 (2022): collision of mammals with vessels and behaviour changing by being present (humans, objects, vessels, machinery etc.). The reduced usage realised at a smaller pilot development would be expected to be enlarged and the benefits enhanced when operating at a larger scale. This is particularly the case when optimised vessels are incorporated into the equation, for which there is interest by some of the ship operators in order to be more efficient in timing and have a higher potential for engaging with multiple activities with singular vessels. To fully capture the benefit of such developments and activities, increased scale of operations are required, in terms of space, where the aquaculture activities are at a larger scale, and also that the activities are operating for longer period of time, so that investment in such combined vessels and training of staff on capacity to engage in said combined activities are not dependant on sporadic demonstration pilot activities, but structurally engaged with through long-term commercial operations.

Raising public awareness of sustainable activities

While all pilots contribute to raising awareness and social acceptability of sustainable energy production and aquaculture, by communicating about project activities and results, the pilots that include tourism activities have a more direct means of doing so. Their tourism activities bring the general public close to the wind farm or aquaculture unit and can thereby increase their understanding of the scale and impact of these two sectors. As the sectors continue to develop and expand, such awareness and literacy initiatives must be consistent and continual to ensure that the changing landscape and scale of operations and impacts are understood, well communicated, and appreciated by society and all actors.

Pilot scale

Something that was pointed out in the pilot sections above and described in more detail in UNITED D4.3 (2022) and UNITED D4.4 (2023) is that, given the small scale of the pilots, it is difficult to assess their environmental impact and the effectiveness of their approach to optimize it. Unfortunately, this means that the current report cannot provide any lessons learned on the long-term effectiveness of the approaches taken in the UNITED pilots as the small scale and duration of the trials does not allow for such an assessment. Through the desk studies executed in the environmental and economic work packages and related deliverables have been able to achieve is a theoretical expansion of such activities and the proposed solutions. In so doing, the realised growth, production, and modelled potential impacts have been addressed and advice on continuous monitoring and betterment of operational and design strategies for multi-use have been proffered.

3.2. Environmental risk reduction of MU

As mentioned above, the small scale of the pilot meant that it was not possible to assess their environmental impact. However, within WP4, an Environmental Impact Risk Assessment (EIRA) has been applied to upscaled projections of the pilots to predict their potential impact and to compare the impact of a single-uses scenario and a multi-use scenario. The results presented in UNITED D4.4 (2023) show that substantial negative environmental impact reductions can be achieved through the implementation of multi-use instead of a single-uses situation without sharing of space, action or infrastructures. The highest reductions reported there are reductions of around: (I) 40% for two ecosystem components, fish and mammals, during the installation phase of upscaled Dutch and Belgian pilots (II) 15% for two ecosystem components, fish and mammals, during the operational phase of an upscaled Dutch pilot (III) 20% for the ecosystem component seabed habitats during the decommissioning phase of an upscaled Belgian pilot. These assessments were executed in the hope to provide insights and recommendations on the potential conditions and impacts that would result from the upscaling of activities to a commercial dimension, resulting in larger spatial coverage and density of the concerned activities and also over a longer time span. Where the UNITED pilots operated for 2-3 years, scaled operations would be present and operating continuously at higher densities than realised in this research demonstration project, and the impacts and changes in the environmental conditions resultant thereof must be considered. Monitoring and assessing such impacts is not feasible at a smaller scale, but the knowledge and information gained from the UNITED trials and demonstrations can be utilised to support the projection and modelling efforts to provide better support and evidence for the projections and scenarios developed and executed in a desk study manner.

In addition to the application of the EIRA to upscaled projection of the pilots, the EIRA has also been applied to an optimal scenario, that is a scenario in which existing technological and regulatory challenges have been resolved and in which the combination of the activities within the multi-use concept have been enhanced, as presented in UNITED D8.3 (2023). Their analysis demonstrates that, in a future that fully enables multi-use projects, those projects can provide considerable reductions in environmental impact risk.

3.3. Added value of MU through environmental benefits

The EIRAs, which focussed mainly on the reduction of negative environmental impact, have been supplemented with an analysis on the positive wider consequences of multi-use projects. This analysis was performed under task 4.4 of WP4 and has been described in UNITED D4.4 (2023). Their assessment was based on a literature and on workshops with the partners of the UNITED pilots during the General Assembly of the project in February 2023. UNITED D4.4 (2023) describes the following wider consequences: oyster reef restoration or creation, biodiversity increase, nutrient cycling, carbon sequestration, commercial fish species increase, sustainable food production, more space for conservation, reduction of conflicts over space use, and increased social acceptance of offshore wind farms and low-trophic aquaculture.

3.4. Design of offshore wind farms for multi-use

Besides the wider consequences of multi-use, UNITED D4.4 (2023) also discusses several optimization measures to make offshore wind farms and aquaculture more suitable for multi-use. UNITED D4.4 (2023) elaborates on the following four aspects: nature inclusive design, rethinking decommissioning of offshore wind farms, using an electrical fleet to operate at sea, and using biodegradable materials in aquaculture farms. Their considerations can serve as guidance for future project developers. This includes the development and planning of the combined activities form the onset. This is a critical point in order to optimise the layout, configurations, and objectives of the planning and development of off-shore combined use zones. In consideration of the spatial extent of such developments, if the objective is maximize the use of the spatial footprint within the ecological carrying capacities and ensuring no ecological degradation and/or supporting restorative efforts, the delineation of zones and placement of structures from a design and management perspective results in a different configuration than when optimising to have the maximal energy production output with minimized costs. As such installations are often serving an operational lifespan in excess of 20 years, ensuring that the objectives for off-shore development and multi-use ambitions are embedded and utilised in the near-term, to best coincide with the projected expansion of the offshore renewable energy production, is critical in managing the spatial configuration of said development to allow for, and enable optimal configurations for combined activities.

3.5. Commercial benefits and environmental impacts

The economic analyses that have been performed within the project and reported in deliverables of WP3 and WP8 also paid attention to environmental impacts of ocean MU. However, during the analysis, several challenges were encountered, for example, the unavailability of information regarding ecosystem services at the pilot locations, information that is essential to establish the baseline for the analysis (UNITED D8.2, 2023).

As reported in UNITED D8.2 (2023), the evaluation grid that was created to assess the critical aspects of applying the economic analysis within the project contains the sub-element "costs of negative environmental externalities" as one of the three sub-elements for "Economic costs". However, the authors' analysis revealed a clear lack of data regarding this sub-element, which they attribute to challenges associated with both the research-oriented character of the UNITED pilots and the reasonably new status of the sectors involved in them (UNITED D8.2, 2023). The scales of development are critical in order to fully be able to attribute economic benefits to the deployment of such activities at sea, as well as the conditions in which the development occur. It has been reported across a number of the economic deliverables of the UNTIED project that the

One of the lessons learned from the economic analysis, connected to the environmental pillar, is that performing an ex-ante economic analysis proved to be challenging and that additional ex-post analysis, at a later development stage, would be needed to gain a more comprehensive understanding of the full economic impacts, especially for the environmental benefits (UNITED D8.2, 2023).

3.6. Conservation benefits

A discussion of the conservation benefits of multi-use has been presented in a report on the environmental assessment and validation, UNITED D8.3 (2023). This discussion focuses on the potential of ocean MU as a tool to achieve European environmental goals and strategies, including its potential to either achieve or maintain Good Environmental Status (GES) as defined in the Marine Strategy Framework Directive (MSFD). For each of the eleven descriptors that together define the GES, UNITED D8.3 (2023) evaluates the potential positive or negative impact that ocean MU may have on it. In addition, their report also elaborates on the role of ocean MU regarding Marine

Spatial Planning (MSP) and the Green Deal. In consideration of the spatial requirements to achieve the target and ambitions being set forth by European member states for energy production as well as low-trophic aquaculture biomass and food-stuff production, the conservation benefits and potential is critical to account for. With the demand on marine space increasing, and ambitions for conservation reaching higher levels in order to protect and restore our marine space for current and future generations, such assessment and metric stand to inform and direct choice for the soon to come development plans. While the deliverable is not able to ascribe concrete numbers on the impacts large scale or high density development will impart onto the environment, they do give indications for required modelling and impact projects for future project and scaled applications. As noted as commercial applications for the offshore renewable energy development (either solar or wind) and aquaculture have considerably longer operational requirements and larger spatial extents in order to be commercially viable, the extent to which environmental benefits or conservation objective can be enhanced, support, or hindered must play a role in the selection of methods, locations, and densities of these activities.

4. CONCLUSION

The first part of this deliverable has presented the approaches taken by the five UNITED pilots to optimize their environment impact and highlighted the overlap between them. Unfortunately, it was not possible to quantify to effectiveness of these pilot-level actions, given the small scale of the pilots. The second part of the deliverable guides the reader to the key results and lessons learned for the environmental pillar of the project, as reported throughout the deliverables of WP4 and WP8. This directs them to reports with in-depth analyses and discussions regarding environmental risk reduction of MU, added value of MU through environmental benefit, design considerations of offshore wind farms for multi-use, the link between economic benefits and environmental impacts, and the conservation benefits of MU. The key results and recommendations of the environmental pillar feed into the Catalogue of multi-use blueprints (D1.5), one of the main outputs of the project that combines the results of the UNITED multi-use cases and serves as guidance for future offshore MU development. The catalogue contains four blueprints, one for each type of multi-use combination implemented within the UNITED project. Thus, the approaches taken by the pilots to reduce the negative environmental impact, reported in chapter 2 have been included as examples in these how-to guides. For example, those from the German, Dutch and Belgian pilot have been included in the blueprint for the combination “Offshore wind and low trophic aquaculture”.

REFERENCES

Borgwardt, F., Robinson, L., Trauner, D., Teixeira, H., Nogueira, A. J., Lillebø, A. I., & ... & Culhane, F. (2019). Exploring variability in environmental impact risk from human activities across aquatic ecosystems. *Science of the total environment, 652*, 1396-1408.

Dongen, V. (2021). *Simulating wave attenuation by an offshore floating solar system.* MSc-thesis. Retrieved from http://resolver.tudelft.nl/uuid:f0248757-0bd6-4065-8cc1-8b54884d7ef5

MacDiarmid, A., Beaumont, J., Bostoc, H., Bowden, D., Clark, M., Hadfield, M., & ... & Ching, N. (2011). *Expert Risk Assessment of Activities in the New Zealand Exclusive Economic Zone and Extended Continental Shelf Prepared for the Ministry for the Environment.*

UNITED D4.1. (2020). *Revision of the Current Environmental Assessment and Status of Pilots.* Deliverable 4.1 of the European Horizon 2020 UNITED project. Retrieved from https://www.h2020united.eu/images/PDF_Reports/D41_current_environmental_assessment_and_status_of_the_pilots_revised_dec2021_220207.pdf

UNITED D4.2. (2021). *Assessment Framework to Determine Ecological Feasibility of Multi-Use Platforms.* Deliverable 4.2 of the European Horizon 2020 UNITED project.

UNITED D4.2 Annex 9. (2021). *ANNEX 9. Manual for the implementation of environmental assessments in the UNITED pilots: establishing uniformised integrated Cumulative Effects Assessment.* Annex 9 in UNITED Deliverable 4.2 of the European Horizon 2020 UNITED project.

UNITED D4.3. (2022). *Application of Assessment Framework within Pilots.* Deliverable 4.3 of the European Horizon 2020 UNITED project.

UNITED D4.4. (2023). *Environmental Impact Assessment Models for the Commercial Rollout of Multi-Use Platforms.* Deliverable 4.4 of the European Horizon 2020 UNITED project.

UNITED D8.1. (2023). *Report on technical assessment and validation.* Deliverable 8.1 of the European Horizon 2020 UNITED project.

UNITED D8.2. (2023). *Report on socioeconomic assessment and validation.* Deliverable 8.2 of the European Horizon 2020 UNITED project.

UNITED D8.3. (2023). *Report on environmental assessment and validation.* Deliverable 8.3 of the European Horizon 2020 UNITED project.

UNITED D8.4. (2023). *UNITED auditing procedures and TRL assessment manual.* Deliverable 8.4 of the European Horizon 2020 UNITED project.