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DELIVERABLE 8.5

IMPLEMENTATION PLAN FOR THE OPERATION AND MAINTENANCE

Work Package 8

Assessment and Validation

December 12th, 2023

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Abstract	This deliverable provides a detailed implementation plan for the operation and maintenance (O&M) of multi-use offshore platforms within the UNITED project. The key points of the implementation plan discussed in this deliverable are: 1. Project Definition, 2. O&M Philosophy & Methodology, and 3. Pilot-specific O&M. This deliv-erable serves as a comprehensive resource, offering guidance for future multi-use projects on effectively managing the complexities of offshore operations. It emphasizes that successful O&M

	planning should commence early in the project's conceptual design phase, ensuring the project's goals are not only achieved but sustained throughout its lifecycle.
Keywords	Multi-use, Energy production, Aquaculture, Seaweed, Tourism, State-of-the-art, Europe, O&M, Operation & maintenance

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ACRONYMS

ADCP	Acoustic Doppler Current Profiler
CCT	Coordination Committee Team
CSET	Core Services Exploitation Team
CT	Consortium Coordination Team
EC	European Commission
IPR	Intellectual Property Right
O&M	Operation and Maintenance
PA	Partner Assembly
PM	Project Management
SAB	Stakeholder Advisory Board
WP	Work package
FINO3	Forschungsplatform in Nord- und Ostsee Nr. 3

EXECUTIVE SUMMARY

This deliverable provides a detailed implementation plan for the operation and maintenance (O&M) of multi-use offshore platforms within the UNITED project. The project's primary objective is to promote cost-effective and eco-friendly production in sustainable marine activities. This report emphasizes the importance of aligning the O&M plan with the project's overarching goals and provides a systematic methodology for developing a robust O&M plan.

The key points of the implementation plan discussed in this deliverable are:

1. Project Definition: The importance of defining the project's main goals, duration, budget, location, design, roles and responsibilities, stakeholders, and required facilities/assets is highlighted. This early consideration ensures that the O&M plan aligns with the project's objectives.
2. O&M Philosophy & Methodology: In this chapter the philosophy guiding O&M during the operations and maintenance phases is discussed, emphasizing the need for proactive monitoring, maintenance, and adaptability. In addition, the importance of documentation throughout the project is underscored. The methodology section explores the two primary methods of obtaining information for O&M – remote monitoring and inspections. It also outlines essential procedures and safety protocols for offshore work, along with the importance of comprehensive documentation.
3. Pilot-specific O&M: Lessons learned and recommendations are provided for the specific pilot locations (Germany, The Netherlands, Belgium, Denmark and Greece). These insights cover a range of topics, including permitting challenges, flexibility in O&M, safety considerations, and adapting to external factors like the COVID-19 pandemic.

This deliverable serves as a comprehensive resource, offering guidance for future multi-use projects on effectively managing the complexities of offshore operations. It emphasizes that successful O&M planning should commence early in the project's conceptual design phase, ensuring the project's goals are not only achieved but sustained throughout its lifecycle.

1. INTRODUCTION

1.1. Scope & objective deliverable

The UNITED project aims to boost cost-effective and eco-friendly production in sustainable marine activities with multi-use offshore platforms demonstrators. Part of operating offshore multi-use in a cost-effective and eco-friendly way is the successful implementation of the operation and maintenance (O&M). Within the UNITED project five different multi-use pilots were operational. The lessons learned within these pilots are the input for the "implementation plan for the operation and maintenance" of offshore multi-use presented in this report.

The goal of this O&M document is to enable future multi-use pilots & projects to successfully operate & maintain their offshore multi-use for the full intended life cycle. This document should be read before the detailed design of a potential multi-use project as the O&M plan can impact or influence the final design. It is also helpful for those who have already developed their multi-use project to identify what to consider or make for the O&M phase of their project, although it would be more effective if done at an earlier stage.

1.2. Outline of the report

This deliverable will document the implementation plan for the operation and maintenance of multi-use pilots. It begins by helping the reader reflect on the main goals of their offshore multi-use project, on how it would impact the resulting O&M plan, and if any decisions regarding the design or budget allocation of the pilot, for example, need to be made on behalf of O&M (chapter 2). Next, the general O&M philosophy & methodology for offshore operations will be discussed (chapter 3). Finally, the additional pilot specific lessons learned and recommendations for O&M of the different types of offshore multi-use are discussed (chapter 4). The report finished with the conclusions and references (chapter 5 & 6).

2. PROJECT DEFINITION & OUTLOOK FOR O&M

Before developing an Operations & Maintenance plan, it is useful to first reflect on the offshore project being developed. How far offshore will it be? How long will it be operational? What are the goals of the project or pilot? These are just some examples of questions that should be answered or taken into consideration during the conceptual design phase of any given offshore pilot. Reflecting on them will impact the resulting O&M plan which will impact the conceptual design correspondingly. This chapter will serve as a guide to work out the characteristics of the given pilot so that they can be expanded upon in relation to O&M in the next chapter.

2.1. Main Goal

First of all, it is important to define the main goal of the project or pilot in a concise way. This is initially in the form of a mission statement and followed up by the system requirements, stakeholder requirements, etc. The mission statement should describe what the project will do and not go into the detail about how it works or what it is exactly. This is a useful first step to make sure that all stakeholders are in agreement with the goal of the project.

Furthermore, initial requirements should be worked out to define the constraints of the project and take into account the needs of any partnered stakeholders in the process. These should follow the "S.M.A.R.T." methodology commonly used in engineering practices (specific, measurable, achievable, relevant, time-based) where applicable. These will greatly shape the design of the project and similarly, the O&M plan. Later on, requirements will be worked out in more depth for the design to enable successful operation and maintenance phases of the pilot. Examples:

Mission Statement: The Offshore Solar Pilot will demonstrate that offshore solar installations can survive a full year in the conditions of the North Sea.

System requirement: The pilot's structure shall not require operational maintenance for the duration of 1 year.

Stakeholder requirement: All vessels used in the operation and maintenance of the pilot must feature at least level 2 dynamic positioning.

By defining the goal and requirements in a concise way, direction is already given to the content of the operation and maintenance plan. This also applies to the aspects mentioned in the following paragraphs.

2.2. Duration

The full life cycle of the pilot or project should be figured out before the start of the project. This should include all of the relevant phases (Design, Manufacturing, Operation, Decommission, etc.). Be sure to include major milestones within the phases and initial estimations for the start and end of each phase. Having the length of the operation phase worked out is absolutely key to developing a successful O&M plan. It is also advised to work in extra margins and buffer for delays or things that might go wrong.

2.3. Budget

Before starting the development of an O&M plan, one should have an idea of the total O&M budget that the project can expect to have for the entire duration of the project. One could already break it down into preliminary categories based on the different phases of the project. It is likely going to change quite a bit after the formation of the O&M plan, so there is no need to work the budget into too much detail yet.

2.4. Location & Logistics

If possible at this stage, it is highly beneficial to already have the location of your pilot or project figured out. This will allow much more detailed plans to be made as one knows where it will be located offshore, what conditions it will then be subjected to, and how close any required facilities are. This will have a massive effect on the design of your project. For example, pilots located far offshore shouldn't require frequent monitoring trips or should be monitored remotely. The necessary trips will require more planning, preparation, and possibly different ships to ensure successful visits. Pilots located closer to the shore can get away with more frequent trips, smaller ships, and maybe less planning in advance.

2.5. Design of the installations

An important aspect for the O&M is the design of the installations of the multi-use project. This works two ways. On one hand, the design of the installations determines the necessary O&M activities during the project. On the other hand, the requirements and possibilities in O&M can also result in changes in the design. This holds for the overall concept of the design and for the more detailed sub-system designs of the installations and monitoring equipment.

2.6. Roles and responsibilities

Roles and responsibilities play a crucial role in the effectiveness of an O&M plan, particularly in the context of offshore multi-use installations, due to the complex and challenging nature of these environments. They promote safety, efficiency, compliance, and collaboration, all of which are essential for the successful and sustainable operation of complex offshore facilities.

2.7. Other Stakeholders

Before detailed development of a (pilot) project can begin, a full list of the various stakeholders who will be involved during the different phases of the project should be established. This can aid in the development of the requirements and other constraints of the project in an early stage.

A very important aspect to consider are the needs which stem from the location of the pilot. Depending on who is responsible for the section of ocean used by the project, there will be different requirements one must adhere to and/or licenses, permits, etc. which must be acquired before the start of the pilot. If the pilot can be situated somewhere where another pilot has already taken place, this will help speed up the process as the stakeholder will likely already have a set of requirements the pilot must follow. It is recommended to start this conversation as soon as possible, even more so if there is no history of other pilots taking place there, as it will take longer to come to a good understanding with the stakeholder responsible for that section of ocean.

2.8. Needed Facilities/Assets

It should also be preliminarily determined what facilities and assets will be needed for each phase of the pilot or project. This will impact the list of stakeholders from the subsection above and correspondingly your requirements. It might also change budget allocation for certain areas depending on what things need to be acquired for the pilot. Examples include boats (and what types), machines, spaces, storage, and offshore equipment. This list will be extended as the pilot is designed and in relation to the O&M as it is worked out (such as spare parts, maintenance equipment, etc.). This is discussed further in the next chapter.

If the types of boats are known in advance, one can work the O&M plan out in further detail regarding aspects like whether a crane will be available, how high up the boat’s deck is from the water surface, and what the range is of the vessel. Working with the stakeholder who owns or manages the location of your pilot is recommended, in order to determine any requirements regarding the vessels which can operate there such as dynamic positioning.

3. O&M PHILOSOPHY & METHODOLOGY

After covering the defining characteristics of offshore pilots in the previous chapter, this chapter will go over overall O&M methodology and how it relates to the characteristics previously defined.

3.1. Philosophy

3.1.1. Operations Phase

The Operations phase can be described as the period where the pilot is running as planned, monitored, and assessed. This is done through methods and procedures worked out in the O&M plan and done by the personnel of the pilot qualified to do so. The pilot should be assessed regarding its performance in relation to its main purpose, the performance of its offshore structure, the budget required to operate it, its ecological impact, the logistics required to operate it, etc. Any problems which arise should be documented as well as the corresponding recommendations for the future.

3.1.2. Maintenance

The purpose of maintenance is to enable the pilot to survive for the total duration of the Operations Phase. A large aspect of this is the inspection and monitoring of the pilot from a maintenance point of view. In comparison with the monitoring done for Operations (e.g. how well is the seaweed growing), the monitoring done here is for matters like how well the structure is surviving offshore, what damage can be observed, and if any functional parts impeding the operation need to be replaced. Any issues that arise during the operation of the pilot, that can be fixed, are also identified. The steps taken as a result of these issues can be both reactive and proactive, to prevent failure later down the road. Information about the failures, how they were mitigated, and whether it was successful are recorded. Overview of the spare parts stockpile and which are used is also recorded.

3.1.3. O&M Plan & Usage

The Operations & Maintenance Plan should enable the pilot to perform at its required level for the entire duration of the operations phase within budget and without delay. The plan developed for any pilot will be evolving until the last minute and throughout the operations and maintenance phase itself. That does not mean that no preparation is needed. One should develop a preliminary O&M plan after the initial concept development and should update it following every iteration of the design. That being said, it is also worthwhile consulting the O&M plan first before completing another iteration of design. It might give you added awareness to factors that should be taken into account. It is best to have these factors represented in your list of requirements for the pilot. This is shown in the following two figures. The design and operation of a pilot has several phases which are summarized in Figure 1. Operation & Maintenance as considered in this deliverable starts after the installation phase and is followed by the decommissioning.

Figure 1: Different phases of design and operation of a pilot

However, decisions on how to do perform this O&M should be considered in the design phase already. Figure 2 shows an example from the systems engineering. This states that the plan for O&M should already be considered in the design process. This is at an early stage, before starting to dive into the system requirements and more detailed design. The same applies for multi-use pilots: the O&M plan should already be developed in an early stage. The design of the pilot might be adjusted during development of these elements. For example, the budget for operation might need to be adjusted if a larger ship with a crane is needed to inspect the pilot or if remote monitoring options are desired. Similarly, the design of the pilot could be altered such that inspections could be carried out with a smaller ship. All of these things are interconnected. As mentioned before, the O&M plan can of course be adjusted during the pilot due to additional or external circumstances.

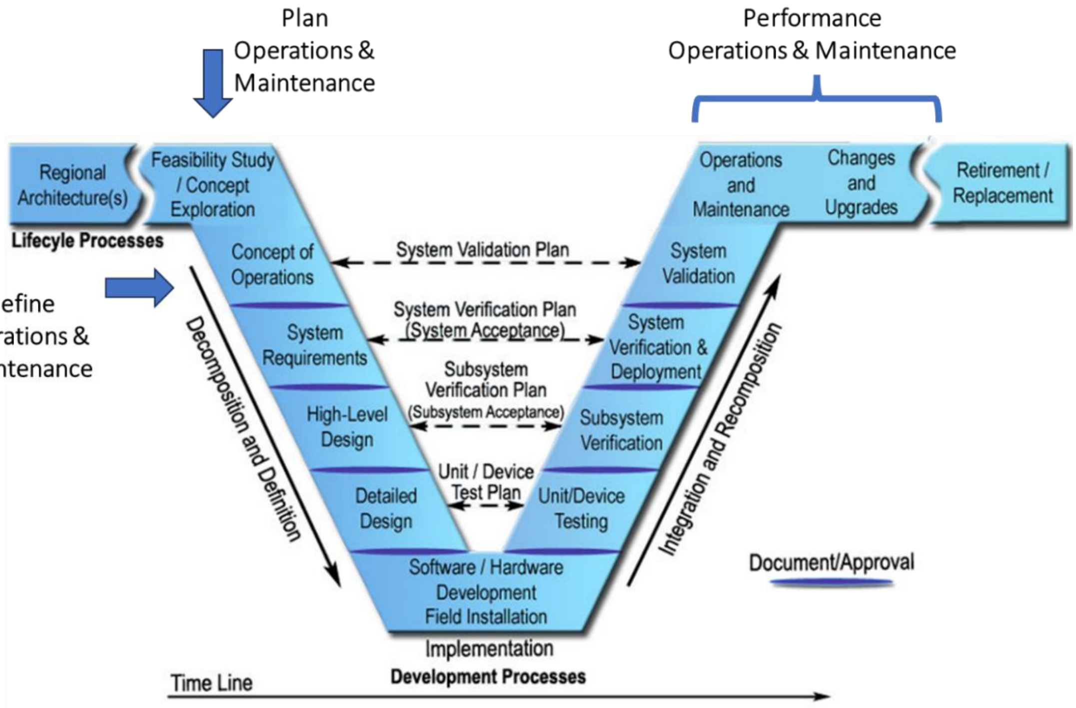


Figure 2: Operations & Maintenance in the V-model of Systems Engineering [1]

3.2. Methodology

After discussing the philosophy and important aspects for setting up the O&M implementation plan, time to dive into the methodology. Two different methods to get information on the needed O&M are discussed. Next, the useful procedures to operate in a safe way are mentioned. The final paragraph is on the documentation of all the O&M activities.

3.2.1. Remote monitoring

The first way to retrieve the necessary information about the status of and conditions of the multi-use pilot is via remote monitoring. Depending on the goal of the multi-use pilot and the costs, decision on what to monitor remote via sensor equipment can be made. In addition, choices need to be made about what data should be available via life stream, so it is visible from land / dashboard when O&M is needed. This results in a requirement list for remote monitoring for a specific multi-use pilot or project. More insight on remote monitoring and data collections within the UNITED project can be found in deliverable D10.3. An example of a remote monitoring dashboard from the Dutch pilot is shown in Figure 3.

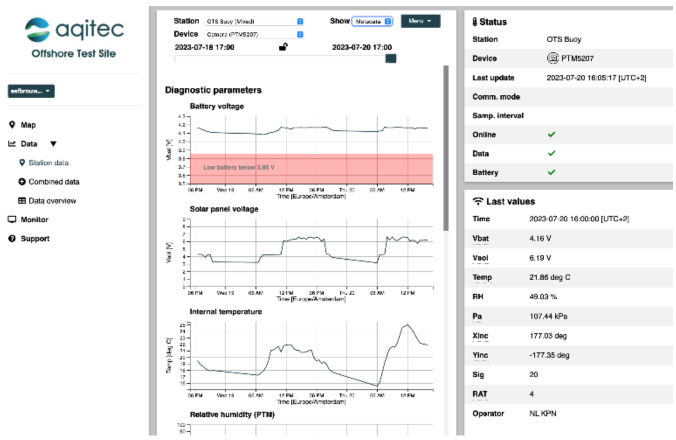


Figure 3: Example of a remote monitoring dashboard from the Dutch pilot

[1] *Systems Engineering for Intelligent Transportation Systems – An introduction for Transportation Professionals, Department of Transportation*, Office Operations, January 2007

3.2.2. Inspections

Another way of retrieving the information on the multi-use pilot is via physical inspections. If needed, action can be taken immediately as a vessel is already offshore. Inspections can be planned up front, as part of the O&M plan, or based on the information retrieved via remote monitoring. Before the start of a project, a schedule for the planned inspections must be made. Depending on the activities, the right vessel has to be chosen and the necessary equipment must be on board. An example of two vessels used for inspections at the Dutch pilot are shown in Figure 4.

Figure 4: Example of two different vessels used for inspection in de Dutch pilot

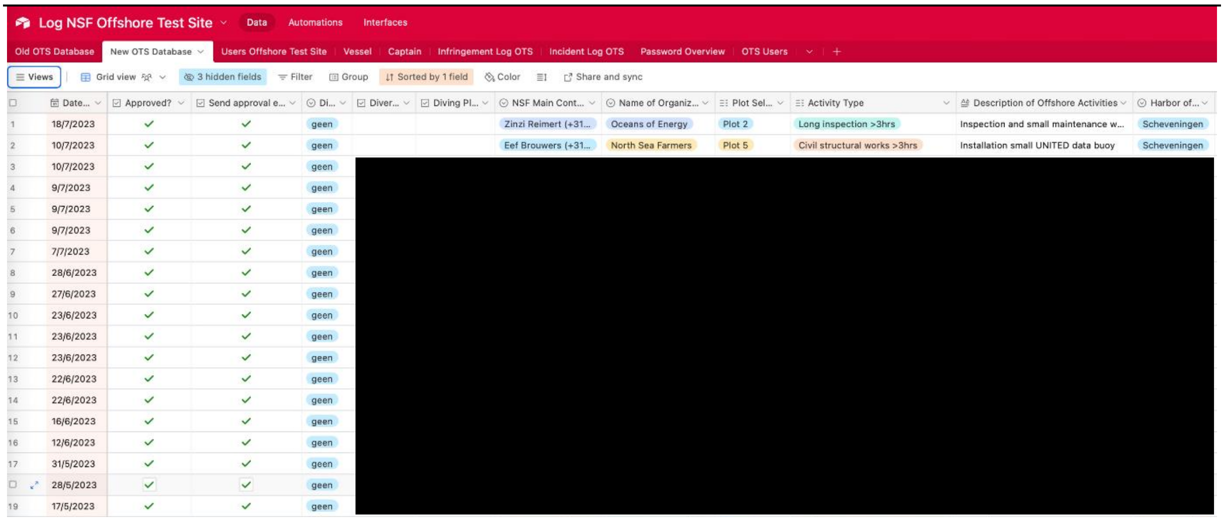
3.2.3. Procedures

During the execution of the O&M plan, the right procedures must be followed. This can be done in several ways, an example of list procedures to consider follows:

- Risk analysis & mitigations
- O&M procedure
- Safety management
- Emergency Response Plan
- Offshore training for staff / personnel trainings
- Offshore work planning / inspection schedule
- Spare parts register
- Maintenance log
- Offshore monitoring plan (remote or physically done)
- Report template & guidelines

3.2.4. Documentation

Documentation of offshore multi-use operation and maintenance activities is of paramount importance for a variety of reasons. In the challenging and complex environment of offshore installations, proper documentation serves as a foundational element for effective management, safety assurance, regulatory compliance, decision-making, and long-term sustainability. An example for the Dutch pilot (at the North Sea Farmers Offshore Test Site) is shown below. All activities undertaken are recorded in this dedicated activity log. Depending on the size of the pilot or project and the corresponding risks, the documentation will be more elaborate. The documentation of offshore multi-use operation and maintenance activities is essential for safety, compliance, accountability, efficiency, knowledge preservation, and informed decision-making. It helps ensure that these complex installations are managed effectively, minimizing risks and optimizing their performance over their operational life.



	Date...	Approved?	Send approval e...	Di...	Diver...	Diving Pl...	NSF Main Cont...	Name of Organiz...	Plot Sel...	Activity Type	Description of Offshore Activities	Harbor of...
1	18/7/2023	✓	✓	geen			Zinzi Reimert (+31...	Oceans of Energy	Plot 2	Long inspection >3hrs	Inspection and small maintenance w...	Scheveningen
2	10/7/2023	✓	✓	geen			Eef Brouwers (+31...	North Sea Farmers	Plot 5	Civil structural works >3hrs	Installation small UNITED data buoy	Scheveningen
3	10/7/2023	✓	✓	geen	[redacted]							
4	9/7/2023	✓	✓	geen	[redacted]							
5	9/7/2023	✓	✓	geen	[redacted]							
6	9/7/2023	✓	✓	geen	[redacted]							
7	7/7/2023	✓	✓	geen	[redacted]							
8	28/6/2023	✓	✓	geen	[redacted]							
9	27/6/2023	✓	✓	geen	[redacted]							
10	23/6/2023	✓	✓	geen	[redacted]							
11	23/6/2023	✓	✓	geen	[redacted]							
12	23/6/2023	✓	✓	geen	[redacted]							
13	22/6/2023	✓	✓	geen	[redacted]							
14	22/6/2023	✓	✓	geen	[redacted]							
15	16/6/2023	✓	✓	geen	[redacted]							
16	12/6/2023	✓	✓	geen	[redacted]							
17	31/5/2023	✓	✓	geen	[redacted]							
	28/5/2023	✓	✓	geen	[redacted]							
19	17/5/2023	✓	✓	geen	[redacted]							

Figure 5: Example of an activity log at the Dutch pilot (part blocked due to privacy reasons)

4. PILOT SPECIFIC O&M

During the UNITED project, each pilot faced specific challenges and drew lessons learned during their O&M phase. In the next sections, for each pilot, these lessons learned and recommendations will be discussed. Both pilot specific elements (for example the location of the pilot) as well as general multi-use items are described. For the overview: the next table shows the different types of multi-use per pilot.

Table 1: Overview types of multi-use per pilot

	Mussels	Algae / seaweed	Oyster	Fish	Floating solar	Wind energy	Tourism/aquaculture	Lander / data buoy
1. German pilot	■	■						■
2. Dutch pilot		■			■			■
3. Belgium pilot		■	■			■		
4. Denmark						■	■	
5. Greece				■			■	

4.1. German pilot

The German pilot site “FINO3- Forschungsplatform in Nord- und Ostsee Nr. 3” is situated 80 km north of Helgoland in the highly exposed marine environment of the North Sea. The study site features the "FINO 3" sensor tower, which stands 120 meters tall with a working platform positioned 22 meters above sea level. The primary purpose of the tower is to conduct research to support the establishment of wind farms in the area. Within the 500-meter safety zone around the "FINO 3" tower (Figure 6), the aquaculture project has been implemented, focusing on mussel and algae cultivation. The coexistence of the tower and aquaculture provides a demonstration of potential multi-use applications in the marine environment. Additionally, the "FINO 3" pilot site is adjacent to the DanTystk windpark, comprising 80 wind turbines generating 288 MW of power (www.dantysk.de).

Figure 6: FINO3 tower

The aquaculture system consisted of a mussel and an algae-cultivation line. Positioned between both lines was a monitoring system that was connected to the FINO3 platform by a sea cable for data transmission, see Figure 7. The monitoring system comprised a stationary base platform equipped with a multibeam echosounder and an Acoustic Doppler Current Profiler (ADCP). On top of the stationary base, there was a winch system equipped with different sensors that could be moved vertically through the water column to monitor oxygen, algae density, and nitrogen compounds. The multibeam echosounder was designed with three sounding heads to monitor algae and mussel growth, as well as the occurrence of fish and marine mammals in the vicinity surrounding the aquaculture system. Meanwhile, the ADCP allowed for accurate measurements of water currents, enabling a comprehensive assessment of the flow patterns and potential impacts on mussel and algae growth.

Lessons Learned

The first hurdle to be overcome was the acquisition of all necessary permissions for the installation of the system. Typically, a period of 6 weeks is sufficient to secure all required permits. However, as this marked the inaugural instance of an offshore multi-use system in the German North Sea, the permitting process extended to 8 months, and specific requests for monitoring endangered species were made to obtain the permit. Nevertheless, it was successfully obtained, and in the course of this process, a strong connection with the regulating body, the BSH, was established, paving the way for future undertakings to be expedited. During the operation and maintenance phase several other challenges arose.

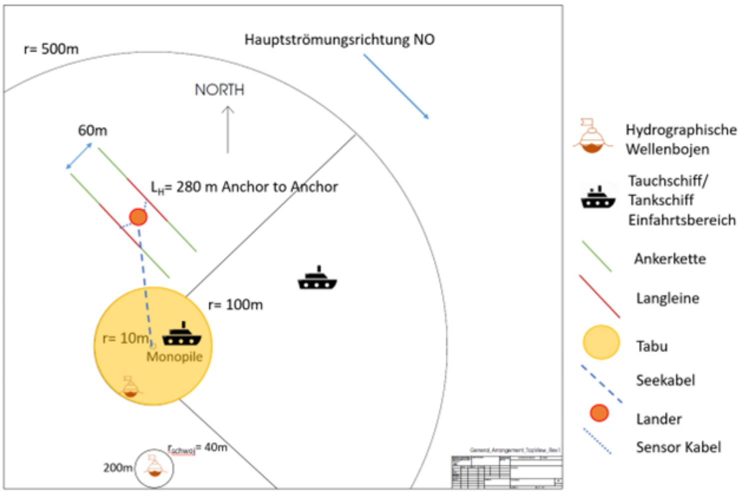


Figure 7: Overview German pilot location

Availability of vessels

Operating the mussel and algae aquaculture system near an offshore wind park has been affected by vessel availability issues. No specialized vessels for the dual tasks of aquaculture and wind park maintenance exists. In general, offshore vessels are in high demand. Often, these vessels are booked for wind farm maintenance and other offshore works, that are more profitable, leaving limited windows for pilot sized aquaculture activities. The scarcity of suitable vessels has led to delays, leading to adjustment of maintenance plans.

Weather conditions

The success of offshore operations is highly dependent on weather conditions. The marine environment can be unpredictable, with adverse weather conditions such as high winds, heavy seas, and storms posing significant risks. These conditions can lead to downtime, where operations must be halted to ensure the safety of personnel and equipment. This unpredictability can disrupt both mussel and algae cultivation and maintenance processes. Especially the limit to a maximum wave hight of 1 m for maintenance work of the aquaculture system limits drastically the work windows available due to weather conditions. Furthermore, extreme weather events can cause physical damage to the cultivation infrastructure that could be prevented due to extra rigid construction. However, the more delicate monitoring equipment on the lander did suffer tremendously under the harsh offshore conditions and several components were lost. Only due to sufficiently planned monitoring backup no crucial data was lost.

Restrictive health regulations during and after the pandemic

The COVID-19 pandemic introduced restrictive health regulations that have had lasting impacts on offshore operations. These regulations include social distancing measures, quarantine requirements, and limitations on crew rotations. Ensuring compliance with these health regulations can be challenging in the confined spaces of vessels. Moreover, the need for regular health monitoring and potential quarantine periods can reduce the availability of skilled labour and increase operational costs. The pandemic has also highlighted the need for robust health and safety protocols to prevent outbreaks in remote offshore settings, adding another layer of complexity to operational planning

Increase in costs due to rising fuel prices

Rising fuel prices had a significant impact on the cost structure of offshore operations. Vessels used for transportation, maintenance, and cultivation activities consume large amounts of fuel, and any increase in fuel prices directly translates to higher operational costs. This can affect the economic viability of the mussel and algae cultivation system. Higher fuel costs lead to increased transportation fees, higher prices for goods and services, and will lead to overall reduced profit margins. By considering fuel-efficient practices such as combining different work steps, rising fuel prices were mitigated.

Delivery problems of material and increase in material cost

Supply chain disruptions have become a persistent problem, leading to severe delivery issues for essential materials needed for operation and maintenance. Delays in receiving construction materials, spare parts, and other critical supplies have stalled projects and maintenance activities. Additionally, the rising costs of materials have added another layer of financial burden. These supply chain issues have forced the pilot lead to diversify their supply sources, increase inventory levels, and strengthen synergistic work among all pilots to stabilize costs and ensure timely availability of necessary resources.

In conclusion: Within the German pilot operating a mussel and algae aquaculture system near an offshore wind park has proven to be fraught with challenges. Vessel availability issues, adverse weather conditions, restrictive health regulations, rising fuel costs, and supply chain disruptions have all significantly impacted the efficiency of the operation. These challenges have necessitated constant adjustments, innovative solutions, and effective risk management strategies to ensure the sustainability and success of this integrated offshore pilot. The experience underscores the need for comprehensive planning and resilient operational frameworks to navigate the complexities of such multifaceted offshore operations.

Lessons learned for the German pilot: Operating a mussel and algae aquaculture system near an offshore wind park has highlighted several significant challenges and valuable lessons. The scarcity of suitable vessels, exacerbated by the high demand for offshore wind farm maintenance, necessitates the development or designation of specialized vessels for dual-purpose tasks. Securing vessel bookings in advance can mitigate delays and maintenance adjustments.

Weather conditions play a crucial role in the success of offshore operations. Adverse weather, such as high winds and heavy seas, can cause significant downtime and damage to infrastructure. Investing in robust, weather-resistant infrastructure and implementing comprehensive weather monitoring and flexible scheduling can optimize work windows and minimize disruptions.

The COVID-19 pandemic introduced restrictive health regulations, which increased operational costs and reduced the availability of skilled labour. Developing adaptable health and safety protocols for quick implementation during health crises and enhancing remote monitoring capabilities can improve resilience against such disruptions.

Rising fuel prices have significantly impacted the cost structure of offshore operations, leading to increased transportation fees and will reduced profit margins. Adopting fuel-efficient practices, exploring alternative energy sources, and investing in energy-efficient vessels can mitigate the impact of rising fuel costs.

Persistent supply chain disruptions have caused delivery issues and increased material costs, affecting the timely availability of essential supplies. Diversifying supply sources, increasing inventory levels, and fostering synergistic collaborations can stabilize costs and ensure a steady supply of necessary resources. Building stronger relationships with suppliers and exploring local sourcing options can also enhance supply chain resilience.

In conclusion, addressing these challenges requires comprehensive planning, innovative solutions, and effective risk management strategies. Learning from these experiences can better prepare future operations to navigate the complexities of integrated offshore projects, ensuring their sustainability and success.

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

4.2. Dutch pilot

The Dutch pilot is located 12km off the coast of Scheveningen, The Hague. Therefore, it has the offshore conditions you can find in a wind park, but not the long travel time. In addition, the harbour itself is directly linked to the sea and it is big enough to accommodate the necessary large vessels, but small enough to easily arrange the operations. This makes it a perfect location for a pilot project. See for impression Figure 8.

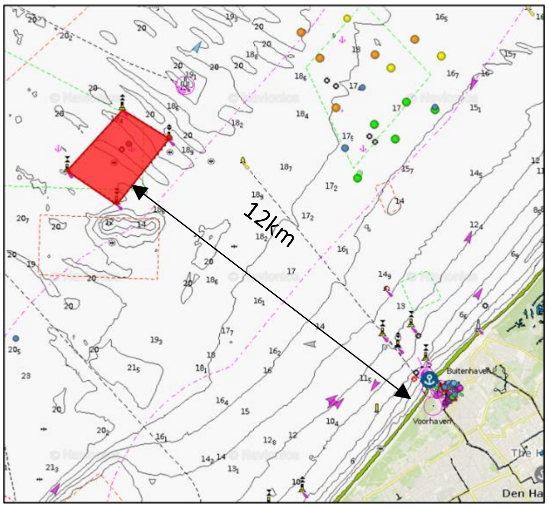


Figure 8: (Left) location of the Dutch pilot at the North Sea Farmers Offshore Test Site 12km of the coast & (right) the harbour of The Hague (Scheveningen) with easy access to sea

North Sea Farmers has a permit for multi-use pilots at this location. This includes the operations & maintenance activities. Therefore, no additional permits were necessary for the pilots with floating solar, data buoys and seaweed cultivation. These are the lessons learned and recommendations for the Dutch pilot, this specific location and the types of multi-use:

- GPS sensors were installed on all floating elements within the Dutch pilot. This, in combination with cameras making shots on a regular basis, was very convenient to monitor if the installations were still in the right place and/or if an element broke loose. It helped in reducing offshore maintenance trips, as they were only needed when something seemed wrong.
- Flexibility in the operations and maintenance is key, as the conditions (weather, tide, waves, etc.) are leading in the planning. It is wise to have several suitable vessels available that can be deployed for the O&M. Even better, in the Dutch pilot, Oceans of Energy arranged their own vessel (see Figure 9) with a berth in the harbour. They also trained their own staff to do O&M offshore work. This made the execution of the O&M really flexible, as vessel & personnel availability was not an issue for their pilot anymore. In addition, having a place in the harbour where all the preparations for the offshore work can be done is favourable as well.

Figure 9: O&M vessel Oceans of Energy

Figure 10: Example of seaweed growth inspection

- For seaweed cultivation it is important to determine the optimal harvest date based on the inspections during the O&M phase. Next to the remote monitoring activities (for example the water temperature is an important factor), the inspections were used to measure growth during season, see Figure 10. Biofouling is an important aspect of the monitoring and should be recorded with photos during inspection periods as well.
- As offshore work is high risk activity, it is important to be well prepared, but also to document the activities. For the Dutch pilot location, the North Sea Farmers Offshore Test Site, a permit-to-work system was established. This served both as a safety check before O&M activities as well as a documentation log.
- At the moment there is no offshore training for personnel specific for offshore multi-use. It is recommended for this to be established, as the risks related to multi-use are different from the offshore wind/gas/oil, diving and/or fishery activities, which are now leading in offshore trainings.

4.3. Belgian pilot

The Belgian pilot is situated at two test locations in the Southern North Sea. The nearshore test site is 5 km off the coast at Nieuwpoort (Westdiep), and was used to work on 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 11), with a total capacity of 165 MW, powering up to 175 000 households.

During the pre-operational and operational phase, many lessons have been learned, ranging from initial planning and designing of the multi-use pilot, installation, monitoring and decommissioning. To mitigate any risks, careful planning of the activities, their requirements and implementation are key and require sufficient time before the practical start of the activities. One very important task requiring early consideration is the performance of an independent risk analysis for acquiring insurance for the offshore project implementation.

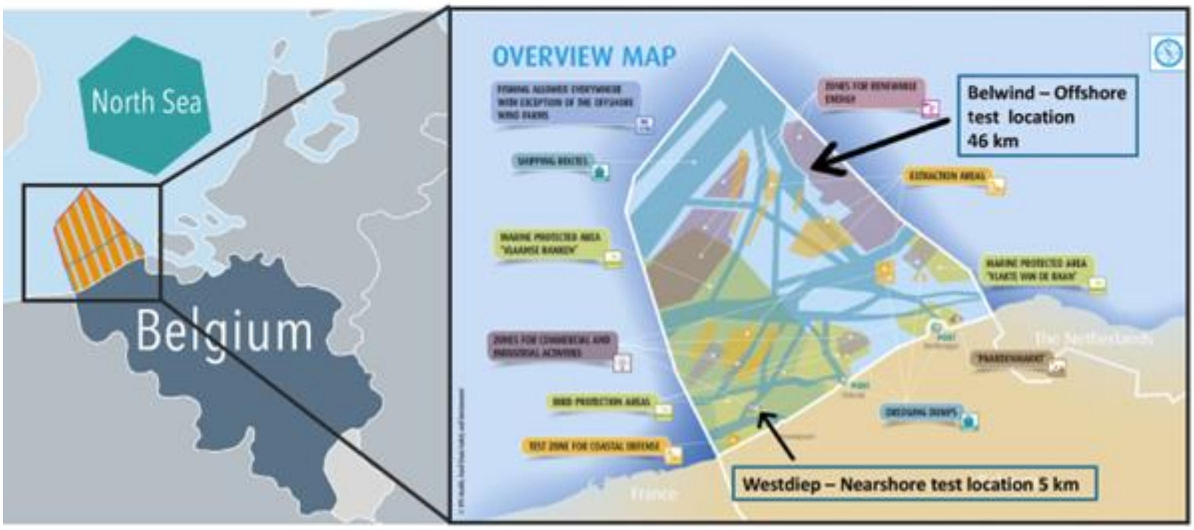


Figure 11 Belgian pilot test locations of the Westdiep (nearshore test site) and Belwind (offshore test site) and marine spatial plan of the Belgian part of the North Sea.

Several lessons have been learned concerning more general operational procedures. Firstly, installation, monitoring and harvesting offshore aquaculture systems require very calm weather conditions which greatly limit operational windows at the offshore locations. Operational limits were set to waves <1 m, currents of <0.5 m s^{-1} which occur during tidal changes around neap tides as well as low wind conditions of preferably <5 m s^{-1} to ensure safe operation within the offshore wind farm. Therefore, the offshore missions require careful planning and are subject to delays. This is complicated by the fact that for example, the seaweed system is usually installed in autumn, when frequency of storms is higher. The strong weather dependency also limits the securement of suitable vessels, which often need to be booked well in advance, outside of reliable weather forecasts.

Furthermore, offshore wind farms are access restricted areas and vessels must be registered and approved in the safety operation system of the wind farm operator, to receive permission to enter and operate within the wind farm. This requires high administrative input from the vessel operators and can result in delays and higher costs as vessel operators need to allocate a higher amount of preparatory time. Overall, vessels that met the requirements of the wind farm operators, e.g. DP2 system, had experience with aquaculture installations, were located close by, but availability was very limited, resulting in frequent delays of planned missions.

Seaweed cultivation techniques were optimized during two cultivation cycles at the nearshore test site for the harsh environmental conditions at the offshore cultivation site. Several substrates were compared and two were identified to be suitable for further testing offshore (AtSeaNova offshore net type, rope based net). Furthermore, different seeding techniques were tested to apply the juvenile seaweeds onto the substrate before out planting. For successful seaweed growth, seeding technique was observed to be a crucial factor. Different seeding methods exist – seeding of seaweed gametophytes, followed by a nursery period of minimum 4 weeks under optimal controlled conditions before installation at sea, or direct seeding, where juvenile seaweeds are mixed with a seaweed binder and applied on the substrate prior installation at sea. While direct seeding method makes the seeding more efficient by skipping the nursery period, it turned out to not be reliable in terms of success of cultivation and harvestable yield at the end of the growth season. Net cultivation systems were chosen for the cultivation of seaweed as they greatly lower the risk of entanglement and flipping over the backbone. However, direct seeding would be the favourable seeding method over incubation of seeded substrates in a nursery, which is more difficult to implement using net substrates with regard to space limitation. Therefore, the direct seeding method requires further optimization.

Pilot testing of oyster cultivation methods took place in the offshore Belwind site from October 2022 to July 2023. Four different types of cultivation structures were distributed on the long line system, including 6 cylindrical

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lantern baskets, 12 ropes with oysters cemented, 2 heavy metal cages, and 4 metal frames each containing 4 SEAPA baskets. Survival rates were high across all cultivation methods except for the ropes. However clear differences were noticed between the different structures in terms of structural integrity, biofouling, and influence on shell morphology.

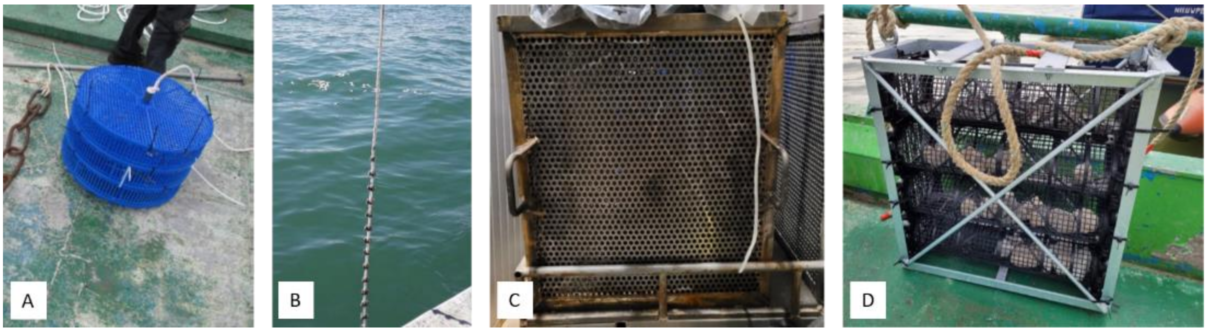

Figure 12: Oyster cultivation structures tested in the Belgian pilot (A) Lantern basket (B) Oysters cemented onto rope (C) heavy metal cage (D) metal frame containing four cylindrical SEAPA baskets, stacked horizontally

The structural integrity of different cultivation methods may be the most important factor, as some of the structures detached from the longline and were lost at sea before they could be retrieved. Five out of six of the lantern baskets were lost, two out of the twelve ropes (most of the oysters were lost from the ten ropes that were retrieved), and one out of the four metal frames with SEAPA baskets was lost. It is unclear exactly when each of these structures would have detached from the backbone, and whether it was due to unusually strong storm activity or the normal current and wave energy at this site. The retrieval of lost material adds complications to the operational procedures of the Belgian pilot. The metal frame that was lost has a pinger which can be detected by a receiver set to the same frequency within 1.5 km. This, however, necessitates an additional sea mission and possibly an ROV mission to find and retrieve the structure. The ropes and plastic lantern baskets that were lost, however, are not likely to be found.

The cultivation structures that were successfully retrieved displayed differing levels of biofouling. The one lantern basket retrieved had the most severe internal biofouling, while the heavy metal cages had the least. The oysters contained in the SEAPA baskets also had lighter fouling. We hypothesize that the internal movement or tumbling effect facilitated by the structure of the heavy metal cages and SEAPA baskets is responsible for the decrease in fouling organisms as compared to the lantern basket. This is an important lesson from a maintenance point of view as moving operations offshore makes regular cleaning less feasible. The less biofouling accumulated by a cultivation structure, the less maintenance it will need.

The heavy metal cage and the SEAPA baskets also had some unexpected effects on shell morphology. The oysters cultivated in the metal cage had shells that were stained orange from rust. This may have also been a contributing factor in the low level of biofouling. Alternatively, the oysters contained in SEAPA baskets formed shells that were dramatically thicker and smoother than is the norm for European flat oysters.

Finally, although the metal cages performed well in terms of structural integrity and biofouling resistance, they were also found to be too heavy for easy handling and therefore impractical for offshore oyster cultivation. Therefore, the recommendation from the Belgian pilot is to use SEAPA baskets for oyster cultivation moving forward. However, further investigation into market preferences will be necessary to determine the marketability of the unusual shell morphology the SEAPA baskets seem to encourage. Drawing on lessons learned from the structural integrity of the cultivation systems will also be important for designing the next iteration of offshore oyster aquaculture in the Belgian part of the North Sea.

4.4. Danish pilot

The Danish pilot is combining the production of wind with tourism. One or two of the existing wind turbines – in total 20 turbines (Bonus today Siemens Gamesa each 2 MW from 2000) are used for visiting. In 2000 Middelgrunden Wind Farm was the largest offshore wind farm in the World. The wind farm is situated 3.5 km from the shore.

Operation and maintenance of the wind turbine is carried out independent of the UNITED project. Operation of the tourism is organized by SPOK ApS on behalf of the board of the Middelgrunden Wind Cooperative owning 10 of the wind turbines.

The operation of the tourism activities depends on informal agreements between the SPOK and the freelance guides not directly employed by SPOK and the 2 boat companies doing the transport. An agreement between the owner of the wind Farm exists about paying compensation for lost production and about avoiding any kind of conflict with the wind farm service provider. There is no maintenance related to this activity.

Improvements for the tourism.

During the open house visit in 2023 we realised that some people try to climb up even though their constitution may not be good enough. A women get dizzy and fainted during the climb. She twisted here ankle and broke a small bone in the foot. It took 3 hours to evacuating here for the professional rescue team. Therefor we have equipped the upper 8 flores of the two visiting turbines with a special chair on the platforms so a dizzy person can sit down easily. Also, we have equipped the guides and boat captain with special walkie-talkies to be able to communicate from the inner of the tower.

This installation is not needed if only service people are climbing the turbines.

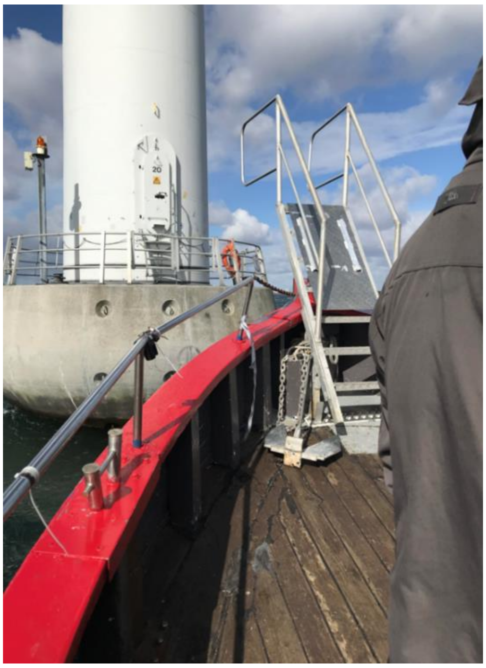

Figure 13: Maintenance is needed by the boat operator, like maintenance of the special access ladder from the boat to the top level of the foundation.

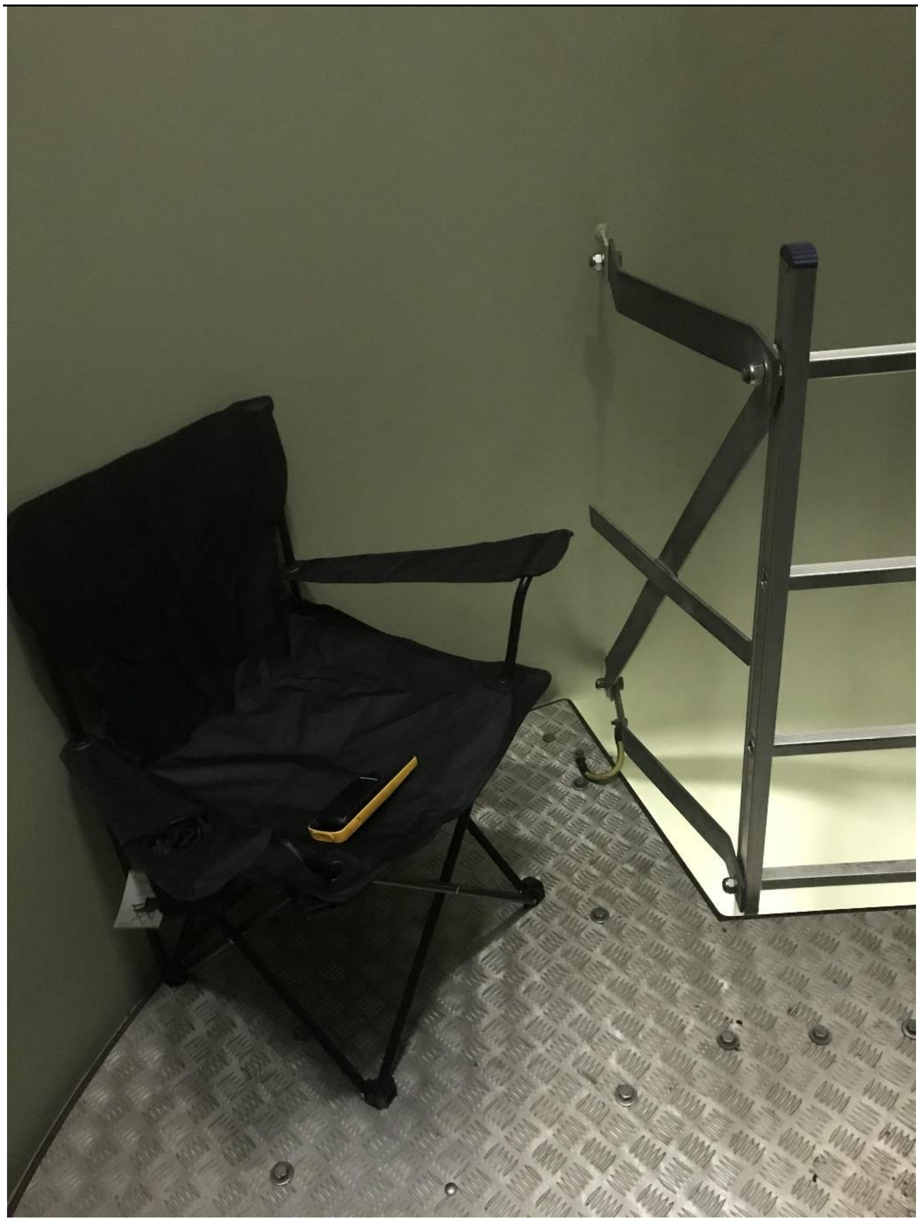

Figure 14: The installed chair and the walkie-talkie on the floor in the turbine.

Recommendations:

- Develop comprehensive safety guidelines and protocols for tourists during windmill tours.
- Collaborate with local tourism authorities to promote windmill tours and educate visitors about renewable energy.
- Only wind turbines of the old type from before 2007 where there are more floors in the turbine, are suitable for tourism where you want to climb the turbine. In modern wind turbines is only possible to climb with safety equipment (8 meters between the floors is the maximum).
- The visiting (climbing the turbine) is only possible when the turbine owners allow it.

Visiting without climbing is used by 50% of the guests and here you can do it just by a boat ride usually without having permits from the turbine owner – depends how close you want to go.

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4.5. Greek pilot

The Greek Pilot site, PATROKLOS, nestled within the ecologically significant area of Cape Sounio and protected by NATURA 2000 and the Treaty of Barcelona, provides valuable lessons and recommendations for the operation and maintenance of multi-use sites. Its unique blend of aquaculture and tourism activities presents a dynamic landscape worth exploring.

Figure 15: Overview location Greek pilot

The importance of selecting sites with ecological significance, such as NATURA 2000 areas, cannot be overstated. These sites are not only rich in biodiversity but also hold historical and cultural importance. Ensuring the necessary permits and protections is vital for preserving these delicate ecosystems.

Moreover, regarding the technological part, the experience with wired connections highlighted the need for technological resilience. Vulnerabilities, such as operational vessels accidentally cutting wires and aquaculture operators turning off power, emphasized the importance of wireless solutions. Initially, challenges were faced with wired connections, particularly between cameras and sensors, utilizing a router for both power and internet supply. This setup proved vulnerable to disruptions caused by operational vessels accidentally cutting the wires and occasional power shutdowns by aquaculture operators. These experiences underscore the critical need for more robust and flexible connectivity solutions. Future multi-use projects should explore wireless communication technologies that are less susceptible to disruptions, employ redundant communication paths, and implement resilient network designs to ensure continuous data transmission. The decision to expand to other geographical locations was driven by the need to overcome limitations in data coverage, enhance data reliability, facilitate comparative analysis, delve deeper into ecosystem complexities, and accommodate the spatial extension of activities. This expansion was a strategic response to these challenges, ultimately contributing to the project's scientific validity and robustness.

Scheduling improvements

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 (Figure 16) 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.

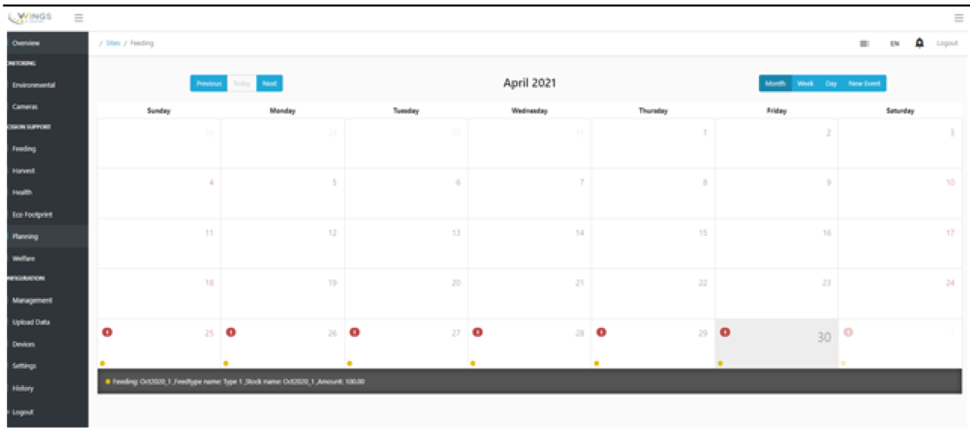

Figure 16: The planning tool of AQUAWINGS platform

Apart from that, communication through calls were 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.

Solar Power

To address power supply challenges, solar panels were installed, attached to the mooring system (Fig. 17). This transition to solar power not only increased the reliability of our power source but also contributed to the project's sustainability and environmental responsibility. Future multi-use projects should explore renewable energy solutions to reduce dependency on conventional power sources, ensuring consistent power availability for monitoring systems.

Figure 17: Solar panels were installed, attached to the mooring system

Impact of COVID-19

The COVID-19 pandemic had a tangible impact on the operation of touristic activities during the operational phase of the pilot. Navigating safety protocols while conducting tourist diving expeditions proved to be a challenge. However, as lockdown restrictions were gradually lifted, we managed to resume these expeditions successfully. This experience underscores the need for adaptable planning and real-time responsiveness to changing circumstances. Multi-use projects should develop strategies that allow operations to continue while adhering to health and safety protocols, ensuring adaptability to evolving conditions.

Reduced Tourist Diving

Economic factors, including increased fuel charges and associated diving fees, played a significant role in the reduction of tourist diving activities during the pandemic period. A nearly 20% increase in diving fees, coupled with the distance to Lavrio from Athens and the resulting commuting costs, contributed to the decline in local divers' participation. This shift prompted a move towards more cost-effective shore diving and a decrease in boat diving. To address this, future multi-use initiatives should conduct thorough economic assessments and consider pricing strategies that balance the cost of participation with economic factors. Additionally, diversification of offerings, such as introducing shore diving options, can cater to a broader audience and enhance participation.

Economic Considerations

Economic factors, such as increased fuel charges and commuting costs, can significantly impact tourist participation. Understanding these economic influences is crucial for making pricing and service adjustments to meet evolving preferences.

Weather conditions

Unfavourable weather conditions such as high winds, rain and storms can lead to the cancellation of tourist activities namely diving and boat tours. This directly affects revenue and can damage the site's reputation if cancellations are frequent. Rough seas and storms can disrupt feeding schedules, monitoring, and maintenance of aquaculture systems. Bad weather can also delay harvesting and transportation of aquaculture products, impacting supply chains. Monitoring and communication systems were resilient to weather-related disruptions. Wireless solutions, redundant systems and durable equipment were essential to maintain continuous operations and safety monitoring.

Recommendations

- Integrate renewable energy sources, such as solar power, into the infrastructure of multi-use sites. This not only increases the reliability of power supplies but also aligns with sustainability goals. Ensuring a consistent power supply for monitoring systems is crucial for the smooth operation of these sites.
- Develop flexible strategies that allow for real-time responsiveness to changing conditions, such as those experienced during the COVID-19 pandemic. This includes adhering to health and safety protocols and being prepared to adjust operations as needed to maintain continuity.
- Implement robust environmental monitoring systems to continuously assess the impact of multi-use activities on the ecosystem. Use data collected from sensors to adapt management practices and mitigate any negative effects on biodiversity and habitat health.

5. CONCLUSION

In conclusion, the implementation plan for the operation and maintenance (O&M) of multi-use offshore platforms within the UNITED project reflects a comprehensive and forward-thinking approach to ensure the long-term success and sustainability of marine activities. The project, driven by the goal of boosting cost-effective and eco-friendly production, has developed an O&M document that serves as a valuable guide for future multi-use pilots and projects.

Various critical aspects have been identified, starting with the importance of aligning O&M with the overall goals of the project. There is a need for early consideration of key factors such as project goals, duration, budget, location, design, roles and responsibilities, stakeholders, and necessary facilities/assets. Next, it is important to provide a systematic approach to develop a robust O&M plan, covering aspects like remote monitoring, inspections, procedures, and documentation.

The pilot-specific insights from different locations (Germany, The Netherlands, Belgium, Denmark and Greece) provide valuable lessons learned and recommendations. These insights cover a range of topics, including permitting challenges, the importance of flexibility in O&M, safety considerations, and the impact of external factors like the COVID-19 pandemic.

Overall, for future multi-use projects it is important to navigate the complexities of offshore operations effectively with a comprehensive O&M implementation plan. Successful O&M planning begins early in the conceptual design phase, and a forward-thinking approach ensures that the project's goals are not only met but sustained over the entire life cycle.

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