TASK 2.2 DESIGN AND CONSTRUCTION PLANS FOR THE PRE-OPERATIONAL PHASE OF THE PILOTS

Work Package 2

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Abstract	This report presents the technological challenges of multi-use and co-location aspects of five UNITED pilots. Challenges, requirements, solutions and unsolved issues are given in three themes for each pilot. These three themes are monitoring and

	docking systems, deployment design and mooring systems and management systems. Note that some pilots are already operating in an existing infrastructure (e.g. wind farm). Hence, not the full design and construction of already existing components are given, but rather the additional challenges that multi-use and co-location bring are discussed. Results are summarized in tabular format in chapter 3.
Keywords	Multi-use engineering, design and construction plans, moni-toring and docking systems, management systems, anchor-ing, mooring

ACRONYMES

AIS	Automatic Identification System
CCT	Coordination Committee Team
CSET	Core Services Exploitation Team
CT	Consortium Coordination Team
EC	European Commission
ERP	Emergency Response Plan
GMDSS	Global Maritime Distress and Safety System
IPR	Intellectual Property Right
MC	Marine Coordination
MUCL	Multi-use and co-location
PA	Partner Assembly
PM	Project Management
PPE	Personal Protective Equipment
PWD QHSSE	Parkwind Quality, Health, Safety, Security, and Environment
RAMS	Risk Assessment and Method Statement
SAB	Stakeholder Advisory Board
SOS	Safe Offshore operations System
WP	Work package

EXECUTIVE SUMMARY

This deliverable reflects of a specific subset of technological challenges with regard to the multi-use and co-location aspects in the maritime domain of the UNITED pilots. These are presented here as the design and construction plans. Challenges, requirements, solutions and unsolved issues are reported across different themes. These themes are:

- monitoring and docking systems
- mooring and deployment design
- management systems

Mutual challenges between pilots are the long distance offshore and associated rough sea and weather conditions. These have specific implications for the requirements of monitoring equipment, mooring and deployment design and management systems. The pilots that have an aquaculture component (Dutch, German, Belgian and Greek) require remote data access and power supply and a robust aquaculture system that can withstand rough conditions. The tourism-oriented pilots(Danish and Greek) have design and construction plans that are focused on monitoring and management systems as both pilots operate in an individually existing platform. Even though we focus on multi-use and co-location, note that some pilots operate in an already existent infrastructure (e.g. a wind farm). We abstain from presenting construction and design plans of these single use aspects but have rather focused on the requirements of additional functionalities. Chapter 3 provides a summary table of challenges, requirements and solutions for each pilot.

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1. INTRODUCTION

1.1. Background

UNITED enables the large-scale installation of the multi-uses of marine space through the development of pilots in marine environments elaborating on five different pillars: technology, regulatory, economy, social and environment. Optimal multi-use concepts and co-location activities will be implemented in close cooperation of local stakeholders and industrial actors. UNITED will enhance the technology readiness level of the technology validated in a relevant environment (TRL5) to demonstration in an operational state (TRL 7+), handling difficulties and offering solutions at the five pillars to promote the economic benefits for key industrial actors, highlighting the sectors renewable energy, aquaculture, and tourism.

Based on identified promising designs and tackled regulatory and technological barriers for Multi-Use platforms and/or Co-Location at platforms (MUCL) from previously funded projects, UNITED will enhance on the five pilots across the North Sea, the Baltic and the Mediterranean, involving industrial actors and integrating the knowledge, technologies and facilities, in multi-use platforms and/or co-location of different activities in a marine space. The five pilots exhibit a wide range of dynamic conditions in different regional seas and demonstrate the benefits, challenges and risks of different combinations of marine activities. UNITED elaborates on the economic situation and benefit of combining activities for renewable energy (wind and solar), aquaculture, bio-resources, environmental restoration (oyster beds restoration), maritime transport, and tourism services, in the same marine space. This is achieved by developing monitoring solutions suitable for offshore MU operations and increasing their efficiency ; dividing and reducing the costs of offshore operations and the demand on space; and expanding and enhancing previously developed business models to reduce risks for operators and investors.

WP2 (Technology) will address the technological requirements of the pilots to achieve feasibility of multi-use production sites, building on the findings from WP1. The enhancements to observational and automated networks within the existing pilots will be designed in WP2 in order to allow for an integrated system which collects, processes, and stores information from a range of sensors, thereby enhancing operational aspects of multi-use platforms and space.

For MUCL there is a special subset of technological challenges in the co-location and co-use of maritime space. Such challenges include the need for specialized monitoring equipment with multi-functionality i.e. capturing a wide spectrum of variables required to evaluate and manage multiple co-located uses which are not traditionally integrated while also adapt the equipment to the specific conditions of an offshore location, such as severely limited accessibility. In this report, the monitoring, mooring, docking, and management systems of the marine platforms will be explained, including the optimizations that were needed to carry out the MUCL activities and have been achieved in the UNITED project. This report is established in close collaboration with each of the pilots in order to precisely and effectively combine the platform and special requirements with the available technologies and infrastructure to be implemented at the pilot.

1.2. Objective

The aim of this report is to collect and disseminate the design and construction plans for the pre-operational phases of the pilots. Also, cross-links will be made between the pilots in case of parallel or overlapping activities, to generate the generic lessons that we can learn in the unique situation of multiple pilots in one project.

1.3. Methodology

Each pilot documents challenges, specific requirements and solutions for the following three technological pillars:

- Monitoring and docking systems;
- Deployment design and mooring systems;
- Management systems.

Chapter 2 describes the main characteristics of these three technological pillars per pilot. This information has been provided directly by the pilot coordinators. It is noted that this is information, which is available up to November 2021, just before the deadline of this deliverable.

Chapter 3 reports the generic lessons that can be learned from the individual contributions of the pilots reported in Chapter 2 and is categorized as follows:

- Challenges identified from previous deliverables/meetings and updated by pilots
- Specific requirements needed to overcome challenges
- Design and construction plans / solutions / in case not solved, unsolved problems

1.4. References

The information described in this report is based on direct contributions from the pilots and relies on and feed to a number of other UNITED project deliverables. The most relevant deliverables that have been used as a basis for the preparation of this report are the following:

- D7.1 : Review of pilot TRL, legal aspects, technical solutions and risks
  This deliverable contains a state-of-the art description of the planned offshore activities in each of the project's pilots, including aqua culture, energy production and tourism. Technical, societal, economic, environmental and legal aspects will be considered.
- D7.2: Blueprint for the offshore site operation
  This deliverable contains a blueprint of the offshore activities, building on the state-of-the-art review in D7.1. Also in this report, technical, societal, economic, environmental and legal aspects will be considered

2. PILOT'S DESIGN AND CONSRUCTION PLANS

2.1. The German Pilot

The German pilot's offshore site is located at research platform FINO3 in the North Sea, 80 km west of the German island Sylt half a sea mile away from the three wind parks Butendiek, DanTysk and Sandbank (Figure X). This pilot demonstrates the multi-use combination of offshore wind research, seaweed and mussel aquaculture. Two of the core challenges for the design and construction are 1) the long distance from the coast (80km); 2) the rough North Sea conditions with maximum wave heights reaching 9 m every year and 16m in the 10-year-period. These two pose challenges on design and construction aspects of the pilot stress the need for solutions for the specific multi-use combination of the German pilot. Findings and solutions will be discussed according to the following core themes: monitoring and docking systems, mooring and design systems and management systems.

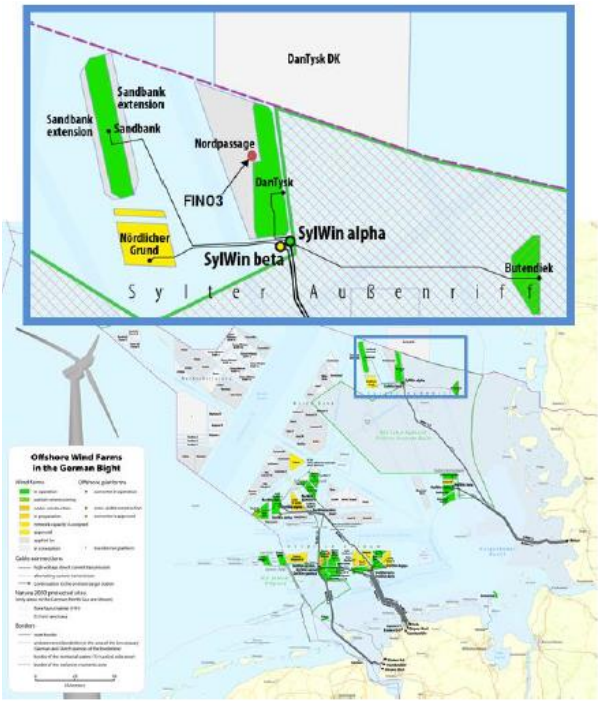


Figure 1 Location of the German Pilot in the North Sea, Germany

2.1.1. MONITORING AND DOCKING SYSTEMS

Challenges

The following challenges regarding the monitoring and docking system have been addressed in previous deliverables (e.g. D1.1, D7.2). Here the output of the interim development of the German Pilot are presented as plans and solutions.

- Automation of remote data recording (D1.1)
- Requiring minimal automated maintenance of aquaculture (D1.1)
- Damage due to adverse weather conditions (D1.1)
- Common data collection and dashboard solution (pilot alignment meeting)

Remote monitoring is based on a reliable and functional technical equipment. These requirements become even more important in very exposed offshore locations like the German pilot offshore site. Maintenance and operation of these systems is very costly and difficult to achieve since they depend on very rare suitable weather conditions. Therefore, the challenge is to work out a design, setup and management for an offshore operation that provides a high chance for as much automatization of remote data recording as possible.

The aquaculture part of the pilot is facing the same challenges due to the same reasons.

A sophisticated risk analyses was conducted to investigate the most important challenges (D1.1). The most critical challenge for material, cultured species and especially technical monitoring systems are the harsh weather conditions in remote exposed environments.

The development of a common data collection and dashboard solution to provide access to the data collected of five pilots is another challenge and part of the monitoring plan.

The resulting specific requirements and construction plans including solutions are presented in the following paragraph.

Specific requirements

- Real-time data access for the most critical parameters and monitoring devices is a must to tackle the above-mentioned challenges. An intensive research for sensors suitable for these specific conditions, affordable and delivered in time despite the collapsed retail chains was a time-consuming and mandatory task.
- Energy supply and energy consumption have to be on a level to allow maintenance routines of approximately every three months or until decommissioning.
- Materials have to be compatible with each other (especially different metals) to avoid chemical reactions between them.
- Anti-fouling measures, suitable for the production of food for human consumption, have to be found.
- Staff has to be experienced and trained to operate and maintain not only the offshore facilities but also the associated onshore equipment (e.g. enough data storage of 1TB, pre-fabrication and adaption of monitoring equipment, spare parts, …)
- The calculations and simulations for the aquaculture systems needed to be validated with "real data"

How these requirements can be met to provide a functioning monitoring process is described in the next chapter.

Design and construction plans

- The real-time data transmission of sensors installed directly at the mussel-system is using a LoRaWan system located and maintained at the offshore research platform FINO3 (Fig 1).
- All possible sensors on the lander will be connected via sea cable to transfer the data to a server based on FINO3 and to supply them with energy. Power supply is ensured by three redundant generators on the FINO3 platform.
- The AquaTroll sensor was selected by the German, Dutch and Greek pilot to harmonize the monitoring of essential hydrological parameters.
- To ensure the monitoring of important parameters a backup monitoring system has been developed. Additional comparable cheap sensors will be attached directly on the aquaculture systems. A compromise was met between quality of sensors and costs for this backup option. Thus, an AquaReal buoy will be set up at the mussel net and send data to a receiver at the FINO3 platform. The data buoy is equipped with solar panels for power supply. HOBO light loggers are attached directly to the mussel net as another backup solution if other sensors or data transmission systems fail. These loggers will measure light and water temperature in a fixed interval. To retrieve the data, the loggers need to be read out individually via Bluetooth during maintenance trips or after decommissioning. The battery life will last for more than two years. Furthermore, a handheld multiparameter probe from Horiba, which determines the most critical parameters can be used if data transfer does not function properly. With the

Horiba device engineers on the FINO3 tower can measure directly from the platform since the device is equipped with a 30m cable.

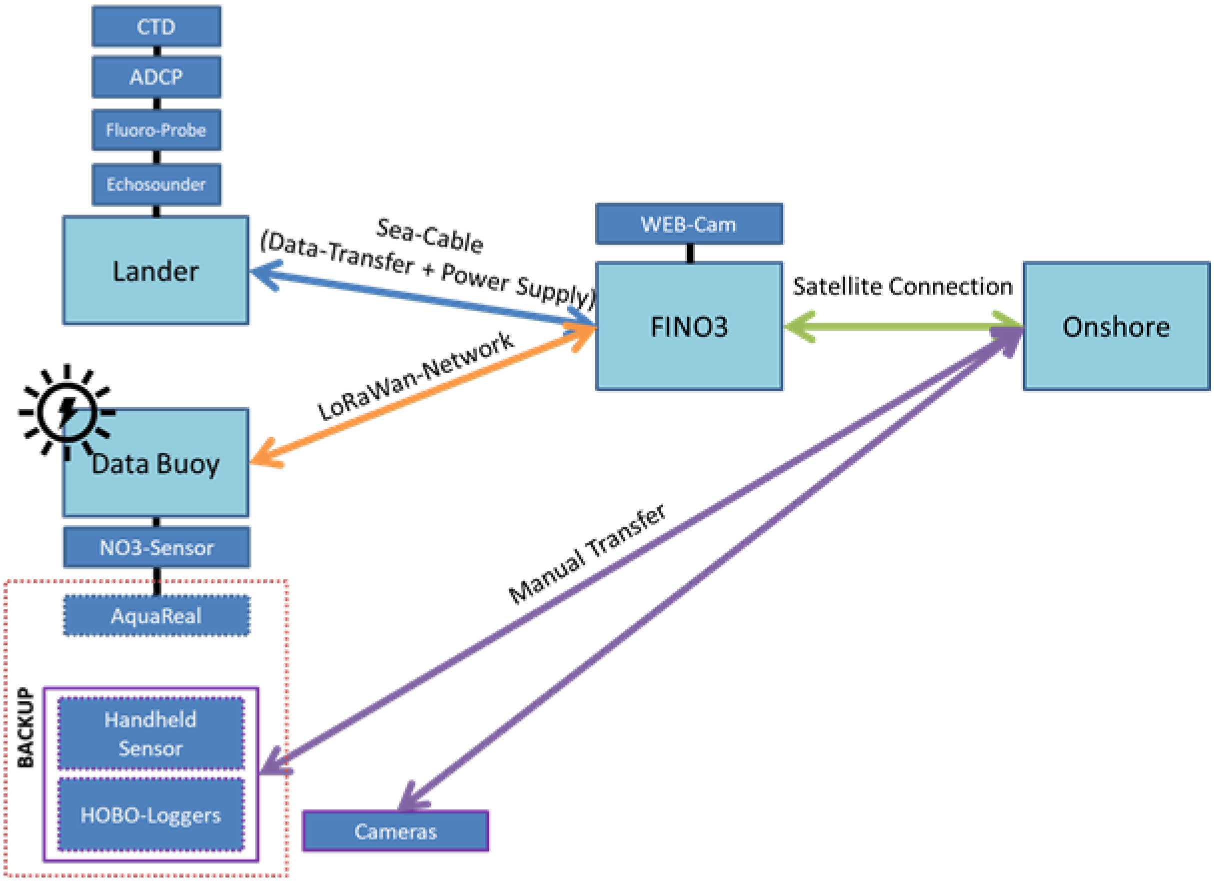


Figure 2 Set-up for the monitoring data transfer solutions and backup of the German Pilot at the offshore platform FINO3, North Sea, Germany. The symbol at the data buoy represents solar energy as energy supply

Cameras attached to the aquaculture systems will monitor the development of the cultured species but also the interaction of the structure with the environment. It was decided not to take any videos to maximize the needed maintenance trips for replacing batteries and SD cards. A detailed setup mode was developed on how many pictures at which light conditions can serve to answer the questions without draining the batteries before the planned maintenance schedule (appr. every three months).

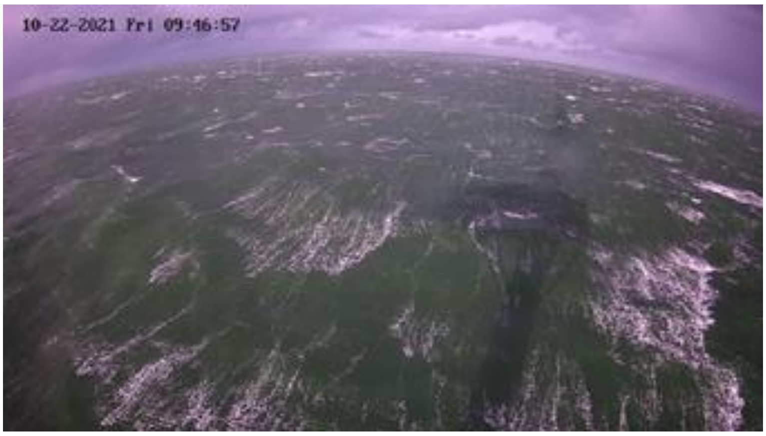


Figure 3 Webcam screenshot of the aquaculture area at FINO3, North Sea before installation (wave height ~4-5m)

In addition, a webcam is installed at the FINO3 tower to monitor the aquaculture area 24/7(Figure 3). In case of any damage, loss of equipment or unauthorized access to the area, countermeasures can be taken immediately. The developed transmission capabilities on FINO3 provides the option to inspect the pilot site live, at any time of day and in any weather condition, despite its physical isolation.

Table 1 Overview of selected monitoring equipment, monitored parameters and data transmission option at the German pilot located at the offshore platform FINO3, North Sea, Germany

No.	Sensor	Company	Type	Parameters	Measurement interval; data transmission
1	Combined CTD and O2-Sensor	AML Ocean-ographic	° AML-6 ° X2 series inter-changeable sensors	conductivity; water temperature; water depth; turbidity; dissolved oxygen; PAR light intensity	Continuously; remote moni-toring solution
2	Fluoro Sen-sor	bbe Moldaenke	FluoroProbe	Chlorophyll-a, algae classification, temperature	Continuously; remote moni-toring solution
3	Echosounder	Kongsberg	° Simrad WBAT (Wideband Auton-omous Transceiver) ° Simrad ES200-7CDK (split beam transducer) ° Simrad ES333-7CDK (split beam transducer)	pictures[echograms] (growth of mussels and seaweed and existence/ impact on marine fauna)	continuously remote moni-toring solution

4	ADCP	Nortek AS	Signature500	wave-height, -length, -period, -direction; current-speed, -direction, -profile; water depth; tilting; orientation (compass)	Continuously; remote monitoring solution
5	NO3 Sensor	TriOs	TriOs OPUS 10mm path	NO3	Continuously; remote monitoring solution
6	multiparameter - handheld sensor	Horiba	Horiba U-52(30m)	pH; oxidation reduction potential (ORP); dissolved oxygen; conductivity; salinity; total dissolved solids; water temperature; turbidity	manual measurements whenever possible at FINO3
7	HOBO Logger	HOBO	HOBO MX2202	Water temperature; light	Continuously; via Bluetooth at maintenance trips
8	Camera	GRALmarine	SLR Camera	Photos; water temperature	Continuously; manual exchange of SD cards
9	WEB-Cam	Hikvision	Hikvision DS-2DE3204W-DE(B) IP PTZ	photos; videos	Continuously; remote monitoring solution
10	C-Pods (Porpoise Click Detectors)			Acoustic monitoring of harbour porsoises	Continously, manual exchange of SD cards and batteries

2.1.2. DEPLOYMENT DESIGN AND MOORING SYSTEMS

The challenges for a secure mooring solution and deployment at such an exposed offshore site, as the German pilot, are manifold. This deliverable will address the most important ones as there are.

Challenges

- Damage due to extreme environmental conditions (D1.1)
- Anchoring & mooring
- Buoyancy design
- Biofouling
- Harbour porpoise monitoring

Specific requirements

- *Damage due to extreme environmental conditions*
  - The whole deployment procedure must be planned in such a way that the time offshore is as short as possible to be able to use short mild weather conditions (max. a few hours) and to keep costs as low as possible.
  - All steps of the deployment must be tested and staff trained to enable a safe and smooth procedure offshore.
  - The mooring for the seaweed and mussel systems has to withstand a 5-year extreme event of different combinations of wave height and current.
  - The deployment procedure has to be compatible with the legal requirements for a licence.
  - In the event of failure, the systems must not affect the ease and safety of marine traffic.
  - Other usage within the offshore site and the operation of the FINO 3 platform itself as well as the wind parks nearby must not be affected by the German Pilot.
- *Anchoring & mooring*
  - Mooring has to be affordable, state of the art and suitable to be installed maximum within a few hours.
  - The mooring solutions must be easy to install and deinstall with standard tow ship equipment.
  - The anchoring and mooring solution must comply with the licence specifications of the Federal Agencies.
  - The mooring systems must pass plausibility checks and simulations of an independent engineering office and fulfil different international safety codes.
- *Buoyancy design*
  - The weight of the nets will increase due to biomass growth. The seaweed and mussel system must provide enough buoyancy material to keep it at a definite water depth during the whole operation period preferable without the need of attaching extra buoys to limit the offshore maintenance time. Furthermore, the systems must be equipped with sufficient buoys without causing strong "shaking movements" due to waves.
- *Biofouling*
  - Biofouling on sensors and cameras can cause extreme intensive maintenance. State of the art and tested antifouling measures must be applied to keep the intervals between maintenance trips as long as possible and the maintenance trips itself as short as possible to save costs.
  - The biofouling material has to fulfil the legal requirements for the production of food for human consumption.
- *Harbour porpoise monitoring*
  - Due to restrictions from the Federal Maritime and Hydrographic Agency (BSH) it is necessary to monitor the occurrence and frequency of harbour porpoises at the German Pilot site with C-PODs[1]. The C-PODs must be maintained in an interval of at least two months. Therefore, the devices must be attached to the systems in such a way that they can be picked up and read quickly and easily during maintenance trips.

[1] C-POD (Cetacean-Porpoise Detectors) are independent floating devices for the study of harbor porpoises (Phocoenidae). The devices record, process, and store the click sounds of porpoises with acoustic sensors.

Design and construction plans

- *Damage due to extreme environmental conditions*
    - The suitability of mooring designs, materials and deployment procedures for the extreme conditions cannot be tested at the nearshore site as it is situated in the Baltic Sea with lower wave heights and less current. Hence, the equipment was tested for all possible and reasonable parameters and has been adapted to withstand the offshore conditions at the FINO3 site.
    - Simulations of the seaweed and mussel-system by University of Ghent (only Seaweed) and two external companies have shown, that the maximum design loads will not exceed the chosen material braking loads. Both systems have been simulated for a 50-year return event.
    - The table below shows an excerpt of the simulation results for the mooring chains of each system (Table 1 and Figure 3)
    - Both systems are designed in such a way that only one weak link will break in case of failure (Figure 4). In such a case it will float in the water like a flag without drifting into the neighbouring wind parks. The load on the remaining link is then significantly reduced since the system is no longer under tension but "freely" drifting.

Table 2 Excerpt from the simulation results for the seaweed- and mussel-system of the German pilot for the offshore site FINO3, North Sea, Germany

System	Mooring Code	Line Type	MBL [kN]	Peak Load [kN]	Design Load [kN]	UC [-]
Seaweed-System	Scottish Standard	48 mm Mooring Chain	1279.39	221.52	1273.77	1.0
	ABS Operating				443.05	0.35
	ABS Survival				232.60	0.18
	DNVGL (Non-Redundant)				469.41	0.37
Mussel-System	Scottish Standard	19 mm Mooring Chain	440.00	110.34	380.69	0.87
	ABS Operating				220.69	0.5
	ABS Survival				115.86	0.26
	DNVGL (Non-Redundant)				239.17	0.54

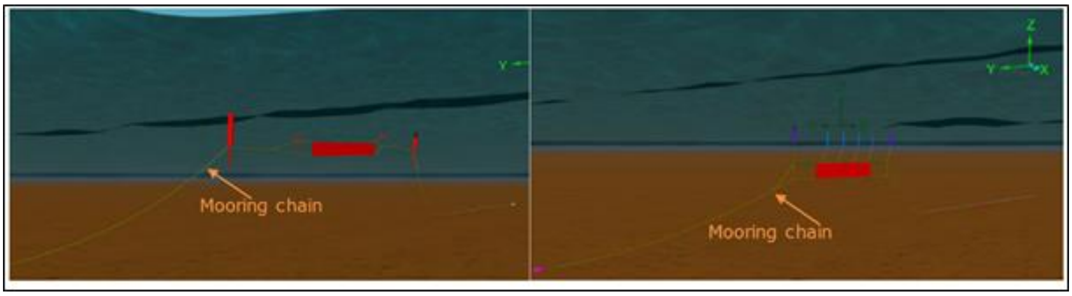


Figure 4 Snapshot of simulation for seaweed-system (left) and mussel-system (right) during 50year return event

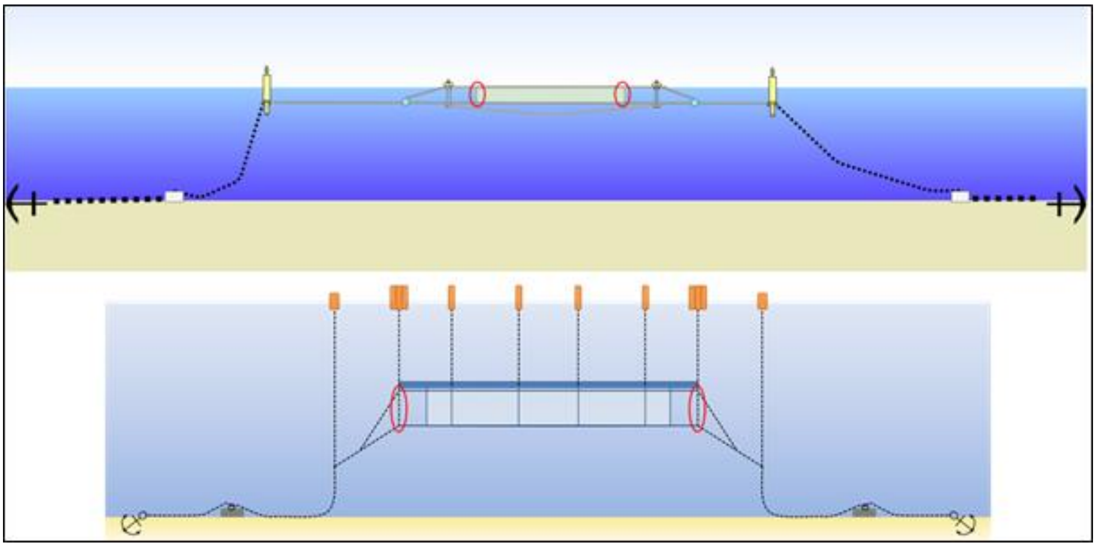


Figure 5 Sketch of weak links (red marks) of seaweed-system (top) and mussel-system (bottom) of the German pilot

- *Anchoring & mooring*
  - Different anchoring types are possible from a technical point of view. For example, screw anchors, heavyweight anchors or small monopiles could be used to hold the system in place. All these types have in common that they are relatively inexpensive to purchase but due to their nature of size or installation procedure the consequential costs for installation and handling are very high. Furthermore, special equipment and/or staff is needed to install screw anchors or monopiles. Even though screw anchors or monopiles are the way forward for large scale aquaculture farms in our case they are not affordable and bring too many risks due to dependencies of further third-party suppliers during a worldwide pandemic.
  - After long research for affordable equipment and with the close exchange of the Dutch-Pilot both systems of the German Pilot have been designed with a combination of drag-anchors and heavyweight anchors. Naturally drag-anchors are expensive when purchasing them, but since the systems will be installed for a short period of time only, rental of the anchors was the better solution.
  - Solutions and plans to fulfil the specific requirements, please see above under "Damage due to extreme environmental conditions".
- *Buoyancy design*
  - To keep both systems (seaweed and mussel) floating during the whole growth period it was decided to build the systems with sufficient buoyancy including a reserve for extreme growth and biofouling. Naturally, the extreme uplift at the beginning of the season would cause the systems to bounce up and down in the waves in a quite turbulent manner. Therefore, the buoys were designed as spar buoys, as they react very slowly to wave movements and thus the wave movement is transmitted to the actual carrier system in a damped form.
  - With a web-cam on the FINO 3 platform transmitting 24/7 it is possible to identify damage or loss of buoys and repair/or maintenance trips can be planned immediately. Furthermore, the FINO 3 engineers will frequently check the aquaculture site with binoculars when working offshore.
- *Biofouling*

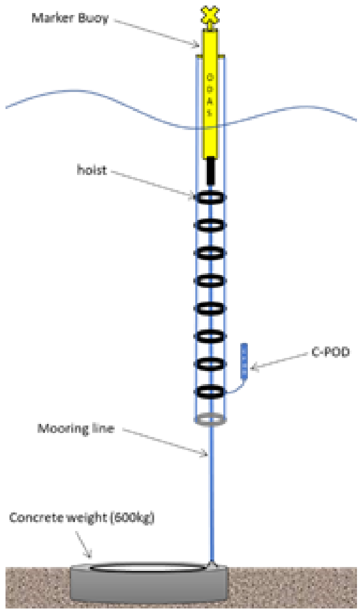
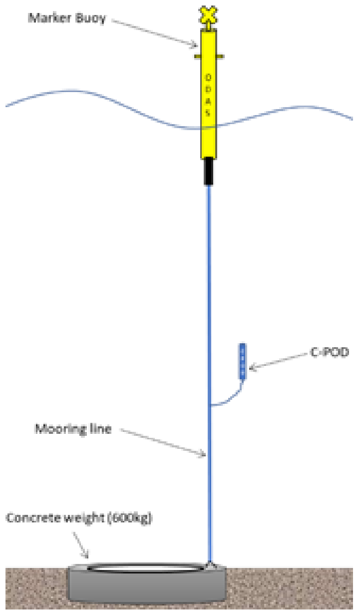
- An intensive literature research and exchange with other offshore projects resulted in the chosen solution for antifouling. Wipers turned out to be the most reliable and effective option to extend maintenance intervals on camera-lenses and sensors (Figure 5). In 2020 and 2021 long-term tests of different antifouling measures for both lenses and housing have been conducted at the near-shore site to find the most effective type which fulfils the specific requirements stated above. The product "Abio (Acorros 2021) showed the best results. This product will be applied onto camera and sensor housings to shorten cleaning times at the offshore site (Figure. 6).

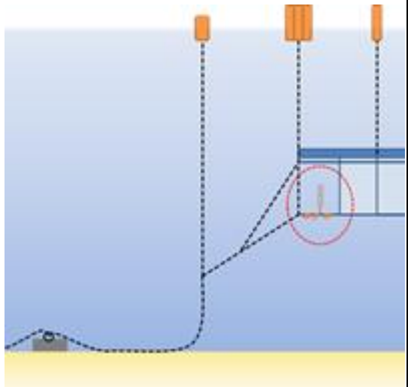
Figure 6 Underwater camera with wiper on the lens (left) and NO3-Sensor with wiper at the measuring device (right)

Figure 7 Test plates with non-biocide coating (Abio) after two months at the nearshore site (only the three white squares have been coated, the carrier plate was not coated)

- *Harbour porpoise monitoring*
  - Several ideas have been intensively discussed how to attach the C-PODs either directly at the sub-merged aquaculture systems, or at the mooring of the buoys, which are marking the aquaculture area.
  - Usually C-PODs are installed with an individual mooring system, which is attached to a bigger mooring system of marking buoys via a ground line. In our case the given space at the site at FINO 3 is limited due to the boarders of the safety-zones and due to other projects around the FINO 3 platform (multi-use area).
  - Several ideas have been developed, all with advantages and disadvantages (Table 2)
    1. Attachment with a kind of bottle hoist to the marker buoys for easy recovery from an inflatable boat
    2. Fixed attachment to the mooring line of the marker buoys
    3. Fixed attachment to the backbones of the seaweed- and mussel-system

Table 3 Overview of different options of C-POD moorings at the German pilot, FINO3, North Sea, Germany

No.	Advantages	Disadvantages	Sketch
1.	• Can be installed to the existing mooring system • Can maybe lifted by hand from an inflatable boat	• Additional material/equipment for attachment is necessary • Probably becomes entangled due to tidal changes o In this case the whole buoy (6m length) and mooring incl. 600kg deadweight anchor needs to be lifted to recover the C-PODs	
2.	• Can be installed to the existing mooring system • No further material/equipment is needed to attach the C-PODs	• For each maintenance action the whole buoy (6m length) and mooring incl. 600kg deadweight anchor needs to be lifted	

3.	• Can be installed to the existing mooring system • No further material/equipment is needed to attach the C-PODs	• C-PODs are relatively close to the noise of mooring chains of seaweed- and mussel-system • Maintenance ship needs to lift part of the seaweed- and mussel-system	

- The final solution still needs to be found/decided together with the vessel supplier who will retrieve the C-PODs.

2.1.3. MANAGEMENT SYSTEMS

Challenges

The challenges of developing a practical management system for an exposed offshore site in harsh conditions used by different other parties are constantly changing with new users at the site and long licencing procedures are:

- Develop specific detailed installation schedules
- Find suitable installation procedures (including a checklist with key points and excerpt of an installation manual)
- Respond to last minute restrictions
- Access and organize site-dependent seaweed yield

These needed to be discussed between all parties involved and regularly updated.

Specific requirements

- *Installation schedules*
    - One major difficulty is to find a weather window with very low wave heights for the installation. For the installation of the lander divers are required that can only operate with a wave height below 1m and only during the backwater period. All materials and specific preparatory works must be integrated into the schedule individually for each component. All single steps must therefore be well coordinated in terms of time. Some examples are: The customised seaweed net has to be prepared and delivered before the seaweed seedlings are ready to be applied to the net. There is only a short time slot between the date when the seaweed reaches the stage when it must leave the hatchery, to prepare the glue to seed the net and to find a suitable and stable weather window for the installation of the seeded seaweed net. At the same time all experts involved have to be on stand by and available.
- *Installation procedures*
    - Manuals and procedures have to be step-by-step guides and should be easy to understand for everybody to avoid misunderstandings between ship-crew, divers and client and substitutes. Several meetings with all involved persons, ship crew, technicians, biologists and suppliers are needed to agree on one procedure which considers all requirements.
- *Last minute restrictions*

- Due to the nature of the approval process at the BSH, the entire design had to be ready before the application was submitted, which resulted in requirements that had to be implemented at short notice after approval was granted and the design was completed.

- *Site-dependent seaweed yield*
    - Seaweed yield turned out to differ significantly between locations. Therefore, a across pilot (Germany, Belgium, Netherland) comparison of a standardized method is developed to exclude differences in e.g. materials or seeding technique as a source for different yields.

Design and construction plans

- *Installation schedules*
    - Due to sudden and unforeseen problems (lander delay, delayed installation permit, additional restrictions) the original plans for the installation in March/April 2021 had to be postponed several times. Regular meetings (at important stages of a daily schedule) have been organized to ensure a common level of knowledge for all partners involved.
- *Installation procedures*
    - For each part of the installation a script with a step-by-step guide including sketches and photos (Figure 7) was developed. The manual will help to keep track of the installation and to check whether no step has been forgotten and if all steps have been executed completely.

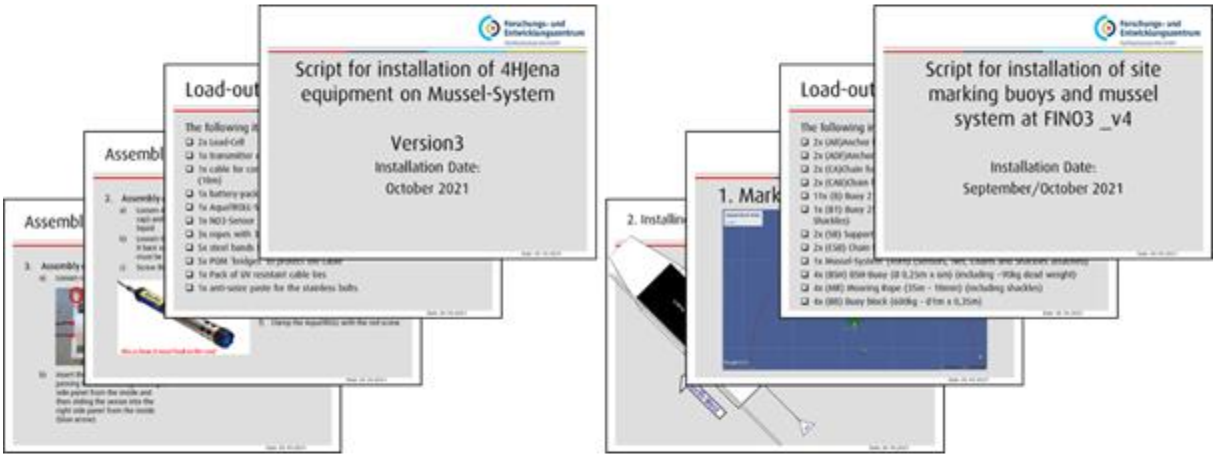


Figure 8 Example of installation scripts (excerpts) – (left) Script for sensor equipment of mussel-system and (right) script for mussel-system installation of the German pilot

- *Last minute restrictions*
    - The delay of the permission and the last-minute restrictions imposed by the BSH, e.g. harbour porpoise monitoring, have led to further delays in the installation planning. The complete material of the mussel-system was delivered to the harbour in Cuxhaven in May 2021. From this date the vessel supplier in Cuxhaven had to store the equipment and the pre-installation of the mussel-system onshore had to be postponed again and again. In August 2021 permission was granted with several restrictions that required further preparatory work
        - A third-party company had to be found that rents C-PODs and can provide an evaluation of the monitoring data at intervals of two months.
        - Funding of these unplanned costs have to be organized
        - Solutions for the attachment of C-PODs directly on our aquaculture systems or close by have to be found (see Table 2).

- Further restrictions subject to changes led to a higher workload in the management of the German Pilot.
    - Placement of harbour porpoise deterrents (Pingers) for at least the first six weeks after deployment or until complete coverage of the seaweed- and mussel-systems with biomass.
    - Maintenance of the C-PODs and transmission of the data in bi-monthly intervals.
    - Transmission of growth monitoring (lander data).
- Implementing additional trips for C-POD maintenance and collection of Pingers into the multi-use maintenance catalogue gives the opportunity to combine even more tasks at one trip but also has the risk of not getting all the tasks done within the given time frame.

- *Site-dependent seaweed yield*
    - To determine the site dependent seaweed yield across the UNITED Pilots, a uniform test setup was developed in cooperation with a commercial seaweed hatchery.
        - All seaweed cultivating Pilots include an aligned seaweed cultivation substrate into their aquaculture practice. Half of the lines will be pre-seeded (by hatchery) while the other half will be directly seeded with the individual seaweed strain endemic to the pilot location.
        - Also, direct seeding follows a standardized protocol, developed by the hatchery, which is based on best practice experiences.

2.2. The Dutch Pilot

The Dutch pilot is located at an already existing offshore test site, which is operated by the UNITED project partner North Sea Farmers. The site is positioned in the North Sea 12 kilometres off the coast of Scheveningen, The Hague, and measures 6km^2(3km x 2km). Research plots 2 and 3, depicted in Figure 9, host the UNITED pilot of floating solar and seaweed cultivation respectively. The Dutch pilot's main challenges are related to its distance offshore and the rough conditions with a significant wave height of 5m. Apart from this, the Dutch pilot is also affected by the region's freshwater influence.

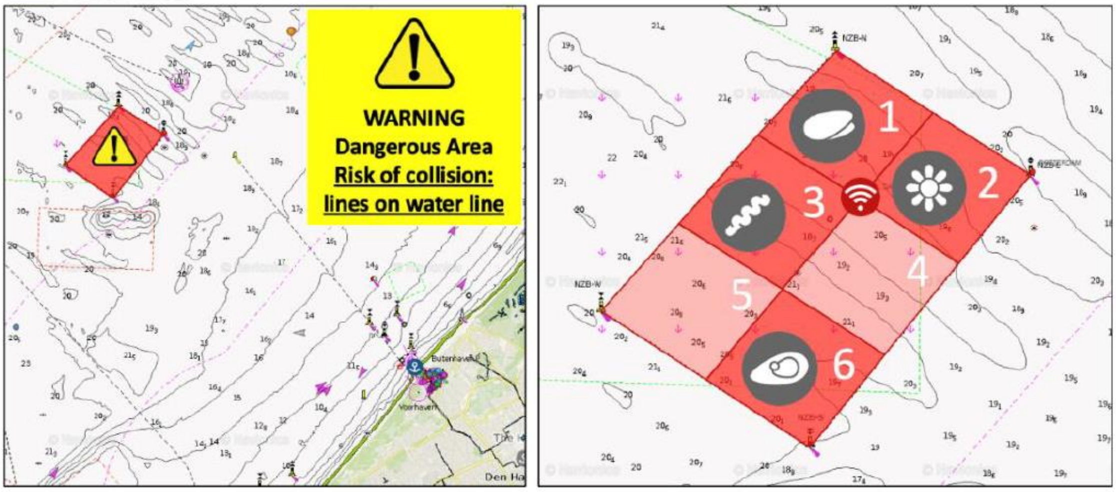


Figure 9 Location of the Dutch pilot in the North Sea, The Netherlands

2.2.1. MONITORING SYSTEMS

Challenges

- Mooring force measurements and remote monitoring: "It will be useful if mooring force measurements as well as remote monitoring systems could be employed" (D7.1)
- Damage due to extreme environmental weather conditions (D1.1)
- Common data collection and dashboard solution (pilot alignment meeting)
- (Seaweed) A robust solution for visual real-time monitoring was not available in year one. Will be implemented as of year 2.
- (Both) Real-time monitoring of certain parameters (mooring forces)
- (both) Consideration for operation: serviceability and intervention (offshore)
- (Solar) Workability of high tech OMM tools (e.g. aerial drones) operated from small RHIBs

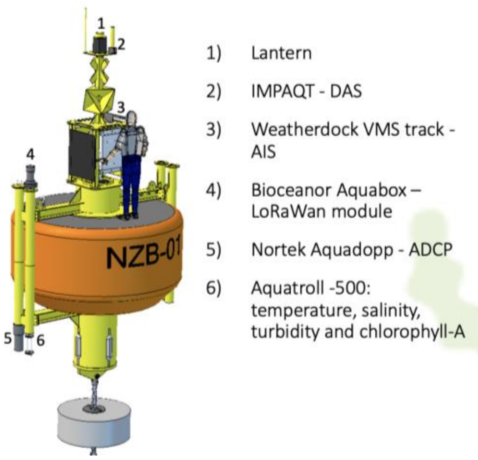
Specific requirements

- (Solar) High level of robustness and dependability (against e.g. heat dissipation, seawater, salt mist, submerged conditions, *wave slamming, biofouling)*
- (Both) Integration and combining functionalities a must for cost reduction and upscaling
- (Both) Minimization of offshore operation resource use, through dependable power supply and data off-loading solutions
-

Design and construction plans & unsolved problems

- (Both) Construction plans completed leading to successful deployment of both solar and seaweed system
- (Seaweed) For the seaweed system the design of the moorings remains to be a challenge. A better understanding of the hydrodynamic behaviour of and forces in the system is critical. Better technical solutions to get this data are required

- (Solar) Successful design of an additional power supply module that can support any (and very different) monitoring peripherals attached to the floater (e.g. to measure forces for instance). Such a stand-alone power supply module must also have the capacity to provide power for several days in case the PV is not capable of supplying any (because of weather conditions) and have a form factor that allows for integration on top of gangway deck (of solar farm)
- (Solar) Remote camera in place (Figure 10). The camera system that we use is a 12-megapixel Obscape time-lapse camera. We currently have four cameras in use that take every 30 minutes a still image. We have mounted them on poles that stick 1.5 meter above sea level. We use the images to check the conditions of the floaters and the PV systems on top, and to keep track of any wildlife passing by. This camera system is ideally suited for long-term visual monitoring as it is completely wireless, powered by solar panels (built-in the camera) and the images are transmitted in real-time using a 3G (or 4G) cellular connection.
- (Both) Monitoring buoy with sensors (Figure 11)
  - In-situ Aquatroll 500: turbidity, chlorophyll-A, salinity and temperature
  - Nortek Aquadopp ADCP –Tidal current measurement with depth profile
  - Pendant HOBO loggers: light & temperature
  - Weatherdock A193 vmsTRACK-PRO: AIS
- (Both) Telemetry (via internet-based dashboards)
  - Bioceanor Aquabox: LoRaWan module
  - IMPAQT: DAS



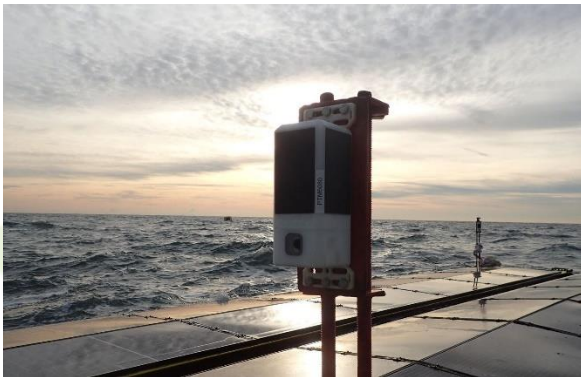


Figure 10 Obscape camera for monitoring floating solar (right)
Figure 11 Monitoring buoy of the Dutch pilot with sensors and components (left)

2.2.2. DEPLOYMENT DESIGN AND MOORING SYSTEMS

Challenges

- Mooring force measurements
- Damage due to extreme environmental conditions (D1.1)
- Commissioning and maintenance opportunities are limited in offshore conditions

Specific requirements

- Deployment must be possible with preselected vessels
- Fair weather window for installation schedule
- Cost should stay within budget

- Maintaining safety standard during offshore operations

Design and construction plans & unsolved problems

- (Seaweed and data buoy) Installation scripts were developed for the installation of the cultivator systems
- (Seaweed and solar pilot) Offshore trainings were followed by relevant personnel
- (Seaweed) Load sensors were procured, tested and installed in both cultivator systems. It remains a challenge to connect them to the remote monitoring system. Load sensors had been placed on top of each other (in top line and bottom line of structure). However, after inspection it appeared that they smashed against each other. In second season the position of load sensors will be adjusted accordingly.
- (Seaweed) Various attempts were made to connect a probe sensor to the seaweed system but this proved not workable once offshore and was abandoned. This remains a challenge. Connecting probe sensors in the seaweed system in a sensible way so that significant data can be obtained without getting damaged and losing the data.
- (Seaweed) In order to have a flexible, soft growth system, special 10-meter long spar buoys were designed. As well, a backbone structure with lines and flotation buoys. After harvesting, all elements were free of biofouling, however it is expected that a biofouling clean-up is needed before deployment in year 2.
- (Seaweed) An innovative net structure had been designed (so called 'rope-based net'), however due to material failing, net structure didn't remain intact. For the second season substrate changes will be implemented.
- (Seaweed) Several connecting plate designs turned out to have a high risk that connecting ropes and lines could scratch the plate and ultimately break. A new design will be made for both the plates as well as the rope egg thimbles and connecting plates will be replaced in year 2
- (Seaweed) One out of 4 nets(in the in-line system, Figure 12) happened to have twisted due to heavy weather (resulting in damage to a flotation buoy). Design will be improved and measurements taken, in order to prevent twisting of the nets in year 2.

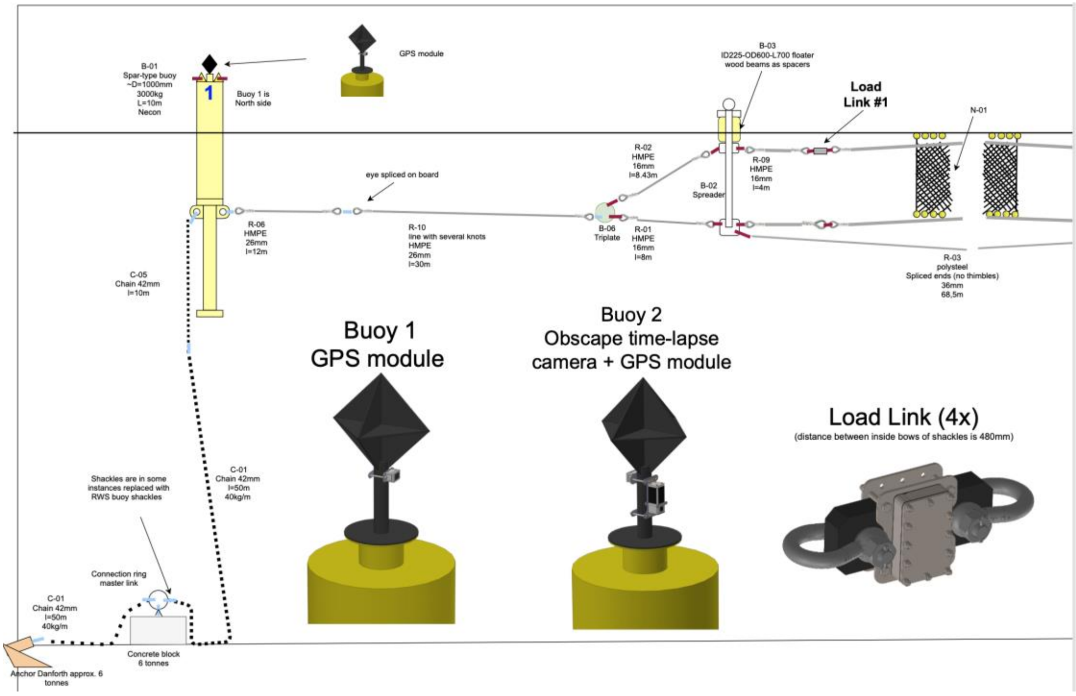


Figure 12 Load links in the in-line seaweed Cultivator system

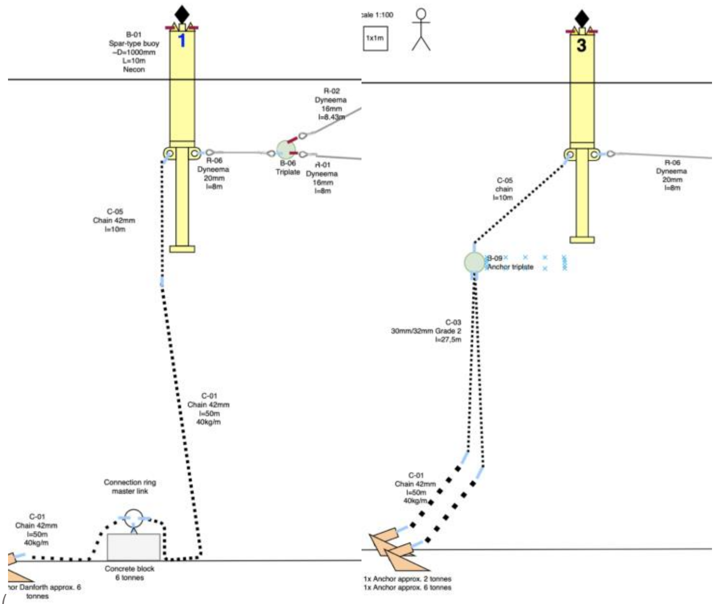


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Figure 13 Anchoring systems for both the inline (left) and transverse (right) seaweed system

- (Solar) Note that the implementation of floating solar, with regard to the design, materials, assembly and orientation are restricted to our responsible partner only, in line with the Consortium Agreement. Hence, limited information on these aspects can be presented here.
- (Solar) Successful installation and decommissioning of a small modular floating solar farm (50 kWp) with multi-cat (tow out and hook up) and small tugboat (installation of anchors);
- (Solar) Successful 2nd installation of first batch of a larger modular floating solar farm (MW-scale farm is planned for summer 2022)
- (Solar) Successful operations (sometimes combined with seaweed inspection trips) carried out with small RHIBs; safety procedures in place
- (Solar) Still (sometimes) issues with measuring mooring forces with using load shackles.
- (Solar) The floating array is moored with a four-points anchor system. Each leg of the anchor system contains of an anchor, anchor chain, a buoy and a horizontally floating line connecting to a corner piece of the floater array. Installation takes place in two phases. In a first phase the anchors have been de-ployed, in a second phase the floaters are towed from the harbour of Scheveningen to the offshore site using a multi cat and hooked up between the four-points mooring system (Figure 15).

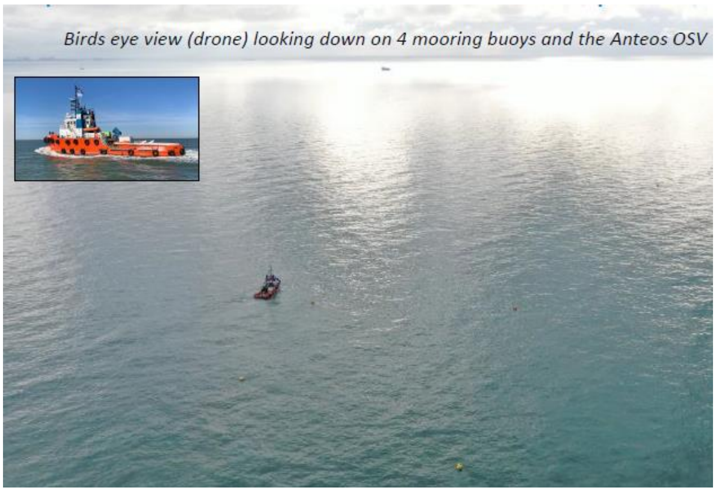

Figure 14 Birds eye view of a drone looking down on 4 mooring buoys and the Anteos OSV

Figure 15 Multicat KRVE towing floaters with 2 cameras on top

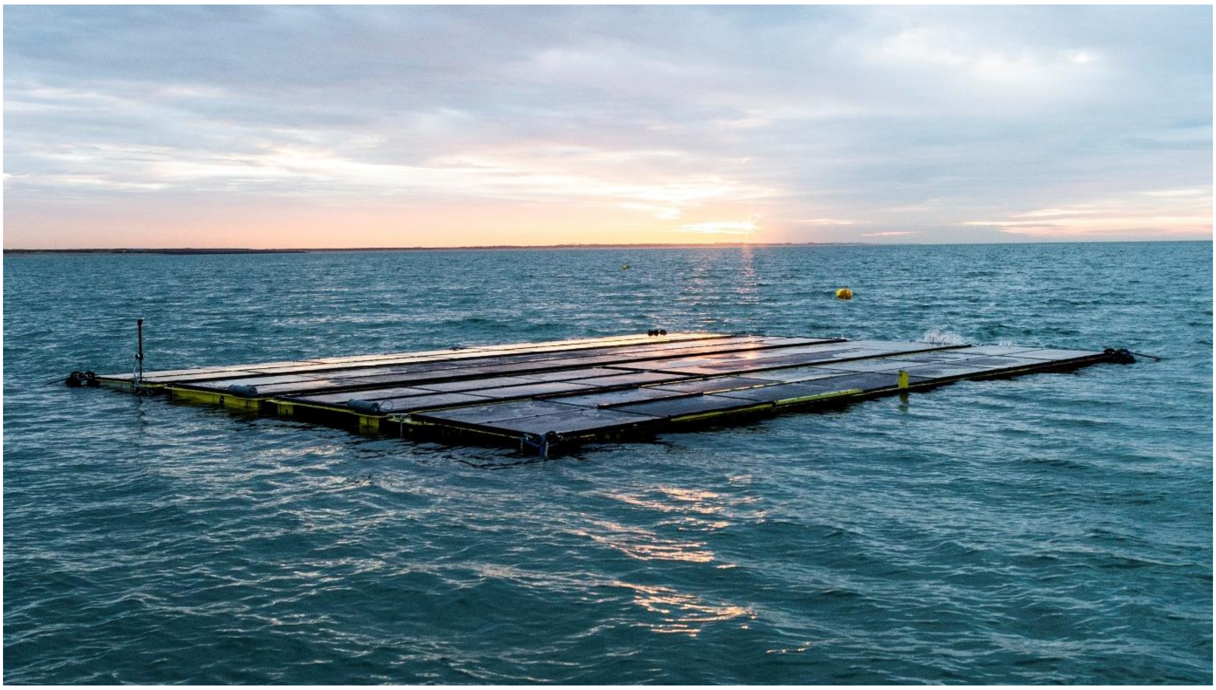

Figure 16 Photo of the floating solar platform

2.2.3. MANAGEMENT SYSTEMS

Challenges

- Management of the pilot site for safety and marine coordination
- Remote monitoring of status and performance.
- Inadvertent ship traffic in the pilot site
- Design a product life cycle and maintenance management system that allows for smart and efficient OMM for any upscaled floating solar farms
- Creating a data infrastructure & management for the various monitoring systems and 3rd party services

Specific requirements

- Validated time series of parameters of interest
- No ship traffic in the pilot area
- Ensure all activities are up to offshore safety standards

Design and construction plans & unsolved problems

- Setting up a permit to work system, this work is in progress
- Installation of various sensors for waves, (a)biotic parameters
- Installation of cameras - still no commercial solutions available for live camera feed (cost, power consumption)
- Remote, real time monitoring of infrastructure integrity with load shackles - still not available

2.3. The Belgian pilot

The Belgian pilot is located in the Belwind offshore wind farm operated by Parkwind roughly 50 km off the Belgian coast (Figure 16). The 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. The Belgian pilot's challenges for design and construction are mainly related to: 1) its relatively long distance (50 km) from the coast; 2) rough conditions with 6 m waves not being an exception; 3) its location in a wind farm, posing requirements on risk assessments. These challenges are discussed through the core themes: monitoring systems, mooring and design systems and management systems.

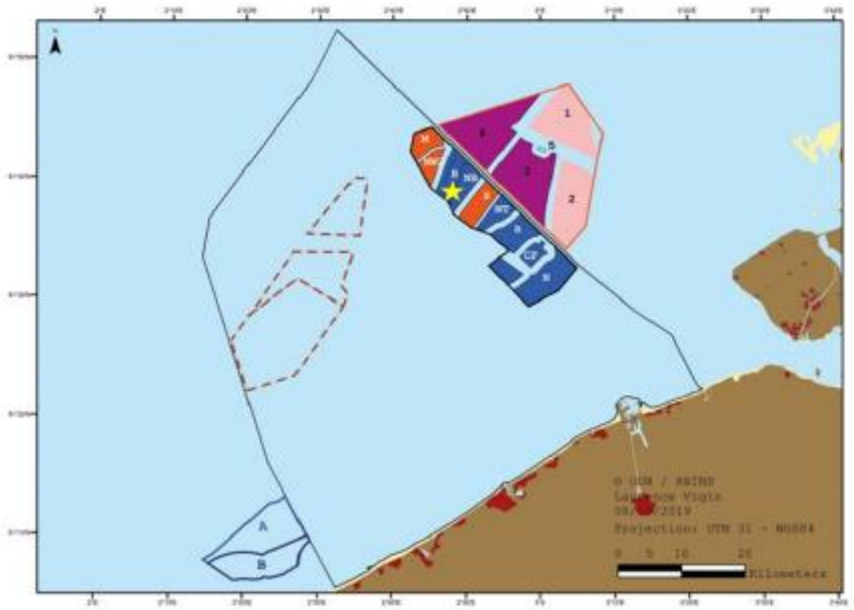

Figure 17 Location of the Belgian Pilot (yellow star) (© Laurence Vigin, RBINS).

2.3.1. MONITORING SYSTEMS

Challenges

- At the start of the project, it was assumed that in-situ *monitoring of water quality parameters and environmental conditions* in the Belgian pilot could be organized by sharing the Lander that is developed for the German pilot (rotation of use between pilots) and/or by building a small version of the Lander. However, soon it became clear that sharing the Lander was not a feasible option due the logistics that are involved to remove and re-install the Lander. Also, the entire foreseen budget for the Lander in the German pilot was needed to build it, so there was no room for an additional smaller version (pilot alignment meeting). As a solution, similar data will be obtained from remote sensing and modelling products, albeit less detailed.
- As indicated in the survey by WP6 and in D1.1., the extreme weather conditions in the Belgian part of the North Sea are the main challenge to overcome, technically speaking. This has not only major consequences for the design of the systems (D7.2), but also for the *methods used to monitor the biological performance of the systems and for the planning of the sampling activities*. The fact that the oyster longlines will be submerged at -10m under the sea surface, in order to protect the line against the wave action, complicates further the sampling activities and monitoring.
- In order to centralise all the data that is retrieved by the different partners in the Belgian pilot (UGent (Lab for Aquaculture (oysters), Lab for Phycology (seaweed), RBINS (fouling, oysters)), the *data* will be stored on the HiSea Platform, a dashboard that will be commonly used by all UNITED pilots (pilot alignment meeting). The challenge is however to understand how the data can be uploaded, going from

This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement no 862915

field data on the biological performance of oysters and seaweed to remote sensing data on temperature, suspended solids and PAR.

Specific requirements

- During the pre-operational phase, the installation of the restoration tables on the scour protection of the wind turbines and of the longlines with oysters and seaweed needs to be prepared, based on the experience nearshore. The Belgian pilot is situated inside the Belwind offshore wind farm, which brings along specific requirements that need to be fulfilled. The vessel and crew that will carry out the sampling need to be approved by the wind farm operator in advance. The following certificates need to be in order at least 48h before a sampling campaign. This means that, before the vessel has access to the Belwind site, it has to comply with:
    - PWD QHSSE expectations (including Contractor's own ERP)
    - Parkwind MC procedure (including as sailing route, SOS procedures, work permit, personnel registration, transfer plan, PPE vessel and crew matrix…)
    - Blighbank ERP (contractor must provide the Vessel ERP Bridging Documents).

The scheme below (Figure 17) summarizes the different steps that need to be followed.

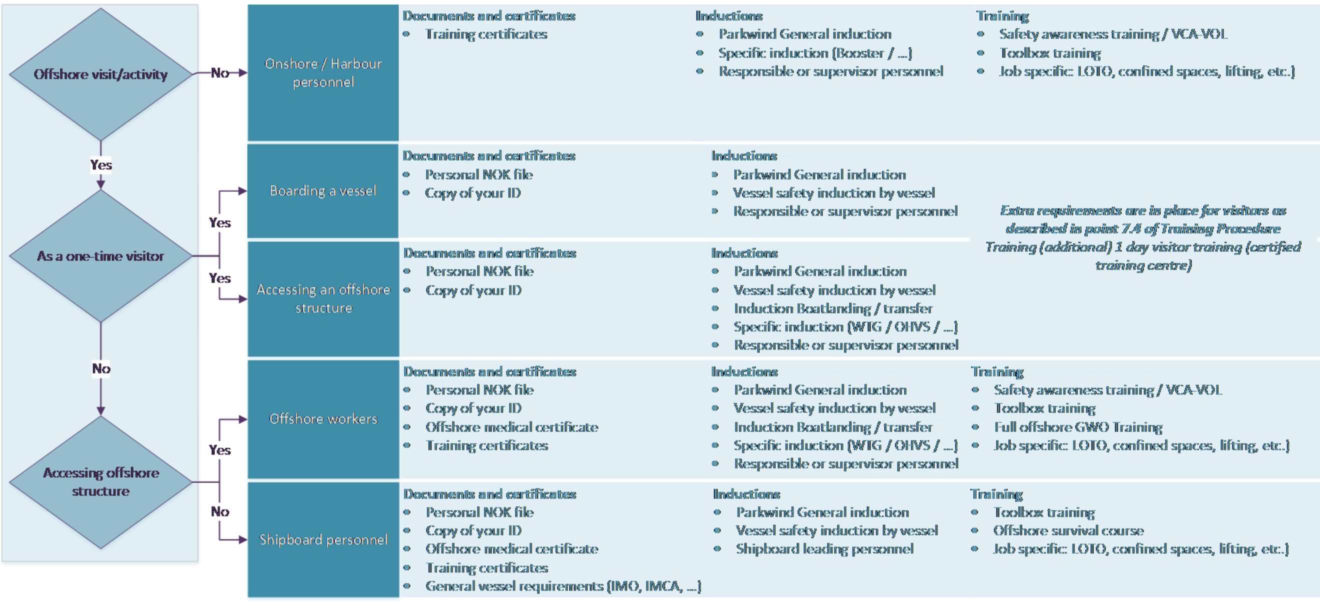

Figure 18 Off-shore visit protocol

- *Vessel requirements*: In general, the vessel used for operation must be (i) administratively approved by MC, this means that the owner has to complete the SOS system (SafeOffshoreOperationsSystem). This includes general vessel info and vessel documentation/certificates. In addition, (ii) the vessel will be inspected (vessel vetting) if the inspection was not done before or has expired. In terms of equipment on board, the following items should be present:

- Each vessel shall have an operational SOLAS approved Class A AIS system whenever working at the project.
- The crew vessel should have an operational mobile phone on board through which the bridge is continuously accessible. The phone shall be dedicated to the specific vessel and -in Belgium- use the Base network or have a foreign subscription.
- Each crew vessel shall upon request have two (2) seats for employer's staff available.
- The vessel's radio communication equipment shall be GMDSS compliant.
- The contractor shall ensure that all information requirements from authorities on vessel movements are met and available 7 days before start of the works.
- Each crew vessel shall have an operational signal receiver and direction finder operational frequency 121.5Mhz for Personal Locating Beacons (PLB) of a type such as "sea marshall" and/or equivalent AIS PLB.
- The checklist of required equipment (general equipment, fire equipment, safety equipment, navigational equipment) can be found in Table 4 below and depends on the size of the vessel.

Table 4 Vessel requirements

Vessel type	WHO	Vetting	Based upon
Vessels of less than convention size: < 150 GT	MC or QHSSE	Annex 1	IMCA M189 + IACS 99 + MCA MGN 280 (area cat 2)
Vessels of less than convention size: ≥ 150 GT and < 500 GT	MC or QHSSE	Annex 2	IMCA M189 + IACS 99
vessels ≥ 500 GT	QHSSE	Annex 2	IMCA M189 + IACS 99
Special (DP, Diving, jack-up, ...)	QHSSE	Annex 2	IMCA M189 + IACS 99

- *Requirements for crew.* A transfer plan is prepared in advance which includes personal and training info of the crew members. This includes the ID, the personal profile that was created online in the SOS system, medical offshore certificate, certificate Sea survival training (minimum STCW), certificate of successful general Parkwind induction training. A document is available that describes the required minimum training level of the people onboard.
- *Requirements to deploy activities.* Work permit: Every sampling activity needs to be described in detail by the partners that will carry out the sampling and needs to be approved by Parkwind, and more specifically by the department HSSE (Health Safety Security and Environment). This document, called the Risk Assessment and Method Statement (RAMS), describes in detail which activities will be carried out and how (e.g. use of crane, A-frame, position of the boat during activities, actions to be taken in case of risks) taking all Parkwind requirements into account. When diving activities are planned, a diving plan needs to be provided (before activity) while a dive checklist and completed logbook needs to be provided after the activity.

Design and construction plans & unsolved problems

- The nearshore activities which are part of the pre-operational phase of the project, gave us clear indications on what is working and what not in terms of aquaculture systems for flat oysters and seaweed. Monitoring of the aquaculture lines involved cleaning of the systems (oyster baskets) and taking samples. This was done with the vessel of Brevisco "Stream" whereby the backbone was first captured with a hook and consequently lifted with an A-frame. *Cleaning* of the oyster baskets and lanterns from fouling was done with a high-pressure hose. Other systems such as the ropes and sticks could not be cleaned out of fear to lose the animals that were glued or cemented to the ropes and sticks.

Figure 19 Oyster rope with cemented oysters at installation at near-shore test location (2nd June 2021) © Annelies M. Declercq

Figure 20 Oyster rope with cemented oysters at nearshore test site at 2nd of August 2021 © Annelies M. De-clercq

Figure 21 Oyster spat collection frame with on top 4 SEAPA-baskets filled with mussel shells and below sticks with glued mussel shells nearshore 02/08/2021 (© Annelies M. Declercq)

- *Sampling or harvesting* of oysters was done in a similar way, whereby the aquaculture systems were cut loose from the backbone and hoist on deck of the ship. Some parameters, such as total weight of the ropes, were taken immediately after harvest. Oysters are also removed from sticks and ropes for later processing, such as measuring wet weight, dry weight, meat content, shell weight, length etc. Oyster baskets with oysters or mussel shells were checked in the harbour. In case of the seaweed, the net system was lifted similar to the oyster cultivation systems – the backbone was captured with a hook and lifted with an A-frame to allow sampling. For the harvesting, the nets could be removed from the backbone by opening the Velcro® connections. Seaweed was carefully sampled, weighted and measured once the boat was back in the harbour.
- *The restoration tables* were only sampled after one year of deployment. The indicator buoys that were originally connected to the tables, were lost. Fortunately, the exact GPS positions of the tables were recorded. To collect the table, it was necessary that first a diver connected a pulling rope to the table. A buoy connected to the pulling rope facilitated the retrieval of the rope, once the diver was onboard again. With the aid of the A-frame, the table is then lifted on board. Samples for fouling from the restoration tables were collected once the boat was back in the harbour, by people of RBINS. Spat fall of flat oyster, the major parameter to follow up, was evaluated by checking every stone. In order to do a proper job, the four kinds of stones, which were stocked according to a known matrix, were cleaned with a high-pressure hose.

Figure 22 Sampling restoration table nearshore 28/10/2021 (© Annelies Declercq)

- *The monitoring and sampling activities* nearshore taught us that following challenges should be taken into consideration when programming for the offshore monitoring:
  - Indicator buoys at the surface are easily lost. Records of the GPS locations is imperative;
  - The sampling and monitoring of the backbones are only possible every 2 weeks at slack tide during neap tide (window of 1-1h30h);
  - The collection of restoration tables is less tide dependent, but the use of divers is unavoidable. The use of an ROV could be an alternative solution, in order to reduce risks, but this is very costly and not foreseen in the initial budget.

2.3.2. DEPLOYMENT DESIGN AND MOORING SYSTEMS

Challenges

- The major constraint for aquaculture offshore in the Belgian part of the North Sea, are the extreme weather conditions (D1.1). Waves of 6m are not an exception as are currents of 1m/s. The very corrosive environment of seawater discourages the use of steel (like anchor chains) and encourages the use of ropes.

Specific requirements

- The specific requirements mentioned under 6.3.1. are of course applicable for this section as well.

Design and construction plans & unsolved problems

In the design of the final backbones, both for seaweed and oyster, the largest waves and strongest currents occurring in a 50-year period have been used to calculate the necessary dimensions of anchors, mooring ropes and backbones, while in addition, a safety factor of 3.45 has been applied (D7.2)

- In order to reduce the impact of the waves, the "oyster" backbone offshore will be hung 10m below the sea surface (D7.2). This could not be tested during the pre-operational phase since the nearshore longline had been installed for another project in the Westdiep area and was made available for the Belgian pilot within the UNITED project. Simulation with the Moordyn-UGent software gives enough information to estimate the risks involved when installing such a backbone between wind turbines. In addition, a risk assessment is carried out by the advisory company Mott MacDonald that has Parkwind as client and a proper third-party insurance has been taken.
- The Belgian pilot decided to opt for screw anchors to anchor the backbone offshore. There is expertise with this technology nearshore: Brevisco has been working together with Fielder Technics (SME from UK) for many years and has installed more than 20 lines nearshore with screw anchors. It proved to be a reliable technic and economically very interesting. However, there is no expertise in Europe with the installation of these anchors offshore for aquaculture purposes, and certainly not inside offshore wind farms. One of the major concerns during the installation, is to keep the vessel fixed at the location while drilling. The methodology deployed nearshore (using clump weights to stabilize the boat), can't be translated to offshore locations. Use of ROV, 4-point anchoring or DP2 are some of the options that can be considered for installation in offshore wind farms. The partner JDN is carrying out an extensive market study to identify the most suitable partner.
- The location where the backbones and the restoration tables will be installed, takes into account the biological requirements of flat oysters but are chosen and approved by the HSSE of Belwind, such that the consequences of a loose backbone or problematic deployment of the tables are minimized (at the outskirt of the wind farm, away from cables).
- In order to reduce corrosion due to electrolysis of the galvanized stainless-steel restoration tables, sacrificial anodes in zinc are attached to the tables. The nearshore tables that are now one year in the seawater only show minor signs of corrosion.
- Several aquaculture systems have been tried out nearshore and these are the recommendations that are made for offshore use:

1. *Grow-out oyster systems*

a. Baskets in frames: this was first considered a good option despite fouling. It is difficult to predict whether the same fouling organisms will be found offshore. The main problem nearshore are the settlement of mussels. This may be less of a problem offshore, since it is documented that mussel spatfall is much higher nearshore than offshore. We expect however more problems with the tube-building amphipod *Jassa herdmani* (crustacea). Another problem is that a large number of the baskets were lost from the frame where they were attached to. This needs special attention and better alternatives of baskets in tailor-made racks are looked into, which are currently being tested nearshore.

b. Ropes: oysters were lost in the lower part of the 4m ropes. A heavier weight or larger distance between the ropes offshore may solve this problem. Cementing oysters to ropes worked better than gluing the animals. Fouling did not seem to harm the oysters, although growth comparison between the different systems is still under analysis.

c. Sticks: the wooden poles (first design) proved to be unworkable. The use of bamboo sticks was easier. In this case, gluing the juvenile oysters to the sticks worked better than cementing. However, the robustness of the system was substandard. It will not be pursued for offshore application.

d. Lantern nets/baskets: as these were hung at three different levels, we saw that the two levels had several compartments which were seriously damaged. This is probably a result of the shallow nearshore location (15m), leading to collisions between baskets or with the sea floor during stormy weather. Also, the mesh size was not appropriate, so quite a lot of spats were lost. The lantern baskets will be applied offshore, however the set-up will be changed in that only one level will be prepared and the mesh size will be adjusted.

2. *Spat collectors oyster systems*

Empty mussel shells are described to be one of the preferred substrates for flat oyster to settle on. The use of baskets filled with shells and shells glued to bamboo sticks were compared nearshore. Based on the results and the weakness of bamboo sticks, only filled baskets are considered for offshore application.

3. *Restoration tables*

The nearshore activities also involved the design and deployment of two restoration tables that tested different scour material as substrate for flat oyster spat, in the presence or absence of flat oyster adults (D.7.2).

The restoration tables proved to be successful nearshore, but intermediate sampling was not possible. Therefore, a new approach was sought for the offshore tables. An adapted table was designed with input from the different partners, and in close collaboration with the diving team of RBINS who will carry out the sampling. It was important to come to a practical solution, since the diving window offshore is very short.

JDN will use the same material (galvanized stainless steel) as for the tables nearshore, since it earned its merits. Because the difference in settlement of flat oyster seed on the four different scour materials were minimal, it was decided to use only 1 type of stone (Norwegian granite) for the offshore experiment.

4. *Grow-out systems for seaweed*

Nets were used for the seaweed grow-out systems as they provide a larger cultivation surface in comparison to a single line. Different net types, appropriate for the attachment of seaweed rhizoids, as well as different seeding techniques were tested nearshore. Strong differences between the net types in terms of their durability to withstand the harsh conditions were observed and adjustments were conducted in preparation of the offshore installation. Some of the experimental treatments included the intermediate step of a hatchery where the gametophytes were allowed to attach and develop into sporophytes before deployment in the sea. This step appeared to be crucial for the successful attachment of the juvenile seaweed.

Together with the German pilot, a comparison between seeding techniques is designed to investigate the impact of the different exposure levels on the grow-out of sugar kelp dependent on the seeding technique. Pre-seeded ropes as well as sporophytes for direct application to the substrate using a glue (AlgaeBinder) will be provided to the different partners by Hortimare to ensure a standardised approach. In the Belgian pilot, these ropes will be tested nearshore.

2.3.3. MANAGEMENT SYSTEMS

Challenges

- A location on land is essential to prepare the missions, to store materials and equipment, and to accommodate holding tanks for living material before missions.
- Timing is very important since living organisms need to be prepared before the sea mission takes place. However, since the sea missions are very dependent on the weather conditions which are to a large extent unpredictable, it remains a challenge to have all pieces of the puzzle fall into place.
- The sampling and the processing of samples needs to be prepared well, since it implies some logistics (transport, cool boxes, space in freezers etc.) in order to maintain the quality of the samples.

Specific requirements

- The supply of the flat oysters, both seed and adults, is a real challenge for the Belgian pilot, since only the introduction of certified *Bonamia* free oysters is allowed offshore in the North Sea. Since these animals are only found in a few specific areas (Norway, United Kingdom), cooled transport needs to be organized well in advance. The aim is to reduce the transit time as much as possible to reduce stress and mortality.
- Large tanks to keep the oysters for several weeks (e.g. when the sea mission is cancelled) in good conditions are not widely available.
- Diving activities in the Belwind offshore wind farm need to be reduced to the strict minimum. It is allowed to rely on divers for sampling purposes (including preparation for decommissioning during sampling) (10 diving days in total), but extra dives are not allowed.

Design and construction plans & unsolved problems

- One of the partners, Brevisco, offered a storage location to the partners of UNITED that allows not only storage of the materials but also the preparation of the frames and other test equipment.
- The Institute for the Sea (VLIZ) has a state-of-the-art recirculating system in Oostende (MSO) that can be used by universities for their marine research. Ghent University has become a regular user of this facility to store flat oysters before they will be transported to the sea, to store oysters after sampling or to incubate pre-seeded seaweed nets.
- Oyster baskets were also kept in the harbour in Nieuwpoort during winter 2019-2020, after getting the permission of the authorities.
- Diving activities can be replaced by ROV under certain conditions. Although technically possible, it is not foreseen in the budget.

2.4. The Danish Pilot

The Danish pilot corresponds with the Middelgrunden wind farm that is situated 3.5 km from Copenhagen harbour on a natural reef at 3 – 6 m water depth (Figure 22). The wind farm consists of 20 turbines of 2 MW each. This pilot combines tourism with existing offshore wind. Therefore, design and construction plans are not as elaborate as for other pilots. It's main challenge for design and construction relates to extreme weather conditions (including ice) that can occur at the pilot side. Specific challenges and solutions are summarized below for: monitoring and docking systems, mooring and design systems and management systems.

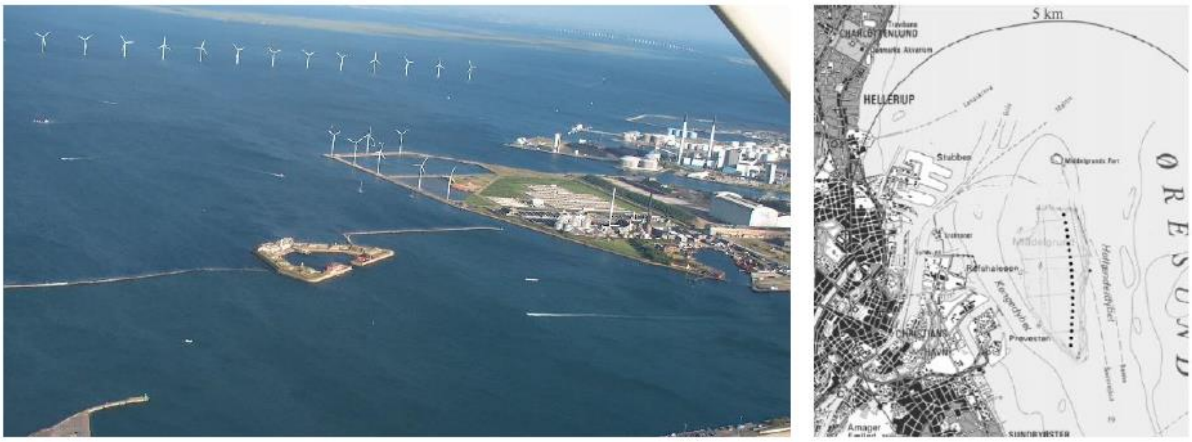

Figure 23 Danish pilot site aerial photo and map

2.4.1. MONITORING AND DOCKING SYSTEMS

Challenges

Unknown and changing weather conditions not allowing tourists to access the turbine foundation and tower.

Specific requirements

Unknown and changing weather conditions not allowing tourists to access the turbine foundation and tower: during visits with a new type of boat incorporated recently (RIB Boat) we have experienced that the combination of increasing wind with waves and currents from one particular direction (quite rare indeed) makes the tourism visit to the turbines impossible. However, we have not been able to know about these conditions at the harbour or before departing. Instead, we can first realise about the combination of weather conditions once offshore nearby the mooring point of the RIB boat. There is only one ladder for accessing the turbine from the sea surface, which limits the possibilities for access. Another challenge comes up when weather conditions change rapidly, and the tourist group is hosted on top of the turbine and needs to board back to the RIB boat after the visit. If the weather conditions are not favourable, unpleasant waves and current can affect the possibility of picking people up with small boats like RIB boats.

Design and construction plans & unsolved problems

Unknown and changing weather conditions not allowing tourists to access the turbine foundation and tower: there are two possible solutions to trying to solve the problem.

- The first one is to choose bigger boats which can sail and approach the turbines independently of rapidly changing weather conditions. However, it is usually the client (the tourist operator / industry group / academia group), who chooses beforehand (Indeed the planning of the visit can take form up to 1 year in advance), which type of boat they would like to rent, in accordance to their budget, schedule and size of the group. The alternative of changing the type of boat the same day of the trip is almost unrealistic, as these kinds of boats are rented for different purposes (fishing tours, sightseeing, group sailing adventures, etc.) and have relatively tight schedules during the spring and summer seasons.
- Include more experienced and trained staff able to deal with changing weather conditions. This has been recently the approach of RIB boats, who have decided to have two people of their crew onboard instead of only one.
- Availability of a forecasting system providing near-future forecasts of metocean conditions in the region of the wind turbine. With this information, the boat operator can decide upfront of the trip if the conditions are favourable enough to make the trip and safely drop -off tourists at a wind turbine.

2.4.2. DEPLOYMENT AND MOORING SYSTEMS

Challenges

- Damage due to extreme weather conditions (D1.1)
- Ice risk on Middelgrunden location.

Specific requirements

- The ladder foundations of Middelgrunden Wind Farm can suffer of damage due to extreme weather conditions – ice forming every 5/6 years.

Design and construction plans & unsolved problems

- Concrete gravity foundations designed and built with bulbous (wine glass) shape: it assists in ice breaking and easing the flow of ice around the wind turbine, thereby reducing loads on foundation. In Middelgrunden site every 5-6 winters ice can be up to 0.5m thick
- The ladders are constructed with failure weakness so only the lower parts of the ladder are breaking off when having ice. This makes repair work cheaper.
-

2.4.3. MANAGEMENT SYSTEMS

Challenges

- Guiding tours and tourism very limited due to Covid-19

Specific requirements

- *Guided tours and tourism very limited due to the Covid19*: due to the effects of the pandemic, national restrictions and travelling restrictions, the number of tours in year 2020 and beginning of 2021 have been very low in comparison to the average number of tours of previous years (around 40). Indeed, last year there was a trend indicating that the national as well as international interest in the tours was increasing. Visitors from abroad came mostly from Asia (South Korea, Japan and Taiwan) and America (US). To cope with this new situation, a solution has been proposed: the development of Virtual Tours.

  In addition, it is desired that the solution of implementing the virtual tours will benefit two purposes. The first one: reaching a wider audience (the more general public and tourists who might know about the possibility of visiting the wind farm) and the second one: to promote and train about the wind farm beyond Danish borders.

Design and construction plans & unsolved problems

- *Guided tours and tourism very limited due to the Covid19*. The development of Virtual Tours: the Danish Pilot has tried to conceive other means of trying to involve tourism into the existing Middelgrunden Off-shore Wind Energy Farm. The existing wind farm is relatively present in the Landscape of the city of Copenhagen. It can be seen from an eye-view when landing with an airplane, from different points of the city centre (the Round Tower, the City Hall, the long bridge, the waterfront at Nordhavn) and from the popular beach of Amager, among others. It then became an idea to try integrating the *expensive* visits to the wind farm into an affordable tour to everyone visiting the city centre. It is the plan that QR codes will be placed around iconic sites of the city, which will give access to a number of virtual tours (about 6 to 8 tours, of which the first one is already published and available). Through these visits, the understanding of wind energy and how a wind turbine works may be more available to the general public; and if interest is arisen, they would be able to also book a tour.
  The virtual tours will cover the following topics:
    - A Tour to the Top – available in this link[2].
    - The Construction of Middelgrunden Wind Farm
    - Environmental Aspects
    - Electricity Production: from a wind turbine to our plug at home
    - The location of Middelgrunden

[2] https://youtu.be/VGpXKW0CAnQ

2.5. The Greek Pilot

The Greek pilot corresponds with Patroklos and is situated nearshore, 59 km of Athens in Greece. The wider area is protected by NATURA 2000 and the Treaty of Barcelona due to a number of significant characteristics that this pilot site has to offer. The site is currently operated by Kastelorizo Aquaculture. This pilot combines fish aquaculture with tourism (scuba diving in particular). It's main challenges for design and construction relate to the adequate remote monitoring of the environmental parameters around the pilot to assist in decision support.

Figure 24 Greek pilot site

2.5.1. MONITORING AND DOCKING SYSTEMS

Challenges

- Network connectivity issues (D1.1). Regarding the Greek pilot site, the communication needs were served through a satellite network provided by a Greek mobile operator, offering an insufficient bandwidth for the security and operational needs. KASTELORIZO has proceeded with adding equipment that would provide 4G services, which might also not seem to be sufficient when the site will have 5 underwater cameras live-streaming.

Specific requirements

- *Fish being stressed while scuba-divers swim close to the cages:* aquaculture farmers noticed that fish are usually stressed when large wild fish (e.g. tunas) swim at the bottom of the cage. This has an impact on the normal fish growth and most importantly on the costs of lost feed (while feeding the fish, if these suddenly get stressed, they stop eating). Therefore, one important requirement posed from the aquaculture farm is to ensure fish are not disturbed by the presence of scuba divers when they are swimming close to the cage. For the specific requirement described above, WINGS has already installed one camera (initially for testing purposes) and now has proceeded with the installation of four more cameras to be installed in the cages in order to monitor fish behaviour during the project's lifetime. Image below depicts the video analysis of fish behaviour that has been developed by WINGS, in AQUAWINGS platform.

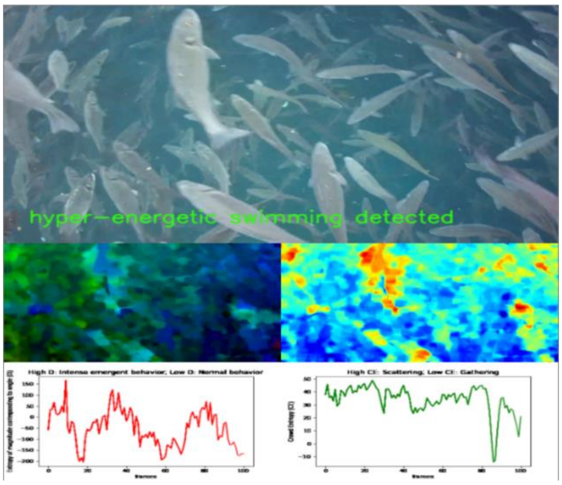

Figure 25 Sample images Greek pilot

- *Remote monitoring of physical conditions at site:* During the operational phase, remote monitoring of the farm using sensor data for physical/biological/chemical parameters will be applied on site, gathering data from multiple sources.
- *Security and Infrastructure Maintenance:* Monitoring and maintenance of an aquaculture site is very important, both for the physical security of the infrastructure as well as the welfare of the fish regarding the activities that occur during the operation of an aquaculture farm (e.g. monitoring the integrity of the net pens to prevent escapes). In order to identify the gains that these activities have from the multi-use, the test case will include camera (underwater, ROV) input to enhance the overview of the infrastructure for the operator.
- *Fish monitoring:* The welfare of the fish depends on multiple factors, such as environmental causes, predator attacks, health issues, etc. By monitoring the behaviour of the fish through underwater cameras, the operator will be able to quickly identify such situations and take measures regarding their amelioration. Bandwidth and throughput will also be measured in this test case.

Design and construction plans & unsolved problems

Currently the following equipment for monitoring purposes has been installed at the site. The main challenge is to prevent any damage from weather and seawater to the sensory equipment as well as to prevent any accidental damage from the aquaculture operators:

- *Imenco Labrus Underwater Camera*

High Quality Low-cost Wide-Angle IP Camera for shallow waters. Housing in POMK (Delrin), Front Port in Perspex. Can be supplied with different Fields of View and in PoE version.

- *Aquaread AP5000 Multiparameter probem*

A multiparameter probe for water quality monitoring is placed at a central point in the aquaculture site at a depth of 4-7 meters. It measures a total of 12 main parameters including Dissolved Oxygen (DO), pH, temperature, electrical conductivity, total dissolved solids (TDS), turbidity, salinity, Chlorophyll-a, Nitrates ($NO3$) and ammonium ($NH4$). The probe is connected to the Aqauread BlackBox data converter.

- *Valeport Model 106*

The Model 106 Current Meter is a light weight, cost effective impeller current meter, designed for real time current measurement or short to medium term autonomous deployments. Titanium construction ensures durability, and the optional temperature and pressure sensors increase the versatility of the instrument. Ideal for use in rivers and coastal applications, or from small boats, the Model 106 is simple to use with either the Windows based PC software supplied, or an optional dedicated display unit.

- *WINGS Smart NB-IoT/4G/5G gateway*
  The device used for transmitting data over the network. The BlackBox for the AP5000 sensor and Oxyguard are directly connected to this device for data logging and transmitting measurements. Widely used communication protocols RS485 and RS232 are supported to read from different sensors. The device can also support transmission over NB-IoT and 4G/5G.

2.5.2. DEPLOYMENT DESIGN AND MOORING SYSTEMS

The KASTERLORIZO SA has already installed the mooring system for the aquaculture production. In the Greek pilot case, the main deployments that are planned to take place for the purposes of the multi-use, are

Challenges

- Establish a robust, remote monitoring system, by taking into account the most appropriate options regarding connectivity, sensory devices and cameras.

Specific requirements

- Wired connection with power and internet seems impossible (farm operators often accidentally cut the wires with the passing vessels). Therefore, a wireless option for network connectivity as well as an alternative source of power should be considered.

Design and construction plans

As a pilot lead and technical manager of the pilot, WINGS has installed different types of sensors for measuring water quality parameters, in the fish pens of the aquaculture. Underwater cameras were also installed in site to monitor fish behaviour and for disease prevention as well as to facilitate in measuring the food waste that remains in the cages. WINGS smart gateway, a device produced by WINGS, is responsible for transferring the data coming from sensors and cameras to the cloud (via the available network). In the cloud platform of WINGS, advanced algorithms based on Artificial Intelligence will produce Advanced Analytics through the data measurements that will facilitate the understanding of the overall production to the aquaculture owner. The WINGS platform provides a Decision Support System that facilitates the operational procedures and the optimization of the production. The Dashboard is used for the data visualization to present the results of the algorithms developed in the platform. To sum up:

Smart Gateway:

- Collecting data from sensors, cameras
- Sending information to cloud through Network transmission

Cloud platform:

- Production management
- Decision Support System
- Advanced Analytics

Dashboard:

- Management and monitoring
- Data visualization
- Business decision support
- Ecological Footprint

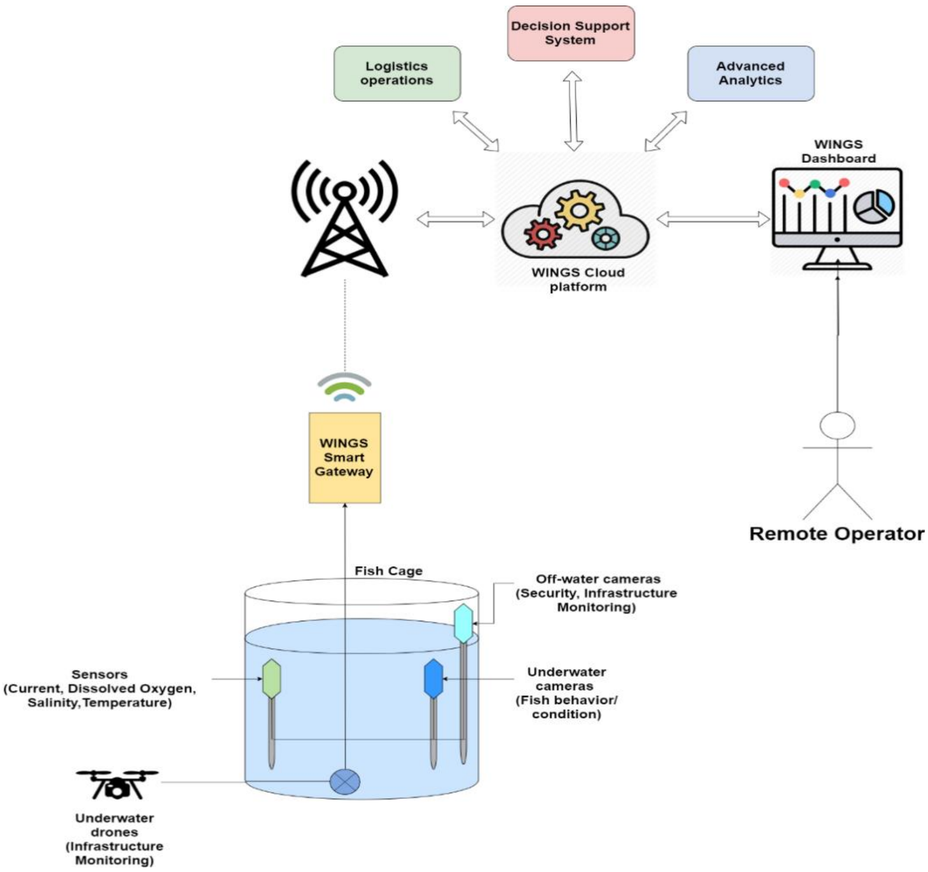

Figure 26: Greek pilot site architecture

Transmission methodology:

- 4G/NB-IoT if available
- WiFi if possible, from the device to the network infrastructure available
- LoRa or other protocols

Implementation

The deployment of the pilot will take place in a series of steps that are described as follows:

- *Equipment*: One underwater camera installed in the site, while another one for lab testing, ii) One multi-parameter unit sensing water quality parameters such as temperature, dissolved oxygen, salinity, turbidity, chlorophyll-a, pH etc. iii) One current meter for monitoring the water currents at the site.

- *Transmission devices manufacturing*: The gateways that are going to handle the transmission of the data from the site to the cloud platform were manufactured to satisfy the requirements of the sensors and cameras.
- *Lab testing*: The equipment and transmission gateways were excessively tested in a lab environment before moving to the actual aquaculture site.
- *Deployment*: The actual deployment of the multi-parameter sensor and the underwater camera has been completed.

Resolving the issue with the wired connection of the sensors and cameras for power and internet: WINGS has proceeded with the installation of solar panels for powers, attached to the mooring system. To solve the internal issue, the WINGS Smart Gateway device has been adjusted accordingly to get internet connectivity with the use of a SIM card. Below an indicative photo depicts the new installations.

Figure 27: Solar panel installation to power the cameras and sensors of KASTELORIZO

2.5.3. MANAGEMENT SYSTEMS

Challenges

- Installation/Decommissioning: Time management by multi-sharing of infrastructure such as use of existing platform for diving or third-party vessels (D1.1)

Specific requirements

There are specific requirements to be defined for the enhanced management of the multi-use activities as well as for the optimization of the aquaculture production. More specifically, the management system to be applied in the Greek pilot use case, needs to:

- Effectively monitor various production and environmental parameters responsible for the farm's environmental footprint.
- Monitor and provide recommendations on operational activities to track and optimize production, with the digital transformation of the farm and stock information such as average weight, biomass, feed conversion ratio (FCR), fish volume, stocking density, all in a paper-free way;
- Produce early warnings/alerts, and suggestions for:

- Optimal Feeding
- Optimal Harvesting & Seeding
- Disease Prevention and Mitigation
- Planning

- *Planning tool:* A scheduling system, to plan the multi-use activities. Planet Blue and KASTELORIZO can have access to the calendar and be able to check availability of the aquaculture and book a co-use activity. These activities could be:
  - Mapping of underwater landscape of aquaculture site with the use of ROV (owned by Planet Blue)
  - Diving expeditions to the aquaculture site (unique wetland for divers to see)
  - Diving expeditions for cleaning aquaculture area from waste
  - Inspection with the use of (Remote Operating Vehicle) ROV of the aquaculture diver while repairing the infrastructure
  - Inspection with the use of ROV of the aquaculture infrastructure that are placed in great depths (anchors)

Design and construction plans & unsolved problems

Embedded Intelligence

The software running on WINGS Smart sensor gateway includes additional functionalities other than reading and transmitting data from the connected sensors. Specifically, it introduces the early identification of increasing/decreasing trends as well as the threshold violation of certain parameters. Such observations are instantly reported to the operator in the form of warnings/alerts.

Data Management System

The AQUAWINGS Data Management System includes a variety of features that are used for the evaluation of the conditions of the aquaculture site. These conditions are considered using the monitoring system that the platform provides and more specifically the multiple sources of data that are integrated. In order to manage such heterogeneous data (like operational inputs, satellite images and sensor data), a complex data management system has been developed, offering data ingestion and data consumption functionalities to external components. A visualization dashboard is also available to provide an overview of the status and conditions that take place at the site.

Specifically, the system consists of the following components:

- *Database*: The basic storage system that implements the Data Model and stores all available data.
- *Data broker*: The data bus that integrates all data transfers inside the system to efficiently provide it to all applications that need to subscribe and consume incoming data at real-time.
- *Data acquisition*: The system that integrates all subcomponents that take up to receive data from heterogeneous data sources. For the purpose of integrating with the sensor data sources a UDP server is set up to receive all available data.
- *Data consumption*: The components that are attached on the data bus (broker) to forward incoming streams to external applications

This is the core system that enables the functionality of all other components. This is why a specific architecture along with the corresponding interface has been explicitly defined. This is displayed in Figure 20.

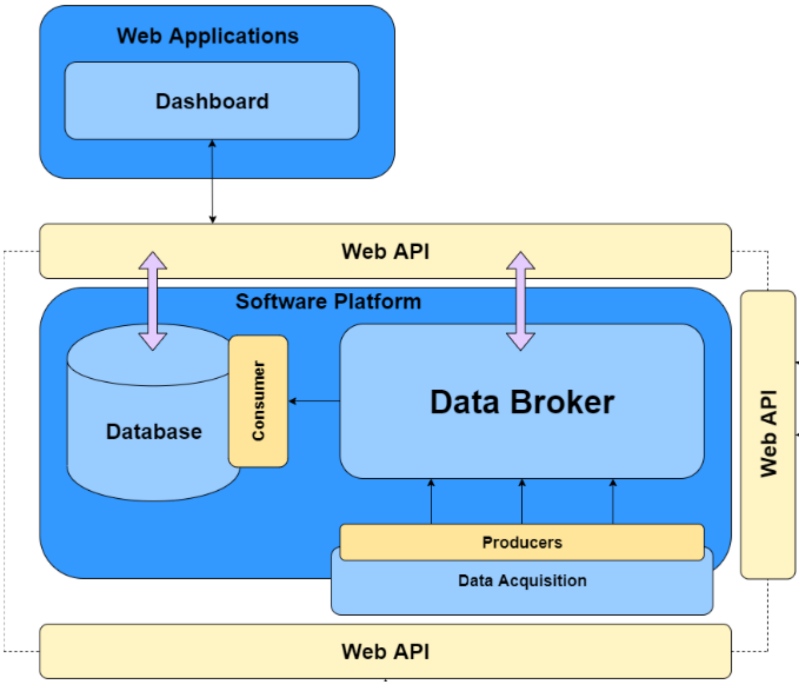

Figure 28: Data management and visualization

Water Quality Analytics

The Water Quality algorithms of the AQUAWINGS platform analyze the measured parameters' time series to recognize outlier values that may indicate irregularities in the system and calculate the probability of external events that may have caused this deviation. Corresponding messages are generated recording these results as automatic observations. Additionally, trend lines and predictions for the parameters are generated, producing predicted time series, while raising alerts for threshold violations and warnings for values getting close to the specified thresholds.

Decision Support System

The Decision Support System of the AQUAWINGS platform is based on a set of business requirements that have been considered to drive the business logic of the system and assist the operator to make decisions regarding different aspects of the operation. These algorithms exploit the available collected data to answer specific questions for the user or provide an overview of the status to facilitate decision making.

In specific, the following aspects are considered for the main functionality of the algorithms:

- *Optimal feeding*: Provides the suggested amount of feed that is needed for each stock and validates automatically if and how the feeding process can be executed.
- *Production planning*: Provides suggestions about the time frames of the harvest and seeding procedures and validates the circumstances for efficient planning.
- *Optimal grading*: Provides feedback to the operator about efficient grading scheduling, taking into consideration stock distribution inside cages, preventing large variations.
- *Breeding*: Provides to the operator a way to monitor fish breeding and try out efficient breeding, filtering fish over a series of criteria and matching healthy males to females.
- *Disease prevention and mitigation*: Evaluates specific observations as well as the recorded environmental data to suggest actions/protocols that can prevent or mitigate specific diseases.
- *Infrastructure, stock integrity and security*: Provides task planning for possible damages observed, as well as prevention measures such as maintenance actions.
- *Environmental footprint*: Provides long-term suggestions concerning environmental sustainability as well as environmental threshold violation monitoring and predictions.

- *Stock welfare*: Calculates a series of indices related to Water Quality, Behavior, Condition, Infrastructure, Husbandry, Feeding, Environment by evaluating all available data, offering a quantified overview of the status at the site.
- *Reporting*: Provides a set of reports to display information about environment regulatory thresholds, production status, health conditions, traceability and ISO standards to enhance the operator's decision support.

Dashboard

All the aforementioned features become available to the operator over a user-friendly dashboard, specifically designed to enhance monitoring water quality parameters as well as management and decision making. The provided functionalities are described below:

- *Production monitoring*: Production parameters such as stock density, feed conversion ratio (FCR), stock size and more information are all visualized at the homepage of the site as well as in each specific structure's dedicated information page.

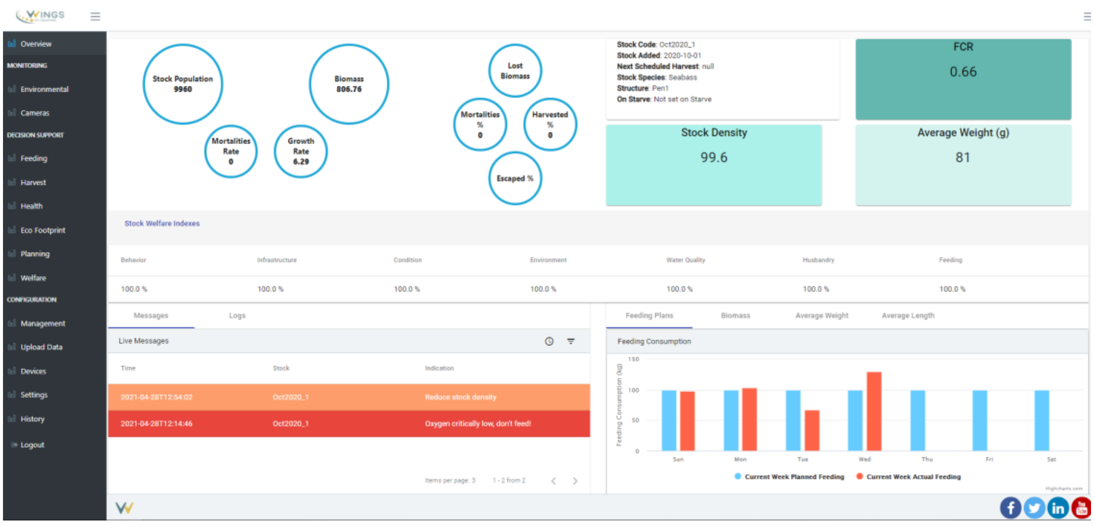

Figure 29: AQUAWINGS production overview dashboard screenshot

- *Environmental monitoring:* Environmental parameters can be monitored at all times via the dashboard. Important values are always displayed on the dashboard, while the user can always access each individual sensor and check the evolution of their parameters' time series in dedicated charts.
- *User data input*: Operational data such as manual observations or husbandry operations can be regularly reported through a series of input forms.
- *Decision making support*: The dashboard provides a rich interface to interact with the Data Management System, but also with the Decision Support System to utilize it and support a variety of different features that are offered regarding optimal feeding, production planning, disease mitigation, environmental footprint, etc.
- *Planning tool*: A scheduling system, to plan the multi-use activities between the aquaculture unit, the touristic expeditions (and all the linked activities and scenarios between the two). Planet Blue, or KASTELORIZO can have access to the calendar and are able to check availability of the aquaculture and book a co-use activity. These activities could be:

- Mapping of underwater landscape of aquaculture site with the use of ROV (Remote Operating Vehicle) owned by Planet Blue
- Diving expeditions to the aquaculture site (unique wetland for divers to see)
- Diving expeditions for cleaning aquaculture area from waste
- Inspection with the use of ROV of the aquaculture diver while repairing the infrastructure
- Inspection with the use of ROV of the aquaculture infrastructure that are placed in great depths (anchors)

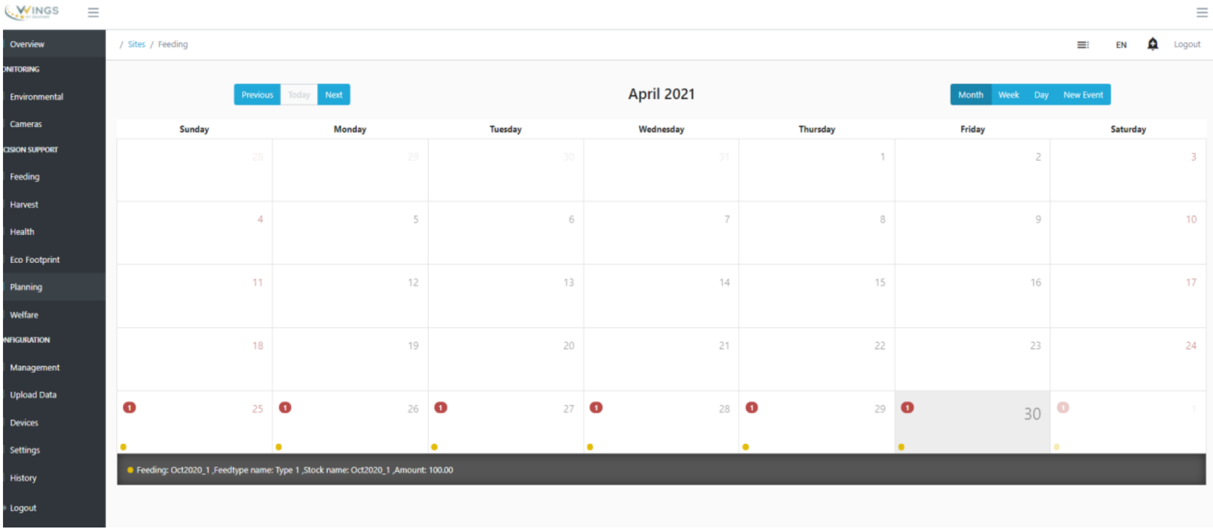

Figure 30: AQUAWINGS planning tool

- Configuration: A settings page allows the operators to declare their preferences in terms of parameters, protocols and other options. Additionally, the configuration of the site can be modified here, editing the structures, the species residing on site and other characteristics of the farm.

3. CONCLUSIONS AND RECOMMENDATIONS

In the previous chapter, the design and construction plans per UNITED pilots are described in separate sections, subdivided in a number of sub-topics being 'Monitoring and docking systems', 'Deployment Design and Mooring Systems' and 'Management Systems'. Some of the pilots are facing similar challenges, however sometimes propose different solutions. The aim of this chapter is to collect some of those challenges and present them in tabular format for the different pilots. This helps the reader who is interested in a particular challenge to quickly understand how the different pilots are addressing it, without having to search for this information in the different sections of each pilot in the previous chapter. It adds to the overall aim of the UNITED project to interlink the challenges and lessons of the different pilots to enable upscaling of the multi-use and co-location in marine waters.

It is paramount that the technological challenges increase with an increase in offshore distance. Frequent maintenance and sampling activities become more difficult. Therefore, some of the UNITED pilots have been addressing this with low-maintenance monitoring equipment that reduces biofouling. Another major challenge for offshore monitoring is a reliable power supply, real-time data feed and monitoring the physical behaviour of the systems (e.g. load sensors). A critical element of the design and deployment of the systems in the UNITED pilots is the anchoring choice. Pilots have been exchanging knowledge which resulted in tailor-made anchoring designs for different pilots. Criteria for management systems are pilot specific and involve various aspects like ocean conditions, legal constraints, aquaculture logistic constraints.

The subsequent sections list the challenges in tabular format and presents them against the (proposed) solutions of each pilot. Each of the above-mentioned sub-topics come with a separate table.

3.1. Monitoring and Docking systems

Table 5 Monitoring and docking systems pilot overview

Challenges	Rough sea & weather conditions	Long distance offshore	Monitoring environmental conditions & impact
German Pilot	**Requirements:** monitor system with robust equipment **Solution:** Data buoy; Lander (with CTD, ADCP fluoroprobe); webcam and subsea-camera; CPOD monitoring solution **Remaining issues:** C-POD monitoring choice to be decided (also mentioned under anchoring & mooring)	**Requirements:** Remote monitoring and data access **Solution:** LoRaWan real time data transmission above water level; subsea-cable for power supply and data transfer **Remaining issues:** none so far	**Requirements:** Monitoring water quality and impact on aquaculture **Solutions:** Echo-sounder; fluoroprobe; combined CTD and O2 sensor; HOBO Logger, subsea-cameras **Remaining issues:** none so far

Dutch Pilot	**Requirements:** monitor system with robust equipment **Solutions:** Monitoring data buoy and load sensors; remote cam-era's **Remaining issues:** load sensors with real-time connection still not available	**Requirements:** Re-mote monitoring and data access; power supply **Solutions:** Remote data access via te-lemetry: LoRaWan module and IMPAQT dashboard **Remaining issues:** re-mote data access for load sensors; probe sensors in the sea-weed system	**Requirements:** Moni-toring water quality and impact on aquacul-ture **Solutions:** Data buoy with sensors monitor-ing turbidity, chl-a, sa-linity, temperature, currents, light **Remaining issues:** The sensors are not availa-ble for offshore appli-cation
Belgian Pilot	**Requirements:** monitor system with robust equipment **Solutions:** diving & sampling expe-ditions with vessels to gather bio-logical data on seaweed and oys-ter growth; galvanized steel oys-ter restoration tables **Remaining issues:** indicator sur-face buoys easily lost; high-costs of remote monitoring systems	**Requirements:** Sam-pling and monitoring plan **Solutions:** 2-week sampling and moni-toring expeditions every 2 weeks; use of divers for restoration tables **Remaining issues:** la-bour intensiveness	**Requirements:** Moni-toring water quality and impact on aquacul-ture **Solutions:** using buoy network, modelling & remote sensing prod-ucts **Remaining issues:** costs for monitoring equip-ment makes this pilot depended on remote sensing and modelling products; ROV can po-tentially replace diving expeditions, but was not budgeted
Danish Pilot	**Requirements:** accessibility of the tourist site with unpredictable rough weather conditions **Solutions:** improve forecasting ca-pability; bigger boats or experi-enced staff **Remaining issues:** client choses boats based on budget	**Requirements:** pre-diction of rough sea conditions and cur-rents **Solution:** More expe-rienced personal/ double personal; metocean forecast **Remaining issues:** currents very unpre-dictable	Not applicable

Greek Pilot	Not applicable, due to its near-shore location	**Requirements:** Remote monitoring of aquaculture production, fish behavior and welfare and scheduling of co-activities **Solutions:** Imenco Labrus Underwater Camera; Valeport 106 model current meter; Aquaread AP5000 Multiparameter probeam; WINGS Smart NB-IoT/4G/5G gateway **Remaining issues:** Re –Installation of the cameras in the pilot site, in order to be completely wireless	**Requirements:** monitoring water quality conditions & impact **Solutions:** multi-parameter unit sensing water quality parameters such as temperature, dissolved oxygen, salinity, turbidity, chlorophyll-a, pH; underwater camera to monitor fish behaviour

3.2. Deployment design and mooring systems

Table 6 Deployment design and mooring systems pilot overview

Challenges	Anchoring & mooring	System deployment	Biofouling & environmental suitability
The German Pilot	**Requirements:** affordable; easy install /de-install; licensed and plausibility checks; storm proof **Solutions:** Rental of drag anchors and heavy-weight anchors; model validated for 50-year storm return event; design where risk of free drift is minimal **Remaining issues:** for scale-up scenario's screw anchors or monopiles recommended (more costly)	**Requirements**: Sufficient buoyancy of seaweed and mussel longlines throughout growing season **Solutions:** Spar buoys for dampening effect **Remaining issues:** none so far	**Requirements**: low maintenance equipment **Solution**: underwater cameras with wipers to avoid biofouling **Remaining issues:** none so far
The Dutch Pilot	**Requirements:** affordable; pre-selected vessels; measured mooring forces; storm proof **Solutions:** drag anchoring model validated for 50-year storm return event	**Requirements**: Sufficient buoyancy of seaweed and mussel longlines throughout growing season **Solutions:** Spar buoys for dampening effect	**Requirements**: low maintenance equipment **Solutions:** limited biofouling was observed on spar buoys, but cleaning need expected before year 2

	Remaining issues: connecting plate designs caused damage; innovative rope-net tested, but material failed. Forces and hydrodynamic behavior unknown	**Remaining issues:** more knowledge on biofouling of various rope types	**Remaining issues:** cleaning needs expected before year 2
The Belgian Pilot	**Requirements:** Storm proof, wind park access and constraints **Solutions:** screw anchors for seaweed; Model validated for 50-year storm return event; oyster longlines backbone 10-m below surface **Remaining issues:** during the installation of the anchors, a concern is to keep the vessel fixed at the location while drilling.	**Requirements**: environmentally friendly material; environmentally suitable conditions; offshore wind farm safety; **Solutions**: galvanized stainless-steel oyster restoration gabions; cable-free location within offshore wind farm **Remaining issues:** none so far	**Requirements**: environmentally suitable; limited biofouling **Solutions**: lantern nets/baskets for oyster grow-out; filled empty mussel shell baskets for spat oyster collector; galvanized stainless-steel gabions for oyster restoration; pre-seeded ropes for seaweed grow-out; cleaning oyster baskets and lantern with high pressure hose **Remaining issues:** none so far
The Danish Pilot	**Requirements:** safety and reduce stress loads by ice **Solutions:** wind park has concrete foundation specifically suitable for ice-breaking to reduce loads **Remaining issues:** Ice damage to wind monopiles is still a risk	No further deployment of a system was applicable	Biofouling is not an issue, as there is no other additional system deployed
The Greek Pilot	Fish cages where installed prior to UNITED, consequently no mooring solution is part of UNITED	**Requirements:** wireless option for network connectivity as well as an alternative source of power **Solutions:** WINGS Smart NB-IoT/4G/5G gateway; WiFi;LoRa **Remaining issues:** none so far	Not problems experienced, because of near-shore location

3.3. Management Systems

Table 7 Management systems pilot overview

Challenges	(Data) management & decision support	Pilot safety, logistics & installation
The German Pilot	**Requirements**: Common seaweed yield comparison; common data storage; **Solutions:** common seaweed methods for seeding & selection; common data platform (HiSea based) **Remaining issues:** none so far	**Requirements:** installation schedules **Solutions:** installation schedules and procedures **Remaining issues:** None so far
The Dutch Pilot	**Requirements:** Design a product life cycle and maintenance management system for upscaling floating solar **Solutions:** work permit for the area (in progress) **Remaining issues:** Remote, real time monitoring of infrastructure integrity with load shackles - still not available	**Requirements:** maintain ship free zone **Solutions:** work permit for the area (in progress) **Remaining issues:** safety zone not yet organized by regulators
The Belgian Pilot	**Requirements:** storage location and decision support for transport of oysters; forecasting capabilities for seaweed oyster growth & decision support **Solutions:** temporary storage facilities before and after going offshore **Remaining issues:** ROV can possibly replace diving expeditions, but due to high costs that could not be realized	**Requirements:** Vessel requirements; crew training; work permit **Solutions:** adhere to the above legal requirements **Remaining issues:** None so far
The Danish Pilot	**Requirements:** guided tours or exposure despite Covid19. **Solutions:** Virtual tours with QR codes **Remaining issues:** Remaining Covid19 limitations	**Requirements:** safe transport of visitors during rough conditions **Solutions:** possibly metocean forecast; double personal on RIB boats **Remaining issues:** ocean currents very unpredictable and event-specific
The Greek Pilot	**Requirements:** *Planning tool:* A scheduling system, to plan the multi-use activities. Planet Blue and KASTELORIZO can have access to the calendar and be able to check availability of the aquaculture and book a co-use activity. **Solutions:** *AQUAWINGS Decision Support System,* producing early warnings/alerts, and suggestions. *Farm Performance and Assessment* provides records of farm performance by keeping farm and stock information. *Advanced monitoring* of environmental parameters responsible for the farm's productivity and sustainability.	**Requirements:** Scuba diving expeditions to be carried out taking all the health and safety measures possible. **Solutions:** planning tool for diving expeditions, inspections etc. **Remaining issues:** None so far

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