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DELIVRABLE 7.2

BLUEPRINT FOR THE OFFSHORE SITE OPERATION

Work Package 7
Implementation of Multi-Use Concepts within Pilots

April 30th, 2021

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ACRONYMES

AIS	Automatic Identification System
BNatSchG	Federal Nature Conservation Act
BNetzA	German Federal Network Agency
BPNS	Belgian part of the North Sea
BSH	Federal Maritime and Hydrographic Agency
CCT	Coordination Committee Team
CSET	Core Services Exploitation Team
CSF	Critical success factor
CT	Consortium Coordination Team
DG	Director General
EBS	Emergency Breathing System
EC	European Commission
EEG	Renewable Energy Sources Act
EEZ	Exclusive economic zone
EIA	Environmental impact assessment
EIS	Environmental Impact Study
EnWG	Energy Industry Act
EMBRC	European Marine Biological Research Centre
EU	European Union
FEA	Financial and economic analysis
FEP	German maritime site development plan
FFH	Fauna-flora-habitat
FINO3	Offshore research platform in the North Sea, belonging to the German Pilot
FOD	Federal Public Service
GDPR	General Data Protection Regulation
GVA	Gross value added
IPR	Intellectual Property Right
KMF	Kiel Marine Farm (project partner)
KPI	Key performance indicator
MBL	Minimum breaking load
MSP	marine spatial planning
MU	Multi-use
MUCL	Multi-use colocations
MUMM	Management Unit of the Mathematical Model of the North Sea
NA	Not available
NGO	Non-governmental organization
NL	Netherlands
NO	Norway
NW-SE	North west – south east
OSPAR	Oslo and Paris Conventions

OWF	Offshore Wind Farm
PA	Partner Assembly
PAR	Photosynthetically active radiation
PPE	personal protective equipment
PM	Project Management
ROV	Remote Operating Vehicle
SAB	Stakeholder Advisory Board
SeeAnlV	Offshore Installations Ordinance
SE-NW	South east - north west
SH	Stakeholder
TRL	Technological readiness level
TSC	The Seaweed Company (project partner)
ULS	Ultimate Limit State
UNITED	Multi-Use offshore platforms demoNstrators for boostIng cost-effecTive and Eco-friendly proDuction in sustainable marine activities
WindSeeG	Wind Energy at Sea Act
WP	Work package

1. ABSTRACT

Offshore projects, especially when implemented with a multi-use approach incorporating various kinds of aquaculture systems, are facing manifold challenges due to the fact that existing onshore technologies (often installed in protected coastal locations) need either specific adaptations to the harsh offshore environment or need to be newly developed and require still in-situ testing. Thus, highly specialized technical requirements under novel settings will have to be employed, not only with new technologies but often operating under unclear legal situations while regulatory systems that yet seldom incorporated the needs of the new development. Also, high financial demands are critical and the entire development needs to obtain the necessary social acceptance by all stakeholders involved. Certainly, with regard to combined and coordinated area use of offshore energy and aquaculture can greatly benefit from past ICZM (integrated Coastal Zone Management) approaches, for each type-combination a set of specific „blueprint" guideline is required for which mostly a solid data base is still lacking.

Over the past thirty years, various multi-use projects were conducted in the coastal zone, in order to promote the commercial development of combining different activities (multi-use) and in many jurisdictions oil-and gas explorations have attained much attention while offshore wind energy systems are a more recent consideration. To incorporate offshore aquaculture is warranted to make more efficient and sustainable use of marine space. Although, many approaches and diverse solutions have been formulated, they often represent technological readiness levels of <6 (Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies). However, we work towards a minimum TRL of 7 (System prototype demonstration in operational environment) for the five Pilots to be reached at the end of this project. This technological leap will be acquired by three subsequent Pilot development stages: (a) pre-operational phase, (b) operational phase and (c) post-operational (decommissioning) phase (in case the activity is being terminated).

The report's purpose is to summarize the results of Task T7.2 "Operational phase offshore", presenting an overall blueprint of the activities conducted during the pre-operational phase. Hence, the blueprint synthesizes pre-test activities (tests on biofouling and monitoring tools development of site-specific monitoring programs, seaweed net and seeding strategy tests, material tests of oyster cultivation, etc.), material choices (selection of scour protection material, instrument choices, installation procedures, etc.), design set-ups (method of mooring, connectors, net systems vs. longlines), technical requirement specifications (e.g. estimation of minimum breaking loads), training and capacity building of personnel (e.g. offshore sea survival course, offshore first aid course) as well as health and safety issues, on which the operational offshore phase builds upon. The report depicts the planning stages (primarily from the biotechnology point of view as the planning of the licensing procedures are highly variable in various jurisdictions and will always require a site-specific approach) as well as a detailed description of the development trajectory of offshore multi-use concepts: combination of wind energy and seaweed-/ blue mussel research and production (German Pilot), floating solar energy production and seaweed culture (Dutch Pilot), wind energy production and seaweed-/oyster culture (Belgian Pilot), wind energy production and tourism (Danish Pilot) as well as fish aquaculture and tourism (Greek Pilot). Furthermore, simulations of the seaweed net design for the German, Dutch and Belgian Pilot were performed to determine an optimum choice for each site. In order to generate a complete report, not only concerning technological matters, but also most relevant environmental issues (i.e. revised assessment needs that differ from conventional approaches), social aspects (i.e. stakeholder engagement and consensus building), economic considerations (i.e. key performance indicators, specific to each pilot). Also, the legal aspects (i.e. national regulations & insurance specifically for the project partners but not EU wide) are addressed regarding every Pilot and pivotal requirements are presented and discussed.

2. INTRODUCTION

The ocean multi-use (MU) concept (e.g. wind energy production combined with aquaculture) has been frequently discussed as a potential solution to coastal marine space scarcity and thus, has been subject of numerous international projects (e.g. TROPOS, MERMAID, MUSES, MUSICA, SOMOS, EDULIS, MARIBE, Space@Sea, H2Ocean, MPOP, Norway Ocean Farming AS, SALMAR, MOBIDOCK, AquaLast, Roter Sand, MytiFit, GIS German Bight, Coastal Futures, Open Ocean Multi-use, Cobra-Besmar) (Buck, 2012). While aquaculture is one of the key Blue Growth sectors with a growing contribution from marine areas, the marine space close to shore is limited for expansion, not only for biological reasons

but also may hold potential for conflicts with already existing and expanding activities such as tourism, fishing, energy production and other new resource users. Consequently, EU politics consider including MU-concepts into maritime spatial planning. However, a comprehensive standardized MU implementation approach is still missing, due to technological limitations, unclear legal and political situations as well as economic, social and environmental concerns.
The UNITED (Multi-Use offshore platforms demoNstrators for boostIng cost-effecTive and Eco-friendly proDuction in sustainable marine activities) project addresses the integration of a relatively new economic branch into an already existing set of offshore activities, to increase the potential for synergetic effects, enhancing the idea of multi-use colocations (MUCL) at sea. In order to assess the benefits of offshore MU activities, five demonstration Pilots, of different contexts and environmental settings, are set up in the North Sea, the Baltic Sea and the Mediterranean Sea, of which four Pilots address the combination of offshore wind farms or offshore wind research with either tourism or aquaculture. Over the course of the project the technical, regulatory, economic, social and environmental viability of the demonstration Pilots is assessed. The German Pilot (FINO3, North Sea) evaluates the feasibility of an offshore wind research platform, in close proximity to three wind farms, combined with seaweed and blue mussel cultivation. The Pilot examines the synergetic effects, resulting from the shared use of automated data collection, jointly obtained licenses, certified offshore staff trained to deal with operational requirements of each of the involved industries, optimized scheduling of combined logistics for maintenance, reduced energy needs and commonly defended conceptualisation of the approach to increase social acceptance of MU solutions within and beyond the directly involved stakeholders. The Dutch Pilot (North Sea) studies the up-scaling potential of seaweed cultivation, in combination with floating solar energy production. Integrating native flat oyster cultivation and restoration as well as seaweed production in wind farms is examined by the Belgian Pilot (North Sea), while the Danish Pilot (Baltic Sea) considers multi-use of tourism and offshore wind farms. The Greek Pilot (Mediterranean Sea) investigates the MU potential of tourism in the form of diving expeditions combined with fish aquaculture.
Risks and challenges of MU systems strongly vary between activities and sites, requiring adjusted planning, and consideration of specific environmental, socio demographic and geographic conditions. Hence, the project aim is to raise the technological, commercial readiness and innovation capacity of selected MU solutions, while reducing associated risks through the development of demonstration Pilots in real life environment. This way, additional benefits to multiple sectors may be generated, infrastructural synergies may be created and the competitiveness of maritime businesses and economic opportunities could be increased within limited marine areas. In pursuing a more efficient use of ocean space and resources, synergetic effects shall be exploited, while reducing the overall environmental impact of a given use by combining it with another profitable activity. The five demonstration Pilots elaborate on different concepts of MU and how they may be implemented, following this blueprint of social, environmental, technical, economic and legal requirements as well as best practices. Moreover, personnel will be trained and properly qualified for the offshore operations lying ahead by attending not only sea survival and first aid courses but also participating in training courses on the specifics of disciplines needed for each of the stakeholder activities. This deliverable synthetizes the results of the pre-testing and re-design of offshore unit components, material (e.g. long-lines, connectors, moorings, linking units) and equipment, with regard to robustness, fouling and ease of handling, generated during the pre-operational phase at near shore sites. Especially pre-testing of multi-factor monitoring systems and their handling (e.g. calibration, maintenance) required, as anticipated, extensive expenditure of time due to several feedback loops and adjustments.

3. EXECUTIVE SUMMARY

3.1. Background and context

Although, the idea of MU is not new and has existed for more than 30 years, with a number of research projects conducted in the Caspian Sea (1987), China (1990), the Gulf of Mexico (2000) and the North Sea (1974) (Holm et al., 2017), its overall potential remains untapped with no optimized approaches that permit commercially available solutions to be embedded in local-regional and international regulatory frameworks. The overall development of marine spatial planning (MSP) in EU member states was greatly incentivized by the Union's Integrated Maritime Policy (IMP) (European Commission, 2012) entailing the commitment to the Blue Growth strategy (Schupp et al., 2019). The Blue Growth strategy foresees a high potential for sustainable growth and employment in aquaculture, coastal tourism, marine biotechnology, ocean energy and seabed mining (European Commission, 2017). The IMP approach allowed for a much-aspired facilitated MSP by making balanced decisions between multiple ecological, economic and social marine exploitation objectives (Stelzenmüller et al., 2017). The Directive 2014/89/EU (article 3) of the European parliament and council indicates how MSP is perceived as a trans-sectorial instrument for promoting sustainable development and facilitating the management of spatial uses and conflicts in marine areas (EPC 2014). Furthermore, the directive actively requests EU member states to assess the sustainable MU development of offshore energy, maritime transport, fisheries, and aquaculture, with regard to national law and politics (Stelzenmüller et al., 2017). In spite of the advantages MU may imply, at present the main advocates of MU concept are academia and policy makers. In order to gain momentum and promote marine economic growth and sustainable development through MU, the EU launched the "Ocean of Tomorrow" cross-thematic calls in 2010–2013 (Schupp et al., 2019). Among other projects, the H2020 MUSES project provided an overview about the current state of MU progression across the EU addressing drivers, barriers, added values, and possible negative impacts as well as engaging sectorial and regulatory stakeholders in order to provide a clear overview of compatibility, regulatory, environmental, safety, societal, and legal issues on MU (Zaucha et al., 2017). On the basis of the results provided by prior research projects, UNITED addresses major steps along the path of realizing a MU project in an orderly fashion, of which this report is one piece of the overall mosaic. Utilizing five demonstration Pilots as practical examples for different MU combinations and country specific approaches will greatly contribute to the path of MU commercialization, now specifically involving the industrial sector.

3.2. Pilot Overview

3.2.1. German Pilot

Figure 1: FINO3 research platform, located in the North Sea, Germany

The German Pilot (Figure 1) aims to demonstrate the economic, environmental and societal benefits of the multi-use offshore wind farming and aquaculture activities, while reducing the technological, financial, health, safety, and environmental risks for both mariculture and offshore platforms. In doing so, challenges of developing a technological support systems as well as planning and operating (e.g. harvesting) a complex MU system in a real live offshore environment will contribute to the business cases and blueprints (business plan, business model canvas, PESTEL analysis, SWOT analysis) Additionally, the knowledge on interactions between target culture species with natural biota and the effects of aquaculture farms on the offshore environment other natural biota and the effects of aquaculture farms on the offshore environment is part of the overall UNITED Assessment Framework. Furthermore, the Pilot aspires to provide a platform for exchange between stakeholders of different backgrounds (NGO, industry, scientific community, authorities) to increase the overall acceptance of MU in the North Sea and explore local cooperative ownership opportunities.

Table 1 German Pilot - Tasks during pre-operational phase

German Pilot: Tasks during pre-operational phase			
	Completed	Ongoing	Unsolved
Results of Pre-operational tests at near-shore site → Conceptual design and requirement specifications framework: - long-lines, connectors, moorings and linking units to the platform, - harvesting equipment, - units appropriate for the attachment of seaweed rhizoids as well as the - various types of ropes to be tested as substrate for seed	X X X X X		
Training and capacity building of personnel - Sea survival training - Training use of equipment (maintenance, calibration, handling) , also at nearshore site	X X		
Conducting bio fouling tests and analysis of results		X	
Adapting monitoring tools: - installation manual, - AuqaREAL installation, handling, calibration, maintenance	X X X		
Conduct feedback loops and pre-tests of monitoring equipment at near-shore site		X	
Obtaining and testing of pH sensor (Sea-Bird scientific)			X
Completed: The training and capacity building of personnel was successfully accomplished and all required certificates obtained (October 2020). The longlines were tested at the nearshore site and most promising material were selected. Testing of mooring solutions in real life environment was not applicable as nearshore conditions cannot adequately represent offshore challenges. Hence plausibility simulations were run for material (shackles, chains, rope) and mooring (drag anchor, weight anchor, chains). **Ongoing:** The testing of echosounder equipment and transducers remains ongoing as harbour (nearshore site) was closed in 2020 and prolonged delivery times of technical equipment was experienced due to the COVID19 pandemic. Therefore, test at the nearshore site have been conducted after the reporting period of this deliverable. **Unsolved:** Testing of pH-sensor (Sea-Bird scientific) was not feasible due to supply difficulties, hence pH-Sensor from Sea-Bird was cancelled Thus pH will solely be measured using the AquaTROLL 500 multiparameter probe attached to the AquaREAL buoy.			

3.2.2. Dutch Pilot

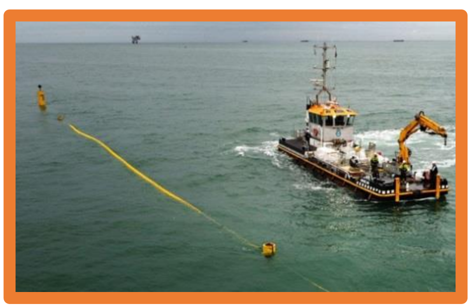

Figure 2: Dutch Pilot, during seaweed net installation in 2020, North Sea, Netherlands

The Dutch Pilot (Figure 2) demonstrates the integration of an offshore solar unit as well as seaweed cultivation, assessing technological risks as well as the economic feasibility. These investigations will provide the basis for a contractual framework regulating a commercial roll-out. With regard to the floating solar array, the wave dampening effect and its potential benefits to seaweed cultivation is examined via field measurements and numerical modelling. Moreover, the technical feasibility of using the solar power production system as an energy and communication hub for aquaculture is studied.

Table 2 Dutch Pilot - Tasks during pre-operational phase

<table>
<tr><th colspan="4">Dutch Pilot: Tasks during pre-operational phase</th></tr>
<tr><th></th><th>Completed</th><th>Ongoing</th><th>Unsolved</th></tr>
<tr><td>Framework of the technical requirements:
- improve the results with feedback loops from wind turbine operators (Ventolines) and offshore solar farm operators (OOE).</td><td></td><td>X</td><td></td></tr>
<tr><td>- Configuration options for electrical integration offshore floating solar and wind</td><td>X</td><td></td><td></td></tr>
<tr><td>- O&M of offshore solar and wind combined Production of the components of the offshore unit based on the pre-testing outcomes of Subtask 7.1.3. This includes the major components for the floating solar-PV system and integration system, production of the components of the offshore unit based on the pre-testing outcomes, long-lines, connectors, moorings and linking units to the platform, harvesting equipment, units appropriate for the attachment of seaweed rhizoids as well as the various types of ropes to be tested as substrate for seed.</td><td>X</td><td>X</td><td></td></tr>
<tr><td colspan="4">Completed:
First inventory made of technical risks and challenges of integrating floating solar at wind via turbines, turbine strings, before the trafo's at TenneT power station, after the trafo's at TenneT power station.

Offshore seaweed cultivation in 2020/2021 and harvest. The seaweed system was designed based on lessons learnt prior to UNITED. This suggests a design & build setup with steps such as requirements-design-testing of components – improve design – procure&manufacture- assembly – install. The only thing we could include is the pre-operational test on the rope that was used for the seaweed nets. All the other components are off the shelve/proven components that were assembled for the seaweed pilot. Basically, the entire first pilot season is a pre-operational and operational phase in one.

Ongoing: Seaweed cultivation for season 2021/2022.
Cumulative installations of the solar farm growing from a 50 kW system to a 1 MW system by 2022/2023.
Ongoing work together with Ventolines and Oceans of Energy to set up a contractual framework to integrate offshore solar with existing windfarm

Unsolved: none*
*The design, build & installation of the solar pilot is not part of UNITED. The pilot includes facilities in two plots (2&3). They are currently operating on TRL7 for the seaweed Pilot and the solar farm Pilot, i.e. system prototype demonstration in operational environment. Nevertheless, it is important to note that the TRL level of the solar farm is not relevant to this project as the farm itself is not developed as part of United. It's only used to perform relevant enabling research associated with multi-use installations such as solar farms (see grant Agreement). In addition, the seaweed prototype includes various elements that have a lower TRL6.</td></tr>
</table>

3.2.3. Belgian Pilot

The Belgian Pilot (Figure 3) evaluates the potential of wind farms as locations for restoring native flat oyster reefs as well as culturing flat oysters for human consumption. This includes the development of suitable scour protection fulfilling all the technical requirements as well as offering a substrate that attracts oyster larvae to settle on. Moreover, a long line with tailored seed collectors and grow-out systems is developed that enables a commercially flat oyster cultivation in offshore conditions. Additionally, seaweed nets are installed within the wind farm as well, to compare

Figure 3: Belgian Pilot, located within an offshore wind farm, North Sea, Belgium

different seeding strategies and strains under offshore conditions strongly affecting the morphological and nutritional characteristics. As for all Pilots, the different offshore activities (seaweed/oyster cultivation, harvesting and monitoring) require optimized communication and time schedules, which is another objective of this Pilot, in order to improve the efficiency of installation and data collection.

Table 3 Belgian Pilot - tasks during pre-operational phase

Belgian Pilot: Tasks during pre-operational phase			
	Com-pleted	Ongoing	Unsolved
Results of Pre-operational tests at near-shore site à Conceptual design and requirement specifications (framework of the technical requirements): - long-lines, connectors, moorings and linking units to the platform, - harvesting equipment, - units appropriate for the attachment of seaweed rhizoids as well as the - various types of ropes to be tested as substrate for seed	 X X X 	 X	
Training and capacity building of personnel - Sea survival training - Training use of equipment (maintenance, calibration, …)	 X X		
Adapting monitoring tools (Installation manual, handling, calibration, maintenance)		X	
Longlines will be designed by UGent for the German, Dutch and Belgian Pilots	X		
The nature-inclusive scour protection for the promotion of flat oyster reef restoration	X		
Completed: The longlines nearshore have been installed and are operational. Idem for the restoration tables. Longline design for the seaweed and oyster aquaculture lines offshore has also been completed. Several substrates for seaweed cultivation as well as seeding techniques and different sugar kelp strains were tested during the pre-operational phase to identify best practices and adapt seaweed seeding techniques for exposed environments (described under 6.3.2 - Seaweed in the preoperational phase: set-up and first results). Seeding technique was identified as a crucial factor determining the success of seaweed cultivation during the pre-operational phase. Longline design for the seaweed and oyster aquaculture lines offshore has also been completed. **Ongoing:** Monitoring tools are adjusted at every sampling occasion as to keep on improving the monitoring and also as to keep on making easier and more feasible monitoring and sampling of oysters and baskets. Seaweed cultivation net design and substrate are continuously fine-tuned to develop an optimal cultivation substrate for the offshore environment. This is an ongoing process as most seaweed cultivation substrates available have been developed for nearshore cultivation.			

Unsolved: Finding the perfect way to attach the baskets with oysters and substrates in the frames/structures. We are still losing too many baskets. Possibly seals in the neighbourhood loosen the baskets to eat the oysters within, but this is unclear. We hence are testing a new kind of baskets-in-ladder system as to increase ease of handling and avoid losses at sea before we go offshore with these structures. In the wind mill park losses are not allowed, hence we hope to have found a good method now.

3.2.4. Danish Pilot

Figure 4: Danish Pilot 'Middlegrunden wind farm', Baltic Sea, Denmark

The objective of the Danish Pilot (Figure 4) is to identify synergies from off-shore wind energy production and tourism. New tourist concepts around wind parks are developed, including recreational activities such as boat tours. The specially designed platforms around the turbines serve Concepts for including offshore wind farm expeditions and educational trips (e.g. renewable energy production) into visit information centres, museums, observation platforms and further tourist attractions is developed. This also includes exploiting the possibility of using virtual reality (VR) goggles, simulating a flight around the turbines or the VR 360 view from the nacelle, in case of bad weather conditions. These activities will be included in business models and cost-benefit analyses, promoting capacity building for local tourism operators as well as deriving an overall transferable MU concept.

Table 4 Danish Pilot - Taks during pre-operational phase

Danish Pilot: Tasks Completed and Ongoing			
	Com-pleted	Ongoing	Un-solved
Develop health and safety concepts, also legal aspects.	X		
- Test different options and evaluate different versions of health and safety issues as well as preparing respective concepts for the offshore operation.	X		
- General safety, Identification of hazards.	X		
- New Insurance coverage to cover tourist on the turbine.	X		
Creation of virtual guided-tour to approach the general public and give visibility to the wind farm to the more general public.	X		
- *A trip to the turbine* – completed, available in this link (https://youtu.be/VGpXKW0CAnQ)	X		
- *The Construction of Middelgrunden Wind Farm*		X	
- *Environmental Aspects in Middelgrunden Wind Farm*		X	
- *Electricity Production: from a wind turbine to our plugs*		X	
- *The location of Middelgrunden*		X	

Location of QR-codes in approx. 6 rooftops (public locations) around Copenhagen, where citizens can access the virtual tours. - Analysis to evaluate the most suitable place to locate the QR code from the touristic, science and local awareness-raising perspectives - Communication with selected museums/sites initiated.	 X X	X	
Divers: identification of the needs for divers to use the wind farm in dedicated training activities. - Engagement with divers association in Copenhagen. - Study of Maps to understand topology under wind farm, as well as safe access in navigation routes.		X	
Stakeholder engagament with a touristic, science and local awareness-raising perspectives? - Boat operators: Evaluation of more tourist/ fisherman boats offering trips to Middelgrunden Wind Farm. RIB boats now offer weekly tours (spring and summer season). - Travel agencies, Companies & Official bodies organising visits in Copenhagen of different kind	X	X	
Strong communication & dissemination activities: - Several presentations held in webinars and conferences of the multi-use activities related to Middelgrunden Wind Farm, i.e. a cooperative approach where wind powered electricity generation and tourism can take place.		X	
Organisation of Open House Day on 20.09.2021 with open guided tours, where interviews with interested stakeholders on their perception of multi-user activities were carried out.	X		
Discussions on repowering of Middelgrunden wind farm with focus on including multi-use activities. Discussion with the Cooperative and the Board of Middelgrunden, including Multi-use of the future project, with tourism, wind production, possible wave platform and battery use for storage. Discussion with battery suppliers.	X		
Completed: H&S concepts developed. Insurance coverage in place. First virtual tour completed, *A Trip to the Turbine*. Very well-received by museums who will accommodate the QR code. Re-powering discussions held from multi-use perspective. **Ongoing:** Development of remaining virtual guided tours, QR codes and communication with selected key stakeholders (ongoing according to plan). Engagement with boat tour operators and relevant actors who might be involve in the multi-use activity, such as divers (ongoing according to plan).			

3.2.5. Greek Pilot

The Greek Pilot (Figure 5) seeks to facilitate touristic growth in combination with social acceptance of aquaculture activities by offering scuba diving expeditions around the marine area and aquaculture facilities and guided boat tours, informing about sustainable aquaculture. Furthermore, innovative technologies are applied for a more efficient aquaculture production and increased fish welfare management, such as monitoring environmental parameters (salinity, water quality) as well as fish behaviour and stress levels. The Pilot team will develop a concept that increases the use of synergies such

Figure 5: Greek Pilot, fish farm in Patroklos, Mediterranean Sea, Greece

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as sharing common infrastructure (e.g. existing platform for aquaculture, diving or third-party vessels) and improve the overall time management of activities (tourism, fish aquaculture operation and monitoring). This approach will benefit the growth of local businesses, high quality food production and creation of new jobs.

Table 5 Greek Pilot - Taks during pre-operational phase

Greek Pilot: Tasks during pre-operational phase			
	Completed	Ongoing	Unsolved
- Results of Pre-operational tests at near-shore site:			
- Framework of the technical requirements:			
- Sensors with multi-parameters measurements and cameras with proper resolution for video analytics are selected and purchased	X		
- Connectivity options selected, that cover the bandwidth and network requirements	X		
- Installations' design and implementation	X		
- Installation of 4 more cameras at the site (with solar panels for power provision)		X	
- Training of stuff regarding sensors maintenance and calibration of sensors		X	
- Scuba diving expeditions in the pilot site		X	
- Communication with local stakeholders for the advertisement of the multi-use activities in the site		X	
- Dissemination activities: Participation in MSP Platform - MultiuseMED - Session 2 about Soft MU			
- Spreading costs of maintenance of equipment use in the multi-use			X
- Insurance covering the multi-use			X

Completed: *Technological:* One Camera and a solar panel have been installed to the Pilot site. The sensors are working well. The AQUAWINGS platform now successfully receives data from the sensor as well as video from the camera. Alerts and recommendations are triggered by the values received by the sensors, as well as video analytics are estimating biomass of fish, are monitoring fish behaviour and overall welfare of the particular stock. A lesson learned is that they need to be cleaned about 3 times per month to ensure stable measurement. Wings installed four more cameras and changed the installation plan. The cameras were connected to a wire for energy and data transmission. **Another lesson is that wired connection of sensors and cameras for power and connectivity proved to be very risky for the infrastructure.**

Dissemination activities: Several presentations held in webinars and conferences of the multi-use activities related to multi-use of aquaculture and tourism.

Multi-use activities: Touristic expeditions have been carried out despite the difficulties faced by the COVID pandemic. Groups of much less tourists (4 rather than 8) are brought to the site for scuba diving.

Ongoing: Wings is in the process of installing four more cameras and changed the installation plan, with the installation of solar panels for power and a SIM card for wireless internet connectivity. Diving tours and the diving business itself are still very depending on COVID restrictions. Customers are concerned about hygiene.

One problem is that all mouth pieces need to be cleaned and sanitised after use and due to storage capacities also right before use. Pictures from the diving tours at Patroklos show marine live outside the fish cages, which isn't often seen at other diving spots without aquaculture sites (for example Dolphins, Tuna and also smaller fish species). Planet Blue started with the cartography of their underwater map using a ROV. They also started tourist diving expeditions and try to offer as many tours as possible.

Unsolved: None.

3.3. Objective, approach and outcome

UNITED aims at sustainably exploiting the potential of resources from seas and oceans for multiple sectors and across the industries, while restoring nature and biodiversity. It supports a synchronized responsible management of marine activities for healthy, productive, safe, and secure operations which are essential for boosting the blue economy. In order to achieve these aims, solutions within the five Pilots are developed, enhancing the technological readiness level (TRL) from 5 to 7 (German, Dutch, Belgian and Greek Pilot) or from 6 to 8 (Danish pilot), while the experiences and lessons learned from this project are shared in this blueprint. The purpose of D7.2 "Conceptual description of Pilots" of UNITED is to synthesize results for relevant requirements of MU offshore systems, represented by the Pilots, ensuring legally approved, environmentally compatible, economical, technical as well as socially acceptable solutions. The objective of this deliverable is a description of the development trajectory, how to integrate tourism, nature restoration as well as aquaculture (oysters, mussels, seaweed) into an already existing offshore structure at a given location. In doing so, this report and the project provide most valuable information on an innovative field, as practical experience and reporting is rather rare. The impact of UNITED is supposed to raise awareness to the possibility of MU and positively influence actors within the marine and maritime sectors to pursue this these solutions. This blueprint is part of the overall project goal to increase the technological and commercial readiness and innovation capacity of selected MU approaches. The TRL of the demonstration Pilots is intended to be increased and thus further ease the market uptake. Until today, limited examples of successful MUCLs dampen the industries' interest in pursuing co-location of multiple maritime activities, despite encouragement from political advocates and research or the potential for investment and operational savings. Thus, the main research questions the report helps to answer are:

- What aspects are to be considered in terms of social, environmental, economic, legal and technological requirements when planning and realizing a successful MU project in different EU sea basins?
- What are innovative approaches to system integration between offshore infrastructures and additional maritime activities with regard to design, equipment and logistics?
- Which obtained results and lessons learned from the pre-operational phase may foster the commercialisation of MU and increase the overall TRL?

Proving the success of MU activities that are ecologically, legally, socially and economically feasible in offshore wind farms, the way of future multi-use and co-location systems on a broad scale is paved. Enabling the multi-use concept to gain momentum in a real-life environment will add to the EU efforts towards a sustainable and efficient management of space and resources, with the effects extending beyond the project. The following aspects stress the motivation of future exploration of MUCL systems:

1. Lack of aquaculture sites at onshore waters creates a requirement for new sites
2. Maximisation of production from unit area of sea is in the best interest of any nation
3. Suitability of OWFs depends on the co-existence with other profitable users of the sea
4. Reduction of the impact on fishermen's livelihoods from Offshore Wind Farms
5. Synchronisation of activities
6. Reduction of costs for both sectors

Multi-use concepts present a valuable example for the implementation of a balanced ecosystem approach. Also, aquaculture activities integrated in offshore space use with other industries is among the preferred cooperation partners while direct fishing activities may only be possible under specific conditions, provided such "non-static" activity do not possibly disturb the safe operation of the offshore platform and may require specific mandatory methodologies to do so. Moreover, jobs in at least two different sectors can be created. Although, the motives for engaging in offshore MUCL are reasonable, research results on MUCLs exists within the EU member states. Consequently, it is essential to develop design guidelines for combining technologies and, for technology transfer between industries, as well as, resolve technological deficiencies, to enhance technical feasibility of multi-use concepts with regard to offshore structures, equipment, users and the environment.

3.4. Structure of the report

This blueprint consists of eight chapters, of which five Pilot chapters (chapters4-8) individually address the legal-, economic-, and social situation as well as site-specific factors, determining technological challenges of offshore installations. The chapter on the project's background and context is based on literature research, citing historical developments and current trends proposed by Bela Buck and Richard Langan in "Aquaculture Perspective of Multi-Use Sites in the Open Ocean" from 2017 and the Blue Growth strategy defined by the EU in 2017. The project's overall objective and this report's aim in particular are described in the introduction (chapter 1) and the executive summary (subchapter 2.3), while a more detailed explanation is provided in Deliverable D1.1 (published in April 2020) highlighting the "challenges, risks and barriers for large scale commercial role out". Chapters 4-8assess five different MU approaches (Table 6) in three EU sea basins, conducted in five different countries.

Table 6: UNITED demonstration Pilots and their multi-use activities

Pilot	Sea Basin	Multi-use activity
German Pilot	North Sea	Offshore wind energy research, cultivation of blue mussels and seaweed
Dutch Pilot	North Sea	Floating solar and seaweed cultivation
Belgian Pilot	North Sea	Offshore wind farm, cultivation of flat oysters and seaweed, and restoration of oyster ecosystems
Danish Pilot	Baltic Sea	Offshore wind farm and visits to wind turbines (tourists, technicians from the sectors, etc.)
Greek Pilot	Mediterranean Sea	Aquaculture (fisheries) and leisure scuba diving

The project explores MU scenarios not only for one approach, country and sea basin but for several, allowing for comparisons between national legislation, pointing out bottlenecks for future EU cooperation in MSP. Most distinct results are presented in the conclusion (chapter 8). More detailed information about Pilots can be found in the Annex to keep this report well-structured and defined. The scope of this blueprint discusses findings and synthesis results obtained during the pre-operational phase of the UNITED project. A more extensive roadmap about offshore Pilot operation will be provided in subsequent reports (D7.4 & D7.5).

3.5. Structure of Blueprints

Each pilot provides a blueprint for the development of a distinct MU concept. The blueprints address social, environmental, technological, economic and financial aspects, and the legal status of each individual pilot. Depending on the focus of the activities in the pilots, the different aspects have a varying importance for each pilot, but the aspects cannot be separated from each other for a successful implementation. Each blueprint is structured according to these five aspects, the following paragraphs provide a brief overview of the topics and an explanation for the indispensability of their importance.

3.5.1. Social aspects of Pilots: Stakeholder communication

Developing and operating an offshore multi-use platform greatly impacts a variety of interest groups and vice versa is significantly affected by these groups. For this reason, the UNITED Pilots follow a common approach to manage and engage their stakeholders (SH). The project strives to actively include SH in its process, asking for and depending on their input, to contribute shaping the development trajectory of European MU activities. In return, the findings and results shall be shared and distributed among the different parties, to not only achieve overall social acceptability but also to push forward the environmental, social, economic, political and technological progress.

The stakeholder (SH) classification and clustering of all five Pilots, as well as their SH management are based on the "*Stakeholder Framework Guideline*" provided in Deliverable D5.1 (published in July 2020) of the UNITED project. Thus, the general principles of SH identification, mobilization and analysis are aligned with work package 5, to assure a consistent as well as successful stakeholder engagement. All Pilots consider any legal entity or natural person affected, interested in and/or willing to be (positively or negatively) involved in their projects a relevant SH. These interest groups are arranged into different classes, according to the type of organisation they represent (public administration or authority, business, industry, NGO, education and research, local community), the scale to which they may intervene (local, regional, national, European, international) and the sector or industry they belong to (aquaculture, tourism, wind farms, transports, protected areas).

3.5.2. Environmental aspects of Pilots

The existence and evaluation of environmental data is highly recommended even though demanding when planning any offshore operation, especially in an exposed offshore location. Similar requirements for pre-monitoring during the planning phase are conducted in several jurisdictions for near-or onshore aquaculture. The time and cost to obtain such data before the actual planning of an offshore operation is paid off later through a minimized risk in a wide range of aspects e.g. obtaining a licence, involving stakeholders and technical procedures. Depending on the focus of the individual pilots, different environmental aspects are highlighted.

3.5.3. Technological aspects of Pilots

The section on technological aspects of the pilots will mainly deal with the testing, planning and preparation of the MU activities. Depending on the targeting of the single pilots, and the potential for implementing tests on the near-shore site a variety of tests were carried out. Due to the impact of the COVID19 pandemic, some tests started later than planned and were not completed, still ongoing or could not be completed at the time of submission of this deliverable.

3.5.4. Economic aspects of Pilots

A sound financial and economic analysis (FEA) of a project during its planning, appraisal and implementation is essential for achieving the desired economic outcomes and increasing the likelihood of sustained economic benefits of a project. The economic and financial assessment of the UNITED project and its Pilots is crucial because the FEA constitutes an appraisal requirement of most governments and international financing institutions when reviewing project applications. The results of the FEA provide the grounds for making decisions on investment financing a proposed MU activity based on its financial and economic viability (FAO, 2021). Thus, a profound examination of the economic and financial situation of every Pilot is inevitable. The economic assessments applied in UNITED encompasses a variety of processes (cost-effectiveness analysis, cost-benefit analysis, multi-criteria analysis) through which information is gathered, processed and used to support the overall decision-making. The business canvas model examines how the Pilot creates, delivers, and captures value, while the SWOT analysis defines the internal factors affecting the Pilot (see Deliverable D3.2).

3.5.5. Legal Status of Pilots

Each of the five pilots is stationed in a different EU country and has to comply with the laws and regulations of the respective responsible authorities in order to implement MU. The section on legal status will provide an overview of which authorities are responsible in each region and what hurdles and requirements they may create. More detailed information can be found in Deliverable D6.1.

3.6. Connection with other deliverables

This deliverable builds on the previous report (D7.1) about the 'Review of Pilot TRL, legal aspects, technical solutions and risks', where the overall status quo of the Pilots during the pre-operational phase was assessed. As a next step, the Pilots now enter the operational phase, which requires a detailed recap about essential results and lessons learned during pre-tests and design processes. Based on these outcomes, the Pilot offshore installation follows according to best practice requirements. The valuable content generated through hand-on experience feeds into the subsequent deliverables:

- D1.5: Catalogue of multi-use blueprint solutions
- D2.2: Design and construction plans for the pre-operational phases of the Pilots
- D2.4: Report on optimization of scheduling, operations and maintenance
- D2.6: Technical report on design procedure limitations and improvements
- D7.4: Joint production, monitoring, operation and maintenance protocol
- D7.5: Report on harmonized findings from preoperational and operational phase
- D7.7: Synthesis report for Pilots
- D8.1: Report on technical assessment and validation
- D8.4: UNITED auditing procedures and TRL assessment manual
- D9.6: Report on training sessions for technology transfer

Despite the extensive collection of best-practice examples and lessons learned, is this report to be perceived as the first technological blueprint of several, and thus only reflects recent observations without any long-term consequences. The above-mentioned deliverables will address this matter by continuously re-evaluating findings and described examples over the course of the project, to adjust for the current state-of the art. Especially, the close cooperation with work package 2 supported the finding of technical solutions during the pre-operational phase. Further technical adjustments that will be made after the preparation of this deliverable will be presented in the deliverable D2.4 and D2.6 are directly premised on outcomes of WP7. Subsequently, it is strongly recommended to also familiarize oneself with the related deliverables as well as to consult with experts in the field of offshore MU activities. Furthermore, social, legal, environmental and economic situations are covered on a rather generic level as the report's focus lies on the technological progression of the pilots. For this reason, detailed outcomes of those topics shall be looked up in the reports of work package 3 "Economics of multi-use platforms", work package 4 "Environmental gain of multi-use marine space and infrastructure", work package 5 "Societal interactions and engagement", as well as work package 6 "Legislation, politics and governance".

Despite the aforementioned remarks about the structure of the deliverables and work packages it is of pivotal importance to acknowledge the effects of the COVID19 pandemic on the UNITED project. The entire project was planned and founded based on pre-COVID19 circumstances. However, three months after the project started, world-wide lock downs, travel restrictions and closed borders have been implemented. Against this background, especially the Pilots have been confronted with numerous unforeseen obstacles and had – on an ad-hoc basis- to make numerous fundamental decisions to the new situation concerning e.g., restructuring organisation, planning and production procedures. Even while having made every effort possible, some interim solution turned out to be not optimal and further course corrections were made to cope with the massive problems involved in dealing with a « LONG-TERM » pandemic. At the present interim state of affairs, we can state that some goals can be reached due to alternative and flexible solutions but also, we need to point out those items, which we cannot adjust and definitely will have either a negative impact on the performance or will reach only partially satisfactory results. There are items that nature dictates through its biological clock and thus any Pandemic lockdown period cause loss of efficiency or will end with incomplete tasks e.g., spat fall, which remain despite the new situation. Hence, pre-COVID19 objectives, aims and milestones may be adjusted and might no longer or only partly reflect the pristine intended work. During 2020, the project partners established partly new workflows accounting for increased travel restrictions and social distancing, which nonetheless may affect the projects outcome in general and individual deliverables. On the positive side, the unforeseen ad-hoc confrontation of the project with the unclear and continuously changing Pandemic conditions has created a new "innovation climate" that will be of benefit to any future project in an effective and flexible manner.

4. BLUEPRINT OF GERMAN PILOT OFFSHORE OPERATION

4.1. Social aspects of Pilot: Stakeholder communication

4.1.1. Key stakeholder groups

The **internal** SH of the German Pilot are directly part of the German project team (KMF, 4HJena), the other Pilots or the UNITED consortium as well as sub-contractors. The most important subcontractors are considered offshore service and installation companies, companies providing regular transfer to FINO3 via helicopter, the tank ship refuelling FINO3, the insurance company, diver companies facilitating offshore installations and the technical standards organization, regularly examining and certifying FINO3. These SH are predominantly interested in an efficient and safe platform operation as well as long-term service orders/contracts, which makes them very valuable with regard to their expertise and specific qualifications.

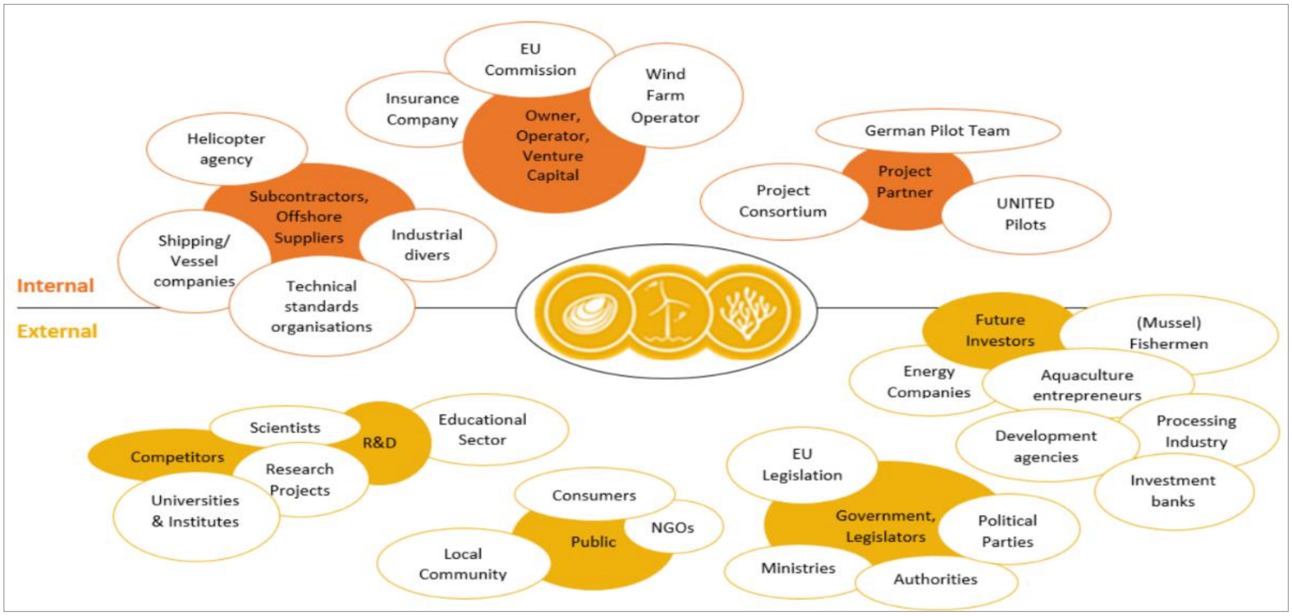


Figure 6: Schematic stakeholder clustering of the German Pilot

External SH are not directly involved in the day-to-day business of the pre-operational, operational, or post-operational activities of the German Pilot. This category of SH is predominantly included in outreach activities such as interviews, workshops and webinars, where they are offered the opportunity to advice on, discuss, learn about and give feedback on particular topics, questions and conflicts. It is this community, the best practices, results, lessons learned and a generic roadmap of UNITED will be shared with, which makes them potential users of the project's output. The German Pilot considers the following parties external SH: the offshore industry, such as wind farm operators (Vattenfall) and corresponding service providers, the licensing authorities (Federal Maritime and Hydrographic Agency; Schleswig-Holstein State Agency for Coastal Protection, National Park and Marine Conservation), ministries (Ministry of Energy, Agriculture, the Environment, Nature and Digitalization; Ministry of Economic Affairs, Transport, Employment, Technology and Tourism) and political parties (Bündnis90 die Grünen), potential future investors (e.g. mussel fishermen, seaweed farm cultivators), development agencies and insurance companies, non-governmental (environmental) organizations (NGO) (e.g. Greenpeace, BUND, Foodwatch), local community, processing and pharmaceutical industry (restaurants, retailing, packaging sector), and the scientific community (Alfred-Wegener-Institute, Fraunhofer Institute, universities, etc.) (Figure 6).

With regard to the SH's **power** and **influence**, it goes without saying that the insurance company and the operator of the wind farm in the near vicinity of the German Pilot are considered highly influential. Realizing any progress within the Pilot depends on their approval and benevolence, which is why they were part of the project planning from the beginning. Furthermore, the EU-Commission (EC) as funding body is a key SH of the entire UNITED project. However, the EC is not actively involved in the project scheduling and implementation steps, but rather in the dissemination

process of results in the form of deliverables and reports. The subcontractors' interests of the German Pilot are rated significant as operation and maintenance require long-time experience and expertise.
Particularly the influence of environmental NGOs is anticipated, as the German offshore industry in general is affected by their demonstrations, legal actions and petitions. The NGOs and public authorities are one important reason, the German Pilot seeks to offer a variety of interdisciplinary workshops as a basis for discussion and direct exchange between industry, science, politics and environmentalists. Although, future investors such as fishermen, looking for new job opportunities, or wind farm operators, exploring new economic possibilities, do not directly influence the German Pilot, they are essential for future commercialisation of MU solutions and hence, raising their interest in this topic is most valuable. Their feedback on the Pilots is essential, once they demand feasible up scaling solutions and make use of government funding and incentives. In the end, future investors decide whether MU is a profitable opportunity and which solutions will become state-of-the-art practice.

4.1.2. Stakeholder engagement and management

Depending on the SH cluster, determined above (Figure 6), the engagement in German Pilot activities will be informing, consulting, collaboration or co-deciding in order to meet the different needs and expectations of distinct SH. At the beginning of the pre-operational phase and the operational phase, internal SH are predominantly involved, as these two stages require extensive planning and complex-collaboration among subcontractors and the Pilot teams. As far as external SH are concerned, only the responsible marine authorities are involved in the license application process. The broad community is only informed about the progress of the German Pilot via the official UNITED website, where news articles are published. During the operational phase, external SH such as political institutions, the industry and scientific community are engaged in the form of training workshops and expert interviews (see Deliverable D9.2). In order to follow the required General Data Protection Regulation (GDPR), every workshop/interview participant signs a content form, stating the informed consent procedure of UNITED.

4.2. Environmental aspects of Pilot

4.2.1. Description of Pilot site

The North Sea is a relatively shallow shelf sea with a wide opening to the North Atlantic Ocean in the north, which influences its oceanic climate. In the southwest, the Atlantic has less influence on the North Sea due to the shallow English Channel and the narrow Dover Strait. The German Pilot is located at the FINO 3 research platform in the North Sea (Figure 7), German EEZ, about 45 nautical miles (80 kilometers) west of Sylt on the edge of the potential aptitude for wind turbines off the Schleswig-Holstein North Sea coast. This great distance to the coast results in numerous considerations during the pre-operational phase which are different from other Pilots and are described in the following subchapters. The coordinates of the location are: 55º 11,7'N, 007º 9,5', which is close to the offshore wind farms: Butendiek, DanTysk and Sandbank. This "neighbourhood" influences also environmental planning aspects of this Pilot as pointed out below. For a detailed description of the German Pilot site, please follow up with deliverable D4.1.

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

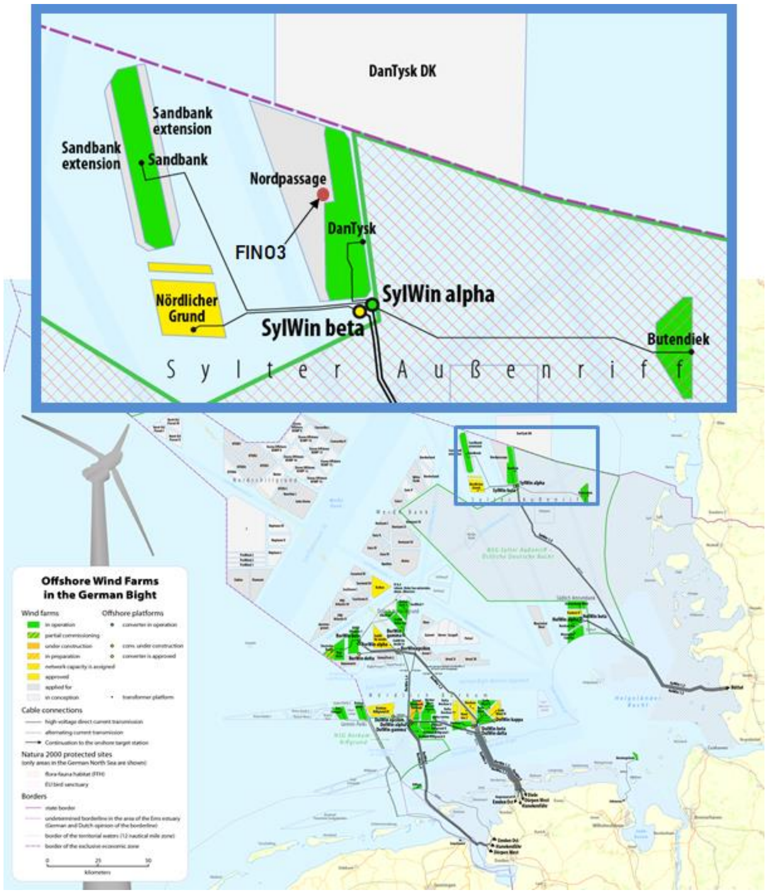


Figure 7: Location of the German Pilot in the North Sea, Germany

4.2.2. Environmental impact assessment

In 2018, a feasibility study of the German Pilot site at FINO3 for its suitability for aquaculture was conducted, assessing biotic and abiotic environmental factors. This study and the option to use existing monitoring data provided a comprehensive bases for the environmental planning of this Pilot. The already existing data of the parameters oxygen (dissolved, saturation), temperature, salinity, turbidity, chlorophyll-a, nitrate, nitrite, maximum swell, and currents were evaluated with a time series analysis as well as a descriptive, statistical frequency analysis. This knowledge about the environmental conditions have been used to adjust the Pilot in different aspects like considerations on useful antifouling methods, best estimate for an operational timeline of the Pilot, choice of materials and last but not least the choice of target organisms for the aquaculture part of the Pilot.

To assess the environmental impact of the MU project at the German Pilot a variety of organisms and their habitats at the site were examined in advance. The detailed results regarding, seabed and seawater, birds, benthos and marine mammals can be found in Annex A.

4.2.3. Revised EIA consideration

All species (mussels and seaweed) to be cultivated at the German Pilot are endemic to the site or originate from a radius of max. 150km (*Saccharina latissima*), e.g. to prevent possible spread of diseases, the import or distribution of invasive species. Positive effects from the introduction of new structures are expected as they provide potential habitats for e.g. juvenile fish (Degraer et al., 2013; Krone et al., 2013). The impact on fauna (e.g. fish) in the immediate vicinity of the aquaculture system will be recorded by cameras and an echo-sounder. Any migration routes of marine mammals won't be affected by the aquaculture installations. The choice of sensors to monitor the effects of the aquaculture operation on the environment and the suitability of the location for such an aquaculture design is based on the literature research and the existing environmental data.

4.3. Technological aspects of Pilot

4.3.1. Current TRL – aimed TRL

One basic project goal is to develop the Pilots to the stage of reaching TRL (Technological Readiness Level) 7 by the end of the project.

The current TRL of the German Pilot is stated as TRL 5 which is defined by the Horizon2020 program as "*Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)*" (NYSERDA 2018). The TRL was not only determined according to the definition of Horizon2020 but also by definitions of the US Department of Energy (U.S. Department of Energy 2009), of the Nuclear Decommissioning Authority (NDA 2014) and of the US Air Force Research Laboratory (AFRL 2003). The detailed analyses of the TRL of the German Pilot is presented in deliverable 7.1.

In order to reach TRL 7, which is defined as *"System prototype demonstration in operational environment" (NYSERDA 2018)* the following technical and other essential determining aspects have to be developed:

- Technological development
- Functionality of ocean multi use
- Environmental data
- Administration / government
- Investors and sales plan

The operation the offshore research platform FINO3 has been constantly revised, adapted and improved since its installation in 2005. This iterative loop of improvements will be continued during the course of the project and supports the goal to reach TRL7. Technical applications and solutions as well as infrastructure and logistics (e.g. transportation of personnel and equipment) need to be well planned and managed to serve both offshore uses of this Pilot. The gained knowledge from many years of combining the operation of the FINO3 platform and installing, operating and decommissioning another offshore installation at the same location have been used during the pre-operational phase to develop the necessary specialized adaptions for the foreseen operational phase of the German Pilot as an example of a multi-use operation.

On the one hand these adaptations of the offshore platform have to meet the requirements of the new activity, the cultivation of seaweed and mussels. On the other hand, the operation of the platform has also to fulfill other demands. So, a compromise has to be made for some points. The more is known about the newly added offshore use the more precise planning is possible. Therefore, the specialities of the aquaculture of these two organisms were well known prior the project start and was further developed at the near shore site at Kiel Marine Farm (KMF) during the pre-operational phase of UNITED. The results of the tests (equipment, installation procedure, service and maintenance) are used for the design and adaption of the planned aquaculture system as well as for the monitoring system.

4.3.2. Training and capacity building of personnel (sea survival)

The experience of more than 15 years of offshore work has led to the following requirements in order to reach the highest possible and practicable standard of safety for personnel working at this multi-use Pilot:

Everyone travelling to the FINO3 platform requires the following safety certificates

- occupational health examination (G41)
- first aider offshore (according to DGUV)
- sea survival and HUET (Helicopter Underwater Escape Training) (according to DGUV)

If climbing is required (for example inside the monopile to connect/plug the sea cable from the lander)

- working at heights (according to DGUV)

If electrical work has to be done (for example when connecting the sea cable from the lander/ when installing server/computer equipment at the supply container)

- electrically instructed person (according to DGUV)

The following personal protective equipment (PPE) is required on the FINO3 platform

- on the flight:
  - survival suits and life jackets with EBS (Emergency Breathing System)
- on the platform:
  - Safety helmet
  - Safety footwear
- Task specific PPE requirements shall be:
  - Safety glasses
  - Safety harness
  - Safety helmet

Everyone who does not belong to the staff of the vessel/ship requires the following certificates:

- negative COVID19-test - no older than 48h

The following PPE is required on the vessel/ship:

- Mouth-Nose-Guard (FFP2 mask)
- safety footwear
- safety helmet
- work overall or work pants and jacket
- work gloves
- life jacket

4.3.3. Synthesis of pre-testing and re-design (pre-operational phase)

This chapter provides an overview of the general technical approach to find the most suitable solutions during the pre-operational phase of the German Pilot. The so called 'Waterfall' methodology (Figure 8), invented by Royce in 1970, presents a linearly approach to manage and structure projects and is often applied when planning and conducting construction projects due to its logical sequencing and ease of implementation (Hüskes 2019; Project Manager 2020). Stakeholder and customer requirements are gathered at the beginning of a project, followed by a sequential project plan, consisting of several phases, to accommodate those requirements. It is important to point out, that in this strict linear order, a phase can't begin until the previous phase has been completed. Although, originally predefined, the phases have been adjusted to fit the course of the pre-operational, operational and decommissioning phase of WP7. Adopting this approach facilitates the estimation of project costs, resources as well as deadlines and progress. The milestones in each phase indicate whether a project is moving forward on schedule, while the discrete phases indicate how close the project is to its overall completion.

1. Phase: Benchmarking

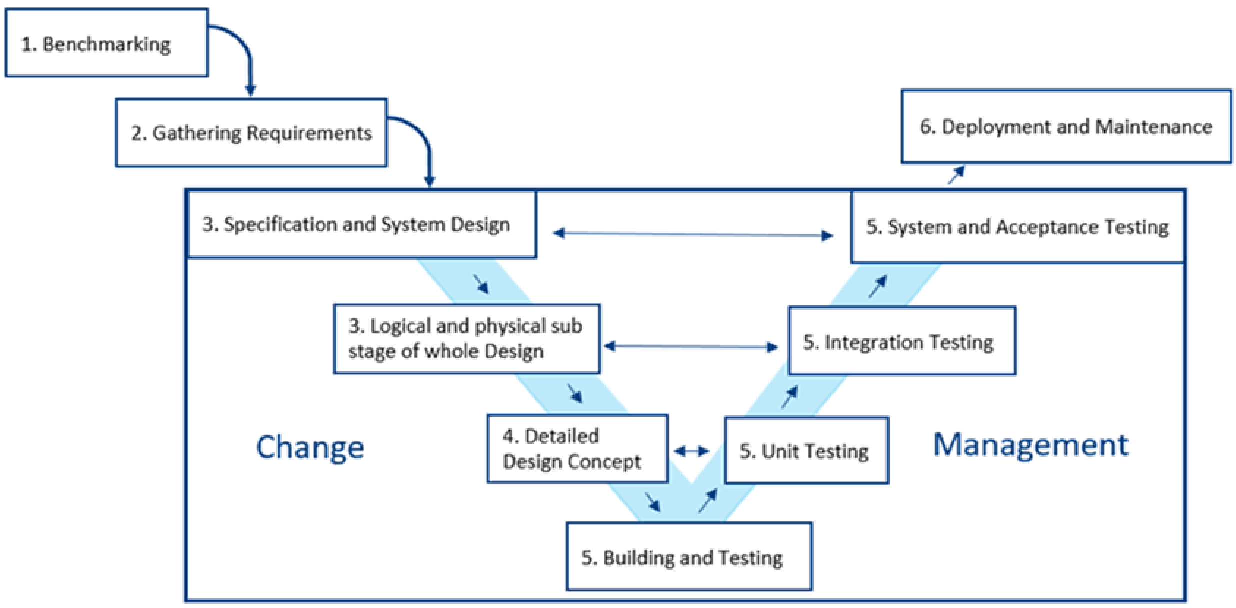


Figure 8: V-Model to manage and structure projects

At this stage, a thorough analysis of the state-of-the-art was done based on existing procedures, innovations and approaches based on literature reviews. It is important, to define the multi-use framework of the project. Therefore, ideas of existing solutions and systems on the market need to be gathered and compared in order not to reinvent the wheel. Once, a clear idea on how the project shall be realized the next phase can start. The main aims of the German Pilot are, in addition to the operation of the research platform FINO3, the construction and operation of two facilities for the cultivation of mussels and seaweed as well as the development and operation of a sensor system to remotely monitor the biological and hydrographical data of the aquaculture systems. Based on this main aims a literature review for existing mussel and seaweed cultivation systems was made. The options and restrictions due to the combination of the specific multi-use needs to be considered in order to organize the search as efficiently as possible.

2. Phase: Requirements

In this phase, comprehensive information about what the project requires is gathered from interviews, questionnaires and interactive brainstorming. By the end of this phase, the project requirements should be clearly outlined, which can be used to derive single requirement specifications in the following stage. The list of general requirements like the description of the location (site specifications), the available space at the offshore site and a general arrangement based on the site specifications is shown in the Annex A. These have always defined in accordance with the various requirements of both uses, e.g. maximum length of sea cable and minimum distance to the offshore platform.

3. Phase: Specification and System Design (rough draft)

This stage can be divided into a so called logical and a physical substage. While the logical stage captures possible solutions that are brainstormed and theorized, the physical stage transfers theoretical ideas into schemes and distinctive specifications. Using the established requirements, the team can now start designing the system. At this stage, specifications are established such as programming languages for the monitoring system or hardware requirements for the aquaculture systems.

A frequently used method to gather design ideas for hardware engineering is the morphological box (Annex A). The system to be developed is logically divided into subtasks. For each of the subtasks different solution ideas are collected, which then together take over the main task of the system. Due to the requirements of the system, some solution ideas make more sense than others. A coherent overall system is then developed from sensible partial solutions (Naefe 2012) (Paul Naefe 2012). For the design found by this method, a detailed list of all specifications and requirements is then created.

4. Phase: Detailed Design (Concept)

At this stage, a functional design concept exists, that is ready to be built and implemented, entailing the "Building and Testing Phase". Here, requirements and specifications from the previous phases are assimilated and lead to a design, which can be built. The output of this phase are the two detailed designs for seaweed and mussel cultivation at the FINO3 location, as well as the design for the subsea lander to monitor the two systems and to record biological and hydrographical data. All materials to be used are chosen and suitable sizes and dimensions of each part are selected. These designs, which are shown in Annex A will be taken to the next phase to verify the applicability for the offshore site.

5. Phase: Building and Testing

The product is built and reviewed methodically to make sure that it meets the requirements laid out at the beginning of the project. Any problems and bugs ought to be detected, documented and solved. In the case of severe problems during testing, it may be even necessary to return to phase one for re-evaluation. The overall building and testing procedure of Pilot1 will be conducted according to the V-diagram. A unique feature to the V-Diagram, is that during each design stage, the corresponding tests are also designed to be implemented later during the testing stages. Thus, during the requirements phase, acceptance tests are designed. This implies that every subsystem that is built is tested and verified accordingly, beginning with testing individual units, then subsystems and finally the whole construction. At the beginning the of the building phase the design is rather vague, throughout the project the design becomes more and granular, leading into implementation and finally back through all testing stages prior to completion of the construction.

The outcome of this phase is a completed design for all systems that can be deployed at the FINO3 site. Since not every item for example for the lander can be tested in the real offshore conditions at our FINO3 site due to high costs for travel and short time windows with suitable weather conditions, all physical test have been made at the near shore site at KMF or at the lab of 4HJena. Also, a total pre-test of the final design for the seaweed and mussel system even at the near shore site is not feasible; hence the total design test of the aquaculture systems is based on a numerical simulation. The results of the physical and numerical tests will be shown in the following paragraphs.

6. Phase: Deployment and Maintenance

At this stage, the construction is complete and ready to be installed. As problems or inadequate features may arise, maintenance and improvements can be conducted easily at the near shore site. The project team applies these fixes as necessary until the whole design setup (long line, anchor, floatation buoys, mooring, lander) proves to withstand the rough high energy environment of the North Sea. With the lessons learned from the pre-tests it is possible to create a detailed manual for installing and operating the whole site. The manual shows step by step instructions for the installation and gives information about the work that needs to be done to maintain the systems.

The Following table shows some exemplary points of the initial plan for the installation order. Some examples for a detailed step by step guide for each system to be installed is shown in Annex A. This table is also intended to be the checklist for the installation where deviations from the original plan can be listed, for example when changes needed to be done due to bad weather or damage/loss of equipment during travel to the installation site.

Table 7: General schedule/order for aquaculture installation at German Pilot

GENERAL SCHEDULE / ORDER FOR AQUACULTURE INSTALLATION					
NO.	Date	MAIN TASK	DONE SUCCESS-FULLY	DONE WITH DE-VIATION	COMMENT
1	March/April 2021	MARKING THE AQUA-CULTURE AREA			-needs to be the first step to ensure that the area is marked even if the next steps could not be finished
2	March/April 2021	INSTALLING THE MUSSEL SYSTEM			-needs to be installed at least mid/end of April due to the biologi-cal timeframe of the mussel larvae
3	xxx	DEPLOYING AND CONNECTING THE LANDER TO FINO3			-in any case the Lander must be de-ployed and connected to the FINO3 before the installation of the SEA-WEED SYSTEM can start since the vessel for lander deployment cannot operate between the two aquacul-ture systems
4	xxx	INSTALLING MOOR-ING FOR SEAWEED SYSTEM AND INTER-MIDIATE LONGLINE			
5	Sep/Oct 2021	INSTALLING THE SEA-WEED NET			-needs to be the last step due to the biological timeframe of the seaweed

4.3.4. Tests at near shore site

The following paragraph synthesises the material and equipment tests conducted at the near shore site, reflecting the fifth's phase of the V-Model described above.

Biofouling test set-up and results

At the near shore site of the German Pilot, different antifouling approaches were tested to identify the most suitable and biocide free (not allowed in human food production) sensor protection. The tests showed that UV-C radiation, worked most efficiently in preventing any fouling. The control group (no UV-C light treatment) indicated, that despite the use of different anti fouling coatings, bio fouling occurred. As a result, from the bio fouling tests, the multi-param-eter probes (CTD, turbidity, O2 and PAR-light) will be equipped with an UV-C lamp. The assembly of the individual sensor probes in the housing does not allow mechanical wipers for anti-fouling protection. Therefore, all sensors are irradiated with one UV-C lamp.

Camera test set-up

The aim was to test the suitability of low budget cameras, which are directly attached to the longline (Figure 10).
The following materials were tested:

- Time-Lapse-Camera: Brinno TLC 2000
- Camera-Housing: Omni-instruments – aluminum housing with 100mm inner diameter and 300mm inner length
- Power supply: Battery-box for 8 AA batteries inside the housing

Two camera tests were set up at the near shore site for a period of two weeks, once in January and again in February 2021. During the first test, the camera performance was assessed when attached to the backbone of the mussel long line at a water depth of 1m (Figure 9). The aim was to check the quality of the pictures and whether these may be blurred, pixelated due to the movement of the backbone, or be of good sharpness.
The second test was conducted at a water depth of 4m to test the light sensitivity of the camera. For both tests the interval between two pictures was set to 10 minutes. In order to detect the point of time, at which there was no sufficient brightness for the camera to take adequate pictures anymore, the camera was kept turned on all the time, to document the transition between insufficient light and sufficient light at dawn. In total 144 photos per day were taken.

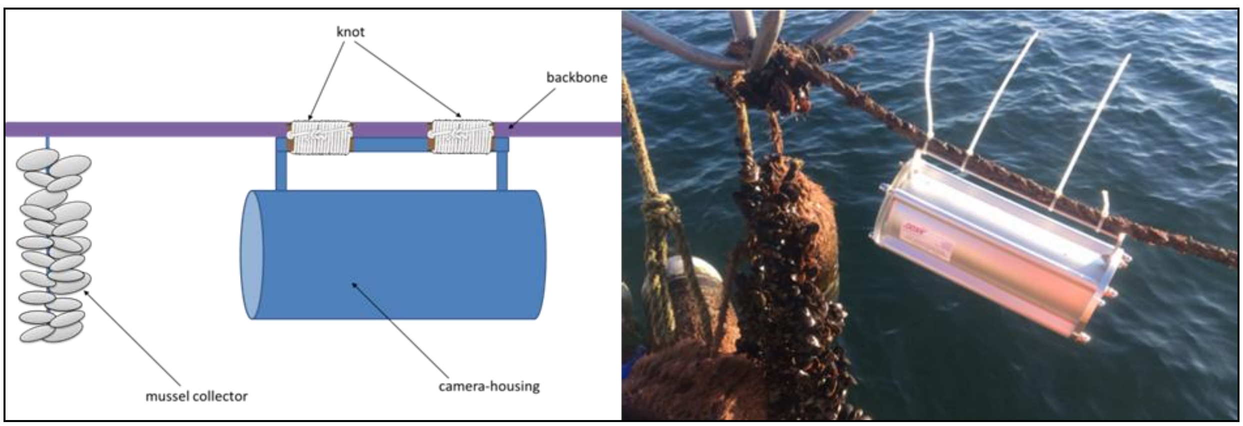


Figure 9: Left: Sketch of camera attachment; Right: Installation at the nearshore site (KMF); Baltic Sea, Germany

Camera-Test results

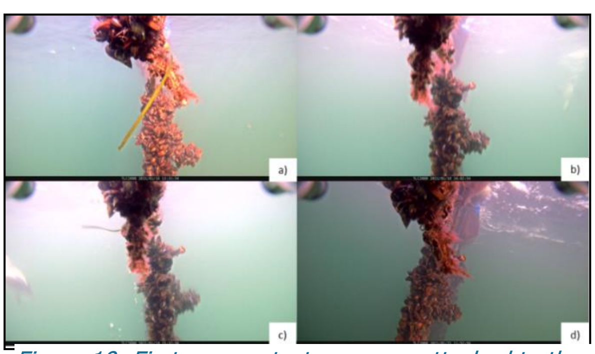


Figure 10: First camera test - camera attached to the backbone at 1m water depth

The results of both camera tests showed that a low budget camera with an internal stepper for interval photography ensures good quality pictures, as shown in the examples below. The examples of the first camera test (Figure 10) show that even at different light conditions, the camera takes good quality pictures and even seabirds b) and c) diving right next to the mussel farm can be spotted.
The samples of the second camera test (Figure 11) show that even at greater water depth, good quality pictures can be taken. In picture a) another diving seabird can be spotted. Picture c) shows increased turbidity due to a storm. Picture

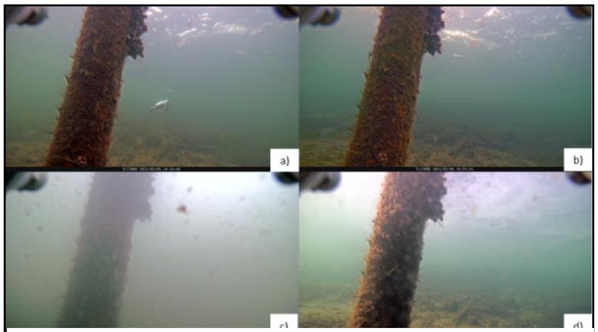


Figure 11: Second camera test - camera attached to the pontoon at 4m water depth

d) illustrates that with a frozen ice sheet still enough light reaches the camera at 4m depth.
The tests indicate that the camera equipped with a water-proof housing is suitable for underwater photography. In order for the camera to be used under water over a longer period of time at FINO3, the housing must be equipped with a wiper against fouling at the see-through cap.

4.3.5. Data collection and remote monitoring solution

Lander

The reasons for implementing a lander at the German Pilot site are:

- to compare the data quality of expensive 'scientific' sensors with cheaper 'industrial' measuring devices
- to provide a stable platform for the echo-sounder
- to facilitate a life data stream and energy supply through a subsea cable connection to FINO3.

The lander consists of a modular, scalable design, which can be adapted according to local conditions and sensor requirements. The initial approach of only one stationary platform on the seafloor was changed in favour of including a 'Winder' unit that enables measurements throughout the water column at regular intervals by autonomously moving up and down with a suite of sensors attached. This allows for better insight into the changing environmental conditions, both temporal and spatially, which, in turn, supports the decision making about the impact on mussel and seaweed production (such as the ideal depth of the netting in relation to light penetration, effects of turbidity and sea-conditions etc.). In addition to the sensors fixed to the lander and the Winder unit, a commercially available measurement buoy will be attached to the mussel-longline. Thus, hydrological parameters, close to the mussel's net, can be collected and compared with the data from the lander. This information may help to define the best monitoring strategy for future MU-platforms and aquaculture installations in terms of sensor quality and positioning.

Key guiding factors and considerations taken into account, to determine the position of the lander in relation to the longlines and FINO3 platform are:

- The position of the longline in relation to the main current, water depth, etc.
- The determination of shipping and safety zones
- The seafloor type and expected impacts (sand drifts, rock movement etc.) affecting lander geometry and stability
- The selection of measurement parameters and the optimal measuring point (monitoring only the seafloor might not be useful in terms of light intensity and temperature)
- Limitations due to power supply (maximum current), cable connections and communication (Wifi, LoRaWAN, 4G etc.)
- Equipment installation and cable routing options (ship and dive team dependent)

The lander is placed between the two longlines, so the echo-sounder transducers can scan both systems. The Winder unit with the sensors will move vertically through the water column, starting from the seafloor (~25m depth) up to approximately 5m below the surface. With a rope length of ~15-20 m there is no risk for the Winder to get entangled with the longlines as they are at least 30 m away (longlines are 60~80 m apart). The lander is located about ~350 m to the North of the FINO3 platform and connected to the plant via 500 m long sea cable. The cable consists of copper wires for power connection and a glass fibre core for data transfer and communication, offering a good solution in terms of cost, weight, performance and installation options. Key considerations for the lander design are:

- Meeting scientific expectations in terms of measured parameters, overall size/weight and cost.
- Adaptability, robustness and overall suitability for the local conditions.
- Combining state-of-the art technologies and methods (type of lander, choice of cable and electronics) with innovative approaches (use of the Winder unit for profiling, echo-sounder to determine mussel & seaweed growth, movement of the longline netting, monitoring bio-activity and algae-blooms via fluoro-probe).
- Deployment options such as the size of the ship, dive-team capabilities etc.
- Local regulations and safety protocols.
- Communication options for data transfer and power limitations.

All sensors selected for the lander have a proven record of reliability and quality of measurements. Every sensor is tested for reliable data communication, power consumption and quality of the data. Measurement frequencies are set according to overall battery runtime, required resolution and data storage (for internal loggers).

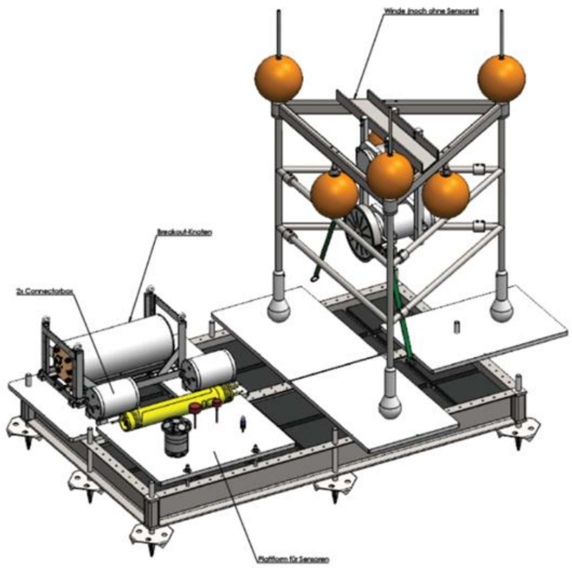


Figure 12: Overview of Lander frame with stationary sensors and Winder unit

Sensor and Lander tests

Sensor equipment for the Lander and the Lander and winder unit itself were tested on functionality. In addition, 4HJena can rely on know-how and feedback from previous installations with similar/identical equipment. Testing at the nearshore site was very limited for the equipment provided by 4H Jena for various reasons. The near shore site does not have sufficient water depth to test the full function of the lander including the winder. Furthermore, the required power supply is not available at the near shore site. Therefore, functional tests of the individual sensors and a final test of the overall function were performed in the laboratory/workshop in Jena.

NO3 sensor: The chosen NO3 Sensor is a widely used sensor equipped with a wiper for biofouling protection. Interval settings, battery and logging capacity have been tested in the lab.

Hobo sensors: Functionality and setup has been tested in the 4HJena lab. Similar sensors are already in almost daily use at KMF, therefore a special test at the near shore site could be avoided.

CTD-sensor including light and O2 measurement: The chosen sensor is a standard equipment from AML Oceanographic for hydrological data monitoring around the world, which is known to function well. Operation and communication were verified in the lab in Jena.

ADCP-sensor: The Nortek Signature 500 is standard equipment that is known to function well and widely used in marine traffic and environmental monitoring. Operation and communication were verified in the lab.

HydroC CO2: Is 4HJena's standard sensor for CO2 measurement, which they have all the required installation and operation know-how. Operation and communication were verified in the lab.

Lander and Winder unit: The equipment is too heavy and the water depth too shallow for testing at the nearshore site. The design is an improvement of an installation already operating at Helgoland in very similar conditions to be expected at FINO. Electrical testing carried out in the lab and after delivery to the harbour at Cuxhaven. The following table shows the final electrical testing of the assembled equipment.

Table 8 Functional protocol of final test for Lander and Winder unit

Functional protocol			
	Functions	Jena	Cuxhaven
1	Converting 800V to 48V	48,5V	Could not be measured directly on the components because sealed
2	Converting 800V to 24V	24,35V	Could not be measured directly on the components because sealed
3	Functioning of all components	x	x
4	Communication Beckhoff PLC	x	x
5	Switching individual channels	x	x
6	Set Maximum Power Channels	x	x
7	Short circuit test of the individual channels	x	was omitted to reduce stress on the equipment
8	Resetting the electronic fuse	x	not necessary, see above
9	UPS operation	x	x
10	UPS Switch off PLC	x	x
11	Communication LabView Land power supply	x	x
12	Communication LabView leak detector	x	x
13	Communication LabView Beckhoff	x	x
14	Communication LabViwe winder	x	x
15	Communication LabView AML	x	x
16	Communication LabView CO2	x	x
17	Communication LabWiew CTD	x	x
18	Communication LabWiew ADCP	x	x
19	Communication Simrand	x	x
20	Winder moves and stops automatically	x	Lander and winder are only joined during installation, test could not be performed
21	Status LED Node working	x	x
22	Endurance test communication over 24H	x	

Furthermore, the final buoyancy trimming of the Winder unit has taken place at the in the harbour basin in Cuxhaven (see pictures below).

Figure 13 Buoyancy trimming of winder unit in harbour basin in Cuxhaven

Lander/platform: No need for testing the platform itself as it is a steel frame with concrete blocks that has been conscientiously and accurately designed and calculated. Offshore installation team and divers have visually inspected the unit and agreed with the mechanical setup and anchor points and adjustment options. Divers will practice any operations to be carried out (sensor leveling, cable connections etc.) on land before deployment.

It is unknown how the Lander will behave once on the seafloor at FINO (mostly sand). It can be affected by shifting sands due to waves and current. The design has been discussed with experts from FINO and others. Only the actual installation will provide insight into how well it will stay in place etc. but this is the nature/aim of the project.

Tests conducted after submission of this deliverable

Echosounder tests

Testing of the echosounder and its transducers was conducted over the summer months in 2021 for several reasons. Due to delayed shipping the equipment was incomplete in 2020. Once the material was procured the harbour at the nearshore site was closed for external people due to the COVID19 pandemic. Furthermore, the echosounder was supposed to be tested with mussel biomass growing on the longlines in order to simulate the offshore set-up as realistically as possible and to get a first idea of how biomass growth is captured and measured by the echosounder translating into a graphic representation. Unfortunately, due to an unusual cold spring the spat fall of mussel larvae was delayed until June, which is why decent mussel biomass growth on longlines hasn't occurred until August 2021. Hence, the time of testing of the echosounder and transducers was postponed until week 32 2021.

Two tests have been carried out at the mussel longlines of the near shore site, to verify the settings and results of the echosounder. The first test provided constructive feedback on how to improve the settings. The transducers were attached to a pole and submerged in three different orientations. First orientation of 200kHz transducer with 30° angle to ground, second orientation with 15° angle to ground and the third orientation, transducer in parallel to the ground The VBS mode of the Echosounder (basic data not high resolution) showed some biomass growth on the line shown in the figure below (Figure 14). The vertical axis of the graph indicates the distance to the object (backbone of mussel longline) in meter and the horizontal axis shows the duration of the backscattering.

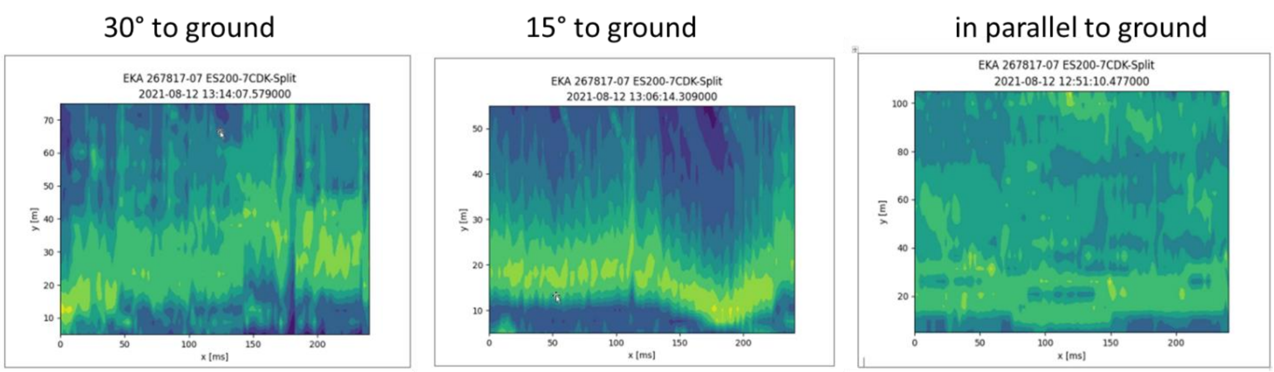


Figure 14 Echograms in VBS mode from first test at near shore site while scattering the mussel longline with different settings

The second test has been performed in week 41 2021. The transducer was 10 and 30m away from the first longline when it was tested. The transducer was oriented at an angle of about 15-20° to the ground. The duration of a single recording was 8 minutes and was performed with a ping every 2 seconds. The lager plots on the left of each setting show the echogram plots created with the EK 80 software (Figure 15). The data for these plots are stored on the WBAT and can only be read out and created after the WBAT has been recovered. The smaller plot on the right of each setting shows the VBS plots. The data for these can be exported in real time via the Console and then plotted. The VBS data are reduced echogram data. Both graphs are read identical with the distance to the irradiated object (longlines) in meter on the vertical axis and the signal duration in seconds on the horizontal axis.

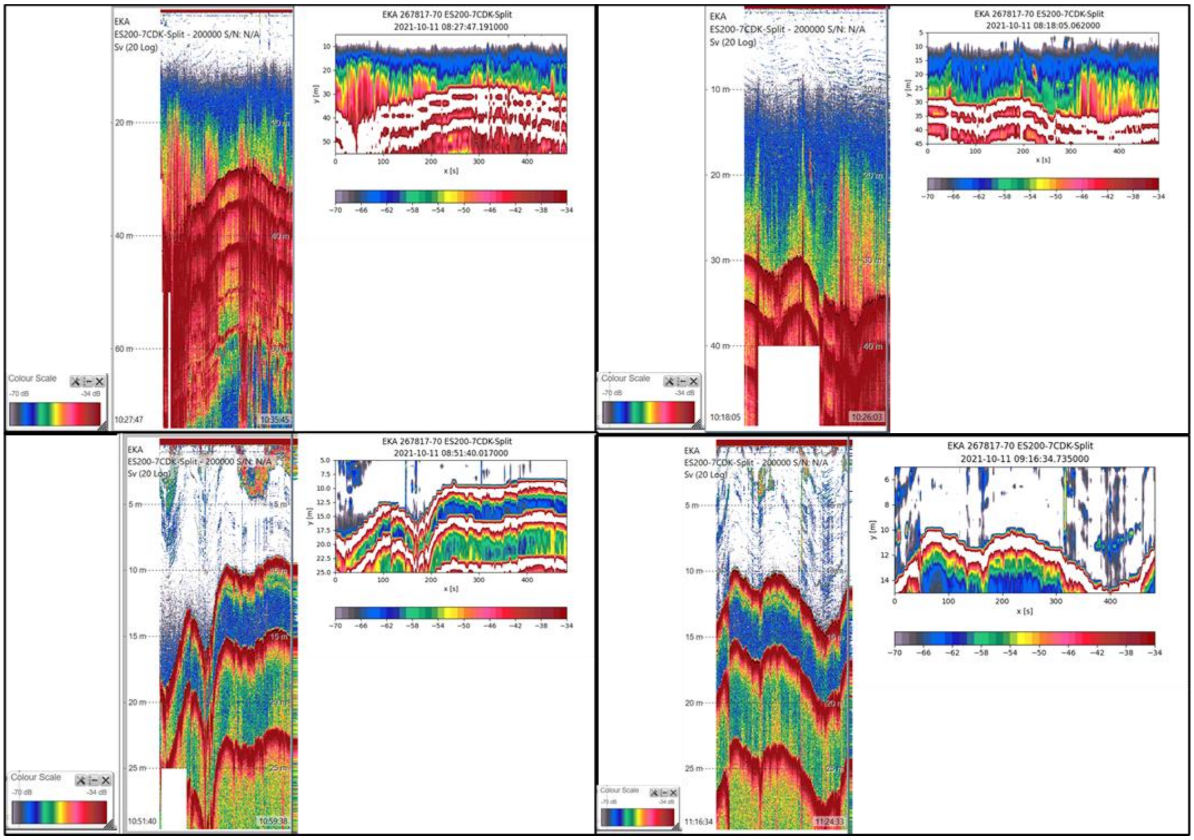


Figure 15 Echograms and VBS modes from second test at near shore site while scattering the mussel longlines with different settings

The equipment itself is widely used in marine traffic, ROVs and sea floor exploration and well known to be robust and functioning well. Remote access to the WBAT allows to make fine tunings to the setup after it has been installed at FINO. It is an experimental setup and it will only be clear how it will really perform once installed at FINO. The shallower depth and different type of longline used at KMF makes more elaborate testing at the nearshore site complicated without having directly comparable results. The setup on the Lander has been made as flexible as possible to account for variations and a novel way to access the WBAT and obtain results remotely (normally autonom) has been implemented. Measurement buoy.

A commercial measurement buoy (AquaREAL from Bioceanor) will be mounted to the mussel longline for hydrological measurements close to the netting/mussels. This way, the performance of highly advanced subsea multi parameter probes (fixed to lander) can be compared with commercial of the shelf solutions. The AquaREAL buoy is equipped with four sensors measuring the following parameters (AquaTROLL):

- Water temperature
- Dissolved oxygen
- pH
- Turbidity

Salinity/conductivity is not included, due to the limit of four sensors per system, as well as this parameter is considered relatively 'constant' with minimal impact on mussel/seaweed production (see paragraph 3.2.2 Seabed and Seawater). Every 20 minutes, data is sent directly from the measurement buoy to a Gateway (LoRaWAN) installed at the FINO3 tower and from there, transferred into 'cloud storage' (requires permanent internet connection). Due to the considerable movement of the longline, the measurement buoy is not connected to the lander.

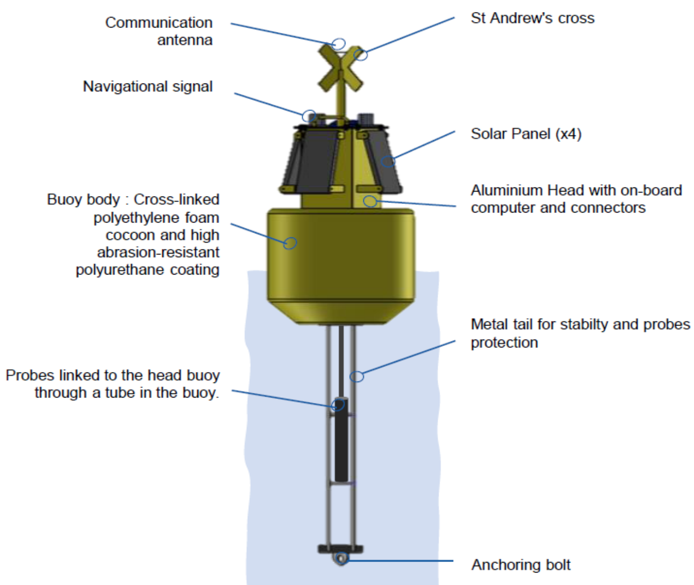
Testing of Measurement buoy

AquaTROLL Sensor: It is a well-known sensor in the aquaculture sector and previously used by the Dutch Pilot with good results. Functional testing and calibration were carried out in the lab.

AquaREAL and Gateway communication: Communication distance was tested from 4HJena office in Kiel across the Schwentine river with good success (more than 300m). Gateway internet connection at FINO was tested by the manufacturer and confirmed to be OK.

Solar panel: Functionality test and charging at the lab with success.

AquaREAL and AquaBUOY Test at KMF



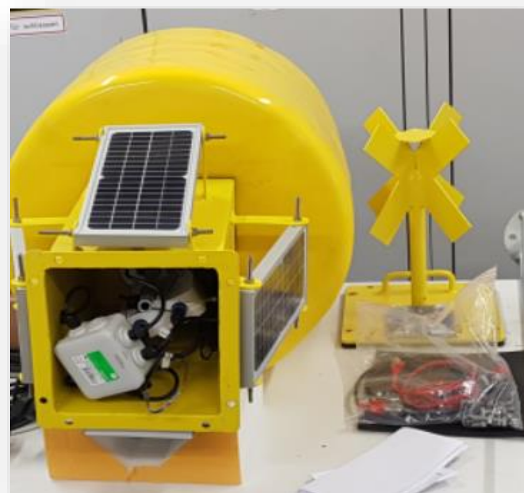


Figure 16 AquaBUOY with AquaREAL device as ordered and delivered

The additionall added AquaBUOY for remote and insitu measurement directly at the mussel system was tested at the near shore site. The first test setup at KMF has shown that the buoy itself with the AquaREAL system consisting of solar panels and the implemented electronics for data transfer are not build for high energy offshore locations (Figure 16). The battery pack of the transponder was empty before the buoy was even installed at the harbour and the solar panels were not able to recharge the system. Moreover, the buoy was not balanced and tended to tilt in one direction. The hardware was not 'fit for purpose' for offshore conditions in the North Sea (not robust and watertight). Further collaboration with the supplier (Bioceanor) addresses these points and the required modifications for an offshore application are made. By resolving the issues that came to light during testing, the existing technology will be improved in order to develop a suitable commercial product for future offshore MU platforms.
Due to the timeframe of this deliverable the modifications have been made after submission.

In consultation with Bioceanor, 4HJena build a frame for offshore use themselves which now can be fitted to one of the solid buoys of the mussel system which are made for offshore porpoise. Furthermore, they have installed the electronics in a housing that was developed during several other offshore projects and that is already being used successfully in many of their applications. Secondly battery capacity was added. The new system was tested for several days at the 4HJena office in Kiel and a connection between transmitter and receiver could be ensured at a distance of more than 300m. The Frame with the solar panels on top will now slide onto one of the foam-filled spar buoys shown in the figure below. Due to lack of time before the original planed offshore installation of the mussel system tests at the near shore site have not been carried out. The risk has been minimized with careful calculations and evaluations with the supplier.


Figure 18 Buoys for mussel system


Figure 17 Frame for AquaREAL made by 4HJena

4.3.6. Mussel and seaweed longline design

Although screw anchors are the most sufficient solution for commercial aquaculture farms, a combination of drag anchors and clump weights was chosen for the German Pilot. The main reason being the additional risk of depending on special equipment and external subcontractors from abroad for the installation, which is impossible to plan during a worldwide pandemic and closed borders. Travel restrictions and the increased possibility of last-minute cancellation due to unforeseen and unpredictable incidents (illness, weather, lockdown, etc.) were considered too great a risk to take. Additionally, the final mussel and seaweed designs are based on already tested systems, which have been adapted to the conditions of the German Pilot location. Both systems include clump weights and/or drag anchor mooring solutions. In order to use screw anchors with these systems, major costly modifications would have been necessary.

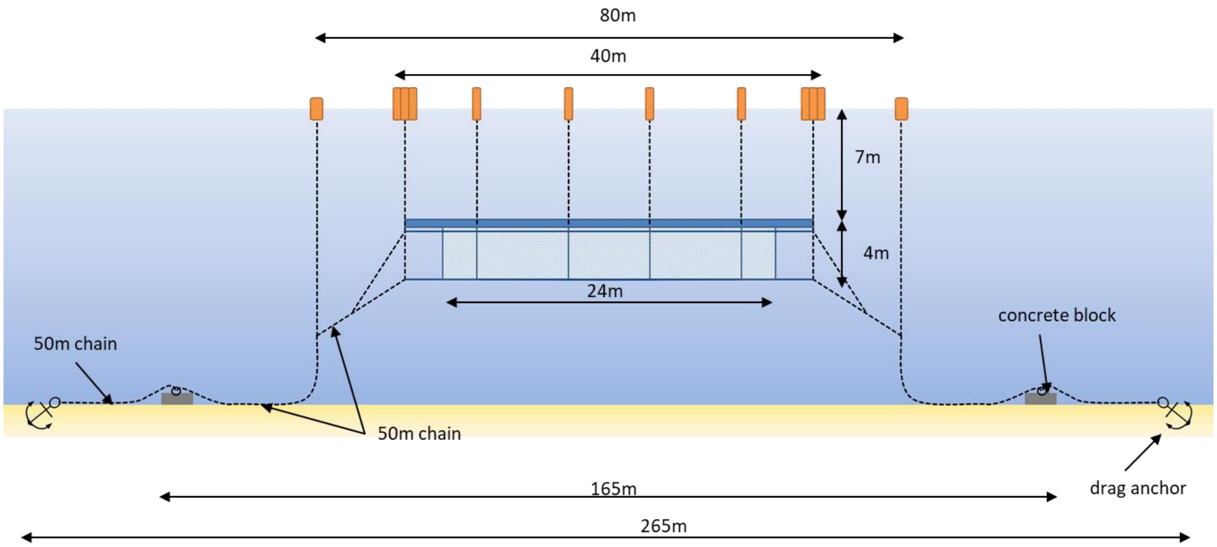


Figure 19: Side view of the mussel longline design – German Pilot

The mussel longline (Figure 19) is a modified and adapted version of a commercially used system. The current design is based on the results of a former project, which was implemented at the nearshore site (Lyngsgaard 2019). It consists of a 40m long backbone (PE tube - 315mm OD, with open ends allowing water to come in) and a net with a total size of about 24x4 m. The net consists of five segments with different mesh sizes and rope materials (Table 9). The backbone is kept afloat through hard plastic fenders filled with foam at a water depth of 7m. In total, there are ten surface floaters with a buoyancy of 240L attached to the backbone. In order to lift the mooring chains at each end of the backbone, three floaters will be combined (together 720L). For indicating the mooring chain, a small floater of 170L is attached about 20m away from the end of the backbone. The longline is moored with a 6t concrete block and a 2,5t drag anchor. The distance between the concrete blocks is about 165m. The drag anchors are placed 50m behind the concrete blocks. The longline has an overall length of 265m (drag anchor to drag anchor). The longline is placed in parallel to the main current direction (NW-SE).

Table 9: Net properties of mussel longline –German Pilot

Quantity	Width [m]	Depth [m]	Mesh size [mm]	Net material
1	6,66	4	90x90	3mm thick and 12mm wide (polypropylene)
1	6,66	4	135x135	3mm thick and 6,5mm wide (polypropylene)
1	6,66	4	200x200	3mm thick and 12mm wide (polypropylene)
2	1,8	4	200x200	Ø 18mm core and Ø 65mm expand "christmas rope" (polypropylene)

The seaweed longline (Figure 20) is a modified and adapted version of the cultivator system installed at the Dutch Pilot site, which was designed by the Seaweed Company. This way, the same system can be tested in two different environments and comparisons with regard to technical implementation and feasibility can be made.

The longline consist of a 30x3m net (12mm nylon with 400x400mm mesh size) equipped with three oval floaters per meter at the top line and three oval sinkers per meter at the bottom line. The main buoyancy for both mooring and the net, is provided by two steal spar buoys with a length of 10m and a total buoyancy of about 3000L each. The spar buoys are placed about 100m apart. The net is spread, using a net spreader-beam at each end, attached to a 230L foam filled floater. The longline is moored with a 6t concrete block and a 2.5t drag anchor placed 50m behind at each end. The distance between the concrete blocks is about 220m. The longline has a total length of 320m (drag anchor to drag anchor) and is placed in parallel to the main current direction (NW-SE).

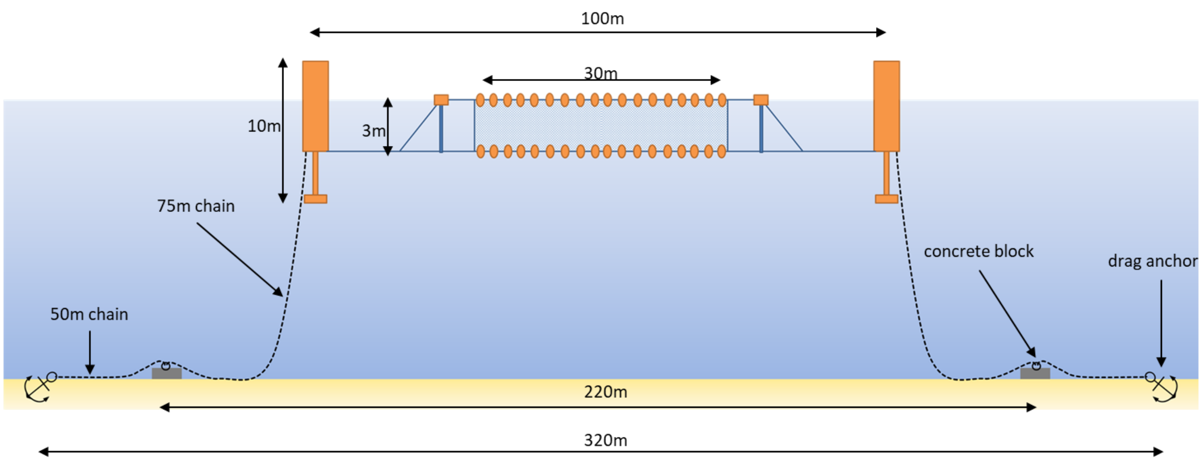


Figure 20: Side view of the seaweed longline design – German Pilot

As stated above, a plausibility check for both systems was conducted as risk management and precaution. Verification by an independent company was commissioned, to revise the loads and movements of the system dynamics and to evaluate the risk of equipment failure. Since there are no standards for offshore mussel and seaweed cultivation systems, the verification is based on mooring standards and standards for fish aquaculture. The recommended standard is the ABS Offshore Fish Farming Installations (2018) Code for unmanned and non-redundant fish farms. The simulations show that on the standards listed below (Table 10), the maximum loads of a 50-year return event never exceed the minimum breaking load (MBL) of the chosen equipment including the respective safety factors.

Table 10: Standards used for design simulation – German Pilot

Organization	Code
ABS	ABS Offshore Fish Farming Installations (2018)
DNVGL	DNVGL-RU-OU-0503 Offshore fish farming units and installations DNVGL-OS-E301 Position Mooring
The Scottish Government	A Technical Standard for Scottish Finfish Aquaculture

4.3.7. Adaptations to COVID19

During the pre-operational phase of the German Pilot several lessons have been learnt. From a logistical point of view, it has become clear that within a multi-use project, all actual users of the allocated space must be included in any planning from the start. This concern on the one hand the area planning, i.e. where can what be placed without affecting others, but also the proper time planning, so that active partners know exactly who carries out which work and when but also other stakeholders operating in the area even though they are not directly linked to the project so that they are aware of potential interactions with the new-comers in the area. Further, it would be advisable at an early stage to be reliably informed for which time periods the project is planned and whether there, are subsequent projects to be anticipated or whether the entire activity is designed as a temporary or permanent exercise.

It has become clear – as is known for many other inter-connected industries - that delays in one part of the project often affects all other components. In the case of the German Pilot, there are further research projects that are planned on and around the FINO3 platform and these plans have to be taken into account when designing a longer-term activity. The space currently reserved for the aquaculture facilities and the lander system cannot be utilized for an unlimited period of time as long-term planning already existed before the planning of this Pilot.

Independent form the above, the advantages of combined activity of the German Pilot with the existing other ongoing activities at FINO3 are obvious even if the time frame is limited to project years only. Installation and maintenance dates for the aquaculture facilities and the lander system can (and will) be coordinated with maintenance work on the FINO3 platform and the ideal combination of service trips is certainly an option that should (and will) be utilized as much as possible Even at the nearshore site of the German Pilot, installation work and test setups had to be planned both spatially and temporally with all partners, since here, too, follow-on and parallel projects are subject to time and space constraints but good integrated planning offers options for benefits for all involved.

Another insight gained from the pre-operational phase is that regularities for one part of the project can only be meaningful if they are also applied by the other users to the extent possible. In concrete terms one example may stand for many others:, In the German Pilot (and certainly this applies also for the others within UNITED) there is a need to prevent the entry and the spread of invasive organisms which may be "hitch-hiking" on service boats while negatively affecting the operation in a long-term, We have to realize that with increasing activities the need for control of transfer of disease agents and pathogens but also unwanted "foreigners" deserves critical attention to avoid any "Pandemic" as we experience in terrestrial systems (there is a lesson to be learned). Therefore, only seaweed from the German North Sea is cultivated and only the mussels that are present at the FINO3 area are collected with the mussel system to avoid transmission of known parasites and diseases occurring in other regions. Installation, diving and maintenance vessels should originate from the same area (larger ecosystem) and preferably not have been recently operating in large harbours with intercontinental ship trading (or if coming from there, should be inspected for unfavourable hull fouling etc.). While for a windfarm alone this issue is of low priority, for operations of the aquaculture facilities it is of critical importance to prevent the exchange of organisms through – for example - ballast water release or cooling systems with internal fouling or hull fouling.

Also, in the field of antifouling measures there are different regulations for different users. Antifouling measures that may be used for the protection of offshore structures are partly in conflict with the regulations for food production and for the well-being of cultured organisms. Here, a serious cross-check with national and international regulations (including fish health regulations and product safety regulations of the EU) is needed and guidance should be developed on possible adjustments (optimisation) of these regulations under local and practical conditions.

4.3.8. Seaweed cultivator numerical analysis

This section summarizes the calculations that have been done by the Maritime Technology Division of Ghent University (MTD-UGent) to the seaweed cultivator designed by Aqitec for the German Pilot offshore Operation. The seaweed cultivator system will be installed at the FINO3 research platform located at 80 km of the coast of Sylt.

The system (Figure 21) consists of a single net of 30 m long and 3 m wide installed vertically. The net has a mesh size of 0.4 m x 0.4 m. The upper part of the net is kept afloat by multiple floaters. Underneath each net, sinkers are used as a counterweight. The net is connected on each side through a series of dyneema ropes to two spar buoys holding the system in place. Each of the spar buoys is connected to a concrete block of 6 tons dry mass resting on the seabed and connected with a chain of 75 m long. Finally, a second chain has a length of 50 m and connects the concrete block with a Delta flipper anchor type.

The numerical calculations have been performed using the in-house developed mooring dynamic solver MoorDyn-UGent, based on the lumped-mass approach (Hall & Goupee 2015; Pribadi et al., 2019). The hydrodynamic forces on all the elements of the system are modelled according to the Morison Equation (Morison et al., 1950).

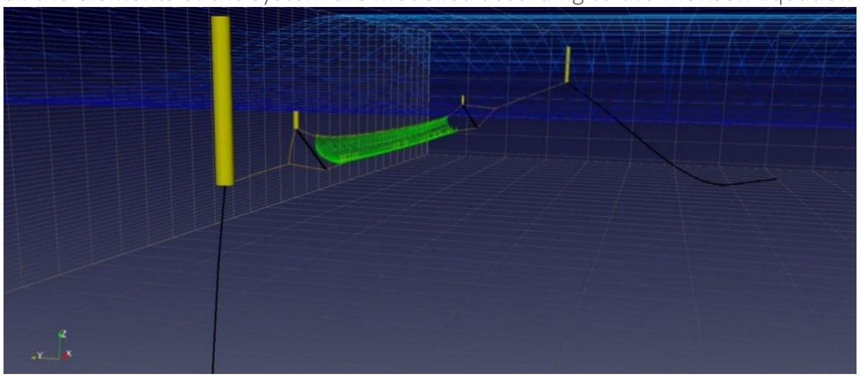


Figure 21: Snapshot of the simplified Algae cultivator system in MoorDyn for the German Pilot, during a combination of 1-year current and 5-year return period of wave, both parallel to the longline

Figure 21 shows a snapshot of cultivator systems in the numerical model MoorDyn-UGent. The numerical net has been modelled as a combination of cylindrical elements with a mesh size coarser than the real net (Figure 22). The presence of the seaweeds on the net has been modelled by considering the seaweed is behaving as fouling attaching to the net. The projected area, volume and weight of the cylindrical elements have been increased accordingly in the numerical model to simulate the behaviour of a net fouled with seaweed (a more detailed description of the numerical approach is included in Annex A). The load combination used for the simulations are based on a 5-year return period of wave and a 1 -year return period of current.

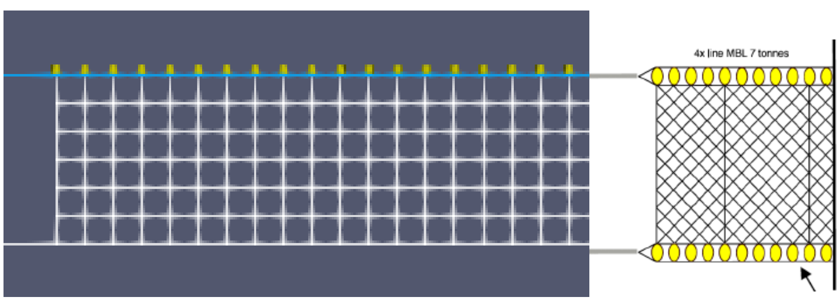


Figure 22: Numerical model of a seaweed net (left) and CAD drawing of the physical net (right)

Based on the numerical study performed on the seaweed cultivator designed by Aqitec for the UNITED German Pilot, the following conclusions and recommendations are included for consideration:

- For a 5-year return period of waves and current, load case 2 (in-line waves and currents) provides the highest loading in the cultivator system compared to the other combinations of the same return period.
- According to a combined safety factor of 2.3, the MBL of the chain (C-01) should not be less than 565 kN. If used chains were to be used, the safety factor is increased to 5.75 and the MBL should not be less than 1414 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 28 mm (R-01, R-02 and R-04) should not be less than 449 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 16 mm (R-05 and R-06) should not be less than 242 kN.

- In all simulation cases, the maximum tension on the strength-ropes holding the net do not exceed the breaking load indicated by Aqitec. This does not consider any safety factors as the net is meant to break under extreme waves and current condition.
- For a 5-year return period of waves and current, the maximum horizontal load transferred to the anchor is 266 kN.
- For a 5-year return period of waves and current, the maximum vertical load transferred to the anchor is 41 kN.
- For a short installation period (3 months of marine growth), fouling does not have a major impact on the structural loads. However, it is suggested by NORSOK-003 (NORSOK STANDARD, 2007) and DNV OS301 (Det Norske Veritas Germanischer Lyold As 2018) to consider a linear increase of marine growth thickness over the course of 2 years to account for the increase in mass and drag area to the system.
- The spar buoys should be able to withstand the hydrostatic pressure at a depth of 10 m.
- In the numerical model the spar buoy has been modelled as a cylinder and the mooring chain connected at the bottom of the cylindrical element. The real spar buoy is connected to the anchor chain in the middle. It is advised to monitor the position of the chain with respect to the lower part of the spar buoy to avoid any possible entanglement.

4.4. Economic aspects & financial implications of Pilot

4.4.1. Economic assessment

During the first project year an economic assessment of every Pilot was conducted (Deliverable D3.1), in order to define a baseline on which a multi-criteria economic assessment framework will build on, in order to examine the economic feasibility of the different multi-use combinations. The following chapter elaborates on the economic aspects and financial implications. The box below summarizes the results of the previous stock-taking exercise of D3.1 regarding economic barriers, identified synergies of MU and potential future markets (Table 5).

Table 11: Recapitulation of the economic baseline assessment of the German Pilot from 2020

Economic Barriers	• Lack of standardized procedures to co-use aspects related to the MUP (i.e., sharing resources) • The biggest cost factor is the charter for vessels: number of suitable shipping companies with reasonable offers for such a comparable small demander is very limited • Insufficient subsidies and incentives from the government, missing external financing concepts • High Insurance and maintenance costs • Market price of produced goods dictates a low price, hence scaling up is necessary • No access to market/marketing strategies that ensures a stable level of turnover
Synergy Effects	• Environmental monitoring data and surveillance is available for all parties involved • The application process for permissions and licenses could be facilitated for MU • Increasing employment capacities for certified offshore staff and multi-disciplinary education of personnel • Sharing logistics and infrastructure (storage space, equipment, vessels, etc.) • Increasing social acceptance by using marine space more efficiently and sustainable • The insurance costs can be shared between wind farm operators and aquaculture farmers • Security of tenure can be increased even after 25 years of activity
Potential Markets	Seaweed • Cosmetics & pharmaceutical industry • Restaurants, organic food trade, food retailing • Construction (insulating material) • Water remediation systems, sewage treatment plants • Agriculture: feed additives for cows, chicken, pigs; plant fertilizers Mussels • Restaurants, organic food trade, food retailing • Farmers markets • Animal food production

Based on the provided Pilot information from all pillars (economic, social, environmental, technological, legal) a tentative business model canvas was drawn up, to capture the status quo of the German Pilot (Figure 23). It has to be pointed out however, that this initial business model canvas is rather a temporary collection of information and not a final version representing the results of the project.

Problem	Solution	Unique Value	Unfair Advantage	Customer Segments
- Bad reputation of aquaculture facilities - Damage to assets due to high energy environment - Difficult to reach due to exposed location - Lack of general technological knowledge of industry involved in MUP - Reliable remote data recording problematic due to harsh environmental conditions (biofouling) - Lack of attractiveness for private investors - High maintenance costs - Lack of standardized procedures to use synergies - Access to market/ marketing strategies - Unknown possibility of harmful algae blooms - Unclear and fragmented regulation for MUPs on national/European level - Lack of established licensing procedures for multi-use projects.	- Development of remote control/operation practices of plant (monitoring devices have to be automated) with high durability - Development of Data Acquisition and Control System (DACS) as well as a communication system - Development of a business case and an economically viable value chain - Operational requirements can be further exploited and learning processes can be designed cost-effectively - Explore local cooperative ownership opportunities - Attract "newcomers" to MUCL systems and develop a basis of trust for long-term cooperation and division of labour **Key Metrics** - Biomass production (kg/m) of seaweed and mussels (growth rate, spat collection) - Quality of mussels/seaweed - No. of operation and maintenance trips - No. of events of toxic algae blooms - Frequency of bad weather events and storm damage to assets	- Increased efficiency of infrastructure and use of synergetic effects - Sustainable aquaculture production - Creating artificial reefs and substrate for flora and fauna to settle on - Local production of seaweed/mussels - Creating new job opportunities - Developing new value chains	- Specific software to analyse collected data - Strategic partnerships to the seaweed industry, ICT companies as well as offshore aquaculture production experts - Established relationships with regulating bodies and politics - Network effects due to the big and resourceful UNITED consortium - Long term experience in offshore operations - Long-term relationships to experts in the field of (offshore) mussel/seaweed cultivation **Channels** - Social media - Newsletter - Website - Dissemination activities (conference presentations, publications) - SH engagement (workshops, interviews) - Selling of products via local restaurants, farmers markets, food retailing	(Diversified customer segment) - Wind farm operators - Seaweed breeding companies - (Mussel) fishermen - Algae and mussel processing companies (cosmetics, pharmaceutical, nutritional, packaging...) - Food retailing - Restaurants/hotels - End consumers

Cost Structure	Revenue Streams
- Value driven: creating high valuable products in a sustainable, environmentally friendly way - High fixed costs: salaries, chartering vessels, infrastructure expenses, O&M of FINO3, licensing - Economies of scope: making use of synergy effects (the same crew that operates/maintains FINO3, to service aquaculture set up, using the same onshore storage facilities, using the same helicopter and general service trips to FINO3...) - Variable costs: equipment (longlines, spat collectors, buoys, anchors, anchor chain...), ICT assets (sensors, lander, cameras, sea cable...)	- Transaction based revenue: H2020 EU funding - Recurring revenues: selling mussel/seaweed, producing offshore energy - Generating revenue stream: In the future WFO could rent/lease the space within their wind farms and their infrastructure to mussel/seaweed producers

Key Partners

Project Partners
- FuE (FINO3 engineers)
- UGent
- KMF, 4HJena
- NSIL, WINGS, SPOK

Service Providers
- Diver company
- Vessel company
- Fishermen
- Helicopter company

Equipment and Material procurement
- Company breeding seaweed on longlines
- Company providing mussel spat collectors
- Marine technology companies (sensors)
- Marine equipment supplier

Consultants/Other
- Marine research facilities and laboratories
- Seaweed processing companies
- Offshore training facilities
- Regulatory bodies, NGOs

Figure 23: Tentative business model canvas, reflecting the status quo of the German Pilot at the beginning of the project

4.4.2. Key performance indicators

The German Pilot formulated key performance indicators (KPI) based on the projects' objectives and critical success factors (CSF), to compare performance with regard to strategic and operational goals (Table 12). Furthermore, the three dimensions of controlling processes were regarded: **quality**, **time** and **costs**, in order to avoid one-sided financial control aimed at short-term optimisation but encouraging future oriented and multidimensional KPIs into account (Lehmann, 2012). The Table below shows the adapted CSF and KPIs, based on the work of Jahangirian et al. (2017) and Lehmann (2012), the German Pilot team has selected and describes how they are implemented.

Table 12: Formulated key performance indicators (KPI) and critical success factors (CSF) of the German Pilot adapted, based on Jahangirian et al. (2017) and Lehmann (2012)

CSF	KPI	Description and implementation in German Pilot
Communication and interaction	Number of communication (meeting, phone calls, etc.) per month throughout the project. **(Quality)**	The frequency in which meetings/discussions occur is a straight forward way to assess regularity. → *The German Pilot team is attending a variety of regular meetings:* • *Weekly meeting for the internal FuE team* • *Monthly meeting with German Pilot team (FuE, KMF, 4HJena)* • *Bi-monthly WP7 meeting together with the other Pilots* • *Monthly CCT-Meeting (WP leads & SAB)* • *Occasional ad-hoc meetings for specific cases* • *Additional WP meetings with other UNITED partners*
Competence of subcontractors/ partners	Number of similar projects, the subcontractor has conducted in this field.	The experience of the subcontractor is best represented by the knowledge content, the time the subcontractor was actively engaged in this branch of industry, certificates, overall best practice recommendations and the number of experts available within the company. → *FuE selected its subcontractors based on their 25 years of experience in the business of offshore operations. Many subcontractors have been working with FuE for years. New subcontractors are selected based on their expertise*

	(Quality)	*in a particular field by assessing their former projects, and reputation (within the UNITED consortium).*
Involvement	Involvement of key stakeholder groups (Quality)	The more organisational units (management, specialists, R&D, etc.) are involved, the better the project has secured appropriate involvements from various key groups. Here, the support of management is indispensable to the overall organisational commitment. The best way to secure their support is to actively involve them in the project. →*Aside from the core FuE team working on UNITED, the management is informed about the project once per week and at times actively included in the decision making process. The FuE offshore engineering team is also consulted on a regular basis. An external specialist on "marine mammals" was contacted in order to account for potential threats the mussel/seaweed designs might have on harbour porpoises and seals. With regard to seaweed cultivation (which strains, seeding method, etc.) project partners from the Dutch and Belgian Pilots were consulted as well as providers.*
Project time table - Punctuality	Percentage of project's lateness (Time)	This KPI is easy account for on time delivery. The agreed upon services/actions/reports are presented on the stipulated date complying with the reliability of the reporting schedule. →*Tasks were derived from the original WPs and deliverables and formulated into action points with deadlines according to the projects' milestones. As a big part of the project concerns technological developments, this part is managed in an extra timetable by offshore engineers. The remaining tasks of the project are listed in another schedule, processed by scientists.*
Flexibility/ Responsiveness	Percentage of change requests from project partners met over the course of the project **(Quality, Time)**	Partners may have interim change requests regarding the project's execution. There needs to be a balanced response by the project lead to these requests. If requests are documented, the percentage of requests met can be a good and easily measurable representative of the provider's flexibility. →*The internal FuE UNITED team keeps minutes from all official project/team meetings, to document the work progress and the decisions that have been made. Changes are noted down within these minutes as well as in the project time schedule and its tasks.*
Operational Planning and Budgeting	Operating cost reduction (Cost)	Following the budget plan without risking expenses that are not covered and were unforeseen. → *In order to not exhaust the UNITED budget, most services that are outsourced to subcontractors as well as equipment follows a tender process. At least three quotes are obtained while usually the most cost-effective solution is pursued.*
Accurate quantifying of opportunities and risks	Risk variance (Cost)	The better the risk management, the lower the variance from the result actually achieved. Here the quality of risk management strongly depends on how managers (risk owners) and risk controllers work together. → *The bottlenecks and challenges, that have the potential to most likely become a risk to the project were carefully examined at the beginning of the project and are re-evaluated as well as amended throughout the course of the project. These re-evaluations take place during the weekly, monthly and bi-monthly meetings.*

4.5. Legal status of Pilot

4.5.1. Applicable Regulations & Restrictions

The exclusive economic zone (EEZ) falls under BSH jurisdiction, where the German Pilot is located. The BSH is responsible for the sustainable development of the German North Sea and the Baltic Sea, which is regulated by the maritime spatial development plan (FEP) (based on Federal Regional Planning Act) BSH (2017). This includes allowing economic uses, where they do not conflict with nature conservation and environmental protection, creating a balance between exploitation and protection of the sea, while ensuring the safety and ease of navigation. The FEP of the German EEZ was last amended in 2017, to implement the EU Directive on Maritime Spatial Planning. In contrast to the territorial sea, the EEZ does not belong to the territory of the federal republic of Germany. Maritime spatial planning must therefore respect the freedoms of the UN Convention on the Law of the Sea, such as the freedoms of navigation, overflight as well as cable and pipeline installations. It is therefore a matter of "limited spatial planning". In the North Sea, OSPAR is currently in charge of international cooperation for marine environmental protection in the North East Atlantic.

Outlook for future offshore operations

The BSH investigates areas designated in the site development plan for tendering. The marine environment, subsoil, wind and oceanographic conditions as well as the traffic suitability of the location are assessed and documented in reports. Based on the results of the investigation, the BSH examines the suitability of the area. If suitability is declared, the reports are forwarded to the Federal Network Agency (BNetzA). The FEP determines the chronological order, in which sites for offshore wind farms are announced for tendering, which is influenced by criteria such as the efficient use of existing and planned grid connections, spatial proximity to the coast, conflicts of use of an area, expected capacity to be installed in the area, technological feasibility and the resulting suitability of the area for cost-efficient power generation. Offshore locations are then auctioned off by the Federal Network Agency, publishing the reports on the site investigations. The bidder, who is awarded a contract, may built a wind farm in the particular offshore location after passing a five step application process (Figure 24).

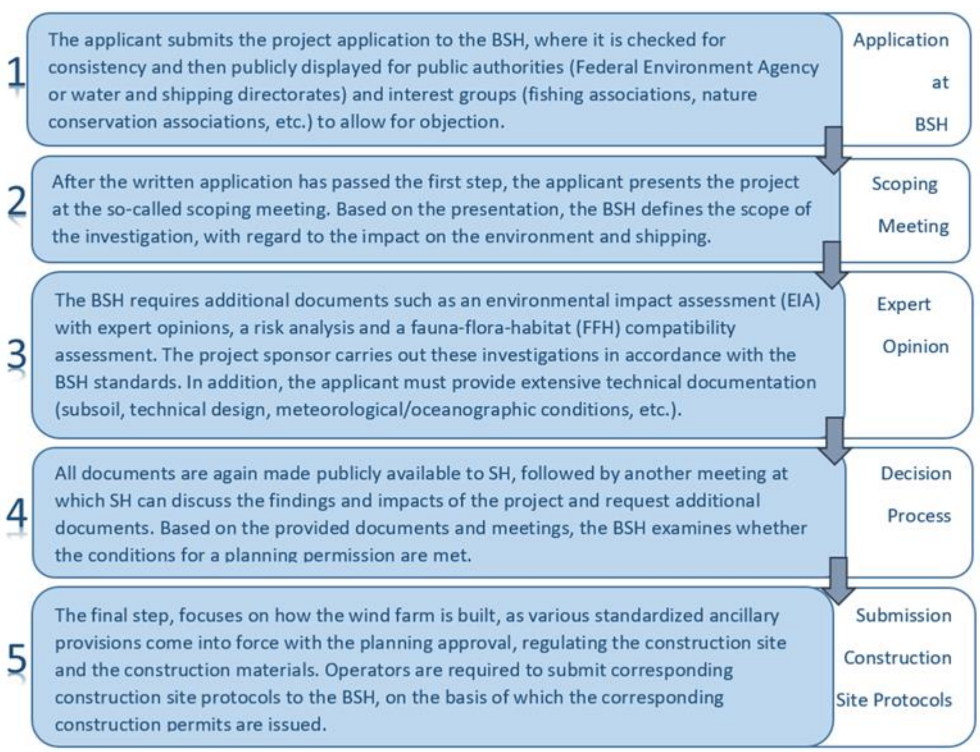


Figure 24: Offshore wind farm application process

On the basis of the Wind Energy at Sea Act (WindSeeG), marine sector development deals primarily with planning wind energy at sea and offshore grid connections. Due to climate and energy policy requirements of the federal government, the capacities of offshore wind energy expanded. By the end of 2017, the BSH approved 34 wind farms with over 2,200 wind turbines and 9 converter platforms. Over 1,000 wind turbines are operated in the North and Baltic Sea.
At this point, the FEP does not mention MU activities. However, the annex (§ 1) of the decree on "Spatial Planning in the German Exclusive Economic Zone in the North Sea," (2017) says, "*multiple use of the space should be encouraged in the sense of saving marine space. In the case of multiple use, it must be ensured that the priority use is not impaired. In certain cases, for example, wind energy use and oil and gas extraction can be realized simultaneously at some locations without conflict*" (AWZ Nordsee-ROV 2017). Aside from the BSH, the first point of contact when planning an offshore project, the following institutions should be informed as well:

- Schleswig-Holstein State Agency for Coastal Protection, National Park and Marine Conservation (LKN.SH)[1], responsible for:
    - for coastal protection on the North Sea and Baltic Sea
    - for flood protection on rivers
    - for nature conservation and sustainable development in the Schleswig-Holstein Wadden Sea and island National Park and Biosphere Reserve
    - for the prevention of hazards caused by shipwrecks
    - for the protection of groundwater, rivers, lakes and coastal waters
    - for the state-owned lakes and the hydrographic measuring service
    - for the storm surge and flood warning service
    - for the operation of state-owned ports
    - for the maintenance of marine ports
    - for sustainable tourism in the national park and world heritage site
- Ministry of Energy, Agriculture, the Environment, Nature and Digitalization[2] and the veterinary inspection office (in case of food production, a monitoring procedure must be established)
- Ministry of Economic Affairs, Transport, Employment, Technology and Tourism[3]
- (Federal Environment Agency)

The European and national laws and regulations, affecting offshore MU activities in Germany are:

- Fisheries law
- Animal protection law
- Food law
- Federal Nature Conservation Act (BNatSchG)
- Water Act of the federal state of Schleswig-Holstein (State Water Act - WasG SH)
- Site Development Plan (FEP)[4]
- Freedoms of the UN Convention on the Law of the Sea
- OSPAR
- Renewable Energy Sources Act (EEG)
- Wind Energy at Sea Act (WindSeeG)
- Energy Industry Act (EnWG)
- Liability regulation

[1] LKN.SH : https://www.schleswig-holstein.de/DE/Landesregierung/LKN/_documents/lkn.html
[2] Ministry of Energy, Agriculture, the Environment, Nature and Digitalization : https://www.schleswig-holstein.de/EN/StateGovernment/V/v_node.html
[3] Ministry of Economic Affairs, Transport, Employment, Technology and Tourism : https://www.schleswig-holstein.de/EN/StateGovernment/VII/vii_node.html
[4] https://www.bsh.de/DE/PUBLIKATIONEN/_Anlagen/Downloads/Offshore/FEP/EN-Flaechenentwicklungsplan2019.pdf?__blob=publicationFile&v=4

- Offshore Installations Ordinance (SeeAnlV)

4.5.2. Insurance

FINO3 of the German Pilot has a liability insurance as well as a hull insurance for all ongoing projects. The liability regulation according to § 17e EnWG[5] protects the offshore wind farm operator from losses due to electricity that cannot be fed into the grid, if disruptions or delays in the required grid connection occur. Furthermore, insurance companies exist, offering tailored solutions to cover offshore and onshore aquaculture farms[6]. The offers mostly focus on fish aquaculture (diseases, pollution, theft, predators, storms or other weather-related events such as freezing or hypothermia "act of god", mechanical failure or electrical failure in onshore operations, change in water quality, including oxygen and salinity levels), while damage to property and equipment including boats, moorings, cages and feed barges may be covered as well. However, additional insurance for the German Pilot is not necessary as no fish aquaculture is planned and the mussel and seaweed designs are covered by the liability and hull insurance of FINO3.

[5] Insurance :https://www.erneuerbare-energien.de/EE/Navigation/DE/Technologien/Windenergie-auf-See/Rechtlicher-Rahmen/Rechtsnormen/rechtsnormen.html#doc153034bodyText5

[6] Aquaculture insurance company AXA : https://axaxl.com/de/insurance/products/aquaculture-insurance

5. BLUEPRINT OF DUTCH PILOT OFFSHORE OPERATION

The Dutch pilot is being performed in an already existing Offshore Test Site that is operated by North Sea Farmers, one of the project partners. In that context many relevant aspects have been addressed a formal regulatory procedure that are already fully in place. All of the below aspects will therefore be explained in that context and refer to the relevant formal procedures as much as possible.

5.1. Social aspects of Pilot: Stakeholder communication

5.1.1. Key stakeholder groups

The Offshore Test Site, in which the Dutch pilot is taking place has already been permitted, the permit is included as Annex B. As part of the permit application process many stakeholders have been approached (Figure 25). Initially by North Sea Farmers to facilitate the permit approval process, at a later stage a formal check by the permit issuing body in The Netherlands, Rijkswaterstaat. Our focus was more the local/regional community whereas Rijkswaterstaat checks all stakeholders formally. These key stakeholder groups (based on D5.1 - summary of SH analysis) involve the following:

- Ship traffic
- Recreational ship traffic
- Parties working in close proximity of our Pilot area
- Users/renters of our Pilot area
- Potential users of our Pilot area
- Municipality of The Hague
- Parties active in the harbour of Scheveningen
- Coast guard
- Ship traffic monitoring company
- Wind farm operators
- Involved ministries
- RWS (governing body of water bodies in NL)

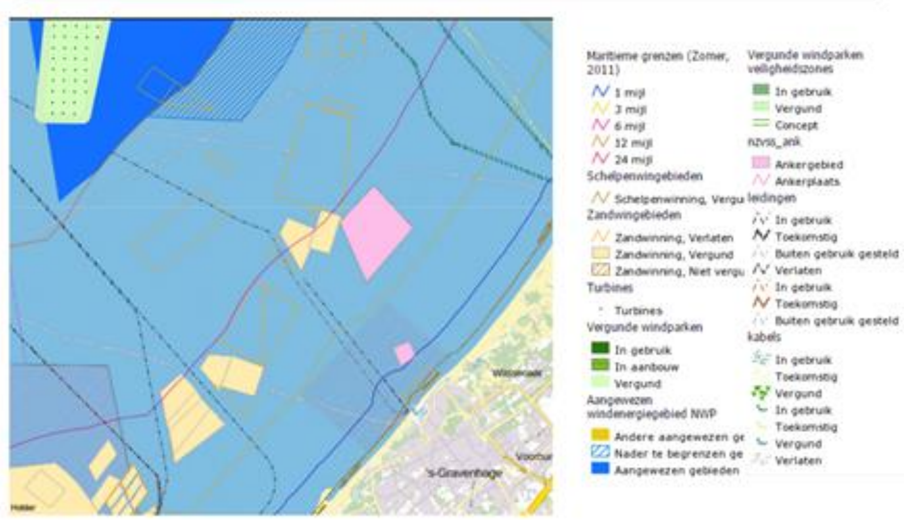


Figure 25: Overview of multiple stakeholders of the Dutch Pilot offshore site

5.1.2. Stakeholder engagement

Stakeholder engagement of the Dutch Pilot based on D9.2.

Stakeholder engagement originally dates back to 2016 when the first version of the Offshore Test Site was conceived.

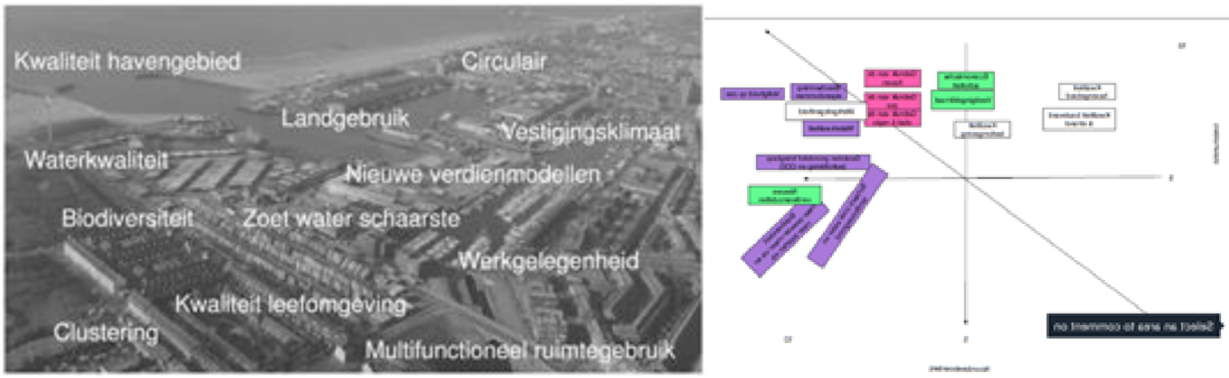


Figure 26: Already back in 2016 stakeholder engagement sessions were performed leading to a final materiality matrix (only in Dutch)

5.2. Environmental aspects of Pilot

5.2.1. Description of Pilot sites

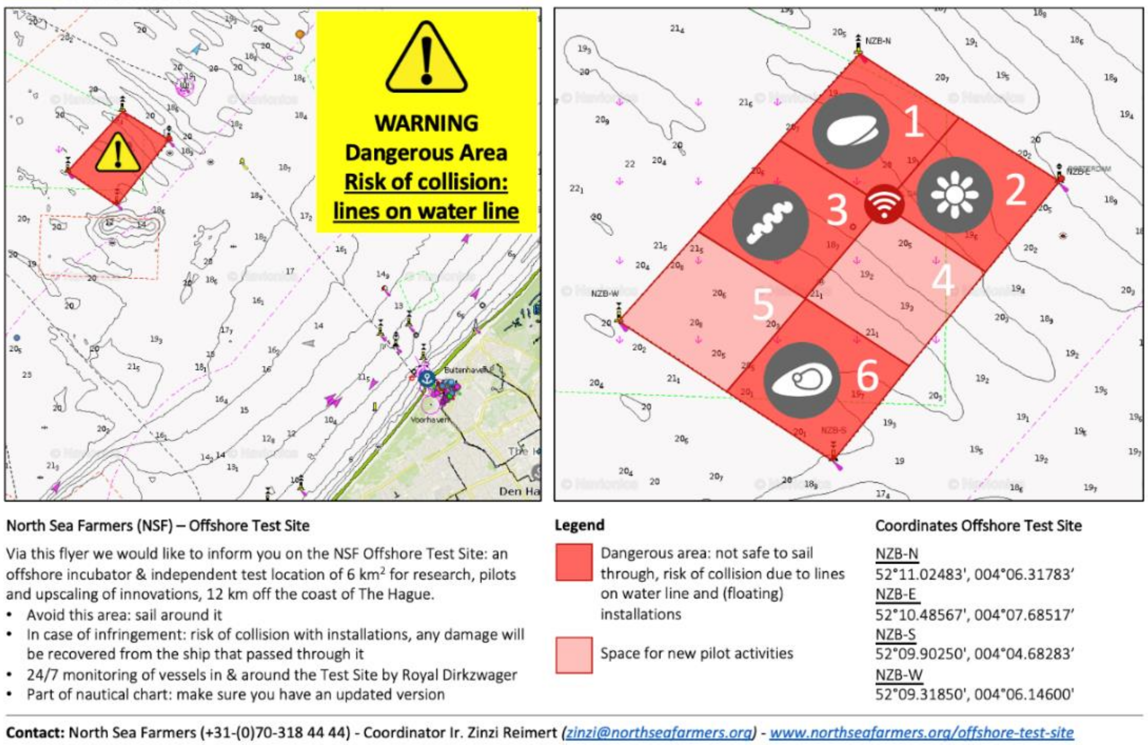


Figure 27: Overview of the Dutch Pilot test site. Plots 2 & 3 include the UNITED Pilots of solar panels and seaweed farm respectively - view is towards north

The Offshore Test Site

The text on the website states: An offshore site of 6km2(3km x 2km) of North Sea with six research plots of 1km² each. It is located 12 kilometres off the coast of Scheveningen, The Hague. This is where members of our North Sea Farmers community meet when testing their innovations in this harsh offshore environment. North Sea Farmers support the pilot projects on the Offshore Test Site with knowledge and experience, local measurement data, logistics, safety and much more. This forms the context for the Dutch pilot where Plots 2 & 3 include the UNITED Pilots of solar panels and seaweed farm respectively. At this site, seaweed is cultivated since 2016. The Pilot site is exposed to offshore conditions with a significant wave height of (Hs) 5m. The salinity ranges between 34 -35 ppt, while the minimum temperature reaches 3 °C and the maximum temperature 18°C. The current follows a NE-SW direction. It has to be mentioned that salinity, temperature and stratification in this region of the Dutch Coast are heavily affected by the freshwater influence. The Dutch Pilot is closely located to the periphery of the mouths of the Maas and Rhine Rivers, causing complex hydrodynamics in this region. Further information on the Offshore Test Site can be found on the North Sea Farmers Website (2021).

5.2.2. Environmental impact assessment

Due to the fact that this Pilot location is intended for smaller scale test projects only, an EIA was not necessary hence was not included as part of the permit application, see Annex B. Furthermore, we adhere to internal standards such as only working with endemic species and preventing/avoiding creating waste for the marine environment as much as possible.

5.3. Technological aspects of Pilot

5.3.1. Current TRL – aimed TRL

The pilot includes facilities in two plots (2&3). They are currently operating on TRL7 for the seaweed Pilot and the solar farm Pilot, i.e. system prototype demonstration in operational environment. Nevertheless, it is important to note that the TRL level of the solar farm is not relevant to this project as the farm itself is not developed as part of United. It's only used to perform relevant enabling research associated with multi-use installations such as solar farms. In addition, the seaweed prototype includes various elements that have a lower TRL6.

Training and capacity building of personnel

In order to reach the highest possible and practicable standard of safety for personnel working at the Dutch pilot the personnel has completed a GWO Training/RIB Handling Training/First Aid Training and will be continuously trained for the whole duration of the project.

5.3.2.Synthesis of pre-testing and re-design (pre-operational phase)

The Dutch Pilot has two main systems that are being tested, the seaweed farm in plot 3 and the solar farm in plot 2.

It's important to realise that pre-testing for the seaweed farm and re-design has happened but not as part of the UNITED project. It builds on design and test efforts already performed in preceding pilots such as under the H2020 IMPAQT project. The same is true for the solar farm. Conceptual design, basin testing, modelling and first offshore tests (and concurrent design improvements) have taken place from 2017 onwards under other (National and European) subsidy projects.

Plot 2 solar farm: The solar farm requirements set is constantly in development towards a viable large scale offshore solar farm. Initially an inshore and near-shore test were performed prior to the UNITED project. That has led to an update of the technical requirements framework and associated solution that were incorporated for the solar farm that was installed in plot2 (also prior to the UNITED project). This solar farm's performance is being validated and will be expanded during the course of the Pilot if the technical solutions show to meet the identified requirements. For the moment the following estimations about the energy production are anticipated, based on a 1kWp photovoltaic panel:

- Photovoltaic Energy production yearly (kWh/kWp): 970 (day avg: 2.66)
- Photovoltaic Energy production by month worst case (kWh/kWp): (Dec) 25.9 (day avg: 0.84)
- PV Energy production by month –best case (kWh/kWp): (May) 127(day avg: 4.10)

All the lessons learnt will be included in the technical requirements set.

Plot 3 – seaweed farm. The seaweed farm has been based on experiences in previous offshore seaweed Pilots, hence a pre-phase for inshore or near shore could not add any value and was skipped. The major insight from previous years is that long-line solutions in whatever configuration will not work offshore. The cost of the mooring is high hence the maximum yield should be pursued for a single mooring. Therefore, the use of nets was selected for UNITED. To ensure that the net-based systems are robust enough for the offshore location they have been modelled and verified via numerical simulations.

In the Dutch Pilot two system setups have been made based on moored spar-buoys with production nets in between. One system is placed in-line with the tidal currents and the other is oriented perpendicular to this current. This should show which orientation has the highest yield, i.e. light availability might differ in both orientations. In addition, load sensors have been placed in order to get a better understanding of the loads in the system since there is still a lack of knowledge in the influence of the seaweed drag in relation to the loads.

During the pre-operational phase lessons learnt from former pilots have been used to develop and improve installation and maintenance procedures as well as to develop a risk register for multi-use operations. Additionally, a detailed activity log with all planned and performed operations, tasks and the involved participants has been processed (Figure 28, Table 7).

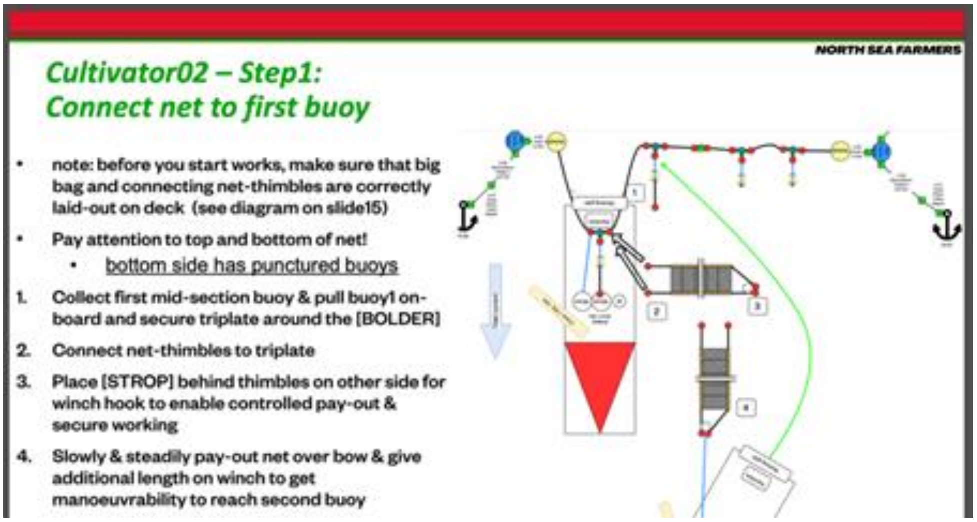


Figure 28: Example of the installation manuel for the seaweed system of the Dutch Pilot

Table 13: Example of the activity log for multi-use operations in the Dutch Pilot

No.	Date	Vessel	Captain	Plots	Activity	Crew NSF	Backup NSF	Crew Users	Toolbox	Remarks
xx	25. January 2021	XX	XX	Plot 2, Plot 3	Inspection seaweed, Inspection solar panels	XX	XX	XX	Yes, checked	Successful
xx	27. November 2021	XX	XX	Plot 2	Replacement 4 main buoys	XX	XX	XX	Yes, checked	Successful

Remote data recording. In order to remotely monitor the ambient conditions around the seaweed plot and the solar panels, the same measurement buoy (AquaTroll) used in the German Pilot, is installed close to the seaweed system, in order to collect hydrological and biological data (temperature, conductivity, chlorophyll-A, turbidity). The measurement buoy is connected via LoRaWAN gateway to a bigger data buoy which was developed during the IMPAQT project. The IMPAQT Buoy transmits the data via cellular network to the shore

5.3.3. Seaweed cultivator numerical analysis

This section summarizes the calculations that have been done by the Maritime Technology Division of Ghent University (MTD UGent) to the seaweed cultivator designed by the Seaweed Company (TSC) for the Dutch Pilot offshore Operation. The mooring configuration of the seaweed longline system is based on the design provided by TSC (see Figure 29, a more detailed description of the numerical approach is included in Annex B). The longline consists of two vertical nets each 50 m long and 3 m wide. The nets have a mesh size of 0.4 m x 0.4 m and are keep afloat vertically by a series of floaters and sinkers. The floaters are connected at the top of the net and the sinkers at the bottom of the net. The nets are connected through a series of dyneema ropes to two large floaters (SPAR buoys) on both ends. The SPAR buoys are connected to 2 fixed points in the numerical model representing a gravity anchor.

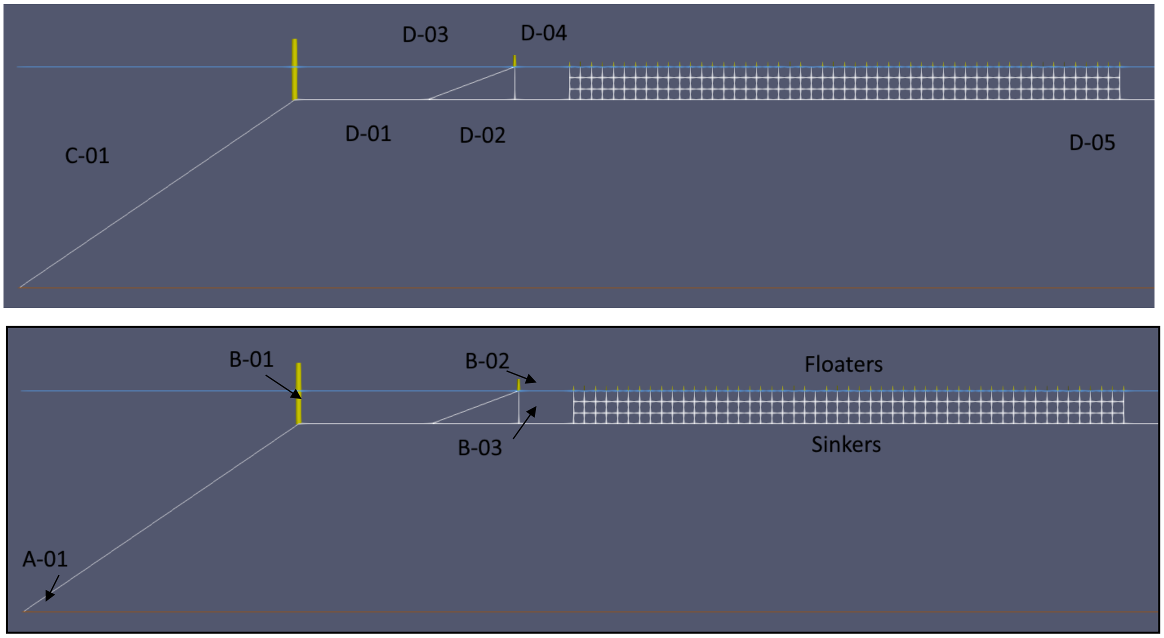


Figure 29: Sketch of the seaweed longline mooring based on the configuration received from TSC as an input for the numerical analysis - the seaweed cultivation system is symmetric around D-05 – Dutch Pilot

The numerical calculations have been performed using the in-house developed mooring dynamic solver MoorDyn-UGent, based on the lumped-mass approach (Hall & Goupee 2015; Pribadi et al., 2019). The hydrodynamic forces on all the elements of the system are modelled according to the Morison Equation (Morison et al., 1950). Figure 30 shows a snapshot of cultivator systems in the numerical model MoorDyn-UGent. The numerical net has been modelled as a combination of cylindrical elements with a mesh size coarser than the real net. The presence of the seaweeds on the net has been modelled by considering the seaweed is behaving as fouling attaching to the net. The projected area, volume and weight of the cylindrical elements have been increased accordingly in the numerical model to simulate the behaviour of a net fouled with seaweed (a more detailed description of the numerical approach is included in Annex B). The load combination used for the simulations are based on a 5-year return period of wave and a 1 -year return period of current.

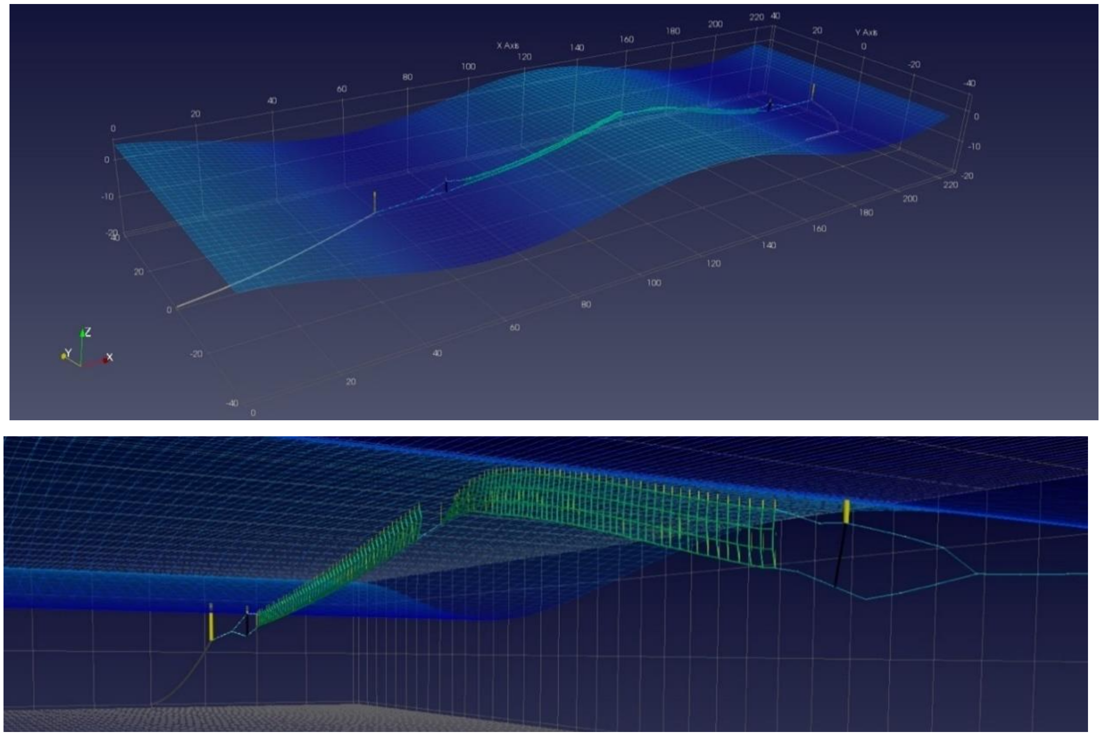


Figure 30: Snapshot of the numerical basin in MoorDyn during a combination of 1-year current and 5-year return period of wave parallel to the longline for the Dutch Pilot

Based on the numerical study performed the following conclusions and recommendations are included for consideration:

- According to a combined safety factor of 2.3, the MBL of the chain should not be less than 555.55 kN. If used chains were to be used, the safety factor is increased to 5.75 and the MBL should not be less than 1388.62 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 28 mm should not be less than 685.93 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 16 mm should not be less than 442.78 kN.
- For a 5-year return period of waves and current, the maximum horizontal load transferred to the anchor is 236.26 kN.
- For a 5-year return period of waves and current, the maximum vertical load transferred to the anchor is 51.30 kN.
- It is expected for a snap load to occur during an extreme waves and current event.
- For a short installation period (3 months of marine growth), fouling does not have a major impact on the structural loads. However, it is suggested by NORSOK-003 (NORSOK STANDARD, 2007) and DNV OS301 (Det Norske Veritas Germanischer Lyold As 2018) to consider a linear increase of marine growth thickness over the course of 2 years to account for the increase in mass and drag area to the system.
- The spar buoys should be able to be submerged at least at a depth of 12 m.

5.4. Economic aspects & financial implications of Pilot

North Sea Farmers have begun to setup a business case for seaweed farms specifically for application in wind farms. However, many of the aspects could also be relevant for any other type of co-use form that is based on floating moored assets (as opposed to founded rigid structures). Main point being that a co-use activity in a wind farm will follow a similar life cycle as the wind farm.

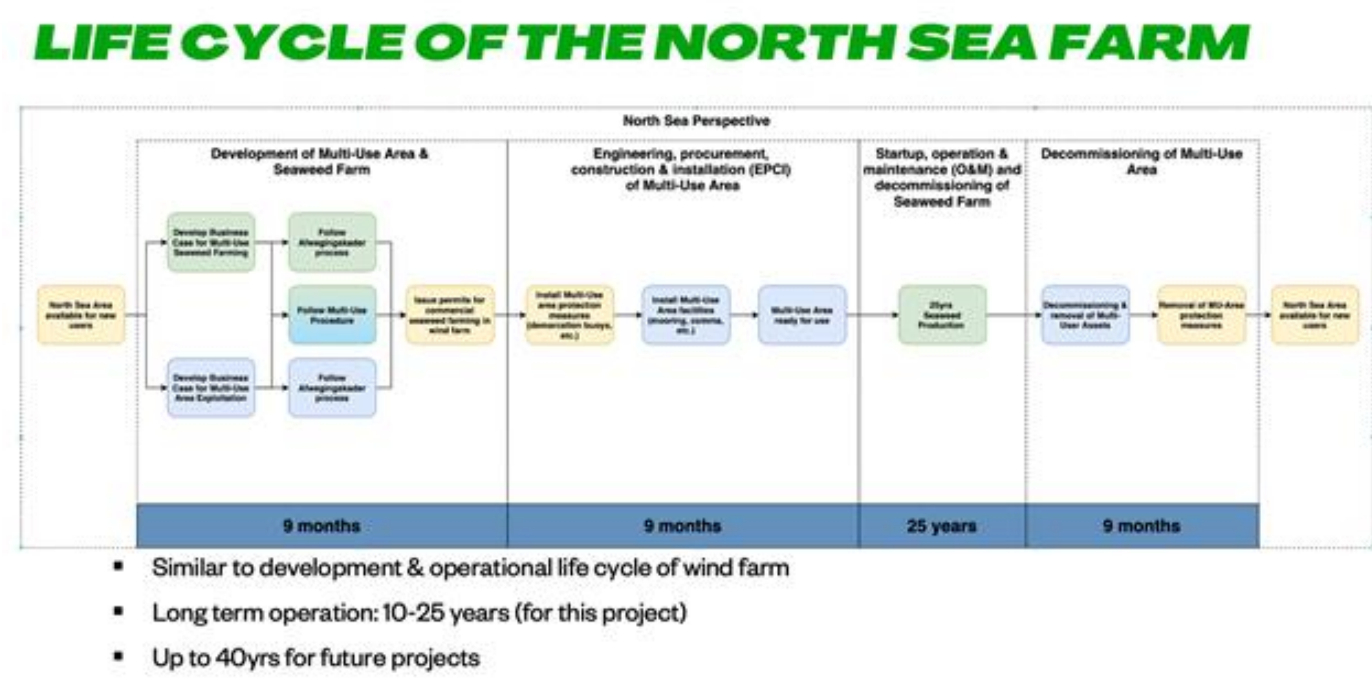


Figure 31: Co-use activities in wind farms will follow a similar life cycle as offshore wind farms

5.4.1. Key performance indicators

The main aspects that should be taken into account is the cost of:

- the cost of the mooring infrastructure,
- the cost of the the production units,
- the cost of the required operational activities
- the expected produce/yield, and
- the selected applications and associated markets

Synergy effects in the Dutch Pilot may be found in combining offshore operations and inspections. This is often possible, especially for inspections but not always. For operational activities this is more difficult due to lack of deck space, time, etc.

5.5. Legal status of Pilot

5.5.1. Applicable Regulations & Restrictions

First of all, reference is made to the permit requirements as applicable for the Offshore Test Sites, see Annex B. This stipulates all requirements that any pilot should adhere to in case of activities on the Offshore Test Site. In addition, relevant policies have been put in place by the Dutch government that enable co-use in offshore wind farms. For the co-location aspect of such co-use activities, the government has setup a specific portal that will help co-users to apply for the required permit, see also the Noordzeeloket-website. Part of this process is to select the most appropriate co-use location in the wind farm and to support this, the Dutch government has setup the system of area passports ("gebiedspaspoorte") to indicate what type of co-use could go where (Figure 32).

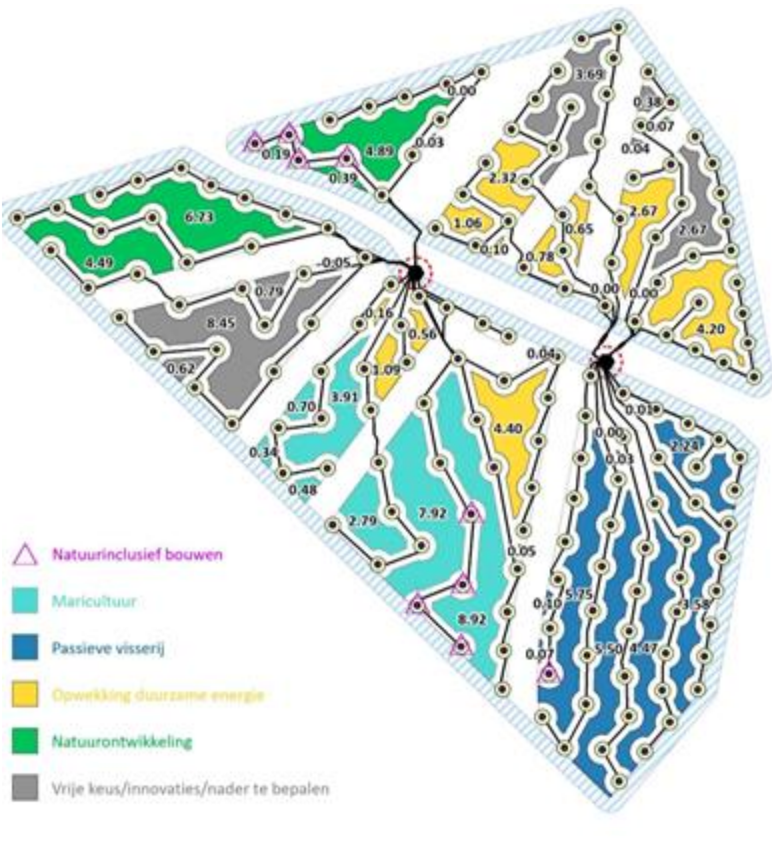


Figure 32: "Gebiedspaspoort" (area passport) for the wind farm Borssele as issued by the Dutch government

North Sea Farmers have also setup a so-called Multi-Use Procedure. This procedure is aimed at supporting any co-use initiative to come to an alignment agreement with wind farm operators. This alignment agreement can then be used as part of the above-mentioned permit application process.

5.5.2. Insurance

Each pilot on each plot, seaweed farm and solar farm, is required to have their own third party liability insurance. This is mandatory for any pilot on the Offshore Test Site. The main purpose of such an insurance is to ensure that affected parties' damage can be financially compensated. This includes other parties that are active on the Offshore Test Site as well as any third parties. Both Oceans of Energy and The Seaweed Company as well as North Sea Farmers have such an insurance. North Sea Farmers have a copy of each Party's insurance policy.

In addition, parties could decide to insurance against damage without any third party involved. However, many do not do so as these systems mainly involve smaller prototypes that will be discarded after the pilot period. It will however become more important when pilots are becoming larger and more costly to include suitable asset insurance as well. Determining the value of the larger pilots may well be an aspect to be investigated further.

Finally, there's a strong recommendation to look into a specific government backed fund/system that would indemnify a co-user in case of natural or man-made disasters as is common in land-based agriculture. This is much more relevant for offshore co-use activities as, for instance a drifting tanker or once in 100yr storm would not only damage the crop of one season but most likely also the entire farm area and infrastructure. This kind of damage would be very complicated to insure and possibly lead to the bankruptcy of the co-use operators involved. Therefore, it is highly recommended to identify suitable land-based solutions that could be employed for this "under-insurance" as well.

6. BLUEPRINT OF BELGIAN PILOT OFFSHORE OPERATION

6.1. Social aspects of Pilot: Stakeholder communication

6.1.1. Key stakeholder groups

For background information on key stakeholder groups and stakeholder communication, please see D5.1 and D9.2. Furthermore, the chapter on stakeholder communication for the German Pilot in the current document is also relevant for the Belgian Pilot, at least for the general characteristics of stakeholder communication.

The internal stakeholders of the Belgian Pilot are directly involved in the Belgian Pilot and/or in the UNITED consortium as partners. These include scientific institutes (Ghent University, RBINS), businesses (Colruyt, Brevisco) and the offshore industry (Parkwind, Jan De Nul). Also, subcontractors can be categorised as internal stakeholders, such as Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) supplying oysters and supporting in the pre-operational nearshore phase, the insurance broker Marsh, and companies supporting the offshore installations and operations, such as GeoXYZ, and Fielder Marine Services.

External stakeholders are not directly involved in the activities of the Belgian Pilot, but are potential users of the outcomes of the project. These include environmental NGOs such as WWF and Natuurpunt, (licensing) authorities such as MUMM, governmental bodies such as the Ministry of the North Sea and DG Environment, business groups such as the Ship Owners for Fisheries (Rederscentrale ter Zeevisserij), Blue Cluster and Belgian Offshore Platform, and scientific institutes such as Flanders Marine Institute and EMBRC Belgium.

6.2. Environmental aspects of Pilot

6.2.1. Description of Pilot sites

The Pilot is situated in the Belgian part of the North Sea (BPNS), more specifically in the offshore wind farm of Belwind, operated by Parkwind (Figure 33).

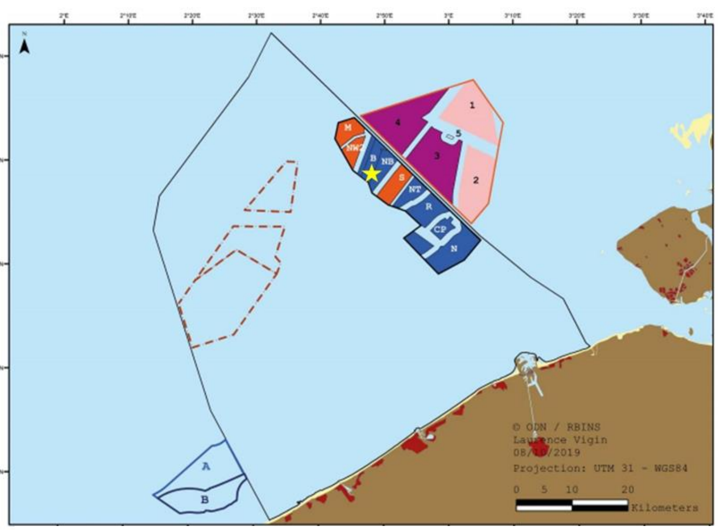


Figure 33: Belgian part of the North Sea with realised and planned offshore wind farm concessions - The approximate position of the Pilot site (at the offshore wind farm of Belwind, operated by Parkwind) is indicated by the yellow star - Figure taken from the WinMon

The BPNS is characterised by a system of submerged sandbanks and gullies, which are predominantly formed and sustained by the tidal currents. The offshore wind farm area is situated at the eastern border of the BPNS, and includes three sand banks (Bligh Bank, Lodewijkbank and Thortonbank) and the adjacent gullies.

- Environmental Parameters - hydrodynamics : Seabed

Belwind, operated by Parkwind, is located at the Bligh Bank (and surrounding gullies). The seabed has a depth between 15 and 37 m. The Bligh Bank is part of a system of tidal banks and belongs to the Hinderbanks. Both banks and gullies are characterised by the presence of mobile sand dunes. Bligh Bank has a steep eastern side and a more gentle-sloping western side. Sand is the pre-dominant sediment, with a grain size of 300-350 µm and a maximum of only 1 % clay. The gully may contain coarser gravel-sands.

Mean (surface) current velocity at Bligh Bank is 0.55-0.57 m/s, and while in the deeper gullies the mean current velocity is lower, maximum current velocity (up to 1.09 m/s) is higher in the gullies than at the sandbanks. In general, current velocity ranges between 0.25-0.95 m/s. Significant wave height is 5.8m, wave peak period: 10.6s, wave direction: 330deg (coming-from), maximum single wave height: 11.2m. The current magnitude is 1.0 m/s (depth-averaged) and the associated direction: 60deg (going-to).

Seawater

In the BPNS, including the Pilot site, mean seawater temperature is 11 °C, which can increase up to 19 °C in summer and decrease down to 0.05°C in winter. Salinity of the seawater ranges between 31 and 35 ppt. Suspended particulate matter content in the offshore BPNS, including the Pilot site, is low, around 4 mg/L.

Atmosphere and climate

Belgium has a temperate oceanic climate. The coldest month has a mean temperature of 3 °C, while the hottest month a mean temperature of 16.9°C. Mean rainfall ranges between 50 and 80 mm/month. At sea, the dominant wind direction is west-south-west, with a mean speed of 9.6 m/s. No relevant statistics on atmosphere (air quality related to pollution) are available for the BPNS, as no measuring station is present at sea, only land-based stations. However, it can be assumed that the air quality at sea is satisfactory at least.

6.2.2. Revised EIA consideration

The epifouling on the wind turbines consisting of mainly *Jassa* and *Mytilus* influences the surrounding sediments by the production of (pseudo-)faeces and the detachment of mussel clumps. Adding aquaculture installations may have the same effect and thus further influences the sediment. One effect is that the sediments can become anoxic on the longer term. This is however a process that will only be apparent on longer timeframes, much longer than the duration of the Pilot. One way to account for this, is to monitor the loss of oysters from the installations, which gives an indication on the accumulation of shells on the seafloor.

The aquaculture structures and individuals can attract non-indigenous species and screening of the fouling community is thus recommended.

Seabirds and marine mammals might be attracted to the aquaculture installation. Ad hoc monitoring by maintenance and scientific crew when operating in the Pilot area is advisable. Special attention should be given to bird and mammal individuals that get entangled in the lines and other structures of the aquaculture installation. When encountering victims, these should be collected and brought to shore to be examined by MUMM or other specialists. The probability of entanglement of sea mammals (especially harbour porpoise) in the seaweed nets is considered very low. These nets have a high acoustic reflectance and are thus easily detected by small cetaceans (Haelters *et al.,* 2020). Optionally, the acoustic reflectance of the nets can be increased to even lower the risk of entanglement. The use of acoustic deterrents such as 'pingers' is thus not recommended, on the contrary, these devices can contribute to an increase in noise pollution in the area.

6.3. Technological aspects of Pilot

6.3.1. Current TRL – aimed TRL

Baseline TRL of the Belgian Pilot

The TRL 5-6 of the Belgian Pilot follows the line of reasoning of the German Pilot and thus, also applies the general definition of the Horizon2020 program Nyserda 2018) *"Technology validated and demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)".* The cultivation and restoration of flat oysters and the cultivation of seaweed are currently being tested in the pre-operational phase at the near shore site of Westdiep, 5km off the coast of Nieuwpoort. The results of these tests are used for the design and adaptation of the planned aquaculture system in the operational phase offshore at the Belwind site, about 35 km off the coast of Ostend. According to the procedure of the German Pilot the technical components for the aquaculture system will be bought off the shelf and combined and adjusted for the environment at the final location. The installation will be in cooperation with a specialised company that has been installing these anchors and longlines in different locations worldwide, also for commercial purposes.

Up scaling to TRL 7 in the Belgian Pilot

As described in the German Pilot TRL assessment, the Belgian Pilot perceives the general definition of the Horizon2020 program (Nyserda 2018) as relevant: "System prototype demonstration in operational environment" to reach TRL7 as well as the according description of the USDOE (2009).

During the development of the Belgian Pilot towards TRL7, technical and other essential determining aspects for a successful up-scaling will be addressed during the operational phase of UNITED. More details can be found in former Deliverable 3.2, Chapter 5. To evaluate further the potential for commercialization and to go to TRL8 or 9, a business case and life-cycle analysis will be drafted by Belgian UNITED-partner Colruyt Group.

6.3.2. Synthesis of pre-testing and re-design (pre-operational phase)

Anchors, backbone material, and buoys for oyster aquaculture and seaweed cultivation near shore

The results of pre-operational tests at near-shore site consist of a summary about longlines, connectors, moorings , harvesting equipment, units appropriate for the attachment of seaweed rhizoids as well as the various types of ropes to be tested as substrate for seed and for the oyster structures.

The near shore longline had been installed for another project in the Westdiep area and was made available for the Belgian pilot within the UNITED project. The seaweed nets were attached to the longline using Velcro® connections. Depending on the time period, weight hung at the line and the species (oysters versus seaweed), 120L yellow buoys were attached, approximately one every 20m. The buoys were attached to the line applying 20mm binding rope.

Spat collection in the pre-operational phase: design and results

Four inox frames, containing spat collection substrates, were deployed in Westdiep, Nieuwpoort, Belgium during the summer of 2020. The spat collection frames were constructed by Brevisco (Ostend, Belgium). The spat collection frames were designed by UGent-ARC (Ghent, Belgium) and Brevisco (Ostend, Belgium) and constructed by Brevisco.

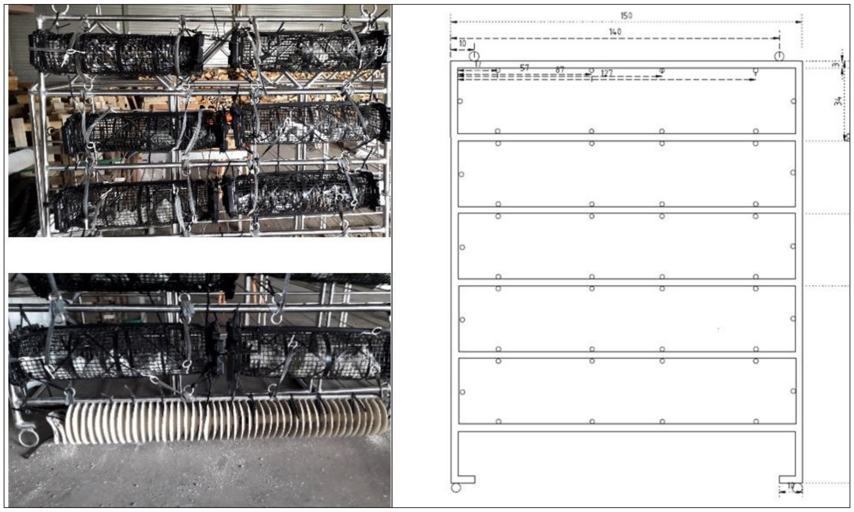


Figure 34: Inox frame preparation for spat collection - Top Left: Frame with SEAPA-baskets (600 basket Mesh, 15L Tube: 12mm) - Bottom Left: Limed Chinese hats - Right: technical drawing of one frame design

One spat collection frame holds ten SEAPA 600 Basket (15L, 12mm mesh, Edwardstown, South-Australia) with premium end caps, and one series of limed non-perforated coupelles on a rod for oyster seed collection, as shown in Figure 34. The SEAPA baskets contained mussel shells (full basket, origin: NL); granite, 0-200mm (1/4 basket, origin: NO); granite 25-125mm (1/4 basket, origin: NO); limestone 90-180mm (1/4 basket, origin: BE) and limed granite 25-125mm (1/4 basket, origin: NO). Depending on its content, each basket was labelled individually via a predetermined code using a combination of tie-wraps. The oyster baskets with substrate were at random and in duplicate attached to the frames, using cable ties and rubber bands with hooks (INTERMAS). Where applicable, granite was coated with a liquid mixture of 1 volume of cement (type 52.5) with 2 volumes of lime-powder (traditional lime). Where applicable, granite was coated with a liquid mixture of 1 volume of cement (type 52.5), 2 volumes of lime-powder Alpha 63 (Lhoist Group, Limelette, Belgium), and natural sea water. Coupelles were coated with Batidol® lime (1.2 lime: 1 sea water; v/v; Lhoist Group).

Frames were mounted one by one to an aquaculture longline with an interval of about 2 weeks. The first frame was deployed end of June 2020 while the last one was set-out at sea by 6th of August 2020 to determine the best period for spat collection in 2020. Frames and individual baskets were labelled. Frames were deployed on longline O1 which stretches between buoy A15 (51°10'875 – 002°39'735) and A16 (51°10'925 – 002°39'864). Frames were hung between two large surface buoys and depth of the frames was therefore -1m.

After having taken samples for biofouling, remaining fouling was removed using high pressure cleaning with natural seawater. The cleaned baskets with substrates were stored in large seawater tanks (5000L) at the Marine Station Ostend (VLIZ, Ostend, Belgium) at a temperature of 14°C over a period of maximum 5 days (Light:dark cycle: 12:12). The water parameters pH, temp, salinity, oxygen, and conductivity were monitored continuously, while ammonia, nitrate, and nitrite were checked daily. A protein skimmer was connected to the system to avoid water quality deterioration upon possible mortality of the oysters and/or remaining fouling organism within the baskets and on the substrates in the baskets.

Robustness and handling of the aquaculture frames

All frames were retrieved on 5 November 2020. The remaining baskets and coupelles were disconnected from the frames. The content of the baskets was analysed between the 5th of November and the 10th of November. The results indicate that the inox frame design could be suited for the scientific goals set-up in the near shore phase. However, a considerable loss of baskets (7 out of 40) was witnessed, hence the way the baskets were tied to the frames might not have been ideal. Some of the remaining baskets were also seen detaching from the frames. The frame did offer for the baskets to hang immobile into a supporting system, which for rough conditions at sea offers good perspective for European flat oyster settlement and growth. The frames were very well-designed and survived the time at sea well. However, for longer periods at sea, addition of a zinc-block to prevent rusting, especially of the smaller bars, might be required. The preparation of the inox frame is also too time-consuming for scaling-up purposes. For the latter reason, this system will be abandoned for offshore applications in the operational phase and instead, more practically feasible solutions for large scale aquaculture farming will be considered.

As for the coupelles: out of four rods with coupelles that were set-out, only one rod was recovered from the sea. The remaining coupelles detached from the frames. The tie wraps were still present, indicating the coupelles must have broken somewhere in the middle of the rods due to frictions caused by high forces at sea. From the one rod with coupelles retrieved, the lime had disappeared, and the coupelles were fully overgrown by biofouling (Figure 37, see further). As due to the intense preparations of the Chinese hats followed by the disappointing results, Chinese hats as prepared in the pre-operational phase will not be applied during the operational phase in offshore conditions.

Results on settlement of European flat oyster larvae on substrates in the aquaculture baskets (submerged few meters below water surface)

The settlement of European flat oysters was seen, although from all settled oysters (in total 3507 counted) retrieved, only 81 of them were macroscopically identified as European flat oysters. *O. edulis* settlement only depends on substrate, with mussels significantly supporting better spat settlement compared to other substrates ($p < 0.05$). Timing of deployment is found not to be significantly different. *C. gigas* settlement depends on both substrate and deployment time, with mussels significantly supporting better spat settlement compared to other substrates ($p < 0.05$). Timing of deployment is found to be significant, with more spat counted on substrates deployed towards the end of July ($p < 0.05$).

As for the settlement on the coupelles; only one settled Japanese oyster was counted. Settlement was probably hindered by the large biofouling that was retrieved on the coupelles.

The nature-inclusive scour protection for the promotion of flat oyster reef restoration

Two galvanized stainless-steel tables (Figure 35, design and production by JDN, Aalst, Belgium) further addressed as "restoration tables" were deployed on the seabed in the Westdiep area. The restoration tables consisted of a metal supporting structure and a one-by-one meter grid container that is subdivided into 16 20x20x20 cm divisions. The four types of scouring protection stones as described higher (limestone, two sizes of granite and limed granite) were placed in the divisions in quadruplicate. The first restoration table was deployed end of June, the second one mid-July. The latter contained adult oysters while the former did not, this to check the effect of addition of adult oysters on the settlement of oysters. For the substrates in the tables, the best settlement is seen in the restoration table where adult oysters are stocked.

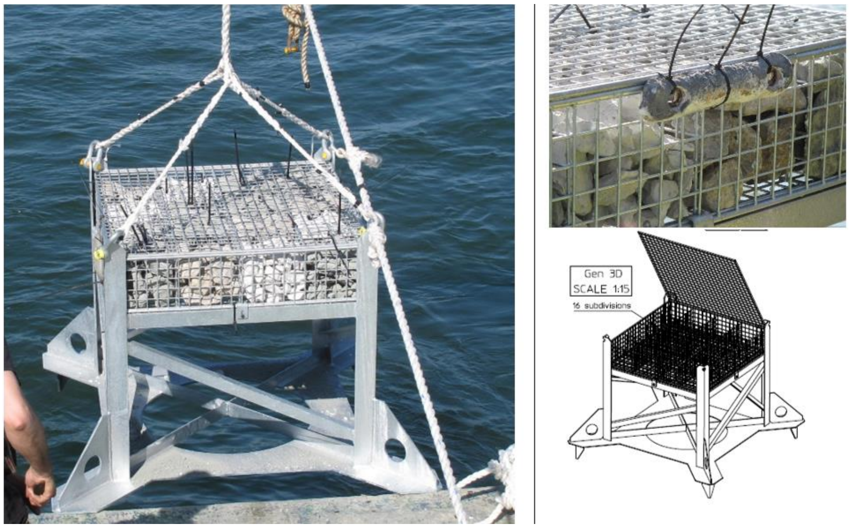


Figure 35: Left: Restoration table (design and production by JDN) filled with four different substrates (two sizes granite, limed granite, and limestone) in quadruplicate to identify best settling materials – Top Right: Detail of substrates and zinc block – Bottom Right: 3D view of the experimental tables placed at the seabed

<u>*Results on settlement of European flat oyster larvae on substrates in the restoration tables (bottom BPNS)*</u>

The two restoration tables were also retrieved on 5 November 2020. The content of the tables was analysed immediately and the two tables were put back at sea the following day to allow further grow-out of settled oysters. Both pacific oysters (*Crassostrea gigas*) and flat oysters (*Ostrea edulis*) were counted. Flat oysters were measured. Flat oysters were distinguished from pacific oysters by colour, shell marks, growth characteristics and if possible, to see by identification of the chomata (characteristic for the European flat oyster) visible bilaterally from the umbo. Although European flat oysters were retrieved, Japanese oysters were seen as the dominant species that had settled. For *O. edulis*, no significant differences ($p > 0.05$) between spat collected on different substrates or between the two tables was found. For *C. gigas*, no significant difference is observed for the number of spat detected on different stone types ($p > 0.05$). A significant difference is however seen between restoration table 1 and 2, in that the substrates from table two (adult oysters supplemented and installed 2 weeks later compared to table 1) contain considerably more *C. gigas* spat ($p < 0.05$).

<u>*Results on robustness and handling of the scour protection materials and restoration tables*</u>

Scour protections have an essential mechanical function of robustness within wind farms. They are added on the base of monopiles to avoid the creation of a pit (also called scour) around monopiles so the monopile stays stable and deterioration of the structure can be hampered. The materials used in the restoration tables (and aquaculture baskets) in the nearshore phase had different gradings, and some were treated with a lime coating. The lime from the limed stones remained on the stones where applied and the stones proved to provide a platform for oyster larvae settlement, as described higher.

As for the table design and use, the following conclusions were drawn:

- Stones stuck together due to fouling and oysters grown between them, this way complicating their removal. The latter however was interesting from a restoration reef building perspective
- Deployment of the tables at the sea bottom was very easy due to practical design of the tables. The four corners had loops through which shackles and ropes could be easily connected to the on-board winch system hence facilitating easy deployment and removal of the tables.
- Tables proved to possess the stability required to withstand the hydraulic load of wave action and currents. Tables stayed upright and did not sink into the sand, which was crucial in order to evaluate their potential for restoration. This as sand would smother the oysters and would not allow oyster growth.

- Exact location determination for retrieval seemed tricky, partly due to poor visibility during the dive. Hence tables need good location marking (e.g., via buoy). Once the exact location was determined, the divers could easily reconnect the shackles and ropes and the tables were very easily lifted from the water
- Variable attractiveness of limed granite (Table 1 good versus Table 2 least)
- Granite (especially size category 0-200 mm) has good settlement, even better than limestone
-

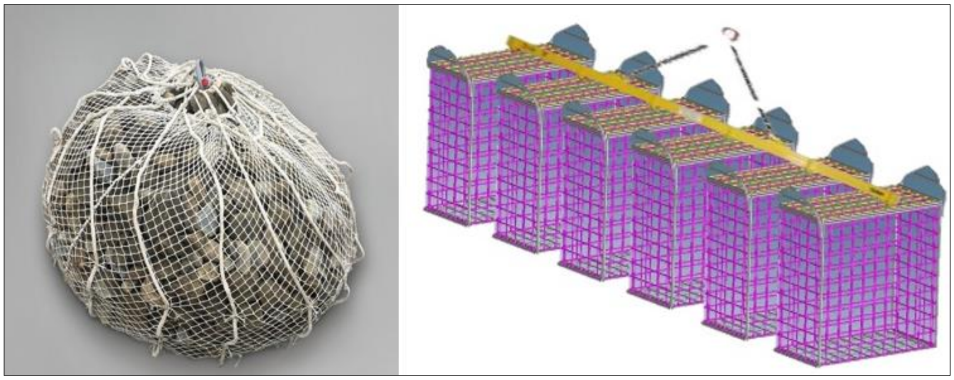


Figure 36: Left: Example of basalt bag. Right: Sketch of gabions

For offshore deployment, several gabions (estimated 1 m^3) will be filled with stones that can be/are used as scour protection for wind turbines. They will be installed on the existing scour protection around two pillars. The setup will include 6 gabions supported by one structure (facilitation of installation) in SW-NE axis and another of those structures on SE-NW axis on each of both pillars. At one pillar, adult oysters will be included to estimate success of self-recruitment. Furthermore, the installation of basalt bags (Figure 36) is being investigated and could be installed at that same turbines in the vicinity of the gabion systems.

Biofouling tests

Fouling was inspected visually during a dive end of July in which one frame and two restoration tables were filmed (Figure 37). Clearly, fouling was present hence in case the frames and baskets therein would be used for aquaculture purposes, the baskets would require frequent cleaning. During the summer months this would be every two weeks.

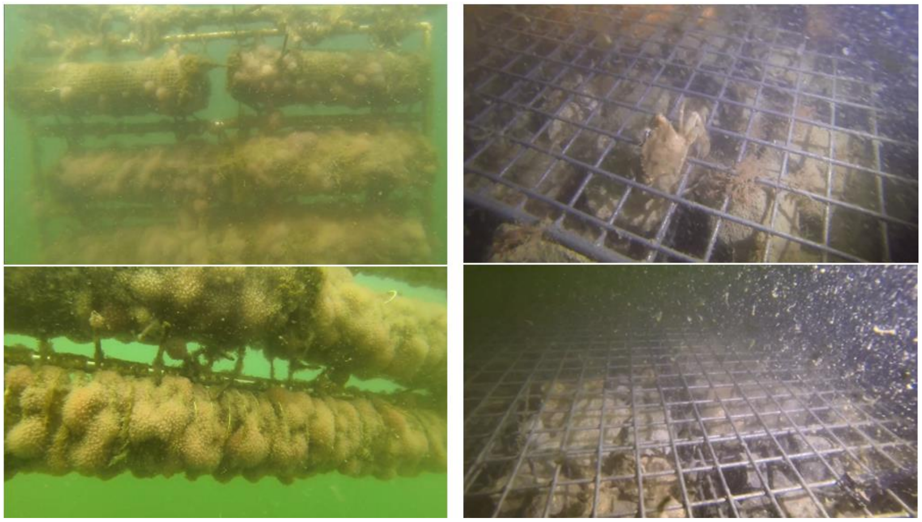


Figure 37: Top Left: Biofouling on one of the frames – Bottom Left: The coupelles – Top Right: One of the two restoration tables (table deployed end of June) Bottom Right: Table installed mid-July

Fouling samples for biodiversity research of both the spat collection frames and the substrates in the restoration tables were taken by RBINS on the 5th of November 2020. The conclusions of both the video images taken end of July and the results from the sampling campaign of November 2020 indicate no surprises for the Belgian part of the North Sea: common early colonisers have settled in high numbers. The dominating species are the following:

- *Tubularia larynx*: massively (video images)
- *Jassa herdmani*: produces a lot of biomass
- *Jassa marmorata:* produces a lot of biomass
- *Caprella equilibra*
- Spirobranchus (*Pomatoceros*) *triqueter*: abundantly on substrates of restoration table
- Barnacles (*Balanus perforatus, Elminius modestus*): abundantly on substrates of restoration table

Seaweed in the pre-operational phase: set-up and first results

In the preoperational phase, six commercial seaweed nets from AtSeaNova (Ronse, Belgium) were seeded with two different strains of sugar kelp (*Saccharina latissima*), originating from the Netherlands and northern France. The initial isolation of the different seaweed strains was severely impacted by COVID restrictions and therefore, the final experimental design ended up differently from what was planned initially. In November 2020, six nets were installed, four of them seeded with the strain originating from the Netherlands and two with the strain isolated from northern France. Furthermore, two different seeding techniques were tested: seeding of gametophytes including a hatchery period of 4 weeks and direct seeding of a mixture of gametophytes and sporophytes applying a glue (AtSeaNova, Ronse, Belgium) just before deployment. Each net was half pre-seeded and kept in the nursery and the other half of the net was directly seeded before installation. Two different types of nets were installed: a near shore net (larger mesh size) and an offshore type (smaller mesh size, stronger) (Figure 38 and Figure 39).

Robustness and handling: The tested nearshore net type was not strong enough to withstand the exposed conditions. The offshore net, in comparison, was robust enough but the smaller mesh size resulted in the net being heavier and

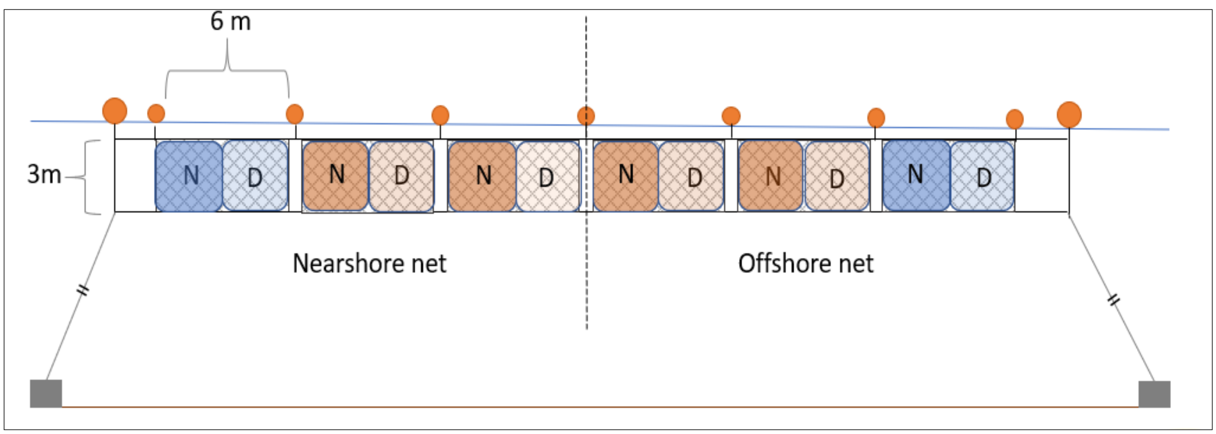


Figure 38: Simplified experimental design of the preoperational seaweed net system deployed near shore - Two nets were seeded with a strain of Saccharina latissima (blue shading) originating from France and four nets were seeded with the strain originating from the Netherlands - Each net was half seeded with gametophytes and kept in the nursery (N), while the other half of each net was directly seeded (D) just before installation at sea

therefore more difficult to handle. Therefore, an adjusted offshore net will be tested in the coming growth season.

Figure 39: Seaweed nets as deployed in November 2020 - Top: Offshore net just before deployment - Bottom Left: Offshore net - Bottom Right: Near shore net

6.3.3. Training and capacity building of personnel (offshore sea survival)

Everyone who does not belong to the vessel crew needs the following certificates that allow the entering of the wind park:

- Basic safety training STCW A_VI/I
- Health certificate after clinical examination from a physician

Safety regulations regarding equipment:

In line with internal procedures of the OWF concession holder, amongst which induction trainings, emergency procedures, good – communication, and training of the crew. Minimum PPE requirements during the execution of the works on deck shall be:

- Safety helmet
- Safety footwear
- Safety glasses
- High visibility clothing

Task-specific PPE requirements shall be:

- Life jacket
- Safety harness
- Hearing protection

When working on the aft deck (zone between accommodation and stern), a life jacket must be worn. Risk assessments will be made for each specific operation offshore and be attached to the method statement.

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

6.3.4. Offshore longline design simulation for seaweed and oysters

a) Oyster longline numerical analysis

The oyster longline system will be installed within the wind turbine park, specifically inside the concession area of Belwind. At this location, the water depth is at -30.1 metre (MLLWS). The longline consists of 57 metres main cultivation line and additional 62 metres of backbone for the purpose of lifting operation during maintenance and installation. The distance between South-West (SW) anchor and North-East (NE) anchor is 250 metres. Figure 40 shows the schematic drawing of the mooring configuration. The impact of marine growth over the course of 21 months has been assessed in this study. Mooring system starts with excess buoyancy during initial installation. If the thickness of marine growth is growing linearly over 50 mm per year (Det Norske Veritas Germanischer Lyold As, 2018; NORSOK STANDARD, 2007), then surface floaters need to be replaced/added between month 9 and month 12 after the installation. Therefore, all surface floaters have to be foam-filled to withstand submergence up to 15 m depth.

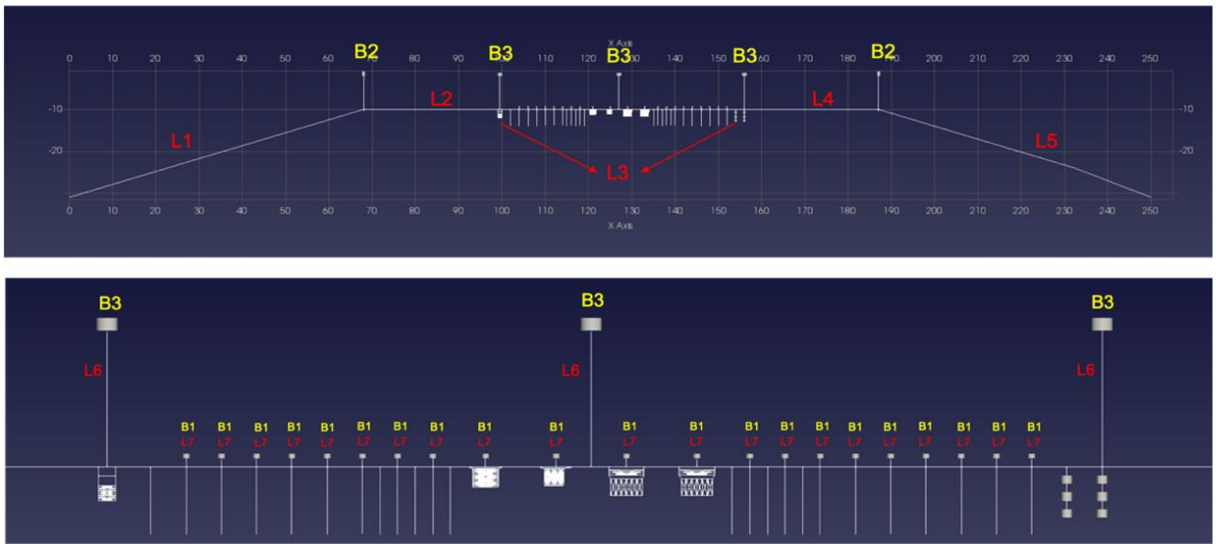


Figure 40: Mooring line configuration of the oyster longline system – Belgian Pilot

Dynamic analysis of mooring setup for the oyster longline is performed by utilizing a lumped-mass based mooring dynamic solver (Hall & Goupee 2015; Pribadi et al., 2019). Hydrodynamic forces are modelled using the Morison Equation (Morison et al., 1950). Consequently, the Morison coefficients used are taken from DNV (Det Norske Veritas Germanischer Lyold As 2018; DNV 2010). The Norwegian Standard NS9415 (Norwegian Standard 2010) defined the ultimate limit state (ULS) as a combination of:

- 50-year return period of wave and 10-year return period of current
- 10-year return period of wave and 50-year return period of current

Summarised in the following table are the load combinations used for the numerical simulations:

Table 14: Summary of the load combinations used in the oyster longline numerical simulations – Belgian Pilot

Simulation number	Regular wave			Depth-averaged current	
	height	period	direction	speed	direction
[-]	[m]	[s]	[going-to]	[m/s]	[going-to]
1	11.6	9.0	North-East	1.4	North-East
2	11.6	9.0	North-East	1.4	North-West
3	8.6	6.57	North-East	1.0	North-East

For the calculation of ultimate limit state (ULS) condition, the 50-year return period of waves and current are used as the input of the simulation, as it is shown in load case simulation number 1. This results in maximum mooring line tension of 125 kN. Taking a combined safety factor of 3.45 (Norwegian Standard, 2010), the breaking strength of mooring and backbone rope should not be less than 431 kN. As for the anchor, with the safety factor 1.3 (DNV GL 2015), the axial capacity of the screw anchor should not be less than 163 kN. Lastly, pretension of 10 kN needs to be applied during the installation when connecting the backbone L2 to the start of main cultivation line L3. As the position of the anchor will have certain deviations, the length of L2 can be adjusted accordingly to achieve the 10 kN of pretension. The extensive report of this numerical analysis can be found in the Annex C.

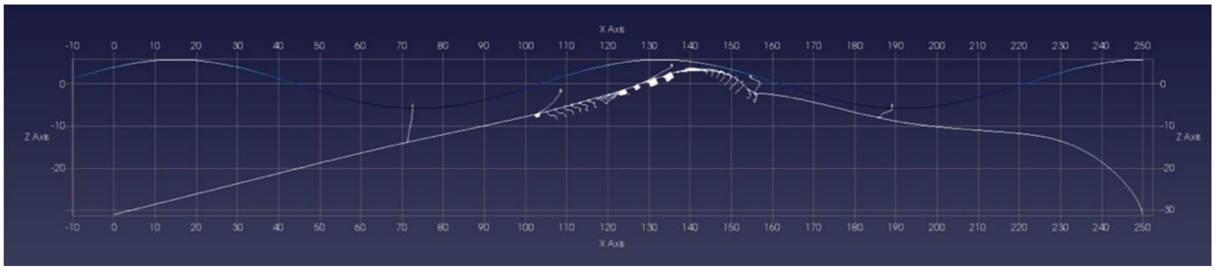


Figure 41: Snapshot of the oyster longline numerical model subjected to parallel waves and current of 50-year return period – Belgian Pilot

Table 15: Summary forces of the oyster longline numerical simulations – Belgian Pilot

Return period of waves and current	Force in x-axis				Force in z-axis			
	SW anchor		NE anchor		SW anchor		NE anchor	
	min	max	min	max	min	max	min	max
[-]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
50-year	1.5	121.4	-9.6	0.2	0.6	29.4	0	6.6
1-year	1.5	68.2	-9.7	0	0.6	20	0	7.8

Seaweed longline numerical analysis

Requirements of the seaweed cultivation system are set by Research Group Phycology, Department of Biology, Ghent University. Figure 42 shows the mooring arrangement of the seaweed longline system. The mooring system consists of eleven floaters supporting 66.5 metres of longline. Seaweed will be grown on eight net structures; each has a dimension of 6 metre x 3 metre. The distance between South-West anchor and North-East anchor is 230 metres.

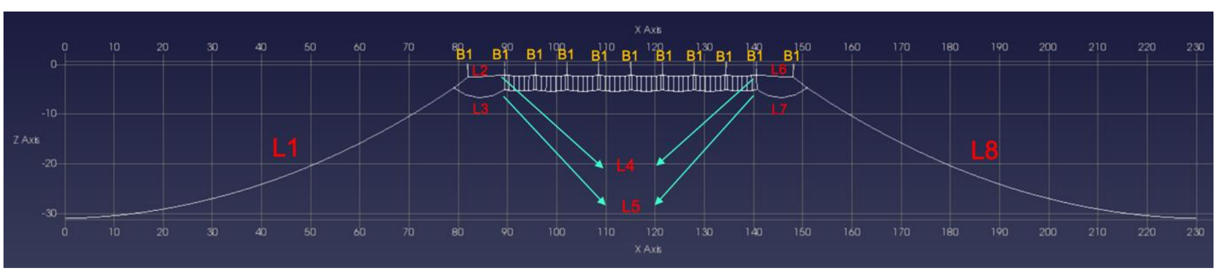


Figure 42: Mooring line configuration of the seaweed longline system – Belgian Pilot

The length of each mooring line is 88 metres, which is connected to the net structures with two lines: 7.5 metres of rope at the top and 11 metres of rope at the bottom. A chain with a dry mass of 3 kg/m is used to provide additional weight with equal distribution underneath the net structures. An in-house lumped-mass based mooring dynamic solver (Hall & Goupee 2015; Pribadi et al., 2019) is utilised to perform the numerical simulations. The physical nets are modelled as an array of numerical cylinders, keeping the buoyancy and weight the same in both cases. Seaweeds are modelled as marine growth on net structures, calculated according to the method described in DNV OS301 (Det Norske Veritas Germanischer Lyold As 2018). Hydrostatic calculations are performed for two conditions:

- Mooring system with only net structures and no presence of seaweeds nor marine growth
- Mooring system with fully grown seaweeds and 6 months of marine growth; calculated according to NORSOK-003 (NORSOK STANDARD, 2007) and DNV OS301 (Det Norske Veritas Germanischer Lyold As 2018)

The results of hydrostatic calculations are used to determine the technical requirements of the floaters. A lifting operation is simulated to assess the load required to lift the longline 36 metres from the seabed. This is done to ensure that the lifting equipment on-board the vessel is sufficient to perform installation and maintenance operation. During a lifting simulation, the tension required to pull each South-West backbone line and North-East backbone line is in the range of 5.0 – 5.4 kN.

The Ultimate Limit State (ULS) simulation has been performed with the following load combination:

- 50-year return period of maximum wave height (11.6 metre) with a corresponding wave period of 9 second parallel to the system
- 50-year return period of current with a depth-averaged magnitude of 1.4 m/s parallel to the system

Based on the ULS calculation, the maximum tension experienced by the system is 150 kN. The Norwegian Standard NS9415 (Norwegian Standard, 2010) suggested a combined safety factor of 3.45 for the use of synthetic rope and dynamic-analysis type. Therefore, the Breaking Strength of the mooring rope should be more than 517.5 kN. Consequently, by taking a safety factor of 1.3 suggested by in DNV OS-C101 (DNV GL 2015), the screw anchor axial capacity should be more than 195 kN. Additionally, a simulation with a 50-year current perpendicular to the system is also performed. During this simulation, the system is fully submerged due to the drag force experienced by the seaweed longline. Therefore, all floaters should be able to withstand a submergence of at least 20 metre depth. The extensive report of this numerical analysis can be found in the Annex C. Snapshots of the seaweed numerical modeling can be seen in Figure 43 and Figure 44.

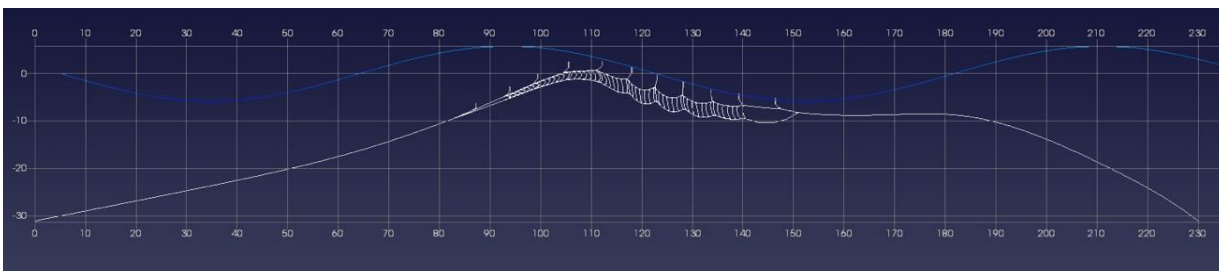


Figure 43: Snapshot of the seaweed longline numerical model subjected to parallel waves and current of 50-year return period – Belgian Pilot

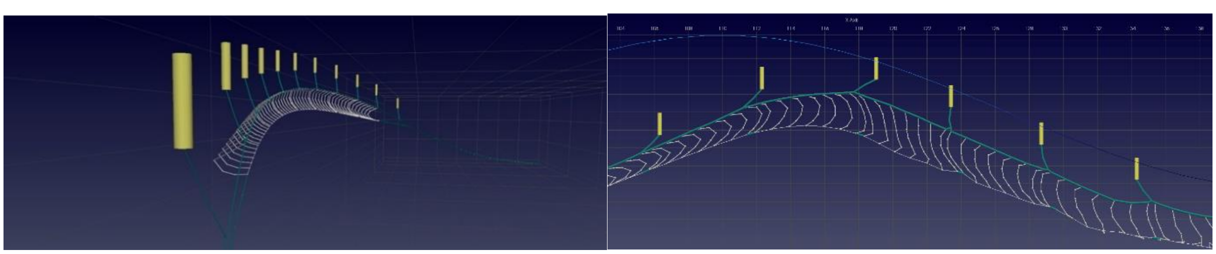


Figure 44: Snapshots of the seaweed numerical net structures subjected to: parallel waves and perpendicular current (left); parallel waves and current (right) – Belgian Pilot

Table 16: Summary forces of the seaweed longline numerical simulations – Belgian Pilot

Return period of waves and current	Force in x-axis				Force in z-axis			
	SW anchor		NE anchor		SW anchor		NE anchor	
	min	max	min	max	min	max	min	max
[-]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
50-year	2	145	-8	0.25	0	34	0	3.72
1-year	2	62	-8	0	0	16	0	0

6.4. Economic aspects & financial implications of Pilot

6.4.1. Economic assessment

The economic analysis will calculate the Net Present Value and the break-even point for the cultivation of consumption of oysters and seaweed. The techniques for calculating this are known techniques from the financing analysis. The crucial point is to collect the correct input data. Drivers for a business case are production costs (investments, personnel, boats), scale (automation) and sales prices (consumer), with the yield as the major risk factor.

The study will identify impacts on employment of the proposed multi-use solution and other potential benefit such as impacts on education and tourism if oysters are commercially cultivated in OWFs.

Ecosystem services of reef restoration may pay up for additional infrastructure costs to OWFs. The economic and ecologic benefits of reef restoration using scour protection will be evaluated for a scenario of full-scale restoration. The impact on the total cost of energy production will be evaluated and the study will reveal to what extent consumers are accepting a higher energy price to support this inclusive way of energy production. (1) A nitrogen balance will be made to evaluate the effect of full-scale restoration on the eutrophication levels in the Belgian part of the North Sea. (2) A larval dispersal analysis will display the connectivity with other native oyster populations or restoration projects. Connectivity is beneficial since genetic variation can be low using hatchery seed. (3) Since reefs are important nursery areas for fish larvae, the beneficial effects of oyster reef restoration on fisheries will be investigated.

Business model

The Pilot is a scientific project, so the reference to the commercialization is meant for future up scaling in case of a successful Pilot. No information is readily available. The study will take into account market value and market demand. Expected products for commercialization are flat oysters (*Ostrea edulis*), seaweed (*Saccharina latissima*), energy and other ecosystem services. Target markets are consumers of seafood and green energy, and users of ecosystem services. Research on oysters and seaweed production for the Belgian and potentially export market will be investigated. Oysters are a regional product in Belgium, the Netherlands, and France. For the commercialization of seaweed, several potential markets exist, for example the food, additives, bioenergy, and biorefinement markets.

6.5. Legal status of Pilot

6.5.1. Applicable Regulations & Restrictions

Permits needed for a scientific experiment within a wind park:

- Inform BMM
  - Matter of weeks.
- Insurances (personnel + material)
  - Nearshore versus offshore
  - Cannot start before risk analysis and project method statements are completed. Once started, can be done on short term (2 to 3 months). UGent is a public institution so it has to go through a tender. The latter is not required for a private company
- Correct signalling on site (buoys)
  - Depending on signalling needed. AIS: takes longer but matter of days to weeks. Other buoys during sea mission.

Permits needed for commercial use at sea:

There are two permits required when applying for a zone for commercial use at sea:

- Environmental permit
  - Final decision by the federal minister of the North Sea
  - environmental impact assessment by DG Environment -> advice MUMM Scientific Department
  - Possible objections from the public opinion
- Exploitation permit
  - FOD Economy - decision federal Minister of the North Sea,
  - With input of Advisory Committee, which include all North Sea stakeholders)

The exact duration of the processes can be found in the "KB ingebruikname"

Extra measures needed for commercialisation within an (existing) offshore wind farm

- Permit exploitation: for all commercial activities in the EEZ an Environmental Impact Study (EIS) and an Environmental Impact Assessment (EIA) is required permit is required (see MUMM website for legal procedures)
  - Procedure/Timing :
    - EIS : 3 - 6 months
    - EIA : 6 - 9 months
- Permission from OWF concession holder
- Procedure: approval of the OWF holder
- Permission access to the OWF with ships, special training personnel
  - Procedure/Timing: operational works in line with the internal procedures (work methodology – insurance – vessel – crew – communication)
  - Correct signalling on site (buoys)
    - Cardinal buoys
    - AIS

6.5.2. Insurance

Table 17 Overview of insurance content

OWN ASSET INSURANCE
Damage done to
Assets during transport on land (anchors, longlines)
Assets on land (oysters)
Vehicles transporting assets on land
Assets in park of BELWIND (e.g., wind turbines)
Assets (anchors, longlines, oysters, seaweed) during transport and installation at sea
Vessel used for placing screw anchors, long lines, oysters, seaweed
Vessel used for placing gabions, bags
Assets (anchors, longlines, oysters, seaweed) after installation at sea
Vessels used for sampling
Vessel used for diving missions (checking infrastructure and restoration)
Vessel used for decommissioning anchors, longlines, gabions, bags

OCCUPATIONAL ACCIDENT INSURANCE (for personnel)
Damage done to
Employees transporting assets on land
Crew placing screw anchors, long lines, oysters, seaweed

Crew placing gabions, bags
Crew used for sampling
Divers used for diving missions (checking infrastructure and restoration)
Crew decommissioning anchors, longlines, gabions, bags

THIRD PARTY LIABILITY INSURANCE
Damage caused by
Transport of assets on land
Placing screw anchors, long lines, oysters, seaweed (incl.: work, vessel and crew)
Placing gabions, bags (incl: work, vessel and crew)
Installed assets (longlines, gabions, oysters, seaweed, anchors)
Installed assets of BELWIND
Maintenance and other activities of BELWIND/PARKWIND
Activity of sampling oysters, seaweed
Activity of sampling gabions, bags
Sampling vessel
Diving missions (vessel and divers)
Decommissioning of anchors, longlines, gabions, bags

7. BLUEPRINT OF DANISH PILOT OFFSHORE OPERATION

7.1. Social aspects of Pilot: Stakeholder communication

7.1.1. Key stakeholder groups

The tourism activities are from the cooperative owner's perspective stated to promote wind energy. It has never been regarded as a business case as the expenses for the visit just have to be neutral. Off course the people/businesses involved have an interest in the visits from a business case point of view. These stakeholders are:

- Boat operators hired for sailing out to the turbines.
- Copenhagen Divers there may want to organise a diver school in the area.
- Tour operators and guides organising tourist event in the Copenhagen region.
- The Danish wind industry involved in international activities as Middelgrunden Wind is one of the only off-shore wind farms with easy access.
- Conference organisers there can include a trip in the tour program for Copenhagen.
- Restaurants close to where the boats depart as a boat trip minimum has a duration of 1½ hour.
- Museums and high-rise buildings with public access (Utility, Waste to energy plant, fitness centre) with sight to the turbines where a virtual visit can be included.
- The service industry behind tourism like: Coach operators and hotels.
- Tourist organisations in general.

7.1.2. Stakeholder engagement

Every two years the shareholders of Middelgrunden Vind (8553) and Hvidovre Vind (2300) are invited to visit the turbine including climbing the turbine. In 2020 this event should take place June 20th. The Covid-19 restriction made that impossible. In September it was possible assemble 50 people and the Open House took place September 20th. 120 people participated. The event was organised by SPOK and went as described:

- The boat could take 30 people and was departing 11:00, 12:00, 13:00 and 14:00 from the Piier 5 at Amager Strand, Kastrup.
- When the boat after 20 minutes arrived to the most southern turbines, the group was split in 2 groups entering each their turbine.
- At the same time the 15 people from pervious tour was ready for return at the turbine foundation.
- After entering the foundation, the group was one by one climbing the turbine and in the nacelle a presentation took place.

As the groups had difficulties to fulfil the general condition of staying with 2 meters distance, each participant must wear face masks (Figure 45). In the boat and on the turbine disinfectant dispensers are available. Fortunately, everybody agreed to the hygiene measures and the event turned out very successful. Other planned trips to the turbine during 2020 were cancelled due to missing tourist groups in Copenhagen.

Figure 45: Left: Visitors on the quay ready for departure - Right: Volunteer guides from the Middelgrunden Vind

7.2. Environmental aspects of Pilot

7.2.1. Description of Pilot sites

Middelgrunden was established on a natural reef with 3 to 6 metres water depth, 3.5km outside of Copenhagen harbour, in the fall of 2000. It is visible from Copenhagen city and surrounding beaches and tourist points of high value, like The Little Mermaid and the Round Tower. The offshore wind farm consists of twenty 2 MW turbines from Bonus Energy, now Siemens Gamesa Windpower, and is owned 50% by HOFOR (Copenhagen local energy and water supply) and 50% by the Middelgrunden Wind Turbine Cooperative with 8,553 members. It is the largest wind farm in the world based on cooperative ownership.

The wind farm consists of 20 turbines, each with a rated capacity of 2 MW. The maximum height of the wingtip is 102 meters. The electricity production is anticipated to be about 100 GWh a year. The turbines are erected on standard gravity foundations, which are placed on firm seabed after the upper layer of soft sediment has been removed.

The Pilot site is located on the natural reef with 3 to 6 metres water depth. For more than 200 years up to 1975, the

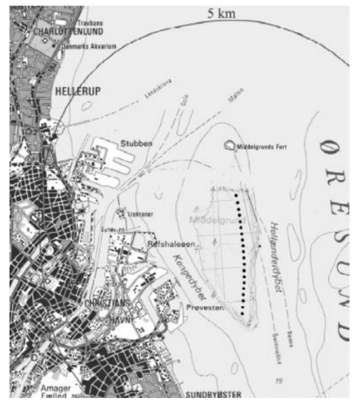


Figure 46: Location of Middelgrunden wind farm outside of Copenhagen harbour, Baltic Sea, Denmark

reef has been used as a dumpsite for harbour sludge and other contaminated waste. Middelgrunden site is heavily influenced by human activity in many respects. For example, the nearest area on land is characterised by technical installations, industry and harbour facilities. The closest recreational areas are the Middelgrunds Fortification (today called Ungdomsøen and operated by the Scout organisations) situated 1.3 km north of the wind farm and Amager Strand Park situated 2.5 km south west of the wind farm. The island of Saltholm is situated 5 km south east of the wind farm, with its surroundings it constitutes an international nature conservation area. Special environmental concern has been taken into consideration during planning and feasibility studies were carried out.

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

7.2.2. Environmental impact assessment

The fish fauna is dominated by cod, flatfish (flounder/plaice limoque obvoluto) and eel. At the edge of the reef many other fish species can be found. The reef is covered by eelgrass 50-60% in the southern part and 25-30% in the northern part (Figure 47). Blue mussel *Mytillus edulis* is another important bottom benthos. Other species at the reef are *Ceramium nodulosum*, *Ulva* and Chaetomorpha. Marine mammals are seldomly observed.

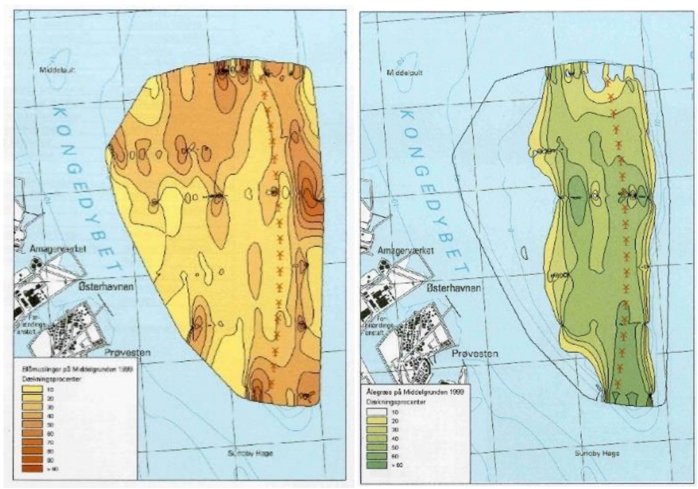


Figure 47: The cover of Common Mussel and Eelgrass before establishment.

The area of the Pilot site is populated by swans, ducks, eiders, and gullets. The reef is not an important site for these birds as the nearby NATURA 2000 area: Saltholm is very attractive. There are no sensitive bird species in the area; the existing birds like swans, ducks, eiders and gullets are not influenced by the operation of the wind farm.

7.2.3. Revised EIA consideration

The tourism activities do not contribute to EIA considerations as the boat traffic related to the visits is marginal compared to the other boat traffic in the Copenhagen Harbour area. It is of course relevant that the boat operators are in charge of preventing any pollution from visitors throwing away their garbage. As the boat operators are used to operate with tourists they are well equipped with bins and relevant instructions.

7.3. Technological aspects of Pilot

7.3.1. Current TRL – aimed TRL

The Middelgrunden Vind tourist activities is at TRL 6 (Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies). The aim is to reach TRL 8, which means that the tourism system is fully rolled out and implemented.

7.3.2. Training and capacity building of personnel

All tour guides are members of the Middelgrunden Wind Turbine Cooperative. Therefore, they are familiar with the functioning and safety measures of the turbines, the mechanisms inside the pile and the nacelle. This particular knowledge is a prerequisite for all guides. According to the multi-use idea, local fishing boats are used for the rides to the turbines. In consultation with the tour guides, routines of the trips are determined and are in line with the safety rules on board of the boats. The personnel are also schooled in the safety rules on board of the boats. The guides are in charge of keeping the number of people on the vessels as well as on the platform of the turbine limited and assign time slots to the visitors to access the turbine. It is at their own discretion to decide, whom to grant a climb up to the nacelle. They are schooled to take certain criteria regarding the tourist's ability and fitness (age, small children, etc.) into consideration.

Safety concepts (pre-operational phase)

A subcontractor maintains the turbines twice a year, whereas the electrical system (30kV) is only inspected once a year and maintained every second year. Daily maintenance is carried out by the administration and includes the following routine inspections:

- Checking the access ladder for damages, which are caused by ice or collision with the larger service vessels.
- Service and maintenance of the drainage system for water condensed in the moist control equipment.
- Repair of cracks in the foundation rails.
- Repair of joints between tower and foundation.
- Checking the rescue equipment and the warning lights on top of the turbines.

The Pilot team formulated guidelines for entering the turbine, based on the standard rules for offshore servicing, while the existing training program for guides was extended to include safety conform COVID19 hygiene measures as a new step in the operational procedure. The instruction manual for the tour boat operators is based on the standards established by Søfartsstyrelsen and are particularly important for docking at the foundation of the windmill. The requirements for the selection of local fishing boats foresee a maximum height to the stairs to assure a save transition to the platform. These aspects will be further improved in the pilot (i.e. better scheduling of the boat and adjusted safety procedures esp. when passengers are stepping over from the boat to the platform). The boat operator has the responsibility from quay site until stepping on the foundation of the turbine. Most importantly, the operators have to assure that people do not fall in the water or are squeezed when departing the boat climbing up the stairs to the turbine. Rules foresee only one person at a time climbing up the stairs and holding on to the rails. It is the boat operator's responsibility to assure a safe step-over on to the foundation. Further safety rules foresee a suite at water temperature below 10°C. Risks related to climbing the turbine are covered by the tour guide's company. The safety rules were developed according to the general rules for service providers that access offshore turbines. As tourists are not carrying equipment or tools safety shoes and helmets are not required. Furthermore, it is crucial to stop the turbine during visitation. The rules are described below (Figure 48).

Figure 48: Boat with tourists docking at wind mill

7.4. Economic aspects & financial implications of Pilots

7.4.1. Economic assessment

The turbine owners consider the tourist activities as "non-profit". It is different to assess the business activity level from the other stakeholders involved. However, some figures may give an estimate about the monetary value of these trips:

40 annual trips with a boat are in total about 400,000 DKK. A boat is operated by two people. The guide fee paid to the approved guides having access to the turbines as compensation for the hours taken from their usual work are for

40 trips about 200,000 DKK. The standard fee for tourist guides in Copenhagen are applied. Together with the group visiting, often an ordinary tourist guide is present.

7.4.2. Key performance indicators

The synergy effect of the tourism activities are first of all that the boat operators in Copenhagen harbour can have more activities using the same boats with very limited investments if any. The KPI's are:

Signature Statement visits Middelgrundens wind turbines, 2019 - 2020

The trip out to the mills and the climb up in them is both a physical challenge and an experience out of the ordinary , but it is also a practical and security challenge . Therefore, it is essential that all guests read this statement carefully and agree to the these conditions and precautions. Persons under 18 may participate if accompanied by a parent who must stand as a signatory below.
This statement is part of the COOP's emergency plan.

When ascending the mill requires that:
- I am not under the influence of alcohol, medicine , or drugs,
- I do not suffer from claustrophobia or fear of heights ,
- I do not suffer from circulatory disturbances , dizziness , epilepsy, etc. and that ,
- I am in good physical shape and not have significantly reduced mobility .

I must pay attention to the markings that are set up in different parts of the mill and respect the instructions given by the guides and staff. At the ladder's in turbines applies that there may be only one person at each section, a maximum of three people on each floor (there are 11 floors) and a maximum of 18 people up in the nacelle – if not more accepted by the guide.
To ensure a steady flow of guests in the mill , it is important that the fastest guests climb up first , but waiting to study the interior of the tower until they are on their way back down. Generally, you must give way to the guests coming down, except if you get a different message from the guides .

Secure loose objects such as mobile phone, camera, video , etc. to be carried in a pocket or small bag with zipper . It is recommended to take rings or to take work gloves while climbing on ladders. Gloves are usually provided by the guide.

When passing from the vessel to the turbine foundation, both hands to be free, and the instructions of the guild and the ship's crew must be strictly followed. When needed safety vests are provided.

Because of risk of dirt and grease in the boat and wind turbines, it is recommended that you wear practical clothes and shoes with rigid non-slip soles. In addition, you should bring a rain jacket (if weather forecast gives risk of rain), a bottle of water and some fruit or chocolate.

In addition to these formal measures, we hope that all guests will positively contribute to the event by being patient in the event of delay and by showing respect for the other guests, so we all have a good experience with us home .

I certify by my signature that I agree with the above conditions and to the whole event takes place at your own risk and that there cannot be any liability claim against Middelgrundens Wind Coop or SPOK ApS in relation to the destruction or theft of clothing or personal items .

Date:

Name: Signature:

Figure 49: Own risk including safety rules – Danish Pilot

- Number of visitors having a boat tour only
- Number of visitors climbing the turbine
- Turnover for boat operators
- Number of hits when looking at the QR codes on buildings around Copenhagen
- Customer satisfaction (tripAdvisor posts)

7.5. Legal status of Pilot

7.5.1. Applicable Regulations & Restrictions

The present Covid-19 restriction with maximum numbers of people in one group does not allow any visits.

7.5.2. Insurance

The risks related to incidents with people (twisted leg from climbing, slipping on oil on the floor of the nacelle etc.) has been negotiated with the Danish insurance company TOPDanmark during the first project year of UNITED. These risks were incorporated in the professional insurance for the SPOK Company. If guides not employed by SPOK, are climbing the nacelle, they must insure themselves. Incidents occurring during boat visits, including entering the foundation, are covered by the insurance of the shipping company.

8. BLUEPRINT OF GREEK PILOT OFFSHORE OPERATION

8.1. Social aspects of Pilot: Stakeholder communication

8.1.1. Key stakeholder groups

The identification of key stakeholders has already been carried out and reported in WP5, enabling an initial understanding the power environment of a project and the position of individual players and the significance of their potential influence. According to the Stakeholder Register Tool, as identified in deliverable D5.1, the UNITED project stakeholders are registered for certain solicitation measures and follow-up actions to be individually specified. At this point, the registries in the Stakeholder Register Tool combine two groups of stakeholders:

- Internal (operational) stakeholders of the different MUs, participating in the MU activities
- External stakeholders, indirectly affected by the MUs, which could find potential in their own businesses through the UNITED project.

As internal stakeholders, can be categorized the aquaculture site owners, Kastelorizo Aquaculture SA, the diving centre that will participate in the MU activities, Planet Blue Diving Centre as well as the Pilot lead that runs all the technical installations in the site in collaboration with Kastelorizo, which is WINGS ICT SOLUTIONS. These internal stakeholders are directly affected by the multi-use to their business operations, as they are the ones that will integrate the multi-use activities into their operations and business models.

As external stakeholders, the division could be carried out in terms of their business interest (e.g. public local authorities, local restaurants, tourist offices, hotels, diving centres etc.). In the Stakeholder Register Tool, there are a number of diving centres that could potentially show interest in the Greek MU activities and scale up similar efforts to a commercial level.

8.1.2. Stakeholder engagement

As reported in D9.2, a number of workshops will be carried out, addressing different aspects of the multi-use at particular phases of the UNITED project. The workshop involving the Greek Pilot is the **"Stakeholder engagement training for Pilot leads"**, which aims to improve capacities of Pilot leads for conducting stakeholder engagement activities to ensure social acceptance of new multi-use developments in Pilots, and reduce risks associated with it. Ideally, stakeholders will be included in the pertinent steps in the development process (co-creation) and their wishes and needs will be addressed to propel the design of supported and commercially relevant multi-use platforms. Specifically, the workshop should teach Pilot leads about:

1) Methods of stakeholder engagement, which may ease the process of Pilot implementation and contribute to more informed Pilot solutions. Such methods may include focus groups to engage tech innovators to advice on technical solutions for Pilots, or interactive meetings with experienced aquaculture farmers to generate ideas for the best choice of species to be farmed, timing, handling of harvest, potential buyers of the harvested product, etc.)
2) Methods for engagement with local communities to help to reduce risks associated with possible complains from local communities (e.g. noise, visual impact) and to increase social acceptance of and awareness about upcoming Pilot developments. Pilots, especially those working close to shore, need to ensure that the local communities are well informed about the upcoming developments and are communicated potential benefits of multi-use.

Another planned workshop that the Greek Pilot will participate in is **"Aquaculture multi-use offshore: Technology, environment and biology"**, aiming to improve capacities and knowledge of aquaculture related businesses in the context of:

3) Environment: regulations related to handling and disposal of wastes in an appropriate manner
4) Technology: focusing on technical challenges and suitable aquaculture technology employed in marine offshore farming
5) Biology: Basic knowledge on the target species employed and offshore aquaculture

The workshop especially focuses on these actors and topics given that the aquaculture offshore and associated value chain is still a relatively 'young sector' in the EU. The workshop has two parts (i.e. two separate days)

- Interactive workshop that will allow for the exchange of lessons learned across Pilots in the sphere of aquaculture and allow for cross-Pilot learning to occur;
- Workshop to communicate and discuss the project findings in the sphere of aquaculture, and demonstrate work conducted at one of the Pilot sites (i.e. field trip).

Ultimately, this training workshop aims to raise the awareness and knowledge about multi-use for those working in the aquaculture sector.

Another workshop that is planned to be carried out by the Planet Blue Diving Centre, aims to inform external stakeholders (other tourist diving centres, diving training centres and relevant organizations) as registered in the Stakeholder Register Tool, about the multi-use activities in the Greek Pilot, the business potential of this multi-use in order to trigger a commercial scale up of the diving activities in aquaculture sites. The workshop will be held online and organised by Planet Blue partners.

8.2. Environmental aspects of Pilots

8.2.1. Description of Pilot site

The Greek Pilot, denoted as the PATROKLOS Pilot site, is situated in the 59th km of Athens-Sounio Ave., Palaia Fokaia, Attiki, Greece, in the wider area of Cape Sounio (Figure 50). 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 area is a charac-

Figure 50: Left and Middle: Proposed Pilot space, the yellow square depicts aquaculture unit (source: Google Earth). Right: Aquaculture unit and islet Patroklos on the opposite - Mediterranean Sea, Greece

teristic example of Mediterranean landscape. It includes an area declared a National Park since 1971 and is regarded as an archaeological site of great importance, furthermore 68% of the area is accessible and declared public. During the Classical and Hellenistic periods, the Cape and the ancient harbour city of Sounion were of prime geostrategic importance located on the main maritime route surveying all traffic and enemy fleets towards the metropolis of Athens and the silver mines of Lavreotiki. Until today there are visible important remains of the sanctuaries of Athena and Poseidon, the fortification circuit and the settlement of the promontory, and of a naval base. The naval base built originally by the Athenians in the 5th century BC lies in the north-western part of the cape and was incorporated in the fortress. It consisted of two rock-cut slipways intended to house light patrol ships.

The current operator of the site is KASTELORIZO AQUACULTURE, a company that operates on the field of production, marketing and exploitation of fish farms with all kinds of fish, shellfish in fresh or frozen form as well as distribution of product at Greek premises and abroad. On the opposite of the aquaculture unit, there is an islet called "Patroklos". The island, has a great coastline where local people as well as tourists from the wider Attica area, enjoy swimming and spending time on the beach. The island can be accessed by private boats, while during the summer a private vessel transfer for tourists exists. Patroklos has been claimed as protected due to remnants of ancient fortification, from two walls and the 1944 shipwreck as well.

The multi-use activities that are going to take place in the site during the operational phase are the combined activities of the aquaculture unit with scuba diving tourist expeditions. These multi-use activities will facilitate touristic growth in the area, as well as help the aquaculture activities to gain social acceptance and facilitate a long-term touristic growth in the wider area. For these purposes, different scenarios have been created to combine these activities with an arrangement of a tour around the marine area stopping at aquaculture facilities, with aquaculture farmers to describe the operational activities as speakers on the diving vessel, and scuba-diving tours, as the seabed within the area of the aquaculture unit carries great interest (food waste from the aquaculture pens attract wild fish), while a common software platform (between the diving centre and the aquaculture) schedules the logistics for the co-activities.

Objectives:

- Software platform receives data from innovative technologies to establish more effective production in terms of aquaculture (monitoring parameters, such as salinity, dissolved oxygen, water quality, water current, fish behaviour and stress levels), also to establish environmental standards met at all times and to facilitate the synchronization of multiple operations of touristic diving boats with the aquaculture operations
- Supporting management and planning decisions for new developments, such as the extension of the aquaculture unit. These require:
- The development and deployment of the software platform that will have three main uses: 1) receive data coming from sensors and cameras installed in the site and produce valuable insights for fish production, 2) monitor the environmental footprint of the Pilot site and 3) combine the scheduling of the parallel activities of both the divers and the farm operations
- The installation of equipment in the site
- Business development and minimizing costs by combining activities from both sectors. Scenarios for these combined activities could be a) diving expeditions to the aquaculture units as a new recreational attraction for divers, b) diving expeditions and use of special equipment (ROVs) from the diving centre to facilitate aquaculture operational activities in cases of emergency or for risky procedures
- Time management by sharing the infrastructure such as the existing platform for aquaculture, diving or third-party vessels
- Monitoring parameters such as water quality to track pollution threats to the marine area
- Facilitate touristic growth in the area in combination with social acceptance of aquaculture
- Aquaculture gains acceptance and continues to grow while producing higher quality food
- Important touristic attractions contribute to growth of local businesses
- Creation of new jobs for trained and certified offshore staff
- Increasing synergetic effects by sharing infrastructure

8.2.2. Environmental impact assessment

The Greek Pilot site (PATROKLOS) is situated in 59th km Athens-Sounio Ave., Palaia Fokaia, Attiki, Greece, in the wider area of Cape Sounio. Cape Sounion is located at the southern end of Attica peninsula. The wider area now, is protected under NATURA 2000[7]. It is a characteristic example of Mediterranean landscape. It includes an area declared a National Park since 1971 and is regarded as an archaeological site of great importance. 68% of the area is public. It is threatened by anthropogenic pressures (crops at the north and east sides of the area, pastures, residential activity that develop mainly along the coastal road) and fires. It is protected by the Treaty of Barcelona. Changing the extent to which anthropogenic activities occupy within the boundaries of the area is important. If the rate of change continues, the problem of maintaining this character will be maximized.

[7] The online data form with Natura's description of the site is: https://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=GR3000005#2.

8.2.3. Revised EIA consideration

Feeding caged fish introduces a large source of nutrients to coastal areas which can lead to eutrophication. This eventually leads to increased algae growth, including toxic species of algae, rendering the water less suitable for certain recreational activities. The disposal also of untreated sewage from vessels can affect aquaculture, especially shellfish beds. For the purposes of the project, sensors and cameras are installed in the aquaculture facility in order to monitor any environmental disturbance in the unit. For the purposes of accurately and timely monitoring and properly managing the infrastructure and the environmental conditions, sensor devices and cameras will be installed at the site. Via the local network, data will be collected and transmitted to a software platform that will be able to monitor the environmental parameters and send notices and alerts whenever necessary. The water quality parameters of interest include temperature, dissolved oxygen, and current measurements, while environmental parameters will also be considered to measure the environmental impact of the activities on the area. Another important parameter for the undisturbed aquaculture operation is maintaining a low stress levels of the fish in the aquaculture unit. Thus, underwater cameras will be installed in the site to monitor fish behaviour.

8.3. Technological aspects of Pilot

8.3.1. Current TRL – aimed TRL

The current TRL is level 5 'technology validated in relevant environment'. Several actions will be taken to increase the TRL to level 7 'system prototype demonstration in operational environment. Two stages are envisaged. The first stage is to enhance the fish farm unit with technological tools to enhance the operations and monitoring of the site. The Pilot aims to increase aquaculture production efficiency, monitor technologies to synchronize activities, and demonstrate the use of Decision Support System for new development. The second stage is to create a set of touristic activities that will require both businesses such as scuba-diving tours in the aquaculture site as well as scuba diving equipment to enhance the operations of the aquaculture site. Some important characteristics of the aquaculture site relevant to the equipment deployment:

- Power: photovoltaic panels reside on a raft
- Connection: ethernet connection (24Mbps) is available on the shore. No 4G network is available
- Mooring systems: rafts, ropes, piers are available
- Special equipment for the installation of sensors and cameras will be considered.

The water quality parameters of interest for the site include temperature, dissolved oxygen, and current measurements, while environmental parameters will also be considered to measure the environmental impact of the activities to the area.

Training and capacity building of personnel

Training activities will be carried out by WINGS using the system installed on the site as a demonstration system and for training for the potential end users (aquaculture operations team, technical staff), to view and get feedback on the system. The Aquaculture management platform would be provided to site's end users also to help validate the correct performance of the platform at real operational conditions. Feedback from the operational as well as the management team will help to re-evaluate and enhance the overall system (hardware and software). The technical staff of the pilot site needs to be aware of the technical infrastructure installed on the site in order to participate in the maintenance activities during the project's duration.

8.3.2. Synthesis of pre-testing and re-design (pre-operational phase)

Some important characteristics of the aquaculture site relevant to the equipment deployment:

- Power: Photovoltaic panels reside on a raft.
- Connection: Ethernet connection (24Mbps) is available on the shore. No 4G network is available.
- Mooring systems: Rafts, ropes, piers are available. Special equipment for the installation of sensors and cameras will be considered.

The water quality parameters of interest for the site include temperature, dissolved oxygen, and current measurements, while environmental parameters will also be considered to measure the environmental impact of the activities to the area. Information that needs to be considered:

- Camera application
- Drone application
- Mooring systems utilization
- Site size and structure
- Depth
- Fish Behaviour monitoring needs (for tracking any stress levels from diving expeditions)
- Species, fish growth period of year (necessary for optimizing production and operations)

Transmission methodology

- Gateway device, collecting data from sensors and cameras in the site and transmitting them to the local network
- 4G/NB-IoT if available
- WiFi if possible, from the gateway device (which will be installed in the site) sending data from sensor measurements to the network infrastructure available
- LoRa (low-power wide-area network protocol) or other protocols

As Pilot lead and its technical manager WINGS plans to install different types of sensors for measuring water quality parameters, in the fish pens of the aquaculture units. Off-water and underwater cameras could also be installed at the site to monitor fish behaviour, prevent diseases as well as to measure the food waste that remains in the cages. WINGS smart gateway, will be installed at the aquaculture site as well, to transfer the data coming from sensors and cameras to the cloud (via the available network). Advanced algorithms of the WINGS cloud platform, based on Artificial Intelligence, will produce Advanced Analytics through the data measurements, facilitating the understanding of the overall production to the aquaculture owner. The WINGS platform will also provide a Decision Support System that facilitates the operational procedures and the optimization of the production. The dashboard will be used for the data visualization to present the results of the algorithms developed in the platform:

1. Smart Gateway
    a. collecting data from sensors, cameras
    b. sends to cloud through Network transmission
2. Cloud platform
    a. Production management
    b. Decision Support System
    c. Advanced Analytics
3. Dashboard
    a. Management and monitoring
    b. Data visualization
    c. Business decision support
    d. Ecological footprint

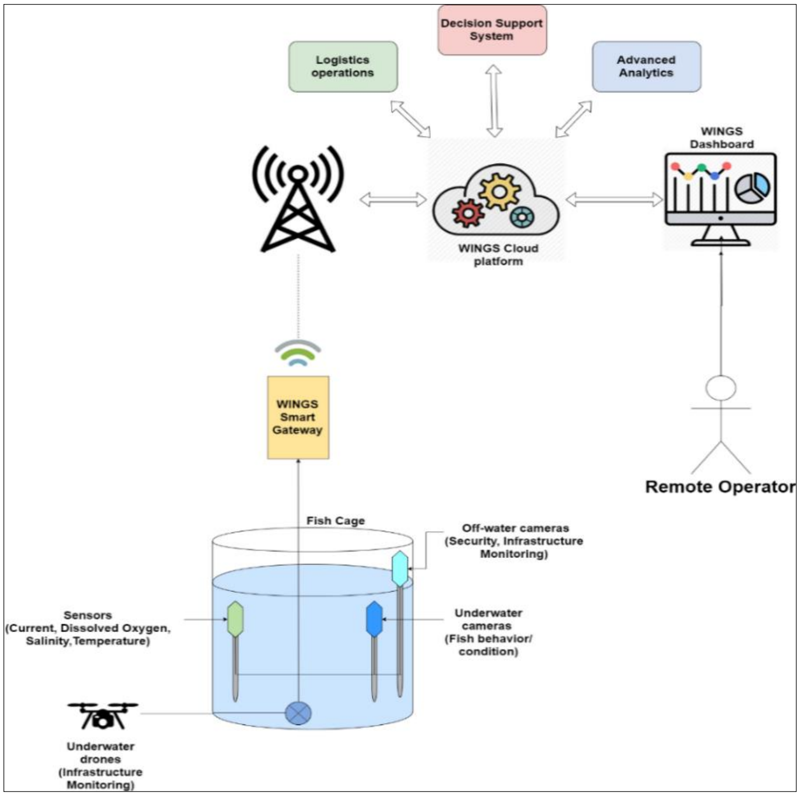


Figure 51: Greek Pilot ICT solution

Implementation

The deployment of the Pilot will take place according to the following steps:

- Order equipment for testing: i) Two underwater cameras, 1 for lab testing and one to be deployed on the field. ii) One multi-parameter unit measuring water quality parameters such as temperature, dissolved oxygen, salinity, turbidity, chlorophyll-a, pH etc. iii) One current meter is also considered 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 are going to be manufactured satisfying the requirements of the sensors and cameras.
- Lab testing: The aforementioned equipment and transmission gateways are going to be excessively tested at a lab environment before moving to the actual aquaculture environment.
- Deployment: actual deployment of the multi-parameter sensor and the underwater camera.
- Additional deployments: Additional equipment such as current meter, water quality sensors or an underwater drone that may be considered necessary at a later stage of the project will be ordered and deployed alongside the rest of the equipment.

Table 18: Gantt chart for 2020, illustrating the timeframe of the implementation steps

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Equipment ordering	■	■							
Gateway manufacturing	■	■							
Lab testing		■	■						
Initial deployment				■	■				
Advanced deployment						■	■	■	■

Below, the choices of sensors considered for the site are displayed.

Table 19: Dissolved Oxygen and temperature

Model	Company	Price (EUR)	Notes
InPro Optical	Mettler Toledo	NA*	Asked for quote. No reply
DO profile probe	OxyGuard	2840	Asked for quote. Price is from partners' list
Oxygen probe	OxyGuard	540.2	With anti-fouling cap, galvanic
Optical DO	YSI	NA*	Proprietary device
Optical DO	Aanderaa	1460	+395 for 10m cable
Galvanic DO	Sensorex	NA	Asked for quote. No reply
Hamilton VisiFerm	Yokogawa	NA*	Asked for quote
Hamilton visiTrace	Yokogawa	NA*	Asked for quote
Lumin-S optical DO	Sensorex	1165.88	316 steel (also comes with titanium encasing)
DO6400	Sensorex	498.46	Galvanic
AnaCont LED	Nivelco	NA*	Transmitter for surface waters, offer by TCB?

Table 20: Turbidity

Type	Company	Price (EUR)	Notes
Turbidity	Mettler toledo	NA*	
Turbidity	Real tech	NA*	
Turbidity	Chelsea Technologies	NA*	RS232, 0-5V, SDI-12 and 4-20mA
Turbidity	Intermountain Environmental Inc	NA*	SDI-12 output
OBS501 Turbidity	Campbell scientific	NA*	SDI-12, RS232 and 0-5V
Turbidity	Aanderaa	NA*	

Table 21: Chlorophyll, Nitrates and ammonia

Type	Company	Price (EUR)	Notes
cphyll	Eureka water probes	NA*	fluorometer
Vlux miniSOnde	Chelsea Technologies	NA	Multi-parameter (includes PAH, BTEX, cphyl a,b, etc)
UviLux	Chelsea Technologies	NA*	PAH, Tryptophan, BTEX, NDSA, PTSA
UniLux	Chelsea echnologies	NA*	Cphyll a, cyanobacteria, rhodamine, fluorescein
Ion PRO probe sensor	Libelium	NA*	Ammonium and NO3 included
ammonium	ECDI	NA*	
Nitrate	ECDI	NA*	

*NA: Not Available

Table 22: Multi-parameter sensors

Multi-parameter probe	Company
AP2000/5000/7000	Aquaread
Aqua TROLL 400/500/600	
EXO 1, 2 ,3	YSI

KASTELORIZO can provide a budget for equipment of 14K each (sensors + cameras + transmission gateways + other equipment) with WINGS also assisting in buying the proper equipment. As for the camera, the model that is going to be initially tested and used is the BARLUS UW-S5-4CS.

A software platform that will facilitate the aquaculture site and the multi-use activities in four ways:

- For added value services, based on Artificial Intelligence that help improve the operational management of the aquaculture unit.
- To monitor environmental conditions of the Pilot site.

- To monitor fish behaviour, in order to track any disturbance to fish of the aquaculture unit from touristic and marine activities.
- To schedule the multi-use activities between the aquaculture unit, the touristic expeditions (and all the linked activities and scenarios between the two).

More specifically, the software platform can provide:

Monitoring and management

- Production monitoring: Production parameters such as stock density, 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.
- 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. Additionally, the water quality analytics that are executed on the background are visualized and indicate trends for specific parameters, as well as identified outlier values or threshold violations that were observed.
- Behaviour monitoring: Behaviour monitoring is available through a dedicated page where the user can select one of the installed cameras (if any) to live stream its output.
- Remote sensing monitoring: Satellite footage is daily recorded in the Pilots. Satellite images can be displayed for the user at any time.
- User data input: Operational data such as manual observations or husbandry operations can be regularly reported through a series of input forms.
- Task management: The management of the maintenance, operational and husbandry tasks is one of the features that is also offered by the dashboard.
- Configuration: A settings page allows the operator 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.

Decision Support System

A Decision Support System (DSS) drives the business logic of the system and assists the operator in making decisions regarding different management aspects. Algorithms are developed based on the aquaculture farm's business requirements and exploit the available data, collected to answer specific questions for the user or provide an overview of the status to facilitate decision making.

Scheduling of the MU activities

A number of multi-use activity scenarios are planned during the operational phase. These scenarios need to be coordinated by the software platform that schedules the events and creates requests for a particular activity from either the aquaculture unit or the diving centre. Such events/scenarios namely could be:

- Mapping of underwater landscape of the aquaculture site using a ROV (owned by Planet Blue)
- Diving expeditions to the aquaculture site (unique wetland for divers to explore)
- Diving expeditions for cleaning aquaculture area from waste
- Inspection of the aquaculture site using a ROV (Remote Operating Vehicle) while divers maintain the infrastructure
- Inspection of the aquaculture infrastructural parts, placed in great depths (e.g. anchors) using a ROV

8.3.3. Base facilities and diving requirements

The diving tours are usually planned a week before but at least 2-3 days prior to the dive, in order to work out a route according to the weather forecast, the current and direction of wind. When the wind exceeds 4 Beaufort, or when the currents are too strong, diving expeditions are cancelled and the customers are reimbursed. Due to these safety measures accidents have been successfully prevented. The number of people participating in the dive as well as their qualification and experience (number of dives in the past and time of last dive) are further criteria that affect the route, while regular visitors may be granted certain benefits with regard to preparation time and spots. All customers with limited or medium experience, who have not dived for the past year, are asked to take a "refresh - test" dive, accompanied by one of the instructors, before the planned dive. This allows the diver to become familiar with the equipment and feel more comfortable and reassured that s/he will be able to follow the group. The dive sites are weather dependant. In total there are 55 dive sites that can be chosen from. When weather conditions allow a boat dive (up to 4 Beaufort) rather open dive spots may be visited. Alternatively, there is always the option of a beach dive, which is much more beginner friendly. The vessels for open water dives (DSV "OCEANIS") can accommodate 10 people, including 2-3 crew members, usually tourist groups consist of 7-8 people. In the case of beginners, two dive guides accompany the dive (3-4 divers per dive guide). Due to the measures against Sars-COVID-19, most dives were cancelled, only allowing a few well-prepared dives with smaller group sizes of 3 people. With regard to necessary diving certificates, the tourists have to own a certificate recognized by the Hellenic Ministry of Merchant Marine including the following organizations: PADI, SSI, EOYDATK, ANDI, IANDT and PSS. The minimum certificate required is the Open Water certificate. Planet Blue is a provider of diving services certified by the Greek authorities. Each year the Bureau Veritas certification EN 14467 is renewed, a standard that applies to dive centres offering training, organized dives, and equipment rental. This standard outlines the requirements for equipment, risk assessment, and emergency provision to ensure that all activities are carried out safely. Also from Bureau Veritas, Planet Blue is certified for its ISO 9001:2015 Management System for:

- Scuba training
- Recreational diving
- Scuba gear rental
- Filling of tanks

Recreational dives (wearing a wet suit) are offered from May until October, when the water temperature is comfortable and allows to dive for take more than half an hour. However, there are regular OW divers that dive almost all year round without.

8.4. Economic aspects & financial implications of Pilot

8.4.1. Economic assessment

The coastal and maritime tourism sector is one of the five focus areas of the Blue Growth Strategy, and is thereby a top priority for European Union policy and projects. There are a number of topics that need to be considered for the creation of the multi-use business model. These topics should cover the value proposition from both sides of the co-use companies. Namely these are:

- Types of supplies: Co-use companies need to determine the supplies components of the product/service or an entire product/service that will provide.
- Market access: Co-use companies need to determine the types of communication channels as well as the access to existing markets or helps create new markets.
- Funding: Co-use companies need to determine the types of funding for more activities in the business model.
- Co-developing & research: Co-use companies need to determine to what extent they will be involved in (technology) development and research activities.
- Knowledge & experience: Co-use companies should provide their knowledge and experience.

- Combined use of space/resource: Co-use companies need to determine the grounds on sharing the same space or resource (because of geographical proximity).

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• Lack of societal acceptance of aquaculture unit • Lack of new scuba-diving attractions • Difficulty in monitoring aquaculture infrastructure in great depths • Limited monitoring of environmental footprint in aquaculture site	• Combination of aquaculture and scuba-diving, using software platform for scheduling activities • Scuba-diving tourist visits to the aquaculture site • Aquaculture farmers used as tour guides • Scuba diving equipment (ROVs) to be used for aquaculture monitoring • Installation of sensors in farm to track environmental footprint • Installation of cameras to monitor fish stress levels	1) Clean water 2) Increased touristic activity in site 3) Social acceptance of aquaculture farm 4) Cost reduction of infrastructure failures 5) Increased revenue 6) Increased crop yield	• Introducing an alternative touristic attraction • A potential win-to win combination compared to same activities existing individually in the pilot site	• Foreign tourists • Local tourists • Local residents • Regional authorities
	Key Metrics • Number of scuba-diving tourists • Number of aquaculture infrastructure failure cases • Revenues		**Channels** 1) Local newspapers/ press 2) Partners 3) Website / social media	

Cost Structure	Revenue Streams
1) Marketing costs 2) Licensing costs 3) Sensors and cameras installation 4) SW development costs 5) Deployment/Hosting costs	1) Scuba diving participation fees 2) Fish products sold 3) Grants
PRODUCT	MARKET

Figure 52: Business model canvas for aquaculture and tourism in Greek Pilot

8.5. Legal status of Pilot

8.5.1. Applicable Regulations & Restrictions

All activities that will take place to the area close to the aquaculture unit should follow the rules of the according authorization that has been granted to the aquaculture site:

Ministerial Order by the Ministry of Environment, Spatial Planning and Energy, granted in the 28th of February, 2020, with the subject: "Approval of Environmental Terms, which concerns the expansion of an existing floating marine unit for fish farming, in the marine area to 29.76 acres (from 20 acres) and an annual capacity to 462.12 t (from 230 t / y), in the place "Kasidiara", sea area "Stenou Gaidouronisiou", Municipality of Saronikos, Regional Unit East Attica, Attica Region, with "KASTELLORIZO SA" as its body."

Regarding the scuba-diving tours, there are no known restrictions in legislation regarding swimming close to aquaculture units. Insurance issues should be investigated regarding the new multi-activity concept. Framework of this business model in potential commercial roll-out should also be examined if it is according to government law. Issues of marine responsibilities (accidents, search and res-cue, spills, etc.) need to be defined between all users of marine space.

8.5.2. Insurance

Individual private insurance is covering most of the potential accidents that could occur both for aquaculture operations and the diving activities.

9. CONCLUSION & RECOMMENDATION

While the overall significance of ocean multi-use concepts is increasing in marine spatial planning and will grow rapidly in the future, the extent of involvement differs and thus the perception of its importance varies widely from country to country, also within the European Union. A comprehensive standardized MU implementation approach is still missing, due to technological limitations, unclear legal and political situations as well as economic, social and environmental concerns. The project partners of UNITED have been aware of these bottlenecks from the start and used the pre-operational phase intensively to find practical and suitable solutions for the offshore phase. Once more the integration of a relatively new economic branch into an already existing set of offshore activities turned out to be a major challenge to operate safely and cope jointly with the conditions prevailing anyhow within these mainly hostile locations. Since this is the situation most multi-use operations have to cope with at least for the next years the following recommendations are highly valuable. Nevertheless, it is self-understood that planning and operational needs will always have to consider that there are country-specific conditions but some principal solutions of the pre-operational phase are transferable within a pre-set framework of future projects. If all intended (or foreseen) offshore activities are included in the planning from the start, a much wider range of synergistic effects and improved efficiencies for each of the activities can be gained while also new options will be discovered and opportunities of their utilization may present themselves.

The following conclusions and recommendations for future multi-use offshore operations are the results of the pre-operational phase. These are selected according to transferability and summarized per characteristic across the five pilots. A detailed description is given in the pilot specific chapters above.

Social aspects

The involvement of specific stakeholders at an early planning stage of an offshore operation has shown to deliver highly beneficial inputs for the objectives and the proper development of at least some of the key elements of the multi-use pilots. Especially the needs and concerns of different offshore users have to be taken into considerations, thus minimizing the risk of conflicts while fostering consensus building and gaining improvement-oriented inputs. Thus, optimal pilot solutions mandatorily require a close communication not only within the pilot but also with potential affected parties during the preparatory but also during the entire implementation phase of the project so that even future application of the project will obtain constructive inputs. Establishing a stakeholder register early on in the project, or even before the project has started (during planning phase), has shown to pay off at several stages later in the project. An elaborated stakeholder register facilitated a variety of decision-making processes and assured to maintain the practical focus of the pilot while also assisted in minimizing or preventing conflicts through early consensus building. Also, when preparing specific dissemination activities, such as the stakeholder-driven workshop series of UNITED, the stakeholder clusters provided essential information about the needs and concerns regarding offshore activities, so that a multitude of aspects beyond the rim of the plate of each stakeholder had been addressed, some of which would likely have been overlooked without these continuous consultations. A practical example for the need of a thorough research about stakeholders was experienced at the urgently needed finding of alternative solutions due to the pandemic-related delays in the technical preparatory period and the problems associated with this. Having access to a knowledge about the offshore engineering business of others contributed to find alternative suppliers which could possibly meet the very unique specifications and this permitted to speed up the otherwise lengthy tender process for subcontractors. Collecting information about the non-governmental organisation (NGO) landscape led to expert discussions with ecologists about the design of the mussel and seaweed systems and how to use avoid or reduce their potential impact on the environment and to improve the social acceptance of offshore activities, especially aquaculture. One recommendation is to conduct early stakeholder interviews as well as to seek advices from the stakeholder advisory board as a significant contributor to the informed process throughout the project. Certainly, there is also a need to be sufficiently alert to recognize those stakeholders (often linked to the public at large) who do have a negative agenda, aiming at preventing any development. Thus, the early involvement of all helps to identify those also at an early date. Further, by always guiding the communication process with a positive and improvement-oriented attitude helps greatly to break barriers and gain constructive contributions. In retrospect, a kick-off workshop at the beginning of the project with relevant stakeholders or additional stakeholder interviews from different clusters is an additional valuable input option for the effective planning and smooth running of a project.

Environmental aspects

The more is known about the relevant environmental parameters of the offshore location the better the chance for specific adaptation of the entire operation to minimize environmental impacts within the pilot and around it. This accounts for a wide range of aspects which are technological (design of the systems), biologically (timeline for installation, sampling schedule, consider growing seasons, assess environmental interactions at the location – e g. biofouling, species aggregation effects and many other aspects affecting the operation.), and scientific (working on applied scientific issues with practical relevance to environmental interactions and bio-performance of the unit, useful comparisons across all pilots or comparison with other offshore operations not yet involved in multi-use concepts but having the option to do so in the future). Also, the choice of suitable aquaculture species or location-specific operations can be made as site-specific as possible (also, in context of future global applications of the concept: market demands may require to consider other species). While trying to choose primarily native (local) species environmental interactions can also be minimized (no risk of introducing foreign pathogens or parasites) and thus the risk for failures (or even minor losses critical to gain any profitability) can be avoided- For some of the pilots a lot of site-specific bio-ecological knowledge is available through long-term research in the past, thus, assisting to make the right choices for continued monitoring during the project from the start. The better part of this information should be available before the start of any offshore operation so that there is a baseline on different aspects before the actual operation starts. Such an approach is highly recommended as it helps to properly design the required environmental and technical data acquisition for the implementation period. The costs of this per-operational effort will pay off well in terms of optimizing the operation and maximizing the probability of success. The availability long-term data (hydrology, geology, flora & fauna) of e.g., the German pilot location, as the most exposed and extreme site of the project, enabled to design an aquaculture system to withstand e.g., challenging wave heights and strong currents (extremes which would not have been known nor anticipated without the data background). Another example is the small-scale knowledge of the seabed structure as it influenced the choice of materials and the choice of the exact location (Belgian pilot) and within all pilots we are in the lucky situation that at least to some degree the required background data can be extracted from previous research.

Technological aspects

Although world-wide there are many aquaculture operations in near shore and semi-exposed locations, final adjustments and adaptations to site-specific conditions are always necessary. There is no chance for a ready-to-run system that can be blindly employed at any location. Therefore, nearshore tests, e.g., of material, proofed to be indispensable. Under no circumstances should a project of this complexity and with this amount of investment be conducted without a "sandbox" test run. Although this is a common procedure in many industries, it is of key importance to properly prepare an actual offshore operation and this issue will be stressed with some simple examples from the pilots. The nearshore tests within the German pilot revealed that a comparable cheap camera worked perfectly well and would satisfy the requirements at the offshore site while providing pictures of good quality and thus the time spent for the development of the waterproof housing and external energy supply paid well off. In this case no highly professional expensive subsea camera system was available on time due to extreme long delivery times because of COVID19 and financial resources were saved which are urgently needed to cope flexibly with other COVID 19 restrictions. Moreover, testing the measurement buoy at the nearshore site revealed that the initial delivered hardware was not 'fit for purpose' for offshore conditions in the North Sea (construction not sufficiently robust and watertight enough, materials not suitable) and required further adjustments before these could be reliably used at the offshore site. Without pre-testing, an employment of such specifically produced system would - in case of failure - damage the entire monitoring thus would not satisfy the needed data acquisition. The mooring tests of the Dutch pilot resulted in the choice of a different sort of anchor and thus prevented the failure at the offshore site. Pre-test of different seeding strategies of the European oyster and seaweed in the Belgian pilot proved to be valuable, especially for the choice of materials (seeding substrates) for a commercial implementation. The use and testing of modern technology and advanced algorithms for aquaculture farm management helped extensively to reduce the nutrient input.

In general, the pre-operational phase has shown that often new solutions for designs had to be found in spite of existing state-of-the art solutions and off-the-shelf "plug and play" equipment sometimes required further adjustments. These are the kind of experiences; one would appreciate to discover during near shore trials rather than offshore.

As anticipated from the start, potential synergy effects have been found not only between users within the same location but also between pilots operating at distant sites in different larger marine ecosystems. Cooperation can thus demonstrate that the same design for a seaweed aquaculture system utilized by the Dutch pilot is also applicable for the German pilot. It is anticipated that similar options may be utilized with other systems develop and operated for a long time in other parts of the world (e.g., Asia, South and North America) but also will always require some engineering work to adjust to specific local conditions.

For the German project some modifications were necessary to meet the highly extreme conditions at the far-offshore exposed location. However, time and resources were saved to just focus on the needs for adjustments and not for developing and testing a basic design. The benefit for both operators will be the implementation of a fairly "standardized" design within UNITED and therefore the opportunity to gain experience during the offshore phase and to improve this system for other locations for upcoming operations (having in mind that almost always some minor but critical adjustments to the standard design will be necessary at each new location).

Another example of inter-pilot synergy effect is the choice of the same seaweed species but with adapted genetic strains and seeding techniques for each location and installation procedure. Needless to say, that in line with common aquaculture practises these strains should be obtained from sources as near as possible while also keeping theses strains initially separate to check whether they are free of diseases and parasites. So, the exchange of knowledge during the pre-operational phase accelerated the planning process and provided the option to examine the cultivation of the same species and its performance at different locations. Inter-location comparability is an important issue in testing the same scientific working hypothesis at remote locations. It is anticipated that the results will provide a broader basis for any upscaling initiatives.

Conclusions of Training and Capacity Building of personnel

With increasing distances from the shore and growing dimensions and complexity of the offshore plants, the offshore industry faces the challenge of recruiting staff that has had a multi-disciplinary education and is also trained to operate inter-disciplinary to achieve a safe, effective and economically viable operation.

UNITED elaborates on the economic benefits of combined activities within the same maritime area. This can also be achieved not only by increasing the exchange of lessons learned from each of the involved operations within a single pilot but also between pilots who operate industry-combinations that differ from each other and thus enhance to capacity building between the project partners and external stakeholders.

Training and capacity building of personnel will significantly reduce operational and economic risks, and increase safety and efficiency of the operations. The pre-operational phase (first project year) has been used by the pilots to determine the essential and future-oriented skills for a safe and professional operation of the multi-use pilot with subsequent selection of personnel (to best ability possible).

By doing so, the involved personnel has now achieved an enhanced standard of knowledge and experience through the participation in diverse trainings and exchanges of experiences.

The operation of each pilot requires different skills according to the very unique combination of different users and also because of highly country-specific regulations.

The gained experience on practicability of various operational procedures, has been particularly useful to develop training objectives and content during the first year of the project will the outcome will be included in the overall UNITED Curriculum for offshore courses (Deliverable 7.3) which determine the content and structure of the upcoming workshops.

To add a more practical component to the workshops described in deliverable 7.3, vivid examples from lessons learned in the Pilots will be presented.

The proposed educational program content, which builds on the trainings described in this deliverable, is highly important for adequate education and skill training of future staff to become prepared for ongoing and future developments of multi-purpose industries and future MU projects.

At the same time, it will enhance the visibility of the of the five United demonstration pilots and will improve the information exchange between United and the stakeholder community.

The aim of the trainings carried out so far was not only to educate internal personnel but also to facilitate a transdisciplinary knowledge exchange of best practices from different offshore operations, to combine skills and possibly tools in order to advance an innovative, sustainable and safer MU sector.

Economic aspects

The selection of a KPIs (key performance indicator) was helpful in documenting and controlling the pilot's overall progress. Especially procuring equipment or tendering offshore work a leading framework will save time during the selection process and investing the available financial resources most efficiently. Moreover, it was considered useful to draft several work-flow approaches regarding the installation to account for all eventualities and potential unexpected budget costs that may follow as long as external uncertainties exist. This approach proved to be of existential importance when new alternatives needed to be developed due to unforeseen changes e.g., a split installation schedule because of different delivery times for technical modules.

Another recommendation for a multi-use offshore operation is to identify and test synergy effects in combining offshore operations and inspections for a commercial up-scaling. This was done in the Dutch pilot and resulted in an adapted logistical schedule because at operational activities the lack of deck space, time, etc. have to be taken into account.

Legal aspects

The legal framework should be elaborated before any detailed planning of an offshore project starts. The legal requirements determine the scope of the operation. So, one of the first activities should always be the investors and potential operators familiarize themselves with the national and international legislation e.g., on the array of permits that have to be obtained in terms of site-specific licences, including environmental protection issues to adjust the whole set-up of the operations according to these binding facts. These requirements are very different within the 3-mile jurisdictions from offshore but often linked to national regulations where the land-base is located. They can greatly vary when it comes to small differences in the application of system parts. For example, the choice of the mooring system was strongly influenced by these regulations (differently in Germany, The Netherlands and Belgium). Another recommendation is the timely identification of the responsible decision making and licensing bodies to plan the installation process since bureaucratic procedures may take longer than anticipated and often are not at all coordinated between all agencies involved. It is a pity that in many jurisdictions' aquaculture has not a lead agency but is regulated by different ministerial agencies. Another important topic is the evaluation of available insurances and what they cover and which risks have to be covered by the operator, by which user in multi-use operations and which ones by subcontractors. The range of insurance costs differ between countries and the combination of users while also these rates may vary dependent on the level to which the aquaculture operator can fulfil the long list of conditions set by the insurance company or already being imposed by the existing cooperating user who. This is a future topic requiring assessment as requested insurance level may become prohibited of the multi-use development. Alternative solutions should be explored.

While the German pilot could make use of a common obtained license and insurance, the Belgian pilot needed to seek for an affordable option. Another important legal point was the different safety frameworks according to national law and to the already established offshore user, who usually determines the requirements for the new user. It is essential to find a compromise of maintaining a high safety standard and giving a realistic opportunity to a new user to operate at the same location if the multi-use operation is to be economic feasible. This compromise was found e.g., in all pilots. Here again the early consultation of stakeholders is essential for consensus building.

Adaptations to COVID19

A major challenge for all partners of the UNITED project was the unexpected outbreak of a pandemic a few weeks after the project started. The planning of the pilots was done at least a year before the start of UNITED project and all technical and logistic plans were based on a world without COVID19. Within a few weeks those operational plans and some of the objectives had become at risk and numerous adjustments (for which only theoretical and no practical experience existed anywhere) had to be prepared without having any guarantee that the totally new solutions created can be realized or need further (almost ad-hoc) adjustments. While doing so, it became obvious that some important parts had even to be partly dismissed. The importance of a highly sophisticated, pre-risk assessment and subsequent management was proofed to be the only way out to cope with the new situation, which has hit all pilots and will –we are sure- continue to require adjustments as there is little hope that a return to conditions which we call "normal" will be reached during the UNITED project. The German pilot considered a whole range of alternative solutions and finally implemented several to achieve the set goals and timelines as much as possible despite new circumstances appearing almost on a daily basis. Flexible schedules, adapted logistics and the use of alternative handling guidelines had to be exploited in order to work with the fixed points in timing schedules (dictated by nature), which cannot be changed as e.g., the season of spat fall. One lesson learned on the basis of a good pre-risk management was the need to develop always alternative plans, even for the most unlikely impairment. Between fixed times every possible flexible operational modus should already be in the drawer before we are confronted with unforeseen events, even though there may not have been an opportunity to test the alternatives, but at least one should be prepared for potential problems (e.g., potential annual shifts of the start of the biological season; for example, spat fall).

One early (in project month four) and major adjustment of the pre-operational phase affected especially, preparatory works such as pre-testing of equipment at the near shore sites. Due to governmental ad-hoc decisions to cope with the Pandemic, we were totally blocked and not allowed to enter the test sites. Those activities, although properly planned and ready to be implemented in a timely fashion, had to be totally interrupted and postponed and subsequently had to be cut short due to closed harbours and lack of time. Another major negative effect of the new COVID19 situation has been the extremely prolonged delivery times for parts of technological equipment (e.g., camera, multi parameter probes, AquaReal). Everywhere the Pandemic caused delays with a terrible "domino-effect" downstream from the source to the end-user (the Pilot) and early orders for parts or full equipment from the US, UK and China, as well as frequent inquiries in asking for speedy deliverable schedules did not help. This further impeded the project's progress substantially without us having any chance to circumvent these delays despite highly "innovative pushing methods" from our side. Different methods and adjustments on alternative monitoring equipment to serve the original plans for data acquisition had to be found which required intensive research and therefore a lot of extra working time. The need for a time buffer to cope with unforeseen obstacles should be considered in manpower planning of future projects so that sufficient flexibility is available to cope with the problems adequately.

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ANNEX A

German Pilot

Additions to Environmental impact assessment

Seabed and seawater

The seabed serves as a habitat for a wide variety of organisms which are an important part of the North Sea ecosystem. The uppermost layer (0-0.5 m) of sediment at the Pilot site consists of fine sand and medium sand with humus admixtures. There are further layers of sandy soil underneath. The sediment distribution is heterogeneous at this site. According to current knowledge, the upper 30 to 50 cm of the sea floor are regularly displaced by natural sediment dynamics. During storm events, larger amounts of sediment can be temporarily relocated and visibly change the conditions on the sea floor. This knowledge led to a specialised and novel design of the "lander" in order to keep it in a stable position and to assess the possible impacts of the foreseen offshore-use regarding the requirements for a license.

The oxygen situation at the FINO3 site is subject to seasonal fluctuations, which, however, seem to have no major impact on mussels, especially since reduced oxygen concentrations are temporarily. However, with ongoing climate change we may see a subtle trend change and more occasionally extremes and thus complex monitoring of conditions is inevitable. The oxygen situation can become decisive for the survival of a wide range of aquaculture species. So, the evaluation of the data led to the choice to cultivate the mussel Mytilus edulis and the seaweed Saccharina latissimi as suitable organisms for this specific offshore site.

The seasonal minimum temperature at the site usually occurs at the end of February/beginning of March, seasonal warming begins between towards end of March and the beginning of May, and the temperature maximum is reached in July and August. The lethal temperature ranges of the target species were not reached at any time during the monitored period. Half of the recorded data are within temperatures ranging between 10 and 19°C, which can be considered – for most of the time- as being within the optimum for the production of *Mytilus edulis* and *Saccharina latissima*. The freezing point was never reached during the time of data recording (2013 – 2016). The temperature data also led to the estimated time of spat fall and the timeline of the whole Pilot e.g. installation dates.

The North Sea is mainly fed by water from the North Atlantic while these water masses are partly incorporated in internal cycling and therefore has a relatively uniform and non-stratified water body regarding salinity. Within the course of a year, the measured fluctuations in salinity are negligible and suitable for a sufficient growth for the targeted organisms and those adapted to salt water. The salinity data from January 2013 to March 2016 ranged between 30 and 35 PSU in -1- and -17-meter water depth.

Turbidity of the water determines the amount of the smallest particles in the water column. The prevailing turbidity conditions at the German Pilot site do not exceed 50 NTU and are optimal for mussel cultivation.

Wave height is a major and highly critical parameter affecting the technical design of the aquaculture systems to achieve not only strong and stable structure but also in guaranteeing proper "all-time" positioning (e.g. unconventional mooring systems). The "biological anchoring structures" of macro algae or mussels (byssus threads) can only resist certain forces caused by wave heights, otherwise these species will detach from the substrate and massive losses will occur. The maximum wave height determined so far was 9 m every year at least on one occasion. Therefore, the entire aquaculture system components were designed to be installed as deep as possible to escape from being destroyed by forces of the extreme waves. Depth of installation is also of concern because the culture organisms have to be exposed to layer of best food (mussels) or light conditions (algal photosynthetic activity). Thus, a compromise as to the best choice of depth had to be made. With regard to currents, the mean current flows reach 5 cm/s while the maximum tidal current reaches 70 cm/s in a north western or south eastern direction. The conclusion was drawn to install the aquaculture farm parallel to the main direction of this strong current so negative effects can be avoided for these organisms.

Birds

Intensive research activities have been conducted to provide information on the variability of species-specific migrations intensities in the daily and annual course in the German part of the North Sea. Based on the available long-term studies, the data situation can therefore be considered as very comprehensive. The location of the German Pilot is along an important migration route for numerous bird species. This data and an intensive literature research according the interaction of birds and mussel and seaweed aquaculture systems have been used to obtain the license for the operation and the idea to install cameras to monitor any possible attraction of birds due to the aquaculture use.

Benthos

Benthos samples were not taken directly from the FINO3 site. However, extensive benthos analyses were carried out in the DanTysk wind farm in the immediate vicinity. A detailed description of the benthos community is provided in deliverable 4.2. One relevant result for the planned aquaculture farm is for example the appearance of the starfish Asteria rubens as it is well known to feed on mussels. So the projected cameras will be used to monitor the influence of this species on the cultivated mussels.

Marine mammals

Regular sightings of harbor porpoises (*Phocoena phocoena*) at FINO3 were recorded over the past years. The Sylt Outer Reef directly borders the harbor porpoise sanctuary west of Sylt, the only cetacean sanctuary in the North Sea (Federal Agency for Nature Conservation, 2008). Moreover, harbor seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) use the area as feeding grounds or pass through on their way to their resting and reproduction sites. The most innovative technical devices to distract harbor porpoises was selected for the aquaculture farm to protect this species. The seaweed and mussel nets will be equipped with cetacean deterrent signalling devices (porpoise alert systems), which signals are specifically designed for porpoise populations endemic to this part of the North Sea. The German Pilot will closely monitor the performance of this new technology to assess its effectiveness under practical conditions and – if possible – to suggest improvements.

Phytoplankton

Plankton are unicellular microalgae suspended in the water column; it forms the basis of the North Sea's productivity. Phytoplankton blooms are brief periods of mass exponential algal growth and are generally observed in the period between March and October. In spring, the first bloom is formed by diatoms, followed by massive blooms of *Phaeocystis globosa*. Phytoplankton blooms may disappear quickly again due to the depletion of nutrients, viral infections and zooplankton grazing. Although several hundred of phytoplankton species occur in the North Sea, only a few can form mass blooms.

Zooplankton

Zooplankton is usually dominated by copepods, which make up a large part of the total biomass in the seawater, forming a key link in the food web. The production pattern of zooplankton is irregular in time and space as a result of variable algae blooms. The phytoplankton and zooplankton composition are determined mainly by natural factors, such as origin and composition of the water, local aspects such as water depth and stratification, and the changing of the seasons. To a degree, human activities also influence the composition of phytoplankton and zooplankton, particularly eutrophication.

Additions to Synthesis of pre-testing and re-design (pre-operational phase)

1. Phase

The environmental conditions at the test site FINO3 are quite harsh due to the very exposed offshore location. In the following table the general environmental parameters are shown. For the two planned systems for the breeding of mussels and seaweed, the design case of the 5-year event is applied. This is more than three times the design period of maximum 18 months and would thus be analogous in the risk assessment to the design of other offshore structures.

Table 23 General environmental parameters at FINO3 – German Pilot

Parameter	Title	ID	Requirement Description	Priority high (H) low (L)	Source
1. Waves	1.1 5 year return wave	1.1.1	design water depth: 26,3m	H	(FuE-Zentrum FH Kiel GmbH 2006b) (DNV 2010)
		1.1.2	designated wave height H_1/3: 7,5m	H	
		1.1.3	designated wave height H_max : 14,6m	H	
		1.1.4	wave length: 147m	H	
		1.1.5	wave period: 9,7s	H	
	1.2 wave directions	1.2.1	first main wave direction: NNW-NW (36% of the waves between 2015 and 2020)	H	(BSH 2020)
		1.2.2	secondary main wave direction SW-SSW (28% of the waves between 2015 and 2020)	H	
	1.3 load spectrum	1.3.1	a simplified load spectrum for 18 Month of operation will be attached in a table below	H	(FuE-Zentrum FH Kiel GmbH 2006a)
		1.3.2	the shortest wave period drives the smallest natural frequency of the system	H	
		1.3.3	to avoid resonance with sea state excitation the natural frequency should be above 0,4Hz	H	
2. Current	2.1 current velocity	2.1.1	max. current velocity at surface: 1,2m/s	H	(FuE-Zentrum FH Kiel GmbH)
		2.1.2	max. current velocity -12m: 0,9m/s	H	
	2.2 current directions	2.2.1	main tidal current direction is from NW and SE	H	(BSH 2020)
		2.2.2	in the first water layer from 0m - 2m below surface the current direction varies from all directions	H	
3. Water level/ Tide	3.1 Water Levels	3.1.1	LAT - marine chart zero: at LAT 0m absolute 21,8m	H	(FuE-Zentrum FH Kiel GmbH 2006b)
		3.1.2	low tide: at LAT +0,2m absolute 22m	H	
		3.1.3	high tide: at LAT +1,2m absolute 23m	H	
		3.1.4	HAT: at LAT +2,2m absolute 24m	H	
		3.1.5	storm surge: at LAT +2,6m absolute max 26,6m	H	
		3.1.6	design water level: at LAT +4,5m absolute 26,3m	H	
4. Wind	4.1 1 year return wind above 10m	4.1.1	1h-average: 27,8 m/s	H	(FuE-Zentrum FH Kiel GmbH 2006a)
		4.1.2	1min-average: 32,3 m/s gust factor: 1,163	H	
		4.1.3	3s-gust: 35,7m/s gust factor: 1,285	H	
		4.1.4	1s-gust: 37,3m/s gust factor: 1,343	H	
	4.4 wind directions	4.4.1	wind directions differs mostly between NNW and SSW	H	(FuE-Zentrum

		4.4.2	main wind direction is W	H	FH Kiel GmbH 2002)
4. Temperature	4.1 Water Temperature at 6m depth	4.1.1	maximum: 22°C	H	(BSH 2020)
		4.1.2	minimum: 1,5°C	H	
		4.1.3	average: 11,4°C	H	
		4.1.4	standard deviation: 5°C	H	
	4.2 Water Temperature at 12m depth	4.2.1	maximum: 20,9°C	L	
		4.2.2	minimum: 0,8°C	L	
		4.2.3	average: 11,2°C	L	
		4.2.4	standard deviation: 4,5°C	L	
	4.3 Water Temperature at 18m depth	4.3.1	maximum: 19,5°C	L	
		4.3.2	minimum: 1,3°C	L	
		4.3.3	average: 11,1°C	L	
		4.3.4	standard deviation: 4,5°C	L	
	4.4 Air Temperature	4.4.1	average: 9,5°C	L	(FuE-Zentrum FH Kiel GmbH 2002)
		4.4.2	monthly average extrema: -4°C to 21°C	L	
		4.4.3	day extrema: -10°C to 30°C	L	
5. Other	5.1 Salinity	5.1.1	salinity: ~3,5%	H	(FuE-Zentrum FH Kiel GmbH 2002)
	5.2 Precipitation	5.2.1	precipitation: ~750mm/a	L	
	5.3 Sunshine duration	5.3.1	sunshine duration: ~2000h/a	H	
	5.4 Thunderstorm	5.4.1	thunderstorm: ~25/a	L	
	5.5 Lightning	5.5.1	lightning incidence: ~2/km²/a	L	

Table 24: General requirements for mussel, seaweed and monitoring system – German Pilot

Parameter	Title	ID	Requirement Description	Priority	Source
1. General	1.1 System description	1.1.1	there will be two aquaculture longline systems to cultivate 1. seaweed (Saccharina latissima) and 2. blue mussels (Mytilus edulis)	H	
		1.1.2	the weight of the system will increase over the operating time due to the growth of the cultivated species (seaweed and blue mussels) and the unwanted marine growth of other species like barnacles and other algae	H	
		1.1.3	to determine various hydrographical and biological parameters, a lander with a sensor package will be installed on the seabed and connected to the FINO3 tower for power supply and data exchange Sensors/cameras that have to be placed on the longlines directly need to be equipped with batteries and wireless communication systems for data transfer	H	

		1.1.3.1	The following sensor-Types will be used to detect various parameters (shown in the brackets) • Combined CTD and o2-Sensor (conductivity, temperature, O2,salinity) • PH-Sensor (pH-Value) • Fluoro Sensor (Chlorophyll a and algae values) • Echosounder and Transducers (water contents) • ADCP (local current velocity and wave spectrum) • Light sensor (PAR light intensity) • Turbidity sensor (turbidity) • Cameras (Photos of water contents) • NO3 Sensor (NO3 value)	H	Grant Agreement 862915
	1.2 Location	1.2.1	the hole system will be placed in the N of the FINO3 Platform to avoid interaction with other projects	H	
		1.2.2	the hole system will be at least 100m away from the FINO3 Platform (nautical safety-zone of the platform is a 500m radius)	H	
		1.2.3	the east-quarter of the FINO3 area (from NE to SE) is the preferred supply vessel zone which needs to be kept free as well	H	
	1.3 Arrangement	1.3.1	The longline systems will be placed in parallel to the main current direction	H	(John C. Bonardelli et al. 2019; Buck 2007a)
		1.3.2	both systems (mussel- and seaweed-system) will be placed in parallel next to each other	H	
		1.3.3	the lander will be placed in the middle of the two longlines to investigate both longlines with two echo sounders looking to each site at the same time	H	4HJena
		1.3.4	the distance between the lander and the FINO3 platform shall not be larger than 280m due to the length of the sea cable (350m total length incl. length of the way from seafloor up to the server rack)	H	

		1.3.5	the longlines should be submerged ~5m below surface to avoid waves smashing the system	H	(John C. Bonardelli et al. 2019; Buck 2007a)
		1.3.6	The whole site will be marked with spar buoys that fit the following requirements: Total length: at least 6m Coating: yellow Top sign: yellow lying cross Labeling: "ODAS" or "Mess-G" Identification: Flash (5) g.20s Nominal carrying capacity: 3nm (with visibility value=0.5)	H	(BSH 2017)
2. Dimensions	2.1 Size	2.1.1	the distance between the longlines needs to be between 60-80m (regarding to requirements of the echosounder and the safety requirements to avoid interaction/collision between the two systems and the lander)	H	(John C. Bonardelli et al. 2019); 4HJena
		2.1.2	the length of the backbone shall be 100m (common length for aquaculture longline systems)	M	
		2.1.2	the length of the mooring chains (from backbone to anchor)shall be four to five times of the water depth (~100m chain length)	H	
	2.2 Anchors	2.2.1	the anchors need to provide the ultimate holding capacity to keep the system in position	H	
	2.3 Buoyancy	2.3.1	the buoyancy of the whole system needs to be high enough to ensure that the system will not sink to the seafloor due to growth	H	
3. Installation/ Decommissioning	3.1 General	3.1.1	all installed materials need to be decommissioned without any remains	H	
		3.1.2	the whole operating period will be 12 to 18 months	H	
		3.1.3	the installation of the mooring for both longlines, the installation of the mussel-longline, the installation of the marker buoys and the installation of the lander need to be done in one trip (March/April 2021)	H	
		3.1.4	The installation of the seaweed-longline needs to be done in one trip (September/October 2021)	H	

	3.2 Anchors	3.2.1	the anchors need to be installed and uninstalled without the need of divers	H	
4. Maintenance/Sampling	4.1 Material	4.1.1	the chosen equipment needs to withstand the conditions described in the environmental conditions table without any maintenance	H	
	4.2 Buoyancy	4.2.1	there should be no need of attaching extra buoyancy to the system within the operating period to avoid extra maintenance trips and to avoid the system of sinking to the seafloor	H	
	4.3 Sampling/ Harvesting	4.3.1	to allow sampling or harvesting it is necessary that the systems can be lifted without loosening any connections	H	

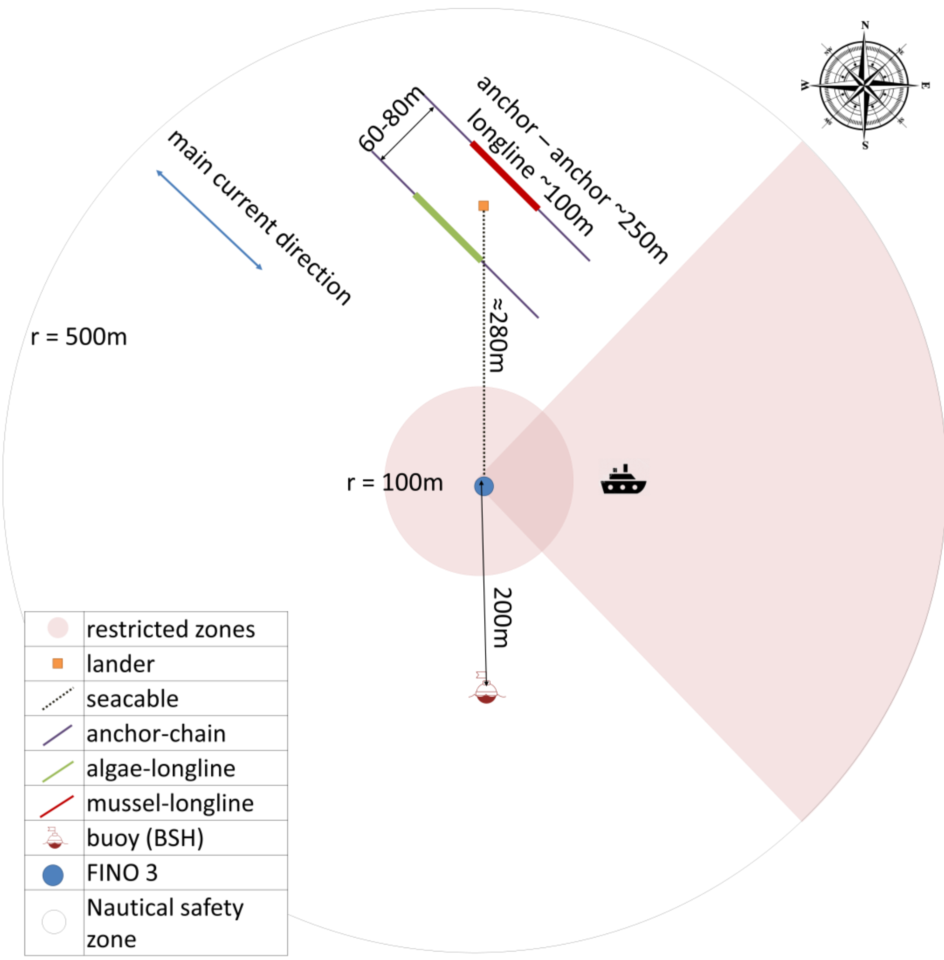

Figure 53: First layout of general arrangement at the FINO3 location – German Pilot

3. Phase

The morphological boxes below (Table 25 & Table 26) show on the left side all sub tasks which together in combination fulfill the main task of cultivating mussels and seaweeds. For each sub task several solutions with pros and cons are shown. Practically it is not feasible to combine all solutions of the sub tasks to get a functional running system. Therefore, only practically useful overall solutions have been combined. These are shown by the colored marks. Based on the general requirements for the systems and taking into account the advantages and disadvantages of the individual partial solutions, we have decided on an overall solution for the seaweed and mussel system consisting of the partial solutions marked in green. For clarity, only the green dots have been connected with lines. The other markings (triangles and squares) could be connected with lines in the same way to symbolize the other overall solutions.

Table 25: Morphological box - mussel system for German Pilot

Parameters	Potential solution														
	A			B			C			D			E		
	A	pros	cons	B	pros	cons	C	pros	cons	D	pros	cons	E	pros	cons
1 Anchoring	concrete blocks	relatively cheap	huge amount is needed depending on the system size difficult to transport a huge number	heavy weight anchors (e.g.discarded train wheels)	relatively cheap	huge amount is needed depending on the system size difficult to transport a huge number touching surface on the souil is quite small	screw anchors	high holding capacity relatively cheap easy to transport perfect for upscaling	special tools/vessels are required divers maybe required difficult/impossible to decomission	drag anchors	high holding capacity easy installation with a suitable vessel easy decomission	expensive if not rented or bough second hand not cost efficient when upscaling			
2 Mooring	mooring chains	high holding capacity damping effect due to high weight	heavy (need to be laid out of the vessel) requires higher buoyancy	mooring ropes	lighter than chains (easy transport)	lower holding capacity less weight leads to less damping									
3 Buoancy for mooring	spar buoys	high buoancy damping effect due to high weight	relatively expensive difficult to transport in one installation-trip	balloon fender	relatively cheap easy to transport	maybe bouncy on the surface	tons/barrels	high buoyancy due to high weight damping effect	huge and expensive difficult to transport	fender	cheap easy to transport less buoncy due to the shape	less buoyancy than ballon fenders			
4 Buoancy for growth	balloon fender	high buoancy cheap easy to transport	bouncing on the surface leads to sharp movements in the system	tons/barrels	high buonancy damping effect due to high weight	huge and expensive difficult to transport	trawl floats	small and cheap	high number required	fender	cheap easy to transport less buoncy due to the shape	less buoyancy than ballon fenders			
5 Backbone	rope	relatively cheap light weight easy to transport	needs to be tight enough to prevent the system from entanglement	wire	high holding capacity less likely to get entangled	more buoyancy is required due to higher weight	pipe	entanglement can be used as a float on the surface	higher drag due to bigger surface in the water difficult to transport						
6 Substrate for spat collection / growth	v-shaped continious fuzzy rope	relatively cheap several suppliers are available sufficient for high current areas only one weight per vis repiered	higher drag due to the fuzzys and small loops compared to a regular belt/rope	fuzzy rope droppers	if one dropper gets detached you will only loose this one	every dropper requires a weight which leads to a higher drag and requires more buoyancy the droppers can get tangeled due to movement in the system	v-shaped continious rough surface belt/rope	lower drag compared to fuzzy rope relatively cheap	the rough surface belts/ropes may not be sufficent for high current areas	rough surface belt/rope droppers	if one dropper gets detached you will only loose this one	the rough surface belts/ropes may not be sufficent for high current areas every dropper requires a weight which leads to a higher drag and requires more buoyancy the droppers can get tangeled due to movement in the system	net (rough surface rope)	bigger surface may lead to higher collection rates no tangeling higher growing rates expected	higher drag than droppers or v-shaped loops rough surface may not be sufficient for high current areas
7 Mooring connection	bow shackles	easy to install high holding capacity	can not be twisted	swivel shackles	allows beeing twisted	huge and expensive if equipped with jaws if equipped with eyes still standard shackels are required									
8 Backbone connction	bow shackles	easy to install high holding capacity	can not be twisted	swivel shackles	allows beeing twisted	huge and expensive if equipped with jaws if equipped with eyes they are cheaper but still standard shackels are required to be connected									
9 Marking	separately spar buoys	can be installed seperatly from the system no extra buoyancy required	needs extra mooring and anchoring only have a little buoyancy and can not lift any other equipment												

Table 26: Morphological box - seaweed system for German Pilot

	Parameters	Potential solution											
		A			B			C			D		
		A	pros	cons	B	pros	cons	C	pros	cons	D	pros	cons
1	Anchoring	**concrete blocks**	relatively cheap	huge amount is needed depending on the system size difficult to transport a huge number	**heavy weight anchors (e.g.discarded train wheels)**	relatively cheap	huge amount is needed depending on the system size difficult to transport a huge number touching surface on the souil is quite small	**screw anchors**	high holding capacity relatively cheap easy to transport perfect for upscaling	special tools/vessels are required divers maybe required difficult/impossible to decomission	**drag anchors**	high holding capacity easy installation with a suitable vessel easy decomission	expensive if not rented or bough second hand not cost efficient when upscaling
2	Mooring	**mooring chains**	high holding capacity damping effect due to high weight	heavy (need to be laid out on the vessel) requires higher buoyancy	**mooring ropes**	lighter than chains (easy transport)	lower holding capacity less weight leeds to less damping						
3	Buoancy for mooring	**spar buoys**	high buoyancy damping effect due to high weight	relatively expensive difficult to transport in one installation-trip	**balloon fender**	relatively cheap easy to transport	maybe bouncy on the surface	**tons/barrels**	high buoyancy due to high weight damping effect	huge and expensive difficult to transport			
4	Buoancy for growth	**balloon fender**	high buoyancy cheap easy to transport	bouncing on the surface leads to sharp movements in the system	**tons/barrels**	high buoyancy damping effect due to high weight	huge and expensive difficult to transport	**trawl floats**	small and cheap	high number required	**fender**	cheap easy to transport less buoyancy due to the shape	less buoyancy than ballon fenders
5	Backbone	**rope**	relatively cheap light weight easy to transport	needs to be tight enough to prevent the system from entanglement	**wire**	high holding capacity less likely to get entangled	more buoyancy is required due to higher weight	**pipe**	entanglement can be used as a float on the surface	higher drag due to bigger surface in the water difficult to transport			
6	Substrate for growth	**longline/backbone**	relatively cheap light weight easy to transport several suppliers are available	lower growth rate	**droppers on backbone**	bigger surface leads to higher growth rate	weights on every dropper are required to prevent them from floating up tangeling between droppers shaking of droppers higher drag in the water bigger mooring is required	**net**	bigger surface leads to higher growth rate	higher drag in the water bigger mooring is required lots of small floats are necessary can not be pre assambled by FuE or KMF			
7	Mooring connection	**bow shackles**	easy to install high holding capacity	can not be twisted	**swivel shackles**	allows beeing twisted	huge and expensive if equipped with jaws if equipped with eyes still standard shackels are required						
8	Backbone connction	**bow shackles**	easy to install high holding capacity	can not be twisted	**swivel shackles**	allows beeing twisted	huge and expensive if equipped with jaws if equipped with eyes they are cheaper but still standard shackels are required to be connected						
9	Marking	**separately spar buoys**	can be installed seperatly from the system	needs extra mooring and anchoring only have a little buoyancy and can not lift any other equipment									

4. Phase

Based on the information and requirements from the former phases the two following designs for cultivation of mussels and seaweed at the FINO3 location have been developed.

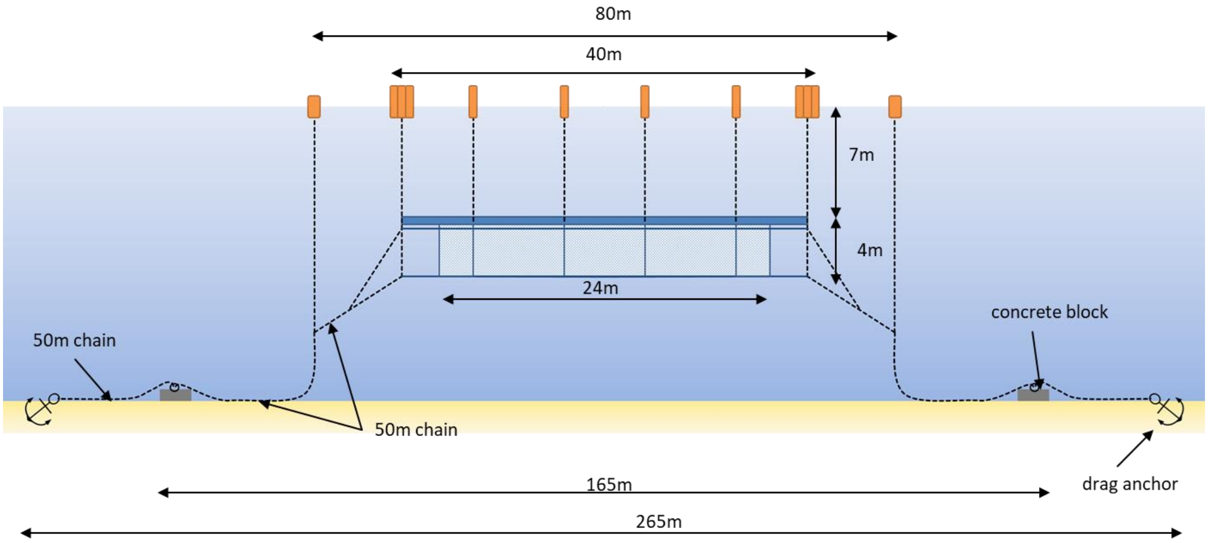

Figure 54: Mussel system design - German Pilot

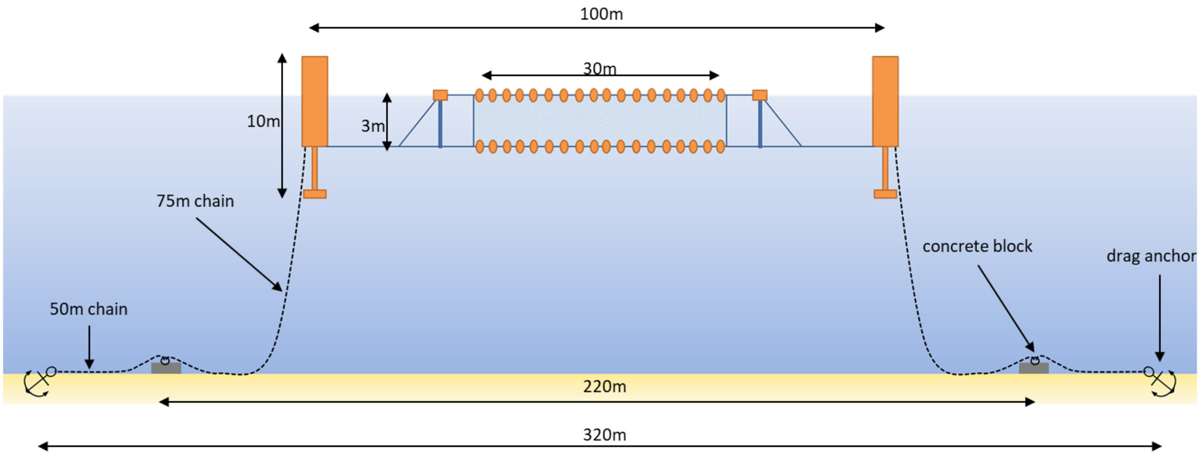

Figure 55: Seaweed system design - German Pilot

6. Phase

Meeting all requirements from the former phases and the final designs for the aquaculture systems the following figure shows the final layout for the arrangement at the FINO3 location

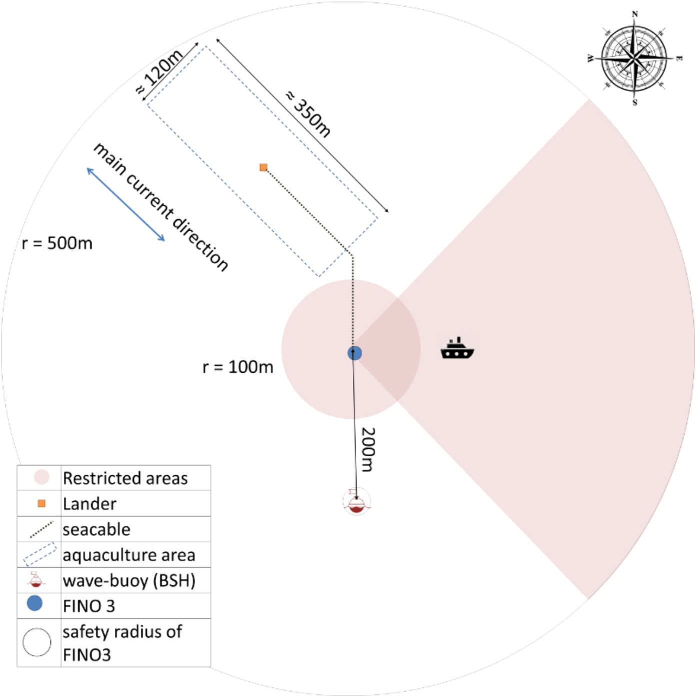

Figure 56: Final layout of general arrangement at the FINO3 location – German Pilot

The following tables show the current status of the installation procedure.

Table 27: Installation procedure - marking the aquaculture area

1. MARKING THE AQUACULTURE AREA				
NO.	TASK DESCRIPTION	DONE SUC-CESS-FULLY	DONE WITH DEVIATION	COMMENT
1.1	SET SPAR BUOY 1 detailed description of single installation steps: e.g. -move and hold in position **N55° 11.94068 E7° 9.30972**			
1.2	SET SPAR BUOY 2 - detailed description of single installation steps			
1.3	SET SPAR BUOY 3 - detailed description of single installation steps			
1.4	SET SPAR BUOY 4 - detailed description of single installation steps			

Table 28: Installation procedure - installing the mussel system

2. INSTALLING THE MUSSEL SYSTEM				
NO.	TASK DESCRIPTION	DONE SUC-CESS-FULLY	DONE WITH DEVIATION	COMMENT
2.1	SET NORTHERN ANCHOR -move and hold in position **N55° 11.91683 E7° 9.32475** -move and hold in position **N55° 11.89777 E7° 9.35817**			
2.2	SET SOUTERN ANCHOR -detailed description of single installation steps			
2.3	MUSSEL SYSTEM detailed description of single installation steps			

Table 29: Installation procedure - deploying and connecting the lander to FINO3

3. DEPLOYING AND CONNECTING THE LANDER TO FINO3				
NO.	TASK DESCRIPTION	DONE SUC-CESS-FULLY	DONE WITH DEVIATION	COMMENT
3.1	DEPLOYING LANDER - detailed description of single installation steps			
3.2	ALIGHNMENT OF LANDER - detailed description of single installation steps			
3.3	CONNECTING LANDER TO FINO3 - detailed description of single installation steps			

Table 30: Installation procedure - installing mooring for seaweed system and intermediate longline

4. INSTALLING MOORING FOR SEAWEED SYSTEM AND INTERMEDI-ATE LONGLINE				
NO.	TASK DESCRIPTION	DONE SUC-CESS-FULLY	DONE WITH DEVIATION	COMMENT
4.1	SET NORTHERN ANCHOR - detailed description of single installation steps			
4.2	SET SOUTERN ANCHOR - detailed description of single installation steps			
4.3	Installation of LINE - detailed description of single installation steps			

Table 31: Installation procedure - installing the seaweed net

5. INSTALLING THE SEAWEED NET				
NO.	TASK DESCRIPTION	DONE SUC-CESS-FULLY	DONE WITH DEVIATION	COMMENT
5.1	HOOK IN THE SEAWEED NET - detailed description of single installation steps			

GHENT UNIVERSITY

FACULTY OF ENGINEERING AND ARCHITECTURE
Maritime Technology Division

FINO3 SEAWEED CULTIVATOR TECHNICAL REQUIREMENTS

UNITED – PILOT GERMANY

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report summarizes the calculations that have been done by the Maritime Technology Division of Ghent University (MTD UGent) to the seaweed cultivator designed by Aqitec for a pilot study under the framework of the UNITED German Pilot project. In this research project, the feasibility of cultivating seaweed in the German part of the North Sea is assessed in terms of biological, technical and economical standpoints. The seaweed cultivator system will be installed in the FINO3 research platform located at 80 km of the coast of Sylt.

The system consists of a single net of 30 m long and 3 m wide installed vertically. The net has a mesh size of 0.4 m x 0.4 m. The upper part of the net is kept afloat by multiple floaters. Underneath each net, sinkers are used as a counterweight. The net is connected on each side through a series of dyneema ropes to two spar buoys holding the system in place. Each of the spar buoys is connected to a concrete block of 6 tons dry mass resting on the seabed and connected with a chain of 75 m long. Finally, a second chain has a length of 50 m and connects the concrete block with a Delta flipper anchor type.

The numerical calculations have been performed using the in-house developed mooring dynamic solver MoorDyn-UGent, based on the lumped-mass. The hydrodynamic forces on all the elements of the system are modelled according to the Morison Equation. The numerical net has been modelled as a combination of cylindrical elements with a mesh size coarser than the real net. The effect of the seaweed on the net has been modelled considering the seaweed is behaving as fouling attaching to the net. The projection area, volume and weight of the cylindrical elements have been increased accordingly in the numerical model to simulate the behaviour of a net fouled with seaweed. The load combinations used for the simulations are based on a 5-year return period of wave and a 1 -year return period of current.

Based on the numerical study performed the following conclusions and recommendations are included for consideration:

- For a 5-year return period of waves and current, if the cultivator system is located in-line with waves and currents provides the highest loading.
- According to a combined safety factor of 2.3, the MBL of the chain should not be less than 565 kN. If used chains were to be used, the safety factor is increased to 5.75 and the MBL should not be less than 1414 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 28 mm should not be less than 449 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 16 mm should not be less than 242 kN.
- The maximum tension on the strength-ropes holding the net do not exceed the breaking load indicated by Aqitec.
- The maximum horizontal load transferred to the anchor is 266 kN.
- The maximum vertical load transferred to the anchor is 41 kN.
- For a short installation period (3 months of marine growth), fouling does not have a major impact on the structural loads
- The spar buoys should be able to be submerged at least at a depth of 10 m.
- It is advised to monitor the position of the chain with respect to the lower part of the spar buoy to avoid any possible entanglement.

1 INTRODUCTION

In the framework of UNITED project, a seaweed cultivator system has been designed by Aqitec [1] for the German Pilot within the UNITED project [2]. This seaweed cultivator will be installed at the FINO3 research platform (see Figure 1. Deployment location of the seaweed cultivator FINO3) in the German part of the North Sea to study the feasibility of growing seaweed in an offshore environment under harsh environmental conditions. This report includes a detail description of the numerical model simulations carried out by the Maritime Technology Division of Ghent University (MTD UGent) to evaluate the dynamic behaviour of the system subjected to waves and current induced load for the following conditions: (i) 1-year return period, (ii) 5-year return period, and (iii) 50-year return period. The numerical simulations have been carried out by MTD UGent using the numerical model MoorDyn-UGent [3]. The standards and guidelines used are included in Section 2. A description of the FINO3 research platform and the prototype seaweed cultivator system provided by Aqitec is summarized in Section 3. The numerical model set-up and inputs are described in Section 4 of this report. Section 5 presents the analysis of the results from the numerical model tests. Finally, in Section 6 test results are summarised and conclusions are formulated.

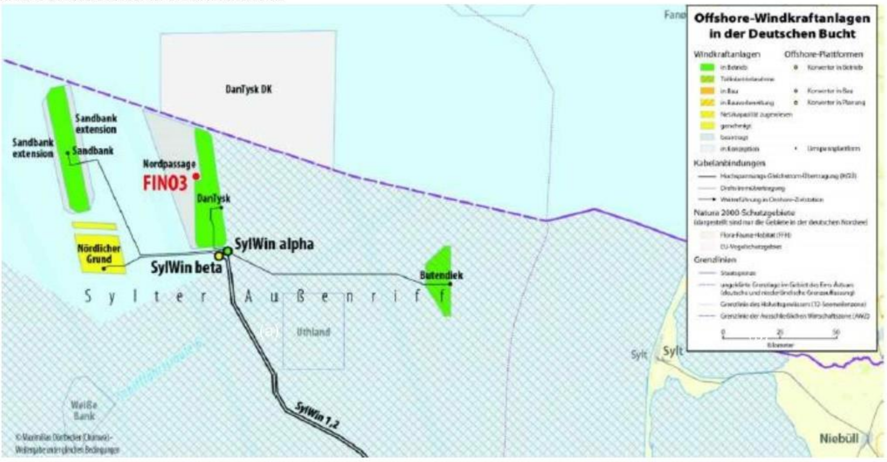


Figure 1. Deployment location of the seaweed cultivator FINO3 [4]

2 GUIDELINES AND STANDARDS

The following documents are used as guidelines and input for the numerical calculations presented in this report:

- Seaweed Cultivator Report produced by Aqitec [4] [5] [6]
- Norwegian Standard NS 9415; Marine fish farms requirements for site survey, risk analyses, design, dimensioning, production, installation and operation [7]
- DNVGL OS-301; Position mooring [8]
- DNVGL OS-C101; Design of offshore steel structures, general – LRFD method [9]
- DNV RP-C205; Environmental conditions and environmental loads [10]
- NORSOK STANDARD N-003; Actions and action effects [11]

3 NUMERICAL MODELLING

3.1 MoorDyn-UGent

An open-source time-domain mooring dynamic solver based upon the lumped-mass approach, MoorDyn [12] has been modified in-house by Maritime Technology Division of Ghent University [3] to include waves and current induced loads. The inclusion of the aforementioned environmental loads is done by the use of Morison Equation, which is a semi-empirical formula that splits the forces into its drag and inertial component [13]. Adaptations also introduced a three degree-of-freedom buoy, clump weight and horizontal seabed interaction. In this approach, the internal forces (line tension, weight, buoyancy) and external forces are calculated at each node to obtain the accelerations. The equations of motions are reduced into a set of ordinary differential equations (ODEs) and solved using a Runge-Kutta second order integration scheme at each time step [12] [3].

3.2 Input data

Environmental conditions

The environmental characteristics are based on the input data used by Aqitec to design the seaweed cultivator. Wave measurements from a wave buoy of the Federal Maritime and Hydrographic Agency (BHS) located at 200 m south of the FINO3 research platform were used as they are representative of the wave climate in the area. Additionally, current information provided to Aqitec by the FuE-Zentrum was used to define the current surface velocity. A more detailed description of the environmental conditions is included in [4]. The seaweed cultivator will be installed aligned with the main current direction "going to" south-west (see Figure 2):

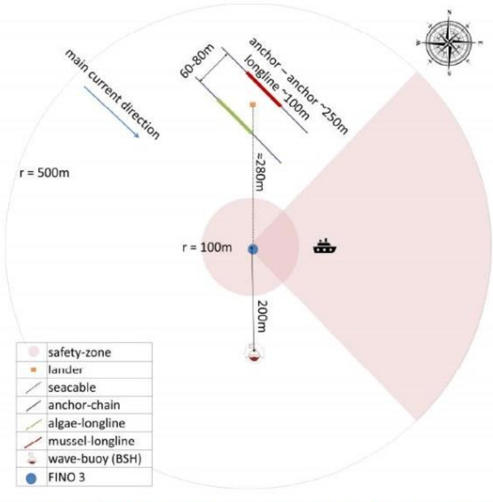


Figure 2: Relative position of the seaweed cultivator in relation to the main current direction [3].

The following load cases have been identified by the MTD UGent to perform the numerical simulations of the seaweed cultivator and have been included in *Table 1. Load combination*:

Table 1. Load combinations

Wave						Current	
Case	input	return period	height	period	direction	speed	direction
[-]	[-]	year	[m]	[s]	[going-to]	[m/s]	[going-to]
1	Regular wave	1	11.1	11.2	South-East	1.20	South-East
2	Regular wave	5	12.1	14.5	South-East	1.20	South-East
3	Regular wave	50	13.9	17.9	South-East	1.40	South-East
4	Regular wave	5	12.1	14.5	South-East	1.20	North-East
5	Regular wave	5	12.1	14.5	North-East	1.20	North-East
6	Regular wave	5	12.1	14.5	North-East	1.20	South-East

Seaweed cultivator design

The seaweed cultivator that will be installed in the FINO3 research has been designed by Aqitec [5] [6]. The system consists of a single net 30 m long and 3 m wide installed vertically. The net has a mesh size of 0.4 m x 0.4 m with a fresh weight of seaweed on air of 7 kg/m and a density of 1183 kg/m3 [14]. The upper part of the net is kept afloat by attaching 3 floaters of 2.75 l per meter of net. Underneath each net, sinkers of 0.75l and 0.955 kg are used as a counterweight placing 3 sinkers per meter of net. The net is connected in each side through a series of Dyneema ropes to two spar buoys of 5270 l. The net is connected on each side through a series of dyneema ropes to two spar buoys holding the system in place. Each of the spar buoys is connected to a concrete block of 6 tons dry mass resting on the seabed and connected with a chain of 75 m long. Finally, a second chain has a length of 50 m and connects the concrete block with a Delta flipper anchor type. Details of the seaweed cultivator are included in Figure 3. A more extensive description of the system can be found in [5] [6].

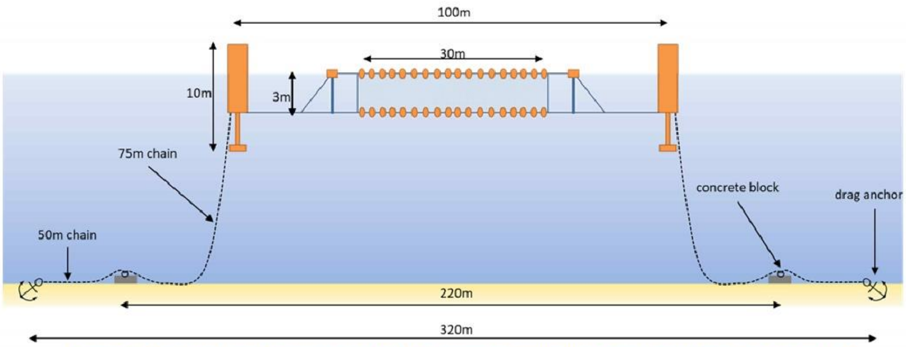


Figure 3. Provided layout arrangement of the seaweed cultivation system received as an input [6]

3.3 Seaweed numerical modelling

Seaweed hydrodynamics

In recent years, several studies have been performed to assess the hydrodynamic interactions of different types of seaweed subjected to various flow characteristics. Xu and Komatsu [15] performed a field experiment of *Sargassum horneri* to determine the drag coefficient exerted by the seaweed in a unidirectional flow. The measurement is done by towing the seaweed attached to a boat. Using the field data obtained during the experimental campaign, the drag coefficients (C_d) for a range of Reynolds numbers (*Re)* between 10^4 to 10^6 can be expressed with the following formula [15]:

$$C_d = 18.295\ Re^{-0.57} \quad (1)$$

On a separate study, Norvik [16] performed a laboratory experiment on an artificial seaweed model of *Saccharina latissima* subjected to a unidirectional flow to compare the behaviour and hydrodynamics properties of two different morphologies: flat and undulate. The conclusion of this study suggests that the undulate model results in higher drag force than the flat model. At higher velocities the cluster undulate model has 3-4 times higher drag coefficients that cluster flat model. However, the behaviour of the two models is different, probably due to the difference in mechanical properties of the artificial seaweed compared to a real sugar kelp. Therefore, it was suggested that in future research a comparison with real undulate seaweed is performed. Furthermore, Vettori and Nikora [17] conducted an experiment in an open-channel flume to measure the load exerted by the presence of real *Saccharina latissima* at a blade scale in a unidirectional turbulent flow. They found that the blade interacts differently as the flow velocity increases, resulting in lower mean force for high velocities. This is due to the biomechanical properties of the seaweed blade that adapts to the flow conditions, creating scale-dependent interactions of wake flow and turbulent eddies. Drag coefficients obtained from this study is within the range of 0.02 – 0.08 [17], well within similar range with the results from Norvik [16] for undulate large seaweed model.

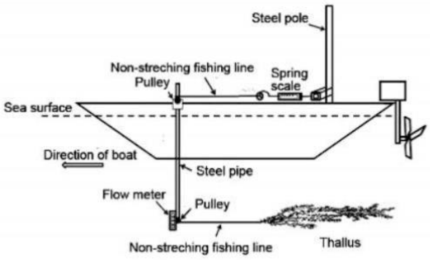
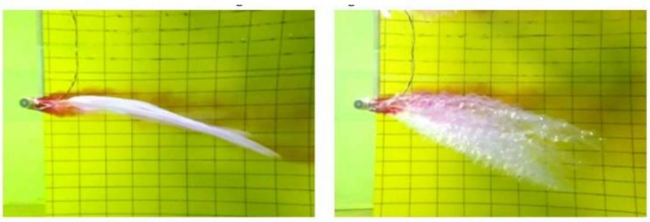


Fig. 2. Schematic diagram showing the system used to measure drag force on a *Sargassum horneri* thallus towed at a constant speed by a boat.

Figure 4. Excerpt from an article published by Xu and Komatsu [15] showing the schematic of their experimental setup



(b) The flat blades suppress the alternating vortex shedding.

(c) The undulate blades suppress the alternating vortex shedding

Figure 5. Excerpt from a master's thesis published by Norvik C. [16] comparing hydrodynamics of flat and undulate artificial seaweed blades

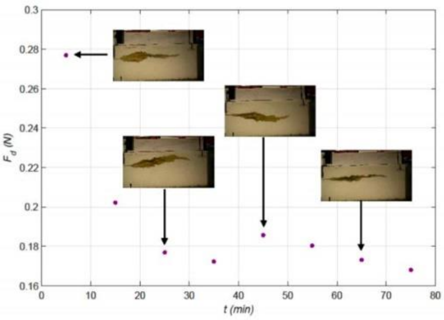


Figure 6. Excerpt from an article published by Vettori and Nikora [17] showing the reconfiguration of the blade as the flow velocity increases over time

Hydrodynamics of net structures

In the past three decades, several experiments had been conducted to study the hydrodynamics of a net structure subjected to current induced load [18] [19] [20] [21] [22]. In the early 2000s, Pal et.al developed a numerical model to simulate the dynamic behaviour of 3D net structures subjected to waves and currents [23] [24]. Their numerical net is modelled as numerous elements connected via nodes where the drag force is based on a semi-empirical formula. In their studies, the drag coefficient as a function of net solidity and angle of attack, is taken from the formula derived by Aarsnes et. al [25] based on extensive model tests performed by Rudi et. al [22]. Essentially, a net is an array of cylinders. The approach of modelling a numerical net represented by an array of cylinders with less elements than the physical model was also done by Fredheim [18] where the numerical calculations results are compared with experiment done by Enehaug [21].

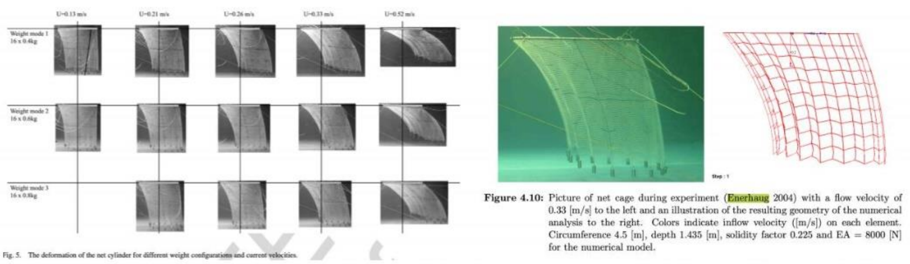


Figure 7. Excerpt from a journal article by Pal et. al [26] (left) and excerpt from PhD Thesis of Fredheim [18] (right)

In their validation study, Pal et. al [26] found that the deformation of a physical net in real life, confirmed by the experiment results, had caused the overprediction in their numerical calculations. The elasticity of the net shall be considered in the numerical model to achieve a more accurate prediction. More than a decade later, Cifuentes and Kim [27] built a numerical net using a lumped mass based commercial mooring dynamic software called OrcaFlex [28]. The hydrodynamic interactions are modelled using the Morison Equation [11]. They tried to address the deformation of the real physical net that causes a deviation in the numerical results by including the reduction of flow velocity that passed through the net. The inclusion of the shielding effects is done via the wake model derived for riser interactions by Blevins [29]. To account for *Re* number dependencies, at each-time step the drag coefficient is calculated based on the instantaneous velocity, which is based on the contribution of body and fluid velocity. Drag coefficient as a function of Reynolds number had been derived from the study done in the 1971 by

Choo and Casarella [30]. Extending the results of Choo and Casarella [30], DeCew and Tsukrov proposed the following formulae [31]:

$$C_{dn} = \begin{cases} \frac{8\pi}{Re\, s}(1 - 0.87s^{-2}),\ 0 < Re < 1 \\ 1.45 + 8.55\, Re^{-0.90},\ 1 < Re \leq 30 \\ 1.1 + 4\, Re^{-0.5},\ 30 < Re \leq 2.33 \times 10^5 \\ -3.41 \times 10^{-6}(Re - 5.78 \times 10^5),\ 2.33 \times 10^5 < Re \leq 4.92 \times 10^5 \\ 0.401\left(1 - e^{-\frac{Re}{5.99}\times 10^5}\right),\ 4.92 \times 10^5 < Re \leq 10^7 \end{cases} \quad (2)$$

Where:

$$s = -0.077215655 + \ln(\frac{8}{Re}) \quad (3)$$

Cifuentes and Kim [27] adapted the time-step dependent drag coefficient based on the formulae proposed by DeCew and Tsukrov [31] by including the shielding effects from wake formula of Blevins [29]. This is done by calculating the drag coefficient in the downstream elements that is affected by the wake of upstream elements. They concluded that this new approach has improved the previously model proposed by Lader [26] by addressing the influence of net solidity and Reynolds number to the drag coefficients.

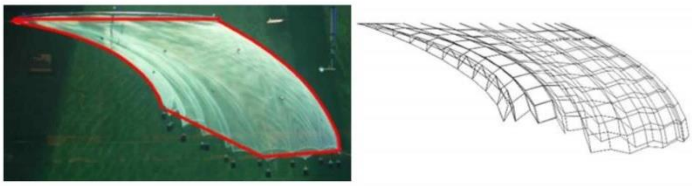


Fig. 3 Net deformation from experiments (Moe-Føre *et al.* 2015) and numerical calculations

Figure 8. Excerpt from a journal article published by Cifuentes and Kim [27] showing the comparison of their numerical model and laboratory physical model

Impact of biofouling on net structures

Observed by Pal et. al the effect of biofouling provides significant contributions to the deformation of net structures in a study performed on two full-scale commercial sea-cages [20]. In the experiment carried by Swift et. al, the increase in the drag coefficient (C_d) on a net impacted by biofouling ranges from 6% to 240% compared to the C_d of a clean net [32]. In another experiment conducted by Gansel et. al [33], the impact of biofouling was assessed for several nets with different solidities. For a net with the same solidity, fouling could increase the drag force by 43% [33]. However, they suggested that future research should by focused on testing nets that have very high solidities to better assess the performance of heavily fouled aquaculture structures. In a more recent experimental study by Niño et. al [34], normal and tangential drag coefficients were derived as functions of Reynolds number and net solidity. The tests were performed on clean nets as well as fouled nets. It is mentioned that the drag coefficients obtained from their experiment are only valid for the biofouling consisting on small bivalve and filamentous algae [34].

Additionally, as a practical engineering guideline in mooring design, *Det Norske Veritas* (DNV) [8] suggests considering the influence of marine growth on a line element by taking the fouling thickness from field measurement or recommendation from NORSOK N-003 [11].

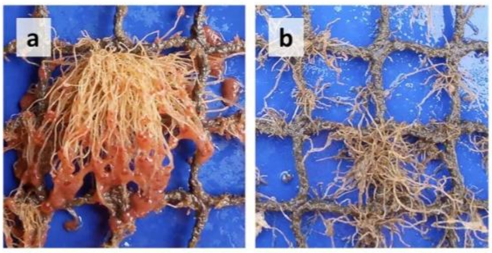


Fig 1. Hydroid fouling on aquaculture nets. The images show net panels on the same fish farm, but at different times with approximately one month between the images. Hydroids found on Norwegian salmon cages have bright pink hydranths (a), but on some nets, probably mostly in late autumn and early winter, hydranths may be lost or retracted (b).

Figure 9. Excerpt from a journal article published by Gansel et. al [33] showing fouled nets

Table 3 – Thickness of marine growth [a]

Water depth m	56° to 59° N mm	59° to 72° N mm
Above + 2	0	0
+2 to - 40	100	60
Under - 40	50	30
[a] The water depth refers to mean water level		

Figure 10. Excerpt table of marine growth thickness that has been increased linearly over the period of 2 years [11]

The following formula are used to determine the influence of marine growth on the system [8]:

$$M_{growth} = \frac{\pi}{4}\left[(D_{nom} + 2\Delta T_{growth})^2 - D_{nom}{}^2\right]\rho_{growth}\,\mu\,(kg/m)\,, \quad (4)$$

$$W_{growth} = M_{growth}\left[1 - \frac{\rho_{seawater}}{\rho_{growth}}\right]\frac{9.81}{1000}(kN/m), \quad (5)$$

$$C_{dgrowth} = C_D\left[\frac{D_{nom}+2\Delta T_{growth}}{D_{nom}}\right], \quad (6)$$

where:

M_{growth} = mass of marine growth
D_{nom} = nominal rope diameter
ΔT_{growth} = marine growth surface thickness
ρ_{growth} = marine growth density (1325 kg/m^3)
μ = 2.0 for chain, 1.0 for wire rope
$\rho_{seawater}$ = sea water density (1025 kg/m^3)
C_d = drag coefficient
$C_{dgrowth}$ = drag coefficient due to marine growth

It is important to point out that in this approach, the drag coefficient ($C_{dgrowth}$) is adapted to account for the increase in drag area due to the additional thickness in the line element from the presence of marine growth (ΔT_{growth}).

Numerical modelling of a net and seaweed as a fouled net using lumped-mass approach

In the aforementioned literature review on seaweed hydrodynamics, the studies were all focusing on a blade scale or cluster of blade scales of seaweeds. As far as the authors' knowledge, a study has not been published regarding an experiment of fully grown seaweed attached to a net (see Figure 11). For the purpose of estimating the hydrodynamic force induced by the presence of fully grown seaweed on net, the approach of assuming seaweed as fouled net is implemented.

Figure 11. Seaweed on a net in the early stage of Belgian pilot nearshore experiment (left) [14] and fully grown seaweed on a net [35] (right)

This section of the report described the methodology used for modelling a numerical net by building a set of homogenous line segments with the properties of cylinders connected by nodes. The internal and external forces are equally transferred to the neighbouring nodes, namely the lumped-mass method [12] [3]. Compression force is not modelled, therefore, allowing each segment to compress as such it resembles the behaviour of a rope. The Morison Equation [13] is implemented to model the hydrodynamic interactions between the line elements and the fluid particles. Consequently, drag coefficient of line elements are necessary for this semi-empirical formula. The drag coefficients of mooring lines, backbone and buoy elements are taken from the recommendation provided by DNV [8] [10]. As for the net without seaweed, formulae derived by DeCew et. al [31] shown in the Equation (2) is used to determine the normal drag coefficient. The tangential drag coefficient is taken according to the study done by Cifuentes et. al [27]. The fully grown seaweed on a net is modelled with the approach suggested by DNV in the case of marine growth in line elements. This is done by firstly determine the thickness of biofouling. Then, the previously calculated *Reynolds*-dependant drag coefficients of the net are adjusted with the formula from DNV OS 301 [8] shown in Equation (6) to account for biofouling due to the fully grown seaweed. In this approach, the density of the marine growth (ρ_{growth}) shown in the Equation (4) is replaced by the seaweed density. A conservative value of 1183 kg/m^3 is used to account for the seaweed as marine growth on an array of ropes, namely net.

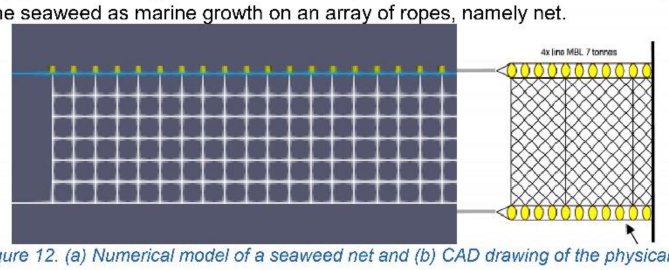


Figure 12. (a) Numerical model of a seaweed net and (b) CAD drawing of the physical net

The net in the physical model has a mesh size of 0.4 m x 0.4 m. The total length of all ropes in the net is 900 m. Two coarser net discretization has been initially defined in the numerical model to study the computationally efficiency and accuracy of the numerical results: (i) a mesh size of 0.5 m x 0.5 m and

(ii) a mesh size of 1.0 m x 1.0 m where chosen. Figure 12 shows a comparison between the numerical net (i) and the physical net.

Both numerical nets consist of equivalent cylindrical elements with homogenous properties. Diameter of each cylindrical element of each numerical net is calculated as such that the total volume of the numerical net is the same as the one from the physical model. This results in having different projected areas between the numerical model and the physical model. However, this is taken into account in the numerical calculations by multiplying the drag coefficient with the ratio between the area of each numerical net model and the physical net model, both for the normal and the tangential components. Figure 14 and Figure 14 show three snapshot of the numerical simulations showing the behaviour of the numerical net with a mesh size of 0.5 m x 0.5 m subjected to waves and currents.

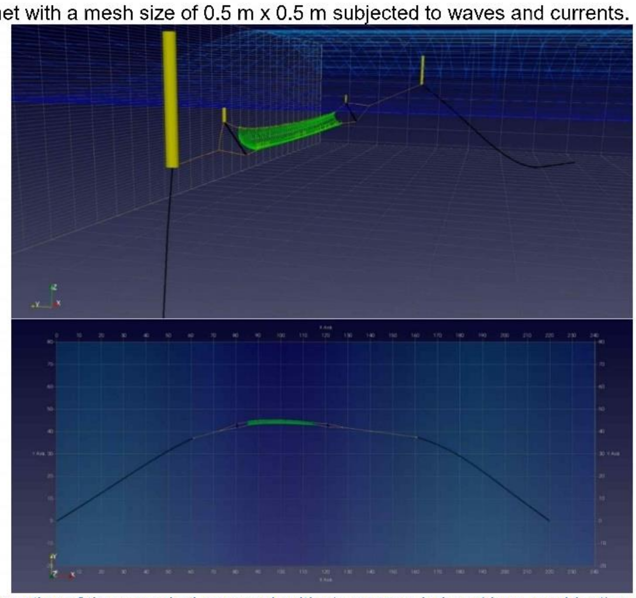


Figure 13 Deformation of the numerical seaweed cultivator system induced by a combination of 1-year current perpendicular to the system and 5-year return period of wave parallel to the longline

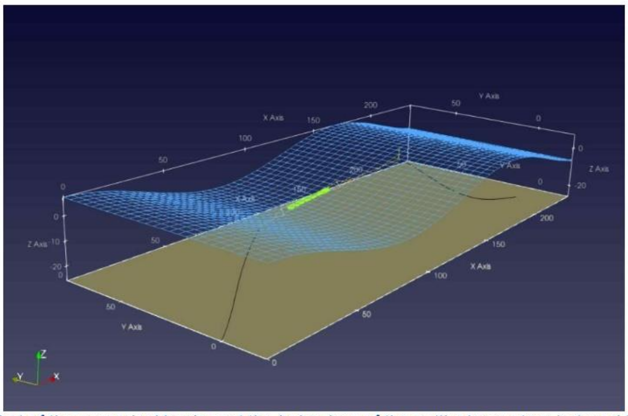


Figure 14. Snapshot of the numerical basin and the behaviour of the cultivator system induced by cross flow of 1-year current subjected to a 5-year storm event

3.4 Numerical model of the seaweed cultivator

The numerical seaweed cultivator system consists of a single net of 30 m x 3 m supported by 61 floaters and 61 sinkers. The net is connected by a series of dyneema ropes (R-04, R-05 and R-06) to two support buoys (B-05) and a spreader beam (B-03). Then, these dyneema ropes are connected to two spar buoys (B-02) using also a dyneema rope (R-01 and R-02). Finally, the two spar buoys are connected to a concrete block of 6 T through a studlink chain (C-01). In the numerical model the concrete blocks have been represented as two fixed points (A-02). This is a conservative approach as there is no information of the seabed properties and it is not possible to estimate the correct seabed friction parameters for the simulation. The total distance between the two anchor points is 220 m. Figure 15a includes a cross-section of the MoorDyn-UGent numerical set-up indicating the line elements used in the numerical simulations. Figure 15b includes a cross-section of the MoorDyn-UGent numerical set-up indicating the buoy elements and anchor points used in the numerical simulation. The most relevant parameters of the line elements, buoy elements and the drag values employed for the numerical simulations have been summarized in Table 2. Equivalent line elements used in the numerical simulations Table 3. Equivalent buoy elements used in the numerical simulations and Table 4, respectively.

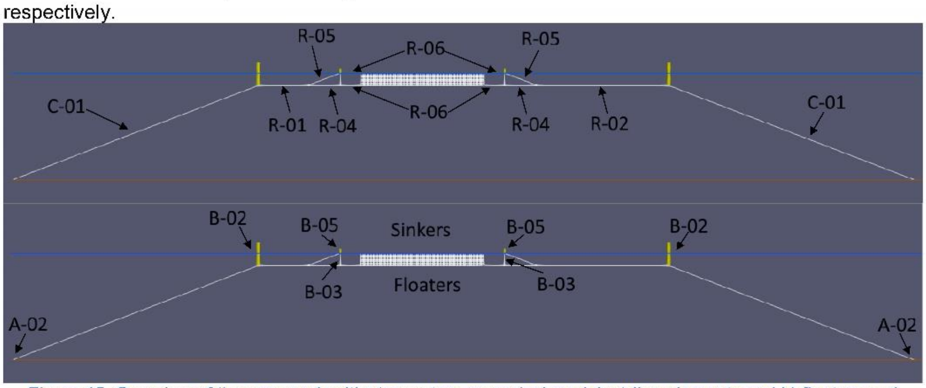


Figure 15. Overview of the seaweed cultivator system numerical model: a) line elements and b) floaters and anchor elements.

Table 2. Equivalent line elements used in the numerical simulations

Element	Type	Length (m)	Diameter (m)	Dry mass (kg/m)
C-01	Studlink Chain 48 mm	75	0.091	52.8
R-01	Dyneema 28 mm	12	0.025	0.49
R-02	Dyneema 28 mm	32	0.025	0.49
R-04	Dyneema 28 mm	8	0.025	0.49
R-05	Dyneema 16 mm	8.43	0.013	0.14
R-06	Dyneema 16 mm	5	0.013	0.14

Table 3. Equivalent buoy elements used in the numerical simulations

Element	Volume (l)	Weight (kg)	Diameter (m)	Length (m)	Quantity

B-02	5270	2377	1.1	5.54	2
B-03	0.019	159	0.089	3	2
B-05	0.23	30	0.523	1.071	2
Floater	0.00275	0.955	0.146	0.165	61
Sinker	0.00075	0.955	0.039	0.603	61

Table 4. Drag coefficients used in the numerical simulations.

Element	C_d	C_t
B-02	0.65	0.4
B-03	0.65	0
B-05	0.65	0.4
C-01	2.2	1.4
R-0X	1.5	0.2
Floaters	0.5	0
Sinkers	0.5	0
Net	0.088	0.001
Net + Seaweed	4.672	0.032

4 SIMULATION RESULTS

Presented in this chapter are the results of numerical calculations performed using lumped-mass approach [12] [3]. The hydrodynamics forces due to waves and current are calculated in the time domain and their impact to the anchors and mooring lines are analysed. Load combinations used for the dynamic calculation can be found in **Error! Reference source not found.**.

4.1 Hydrostatics at equilibrium

Hydrostatic calculations are performed to compare the impact of fully grown seaweed on net structures and 3 months of biofouling to the system's equilibrium. Figure 16a shows the hydrostatic equilibrium of the system after installation while Figure 16b depicts the hydrostatic equilibrium of the system 3 months after installation. As it is shown in Figure 16, it is not possible to visually appreciate any differences in the system. The spar buoys are sinking around 0.1 m while the net is sinking around 0.3 m when considering seaweed and fouling in the hydrostatic calculation with respect to just modelling the net and no-fouling. This indicates a good hydrostatic behaviour of the systems during its operation lifetime.

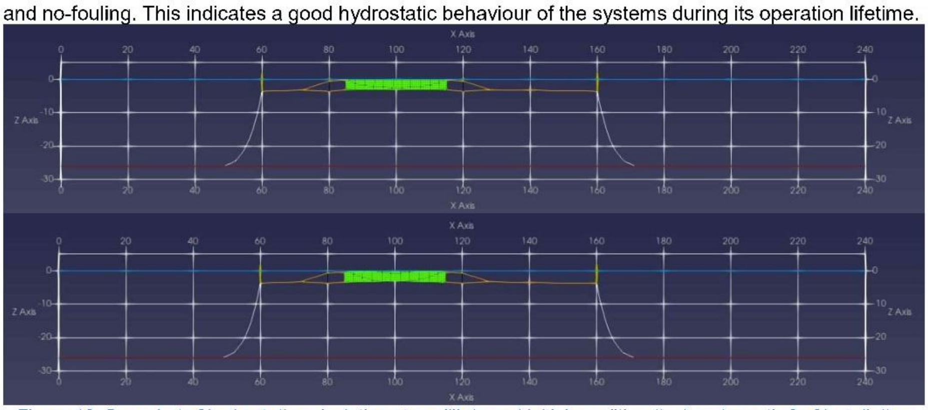


Figure 16. Snapshot of hydrostatic calculation at equilibrium at initial condition (top) and month-6 of installation (bottom)

4.2 Net discretization study

Six simulations were performed using the two net discretization's described in Section 3.4 and load cases 1, 2 and 3 (see *Table 1*). Figure 17 shows the tension that chain C-01 is subjected for the different load cases. As it can be seen in Figure 17, for two different net discretization, very similar results are obtained. The same comparison was made for all the line elements defined in Figure 15 achieving a similar agreement for all the line elements. Additionally, the forces in the anchor points (A-02) were also checked. Figure 18 shows the horizontal force for the north west anchor A-02 for the different load cases. Like in the line tension case a good agreement was found in both anchors for the two different net discretization. All results are consistent with the literature reviewed presented in Section 3.3, where the different studies show that it is not necessary to match the numerical discretization with the real net discretization to model the behaviour of the net.

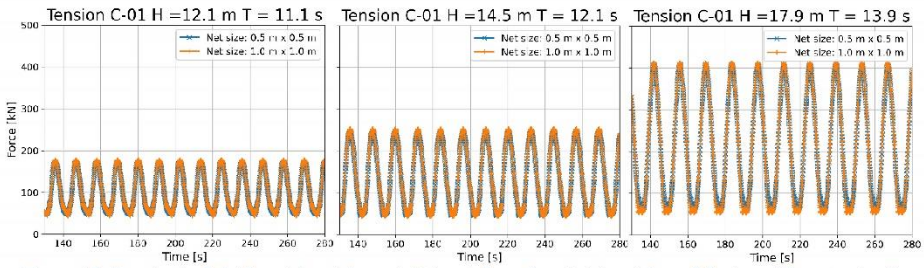


Figure 17. Tension in C-01 for: a) Load Case 1, b) Load Case 2 and c) Load Case 3 for two different net grid discretization.

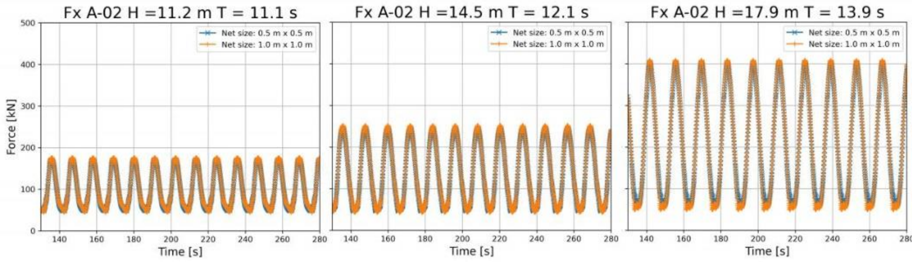


Figure 18 Horizontal force in A-02 for: a) Load Case 1, b) Load Case 2 and c) Load Case 3 for two different net grid discretization.

In terms of computational time, a coarser net (1 m x 1 m) is faster to run due to the reduced number of elements in the numerical model. Nevertheless, in this case it was decided to perform the rest of the numerical simulations using a finer net discretization (0.5 m x 0.5 m) as the computational cost was still reasonable.

4.3 Hydrodynamic Results

Figure 19 shows an snapshot of the hydrodynamic simulation for load case 2 with a net discretization of 0.5 m x 0.5 m. This load case 2 corresponds with the highest tensions that the chains of the system suffer for the load cases of 5-year period of return which is used as the design load for the system. As it can be observed during this simulation the north west chain is under tension taking the highest load, while the south east chain will be laying on the ground reducing the tension that this chain is taken (see Figure 20). It has to be noted that most of the load comes from the wave action on the system as it can be observed on the amplitude of the tension ranging from 48 kN to 246 kN. As it can be seen in Table 5 the maximum tension that any of the anchor chains will suffer (C-01) is not higher than 246 kN for the load cases corresponding with a 5-year period of return.

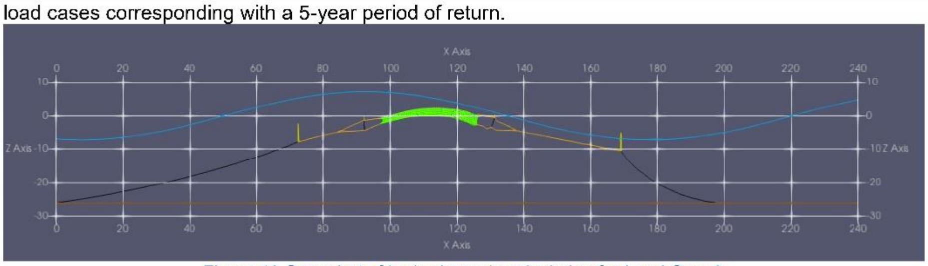


Figure 19 Snapshot of hydrodynamic calculation for Load Case2

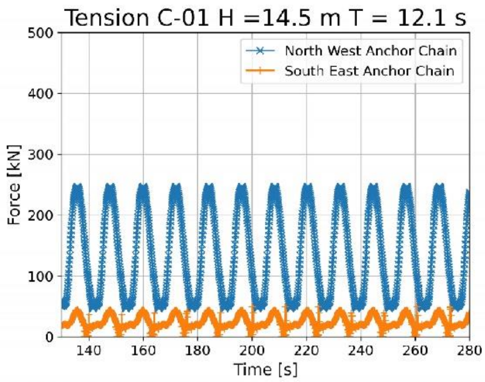


Figure 20. Tension for load case 2 at the north west anchor chain and at the south west anchor chain

The effect of 3 months fouling on the system was checked for all load cases. As it can be seen in Table 5 the maximum loads that the system is experiencing are not higher than 265 kN for the load cases corresponding with a 5-year period of return. This indicates that fouling does not have a major impact on the systems loads during the cultivation process of the seaweed for a short installation and harvesting period. However, if the system would stay longer on the water (e.g. on a commercial project of 15 years) special attention should be paid to fouling on the chains and dyneema ropes. In this case the effect of 24 months of fouling that grows linearly should be considered (according to NORSOK STANDARD N-003 and DNV RP-C205).

Table 5. Maximum tension at C-01

Structural Element	**Maximum Tension at C-01 (kN)**		
Load case	**Aqitec**	**No-Fouling**	**Fouling**
1	160	171	174
2	220	246	249
3	310	408	373
4	-	153	160
5	450	244	265
6	300	121	101

It was observed during the numerical simulation of load case 2 (see Figure 19) that the north west spar buoy is submerged at a depth of 10 m. As it can also be seen in the other different wave and current combinations simulated: in-line with waves and perpendicular to currents (load case 4, see Figure 21), perpendicular with waves and in-line with currents (load case 5, see Figure 22) and perpendicular with waves and currents (load case 6, see Figure 23) the spar buoys are at some stages of the simulations submerged up to a depth of at least 10 m.

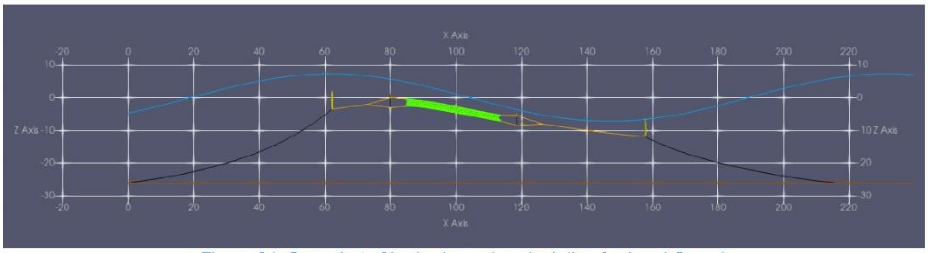


Figure 21. Snapshot of hydrodynamic calculation for Load Case4

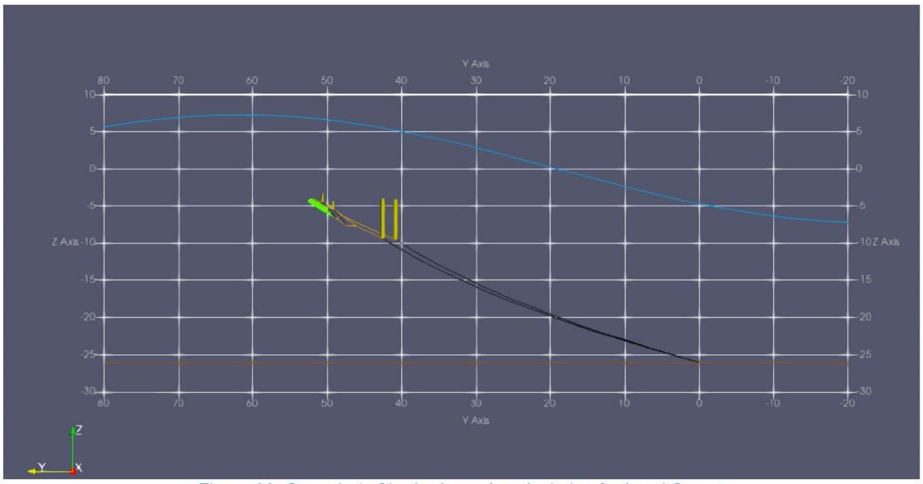


Figure 22. Snapshot of hydrodynamic calculation for Load Case 5

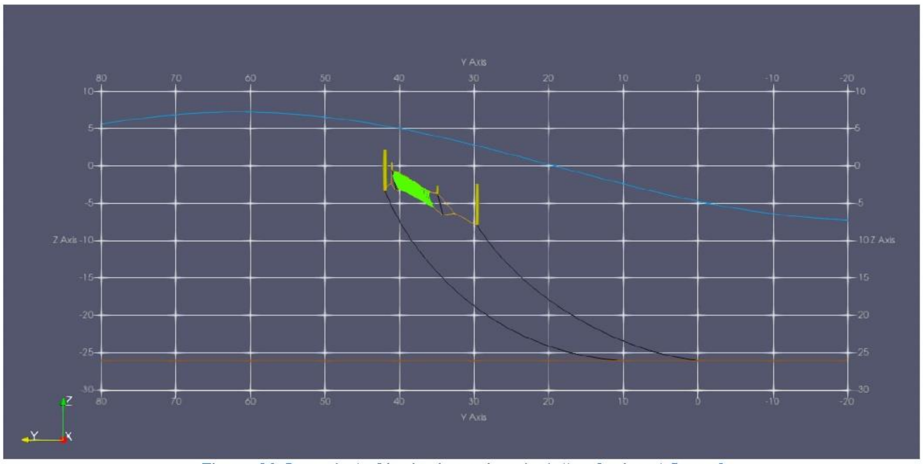


Figure 23 Snapshot of hydrodynamic calculation for Load Case 6

As summarized in Table 6. Maximum tension at R-06 the maximum load expected on the dyneema ropes connected to the net would be of a maximum of 110 kN for the loads cases corresponding with a 5-year return period (load cases 2,4,5 and 6). This is below the expected maximum breaking load of the strength-ropes holding the net corresponding to140 kN (as indicated by Aqitec [3]).

Table 6. Maximum tension at R-06

Structural Element	Maximum Tension at C-01 (kN)	
Load case	**Aqitec**	**No-Fouling**
1	70	50
2	100	70
3	140	120
4	-	63
5	140	111
6	90	31

Finally, the maximum loads suffered by the concrete block and transmitted to the north west anchor and south east anchor have been summarized in Table 7 and Table 8 respectively. For the case of 5-year period of return the maximum horizontal load transferred to the concrete block corresponds with load case 2 with a total horizontal force of 266 kN. The maximum horizontal load is obtained using equation 7. The Maximum vertical force experienced by the concrete block corresponds with 41 kN.

$$F_{max} = \sqrt{F_x^2 + F_y^2} \quad (7)$$

Table 7. Maximum Force at the North West Anchor

Structural Element	Maximum Force North West Anchor (kN)		
Load case	**Fx**	**Fy**	**Fz**
1	171	0	18
2	266	0	32
3	404	0	68
4	132	78	12
5	184	154	41
6	91	44	7

Table 8. Maximum force at the south west anchor

Structural Element	Maximum Force South East Anchor (kN)		
Load case	**Fx**	**Fy**	**Fz**
1	2	0	0
2	12	0	0
3	30	0	0
4	-122	66	-0.88
5	-180	143	40.37
6	-81	83.39	-0.99

4.4 Safety factor check

Based on the results of the dynamic analysis presented in Section 4, the maximum breaking load (MBL) at ULS condition for a design load of 5-year period of return has been obtained for the anchor chain (C-

01), the dyneema ropes of 28 mm (R-01, R-02 and R-04) and the dyneema ropes of 16 mm (R-05 and R-06). The load factor for dynamic analysis is taken from Table 4 of Section 6.6. of the Norwegian Standard NS 9415 (see Figure 24(a)). The material factor for the different materials has been taken from Table 5 of Section 6.6. of the Norwegian Standard NS 9415 (see Figure 24 (b)). The safety factor for calculating the MBL is obtained by multiplying the load and the material factors. The results have been summarized in Table 9: Safety factor check

Table 9: Safety factor check

Structural Element	Load Factor	Material Factor	Safety Factor	Max Load (kN)	MBL (kN)
Chain	1.15	2.0	2.3	246	565
Used Chain	1.15	5.0	5.75	246	1414
Dyneema 28 mm	1.15	3.0	3.45	130	449
Dyneema 16 mm	1.15	3.0	3.45	70	242

Table 4 – Load factors for mooring lines

Type of analysis	Load factor
Static analysis	1,6
Quasi-static analysis	1,15×DAF[1)]
Dynamic analysis	1,15
Accident limit (break in mooring line)	1,0
Spring flood	1,0

[1)] Here is used a factor of 1.15 multiplied by dynamic amplification factor (DAF). Dynamic amplification factor ≥1.1. Choice of value of DAF shall be justified and documented.

Tabell 13 – Material factors for moringlines

Type	Material factor
Synthetic rope	3,0
Synthetic rope with knots	5,0
Chains and chain components	2,0
Used chains	5,0
Coupling discs and other connecting points of steel*	1.5
Shackles	2,0
Rock bolts and other bottom attachments	3,0

*First yield

Figure 24. a) Load factor for mooring and b) Material factor for mooring lines according to Norwegian Standard NS 9415

5 CONCLUSIONS

Based on the numerical study performed on the seaweed cultivator designed by Aqitec for the UNITED German Pilot the following conclusions and recommendations are included for consideration:

- For a 5-year return period of waves and current, load case 2 (in-line waves and currents) provides the highest loading in the cultivator system compared to the other combinations of the same return period.
- According to a combined safety factor of 2.3, the MBL of the chain (C-01) should not be less than 565 kN. If used chains were to be used, the safety factor is increased to 5.75 and the MBL should not be less than 1414 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 28 mm (R-01, R-02 and R-04) should not be less than 449 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 16 mm (R-05 and R-06) should not be less than 242 kN.
- In all simulation cases, the maximum tension on the strength-ropes holding the net do not exceed the breaking load indicated by Aqitec. This does not consider any safety factors as the net is meant to break under extreme waves and current condition.
- For a 5-year return period of waves and current, the maximum horizontal load transferred to the anchor is 266 kN.
- For a 5-year return period of waves and current, the maximum vertical load transferred to the anchor is 41 kN.
- For a short installation period (3 months of marine growth), fouling does not have a major impact on the structural loads. However, it is suggested by DNV OS301 [8] and NoORSOK-003 [11] to consider a linear increase of marine growth thickness over the course of 2 years to account for the increase in mass and drag area to the system.
- The spar buoys should be able to withstand the hydrostatic pressure at a depth of 10 m.
- In the numerical model the spar buoy has been modelled as a cylinder and the mooring chain connected at the bottom of the cylindrical element. The real spar buoy is connected to the anchor chain in the middle (for more details see [5]). It is advised to monitor the position of the chain with respect to the lower part of the spar buoy to avoid any possible entanglement.

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ANNEX B

Dutch Pilot

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

> Retouradres Postbus: 2232 3500 GE Utrecht

RWS INFORMATIE
Noordzeeboerderij B.V.
E.G.A. Brouwers
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Rijkswaterstaat Zee en Delta

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www.rijkswaterstaat.nl

Bijlage(n)
2

Ons kenmerk
RWS-2018/42544

Datum 2 november 2018
Onderwerp Aanbieding besluit Waterwet inzake het North Sea Innovation Lab in de Noordzee westelijk van Scheveningen

Geachte heer Brouwers,

Op 4 september 2018 heeft u een aanvraag ingediend voor een vergunning krachtens de Waterwet voor een gebied in de Noordzee voor de kust van Scheveningen, te gebruiken voor het versnellen van innovaties op het gebied van duurzaam medegebruik middels het faciliteren en ondersteunen van innovatieve testprojecten, door u benoemd als het North Sea Innovation Lab.

Hierbij zend ik u onder gelijke datum en nummer van deze brief de door u aangevraagde vergunning op grond van de Waterwet.

Voor de voorwaarden en de motivering van mijn besluit en de verdere procedure verwijs ik u naar het besluit.

Het besluit zal worden gepubliceerd in week 45 van 2018 en ter inzage liggen tot 21 december 2018

Heeft u nog vragen? Neem dan contact op met de heer H. Duijts, telefoon 06-31777394.

Ik vertrouw erop u hiermee voldoende te hebben geïnformeerd.

Hoogachtend,

DE MINISTER VAN INFRASTRUCTUUR EN WATERSTAAT,
namens deze,
hoofd Vergunningverlening Rijkswaterstaat Zee en Delta

de heer L.R. Minnaar

RWS INFORMATIE Pagina 1 van 1

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Rijkswaterstaat Zee en Delta

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Datum
2 november 2018

beschikking

Datum	2 november 2018
Nummer	RWS-2018/42549
Onderwerp	Watervergunning voor het North Sea Innovation Lab van Noordzeeboerderij B.V., gelegen in de Noordzee voor de kust van Scheveningen.

Inhoudsopgave

Aanhef

De minister van Infrastructuur en Waterstaat heeft op 4 september 2018 een aanvraag ontvangen van de Noordzeeboerderij B.V. om een vergunning als bedoeld in hoofdstuk 6 van de Waterwet (Wtw) voor het verrichten van handelingen in een watersysteem.

De aanvraag betreft een handeling als bedoeld in artikel 6.5 onder c Waterwet: het gebruik maken van het rijkswaterstaatswerk Noordzee door, anders dan in overeenstemming met de functie, daarin, daarop, daarboven, daarover of daaronder werkzaamheden te verrichten, werken te maken of te behouden, dan wel vaste substanties of voorwerpen te storten, te plaatsen of neer te leggen, of deze te laten staan of liggen.

Concreet gaat het om een offshore testlocatie op de Noordzee. De testlocatie is een afgebakend gebied van twee bij drie kilometer op de Noordzee, te gebruiken voor het versnellen van innovaties op het gebied van duurzaam medegebruik middels het faciliteren en ondersteunen van innovatieve testprojecten.

De aanvraag is op 4 september 2018 binnengekomen bij Rijkswaterstaat Zee en Delta en geregistreerd onder nummer RWSZ2018-00013612.

De aanvraag omvat de volgende stukken:

- Aanvraag Watervergunning
- Toelichting Vergunningsaanvraag North Sea Innovation Lab.

Besluit

Gelet op de bepalingen van de Waterwet, het Waterbesluit, de Waterregeling, de Algemene wet bestuursrecht en de hieronder vermelde overwegingen besluit de minister van Infrastructuur en Waterstaat als volgt:

I. De gevraagde vergunning als bedoeld in artikel 6.5 onder c van de Waterwet jo artikel 6.13 eerste lid onder c van het Waterbesluit aan Noordzeeboerderij B.V. te Den Haag te verlenen voor het gebruikmaken van het rijkswaterstaatswerk Noordzee door, anders dan in overeenstemming met de functie, daarin, daarop, daarboven, daarover of daaronder installaties of kabels en leidingen te plaatsen of neer te leggen, of deze te laten staan of liggen.

II. De vergunning te verlenen voor de periode tot 31 december 2028.

III. Aan de vergunning de hierna volgende voorschriften te verbinden met het oog op de in artikel 2.1 van de Waterwet genoemde doelstellingen.

Voor een toelichting op de in deze vergunning vermelde begrippen wordt verwezen naar bijlage 1 van de vergunning.

Voorschriften

Voorschrift 1
Plaatsbepaling werken

1. De werken dienen te worden gemaakt en behouden ter hoogte van de locatie zoals is aangegeven op de bij deze beschikking behorende aanvraag, te weten binnen de onderstaande hoekpunten volgens het coördinatensysteem ETRS89, UTM 31N.

	X	Y
N	4° 6,318'	52° 11,025'
O	4° 7,685'	52° 10,486'
Z	4° 6,146'	52° 9,319'
W	4° 4,683'	52° 9,902'

2. Het gebied waarbinnen de werkzaamheden plaatsvinden dient gemarkeerd te zijn met boeien, zoals deze worden voorgeschreven door de Directeur Kustwacht krachtens artikel 1.1 van de Scheepvaartverkeerswet. Hiertoe moet contact worden opgenomen met het Kustwachtcentrum.

Voorschrift 2
Werkplan

1. De werken/werkzaamheden behoeven de goedkeuring van de waterbeheerder. Hiertoe dient acht weken vóór aanvang van de werkzaamheden een werkplan met betrekking tot de werken/werkzaamheden ter goedkeuring aan de waterbeheer worden voorgelegd. Dit werkplan moet voorzien zijn van:
   - korte omschrijving van het project/de projecten,
   - detailtekeningen van het werk/de werken,
   - een plan van aanpak en
   - een planning van de werkzaamheden.
2. Met de werkzaamheden mag pas worden begonnen als de goedkeuring is verleend. Er staan rechtsmiddelen open tegen dit besluit.
3. De werkzaamheden zoals bedoeld in lid 1 betreffen de aanlegwerkzaamheden en alle gehele of gedeeltelijk wijzigingen –hier wordt mede verstaan een wijziging in gebruik of wijziging van functie van de werken-, vernieuwingen, uitbreidingen of verwijdering van de werken.
4. De werkzaamheden moeten worden uitgevoerd conform het door de waterbeheerder goedgekeurde werkplan.
5. Eventuele wijzigingen in het goedgekeurde werkplan behoeven vooraf de goedkeuring van de waterbeheerder.

Voorschrift 3
Ongewoon voorval

1. Indien zich bij het gebruik van deze vergunning een ongewoon voorval voordoet of heeft voorgedaan, waardoor ernstige hinder of ernstig gevaar ontstaat voor de veiligheid van personen, het waterstaatswerk Noordzee, het milieu, de scheepvaart of de visserij, dan neemt de vergunninghouder onmiddellijk alle maatregelen die nodig zijn om de hinder of het gevaar tegen te gaan.
2. De vergunninghouder meldt een ongewoon voorval zo spoedig mogelijk aan de handhavingsambtenaar, aan het Operationele Centrum van het Kustwachtcentrum en aan de Dienst der Hydrografie.

Voorschrift 4
Aanvang en voltooiing van de werkzaamheden (meldingen)

1. Ten minste 10 werkdagen voordat met werkzaamheden wordt begonnen, meldt de vergunninghouder het voornemen daartoe bij de waterbeheerder, waarbij moet worden aangegeven:
   a. de aard van de werkzaamheden;
   b. de dag waarop de werkzaamheden zullen beginnen;
   c. de voor de vergunninghouder werkzame, 24 uur per dag bereikbare contactpersoon.
2. Zodra blijkt dat de werkzaamheden niet op het in het vorige lid genoemde tijdstip kunnen beginnen, moet de vergunninghouder daarvan zo spoedig mogelijk, doch binnen 24 uur, kennis geven aan de waterbeheerder.
3. Indien het werk gereed is, moet dit uiterlijk binnen 2 werkdagen gemeld

worden aan de waterbeheerder.

4. De meldingen genoemd in lid 1, 2 en 3 moeten ook worden gericht aan:
   - de handhavingsambtenaar, via handhavingnoordzee@rws.nl;
   - de Kustwacht
   - de Dienst der Hydrografie

Voorschrift 5
Uitvoering werken

1. Door of namens de waterbeheerder kunnen met betrekking tot de werkzaamheden aanwijzingen worden gegeven ter bescherming van de betrokken belangen. De vergunninghouder zorgt ervoor dat de gegeven aanwijzingen terstond worden opgevolgd.
2. De vergunninghouder zorgt ervoor dat het uitvoeren van werkzaamheden door of namens de waterbeheerder ongehinderd kan plaatsvinden.
3. De vergunninghouder moet de werkzaamheden zodanig uitvoeren dat zo min mogelijk hinder en geen gevaar voor het scheepvaartverkeer ontstaat.
4. Verankering van de installaties moet zodanig gebeuren, dat deze ankers niet dieper dan 2 meter in de bodem dringen. Als er een verankeringssysteem gebruikt gaat worden dat dieper in de bodem komt, dan behoeft dit de goedkeuring van de waterbeheerder.
5. De te gebruiken materialen mogen niet schadelijk zijn voor de instandhouding van het waterstaatswerk.
6. Afval en bouwafval in welke vorm dan ook mogen in geen geval worden achtergelaten.
7. Na afloop van de werkzaamheden moet de vergunninghouder alle aanwezige materiaal terstond verwijderen.

Voorschrift 6
Verwijderen werken

1. De vergunninghouder zorgt ervoor dat de werken, uiterlijk 31 december 2028 zijn verwijderd.
2. Voor de aanvang van de werkzaamheden stelt de vergunninghouder zich door middel van een bankgarantie aan de Staat, of een ander door de Staat goedgekeurde zekerheidsstelling, garant voor voldoende middelen ten bate van de verwijdering van de werken zoals bedoeld in lid 1.

Voorschrift 7
Historisch belangrijke, archeologische vondsten

1. Indien tijdens de uitvoering van de werkzaamheden voorwerpen, sporen of overblijfselen worden aangetroffen welke, naar redelijkerwijs kan worden vermoed, van historisch, oudheidkundig of wetenschappelijk belang zijn, wordt de vindplaats gemarkeerd en aan de handhavingsambtenaar doorgegeven.
2. Van de vondst wordt onverwijld melding gedaan aan de Rijksdienst voor het Cultureel Erfgoed, Afdeling Strategie en Internationaal. Meldingen moeten tevens aan het Kustwachtcentrum en de Dienst der Hydrografie worden doorgegeven.

3. De vergunninghouder neemt zodanige maatregelen, dat verdere aantasting van aanwezige dan wel aangetroffen objecten zoveel mogelijk wordt voorkomen.

Voorschrift 8
Aanwezigheid vergunning

1. Tijdens de werkzaamheden op de locatie moet voortdurend een exemplaar van deze vergunning aanwezig zijn.

Voorschrift 9
Contactpersoon

1. De vergunninghouder is verplicht één of meer personen aan te wijzen die in het bijzonder belast is (zijn) met het toezien op de naleving van het bij deze vergunning bepaalde of bevolene, waarmee door of namens de waterbeheerder in spoedgevallen overleg kan worden gevoerd.
2. De vergunninghouder deelt schriftelijk binnen 14 dagen nadat deze vergunning inwerking is getreden de handhavingsambtenaar en het Kustwachtcentrum mee, wat de contactgegevens zijn (naam, adres telefoonnummer en e-mailadres) van degene die door of vanwege hem is aangewezen en alle dagen 24 uur bereikbaar is.
3. Wijzigingen moeten binnen 14 dagen schriftelijk worden gemeld.

4. Aanvraag

4.1 Inleiding

De Noordzeeboerderij B.V heeft op 28 juni 2016 een vergunning gekregen met kenmerk RWS-2016/28150 voor het beheer over een gebied van 11 hectare op de Noordzee. Op 10 november 2017 is dit gebied op verzoek van de Noordzeeboerderij B.V. vergroot naar 64 ha via beschikking met kenmerk RWS-2017/43729. De vergunning loopt af op 31 augustus 2019. Aangezien de kabelcorridor vanaf het toekomstige windpark Hollandse Kust (zuid) overlap heeft met het vergunde gebied, is een verdere verlenging van de vergunning niet aan de orde. De Noordzeeboerderij B.V. heeft er daarom voor gekozen een nieuwe vergunning aan te vragen voor een groter gebied op een aangepaste locatie.

De Noordzeeboerderij B.V. gaat in het aangevraagde gebied een offshore testlocatie beheren. Deze testlocatie is beschikbaar voor allerlei initiatiefnemers die op zee hun duurzame innovaties willen testen in een realistische omgeving. Deze testlocatie wordt aangeduid als het North Sea Innovation Lab. Het gaat om een gebied van zes vierkante kilometer met zijden van twee en drie kilometer op ongeveer tien kilometer ten westen van Scheveningen. De locatie is gekozen na overleg met de Kustwacht en Rijkswaterstaat Zee en Delta.

Op grond van artikel 6.13 van het Waterbesluit is het verboden zonder vergunning van Onze Minister als bedoeld in artikel 6.5 lid c van de Waterwet gebruik te maken van de Noordzee door, anders dan in overeenstemming met de functie, daarin, daarop, daarboven, daarover of daaronder installaties of kabels en leidingen te plaatsen of neer te leggen of deze te laten staan of liggen. Het initiatief van de Noordzeeboerderij B.V. is daarom vergunningplichtig.

De Noordzeeboerderij B.V. zal als vergunninghouder het beheer voeren over het North Sea Innovation Lab. Dat betekent dat zij zorg draagt en verantwoordelijk is voor alle activiteiten die onder deze vergunning plaatsvinden op de locatie. Dit kunnen de eigen testactiviteiten van Noordzeeboerderij B.V. zijn, alsook van derde partijen die toestemming hebben van Noordzeeboerderij B.V. om ter plaatse hun activiteiten uit te voeren. Noordzeeboerderij B.V. zal er daarbij zorg voor dragen dat deze derde partijen in alle gevallen en te allen tijde zullen voldoen aan de vergunningsvoorwaarden.

4.2 Handelingen waarvoor vergunning wordt aangevraagd

De aanvraag betreft het gebruik maken van het rijkswaterstaatswerk de Noordzee of de daartoe behorende beschermingszone door, anders dan in overeenstemming met de functie, het daarin plaatsen, in stand houden, monitoren en na afloop opruimen van installaties.

De volgende projecten worden genoemd bij de aanvraag van het North Sea Innovation Lab:

1. Projecten met niet-bodemberoerende activiteiten. Dit zijn projecten waarbij innovaties op het gebied van remote monitoring en/of vaartuigen worden uitgetest. Veelal ter ondersteuning of als aanvulling op andere projecten op het North Sea Innovation Lab die wel bodemberoerende activiteiten hebben. Voorbeelden zouden kunnen zijn:
    a. Uittesten van communicatietechnologie.
    b. Mobiliteit van vaartuigen rondom zeewierinstallaties.
    c. Uittesten van productie-eenheden die een eigen aandrijving hebben.
2. Projecten met bodemberoerende activiteiten, zonder verankering en zonder fundering. Dit zijn projecten waarbij de kernactiviteit zich hoofdzakelijk op de zeebodem afspeelt. Dit kunnen ook projecten zijn met verankeringen of funderingen in het geval dat deze zeer kortlopend zijn (dagen tot maximaal enkele weken). Voorbeelden hiervan zijn:
    a. Herstel oesterbanken.
    b. Uittesten van innovatieve ankers.
3. Projecten met verankering (semi-permanent). Dit zijn projecten waarbij er verankeringspunten op of in de bodem worden geplaatst ten behoeve van de kernfunctie van het betreffende project. Voorbeelden hiervan zijn:
    a. Teelt van extractieve soorten zoals zeewier, mossels, etc.
    b. Energieproductie zoals met drijvende zonnepanelen of getijdencentrales.
    c. Passieve visserij met krabben-/kreeftenkooien.
4. Met funderingen (semi-permanent): projecten waarbij er fundering op of in de bodem worden geplaatst ten behoeve van de kernfunctie van het betreffende project. Voorbeelden hiervan zijn:
    a. Cross-over test: afmering van medegebruik-activiteit (zeewier, zonnepanelen) aan een windturbine fundering.

De vergunning wordt afgegeven voor een in de vergunning bepaald gebied en alle projecten in dat gebied die wat betreft aard en hoedanigheid gelijk kunnen worden gesteld met de bovenstaande opsomming. In voorschrift 2 wordt een werkplan gevraagd ter goedkeuring, voordat met een project kan worden gestart. Hiermee kan het bevoegd gezag op voorhand controle uitoefenen op de geplande en uitgevoerde projecten.

Opgemerkt moet worden, dat in bovenstaande opsomming geen lozingen ten gevolge van de projecten genoemd worden en dat deze niet onder de vergunning vallen.

4.3 Beschrijving van het rijkswaterstaatswerk waarin de handelingen plaatsvinden

De activiteit vindt plaats in de Noordzee, op ongeveer 10 kilometer ten westen van de kust van Scheveningen.

Binnen het oppervlaktewaterlichaam de Noordzee en in de omgeving van de installatie zijn de navolgende beschermde gebieden aangewezen:

- Wet natuurbescherming: De te vergunnen installatie ligt op een afstand van minder dan 20 kilometer van de Natura 2000-gebieden Westduinpark en Meijendel
- Kaderrichtlijn Water: De activiteit vindt plaats in het KRW-waterlichaam K3 Euhalien kustwater. Dit waterlichaam behoort tot de categorie kustwateren en wordt aangemerkt als een natuurlijk KRW-waterlichaam.

De zone tussen de doorgaande NAP -20 meter dieptelijn en de 12-mijlszone is aangewezen als het gebied waar zand gewonnen wordt voor het in stand houden van de kust en voor commerciële zandwinning. Het project ligt in dit gebied.

Ter plaatse van het project vindt scheepvaart en visserij plaats. Verder zijn er in de directe omgeving kabels en leidingen te vinden en ligt op 1,7 kilometer noordoostelijk het olieplatform Q13-A van Neptune Energy.

5. Toetsing van de aanvraag aan de doelstellingen van het waterbeheer

5.1 Algemeen

Artikel 6.21 Waterwet bepaalt dat een vergunning wordt geweigerd, voor zover verlening daarvan niet verenigbaar is met de doelstellingen in artikel 2.1 of de belangen, bedoeld in artikel 6.11. In artikel 2.1 Wtw zijn de algemene doelstellingen aangegeven die richtinggevend zijn bij de uitvoering van het waterbeheer:

a) voorkoming en waar nodig beperking van overstromingen, wateroverlast en waterschaarste;
b) in samenhang met de bescherming en verbetering van de chemische en ecologische kwaliteit van watersystemen en
c) de vervulling van maatschappelijke functies door watersystemen.

Deze doelstellingen vormen in onderlinge samenhang het toetsingskader bij vergunningverlening. Een vergunning wordt geweigerd indien de doelstellingen

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van het waterbeheer zich tegen vergunningverlening verzetten en als het niet mogelijk is om de belangen van het waterbeheer door het verbinden van voorschriften of beperkingen voldoende te beschermen.

De doelstellingen zijn geconcretiseerd via normen en beleid ten aanzien van veiligheid, waterkwantiteit, waterkwaliteit en maatschappelijke functievervulling door watersystemen. De uitwerking hiervan vindt plaats in de Waterwet, in aanvullende regelgeving, in water- en beheerplannen op grond van hoofdstuk 4 van de Waterwet en in beleidsregels. De vastgestelde normen en het beleid vormen het kader bij de toetsing of een aangevraagde handeling verenigbaar is met de doelstellingen voor het waterbeheer. Hieronder volgt een beschrijving van het beleid waarmee bij het beoordelen van de vergunningaanvraag rekening is gehouden.

Bij de beoordeling van de vergunningaanvraag richt het bevoegd gezag zich volgens het toetsingskader op de effecten van uw initiatief op de functies en het effect op de waterkwaliteit van de Noordzee.

De aan deze vergunning verbonden voorschriften volgen uit de overwegingen en dienen ter bescherming van de veiligheid van het waterstaatswerk.

Ten overvloede wordt opgemerkt dat artikel 6.11, eerste lid, van de Waterwet in dezen niet van toepassing is, aangezien dit artikellid ziet op handelingen die plaatsvinden in de Nederlandse exclusieve economische zone (EEZ). De installatie bevindt zich niet in de EEZ, maar in de territoriale zee.

5.2 Beoordeling voor wat betreft het gebruik maken van een rijkswaterstaatswerk en/of bijbehorende beschermingszone

5.2.1 Regelgeving en beleid

De hoofdlijnen van het nationale waterbeleid ten aanzien van veiligheid en het doelmatig gebruik van rijkswaterstaatswerken en de manier waarop daarbij rekening moet worden gehouden met de ecologische doelstellingen die gelden voor KRW-waterlichamen zijn vastgelegd in het Nationaal Waterplan (NWP), planperiode 2016-2021. Een nadere uitwerking en onderbouwing van de beleidskeuzes en de realisatie op het gebied van waterveiligheid vindt plaats in de Beleidsnota Waterveiligheid. Voor de Noordzee is het beleid, zoals dat in het Nationaal Waterplan is opgenomen, nader gebiedspecifiek uitgewerkt in de Beleidsnota Noordzee 2016-2021 (BN).

Het Beheer- en ontwikkelplan voor de Rijkswateren 2016-2021 (BPRW) vertaalt dit beleid door naar het beheer van de rijkswateren, met een onderverdeling naar functie en naar watersysteem.

Uitgangspunt van het BPRW is dat in beginsel aan de eisen van de gebruiksfuncties wordt voldaan wanneer de basisfuncties veiligheid, voldoende water en schoon en gezond water op orde zijn.

In de BN wordt een integrale afweging gemaakt van alle sectorale en thematische doelen voor de Noordzee, waarbij wordt geprobeerd om in de volle breedte zo effectief en efficiënt mogelijk het beheer vorm te geven. Dit wordt onder andere gedaan door het formuleren van een integraal afwegingskader voor vergunningverlening. Hiermee wordt de gebruiker van de Noordzee meer helderheid verschaft over de voorwaarden waaronder activiteiten op de Noordzee toelaatbaar zijn.

Bovendien bevat het BPRW een toetsingskader voor individuele besluiten, dat gebruikt wordt bij het toetsen en beoordelen van vergunningen voor het gebruik van waterstaatswerken. Hierin is vastgelegd op welke manier deze aanvragen getoetst worden aan de ecologische doelstellingen die op grond van het BPRW gelden voor KRW-waterlichamen.

5.2.2 Overwegingen t.a.v. de maatschappelijke functievervulling door watersystemen

Het Nationaal Waterplan kent aan de Rijkswateren verschillende gebruiksfuncties toe, die specifieke eisen stellen aan het beheer of gebruik van het betreffende rijkswater. De functies zijn nader uitgewerkt in het BPRW. Voor de Noordzee ter plekke van het te vergunnen gebied gelden de volgende functies:

- Scheepvaart
- Beroeps- en sportvisserij
- Oppervlaktedelfstoffen
- Archeologie, cultuurhistorie en landschap

De scheepvaartintensiteit ter plaatse ligt op 10-20 schepen per 1000 km^2 en de installatie ligt buiten de doorgaande scheepsroutes. Het aangewezen gebied krijgt de verplichting tot markering met boeien, zodat het scheepvaartverkeer gewaarschuwd wordt voor de aanwezige obstakels. Daarnaast zal de locatie worden opgenomen in de zeekaarten. De plek en type van de boeien wordt in samenspraak met de Kustwacht bepaald. Het totale oppervlak dat door de locatie in beslag wordt genomen bedraagt ongeveer 600 hectare (6 km^2) Op het totale oppervlak van de Noordzee is dat verwaarloosbaar.

Mogelijke archeologische waarden zijn in het gebied niet te verwachten aan het oppervlak. Door de initiatiefnemer is nagegaan of er bekende objecten in het gebied liggen en dat is niet het geval. Zover bekend vallen er geen prehistorische vondsten te verwachten. Gezien het convenant dat Rijkswaterstaat heeft afgesloten met de Rijksdienst voor het Culturele Erfgoed is een voorschrift opgenomen als onvoorzien toch een vondst gedaan wordt. Verder is het niet duidelijk wat er in de diepere ondergrond mogelijk aanwezig is. Om deze diepere lagen te beschermen is in voorschrift 5 een bepaling opgenomen dat ankers niet dieper dan 2 meter in de bodem mogen dringen. Indien een verankeringssysteem wordt gekozen dat dieper gaat, dan moet eerst toestemming aan de waterbeheerder worden gevraagd. In dat geval kan door de waterbeheerder een nader onderzoek gevraagd worden.

De installatie komt op 2,3 km te liggen van de olieleiding van Neptune Energy aan de noordkant en 3,7 km van de olieleiding van TAQA aan de zuidkant. De vergunninghouder zal beide eigenaren van de leidingen over de werkzaamheden moeten informeren. De afstand tot beide leidingen is voldoende groot om de werkzaamheden geen gevaar voor de leidingen te laten vormen.

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De zandwinning gebeurt in vergunde gebieden. Deze gebieden liggen momenteel dichter bij de kust dan het project gesitueerd is. Er vindt geen hinder plaats voor de zandwinning.

De aanvraag is getoetst aan de regelgeving en het beleid. Gelet op de locatie in de Noordzee en de aard van de activiteiten, is er geen invloed te verwachten op de maatschappelijke functies van dit rijkswaterstaatswerk.

5.2.3 Overwegingen t.a.v. de bescherming en verbetering van de chemische en ecologische kwaliteit van watersystemen (waterkwaliteit)

Het gebied is bedoeld voor het uittesten van proefsystemen. Voor de installaties wordt gebruik gemaakt van materialen die geen stoffen in het omringende milieu zullen brengen. Voor de zeewieren zullen inheemse soorten worden gebruikt, waardoor er geen gevaar ontstaat voor introductie van exotische of invasieve soorten. De groeiende zeewieren onttrekken voedingsstoffen aan het water, waardoor de concentraties aan fosfor- en stikstofverbindingen zullen dalen.

Voor zover de aanvraag gevolgen heeft voor de chemische kwaliteit van watersystemen, worden die gevolgen getoetst in het kader van de toetsing aan algemene regels. In dit gedeelte van de vergunning wordt daarom alleen getoetst aan de ecologische doelstellingen van het relevante waterlichaam. Hierbij is gebruik gemaakt van het toetsingskader voor individuele besluiten uit het BPRW 2016-2021, bijlage 5. De centrale vraag die Rijkswaterstaat zich stelt bij het uitvoeren van deze toetsing is of de KRW-doelstellingen, waarop de activiteit mogelijk effecten heeft, nog wel behaald kunnen worden als de activiteit daadwerkelijk plaatsvindt.

De werkzaamheden vinden plaats in het KRW-waterlichaam K3: Kustwateren. In dit type waterlichaam is alleen het ecologische kwaliteitskenmerk fytoplankton van belang. Als maatlat wordt de concentratie chlorofyl-a gebruikt. Het dichtstbijzijnde meetpunt voor de waterkwaliteit is het punt Noordwijk 20. De klassegrens tussen matig en goed ligt op 15 µg/l van de 90 percentiel in de zomer. Voor de toetsing is gebruik gemaakt van de meetwaarden uit de RWS-database (te vinden op http://live.waterbase.nl/). De gemiddelde waarde van het 90-percentiel in de zomermaanden over de periode 2005 tot en met 2014 is 9,4 µg/l. Dat ligt onder de grenswaarde van 15 µg/l, waarmee de kwaliteit als goed kan worden beoordeeld. Aangezien er volgens de toelichting bij de aanvraag geen stoffen in het water terecht komen die de KRM-doelen beïnvloeden, bestaat er geen gevaar dat de KRW-doelen in gevaar komen. Ook de andere kwaliteitskenmerken van het watertype, waaronder temperatuur en zuurstofgehalte, worden niet beïnvloed.

De Kaderrichtlijn Mariene Strategie (KRM) is in 2008 van kracht geworden. De indicatoren en normen voor de KRM worden beschreven aan de hand van 11 elementen, descriptoren genoemd. In het rapport 'Mariene Strategie voor het Nederlandse deel van de Noordzee 2012-2020, Deel I' wordt een opsomming gegeven van de doelen die in 2020 gehaald zouden moeten worden, gebaseerd op een goede milieutoestand, in het voor dit project relevante deel van de Noordzee.

- De descriptoren die gaan over vervuiling zijn niet van belang voor dit project. Er komen geen stoffen of zwerfvuil vrij, dus vindt er ook geen verslechtering plaats.
- Introductie van exotische soorten is niet aan de orde.
- Bodemhabitats en hydrografische eigenschappen worden verstoord bij de verankering van de systemen, maar dat is slechts over een relatief klein oppervlak.
- Toevoer van energie in de vorm van geluid is aan de orde bij het gebruik van schepen. De schepen worden in kleine aantallen en voor een beperkte tijd gebruikt.

Gelet op het voorgaande concludeer ik dat de activiteiten van de aanvrager de beleidsdoelen vanuit de KRM niet schaden.

Gelet op het voorgaande is geen invloed te verwachten op de waterkwaliteit van het watersysteem.

5.2.4 Overwegingen t.a.v. de toetsing aan het afwegingskader van de Beleidsnota Noordzee 2016-2021

Voor alle vergunningplichtige activiteiten, zowel nieuwe, nog niet voorkomende activiteiten, alsook verlengingen of uitbreiding van bestaande activiteiten, moet in principe het afwegingskader van de Beleidsnota Noordzee worden doorlopen.

Voor gebruiksfuncties die vergunningplichtig zijn, maakt het integraal afwegingskader via voorschriften maatwerk mogelijk. Bij de beoordeling van de toelaatbaarheid van de desbetreffende economische activiteit wordt een vaste procedure gevolgd. Hierbij wegen mee: de ruimtelijke aspecten, veiligheid, de gevolgen voor ecologie en milieu en de eventueel aan een vergunning te verbinden voorschriften en beperkingen.

De toetsing bestaat uit vijf stappen die na elkaar genomen moeten worden:
1) Definiëring ruimtelijke claim & toepassen voorzorg
2) Locatiekeuze & beoordeling ruimtegebruik
3) Nut en noodzaak
4) Mitigeren
5) Compensatie van effecten

Stappen 1 en 2 zijn in het voorgaande al behandeld. Gezien het feit dat de activiteit geen significante negatieve ruimtelijke en/of ecologische effect veroorzaakt, hoeft de nut en noodzaak in stap 3 niet verder aangetoond te worden.

6. Procedure

De voorbereiding van de beschikking op grond van de Waterwet heeft conform het gestelde in afdeling 4.1.2 van de Algemene wet bestuursrecht (Awb) plaatsgevonden.

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7. Conclusie

De in de vergunning opgenomen voorschriften waarborgen dat de doelstellingen van het waterbeheer voldoende worden beschermd. Op grond van de overwegingen bestaan er daarom geen bezwaren tegen het verlenen van de gevraagde vergunning.

8. Ondertekening

DE MINISTER VAN INFRASTRUCTUUR EN WATERSTAAT,
namens deze,
hoofd Vergunningverlening Rijkswaterstaat Zee en Delta

de heer L.R. Minnaar

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9. Mededelingen

Voor meer informatie over dit besluit kunt u terecht bij de in dit besluit genoemde contactpersoon. De contactgegevens staan in de begeleidende brief bij dit besluit. De contactpersoon kan uw vragen beantwoorden en het besluit met u doornemen.

Om te bepalen of u meer informatie wilt, kunnen de volgende vragen en aandachtspunten u helpen:
- Is de inhoud van het besluit duidelijk en is helder wat het concreet voor u betekent?
- Kunt u beoordelen of het besluit inhoudelijk juist is of niet? Of heeft u behoefte aan een toelichting?
- Kloppen de gegevens over u in het besluit en heeft u alle gegevens verstrekt?

Ook wanneer u andere vragen heeft over het besluit of de procedure, of wanneer u zich op een of andere manier heeft gestoord aan de wijze waarop bij de besluitvorming met u of uw belangen is omgegaan, kunt u contact opnemen.

Bent u het niet eens met dit besluit?

Dan kunt u op grond van de Algemene wet bestuursrecht bezwaar maken. U moet hiervoor wel belanghebbende bij het besluit zijn.

De volgende vragen en aandachtspunten kunnen u helpen bij het maken van bezwaar:
- Wat zijn de redenen dat u het met het besluit niet eens bent?
- Welk doel wilt u met uw bezwaar tegen het besluit bereiken? Wat verwacht u van Rijkswaterstaat?
- Is het u voldoende duidelijk wat een bezwaarprocedure inhoudt en weet u of u met een bezwaar uw doel kunt bereiken? Kunt u uw doel op een andere, wellicht eenvoudigere wijze bereiken?

Wanneer u vragen heeft of wanneer u zich afvraagt of het indienen van een bezwaarschrift voor u de geschikte aanpak is, kunt u ook hiervoor contact opnemen met de bij het besluit vermelde contactpersoon. De contactpersoon kan met u overleggen over de te volgen procedure en u informeren over andere mogelijkheden die Rijkswaterstaat u eventueel biedt om tot een oplossing te komen.

Hoe maakt u bezwaar?

Om bezwaar te maken moet u, binnen zes weken na de dag waarop dit besluit is bekendgemaakt, een bezwaarschrift indienen. U kunt uw bezwaarschrift sturen naar de Minister van Infrastructuur en Waterstaat, ter attentie van Rijkswaterstaat Zee en Delta, afdeling Werkenpakket, t.a.v. mevr. mr. E.J. Bekker, Postbus: 2232, 3500 GE Utrecht.

Het bezwaarschrift moet worden ondertekend en in ieder geval de volgende gegevens en informatie bevatten:

- uw naam en adres, en liefst ook uw telefoonnummer;
- een duidelijke omschrijving van het besluit waartegen u bezwaar maakt (bijvoorbeeld door de datum en het kenmerk van het besluit te vermelden of door een kopie mee te sturen);
- de reden(en) waarom u bezwaar maakt;
- de datum.

Het indienen van een bezwaarschrift heeft geen schorsende werking. Dat betekent dat het besluit blijft gelden in de tijd dat uw bezwaarschrift in behandeling is. Als u dit niet wilt, bijvoorbeeld omdat het besluit onherstelbare gevolgen heeft voor u, dan kunt u een verzoek om voorlopige voorziening indienen. Dit doet u door de Voorzieningenrechter van de rechtbank in het gebied waar u woont te vragen een voorlopige voorziening te treffen. Indien u niet zelf, maar namens een bedrijf of organisatie een voorlopige voorziening aanvraagt kunt u een voorlopige voorziening aanvragen bij de rechtbank in het gebied waar het bedrijf of de organisatie is ingeschreven. De rechtbank zal daarvoor griffierecht in rekening brengen.

Overige mededelingen:

Het hebben van deze vergunning ontslaat de houder niet van de verplichting om de redelijkerwijs mogelijke maatregelen te treffen teneinde te voorkomen dat derden of de Staat ten gevolge van het gebruik maken van de vergunning schade lijden.

Naast de vergunning heeft u voor het gebruik van staatsgrond- en water nog toestemming nodig van Rijksvastgoedbedrijf. Ik wijs u er op dat het Rijksvastgoedbedrijf aan een dergelijke privaatrechtelijke regeling nog nadere voorwaarden kan stellen, waaronder het betalen van een (marktconforme) gebruiksvergoeding. Pas op het moment dat een privaatrechtelijke regeling is overeengekomen met Rijksvastgoedbedrijf mag gebruik worden gemaakt van staatseigendom(men) ter uitvoering van de vergunde activiteit(en).

Bij de 'Aanwijzingsregeling toezichthoudende ambtenaren en ambtenaren met specifieke uitvoeringstaken op grond van SZW wetgeving' is het Staatstoezicht op de Mijnen (SodM) aangewezen als toezichthouder op grond van de Arbeidstijdenwet en de Arbeidsomstandighedenwet op, vanaf of ten behoeve van werken waarvoor een vergunning als bedoeld in artikel 2 van de Wet beheer rijkswaterstaatswerken nodig is. Laatstgenoemde wet is in 2010 opgegaan in de Waterwet, waarbij artikel 6.5, lid c het genoemde artikel van de Wet beheer rijkswaterstaatswerken vervangt, zoals aangegeven in artikel 2.23 van de Invoeringswet Waterwet. Hiermee is het Staatstoezicht op de Mijnen voor deze beschikking de toezichthouder voor de Arbeidstijdenwet en de Arbeidsomstandighedenwet. Vanuit deze bevoegdheid houdt het SodM toezicht op de arbeid die verricht wordt en kan het in geval van een arbeidsongeval onderzoek doen met betrekking tot de activiteiten. Dit houdt tevens in, dat er Veiligheidsdocumenten (zoals een risico-inventarisatie en –evaluatie, RI&E) voor

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werkzaamheden opgesteld moeten worden en dat deze aan SodM toegestuurd moeten worden.

10. Verzendlijst

Een afschrift van deze vergunning is verzonden aan:

1. De regionaal directeur van het RVB, DV, Postbus 2222, 4800 CE Breda, die zich met betrekking tot het gebruik van staatseigendom(men) schriftelijk tot u kan wenden
2. Directeur van de Rijksdienst voor het Cultureel Erfgoed, Afdeling Strategie en Internationaal, t.a.v. drs. M. Snoek, Postbus 1600, 3800 BP Amersfoort
3. Kustwachtcentrum, t.a.v. Hoofd Nautisch Beheer, Postbus 10000, 1780 CA Den Helder
4. Stichting De Noordzee, Drieharingstraat 25, 3511 BH Utrecht
5. Staatstoezicht op de Mijnen, t.a.v. de heer M.A.M.J van Kuijk, Postbus 24037, 2490 AA Den Haag
6. Koninklijke Marine, Dienst der Hydrografie, Postbus 10000, 1780 CA Den Helder
7. Rijksdienst voor Ondernemend Nederland, t.a.v. de heer J.P.H. van der Sneppen, Postbus 20401, 2500 EK Den Haag
8. TAQA Energy B.V., t.a.v. de heer Koos Huisman, Postbus 11550, 2502 AN Den Haag
9. Neptune Energy Netherlands B.V., t.a.v. de heer Henk Weits, Postbus 474, 2700 AL Zoetermeer
10. TenneT TSO B.V., t.a.v. mw. N. Kaarls, Postbus 718, 6800 AS Arnhem

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Bijlage 1: Begripsbepalingen

Behorende bij de vergunningaanvraag van 4 september 2018 met nummer RWSZ2018-00013612.

In deze vergunning wordt verstaan onder:

1. 'Aanvraag': De aan deze vergunning ten grondslag liggende aanvraag is op 4 september 2018 binnengekomen bij Rijkswaterstaat Zee en Delta en geregistreerd onder nummer RWSZ2018-00013612;
2. 'Afdeling handhaving': de afdeling Handhaving van Rijkswaterstaat Zee en Delta te Rijswijk;
3. 'BPRW 2016-2021: het Beheer- en Ontwikkelplan voor de Rijkswateren 2016-2021, zoals dat op 27 december 2015 in werking is getreden (te downloaden van www.rijkswaterstaat.nl);
4. 'Bevoegd gezag': de hoofdingenieur-directeur Rijkswaterstaat Zee en Delta te Rijswijk namens de minister van Infrastructuur en Waterstaat (p.a. Rijkswaterstaat Zee en Delta, Postbus: 2232, 3500 GE Utrecht);
5. 'Handhavingsambtenaar': de voor deze vergunning aangewezen ambtenaar, werkzaam bij de afdeling Handhaving van Rijkswaterstaat Zee en Delta en handelend namens het bevoegd gezag, e-mail: handhavingnoordzee@rws.nl;
6. 'Kaderrichtlijn Water (KRW)': richtlijn 2000/60/EG van 23 oktober 2000 tot vaststelling van een kader voor communautaire maatregelen betreffende het waterbeleid;
7. 'KRW-waterlichaam': volgens artikel 2, lid 10, van de richtlijn 2000/60/EG is een KRW-waterlichaam een te onderscheiden oppervlaktewater van aanzienlijke omvang, zoals een meer, een waterbekken, een stroom, een rivier, een kanaal, een deel van een stroom, rivier of kanaal, een overgangswater of een strook kustwater;
8. 'Vergunninghouder': diegene die krachtens deze vergunning verantwoordelijk is voor de handelingen die verricht worden in het vergunde gebied;
9. 'Waterbeheerder': de minister van Infrastructuur en Waterstaat, per adres de hoofdingenieur-directeur van Rijkswaterstaat Zee en Delta;
10. 'Werken': de proefinstallaties die door de vergunninghouder worden toegestaan met de daarbij horende werkzaamheden;
11. 'Werkzaamheden': het maken, aanleggen, houden, onderhouden en opruimen van het op grond van de vergunning (te behouden) werken, alsmede alle in de vergunning beschreven handelingen;
12. 'Rijksdienst voor het Cultureel Erfgoed': Afdeling Strategie en Internationaal, t.a.v. drs. M. Snoek, Postbus 1600, 3800 BP Amersfoort, telefoon 033- 4217617, e-mail m.snoek@cultureelerfgoed.nl.
13. 'Kustwachtcentrum': Operationele Centrum van de Kustwacht in Den Helder, alarmnummer 0900 - 0111 of de Duty Officer: telefoon 0223-542300, fax nummer 0223-658358, VHF 16/70;

Rijkswaterstaat Zee en Delta

Datum
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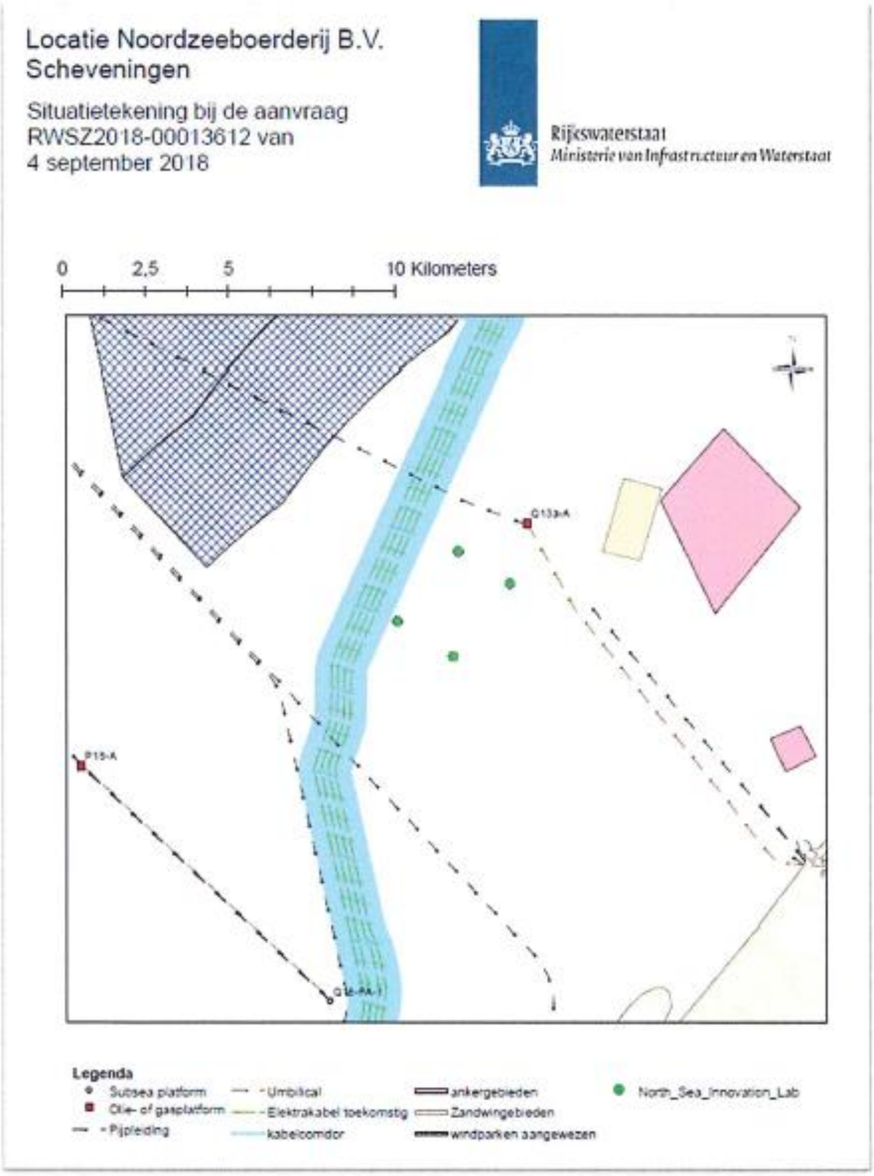

RWS INFORMATIE

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GHENT UNIVERSITY

FACULTY OF ENGINEERING AND ARCHITECTURE
Maritime Technology Division

TECHNICAL REQUIREMENTS OF AN OFFSHORE SEAWEED LONGLINE SYSTEM

UNITED – PILOT THE NETHERLANDS

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report summarizes the calculations that have been done by the Maritime Technology Division of Ghent University (MTD UGent) to the seaweed cultivator designed by the Seaweed Company for a pilot study under the framework of the UNITED-Pilot The Netherlands. In this part of the research project, the feasibility of cultivating seaweed in the Dutch part of the North Sea is assessed in terms of biological, technical and economical standpoints.

The system consists of two nets 50 m long and 3 m wide installed vertically and connected with a dyneema rope of 5 m. The nets have a mesh size of 0.2 m x 0.2 m. The upper part of the net is kept afloat by multiple floaters. Underneath each net, sinkers are used as a counterweight. The net is connected in each side through a series of dyneema ropes to two spar buoys holding the system in place. The spar buoys are each connected to a concrete block of 6 T dry weight resting on the seabed through a chain of 50 m.

The numerical calculations have been performed using the in-house developed mooring dynamic solver MoorDyn-UGent, based on the lumped-mass. The hydrodynamic forces on all the elements of the system are modelled according to the Morison Equation. The numerical net has been modelled as a combination of cylindrical elements with a mesh size coarser than the real net. The effect of the seaweed on the net has been modelled considering the seaweed is behaving as fouling attaching to the net. The projection area, volume and weight of the cylindrical elements have been increased accordingly in the numerical model to simulate the behaviour of a net fouled with seaweed. The load combinations used for the simulations are based on a 5-year return period of wave and a 1 -year return period of current.

A mooring configuration for a seaweed longline system has been designed for a pilot study under the framework of UNITED project. In this research project, a feasibility of cultivating seaweed in the Dutch part of the North Sea is assessed in terms of biological, technical and economical standpoints.

Based on the numerical study performed the following conclusions and recommendations are included for consideration:

- According to a combined safety factor of 2.3, the MBL of the chain should not be less than 555.55 kN. If used chains were to be used, the safety factor is increased to 5.75 and the MBL should not be less than 1388.62 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 28 mm should not be less than 685.93 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 16 mm should not be less than 442.78 kN.
- For a 5-year return period of waves and current, the maximum horizontal load transferred to the anchor is 236.26 kN.
- For a 5-year return period of waves and current, the maximum vertical load transferred to the anchor is 51.30 kN.
- Based on the results shown in Figure 13 it is expected for a snap load to occur during a extreme waves and current event.
- For a short installation period (3 months of marine growth), fouling does not have a major impact on the structural loads. However, it is suggested [NORSOK N003] [DNV RPC205] to consider a linear increase of marine growth thickness over the course of 2 years to account for the increase in mass and drag area to the system.
- The spar buoys should be able to withstand the hydrostatic pressure at a depth of 12 m.

1 INTRODUCTION

In the framework of UNITED project, seaweed longline system will be installed in the Dutch part of the North Sea as part of the offshore pilot campaign that starts in 2021. This pilot study is performed to examine the feasibility of growing seaweed using available space inside wind turbine concession area under harsh environmental conditions.

1.1 Research purpose

The aim of this report is to describe the technical requirements necessary for the mooring system of a seaweed longline that will be installed in the Dutch part of the North Sea. These requirements are the outcome of numerical simulations performed on the mooring system subjected to environmental induced loads of waves and current. Design of the mooring arrangement is provided by The Seaweed Company (TSC) along with the environmental data [1]. Numerical calculations are performed using an-in house mooring dynamic solver based on the lumped-mass approach [2] [3].

1.2 Structure of the report

Input data and numerical modelling of the seaweed cultivation system are described in Section 2. The results of numerical calculations are presented in Section 3 to which safety factor checks are performed for the mooring components (e.g., line and anchor). Lastly, summary of results is presented in Section 4 and conclusions are made based on the numerical analysis that has been performed in this study.

1.3 Guidelines and standards

The following documents are used as guidelines and input for the numerical calculations presented in this report:

- The Seawed Company; TSC Mooring Sketches [1]
- Norwegian Standard NS 9415; Marine fish farms requirements for site survey, risk analyses, design, dimensioning, production, installation and operation [4]
- DNVGL OS-301; Position mooring [5]
- DNVGL OS-C101; Design of offshore steel structures, general – LRFD method [6]
- DNV RP-C205; Environmental conditions and environmental loads [7]
- NORSOK STANDARD N-003; Actions and action effects [8]

2 NUMERICAL MODELLING

An open-source time-domain mooring dynamic solver based upon lumped-mass approach, MoorDyn [2] has been modified in-house by Maritime Technology Division of Ghent University [3] to include waves and current induced load. The inclusion of the aforementioned environmental loads is done by the use of Morison Equation, which is a semi-empirical formula that splits the forces into its drag and inertia component [9]. Adaptations also introduced a three degree-of-freedom buoy, clump weight and horizontal seabed interaction. In this approach, the internal forces (line tension, weight, buoyancy) and external forces are calculated at each node to obtain the accelerations. The equations of motions are reduced into a set of ordinary differential equations (ODEs) and solved using Runge-Kutta second order integration scheme at each time step [2] [3].

2.1 Input data

The mooring configuration of the seaweed longline system is based on the design provided by The Seaweed Company (TSC) [1]. The longline consists of two nets of each 50 m long and 3 m wide. The net has a mesh size of 0.4 m x 0.4 m and keeps vertically afloat by a series of floaters and sinkers. The floaters are connected at the top of the net and the sinkers at the bottom of the net. The nets are connected through a series of dyneema ropes to two large floaters (SPAR buoys) on both ends. The SPAR buoys are connected to 2 fixed points in the numerical model representing a gravity anchor.

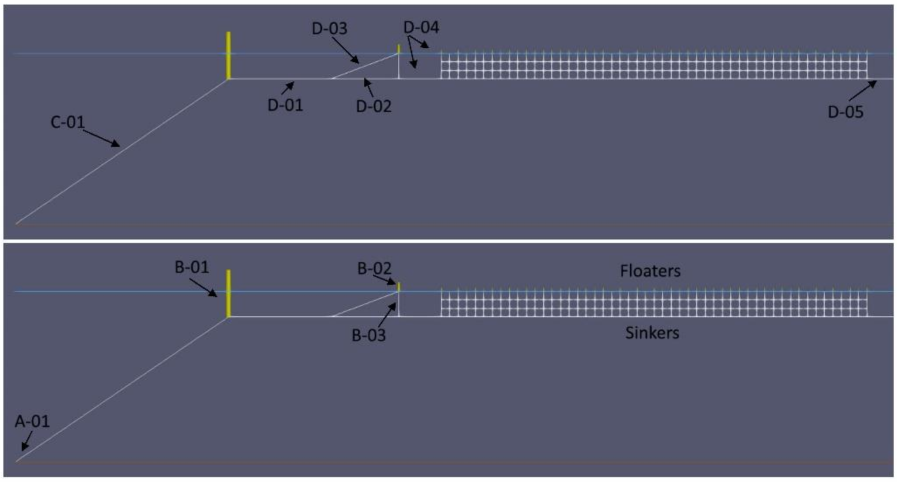

Figure 1. Sketch of the seaweed longline mooring based on the configuration received from TSC as an input for the numerical analysis [1]. The seaweed cultivation system is symmetric around D-05.

Table 1. Equivalent line elements used in the numerical model of the seaweed longline mooring configuration.

Element	Type	Length (m)	Diameter (m)	Dry mass (kg/m)
C-01	Studlink Chain 48 mm	50	0.091	52.8
D-01	Dyneema 28 mm	12	0.025	0.49
D-02	Dyneema 28 mm	8	0.025	0.49

D-04	Dyneema 28 mm	8.43	0.025	0.49
D-05	Dyneema 16 mm	5	0.013	0.14
D-06	Dyneema 28 mm	5	0.013	0.14

Table 2. Equivalent buoy elements used in the numerical simulations

Element	Volume (l)	Weight (kg)	Diameter (m)	Length (m)	Quantity
B-01	5270	2377	1.1	5.54	2
B-02	0.019	159	0.089	3	2
B-03	0.23	30	0.523	1.071	2
Floater	0.00275	0.955	0.145	0.48	101
Sinker	0.00075	0.955	0.039	1.78	101

2.2 Load combination

The numerical simulations are performed based on three simulation cases, which are a combination of environmental induced load parallel to the mooring system. Summarised in are the simulation cases that are based on the 1-year, 5-year and 50-year return period of waves and current.

Table 3. Summary of dynamic simulation cases [1]

Simulation case	Return period	Regular wave			Depth-averaged current	
		height	period	direction	speed	direction
[-]	[-]	[m]	[s]	[going-to]	[m/s]	[going-to]
1	1-year	9	10.6	North-East	1.3	North-East
2	5-year	11.6	11.6	North-East	1.4	North-East
3	50-year	14.3	13.3	North-East	1.5	North-East

2.3 Seaweed numerical modelling

Seaweed hydrodynamics

Various studies have been done to assess the hydrodynamic interaction of different seaweeds subjected to various flow characteristics. Xu and Komatsu [10] performed a field experiment of *Sargassum horneri* to determine the drag coefficient exerted by the seaweed in a unidirectional flow. The measurement is done by towing the seaweed attached to a boat. Based the regression calculated using their field data, the drag coefficients (C_d) for the range of Reynolds number (*Re)* between 10^4 to 10^6 can be expressed with the following formula: $C_d = 18.295\ Re^{-0.57}$ [10]. On a separate study, Norvik [11] performed a laboratory experiment on artificial seaweed model of *L. saccharina* subjected to a unidirectional flow to compare the behaviour and hydrodynamic properties of two different morphologies: flat and undulate. The conclusion of this study suggests that the undulate model results in higher drag forces than the flat model. At higher velocities the cluster undulate model has 3-4 times higher drag coefficients that cluster flat model. However, the behaviour of the two models is different and this is likely that due the difference in mechanical properties of the artificial seaweed compare to a real sugar kelp. Therefore, it is suggested that in future research a comparison with real undulate seaweed is performed. Furthermore, Vettori and Nikora [12] conducted an experiment in an open-channel flume to measure the load exerted by the presence of real *Saccharina latissima* at a blade scale in a unidirectional turbulent flow. They found that the blade interacts differently as the flow velocity increases, resulting in lower mean force for high velocities. This is due to the biomechanical properties of the seaweed blade that adapts to the flow conditions, creating scale-dependent interactions of wake flow and turbulent eddies. Drag coefficients obtained from this study is within the range of 0.02 – 0.08 [12], well within similar range with the results from Norvik [11] for undulate large seaweed model.

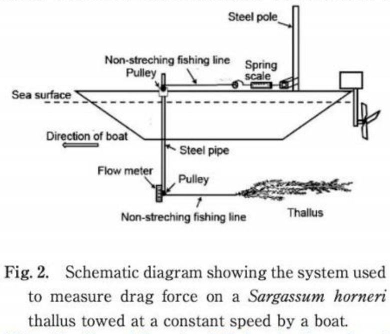

Figure 2. Excerpt from an article published by Xu and Komatsu [10] showing the schematic of their experimental setup

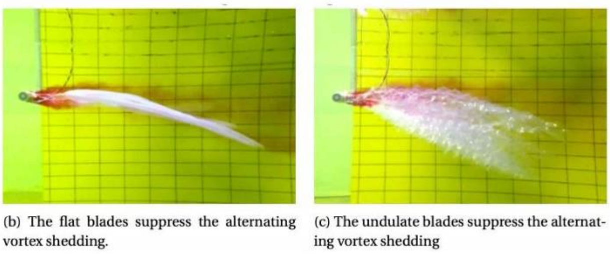

Figure 3. Excerpt from a master's thesis published by Norvik C. [11] comparing hydrodynamics of flat and undulate artificial seaweed blades

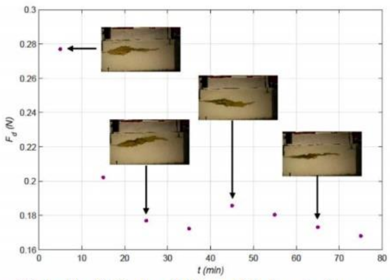

Figure 4. Excerpt from an article published by Vettori and Nikora [12] showing the reconfiguration of the blade as the flow velocity increases over time

Hydrodynamics of net structures

Over the past three decades, several experiments had been conducted to study the hydrodynamics of a net structure subjected to current induced load [13] [14] [15] [16] [17]. In the early 2000s, Pal et.al developed a numerical model to simulate the dynamic behaviour 3D net structures subjected to waves and current [18] [19]. Their numerical net is modelled as numerous elements connected via nodes where the drag force is based on a semi-empirical formula. In their studies, the drag coefficient as a function of net solidity and angle of attack, is taken from the formula derived by Aarsnes et. al [20] based on extensive model tests performed by Rudi et. al [17]. Essentially, a net is an array of cylinders. The approach of modelling a numerical net represented by array of cylinders with less elements than physical model was also done by Fredheim [13] where the numerical calculations results are compared with experiment done by Enehaug [16].

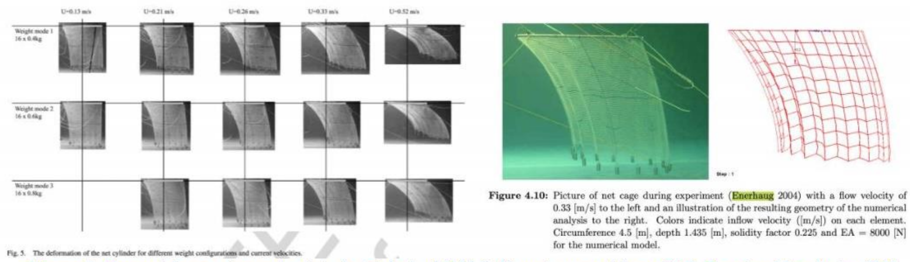

Figure 5. Excerpt from a journal article by Pal et. al [21] (left) and excerpt from PhD Thesis of Fredheim [13] (right)

In their validation study, Pal et. al [21] found that the deformation of physical net in real life, confirmed by the experiment results, had caused the overprediction in their numerical calculations. The elasticity of the net shall be considered in the numerical model to achieve a more accurate prediction. More than a decade later, Cifuentes and Kim [22] built a numerical net using lumped mass based commercial mooring dynamic software called OrcaFlex [23]. The hydrodynamic interactions are modelled using the Morison Equation [7]. They tried to address the deformation of real physical net that causes deviation in the numerical results by including the reduction of flow velocity that passed through the net. The inclusion of the shielding effects is done via the wake model derived for riser interactions by Blevins [24]. To account for Reynolds number dependencies, at each-time step the drag coefficient is calculated based on the instantaneous velocity, which is based on the contribution of body and fluid velocity. Drag coefficient as a function of Reynolds number had been derived from the study done in the 1971 by Choo and Casarella [25]. Extending the results of Choo and Casarella [25], DeCew and Tsukrov proposed the following formulae [26]:

$$C_{dn} = \begin{cases} \frac{8\pi}{Re\, s}(1 - 0.87s^{-2}),\ 0 < Re < 1 \\ 1.45 + 8.55\, Re^{-0.90},\ 1 < Re \leq 30 \\ 1.1 + 4\, Re^{-0.5},\ 30 < Re \leq 2.33 \times 10^5 \\ -3.41 \times 10^{-6}(Re - 5.78 \times 10^5),\ 2.33 \times 10^5 < Re \leq 4.92 \times 10^5 \\ 0.401\left(1 - e^{-\frac{Re}{5.99}\times 10^5}\right),\ 4.92 \times 10^5 < Re \leq 10^7 \end{cases} \quad (1)$$

Where:

$$s = -0.077215655 + \ln(\frac{8}{Re}) \quad (2)$$

Cifuentes and Kim [22] adapt the time-step dependent drag coefficient based on the formulae proposed by DeCew and Tsukrov [26] by including the shielding effects from wake formula of Blevins [24]. This is done by calculating the drag coefficient in the downstream elements that is affected by the wake of upstream elements. They concluded that this new approach has improved the previously model proposed by Lader [21] by addressing the influence of net solidity and Reynolds number to the drag coefficients.

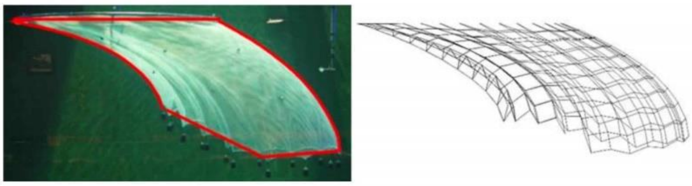

Fig. 3 Net deformation from experiments (Moe-Føre *et al.* 2015) and numerical calculations

Figure 6. Excerpt from a journal article published by Cifuentes and Kim [22] showing the comparison of their numerical model and laboratory physical model

Impact of biofouling on net structures

Observed by Pal et. al the effect of biofouling provides significant contributions to the deformation of net structures in a study performed on two full-scale commercial sea-cages [15]. In the experiment carried by Swift et. al, the increase in the drag coefficient (C_d) on a net impacted by biofouling ranges from 6% to 240% compared to the C_d of clean net [27]. In another experiment conducted by Gansel et. al [28], the impact of biofouling was assessed for several nets with different solidities. For a net with the same solidity, fouling could increase the drag force by 43% [28]. However, they suggested that future research should test nets that have very high solidities to better assess the performance of a heavily fouled aquaculture structures. In a more recent experimental study by Niño et. al [29], normal and tangential drag coefficients were derived as functions of Reynolds number and net solidity. The tests were performed on clean nets as well as fouled nets. It is mentioned that the drag coefficients obtained from their experiment only valid for the biofouling consisting small bivalve and filamentous algae [29].

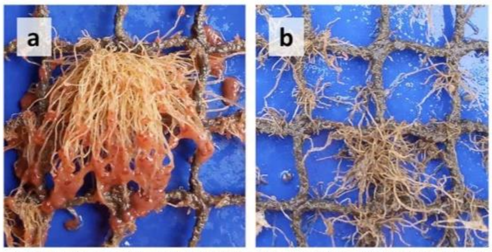

Fig 1. Hydroid fouling on aquaculture nets. The images show net panels on the same fish farm, but at different times with approximately one month between the images. Hydroids found on Norwegian salmon cages have bright pink hydranths (a), but on some nets, probably mostly in late autumn and early winter, hydranths may be lost or retracted (b).

Figure 7. Excerpt from a journal article published by Gansel et. al [28] showing fouled nets

As a practical engineering guideline in mooring design, *Det Norske Veritas* (DNV) [5] suggests considering the influence of marine growth on a line element by taking the fouling thickness from field measurement or recommendation from NORSOK N-003 [8].

Table 3 – Thickness of marine growth [a]

Water depth m	56° to 59° N mm	59° to 72° N mm
Above + 2	0	0
+2 to - 40	100	60
Under - 40	50	30

[a] The water depth refers to mean water level

Figure 8. Excerpt table of marine growth thickness that has been increased linearly over the period of 2 years [8]

The following formula are used to determine the influence of marine growth on the system [5]:

$$M_{growth} = \frac{\pi}{4}\left[(D_{nom} + 2\Delta T_{growth})^2 - D_{nom}{}^2\right] \rho_{growth}\, \mu \; (kg/m) \quad (3)$$

$$W_{growth} = M_{growth}\left[1 - \frac{\rho_{seawater}}{\rho_{growth}}\right]\frac{9.81}{1000}\,(kN/m) \quad (4)$$

$$C_{dgrowth} = C_d\left[\frac{D_{nom}+2\Delta T_{growth}}{D_{nom}}\right] \quad (5)$$

Where:

M_{growth} = mass of marine growth
D_{nom} = nominal rope diameter
ΔT_{growth} = marine growth surface thickness
ρ_{growth} = marine growth density (1325 kg/m^3)
μ = 2.0 for chain, 1.0 for wire rope
$\rho_{seawater}$ = sea water density (1025 kg/m^3)
C_d = drag coefficient
$C_{dgrowth}$ = drag coefficient due to marine growth

The drag coefficient ($C_{dgrowth}$) is adapted to account for the increase in drag area due to the additional thickness in the line element from the presence of marine growth (ΔT_{growth}).

Numerical modelling of a net and seaweed as a fouled net using lumped-mass approach

In the aforementioned literature review on seaweed hydrodynamics, the studies were all focusing on a blade scale or cluster blade scale of seaweeds. As far as the authors' knowledge, a study has not been published regarding an experiment of fully grown seaweed attached to a net. For the purpose of estimating the hydrodynamic force induced by the presence of fully grown seaweed on net, the approach of assuming seaweed as fouled net is implemented.

Presented in this report is the method of modelling a numerical net by building a set of homogenous line segments with the properties of cylinders connected by nodes. The internal and external forces are equally transferred to the neighbouring nodes, namely the lumped-mass method [2] [3]. Compression force is not modelled, therefore, allowing each segment to compress as such it resembles the behaviour of a rope. The Morison Equation [9] is implemented to model the hydrodynamic interactions between the line elements and the fluid particles. Consequently, drag coefficient of line elements are necessary for this semi-empirical formula. The drag coefficients of mooring lines, backbone and buoy elements are taken from the recommendation provided by DNV [5] [7]. As for the net without seaweed, formulae derived by DeCew et. al [26] shown in the Equation (1) is used to determine the normal drag coefficient. The tangential drag coefficient is according to the study done by Cifuentes et. al [22]. The fully grown seaweed on a net is modelled with the approach suggested by DNV in the case of marine growth in

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

line elements. This is done by firstly determine the thickness of biofouling. Then, the previously calculated *Reynolds*-dependant drag coefficients of the net are adjusted with the formula from DNV OS 301 [5] shown in Equation (5) to account for biofouling due to the fully grown seaweed. In this approach, the density of the marine growth (ρ_{growth}) shown in the Equation (3) is replaced by seaweed density. A conservative value of 1183 kg/m^3 is used to account for the seaweed as marine growth on an array of ropes, namely net.

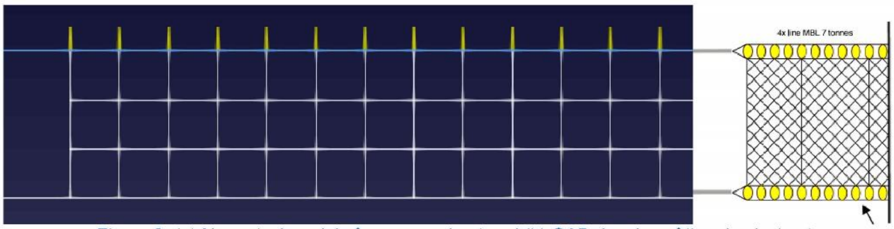

Figure 9. (a) Numerical model of a seaweed net and (b) CAD drawing of the physical net

The physical net used to model the numerical net has a mesh size of 0.4 m x 0.4 m. The total length of all ropes in the net was estimated to be 1500 m. A net discretization with a mesh size of 1.0 m x 1.0 m was chosen. Figure 9 shows a comparison between the numerical net (i) and the physical net.

The numerical net consist of equivalent cylindrical elements with homogenous properties. Diameter of each cylindrical element of the numerical net is calculated as such that the total volume of the numerical net is the same as the one from the physical model. This results in having different projected areas between the numerical model and the physical model. However, this is taken into account in the numerical calculations by multiplying the drag coefficient with the ratio between the area of the numerical net model and the physical net model, both for the normal and the tangential components. Figure 10 shows a snapshot of the numerical simulations showing the behaviour of the numerical net with a mesh size of 1.0 m x 1.0 m subjected to waves and currents.

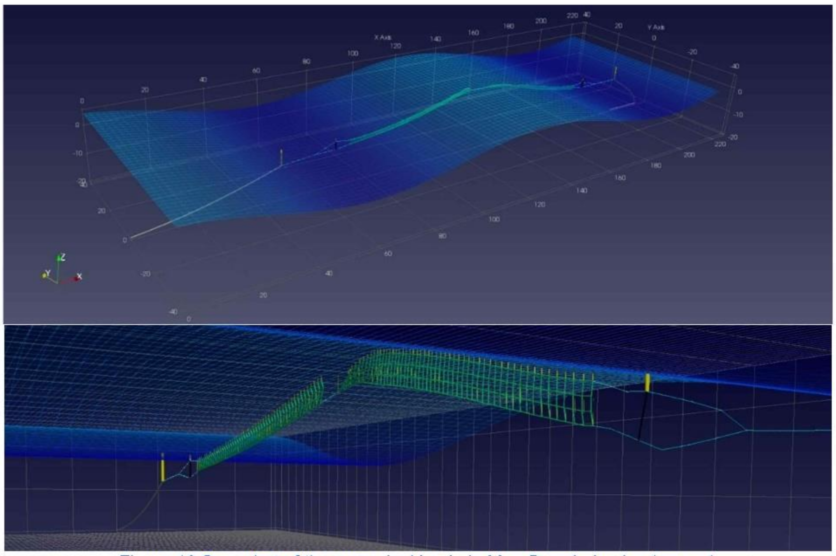

Figure 10 Snapshot of the numerical basin in MoorDyn during load case 1.

3 SIMULATION RESULTS

Presented in this chapter are the results of numerical calculations performed using lumped-mass approach [2] [3].

3.1 Hydrostatics at equilibrium

Hydrostatic calculations are performed to compare the impact of fully grown seaweed on net structures and 3 months of biofouling to the system's equilibrium. Figure 11a shows the hydrostatic equilibrium of the system after installation while Figure 11b depicts the hydrostatic equilibrium of the system 3 months after installation. As it is shown in Figure 11, it is not possible to visually appreciate any differences in the system. This indicates a good hydrostatic behaviour of the systems during its operation lifetime.

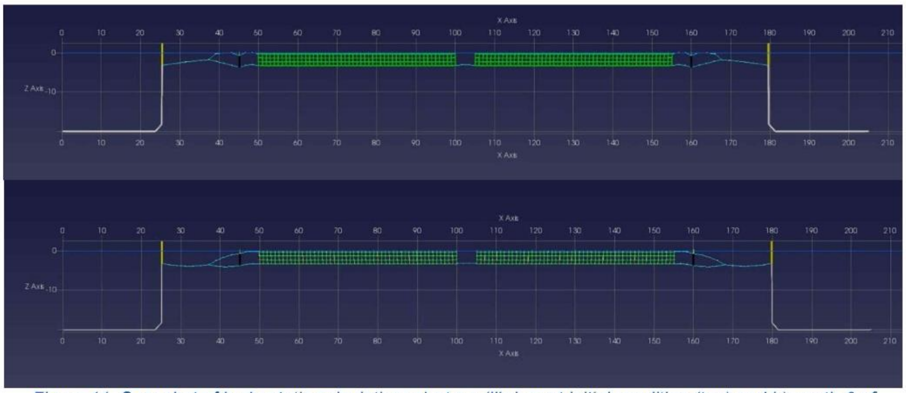

Figure 11. Snapshot of hydrostatic calculation: a) at equilibrium at initial condition (top) and b)month-6 of installation (bottom)

3.2 Dynamic simulations

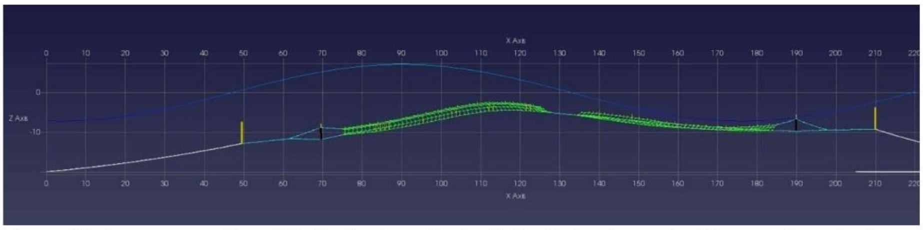

Figure 12 shows a snapshot of the hydrodynamic simulation for load case 1 with a net discretization of 1.0 m x 1.0 m. As it can be observed during this simulation the forward chain is under tension taking the highest load, while the backward chain is laying on the ground reducing the tension that this chain is taken (see

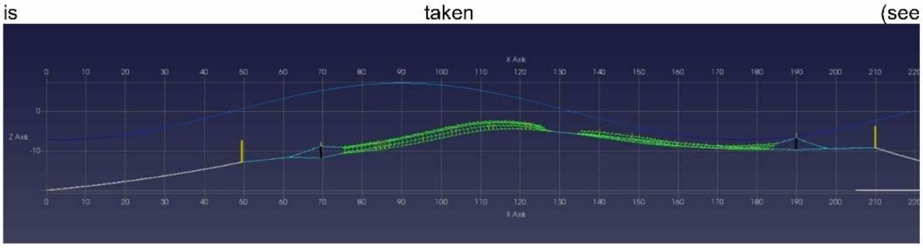

Figure 12). It has to be noted that waves and currents are both contributing to the loading of the system. This can be observed on the amplitude of the tension ranging from 100 kN to 240 kN (see Figure 13. Tension for load case 2 at the forward chain and at the backward chain) for the wave action and a flat value of 100 kN for the current action. As it can be seen in Table 4 the maximum tension that any of the anchor chains will suffer is not higher than 241.50 kN for the load cases corresponding with a 5-year period of return. Finally, it has to be mentioned that in the backward chain (see Figure 13. Tension for load case 2 at the forward chain and at the backward chain), snap loads are occurring during load case 2 with a maximum value of 380 kN. The numerical model is neglecting the dampening effect of the concrete blocks as they are modelled as a fixed point, nevertheless it is expected that during an extreme waves and currents event snap loads can happen. On top of this, It was observed during the numerical simulation of load case 2 (see Figure 12) that the forward spar buoy is submerged at a depth of 12 m (see Figure 12).

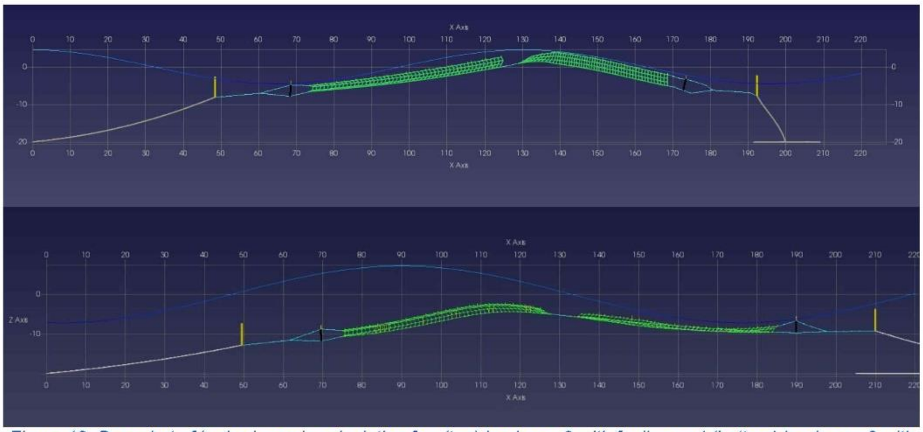

Figure 12. Snapshot of hydrodynamic calculation for: (top) load case2 with fouling and (bottom) load case 2 with fouling.

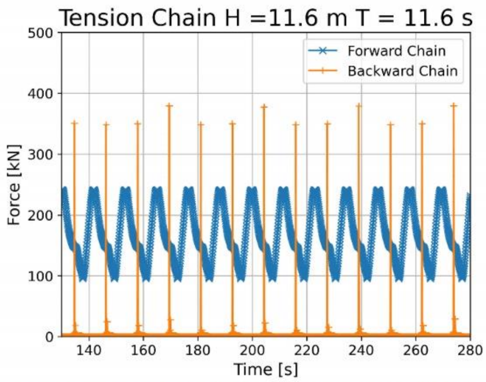

Figure 13. Tension for load case 2 at the forward chain and at the backward chain

The effect of 3 months fouling on the system was checked for all load cases. As it can be seen in Table 4, **Error! Reference source not found.**Table 5 and Table 6 the maximum loads that the system is experiencing do not deviate much between considering fouling in the simulation or not. The relevant structural elements, namely the chains and dyneema ropes suffer tensions with similar order of magnitude in all load cases. This indicates that fouling does not have a major impact on the systems loads during the cultivation process of the seaweed for a short installation and harvesting period. However, if the system would stay longer on the water (e.g. on a commercial project of 15 years) special attention should be given to fouling on the chains and dyneema ropes. In this case the effect of 24 months of fouling that grows linearly should be considered (according to NORSOK STANDARD N-003 and DNV RP-C205).

Table 4. Maximum tension at C-01

Structural Element	Maximum Tension (kN)	
Load case	**No-Fouling**	**Fouling**
1	153.68	152.93
2	241.03	241.50
3	410.04	411.02

Table 5. Maximum tension on dyneema rope of 28 mm ropes

Structural Element	Maximum Tension (kN)	
Load case	**No-Fouling**	**Fouling**
1	144.50	145.61
2	197.86	198.82
3	235.08	235.56

Table 6. . Maximum tension on dyneema rope of 16 mm ropes

Structural Element	Maximum Tension (kN)	
Load case	**No-Fouling**	**Fouling**
1	97.4	98.34
2	127.52	128.34

3	152.00	152.36

Lastly, the maximum loads suffered by the forward concrete blocks and transmitted to the forward anchor has been summarized in Table 7. Maximum Force at the forward anchor. For the case of 5-year period of return the maximum horizontal load transferred to the concrete block corresponds with a total horizontal force of 236.26 kN. The Maximum vertical force experienced by the concrete block corresponds with 51.30 kN.

Table 7. Maximum Force at the forward anchor

Structural Element	Maximum Force Forward Anchor (kN)		
Load case	**Fx**	**Fy**	**Fz**
1	150.69	0	27.92
2	236.26	0	51.30
3	404.58	0	75.85

3.3 Safety factor check

Based on the results of the dynamic analysis presented in Section 3.2. and Appendix A, the maximum breaking load (MBL) at ULS condition for a design load of 5-year period of return has been obtained for the anchor chain, the dyneema ropes of 28 mm and the dyneema ropes of 16 mm. The load factor for dynamic analysis is taken from Table 4 of Section 6.6. of the Norwegian Standard NS 9415 (see Figure 14 (a)). The material factor for the different materials has been taken from Table 5 of Section 6.6. of the Norwegian Standard NS 9415 (see Figure 14 (b)). The safety factor for calculating the MBL is obtained by multiplying the load and the material factors. The results have been summarized in Table 8: Safety factor check

Table 8: Safety factor check

Structural Element	Load Factor	Material Factor	Safety Factor	Max Load (kN)	MBL (kN)
Chain	1.15	2.0	2.3	241.50	555.55
Used Chain	1.15	5.0	5.75	241.50	1388.62
Dyneema 28 mm	1.15	3.0	3.45	198.82	685.93
Dyneema 16 mm	1.15	3.0	3.45	128.34	442.78

Table 4 – Load factors for mooring lines

Type of analysis	Load factor
Static analysis	1,6
Quasi-static analysis	1,15×DAF[1)]
Dynamic analysis	1,15
Accident limit (break in mooring line)	1,0
Spring flood	1,0

[1)] Here is used a factor of 1.15 multiplied by dynamic amplification factor (DAF). Dynamic amplification factor ≥1.1. Choice of value of DAF shall be justified and documented.

Tabell 13 – Material factors for moringlines

Type	Material factor
Synthetic rope	3,0
Synthetic rope with knots	5,0
Chains and chain components	2,0
Used chains	5,0
Coupling discs and other connecting points of steel*	1.5
Shackles	2,0
Rock bolts and other bottom attachments	3,0

*First yield

Figure 14. a) Load factor for mooring and b) Material factor for mooring lines according to Norwegian Standard NS 9415

4 CONCLUSIONS

Based on the numerical study performed on the seaweed cultivator designed by the Seaweed Company for the UNITED Dutch Pilot the following conclusions and recommendations are included for consideration:

- According to a combined safety factor of 2.3, the MBL of the chain should not be less than 555.55 kN. If used chains were to be used, the safety factor is increased to 5.75 and the MBL should not be less than 1388.62 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 24 mm should not be less than 685.93 kN.
- According to a combined safety factor of 3.45, the MBL of the dyneema rope of 16 mm should not be less than 442.78 kN.
- For a 5-year return period of waves and current, the maximum horizontal load transferred to the anchor is 236.26 kN.
- For a 5-year return period of waves and current, the maximum vertical load transferred to the anchor is 51.30 kN.
- Based on the results shown in Figure 13 it is expected for a snap load to occur during a extreme waves and current event.
- For a short installation period (3 months of marine growth), fouling does not have a major impact on the structural loads. However, it is suggested [NORSOK N003] [DNV RPC205] to consider a linear increase of marine growth thickness over the course of 2 years to account for the increase in mass and drag area to the system.
- The spar buoys should be able to withstand the hydrostatic pressure at a depth of 12 m.

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ANNEX C

Belgian Pilot

Additions to Environmental impact assessment

Fish

The fish fauna is dominated by lesser weever *Echiichthys vipera*, whiting *Merlangius merlangus*, common dab *Limanda limanda, solenette Buglossidium luteum* and European plaice *Pleuronectes platessa*. At the sandbanks, *Echiichtys vipera* is the dominant fish species. Since the installation of the wind turbines several species of fish are found in large densities around the foundations of the turbines, such as whiting pout *Trisopterus luscus*, Atlantic cod *Gadus morhua*, Atlantic horse mackerel *Trachurus trachurus* and Atlantic mackerel *Scomber scombrus*.

Benthos

The sandbanks and gullies of the Pilot site are characterized by two *macro benthic* communities: the *Nephtys cirrosa* and the *Ophelia limacine - Glycera lapidum* community. These communities are characterised by relative low density and diversity compared to the more coastal macro benthic communities. Their habitat consists of medium grain-sized sand (300-500 µm), a low mud percent-age (max mean of 4.3 %) and a low organic matter percentage (max mean 0.3 %). Epibenthic organisms at the Pilot site are dominated by Echinodermata and Anomura. A higher density and diversity is found in the gullies compared to the sandbanks. Since the installation of the wind turbines and the accompanied erosion protection layers, hard substrates have been introduced in the otherwise sandy area. The hard substrates are colonised by a number of pioneer species, but the climax community is mainly characterised by the presence of the tube-dwelling amphipod *Jassa herdmani*, plumose anemone *Metridium senile* and blue mussel *Mytilus edulis*.

Marine mammals

In the BPNS, including the Pilot site, five species of sea mammals are regularly spotted: harbour porpoise *Phocoena phocoena*, harbour seal *Phoca vitulina*, grey seal *Halichoerus grypus*, bottlenose dolphin *Tursiops truncates* and white-nosed dolphin *Lagenorhynchus albirostris*.

Birds

The area of the Pilot site is important for two bird species, little gull *Hydrocoloeus minutus* and great *Skua Stercorarius skua*. With the wind farm at Bligh Bank (close to the Pilot site) already installed since 2010, it has been observed that it attracts greater black-backed gull *Larus marinus*, lesser black-backed gull *L. fuscus* and European herring gull *L. argentatus*.

Habitat types

The main habitat type, following the EU Habitat Directive classification, might be characterised as Habitat 1110B – Permanent flooded sandbanks, although the Pilot site (and the complete offshore wind area) has not been appointed as such.

TECHNICAL REQUIREMENTS OF AN OFFSHORE OYSTER LONGLINE SYSTEM

UNITED – PILOT BELGIUM

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

A mooring configuration of an oyster longline system has been designed for a pilot study under the framework of UNITED project. In this research project, a feasibility of cultivating oyster in the Belgian part of the North Sea is assessed in terms of biological, technical and economical standpoints. The oyster will be installed in within the wind turbine park, specifically inside the concession area of Belwind. At this location, the water depth is at -30.1 metre (MLLWS). The longline consists of 57 metre main cultivation line and additional 62 metre of backbone for the purpose of lifting operation during maintenance and installation.

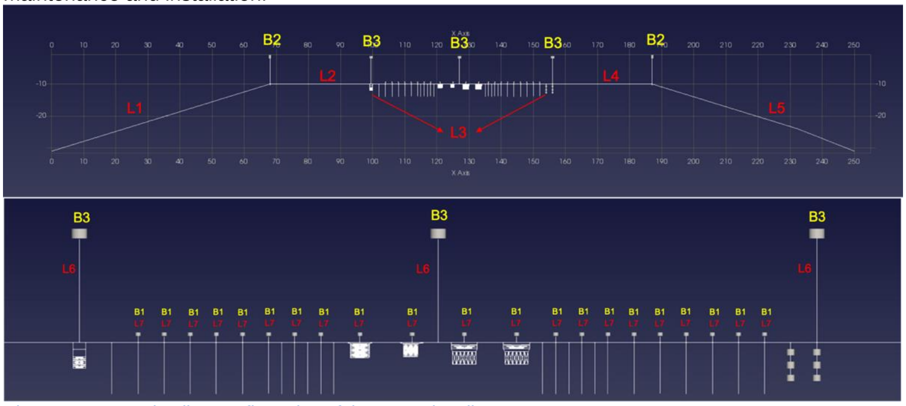


Figure S - 1. Mooring line configuration of the oyster longline system

The distance between South-West (SW) anchor and North-East (NE) anchor is 250 metre. Figure S - 1 shows the schematic drawing of the mooring configuration. The line elements and its properties are summarised in Table S - 1 and Table S - 2.

Table S - 1. Line elements of the mooring configuration

Element (-)	Line length (m)
L1 - mooring line	72
L2 - bakcbone: empty line	31
L3 - backbone: cultivation line	57
L4 - backbone: empty line	31
L5 - mooring line	72
L6 - surface buoy line	8
L7 - submerged buoy line	0.5

Table S - 2. Line properties

Type	Diameter (m)	Dry mass (kg/m)	Density (kg/m)	MBL (kN)
Movline Plus 8 stranded	0.068	2.1	940	737

The impact of marine growth over the course of 21 months has been assessed in this study. Mooring system starts with excess buoyancy during initial installation. However, due to fouling, the middle surface floater (B3) is expected to be fully submerged after 12 months of installation. Therefore, it is of the utmost importance to periodically gather field data with respect to biofouling and compare measurement with the calculations presented in this report. If the thickness of marine growth is growing linearly over 50mm per year, then surface floaters need to be replaced/added between month-9 and month-12 after the installation. The specifications of the floaters are summarised in Table S - 3. Due to a combination of current and waves induced load, the surface floaters are expected to be fully submerged, especially during storm condition. Therefore, all surface floaters have to be foam-filled to withstand submergence up to 15 metre depth.

For the calculation of ultimate limit state (ULS) condition, the 50-year return period of waves and current are used as the input of the simulation. This results in maximum mooring line tension of 125 kN. Taking a combined safety factor of 3.45, the breaking strength of mooring and backbone rope should not be less than 431 kN. As for the anchor, with the safety factor 1.3, the axial capacity of the screw anchor should not be less than 163 kN. Lastly, pretension of 10 kN needs to be applied during the installation when connecting the backbone L2 to the start of main cultivation line L3. As the position of the anchor will have certain deviations, the length of L2 can be adjusted accordingly to achieve the 10 kN of pretension.

Table S - 3. Buoy elements of the mooring configuration

Element	**Net buoyancy (kg)**	**Dry mass (kg)**	**Quantity**
B1 - submerged floaters	29	4	21
B2 - Corner surface floaters	560	55	2
B3 - Intermediate surface floaters	800	73	3

1 INTRODUCTION

In the framework of UNITED project, an oyster longline system will be installed in the Belgian part of the North Sea as part of the offshore pilot campaign that starts in 2021. This pilot study is performed to examine the feasibility of growing oyster using available space inside wind turbine concession area under harsh environmental conditions.

1.1 Research purpose

The aim of this report is to describe the technical requirements necessary for the mooring system of the oyster longline that will be installed in the Belgian part of the North Sea (see Figure 1(a)). A set of boundary conditions for the mooring design have been drawn up as the requirements, both in terms of cultivation system and operational limitations. As part of the cultivation requirement, in total there are five different grow systems that are used in this offshore pilot [1]. These systems are attached to a 57-metre of main cultivation line. Furthermore, the oyster line is required to be submerged at 10 metre depth to minimize the impact of waves to their growth. For the purpose of installation, maintenance and harvesting, the use of diver must be avoided. Therefore, these operations must rely solely on the lifting equipment available on-board of the vessel. For this pilot, a vessel with lifting capacity of 10 kN and freeboard height of 5 metre will be used. During operational condition, the oyster longline system need to be at a minimum distance of 150 metre from each of the wind turbine pole. Furthermore, in the case of 1 anchor loss, the surface floaters must not reach either the poles or the cables (marked with red line in Figure 1(b)). This limits the distance between the two anchors as well as the length overall of the lines. Based upon the aforementioned boundary conditions, design iterations are performed by utilising an in-house numerical tool [2] [3] to analyse the mooring system's behaviour. A dynamic simulation is performed according to the ultimate limit state (ULS) condition defined by the Norwegian Standard NS9415 [4] by taking the 50-year return period of storm as the environmental load. The design criteria are set according to the different guidelines and standards listed in the sub-chapter 1.3.

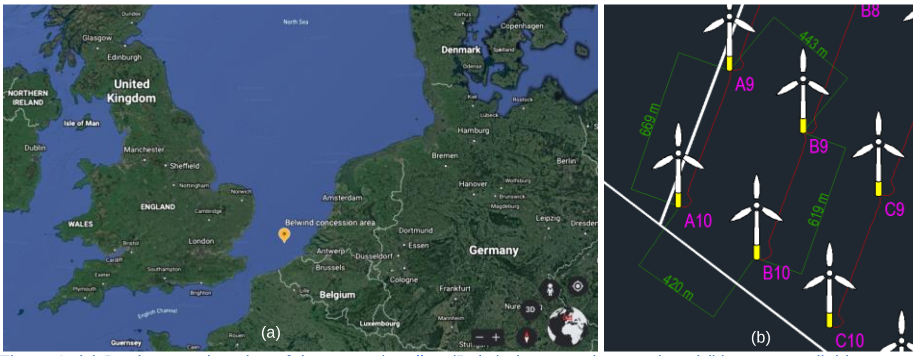


Figure 1. (a) Deployment location of the oyster longline (Belwind concession area) and (b) space available to install the oyster longline system between wind turbine poles. Map data ©2021 Google

A fully submerged system utilising screw-anchor and rope configuration works best when the system is kept under tension. This will prevent the screw anchor to suffer from zero-crossing horizontal forces due to wave induced load. However, this is difficult to achieve when maintenance and installation operation can only be performed by lifting the cultivation system. A slack in the system is then required to perform the aforementioned operations depending on maximum capacity of the lifting equipment and vessel's freeboard height. Therefore, a two-stage design iterations process is done where lifting operation is simulated first. Then, dynamic simulation of extreme sea state (ESS) is performed. The flowchart describing the two-steps design iterations is shown in Figure 2.

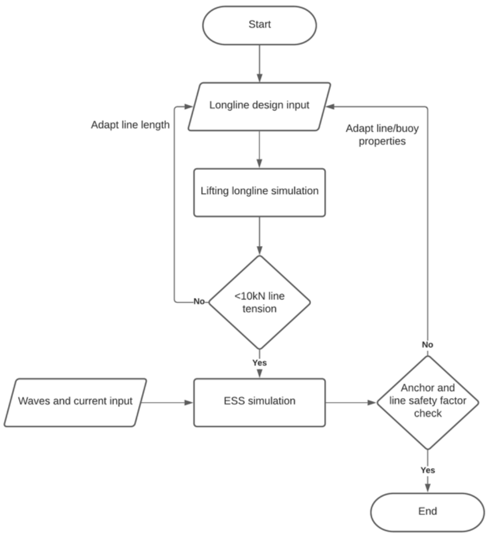


Figure 2. Flowchart of the mooring design iteration process

Lastly, the rate of growth of the biofouling needs to be observed periodically. The target depth of fully submerged grow system relies entirely on the combination of net weight distribution of the main cultivation line and position of the floaters. As the first one is growing at a certain rate, the latter needs to be adapted accordingly to maintain the desired depth of the cultivation line.

1.2 Structure of the report

The design of the grow system is provided by Laboratory of Aquaculture & Artemia Reference Center, Ghent University (ARC UGent), which will be explained in Chapter 2. The numerical modelling of the aforementioned cultivation system and overview of the mooring configuration are described in Chapter 3. The results of numerical calculations are discussed in Chapter 4 to which safety factor checks are performed for the mooring components (e.g., line and anchor). Lastly, summary of results is presented in Chapter 6 and conclusions are made based on the numerical analysis that has been performed in this report.

1.3 Guidelines and standards

The following documents are used as guidelines and input for the numerical calculations presented in this report:

- Norwegian Standard NS 9415; Marine fish farms requirements for site survey, risk analyses, design, dimensioning, production, installation and operation [4]
- DNVGL OS-301; Position mooring [5]
- DNVGL OS-C101; Design of offshore steel structures, general – LRFD method [6]
- DNV RP-C205; Environmental conditions and environmental loads [7]
- NORSOK STANDARD N-003; Actions and action effects [8]

2 INPUT DATA

The requirements of the oyster grow system are set by ARC UGent. Figure 3 shows section view drawing received as an input for the cultivation system [1]. There are five systems used along the 57-metre cultivation line: ladder system, rope system, frame system for grow-out, frame system for spat collection and lantern net/tray. Summarised in the following table is the total dry mass of the cultivation systems connected to the backbone.

Table 1. Total dry mass of the cultivation system [1]

System	Number	Kg/unit	Kg total
Ladder	1	60	60
Ropes 4 m	24	19	456
Frame GO	2	153	306
Frame Spat	2	160	320
Lantern net	2	154	308
Grand total			***1450***

As a requirement, the main cultivation line needs to be submerged at 10 metre depth to reduce the impact of wave actions on the growth of the oyster. On the other hand, during sampling or harvesting operation, the main cultivation line needs to be lifted 5 metre above water level.

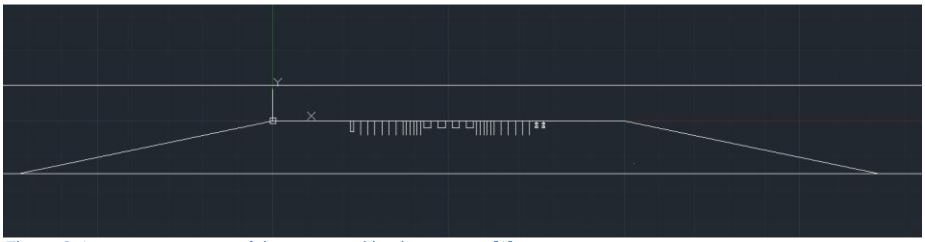
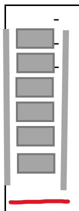


Figure 3. Input arrangement of the oyster cultivation system [1]

2.1 Ladder system

The ladder system consists of six baskets stacked vertically. Each basket carries 10 kilograms of oyster. Figure 4 describes the specification received for the ladder system.



Final stocking density	10kg/basket
Total baskets in ladder	6
Dimension basket	850 x 800 mm
Total liter	15L x 6 =90 L
Total oyster weight	10kg x 6= 60 kg
Total number oysters	60 kg/0.09 kg = 666
Oyster final size	75 mm
Total weight ladder	60 kg

Figure 4. Excerpt of specification for the ladder system [1]

2.2 Rope system

The rope system consisting four main groups (see Figure 5):

- 6 ropes of 4 metre long, with weight of 3kg attached below, at distance of 2 m of each other
- 6 ropes of 4 metre long, with weight of 3 kg attached below, at distance of 1 m of each other

The two groups are each located on the left and right side from the centre of the cultivation line, making it 24 ropes in total.

Type rope	Polyester 10mm
Length rope	4 m
Weight rope	3,1 kg
Number of oysters	3 oysters/7cm so total 171 oysters
Final size of oysters	75 mm
Weight oysters	171 * 0.09kg=15,4kg
Total weight rope	18,5 kg

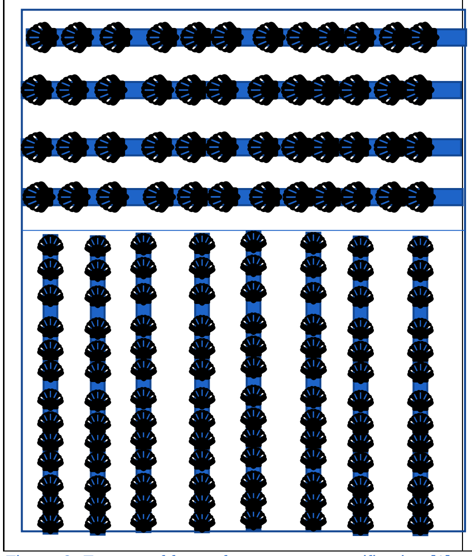
Figure 5. Excerpt of rope system description [1]

2.3 Frame system for grow-out (GO)

There are two frames that will be used as oysters grow-out:

- 1 frame consisting vertical sticks
- 1 frame consisting horizontal sticks

The oysters are grown and attached along the sticks (see Figure 6).



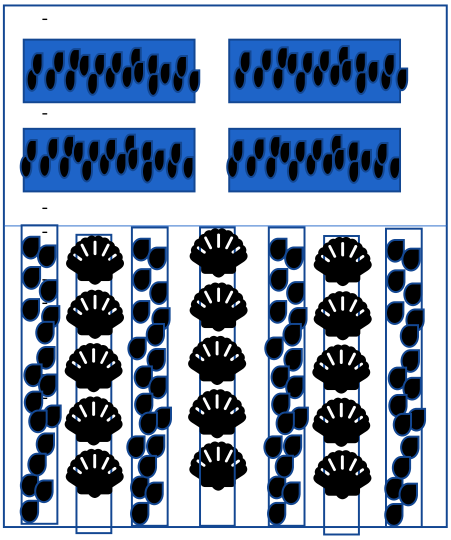
Dimension frames	150 x 180 cm
Weight frame	60kg
Dimensions sticks	Vert. sticks : 5*5x100 cm Horiz. Sticks: 5*5x 145 cm Sticks at 10cm of each other
Weight 12 sticks	28kg
Number of oysters/stick	13 groups of 4 oyster per metre (at 7cm distance from each other
Total number of oyster	8*52 + 4*76 = 720
Final weight oysters per frame	0.09kg x 720 = 64,8 kg
Total weight	60 + 64,8 + 28 kg = 152,8 kg

Figure 6. Excerpt of frame for grow out specification [1]

2.4 Frame system for spat collection

The spat collections are built utilising of two frames

- 1 frame consists of four baskets
- 1 frame consists of a combination of mussel socks and oyster sticks

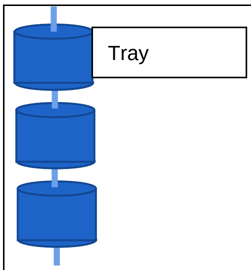


Dimension frames	150 x 180 cm
Weight frame	60 kg
Dimension sticks adults	5*5x100
Weight of sticks	3 x 2kg/m = 6kg
No of Sticks	3
No and weight of oysters	52 oysters*3: 156 ; 156*0.09 =14 kg
Dimension mussel shell sock	15 diameter; 1m long
Weight of socks	10 kg
No of socks	4
Dimension baskets	15L ; 850x800mm
Number of baskets	4
Weight of filled baskets	10kg
Total weight system	60 + 14 + 6kg + 40 + 40 = 160

Figure 7. Excerpt of specification for spat collector frame [1]

2.5 Lantern nets/trays

This system is built upon 3 stacked trays hung with a rope. Each of the tray carries 50 kg of oyster (see Figure 8).



Trays per system	3
Total oyster weight	50kg/tray
Final oyster weight	0.09kg/oyster
Total oysters	555oysters/tray of 1666 per systeem
Oyster final size	75 mm (commercial)
Stack weight	1.2kg/tray x 3 = 3.6 kg
Total weight	3.6 kg + 150 kg = 153,6 kg

Figure 8. Excerpt of the description for tray system [1]

3 NUMERICAL MODELLING

An open-source time-domain mooring dynamic solver, MoorDyn [2] has been modified in-house to cope with elements present in an offshore oyster longline system. Furthermore, the adapted software is now capable of including external forces due to hydrodynamic forces induced by waves and currents [3]. These environmental loads are modelled using the Morison Equation, which splits the forces into its drag and inertia component [9]. The line is discretized into contiguous segments where all the forces are transferred into neighbouring nodes, namely lumped-mass approach. The line tension is a function of material's Young's modulus, rope cross section area and its elongation that is varying depending on its position in time. Consequently, the internal forces (line tension, weight, buoyancy) and external forces are calculated at each node to obtain the acceleration. The equation of motions is reduced into a set of ordinary differential equations (ODEs) and solved using Runge-Kutta second order integration scheme at each time step [2] [3].

3.1 Overview of the mooring configuration

The mooring system consists of 21 submerged floaters (B1), 2 surface corner floaters (B2) and 3 surface intermediate floaters (B3). However, the surface floaters will be fully immersed during storm conditions (see Chapter 4). **Therefore, all surface buoys will need to be foam-filled.**

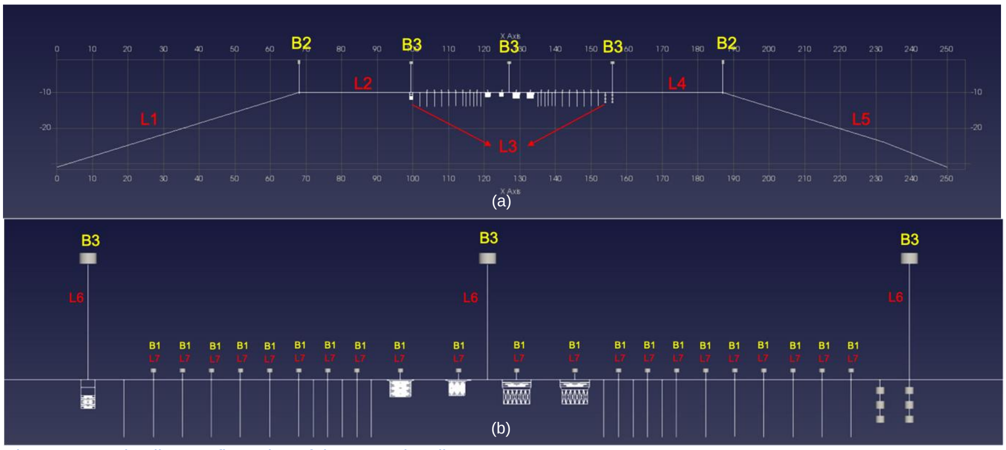


Figure 9. Mooring line configuration of the oyster longline system

The mooring line L1 is connecting the South-West (SW) screw anchor to the SW corner surface floater B2. Similarly, the mooring rope L5 is connecting the North-East (NE) screw anchor to the NE corner surface floater B2. Both L1 and L5 are each 72 metre long. The unused parts of the longline are 31 metre long on each side (L2 and L4). Main cultivation line is 57 metre long (L3). The total length of mooring lines combined with backbone lines is 263 metre. Furthermore, the lines connecting the backbone to the surface floaters (L6) are 8 metre long each. The line elements are summarized in Table 2 to which the properties of this line are shown in Table 3. The dimensions and specifications of all floaters are summarised in Table 4.

Table 2. Line elements of the mooring configuration

Element (-)	Line length (m)
L1 - mooring line	72
L2 - bakcbone: empty line	31
L3 - backbone: cultivation line	57
L4 - backbone: empty line	31
L5 - mooring line	72
L6 - surface buoy line	8
L7 - submerged buoy line	0.5

Table 3. Line properties

Type	Diameter (m)	Dry mass (kg/m)	Density (kg/m)	MBL (kN)
Movline Plus 8 stranded	0.068	2.1	940	737

The drag coefficients of the line elements are according to the DNV OS301 [5] standards for stranded rope.

Table 4. Buoy elements of the mooring configuration

Element	Net buoyancy (kg)	Dry mass (kg)	Quantity
B1 - submerged floaters	29	4	21
B2 - Corner surface floaters	560	55	2
B3 - Intermediate surface floaters	800	73	3

The drag coefficients of the buoy elements used in the numerical model are according to the DNV RP C205 standards [7] for a cylinder with marine growth.

3.1.1 Oyster basket on a ladder

In total there are 6 baskets used for the offshore experiment, each of which has the capacity of 15 litre and filled with 10 kilograms of oyster. Figure 10 (a) shows the basket used [10] for the experiment and Figure 10 (b) shows the numerical approach to model a stack of baskets.

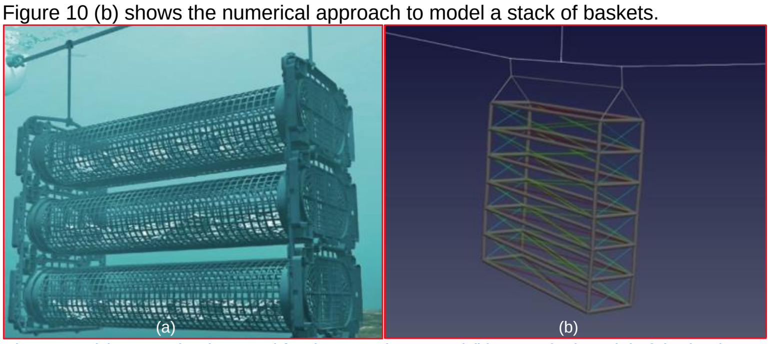


Figure 10. (a) Oyster basket used for the experiment and (b) numerical model of the basket

The drag forces are taken by diagonal tubulars, marked with green, cyan and red colour, representing each of drag projection area in x, y and z axis (see Figure 11 (a, b, c)). Each of the projection area represents the area of the face of the real basket. These diagonal tubulars are set to have neutral buoyancies, thus only contributing to the drag force. The weight and buoyancy properties are transferred into tubular members marked with grey colour (see Figure 11 (d)). These members do not experience drag force as the drag coefficients are switched to zero.

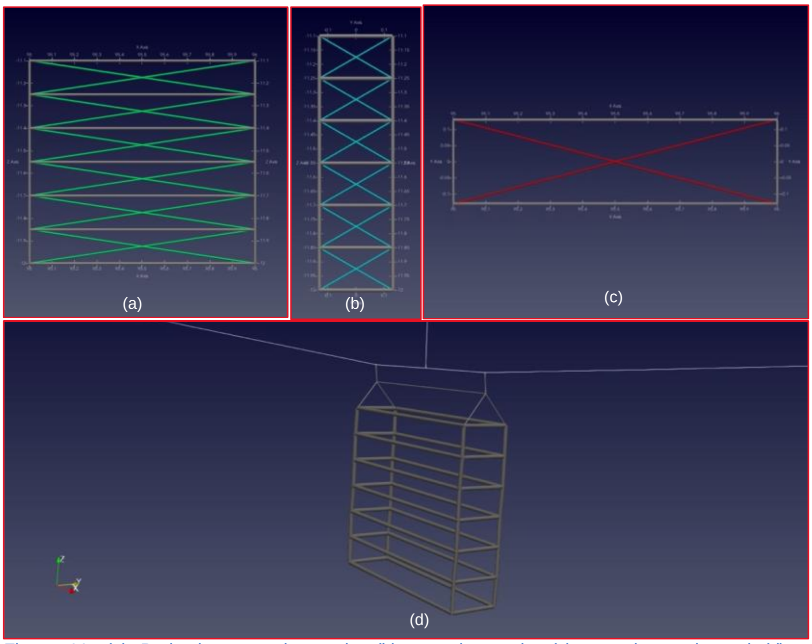


Figure 11. (a) Projection area in x-axis, (b) area in y-axis, (c) area in z-axis and (d) tubular frames verticals/horizontals

3.1.2 Oyster dropper

The dropper is modelled as a line with the weight, buoyancy and hydrodynamic properties of oyster fully attached on a rope. The volume and projection area of the oyster are estimated by taking the density of 1360 kg/m^3 [11] for the oyster. The total weight is distributed equally along each line (marked with green colour in Figure 12).

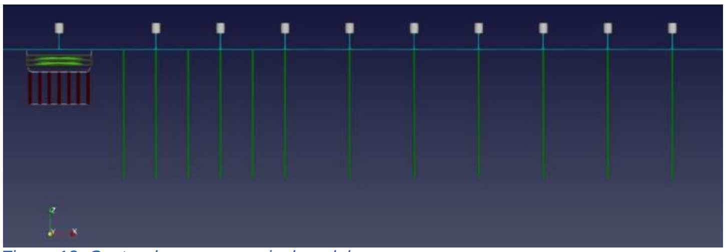


Figure 12. Oyster dropper numerical model

3.1.3 Oyster frame for grow-out

The stick is modelled as a cylinder with compression force, hence, not allowing the structure to deform in axial direction. The total weight is distributed equally to along each stick. The diameter of the cylinder is estimated based on the weight of the oyster along the stick and the density of the oyster (1360 kg/m^3)

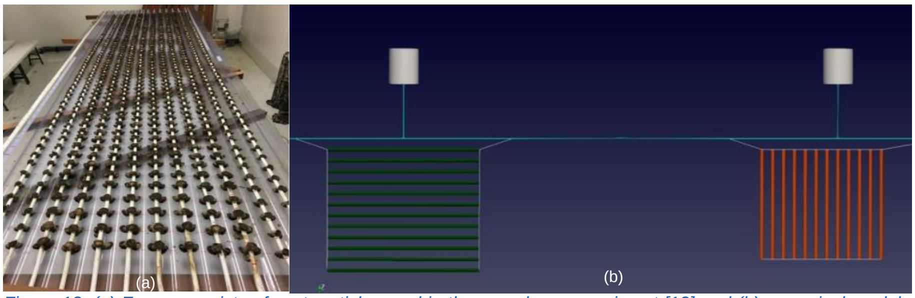


Figure 13. (a) Frame consists of oyster sticks used in the nearshore experiment [12] and (b) numerical model of grow-out frame

3.1.4 Oyster frame for spat collections

The model consists of stacked baskets and frame with sticks. Oyster baskets are modelled with the same principle described in sub-chapter 3.1.1 whereas the sticks are modelled according to the description in sub-chapter 3.1.3. The sticks marked in red in Figure 14 are modelled as homogenous cylinders with the diameter according to the calculated volume based on the total mass of oyster and the density of the oyster.

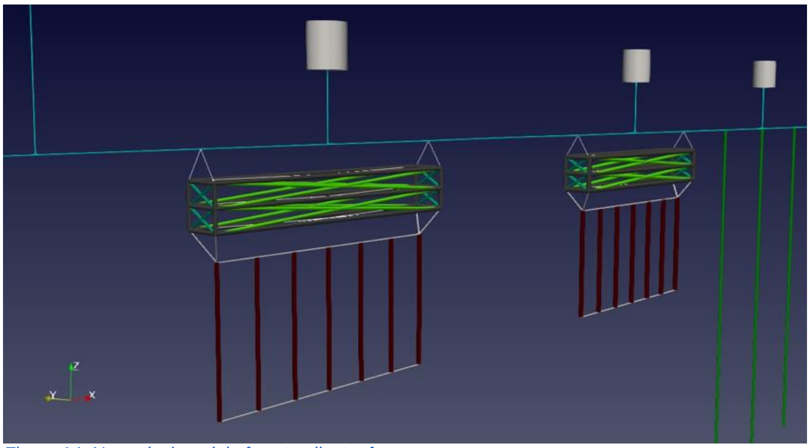


Figure 14. Numerical model of spat collector frame

3.1.5 Oyster trays

The trays used in the experiment are shown in Figure 15 (a) [13]. In the numerical model, the trays are modelled as cylinders (see Figure 15 (b)). The dimensions of the numerical cylinders are representing the volume of each 6-stacks tray, which is calculated based on the dimensions of the physical trays.

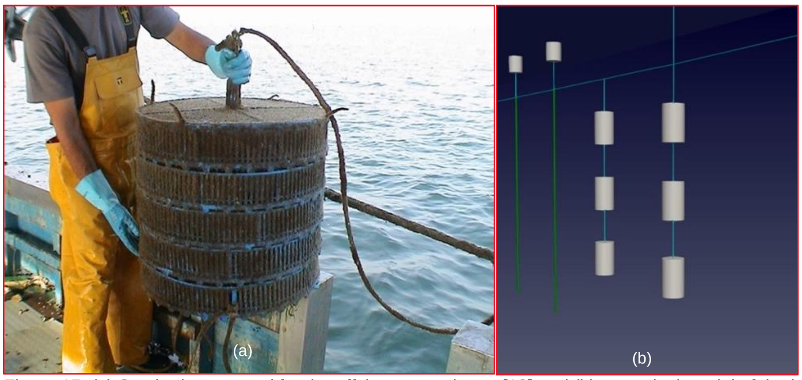


Figure 15. (a) Stacked trays used for the offshore experiment [13] and (b) numerical model of the lantern net/trays system

3.2 Marine growth

According to DNV OS-301 [5], if there is no available field data, then the NORSOK N-003 [8] may be used as a reference. Figure 16 is an excerpt from NORSOK N-003 as a guideline to determine the thickness of marine growth that has been increased linearly over the period of 2 years.

Table 3 – Thickness of marine growth [a]

Water depth m	56° to 59° N mm	59° to 72° N mm
Above + 2	0	0
+2 to - 40	100	60
Under - 40	50	30
[a] The water depth refers to mean water level		

Figure 16. Excerpt of marine growth thickness table [8]

The following formula are used to determine the influence of marine growth on the system [5]:

$$M_{growth} = \frac{\pi}{4}\left[(D_{nom} + 2\Delta T_{growth})^2 - D_{nom}^2\right]\rho_{growth} \quad (kg/m)$$

$$W_{growth} = M_{growth}\left[1 - \frac{\rho_{seawater}}{\rho_{growth}}\right]\frac{9.81}{1000} \quad (kN/m)$$

M_{growth} = mass of marine growth

D_{nom} = nominal rope diameter

ΔT_{growth} = marine growth surface thickness

$_{growth}$ ⊟ marine growth density (1325 kg/m³)
= 2.0 for chain, 1.0 for wire rope
$_{seawater}$ ⊟ sea water density (1025 kg/m³)

Given the diameter of the rope used for the mooring and backbone line is 68 mm and the marine growth over the course of 1 year has the thickness of 50mm, this results in additional dry mass of 21 kg/m or wet/submerged mass of 4.8 kg/m along the rope due to marine growth.

3.3 Load combination

The oyster longline system is oriented parallel to the current main direction (see Figure 17). Load cases for the ultimate limit state calculations (ULS), as defined by NS9415 [1], are a combination of:

- 50-year return period of waves and 10-year return period
- 10-year return period of waves and 50-year return period

Simulation number 1 is a combination of 50-year return period of waves (maximum single wave height) and 50-year return period of current, both parallel with the mooring system [4]. In simulation 2, the 50-year waves are parallel to the system whereas the 50-year current is perpendicular to the system. Lastly, simulation number 3 is taking a 1-year return period of waves and current with both direction parallel to the mooring system.

Table 5. Summary of dynamic-simulation cases

Simulation number	Regular wave			Depth-averaged current	
	height	period	direction	speed	direction
[-]	[m]	[s]	[going-to]	[m/s]	[going-to]
1	11.6	9.0	North-East	1.4	North-East
2	11.6	9.0	North-East	1.4	North-West
3	8.6	6.57	North-East	1.0	North-East

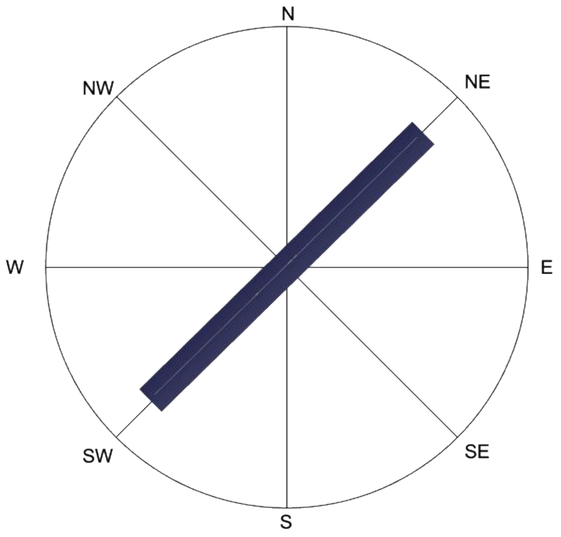


Figure 17. Orientation of the system

4 SIMULATION RESULTS

Presented in this chapter are the results of numerical calculations performed using lumped-mass approach [2] [3]. Firstly, lifting operation is simulated to calculate the tension required to pull the longline during maintenance and installation. Secondly, the influence of marine growth to the hydrostatic equilibrium of the system over the course of 21 months is assessed. Furthermore, the dynamic simulations are performed to assess the impact of waves and current to the mooring components. Lastly, a simulation is done assuming a scenario where one anchor broke down during a 50-year storm.

4.1 Lifting longline – installation and maintenance simulation

A lifting simulation is performed by taking a fixed point (where a node is not allowed to move) at the SW intermediate surface floater that is 28 metre from the middle surface buoy. The vertical position of this fixed point is 36 metre from the seabed, or 5 metre above the sea level (see Figure 18). This simulation is performed to ensure that the tension on each line during installation does not exceed 10 kN (see Figure 19), which is the maximum capacity of the vessel's on-board lifting equipment. **This maximum capacity of 10 kN will be defined as the pretension to be applied during the installation operation when connecting the start of oyster main cultivation line (L3) and the unusable part of the backbone (L2 or L4).**

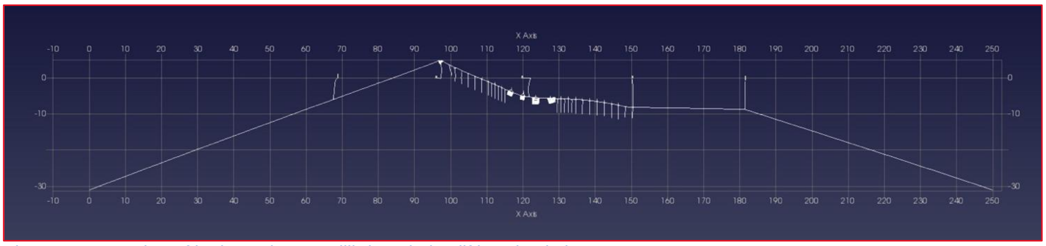


Figure 18. Snapshot of hydrostatic at equilibrium during lifting simulation

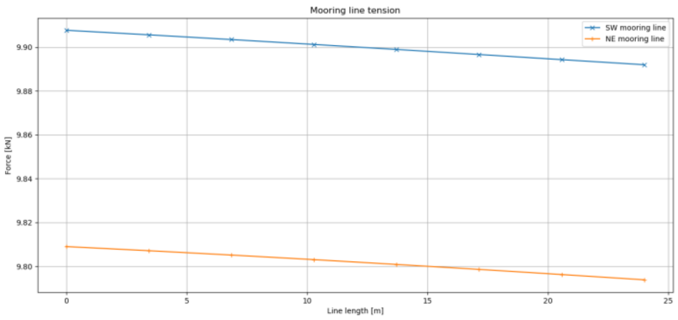


Figure 19. Tension required in the mooring lines for a lifting operation

4.2 Impact of biofouling on the hydrostatic at equilibrium

As it is suggested by NORSOK N-003 [8], marine growth should be taken into consideration as a linear function over the period of two years. Figure 20 shows the influence of marine growth to the mooring system for the following period: initial installation date (M0), month-3 (M3), month-6 (M6), month-9 (M9), month-12 (M12), month-15 (M15) and month-21 (M21).

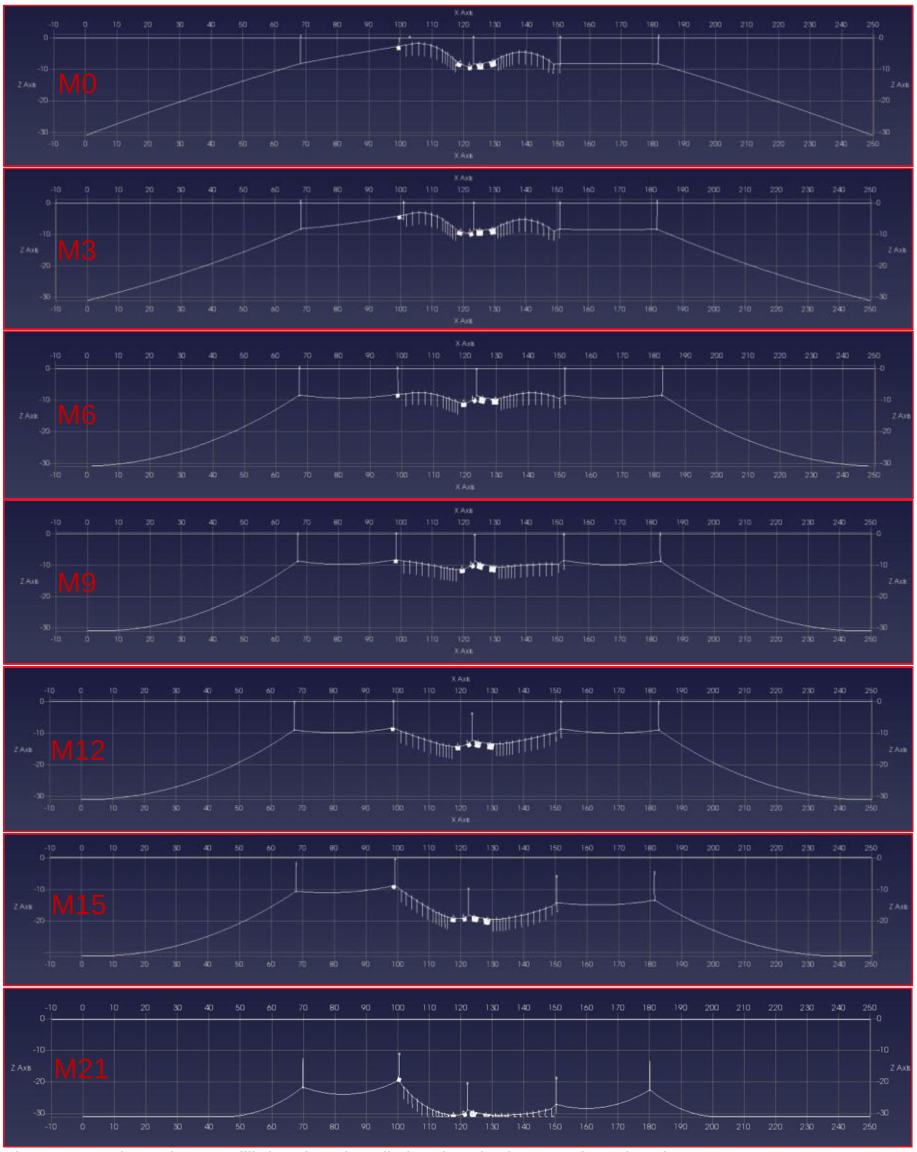


Figure 20. Hydrostatic at equilibrium from installation date (M0) to month-21 (M21)

The system starts with excess buoyancy at M0 and the longline remains with uneven weight distribution even at M3. **At month-6 (M6), the main cultivation line has reached its target depth of 10 metre.** The winter storm is expected to occur between month-6 (M6) and month-9 (M9) after the installation.

However, at M9 the system will start to lose buoyancy due to the biofouling. It is calculated that at month-12 (M12) the middle surface floater will be fully submerged. In Figure 21, it is shown that the axial load at SW anchor is increasing from M6 to M15. This is due to the change in the net vertical force along the main cultivation line, which is compensated by the SW floaters that in turns pulling the SW mooring line towards the NE. At M21, however, the structure is almost fully submerged. Thus, the axial load at SW anchor is reduced at M21.

I**t is very important to monitor the growth of biofouling in a monthly basis by taking samples to measure and compare field data with the calculations presented in this report.** Should the field measurement of marine growth correspond to the assumed thickness calculated according to NORSOK N-003 (50mm per 1 year), **an operation to replace/add surface buoys have to be conducted between month-9 (M9) and (M12).**

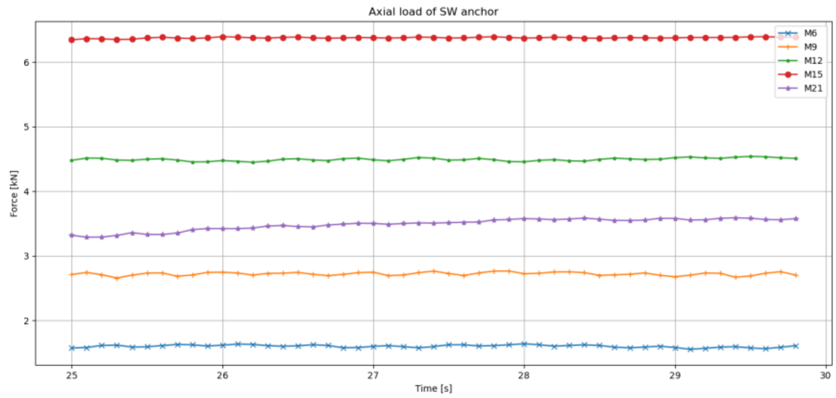


Figure 21. Impact of fouling to the axial load of SW anchor from month-6 (M6) to month-21 (M21)

4.3 Dynamic simulations

The hydrodynamics forces due to waves and current are calculated in the time domain where their impact to the anchors and mooring lines are analysed. Results presented in this sub-Chapter are according to the load combinations summarised in Table 5.

4.3.1 Simulation case 1: 50-year return period wave and parallel current

A 50-year event is chosen according to the recommendations of NS9415 [4]. In this case, the mooring lines and anchors have to withstand a single maximum wave height of 11.8 metre and current magnitude (depth-averaged) of 1.4 m/s. During this simulation case 1, the maximum tension in the mooring line is calculated to be 125 kN.

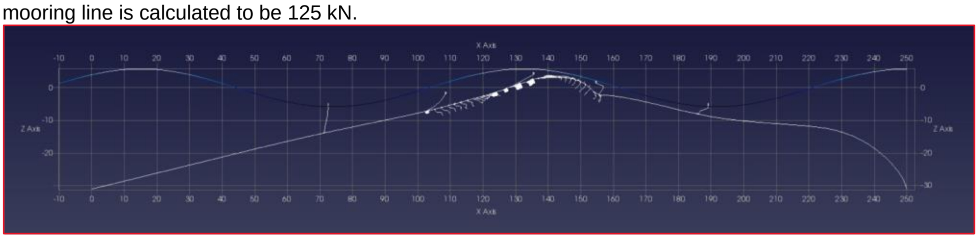


Figure 22. Snapshot of mooring state during simulation case 1

As it is shown in Figure 22, due to the current, SW floaters are submerged, and SW lines (L1 and L2) are under tension. On the other hand, the wave actions are causing the NE anchor to alternate between slack and taut, which is shown by orange line in Figure 23(a). The horizontal load at NE anchor changes directions ever slightly, alternating between 0.2 kN and -9.6 kN, which is shown in in Figure 23(b).

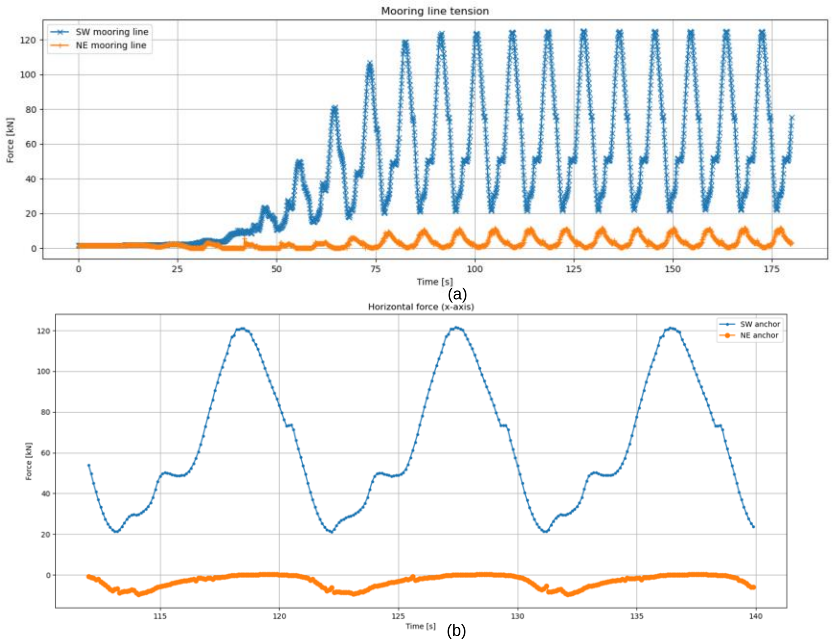


Figure 23. (a) Mooring line tension and (b) horizontal load at the anchor during simulation case 1

4.3.2 Simulation case 2: 1-year return period wave and parallel current

Considering the duration of this pilot project, a sea state of 1-year return period is assessed due to its high likeliness of its occurrences. One of the main concerns is that during this event, due to the use of pile/screw anchors, the horizontal load at the anchor should not change in directions. This is to avoid soil displacement along the contact area of between the seabed and pile anchor.

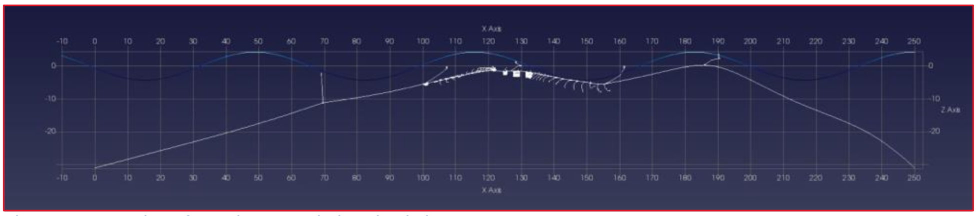


Figure 24. Snapshot of mooring state during simulation case 2

Similar to the behaviour observed in the 50-year event snapshot, it is evident (see Figure 24) that the SW surface floaters will be submerged due to the combination of 8.6 metre of wave and 1 m/s of depth-averaged current. The maximum tension at SW mooring line is calculated to be 71 kN. As it is shown

Due to this loading combination, both of the anchors are taking the current induced load, keeping both of mooring lines under tensions. Furthermore, the taut mooring lines are impacting the corner surface floaters (B2). Both of these floaters are fully submerged up to 12 metre depth, as it is shown in Figure 26 (a). The amplitude of cyclic load on NE anchor is slightly lower because it does not take the drag due to wave horizontal orbital velocities as much as the SW anchor. This is due to the wave direction that comes from SW to the NE. The opposite applies should the wave direction is reversed. With that mind, the maximum load at the mooring line for this simulation case 3 is 106 kN.

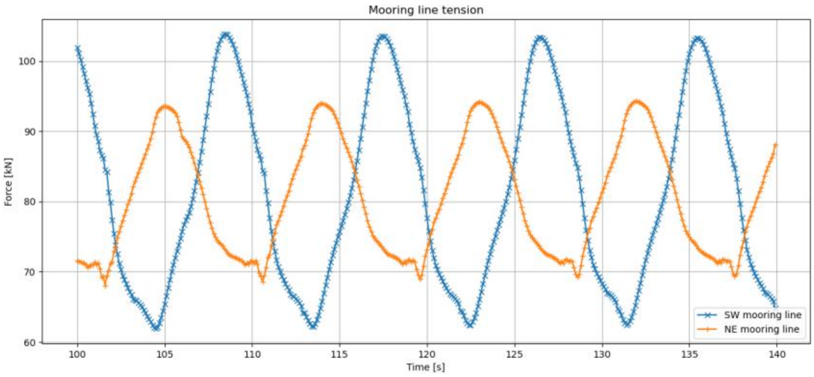


Figure 27. Mooring line tension during simulation case 3

4.4 Loss of 1 anchor: 50-year return period wave and parallel current

As part of the requirement, in the case of 1 anchor failure, the system should not damage wind turbine poles and underwater cables. Therefore, a simulation is performed to determine the radius of the system with respect to the poles and cables. The simulation is done by letting NE anchor to break loose during a storm of 50-year return period of waves and current. Based on the total length of mooring line and backbone line (L1+L2+L3+L4+L6), a radius of 199 metre is calculated to determine the area to which the corner surface buoy will be floating around one anchor. In the case of one anchor failure, the risk zones have been indicated in the drawing provided in Appendix A.

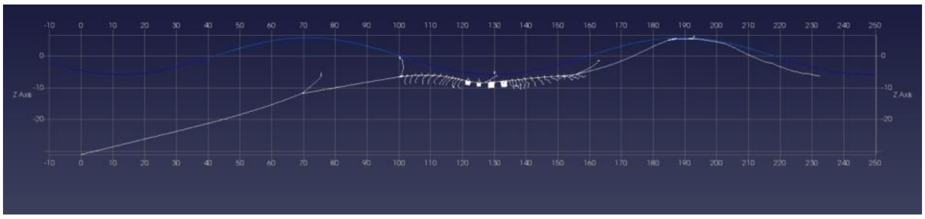


Figure 28. Snapshot of the mooring state during anchor loss event

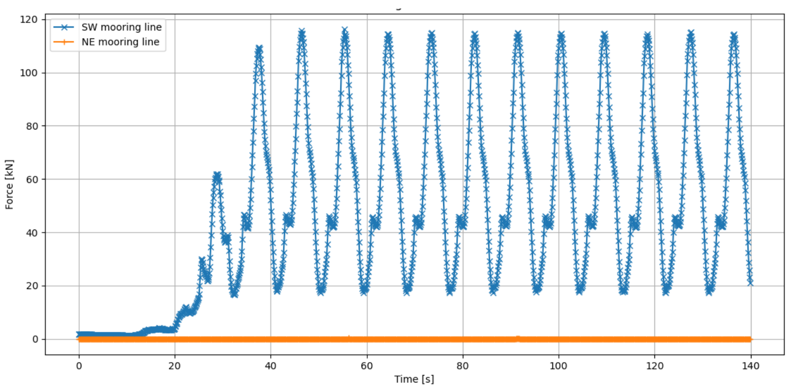


Figure 29. Tension on the mooring rope during the event of an anchor loss

4.5 Safety factor check

Dynamic analysis has been performed to determine the maximum load at ULS condition. The safety factor for this type of analysis is suggested to be 1.15 (see Figure 30 (a)). Furthermore, material factor of synthetic rope has the safety factor of 3.0 (see Figure 30 (b)). Based on these, the combined safety factor is determined, which is 3.45. The maximum tension experienced by the mooring line and backbone as a result of the dynamic analysis during a 50-year storm is 125 kN. Therefore, by taking the combined safety factor 3.45, the rope Breaking Strength (BS) of the mooring and backbone rope (L1, L2, L3, L4, L5) **should not be less than 431 kN.**

Table 4 – Load factors for mooring lines

Type of analysis	Load factor
Static analysis	1,6
Quasi-static analysis	1,15×DAF[1)]
Dynamic analysis	1,15
Accident limit (break in mooring line)	1,0
Spring flood	1,0

1) Here is used a factor of 1.15 multiplied by dynamic amplification factor (DAF). Dynamic amplification factor ≥1.1. Choice of value of DAF shall be justified and documented.

(a)

Tabell 13 – Material factors for moringlines

Type	Material factor
Synthetic rope	3,0
Synthetic rope with knots	5,0
Chains and chain components	2,0
Used chains	5,0
Coupling discs and other connecting points of steel*	1.5
Shackles	2,0
Rock bolts and other bottom attachments	3,0

*First yield

(b)

Figure 30. (a) Excerpt of load factors table and (b) excerpt of materials factors table [8]

According to DNVGL OS C101 [6] material factor of 1.3 should be taken when considering ULS of axial and lateral loads of pile anchor. Therefore, based on the maximum axial load of 125 kN during 50-year storm, the **anchor axial capacity should not be less than 163 kN.**

5 SUMMARY RESULTS AND CONCLUSIONS

An iterative design process utilising numerical tool has been performed and mooring configuration of an offshore longline system has been designed. The waves and current induced loads are calculated for the 50-year and 1-year return period, respectively.
Table 6 summarised the load at the anchor. It is important to note that the horizontal load at NE anchor changes direction during 50-year storm, however, this does not occur in a 1-year return period simulation.

Table 6. Summary of load at the anchor

Return period of waves and current	Force in x-axis				Force in z-axis			
	SW anchor		NE anchor		SW anchor		NE anchor	
	min	max	min	max	min	max	min	max
[-]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
50-year	1.5	121.4	-9.6	0.2	0.6	29.4	0	6.6
1-year	1.5	68.2	-9.7	0	0.6	20	0	7.8

During the 50-year storm, mooring lines (L1, L5) and backbone ropes (L2, L3, L4) are expecting the maximum tension of **125 kN**. On the other hand, a maximum mooring line tension of 71kN is predicted to occur during a 1-year event. **Hence, taking the ULS condition, the line breaking strength should be more than 431 kN to fulfil the safety factor of 3.45 suggested by NS9415 [1].** If a Movline Plus 8 Strands is to be used, then the line diameter should not be less than 52 mm (see Figure 31).

Diameter		Size Circ.	Weight			Breaking Load		
mm	inches	inches	ktex	Kg/100m	lbs/100ft	kgf	lbf	kN
24	1	3	261	26,1	17,5	10.605	23.380	104,0
26	1 1/32	3 1/4	306	30,6	20,6	12.339	27.202	121,0
28	1 1/8	3 1/2	355	35,5	23,9	14.174	31.248	139,0
30	1 1/4	3 3/4	408	40,8	27,4	16.112	35.519	158,0
32	1 5/16	4	464	46,4	31,2	18.253	40.240	179,0
36	1 1/2	4 1/2	587	58,7	39,4	22.842	50.357	224,0
40	1 5/8	5	725	72,5	48,7	27.940	61.597	274,0
44	1 3/4	5 1/2	877	87,7	58,9	33.345	73.512	327,0
48	2	6	1040	104,0	69,9	39.259	86.550	385,0
52	2 1/8	6 1/2	1220	122,0	82,0	45.683	100.713	448,0
56	2 1/4	7	1420	142,0	95,4	52.414	115.550	514,0
60	2 1/2	7 1/2	1630	163,0	109,5	59.450	131.062	583,0
64	2 5/8	8	1860	186,0	125,0	66.996	147.698	657,0
68	2 3/4	8 1/2	2100	210,0	141,1	75.153	165.682	737,0
72	2 7/8	9	2350	235,0	157,9	83.617	184.341	820,0
80	3 1/4	10	2900	290,0	194,9	101.462	223.682	995,0
88	3 5/8	11	3510	351,0	235,9	121.347	267.519	1190,0
96	4	12	4170	417,0	280,2	142.761	314.728	1400,0
104	4 1/4	13	4900	490,0	329,3	165.195	364.186	1620,0
112	4 5/8	14	5680	568,0	381,7	191.707	422.635	1880,0
120	5	15	6520	652,0	438,1	217.200	478.837	2130,0
128	5 1/4	16	7420	742,0	498,6	246.772	544.031	2420,0
136	5 1/2	17	8380	838,0	563,1	277.364	611.472	2720,0

In accordance to ISO 10572-2009

Figure 31. Excerpt of Movline Plus 8 Strands specifications [14]

Furthermore, the surface floater connector line (L6) is experiencing maximum tension of 40 kN. Taking into account combined safety factor of 3.45, the **line L6 breaking strength should be more than 138 kN.** Submerged floaters are connected to the backbone by a 0.5 metre rope (L7). Using the combined safety factor of 3.45, the line breaking strength should be more than 10 kN.

Sampling of fouling thickness needs to be collected at least every 3 months. Between month-6 and month-9, the predicted marine growth needs to be compared with the field measurement. Further investigation needs to be done to determine the additional buoyancy needed on the structure. **If the calculated marine growth presented in this report shows good agreement with field data, the floaters need to be added/replaced between month-9 and month-12.**

Surface floaters are subjected to submergence due to the current and waves, especially during a storm event. **Therefore, all buoys need to be foam-filled to avoid loss of buoyancy due to 15 metre depth of submergence.**

During the installation, the actual positions of the anchors may deviate between 5 to 10 metre depending on the equipment used and other external factors (e.g., GPS accuracy). Therefore, it is of the utmost importance to have a pretension of 10 kN at both of lines, connecting the start of cultivation system and the unusable part of the backbone. **The length of unusable part of the backbone (either L2 or L4) will be adapted in order to achieve this 10 kN of pretension.**

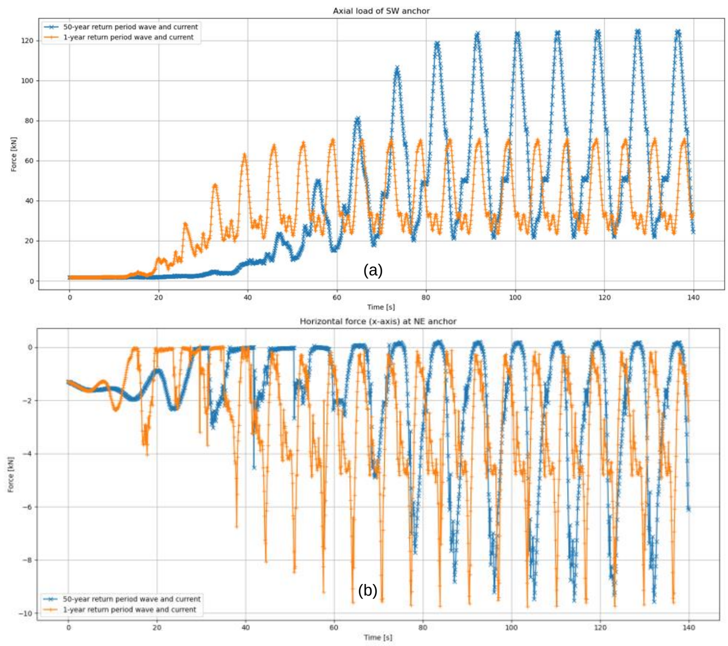


Figure 32. (a) Axial load of SW anchor and (b) horizontal force at NE anchor

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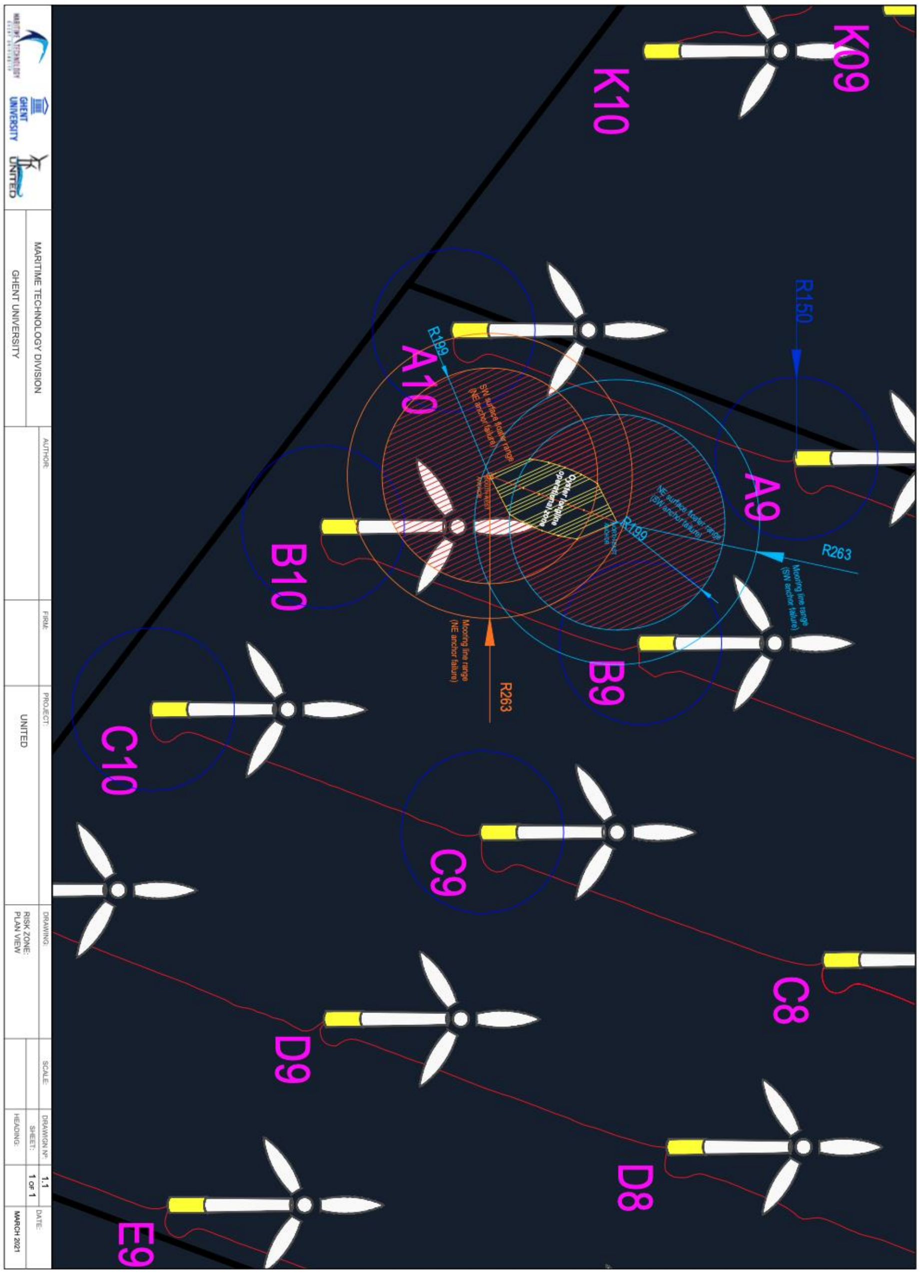
APPENDIX A – RISK ZONES DRAWING



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ANNEX D

Greek Pilot

Additions to Environmental impact assessment

Flora

Most common species are *Centaurea attica* ssp. *Asperula, Centaurea laureotica, Centaurea raphanina* ssp. *Mixta, Dianthus serratifolius ssp. Serratifolius, Fumaria judaica ssp. Amarysia, Galium melanantherum, Lamium garganicum ssp. Striatum, Malcolmia graeca ssp. Graeca, Onobrychis ebenoides*. There are interesting vegetation formations of meadows (wet meadows) and wetlands with a characteristic flora in the area of abandoned salt flats. Species of aquatic and wetland flora have been recorded, such as: a) species of the genus Chara (*Chara canescens, Chara vulgaris* s.l,), as well as the very rare aquatic mammal *Riella helicophylla*. The latter species often characterizes Mediterranean seasonal habitats (priority habitat based on Community Directive 92/43) and has been recorded in very few places in Greece, b) plant species gatherings that resemble natural formations in coastal alimony and almyrova. Coastal lakes (e.g. two small lakes with *Ranunculus aquatilis* agg., extensive formations of Mediterranean fishes (*Juncetalia maritimi*) with various species of junipers (*Juncus spp*.) were found) as well as scattered alophytic vegetation). Typical species that are rare on the coastline and in wetlands of Attica are: *Alopecurus rendlei, Juncus hybridus, Crassula tillea*, and the locally rare *Hymenolobus procumbens*. In general, the conditions of integrity or naturalness of plant communities are degraded, but there is a mosaic of different shapes and characteristic stages of natural succession.

Fauna

The most common invertebrates are *Anisoplia tritici, Anthocharis gruneri, Eopolita protensa, Lindholmiola barbata, Pedinus quadratus, Poecilimon propinquus, Tanyproctus reichei*.

Amphibian: *Bufo viridis*
Mammals: *Monachus monachus*
Reptiles: *Chalcides ocellatus, Vipera ammodytes*

More specifically, the species that have been reported in the Article 4 of Directive 2009/147/EC and the Directive 92/43/EEC are *Miniopterus schreibersii, Rhinolophus ferrumequinum, Testudo marginata* and *Tursiops truncates*. Other important species reported are *Bufo viridis, Centaurea raphanina ssp. Mixta, Chalcides ocellatus, Hypsugo savii, Lacerta trilineata, Onobrychis ebenoides, Pinna nobilis, Pipistrellus kuhlii, Tadarida teniotis,and Vipera ammodytes.*

Birds

Most common bird species are *Ciconia ciconia, Circaetus gallicus, Hieraaetus pennatus, Anthus campestris, Lanius collurio*. The mainland area has not been fully explored for its avifauna and is experiencing significant human distress. Uncontrolled human annoyance (leisure activities often displace birds from the area). However, it is certain that it gathers a remarkable variety of aquatic birds, especially during the spring migration. Thirty-six species of birds were recorded (most importantly the protected species *Ardeola ralloides, Chlidonias leucopterus, Phoenicopterus roseus, Glareola pratincola, Tringa glareola, Philomachus pugnax, Calandrella brachydactyla*). We also know that there is a more complete list of poultry farms than the regular records of the EOE and the wetland is one of the locally important small wetlands for the poultry farm of Attica. The aquatic or wetland fauna of invertebrates, as well as related vertebrates that are dependent on water, have degradation characteristics in relation to the expected reference conditions for such types of coastal wetland formations.