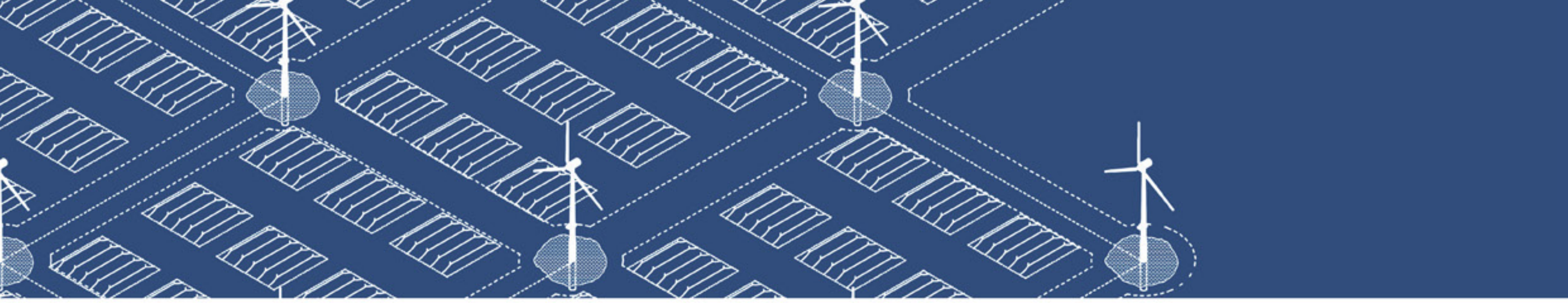
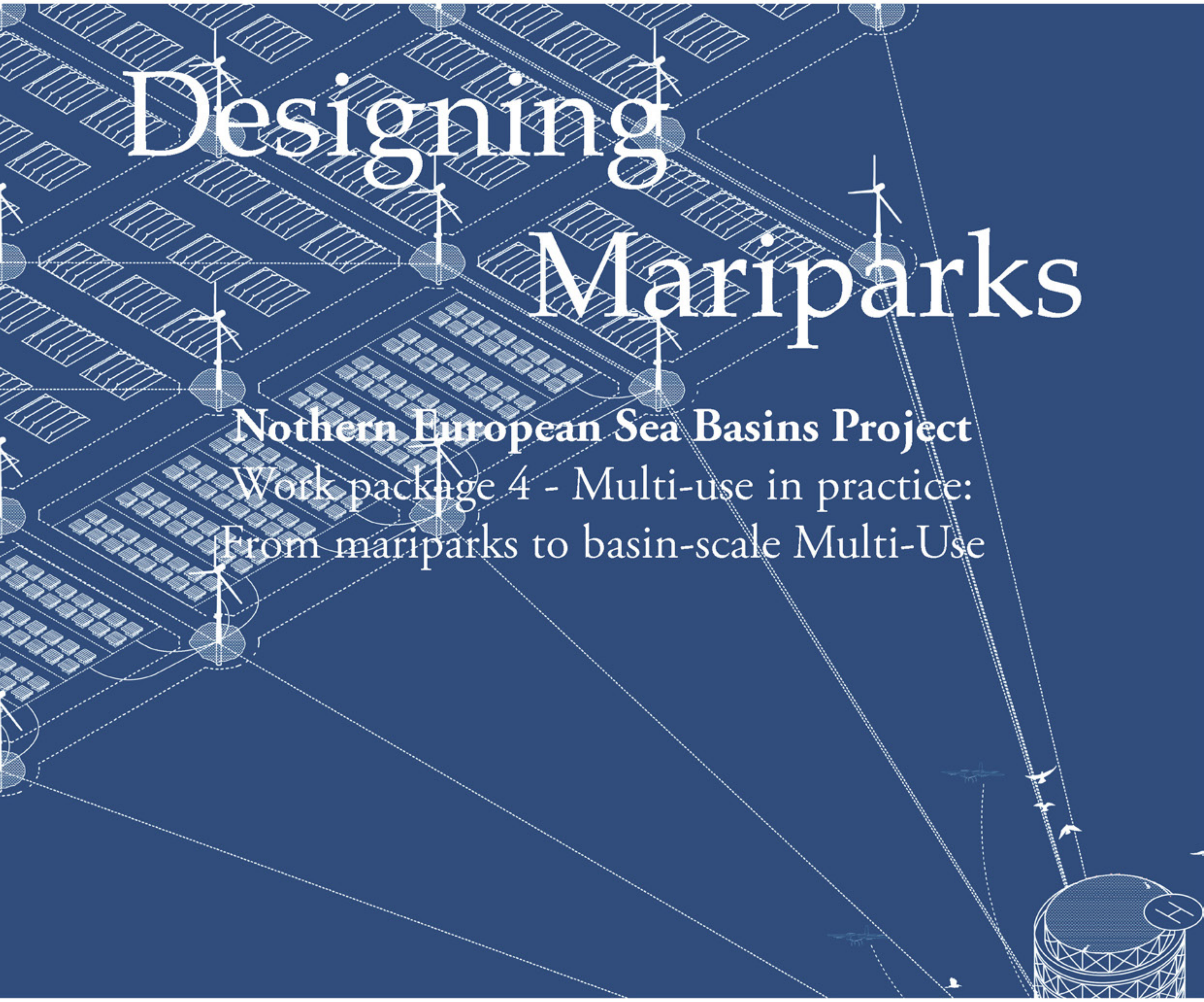


NESBp

Northern European Sea Basins project

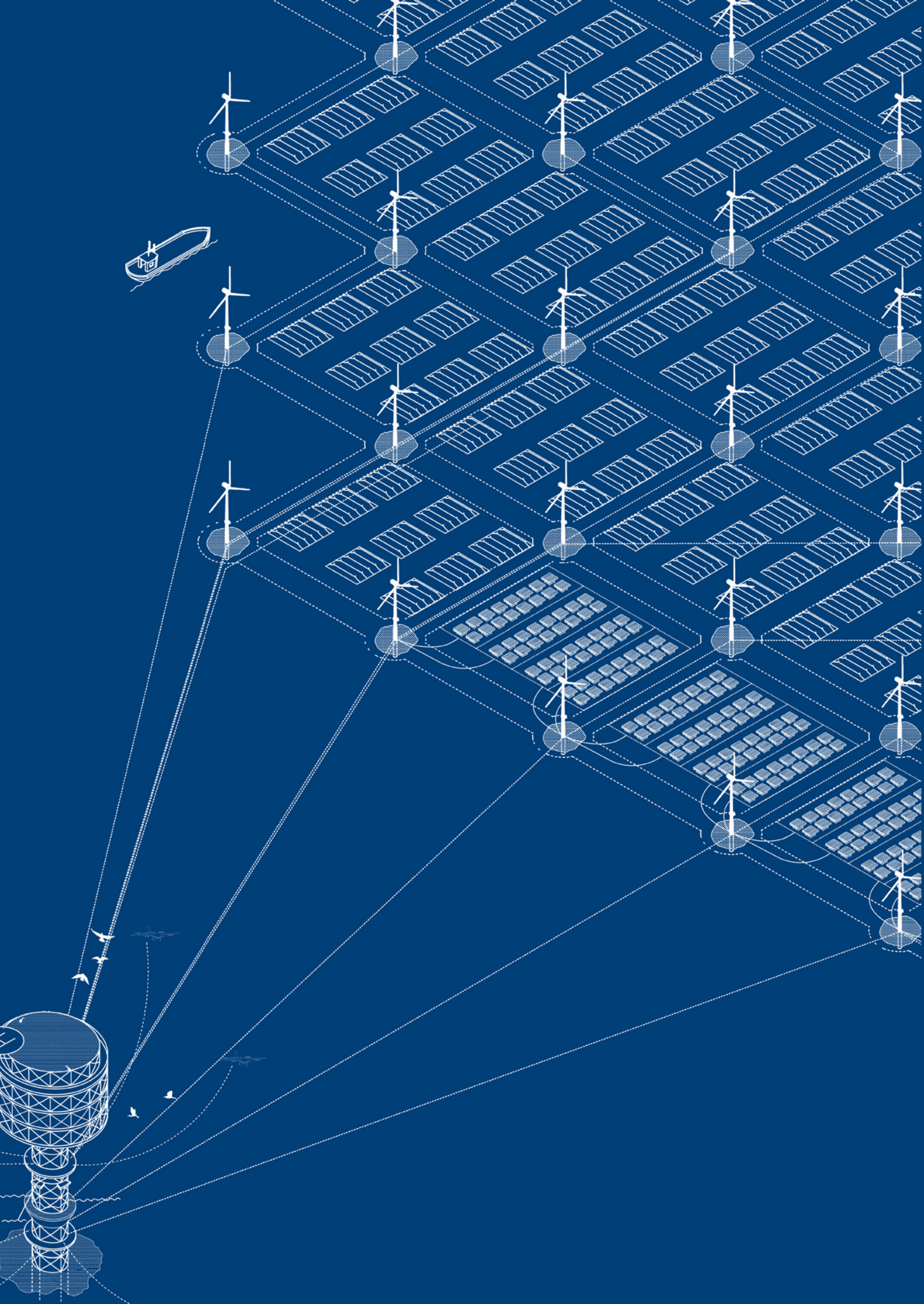


Designing Mariparks

Nothern European Sea Basins Project

Work package 4 - Multi-use in practice: From mariparks to basin-scale Multi-Use

Co-funded by the European Union



NESBp-project description

The NESBp project supports the Greater North Sea Basin Initiative (GNSBI) in fostering international cooperation for maritime spatial planning (MSP) in the North Sea basin, with close ties to the Baltic Sea region. It aims to strengthen collaboration among North Sea countries and between the North Sea and Baltic Sea regions. By linking GNSBI with HELCOM-VASAB MSP WG, the project promotes knowledge sharing and networking across sea basins to enable strategic, efficient MSP, building on insights from the eMSP NBSR project and other EU Green Deal MSP initiatives.

NESBp seeks to overcome siloed approaches by connecting international efforts, aligning marine plans, and encouraging integrative, multi-perspective cooperation. It supports the GNSBI in promoting more cohesive international collaboration and better-connected work among existing cooperation bodies.

WP4: multi use in practice: from Mariparks to basin-scale multi-use

In WP4, the Blue Cluster aims to build on the particular experience gained through the eMSP NBSR project and the research undertaken within the 'Sustainable Blue Economy' learning strand. The findings directly follow the extended policy advice on developing a sustainable blue economy, including the design of the Maripark concept.

Citation: De Beule, K., Rabaut, M., Scheidegger, N., Karper, M., Buytendijk, N. (2023). Policy Brief Towards a Sustainable Blue Economy. Policy brief of the eMSP NSBR Sustainable Blue Economy Learning Strand, available at: https://www.emspproject.eu/results/

The purpose of the follow-up in WP4: Multi-Use on Basin Scale is to elevate the Maripark concept to the next level. To achieve this, five tasks have been designed to address the various elements required for Maripark implementation:

1. establishing an ecosystem-based governance structure;
2. drafting a Maripark Blueprint;
3. developing an environmental monitoring plan for Maripark management, including guidance on adaptive and smart monitoring approaches, as well as safety and security considerations;
4. **conducting an assessment of marketable scenarios and the economic feasibility of activities within the park (energy, food, nature-inclusive design, etc.), including advice for policymakers, investors and stakeholders to support the sustainable development of Mariparks and related activities;**
5. formulating recommendations to enhance European maritime infrastructure across sea basins.

The final deliverable will be a Blueprint outlining sustainable strategies for the implementation of a Maripark.

The deliverable herafter describes the steps taken, together with the analysis of marketable scenarios, economic feasibility, and full scenario development.

"A Maripark can take many forms. Ranging from the co-location of two activities to a fully integrated, multi-use business infrastructure or a shared sea space. It creates synergies by enabling industries to share infrastructure, governance, security, monitoring, and smart services, reducing costs and risks for offshore operations."
(De Blauwe Cluster)

Reading Guide

What might mariparks look like—both today and in the future? What role could they play in shaping the future of the North Sea? And can they be designed in a way that creates value beyond the sum of their individual components? To develop robust and actionable recommendations, we first needed a clear understanding of what feasible mariparks could look like in practice. We therefore began with offshore activities (referred to in the text below as "technologies") that are already operational and considered by experts to be both promising and realistic. An overview of the selected offshore activities is provided in Chapter 3, while their spatial implications are described in the Appendix. Building on these selected activities, we explored a range of maripark scenarios, examining which combinations could function effectively. We assessed whether these combinations are already viable today or whether additional developments—such as technological innovation—would be required to make them work. To explicitly account for the time dimension, we went beyond scenario testing alone. The most promising scenarios were embedded within a phased roadmap, outlining how they could evolve over time. An overview of the selected high-potential scenarios and their corresponding roadmap can be found in Chapter 4. Drawing on the identified offshore activities, the resulting scenarios, and their roadmap, we formulated a set of recommendations. These are presented in Chapter 5. This work was not undertaken in isolation. It was developed in close collaboration with offshore experts, through a series of workshops and numerous bilateral consultations. The co-creative process underpinning this study is described in Chapter 2.

When thoughtfully designed, mariparks can drive a sustainable transition—strengthening the blue economy while restoring the North Sea to a true Sea of Abundance (Pieter Bruegel the Elder, Big Fish Eat Little Fish).

ORG Experts
Chloé Garrido - Martina Bianchini - Hendrik Bloem - Timothy Vanagt - Alexander D'Hooghe

Consulted Experts
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Pieter Jan Jordaens, Offshore energy expert (Sirris/OWI-Lab)
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Experts Work Benches
Alexander Jordaens, Aquaculture Expert (Greentide)
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Jochem Vermeir, Offshore wind farm Expert (Parkwind)
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Acknowledgement
Northern European Sea Basins Project is co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

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This work is done under the NESBp Work Package 4. For more information on NESBp, check the website: https://vasab.org/project/nesbp/

In partnership with

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I. Introduction

A glimpse into the seas of tomorrow

Our world is facing multiple crises. Many people are looking to our seas and oceans to find solutions: it offers space for renewable energy, provides local food, captures CO2, sustainable transport, and more. With recent geopolitical tensions, defense also gets renewed attention. This is in addition to the various functions that have long competed for space: fishing, nature reserves, shipping, sand and fossil fuels extraction, recreation, and so on.

At the same time, we are witnessing severe degradation of the North Sea's ecosystems— in many areas, beyond the point where they can recover naturally. To address this, we need an integrated strategy that tackles these two major challenges: using the available space wisely and restoring biodiversity.

A sustainable use of our seas?

When examining all existing, planned, and potential marine spatial plans for offshore wind farms, it becomes evident that the North Sea is increasingly evolving into an ad hoc organized space. Whenever new demands arise, we carve out yet another portion of the sea to accommodate them. But if we continue to allocate space in the same manner for ever larger offshore wind farms and tomorrow's solutions, we must ask ourselves: is this a sustainable way to use our seas? Are these the marine environments we wish to pass on to future generations—seas that still offer the flexibility and capacity to meet their challenges? Or can we find smarter, more integrated ways to design and manage our shared maritime space?

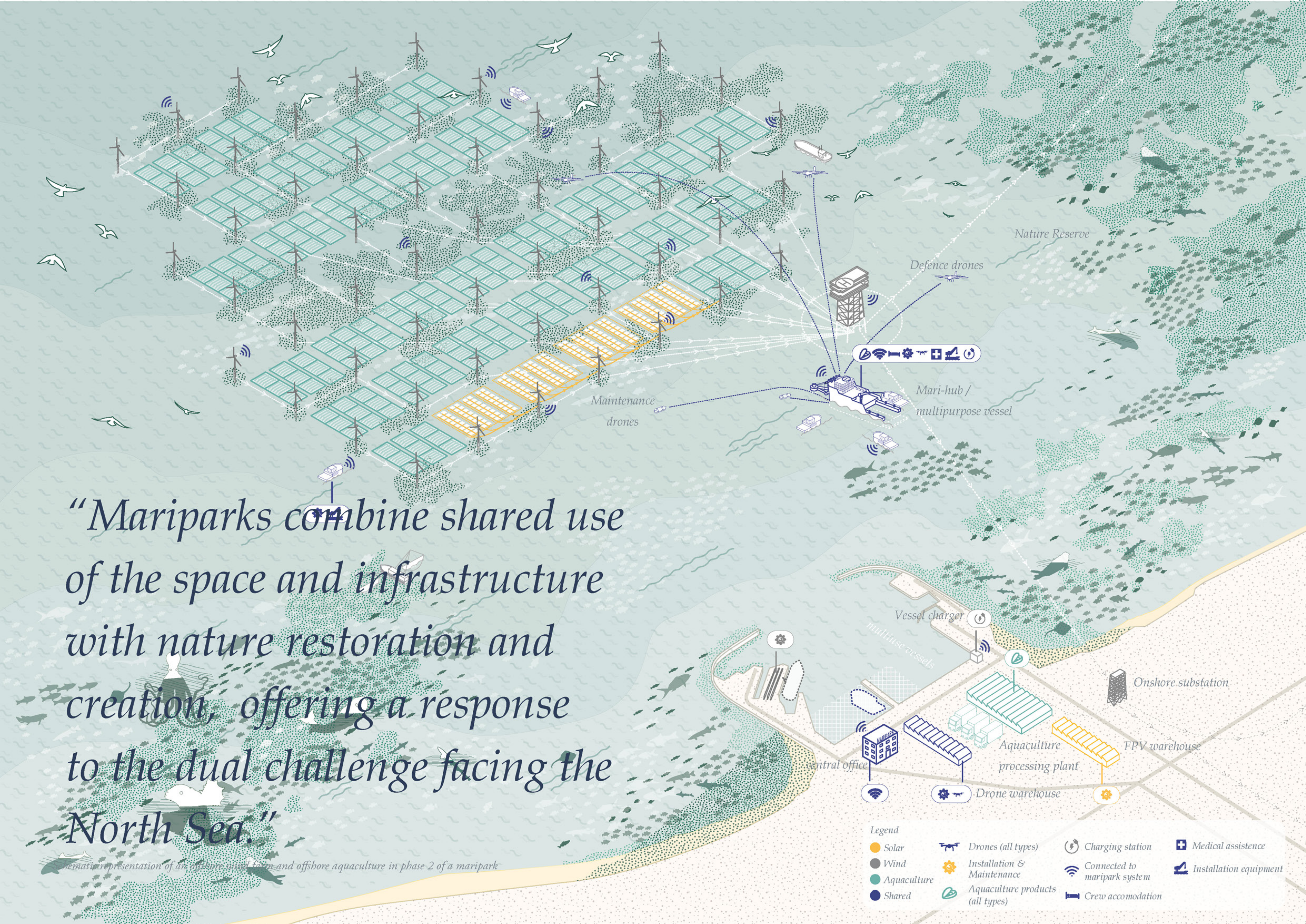
Multi-use is key

During this research, it became clear that using the seas to meet our various needs (energy, food,...) is not straightforward. In many cases, land-based solutions are preferred over expensive and risky offshore alternatives. Nevertheless, the pressure on marine space is very high. If we choose to use this space, multi-use is essential: the efficient and synergetic sharing of the same area and infrastructure by different users. This must be centrally coordinated and managed.

This research therefore focuses on multi-use: Which functions and activities can be combined? What exactly are they sharing? What is already possible today, and what might become possible in the future?

A multiperspective view

To answer this question, various experts in the field were consulted. We specifically chose to collaborate with experts closely involved in the realization of offshore projects. This allowed us to obtain realistic advice based on real experience of working in the field , present the most feasible multi-use scenarios, and identify the main hurdles to overcome to realize this vision.



"Mariparks combine shared use of the space and infrastructure with nature restoration and creation, offering a response to the dual challenge facing the North Sea."

Schematic representation of an offshore wind farm and offshore aquaculture in phase 2 of a maripark

What the North Sea would look like if we continue with business as usual: a proliferation of isolated activities

We were assisted by Pieter Jan Jordaens, an expert in offshore energy (Sirris/OWI-Lab), and Alexander Jordaens, an expert in nearshore aquaculture (Greentide).

During bilateral meetings and workshops, we sought advice from offshore wind farm experts Jochem Vermeir (Parkwind) and Kristof Verlinden (Parkwind and also a defense expert), Nancy Nevejan (independent bivalve expert), Tom van den Nieuwenhuijzen (maripark expert for the Netherlands Enterprise Agency), Nico Buytendijk (maripark expert), and Eveline Buyck (Defense advisor, De Blauwe Cluster). This has led to the scenarios presented in this report.

Offshore wind and Nearshore aquaculture: the base for multi-use

It is no surprise that offshore wind farms have become a primary starting point for exploring multi-use at sea. These large-scale infrastructures are currently designed for a single function—energy production—yet within a typical offshore wind farm, individual turbines are often spaced more than a kilometre apart.

With appropriate safeguards and coordinated design, experts recognise significant potential to use these spaces and their associated infrastructure for multiple complementary purposes. Opportunities for multi-use are also emerging closer to shore, where recent years have seen growing experimentation with nearshore aquaculture and related activities.

The promising partners for multi-use?

To test the robustness of the multi-use concept and avoid drifting into utopian ideals, we have deliberately focused on those functions that are already being rolled out today.

Based on an evaluation of the current activities in the North Sea, and future activities considered to be promising by experts, we identified logical partners for multi-use in offshore wind farms and nearshore aquaculture farms.

The consulted experts agree that offshore wind farms can be combined with other functions such as nature creation and (passive) fishing (e.g. by enriching foundations with nature inclusive design measures), defense (through the shared use of monitoring equipment), floating solar farms (under development), aquaculture (under development). Other potential future functions include hydrogen production and storage and others.

More near shore, most experts consider aquaculture and nature creation to be a logical combination (e.g., drifting oysters that could form the start of an oyster reef on the prepared seabed).

Multi-use in various forms

Sharing the same infrastructure seems obvious. For example: floating solar farms and offshore wind farms can share foundations and/or electrical infrastructure such as transformers, cables, and substations.

Experts also see opportunities for the shared use of monitoring equipment. Data can come not only from fixed sensors, but also from drones operating on or under the water and in the air. The data collected in offshore wind farms is very useful for the defense sector or scientific research, and can easily be shared. Multi-use partners can also potentially use the same Operation & Maintenance infrastructure: e.g. in the Netherlands plans are being developed to build fishing vessels, capable of performing O&M operations in offshore wind farms. (https://projectoctopus.nl/).

Feasibility

Multi-use is not an end in itself: use of marine space comes into play when solutions on land are no longer possible. Multi-use provides a strategy to achieve sustainable and efficient use of the marine space we use. Therefore this research focuses on what is happening in our seas today, rather than on hypothetical future scenarios. Stakeholders identified two main challenges to advancing multi-use in the North Sea: economic and technological. Since offshore applications require a very high level of reliability and robustness (they are used in harsh environments and remote locations), most technologies need significant R&D before large-scale application is possible. Most technologies remain at an early stage of development, and the North Sea's harsh conditions, often only used as a testing ground for new technologies, further underscore these challenges. As is commonly noted, if a technology works in the North Sea, it will work anywhere. Economically, the low demand and high production costs of offshore products—

"... and we ensure that future generations have the space to meet their own needs."

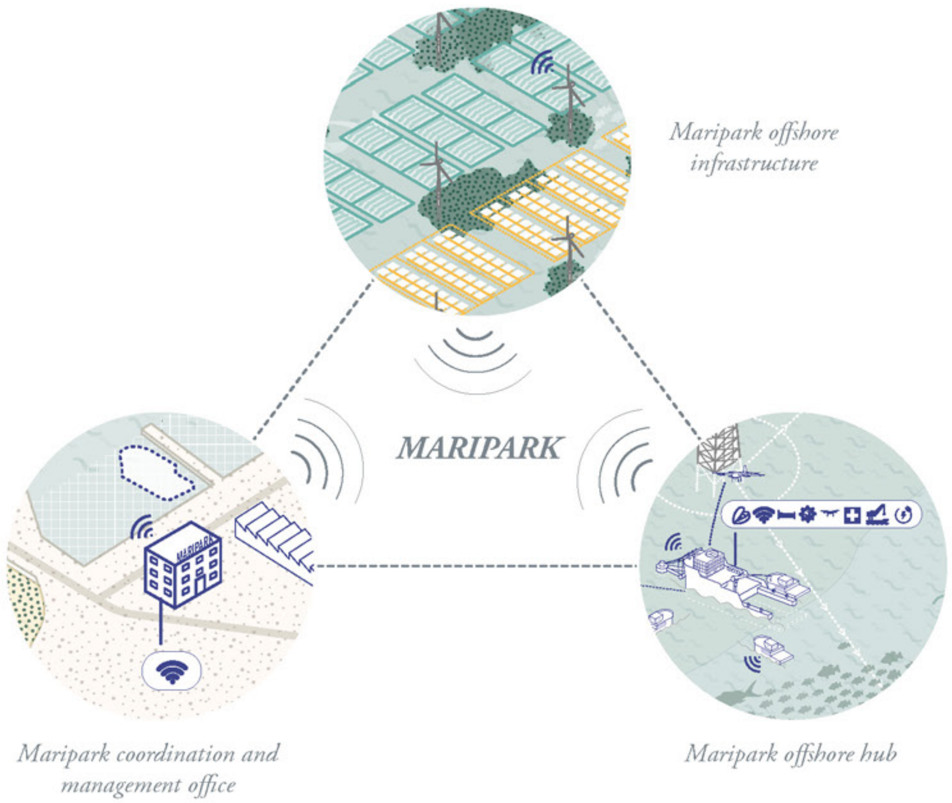
Impression of an offshore wind farm and offshore aquaculture in phase 2 of a maripark such as seaweed, mussels, and solar energy—pose significant challenges to their viability. These costs are largely driven by the distance involved, typically around 50 km offshore or a two-hour sail to reach production sites.

The technical risk, as well as the economic risk, makes innovation challenging and also makes it difficult for investors to easily implement new multi-use technology in the field.

Our research therefore examines the real-world feasibility of multi-use today. We do this not out of short-sightedness, but because of the urgency of the challenge: addressing these issues is a crucial first step toward practical implementation and future development.

Centralized coordination, shared services

In addition to solutions for the technical and economic challenges, there is a need for central coordination and management. All actors in the maripark must be managed and directed from a central point. This ensures mutual coordination for the use of space and facilities, safety, sharing of data and information, etc. Such a management structure does not yet exist, but is essential for the realization of a marine park. Finally, in order to fully unlock the potential, there is a need for a central offshore hub. A shared service hub that provides services to all actors in the marine park. This could take the form of a fixed structure or



*A **Maripark** is defined as the basic shared infrastructure (such as charging stations, mooring and storage facilities, emergency services, and accommodations) located near or within an offshore wind farm, where users share services and goods and work together on activities that promote the realization of transitions at sea for nature, food, and energy.*
*A **Maripark hub** is the central coordination point of the Maripark. The hub provides support for the operation and management of the shared infrastructure. Lastely there is a central management office onshore.*

a floating structure. The preference is for a floating hub that combines various floating services from current offshore players. This hub would be managed by an external investor or developer responsible for ensuring that all necessary infrastructure and supplies are in place to fully support users in their economic activities at sea.

Towards a roadmap for multi-use

The strategic feasibility analysis suggests that the multi-use concept will evolve gradually in response to shifting geopolitical dynamics and technological advancements. At present, the number of potential users in the North Sea for an offshore hub remains limited.

Therefore, the developer, and the supporting infrastructure it offers, must be designed to remain resilient and adaptable, capable of evolving over time to meet changing market needs and emerging opportunities.

Nature creation (and passive fishing) and defense are the primary multi-use partners for offshore wind farms. Foundations can be used for nature creation (and passive fishing). The data collected at offshore wind farms can also be used for defense purposes.

Given proper agreements, offshore wind farms can also provide space for pilot projects involving floating solar energy and aquaculture.

Depending on technological developments and market demand, floating solar and specific forms of aquaculture have the potential to be scaled up.

Nearshore scenarios are limited to combining aquaculture with nature creation / restoration. In this report, we will substantiate and illustrate these conclusions.

Forewarned is forearmed

Although the technologies and business cases for multi-use are still in their early stages and require substantial development before widespread implementation, this should not prevent us from exploring how they could be applied today. Planning and preparing in advance allows us to be ready for the future.

The rapid deployment of offshore wind across the North Sea illustrates the consequences of applying a technology without sufficient foresight: we are now inheriting a North Sea that feels increasingly fragmented and ad hoc. Careful preparation—developing the right tools, frameworks, and approaches—is essential to avoid repeating this pattern and to ensure that multi-use can be implemented efficiently and sustainably.

Work Package 4

This report is the result of the work carried out by ORG within Work Package 4, together with all the experts involved and the work package members.

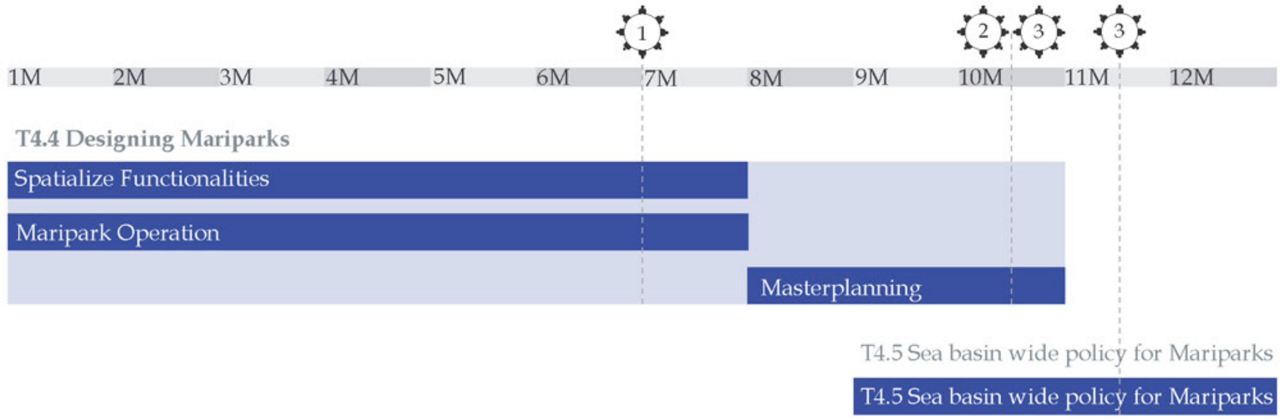
	Role	Company	1st Series	2nd series
Nico Buytendijk	Maripark expert	Rijskdienst voor Ondernemen	X	
Alexander Jordaens	Aquaculture expert	Greentide	X	X
Pieter Jan Jordaens	Energy expert	SIRRIS / OWI-Lab	X	X
Eveline Buyck	Defense expert	De Blauwe Cluster	X	

Bilateral meetings: consulted experts

	Role	Company	WS 1	WS 2 &3	WS 4
Nico Buytendijk	Maripark expert	Rijskdienst voor Ondernemen		X	X
Paul Severens	Maripark expert	Rijskdienst voor Ondernemen	X	X	X
Alexander Jordaens	Aquaculture expert	Greentide	X	X	
Jochem Vermeir	Wind farm expert	Parkwind	X	X	
Kritsof Verlinden	Wind farm & defense expert	Parkwind	X		
Nancy Nevejan	Expert bivalves	Business Leader Shells & Valves	X	X	X
Joep van der Zanden	Maripark Expert	Marin		X	
Tom van den Nieuwenhuijzen	Maripark expert	Rijskdienst voor Ondernemen	X		X

Interactive workshops: consulted experts; members of the different Work Packages are not mentioned in the tables

II. Process



To gain a better understanding of multi-use — its foundations, potential partners, and its phasing over time — we consulted various experts throughout the nine-month process. First series of expert meetings were held to gain insight into the maripark concept and the various activities that could be incorporated within a maripark in the North Sea. Why is it particularly desirable to develop these activities offshore? What are their technical and spatial constraints? And why is it advantageous to realize them under the umbrella of a maripark? Beyond the spatial and technical constraints, these conversations highlighted the scale of investment required to make offshore activities feasible in the first place.

In a subsequent series of expert meetings, we focused on the market conditions necessary to realize a maripark. While bundling multiple functions is highly desirable, the key questions remained: Is it feasible? Or more precisely, what conditions must be met to make it feasible? In other words: are we building castles in the air, or a truly achievable future? This second series of expert meetings concentrated on the functions most realistic in the medium term.

The information gathered was then presented, interactively, during interactive workshops to a panel of offshore experts.

The key questions discussed during the interactive workshops:

- Workshop 1: Based on today's insights, which forms of multi-use are feasible tomorrow, and which could be promising in the longer term?
- Workshops 2 & 3: What societal goals do we aim to achieve with marine parks? And what scale is appropriate for that?
- Workshop 4: From utopia to reality: if we agree on the societal goals and acknowledge that there are currently significant barriers to fully engaging industry, what steps should we take next?

By combining these diverse perspectives, we were able to develop a comprehensive understanding of the reality of mariparks.

The resulting maripark scenarios and accompanying roadmap are the product of these interactive sessions.

III. Multi-use strategy

Realizing offshore projects provides much greater technical and financial challenges compared to onshore projects.

As a result, most offshore businesses favor suitable, shallower locations closer to ports, reducing installation costs, as well as operation and maintenance expenses.

At the same time, there is broad consensus in the offshore sector that offshore wind farms will be the key drivers of the multi-use concept.

Bottom fixed offshore wind is a mature industry, with well-developed technology, logistics, infrastructure, and business models. Emerging sectors can build on this foundation. The result is potentially a win-win: new sectors avoid large — and often prohibitive — upfront investments, while offshore wind farm concession holders diversify their business case by renting out part of their infrastructure - if legally allowed in their concession permit, and if it does not cause any damage or pose a risk of damage to the infrastructure.

From a spatial perspective, this integration is highly desirable. However, a tension emerges: businesses (f.e. aquaculture) prefer nearshore sites to reduce overall cost and to ensure a viable business case, while the most promising opportunities for multi-use are tied to offshore wind farms further offshore. This raises important questions about the overall feasibility of multi-use.

To address this, we first examined which multi-use cases are realistically achievable. We focused on technologies already proven or at an advanced stage of development: wind energy combined with floating photovoltaics, aquaculture (seaweed, mussels, oysters), military co-use, nature creation & sea ranching.

Among these, floating photovoltaics (FPV) and aquaculture stand out for their potential to make a substantial contribution to the business case for mariparks. Furthermore, aquaculture can contribute to the restoration of natural reefs and the ecosystem in general. Accordingly, FPV and Aquaculture receive special attention in this study.

The approach outlined here can later be expanded to include energy system integration solutions.

Other functionalities, such as offshore data centers or floating nuclear energy, were not part of this research, as they only become relevant at geographical areas where land is scarce and offshore is the only alternative.

The defense expert we consulted indicated that the shared use of data generated by sensors and camera's in offshore wind farms is, in the first instance, sufficient for securing our seas. We take this into account in the various scenarios, but do not dwell on it further.

For ecology we assumed a generic form of nature inclusive design of both the offshore wind farm and the nearshore aquaculture farm (see building blocks).

Photo credit: https://www.clarksons.com/broking/renewables/

Roadmap towards solar energy in the North Sea

Step 1:

First, address the demand for solar energy with onshore solar installations (e.g., rooftops). Onshore solar costs approximately €30–60 per MWh, compared to offshore floating photovoltaics, which currently cost around €250-€320 per MWh. For comparison: offshore wind initially cost €185 per MWh before optimizations reduced the price. Floating solar therefore starts with a price disadvantage compared to offshore wind.

Step 2:

Install and test a floating solar pilot at sea

Step 3:

Once onshore potential is fully utilized and offshore floating solar has reached a TRL of 9, move offshore by making optimal use of offshore wind farm capacity. Start by maximizing the performance of your offshore wind farm (achieving the highest annual energy yield). Then, add offshore floating photovoltaics, making use of cable pooling concepts. If the cable capacity is insufficient, assess whether a business case can justify installing an additional export cable to shore.

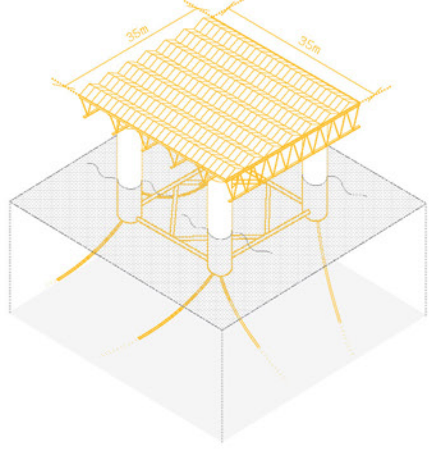
Step 4:

If you need to guarantee a stable annual production level, and wind and solar alone are insufficient, you need to integrate "flexiblity" in your offshore energy asset to interact with the grid infrastructure in an optimal way

> *Option 1: Hydrogen* – enables large-scale, long-term storage, suitable for multiple days and it can also be used as a green fuel for O&M vessels and drones operating in the mariparks

> *Option 2: Batteries* – prioritize onshore (less expensive). If offshore storage is necessary, integrate batteries into the Offshore High Voltage Substation (if space and weight allow) or alternatively into re-used foundations.

Floating Photovoltaics



The added value of floating solar farms lies in three main areas:

- **Improved predictability, leading to lower balancing costs.**
- **From a seasonal point of view wind and solar energy are complementary (Summer: good solar conditions, bad wind conditions and visa versa)**
- **Efficient use of existing infrastructure (cable pooling) where technically feasible**

From an energy perspective, floating solar will almost always function as part of a hybrid energy concept, with wind as the primary driver and solar as a complementary source. This is because offshore wind has a much higher capacity factor (around 39%) compared to floating solar (about 15–17%).

Solar's reduced output in winter and lack of production at night reinforce its role as a supplementary rather than standalone technology. Importantly, combining wind and solar helps lower balancing costs thanks to their daily and seasonal complementarity—when one resource is less available, the other often compensates.

An exception could occur if governments decide to create dedicated floating solar concessions—a "technology-push" scenario, or one designed to avoid bird collisions entirely.

For this reason, we distinguish between four possible scenarios:

1. Floating solar energy within an existing offshore wind farm concession with or without co-use of existing infrastructure
2. Floating solar energy integrated in a new built offshore wind concession
3. Re-purposing scenario
4. Technology push scenario

1 Floating solar energy within an existing offshore wind farm concession with or without co-use of existing infrastructure: The solar farm should be designed so that it can make full use of the existing export cable to shore—specifically by utilizing any spare capacity in the cable, provided it was built to accommodate additional load.

This ensures the existing cable infrastructure is used to its maximum potential. By leveraging these synergies, the levelized cost of energy (LCOE) for solar can be optimized. Experts estimate that, depending on the case and the design of the cables, existing offshore cable infrastructure could allow floating solar to cover 3% to 10% of the offshore wind farm area.

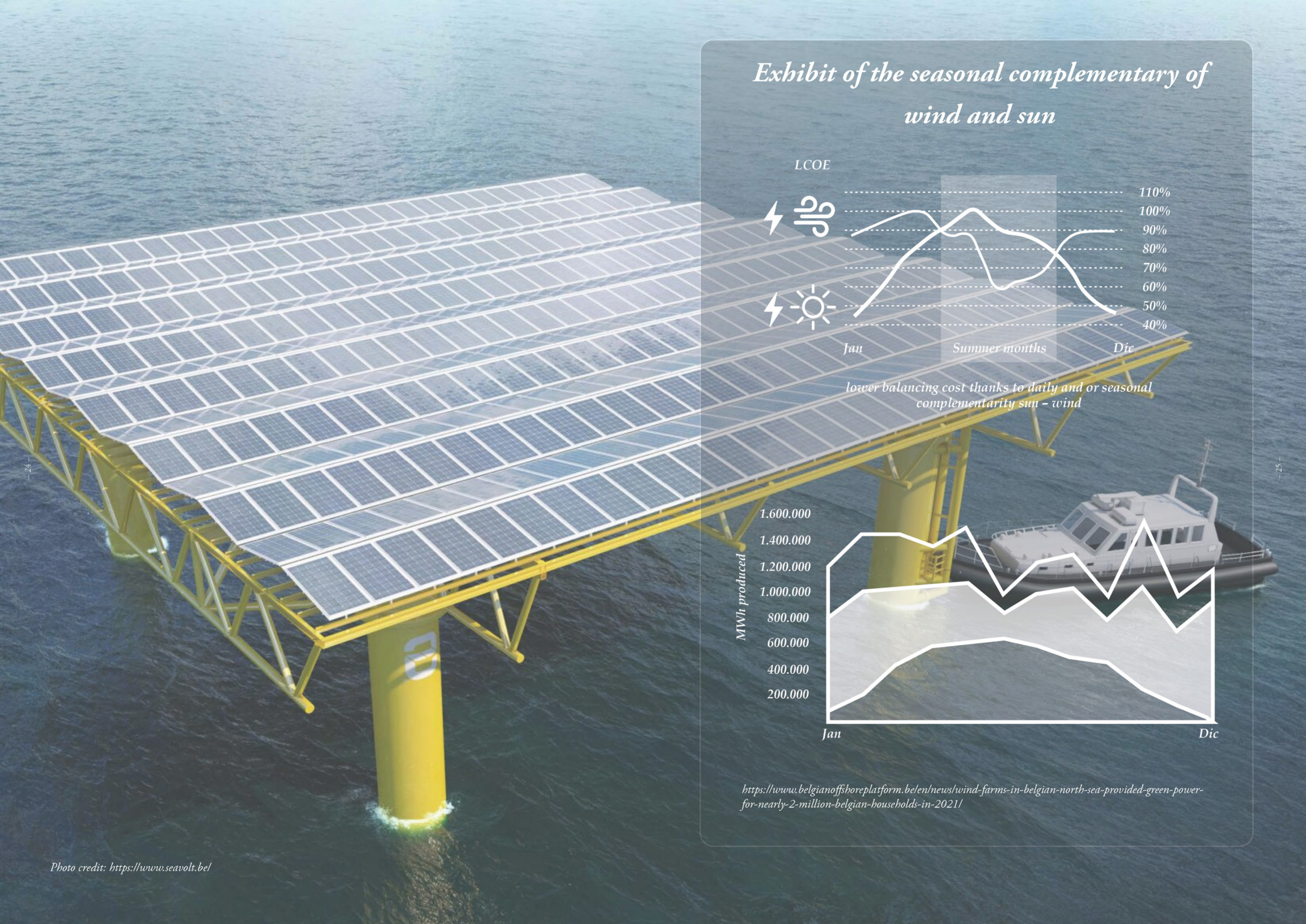


Exhibit of the seasonal complementary of wind and sun

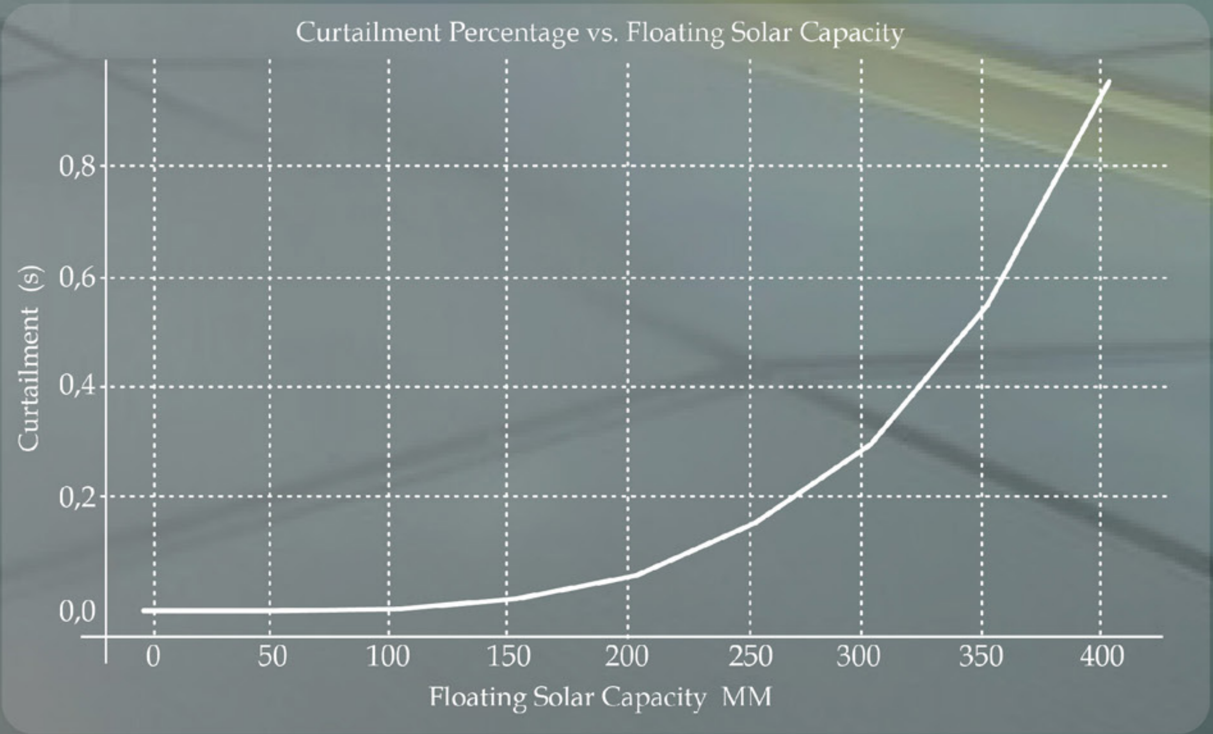
lower balancing cost thanks to daily and or seasonal complementarity sun – wind

https://www.belgianoffshoreplatform.be/en/news/wind-farms-in-belgian-north-sea-provided-green-power-for-nearly-2-million-belgian-households-in-2021/

Photo credit: https://www.seavolt.be/

What could an optimum (solar in offshore wind farm) look like?

Assumptions: Offshore wind farm: 700 MW capacity // Cable capacity: 800 MW // Floating solar additions from 0 to 400 MW // Overlap hours cause curtailment beyond ~100 MW solar capacity
Result (hypothetical): Optimal solar capacity: ~80–100 MW. Beyond that there will be diminishing returns due to curtailment. Or you need high capacity cables. Mind, the onshore grid connection should allow for extra capacity to be connected.



You can see that up to round 100 MW of solar capacity, there's negligible curtailment—suggesting this may be close to an optimal integration point without needing to upgrade the grid connection. As always, THE GRID = THE BOTTLENECK

Photo credit: https://oceansofenergy.blue/

Stand-alone floating solar farms, or solar farms integrated in existing wind farms, must rely on their own transformers and interarray cables. This makes integrating FPV in existing wind farms a challenge, as the current transformers in wind turbines are not designed for this purpose. In new wind farms this posibility can be integrated from the get-go.

Transmission system operators (TSOs) are increasingly curtailing offshore wind generation on days with abundant sun and wind. Inevitably, this would also result in curtailment of offshore solar output. This raises a critical question: are there enough production hours for floating solar to sustain a viable business case?

One alternative would be to install a dedicated export cable for floating solar—connecting either to an offshore hub (if not already congested), an Energy Island (where available), or directly to shore. For larger floating solar farms, a booster transformer station may also be required. The drawback, however, is that this option drives the levelized cost of energy (LCOE) significantly higher.

2 Floating solar energy integrated in a new built offshore wind concession: A more attractive solution is to integrate floating solar directly into the design of new offshore wind farms. In this setup:

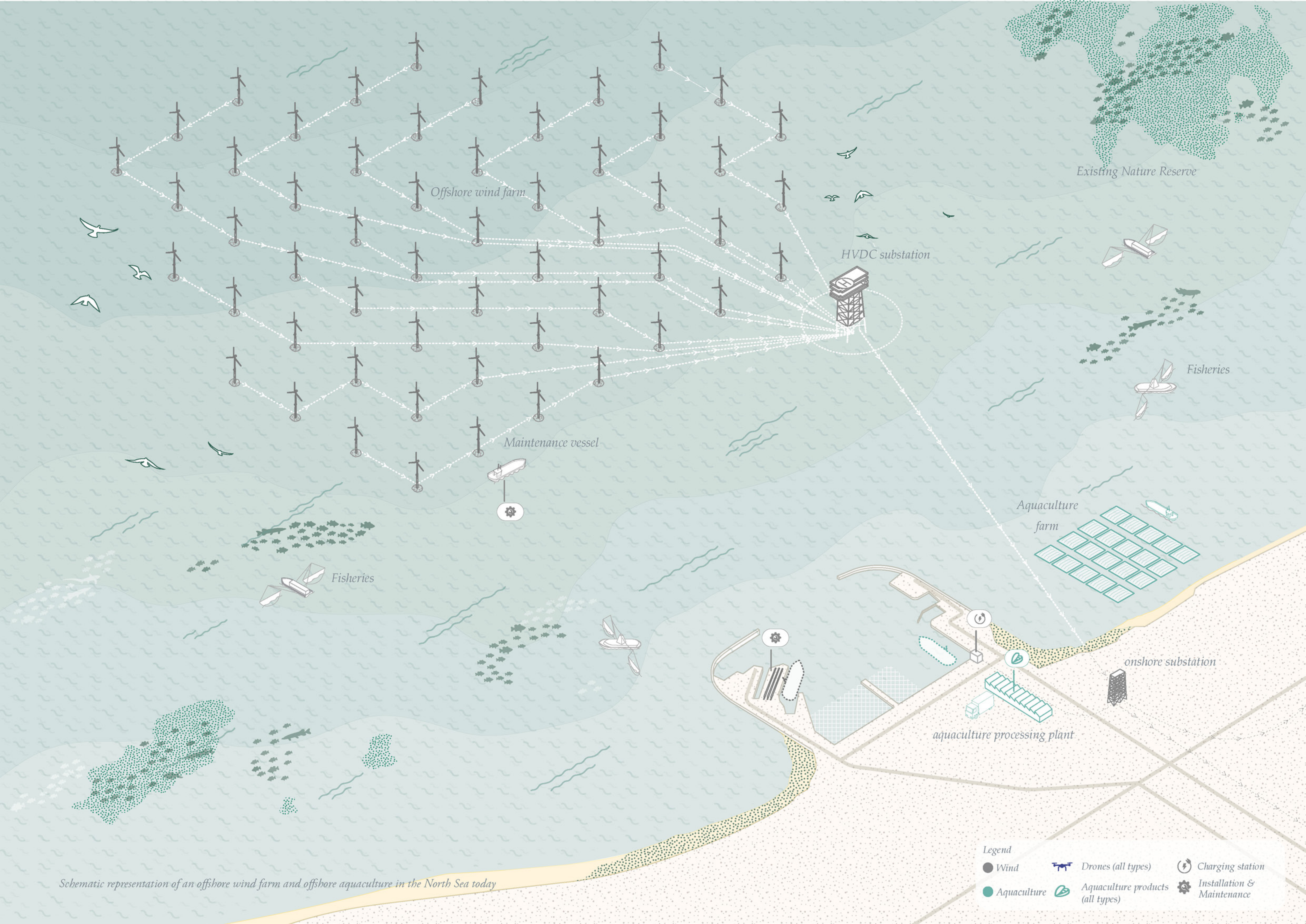
- Cables can be dimensioned to handle the combined maximum power of both wind and solar assets.
- Floating photovoltaics could share transformers and/or (inter array) cables with wind turbines, and potentially even use turbine foundations for anchoring.
- Substations would serve both wind and solar, with cable capacity scaled up if additional solar integration is desired.

That said, there are constraints and trade-offs:

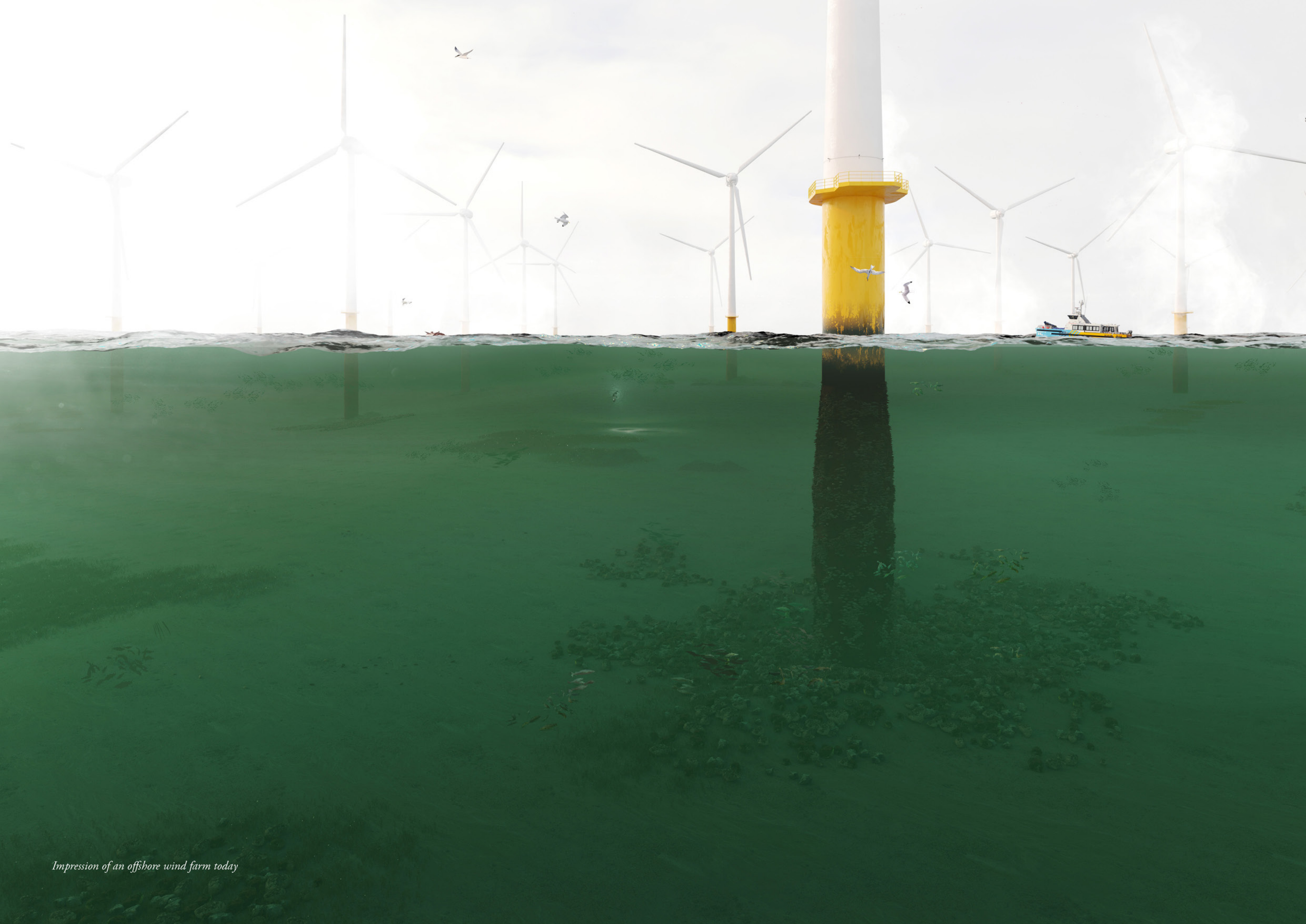
- Grid limits: the onshore connection ultimately caps maximum capacity.
- Technical constraints: interarray cables have an optimal loading range (unless deliberately oversized).
- Physical constraints: shading from turbines, turbulence, wake effects, and zoning requirements (e.g., spacing between turbines, shipping lanes).
- Legal contraints: the concession permits need to allow for multi-use.

Finally, given the higher efficiency and lower cost of offshore wind compared to floating solar, it makes little sense to oversize solar integration. The goal should be balanced hybrid systems that maximize efficiency while minimizing curtailment.

3 Re-purposing scenario: When repowering a offshore wind farm, one option is to shift the turbine layout and replace only a selection of the decommissioned turbines with floating solar installations—limited to sites that do not conflict with the new offshore wind farm (see Scenario Decommissioning). The floating solar farm would then connect to the offshore wind farm substation, using the existing export cable to make the onshore connection.



Schematic representation of an offshore wind farm and offshore aquaculture in the North Sea today



Impression of an offshore wind farm today

A key advantage lies in the longer lifespan of interarray cables compared to wind turbines themselves. While turbines typically last 20–30 years, cables can operate for around 40 years. This creates a 10-year window in which the cables from the decommissioned offshore wind farm could be repurposed to connect floating solar assets to the substation.

For the newly built offshore wind farm, the same design considerations apply as outlined in the previous scenario — allowing for integrated hybrid operation of wind and solar.

4 Technology push scenario: An example of a technology push scenario could be the government supporting the installation of an offshore floating solar pilot project.

We return to this point in the chapter on roadmaps. To give innovative offshore functions a real chance, it is advisable to reserve space within a maripark for the testing and development of pilot projects.

Installation of a nearshore aquaculture farm. In addition to high operation and maintenance costs, offshore conditions require much more robust infrastructure (photo credit: https://www.colruytgroup.com/nl

Aquaculture

The concept of co-locating mariculture (cultivation of marine organisms at sea) with offshore wind energy in the North Sea presents an appealing vision of multifunctional marine space utilization. However, a closer examination reveals significant technical, financial and market-related challenges questioning if offshore mariculture can really break through.

This chapter critically assesses the necessity, feasibility, and economic viability of such integration. And this on a strategic level. The commercial viability of a technology at sea depends on multiple criteria in the value chain, of which the location is an undeniable element.

It is important to first assess whether the technology can be applied on land, such as in aquaculture ponds or inland water bodies. When farmland is limited and countries aim for self-sufficiency in food production, the sea may offer an alternative space, although this comes at a premium cost. This consideration is particularly relevant for low-trophic mariculture, including mussel, oyster, and seaweed farming, and more broadly for any offshore business. There must be a compelling reason to move activities to the sea, weighing the benefits against the higher costs and operational challenges.

For these specific mariculture species, the location of the farm at sea is a critical factor in determining the viability of the business case. Harsh offshore conditions impact both investment and operational costs, which in turn necessitate higher sales prices to generate sufficient revenue to cover expenses. These sales prices are generally higher for offshore operations compared to onshore production, often referred to as a "premium price." This premium reflects the additional value consumers are willing to pay for a product that is perceived as more sustainable or environmentally friendly. In the following sub-chapters, we'll briefly reflect on following questions per species:

- Q1: What are the current production and consumption and what are the needs by 2030 and 2050. This is important before advocating for offshore expansion towards deeper waters.
- Q2: Can we accommodate the needs for 2030 and 2050 using current nearshore farm locations and cultivation technologies and could it positively affect the price, following the economy of scale effect?
- Q3: What are the decisive elements to move offshore as stand-alone farm or co-located inside an offshore windfarm, taking into account an average offshore distance of 50km?

Mind: production rates of Blue mussels (Mytilus edulis), oysters (flat oysters and cupped oysters) and seaweed (Saccharina Latissima, Ulva species and Alaria Esculente) are publically available (however uncertain if they're accurately). Data about consumption in EU is limited/scarce - a mapping of the current production and consumption for North Sea species would be valuable.

Example Zeeboerderij Westdiep (5km nearshore farm)

Zeeboerderij Westdiep is the first commercial off-bottom blue mussel farm located in the Belgian North Sea, five kilometers off the coast of Nieuwpoort. The mussels grow on longlines that are suspended on floating backbones anchored to the seabed. In April/May, empty mussel ropes are suspended on every backbone in order to catch sufficient mussel spat to grow for the next 1.5 years. In 2024, the owner of the mussel farm (Colruyt Group) harvested approx. 50 mT netto blue mussels of which 25 ton was distributed to their premium supermarket Colruyt CRU and the remaining to their wholesale channels. The price of the mussels in retail (Colruyt CRU) was 11-12 €/kg, with a mix of small and large mussels. When comparing ex farm prices from off-bottom blue mussel farming at 5km offshore with the average ex farm prices for bottom farming, the premium retail price is 5-6 €/kg or in others words double the price. In 2024, about 25 tons of off-bottom blue mussels where sold through premium supermarket Colruyt CRU meaning that specific customers are willing to pay this premium price. Colruyt group expects to double the amount of mussels on their ropes, to increase production and lower their loss rates.

Time will tell if above projections can be achieved resulting in competitive retail prices for nearshore off-bottom cultivation. At full scale, Colruyt Group will capitalise 450 hectares of space that offers 2.600 ton of mussels. However, this still neglectable compared to the annual production volumes from other EU member states. For example: The Netherlands produce about 30.000 tons each year.

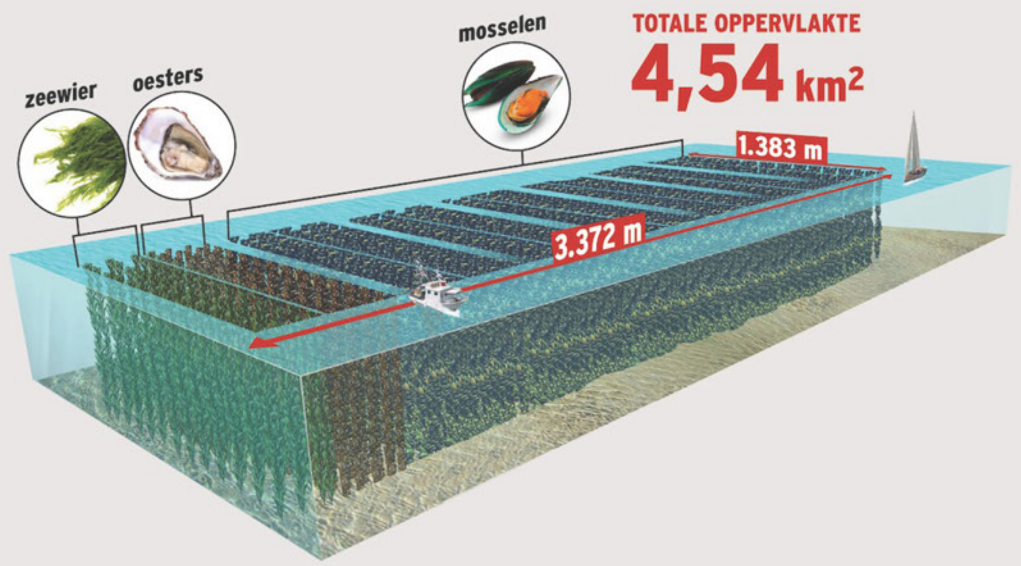


Photo credit: https://www.colruytgroup.com/nl

Mussels (Blue Mussel – Mytilis edulis)

Q1: Current production and consumption and needs for 2030/2050?

Approximately 150,000 tonnes of blue mussels (Mytilus edulis) are produced by EU member states in the North Sea, with France as the leading producer followed by the Netherlands, which primarily relies on bottom farming.

Since only production data are available and consumption figures are very limited, it could be argued that there is no urgent need to scale up production by 2030.

However, considering a projected global population increase of approximately 21% by 2050, with about 6% of this growth occurring in the EU, demand for blue mussels is expected to rise proportionally. Based on this assumption, an additional 10,000 tonnes of blue mussels would be required by 2050.

To put this in perspective, this increase is roughly equivalent to the current production capacity of the mussel farms in the Eastern Scheldt.

2025	Production	Consumption
France-North	60.000 mT (4)	
The Netherlands	30.000 mT (3)	
Ireland	25.000 mT	
Germany	20.000 mT	
UK	10.000 mT	
Belgium	2600 mT (1)	
TOTAL	±150.000 mT	20.000 mT (2)

(1) When Zeeboerderij Westdiep is at full scale, by 2027-2028
(2) Predominantly imported from the Netherlands as Belgium is a large consumer of blue mussels (approx. 2 kg/capita)
(3) The Netherlands are the second largest blue mussel producer in Europe with 6.250 ha area at Waddeneiland and Eastern Scheldt, mainly bottom culture.
(4) On piles and on ropes

Q2: Can we accommodate the needs for 2030 and 2050 using current nearshore farm locations and cultivation technologies and could it positively affect the price?

Blue mussel farming in the North Sea mainly uses bottom culture and off-bottom (suspended) techniques, with some variations depending on location, water depth, and farm size. Because of its low investment and operational cost and economy of scale effects, bottom culture is the most commonly applied method offering low price mussels.

Off-bottom culture is a relatively recent technique that employs long lines, enabling mussel cultivation further offshore. In these locations, mussels are less susceptible to diseases and have access to richer nutrient waters, which can enhance their growth and improve their flavor. This method also offers potential benefits for farm efficiency and environmental sustainability compared to traditional nearshore cultivation.

However, this method requires robust infrastructure, which raises investment costs, and larger vessels are needed for operation and maintenance. Both factors drive higher sales prices. This is reflected in the current retail market: for example, Colruyt offers premium-quality mussels produced using off-bottom cultivation at a price approximately three times higher than mussels farmed in the Netherlands using traditional nearshore methods. This illustrates how offshore cultivation techniques, while potentially improving flavour and quality, also come with a significant cost premium.

Looking ahead to 2050, our ability to meet future demand will depend largely on the existing and new farming locations allocated by the government. These locations will determine the cultivation technique used and, consequently, the market price. It is clear that the farther offshore we go, the higher the sales price will be to offset the overall costs.

	Ex farm price (2024)	Retail price (incl. VAT)
Bottom Culture	1-2 €/kg	4-7 €/kg
Off bottom culture (nearshore)	4 - 5 €/kg	12-14 €/kg

Q3: Assessing the impact of moving offshore on the price and willingness to pay

Moving from authentic bottom farming close to the shoreline towards nearshore (<5km) off-bottom farming in the North Sea results in a premium price which is most likely more than 6 €/kg. this premium price is caused by higher investment cost (e.g. farm infrastructure, marine equipment) and operational cost (labour, vessel rates, maintenance, inspection & monitoring etc.).

In addition, wave impact and current affect the production yields. A combination of higher costs, challenging offshore conditions, and the fact that this is a relatively new method—still requiring lessons to be learned—significantly impacts the price.

When moving further offshore (beyond 40 km), retail prices are expected to rise even higher, exceeding a €6/kg premium. The question remains whether consumers will be willing to pay this price, especially given that bottom-cultured mussels remain a high-quality yet more affordable alternative.

Conclusion

At this stage, it is uncertain whether nearshore (≈5 km) off-bottom blue mussel cultivation can be competitive with current bottom-culture techniques. Customers should therefore be aware that a premium price will be applicable in the short term.

Although some argue that off-bottom mussels have superior taste, this has not been conclusively proven and is often used by farmers and retailers to justify the premium price. Relocating further offshore into wind farm areas, typically 40–50 km from the coast, would likely necessitate an even higher premium price, positioning mussels more as a luxury product rather than a standard commodity.

Moreover, there is no evidence that mussel farming further offshore, within an offshore wind farm, would result in higher production yields compared to nearshore farms.

Given the untapped potential and logistical advantages of nearshore aquaculture, it is our vision to gain experience from nearshore farming before even exploring offshore integration.

This suggests that a viable business case for offshore mussel farming is unlikely in the short term.

Seaweed (brown seaweed species)

Q1: Current production and consumption and needs for 2030/2050

Before examining the numbers for Europe, it is important to understand Europe's position in the global seaweed industry. Asia dominates the market, producing approximately 35 million tonnes of seaweed biomass annually. In contrast, Europe cultivates only around 300,000 tonnes, of which 99% comes from wild harvest. This means that only 2,000 tonnes are farmed on ropes in Europe, with the North Sea accounting for 65% of total domestic production. Clearly, European seaweed farming is negligible compared to the global industry.

This disparity is due to Europe's limited history of seaweed cultivation compared to Asia, as well as high labor costs, which drive up prices and make large-scale production less attractive. Consequently, all current seaweed farms in Europe (UK, Ireland, Sweden, Norway, Faroe Islands) are located in sheltered, nearshore areas with a reason.

At present, the demand and supply of seaweed are

2025	Production	Consumption
France - West	200 mT	Not available
Ireland	200 mT	Not available
UK	100 mT	Not available
Norway	600 mT	Not available
Sweden	150 mT	Not available
Denmark	50 mT	Not available
Iceland / Faroer	400 mT	Not available
TOTAL	± 2.000 mT	270.000 mT (1)

(1) *Mainly imported seaweed from Asia*

imbalanced, which discourages farmers from scaling up production due to uncertainties in off-take agreements. This situation allows buyers to source seaweed from Asia, limiting local market growth. Consequently, we do not expect a significant increase in European seaweed production by 2030, given the current economic and geopolitical conditions that has led to some bankruptcy of seaweed farmers. However, by 2050, the situation could change, as seaweed is a highly versatile resource with potential applications across multiple sustainable markets (e.g. food/ feed/bioplastics/biofuels/nutraceuticals/ pharmaceuticals etc.). Additionally, the ongoing shift toward alternative proteins could boost demand for seaweed as an ingredient in hybrid meat products, potentially accelerating the growth of seaweed farming in the EU by mid-century.

Photo credit: https://jeugdjournaal.nl/artikel/804637-15-kilo-zeewier-in-de-noordzee

Q2: Can we accommodate the needs for 2030 and 2050 using current nearshore farm locations and cultivation technologies and could it positively affect the price?

The existing technology is seeded twines that are deployed onto floating backbones which are anchored in the seabed. Same technology is applied in Asia though at a very high density with low cost marine equipment and labor cost. To accommodate the growing demand for seaweed for all relevant sustainable commercial products, Europe has to allocate sufficient concession zones across the North Sea. Current areas used for seaweed cultivation across the North Sea are located inside bays, sheltered areas, fjords and hence situated on the west coast of Denmark, Sweden, Norway as well as Ireland and UK.

	Ex farm price (2024)	Retail price
EU brown seaweed	2-3 €/kg wet weight	40-50 €/kg dry weight
Asia brown seaweed	0.10-0.30 €/kg wet weight	5-10 €/kg dry weight

The table above shows that the current price of EU brown seaweed is approximately €35/kg more than Asian brown seaweed, representing a significant premium. However, given the potentially high logistics costs for import, this premium is lower though still significant. Despite this price difference, EU customers are willing to pay this premium price due to higher quality standards and transparency.

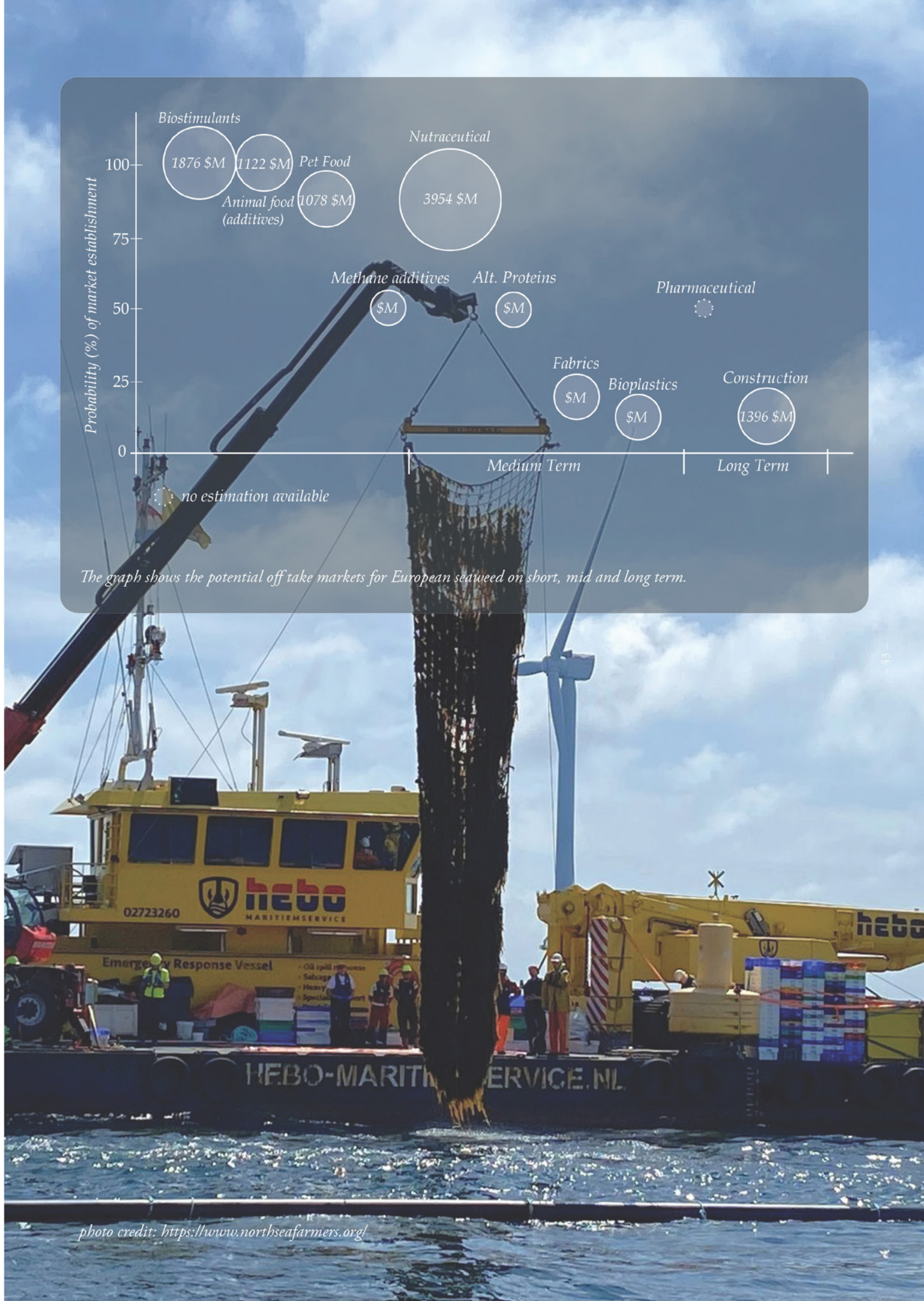
We anticipate that government funding and supportive policies will help reduce the cost of seaweed production in the EU and stimulate higher production volumes. A crucial first step is to establish a robust value chain, ensuring that producers have reliable markets for their biomass, while also expanding the number and scale of farms in sheltered coastal areas. This foundation could serve as a stepping stone toward offshore cultivation in deeper waters, where more stable temperatures could allow for biannual harvesting instead of the current single annual harvest, effectively doubling yearly yields. By 2030, significant expansion may still be limited due to economic, logistical, and technological constraints. However, by 2050, we expect seaweed to have become a mainstream commodity - cultivated both nearshore and further offshore - serving a wide array of sustainable product markets, including food, feed, biostimulants, nutraceuticals and biobased materials. A graph on the next page indicates the potential of various seaweed markets on the medium (2030-2040) and long term (2050).

Q3: Assessing the impact of moving offshore on the price and willingness to pay

While moving mussel farms further at sea does not necessarily increase yields, the situation is different for seaweed. Currently, nearshore seaweed farms in the North Sea are limited by rising seawater temperatures during the spring and summer, resulting in a cultivation cycle of only 6–8 months and a single annual harvest. In some Nordic regions, however, seawater temperatures are more stable throughout the year, allowing farmers either to extend the growing period for greater biomass or to run two cultivation cycles annually. Moving further offshore and into deeper waters could similarly take advantage of more stable temperatures, potentially increasing annual production volumes. However, this approach also entails higher costs due to the need for more robust infrastructure, specialized vessels, and operational complexity.

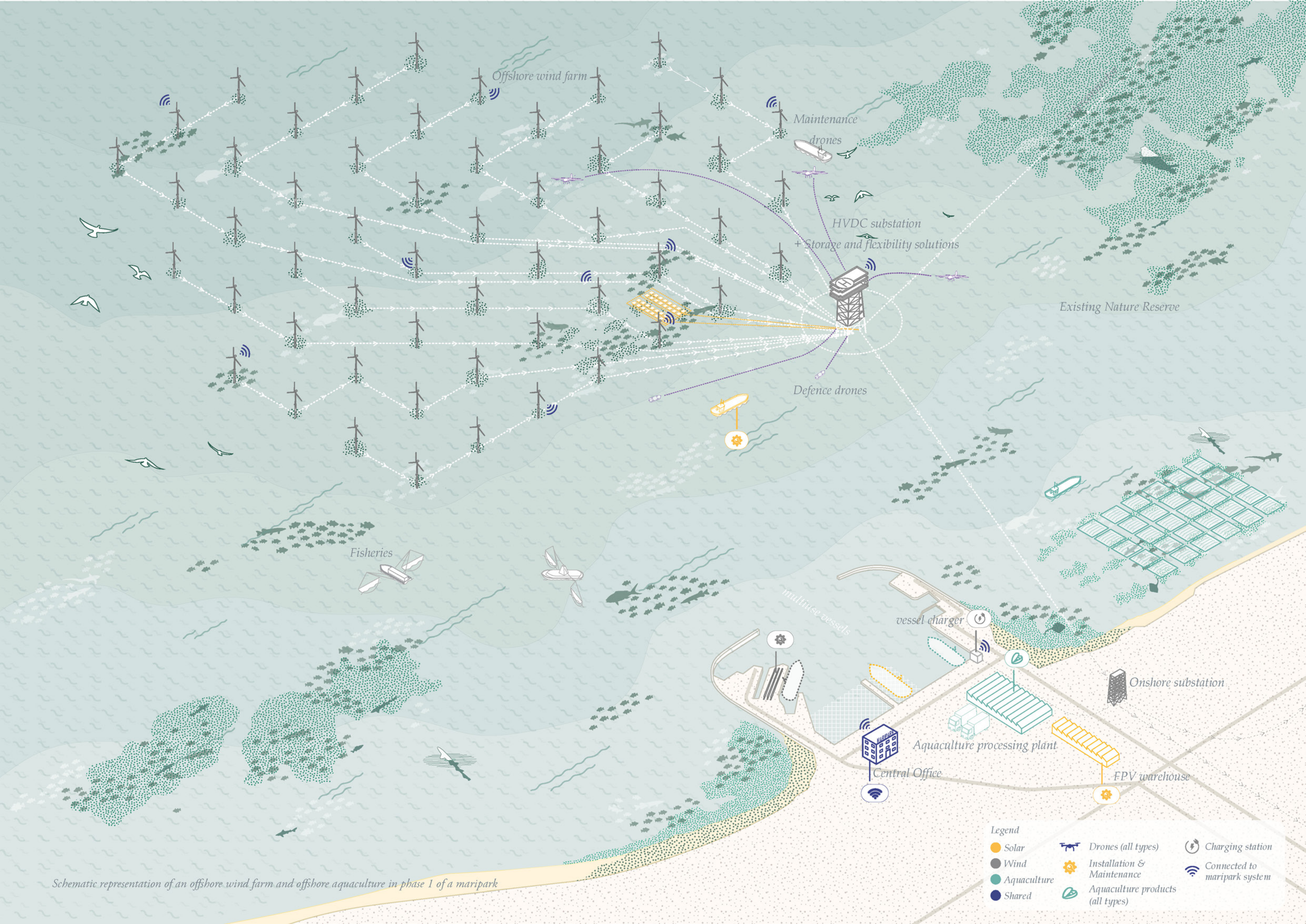
Conclusion

When thinking about bringing mariculture species to deep offshore areas, seaweed might be the only species that can provide more biomass than its nearshore application. However, it comes with an extra investment and operational cost as well as potentially lower densities resulting in larger areas. As seaweed is gaining traction in Europe due to its sustainable growth characteristics and versatile range of sustainable applications, we believe that by 2050, most nearshore locations will be occupied by seaweed farms. At this stage, the exact availability of nearshore (sheltered) space in the North Sea remains uncertain, making it difficult to accurately predict the sector's full potential. However, we believe that with strategic planning and the development of a robust value chain, nearshore areas could support the initial expansion of the seaweed business in Europe serving as a foundation for gradual growth into deeper offshore waters over time.



The graph shows the potential off take markets for European seaweed on short, mid and long term.

photo credit: https://www.northseafarmers.org/



Schematic representation of an offshore wind farm and offshore aquaculture in phase 1 of a maripark

Impression of an offshore wind farm and offshore aquaculture in phase 1 of a maripark

Oysters (flat EU and cupped Pacific)

Q1: Current production and consumption and needs for 2030/2050

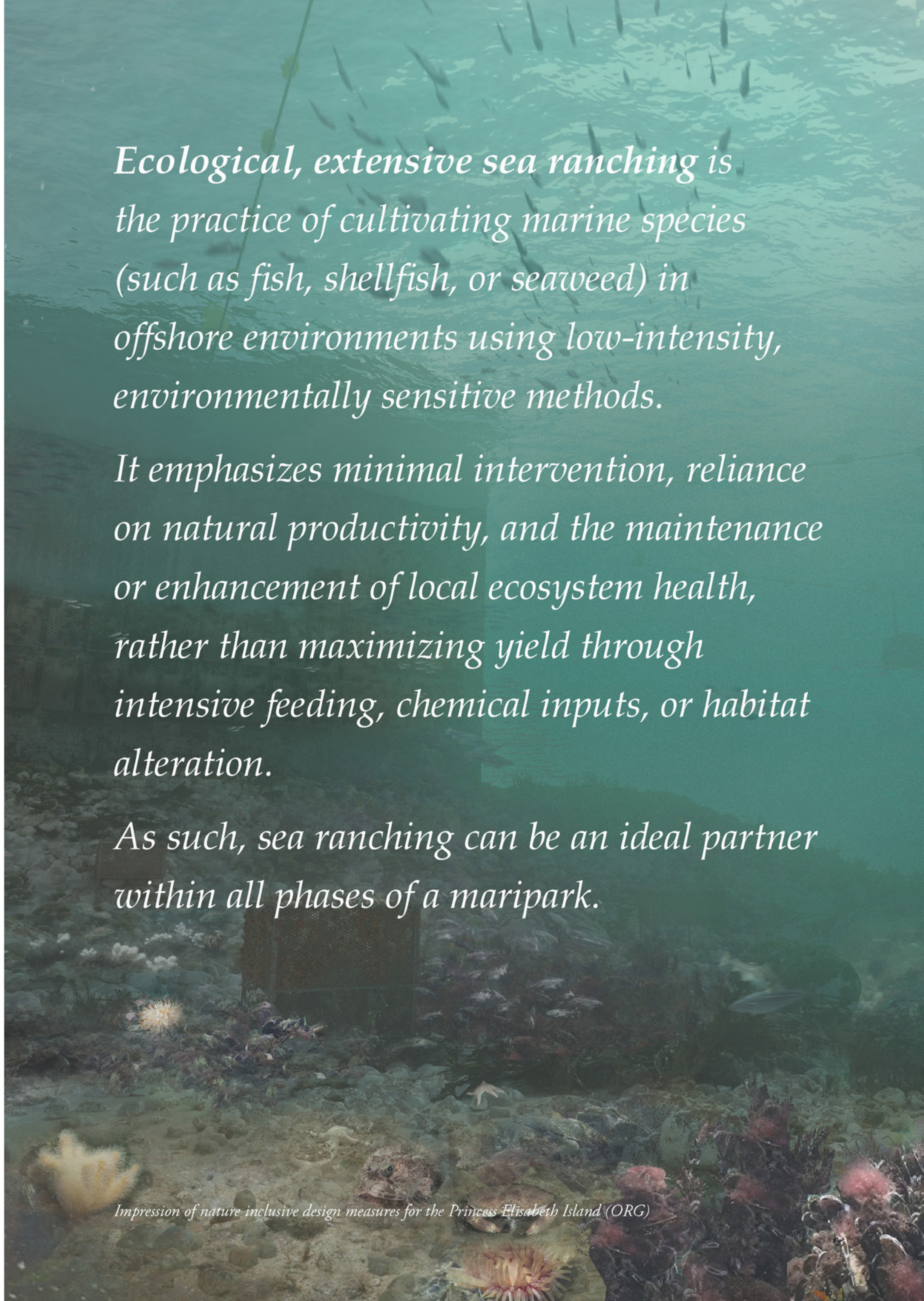
Approximately 100,000 tonnes of oysters are produced by EU member states in the North Sea, with France as the leading producer. Since only production data are available and predictions on consumption demand is very limited, it can be argued that, at present, there is no urgent need to scale up production. However, looking ahead to 2050, an expected population increase of around 6% in Europe would imply a need for 6.000 tonnes of more oysters annually. To put this in perspective, this increase is roughly equivalent to 3 times the current production capacity of the oyster farms in the Eastern Scheldt.

2025	Production	Consumption
France - North	80.000 mT (1)	125.000 mT (1)
Ireland	10.000 mT	2.000 mT (3)
The Netherlands	2.000 mT (2)	NA
Others (not North Sea)	8.000 mT	NA
TOTAL	±100.000 mT	127.000 mT <

(1) Representing 80% of the EU production of oysters and 50% of their current aquaculture business. Majority of the production is used for own consumption
(2) Mainly Oosterschelde, limited amount in Grevelingenmeer
(3) Ireland is mainly an export country

Q2: Can we accommodate the needs for 2030 and 2050 using current nearshore farm locations and cultivation technologies and could it positively affect the price?

The current oyster farming techniques are off bottom in racks and bags (France) as well as bottom cultivation (NL) and highly depends on the local conditions. The current retail prices for oysters are in the range of 5 to 11 €/kg, of which 50% is determined by labor cost.



***Ecological, extensive sea ranching** is the practice of cultivating marine species (such as fish, shellfish, or seaweed) in offshore environments using low-intensity, environmentally sensitive methods.*

It emphasizes minimal intervention, reliance on natural productivity, and the maintenance or enhancement of local ecosystem health, rather than maximizing yield through intensive feeding, chemical inputs, or habitat alteration.

As such, sea ranching can be an ideal partner within all phases of a maripark.

Impression of nature inclusive design measures for the Princess Elisabeth Island (ORG)

	Ex farm price	Wholesale price	Retail price
France	1.80 – 5.50 €/kg	3.40 – 6.50 €/kg	4.83 – 9.30 €/kg
The Netherlands	1.80 – 5.50 €/kg	3.92 – 7.77 €/kg	5.59 – 11.10 €/kg
Ireland	3.10 – 4.55 €/kg	3.70 – 3.90 €/kg	5.40 – 5.70 €/kg

Q3: Assessing the impact of moving offshore on the price and willingness to pay

Oysters are highly sensitive to sea conditions, so relocating their cultivation further offshore is unlikely to improve survival rates or significantly influence pricing. As oysters are already considered a premium and luxury product, consumers are unlikely to pay substantially more for oysters farmed within an offshore wind farm. Premium oysters require careful handling and specific conditions to achieve the best quality in terms of shape, meat, and flavor. Offshore cultivation could compromise these qualities, potentially making the product less exclusive and reducing off-take volumes. Furthermore, the higher operational and infrastructure costs associated with offshore farming would likely outweigh any potential benefits, rendering such a move economically unattractive. Therefore, we believe that commercial oyster farming is not viable within offshore wind farms. However, offshore sites could be suitable for restoration purposes, such as the reintroduction of red-listed or endangered species like the European flat oyster.

Conclusion

Given the untapped potential and logistical advantages of nearshore oyster farming, it is prudent to optimize these areas before considering the complexities of offshore integration.

Final Statement: A Call for Strategic Reassessment

The integration of mariculture (mussels, seaweed, oysters) within offshore wind farms, while conceptually attractive, faces significant technical, economic, and practical challenges. Current supply-demand imbalances, the untapped potential of nearshore sheltered mariculture, and the high costs and operational complexities of offshore cultivation suggest that immediate large-scale offshore expansion is not viable. Specifically:

- **Optimize nearshore aquaculture practices:** Focus on improving efficiency, resilience, and sustainability in sheltered coastal areas where environmental conditions are more favorable affecting the price positively
- **Assess available nearshore space:** Conduct detailed mapping of suitable areas for mariculture among EU member states along the North Sea, considering ecological, regulatory, and logistical factors. This is an open call to the reader to take action on this topic to better understand the expansion potential of mariculture in the North Sea
- **Evaluate supply and demand dynamics:** Invest in market studies to quantify current and projected demand for mariculture species and to identify opportunities for scaling production in line with population growth and market trends. This is an open call to the reader to take action on this topic to better understand the expansion potential of mariculture in the North Sea
- **Consider offshore cultivation cautiously:** While offshore farming may eventually increase production volumes, especially for seaweed, it involves higher costs, operational challenges, and potential quality trade-offs. Offshore expansion should therefore be approached gradually and strategically, leveraging technological advances and stable environmental conditions to maximize viability.
- **Engage with offshore wind developers:** Engage with offshore wind developers to gain a clear understanding of the technical, environmental, and operational risks associated with integrating aquaculture, as well as to identify potential opportunities for collaboration, shared infrastructure, and mutually beneficial strategies that can enhance both energy and food production at sea

By prioritizing nearshore development and building a strong foundation in infrastructure, market knowledge, and ecological understanding, the EU can lay the groundwork for a sustainable and scalable mariculture sector capable of future offshore integration.

Hypothesis: Could a protein shift be the driver for large-scale development of offshore aquaculture?

Proteine shift

Implementing mariculture in both nearshore and offshore areas has proven challenging given the conditions and constraints outlined above, as well as the current geopolitical and economic climate. While our analysis has primarily focused on the technical and financial feasibility of such operations, we have also considered a broader perspective by examining this topic in the context of the ongoing global protein shift.

This approach could highlight the potential of mariculture, not only to contribute to sustainable food systems and diversify protein sources but also to enhance food security and strengthen national food sovereignty. By producing more locally and sustainably, mariculture can reduce dependency on imported seafood and protein products, supporting resilience in European food supply chains.

Therefore we looked into animal-based proteins versus plant-based proteins as well as onshore (agriculture) versus offshore (aquaculture).

The global protein shift refers to the transition from traditional animal-based proteins toward more sustainable plant-based proteins, driven by rising population and the high greenhouse gas emissions associated with livestock.

Currently, global protein consumption is roughly 60% animal-based and 40% plant- or alternative-based. The goal of the protein shift is to move toward a more balanced ratio of 40% animal-based and 60% sustainable proteins, reducing environmental impacts while meeting the nutritional needs of a growing population. While agricultural plant-based proteins are leading this transition, we've looked into how marine proteins can contribute to this.

At first, what most people don't realize is that according to the World Health Organization (WHO), the current daily protein intake in the European Union exceeds the recommended levels with almost 50% (!). Essentially, EU citizens consume more protein than the body actually requires, so reducing our daily intake could already have a meaningful impact on climate change. When lowering your daily consumption, we might reach already the protein goals without the need for adding more (marine) proteins into our food system.

Key lesson learnt 1: lower your daily intake of proteins, particularly animal-based proteins

Experience over the years has shown that completely eliminating meat consumption is unrealistic, while plant-based alternatives alone have not yet achieved widespread adoption. This underscores the need for a diversified approach to combine animal-based proteins with plant-based such as hybrid meat.

The key challenge is to create a healthy and sustainable protein alternative that combines taste, consumer appeal, and affordability, making it a viable choice alongside traditional options.

Key lesson learnt 2: Completely eliminating meat from our daily diets is unrealistic, so we should focus on hybrid solutions.

Sustainable protein alternatives often come with higher production & marketing costs, resulting in a premium price for consumers.

When comparing the cost of protein per unit of product, conventional agricultural proteins such as chickpeas and yellow peas remain low-cost, high-protein sources.

Other emerging protein sources, including insect-based proteins and cultured meat could also influence market dynamics and consumer choices however this wasn't further assessed. Below table provides a generic overview of the retail price per kg protein for onshore & offshore plant-based/animal-based proteins.

With below table we may conclude that marine proteins from mussels are, at first glance, priced similarly to beef steak. If subsidies currently allocated to meat production were redirected to mussel farming, we could even lower the price with 10% however it won't reach the price range of agricultural proteins.

In addition, these figures are based on retail prices from (sheltered) bottom-culture farms in the Netherlands. When considering the current retail prices of nearshore mussel farming, such as those from Colruyt's mussel farm, the cost of mussel protein is approximately three times higher than that of conventional meat and up to fifteen times higher than that of agricultural proteins like peas or chickpeas.

With this we can conclude that when we go further offshore and apply new ways of cultivating mussels on ropes, we'll end up with very high protein cost.

Additionally, it is important to note that marine proteins can contain high levels of minerals and heavy metals, which may necessitate limiting consumption to safe levels.

Some may argue that simply comparing retail prices is not sufficient, and that true pricing should be used to capture the full spectrum of direct and indirect costs, including environmental impacts, health-related expenses, and societal externalities. This approach provides a more accurate understanding of the real cost of protein sources and can better inform decisions in the context of sustainable food systems and the protein shift. Based on scientific reports, we should add therefore 50% price increase to pork meat, 40% to cow meat and 25% to chicken meat .

		Retail price (2025)	Protein Content	Price per kg protein
Plant-Based Onshore	**Chickpeas (roasted)**	**4-5€/kg**	**21g protein/100g [high]**	**20-25 €/kg**
Animal-Based Onshore	Minced meat 30% cow – 70% pig	**7-8€/kg**	20g protein/100g [high]	**35-40 €/kg**
Animal-Based Onshore	Minced meat 100% cow	**12-13€/kg**	20g protein/100g [high]	**60-65 €/kg**
Animal-Based Offshore	Blue Mussels (meat only) (1)	**10-15€/kg**	14g protein/100g [medium]	**95-100 €/kg**
Animal-Based Onshore	Steak 100% cow	**20-25€/kg**	23g protein/100g [high]	**105-110 /kg**
Plant-Based Offshore	Seaweed (dried flakes)	**40-45€/kg**	10g protein/100g [medium]	**400-410 €/kg**
Animal-Based Offshore	Blue Mussels nearshore (meat only) (2)	**30-45€/kg**	14g protein/100g [medium]	**290-300 €/kg**

(1) Mussels from bottom culture (NL)
(2) Mussels from nearshore off bottom culture (BE)

The table above indicates that agricultural proteins are at the forefront of the protein shift, due to their high protein and nutrient content combined with low production costs. Furthermore, these proteins can, and are already, being cultivated on Belgian soils.

This table also concludes that the true pricing of meat is still beyond the price of marine proteins.

Mussels could be an alternative protein source, but consumption is often limited due to heavy metal contamination. This has led companies to invest in onshore aquaculture systems, which significantly reduce contamination risks and enable people to consume cleaner, safer fish.

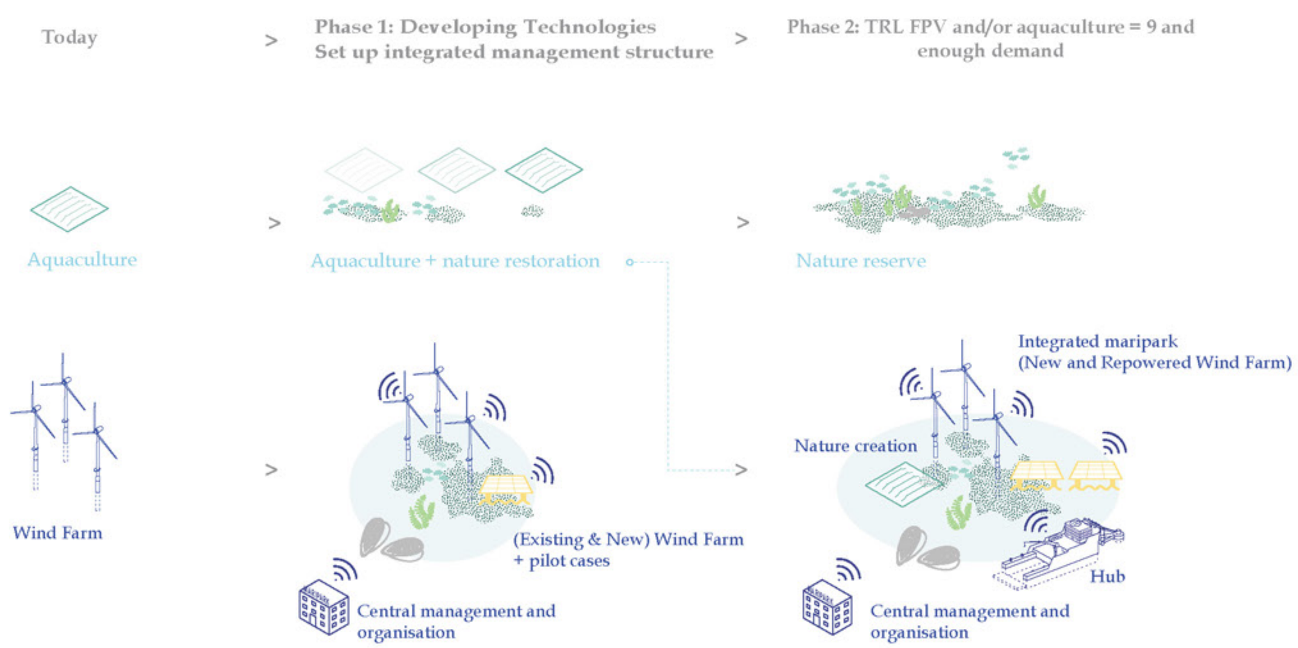
Seaweed remains relatively expensive, so achieving competitive protein pricing will take time. However, it has unique functional properties, such as a high water-binding capacity, which can be leveraged in food production.

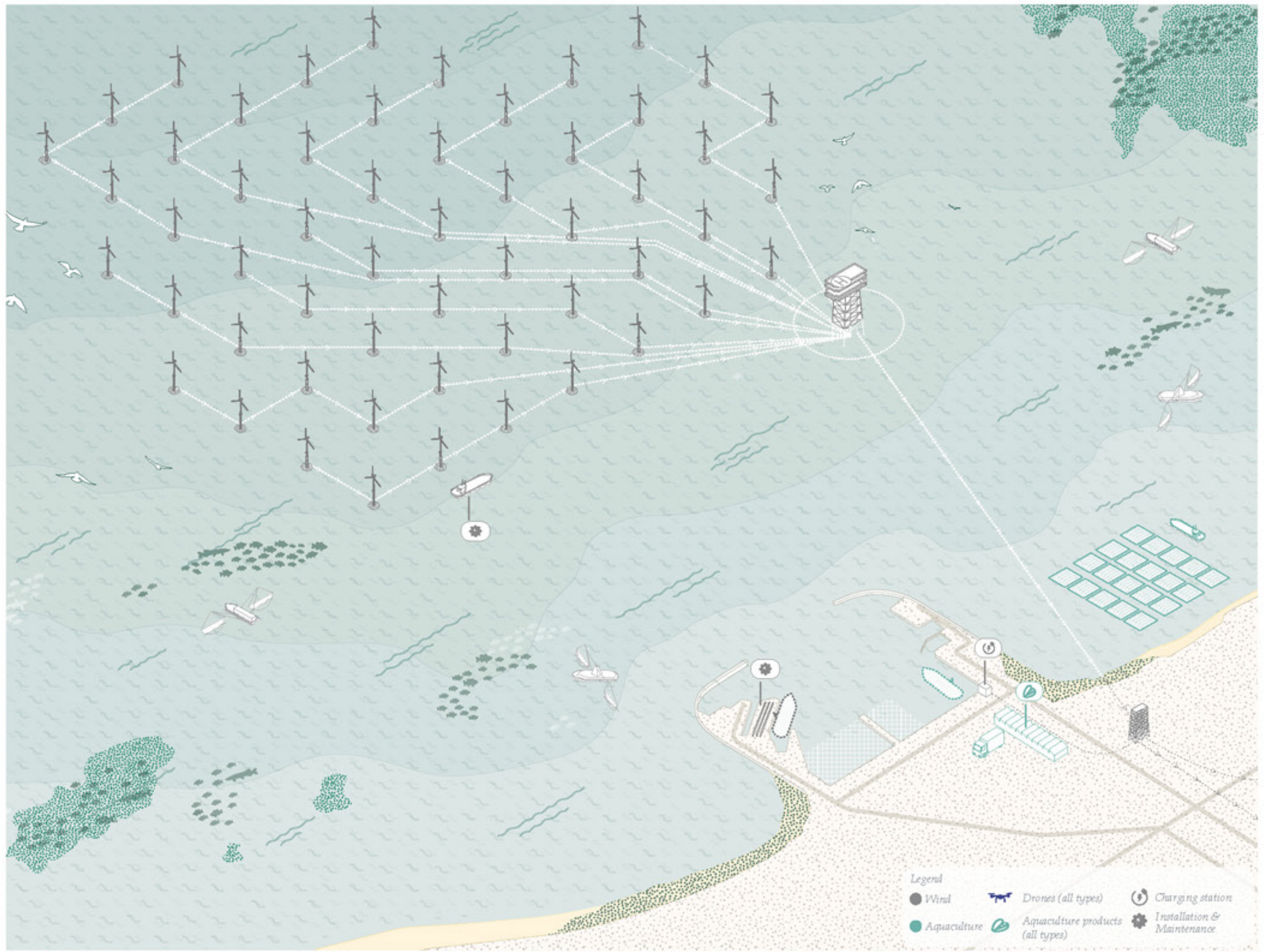
For example, seaweed can be incorporated into meat products to retain water, increase volume and weight, and simultaneously reduce the overall amount of meat required.

This not only helps lower costs and environmental impact but also aligns with the goals of the protein shift by partially substituting animal-based proteins with sustainable alternatives.

As a result, while the policy shift could help lower the relative cost of plant proteins, especially from terrestrial crops, its impact on more expensive marine-based proteins would be limited.

IV. Scenarios & Roadmaps





Schematic representation of an offshore wind farm and offshore aquaculture in the North Sea today

Building on the potential drivers for multi-use concepts—wind energy, solar energy, and aquaculture—a diverse set of scenarios is expected to emerge over time.

These scenarios differ in application (nearshore vs. offshore) and can be grouped into three phases:

- Phase 0: the current situation.
- Phase 1: expansion of existing offshore applications (e.g., nearshore aquaculture) alongside pilot projects for new applications such as offshore aquaculture and floating photovoltaics (FPV).
- Phase 2: full-scale deployment, with offshore aquaculture and/or FPV reaching TRL 9 and supported by sufficient market demand.

For each phase, we present both a nearshore and an offshore scenario.

The current situation

We assume mono-use, as it is today, with each offshore activity developed independently: offshore wind farms separate from aquaculture, aquaculture separate from nature restoration, and so on. This leads to the following situation:

Nearshore: Aquaculture remains small-scale, similar to the Zeeboerderij Westdiep example.

Offshore: Offshore wind farms continue as they are today—mono-use, without nature inclusive design. Floating photovoltaics (FPV) have not yet been deployed.

Each activity operates independently, with its own Operation & Maintenance (O&M) vessels, from which drones are launched as needed.

Phase 1: developing technologies

Phase 1 focuses on the development and refinement of aquaculture and floating photovoltaics (FPV). Nearshore aquaculture farms are optimized, with nature creation and restoration integrated as standard practice. At the same time, offshore pilots are installed within offshore wind farms to test the feasibility of combining aquaculture with offshore wind. Similarly, offshore wind farms serve as testing grounds for floating photovoltaic installations, exploring their performance and integration potential.

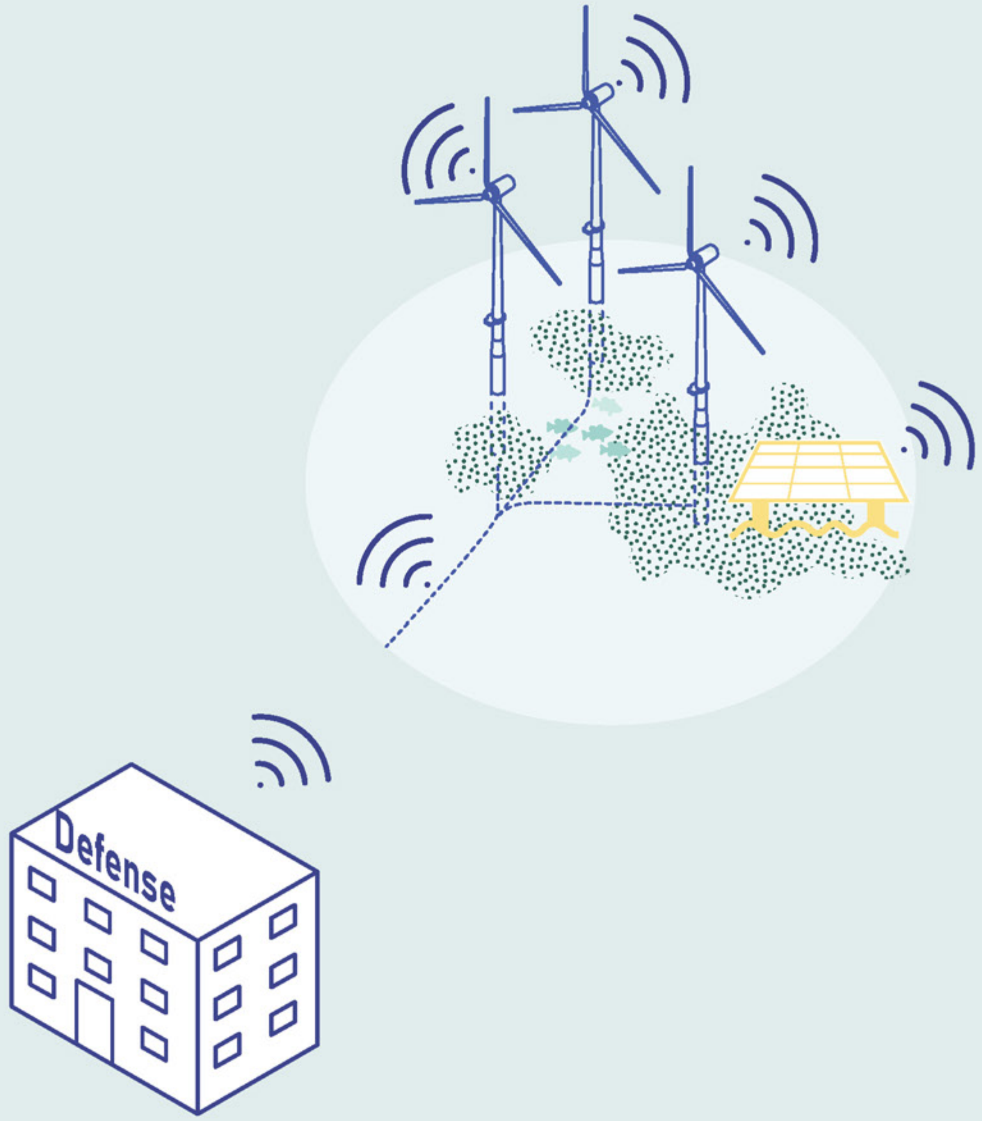
Nearshore: Small-scale aquaculture farms, modeled on a multiplication of the Zeeboerderij Westdiep, are combined with nature creation and restoration measures.

Offshore:

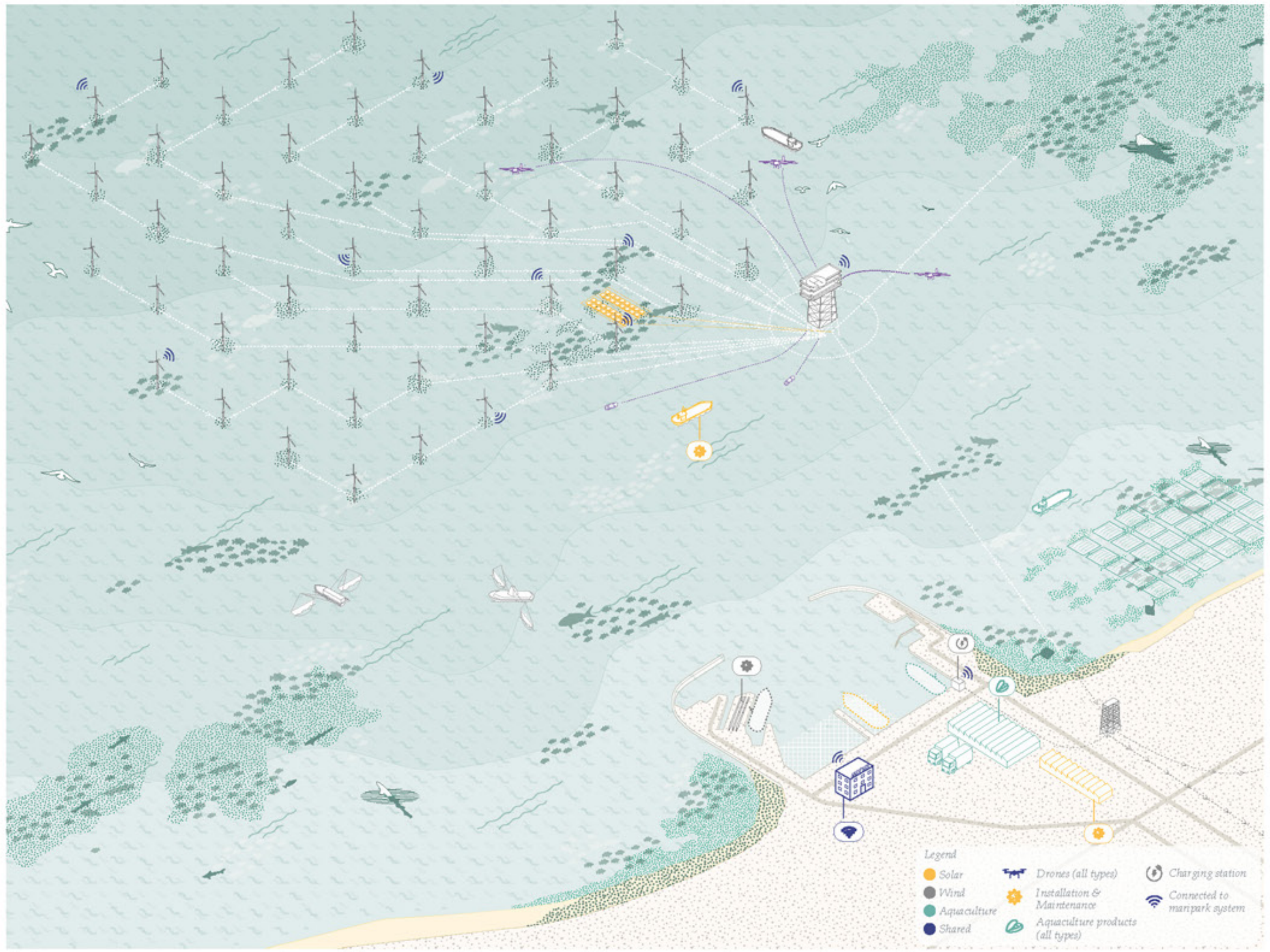
- Offshore wind farms continue as today but incorporate nature inclusive design measures, as well as sea ranching features (e.g., cages) and support passive fisheries.
- Military operations make use of existing sensors and drones.
- Aquaculture pilot projects are installed

NESBp

Shared use of wind farm monitoring data for defense purposes



During the creation process, the consulted defence expert indicated that offshore wind farms and mariparks offer opportunities for securing our seas. Offshore wind farms are continuously monitored by wind farm operators. Thanks to this monitoring equipment, suspicious movements in the surrounding area can also be detected. Where necessary, existing offshore wind infrastructure could also be used as an offtake location for defence drones. Hosting drones and collecting data will be inherent to the operation of mariparks. It therefore goes without saying that mariparks can also be suitable partners for defence.



Schematic representation of an offshore wind farm and offshore aquaculture in phase 1 of a maripark

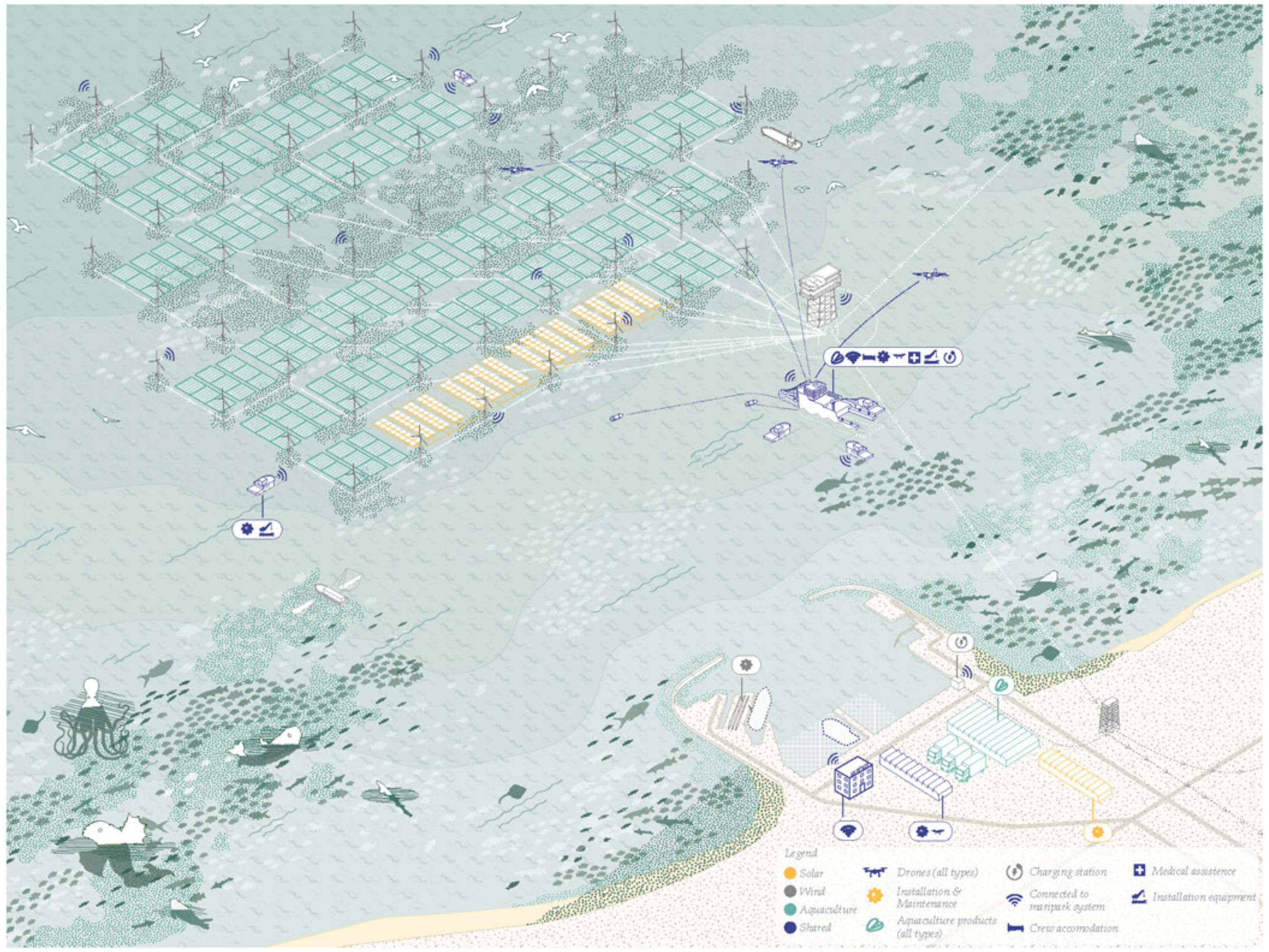
within the offshore wind farm, with an assumed scale of 100 ha per pilot.

- Floating photovoltaic (FPV) pilot projects are also deployed within the offshore wind farm, with an assumed capacity of 0.5 MW over 100 ha per pilot (source: Oceans of Energy), leveraging the offshore wind farm substation and export cable.
- Storage and flexibility pilot projects are installed using the offshore wind farm substation.

Each functionality typically operates its own Operation & Maintenance (O&M) vessel, from which drones are launched. Some pilots test multifunctional vessels, while drones are launched from the substation roof or from a mother vessel serving multiple farms. The Maripark management company is established.

Phase 2: TRL 9 and enough market demand

In the subsequent phase—once floating photovoltaics (FPV) and/or offshore aquaculture farms have reached Technology Readiness Level 9 and there is sufficient market demand—offshore wind farms are developed as integrated parks, combining wind, FPV, and/or aquaculture. Nearshore aquaculture farms will be relocated to the offshore wind farms once they reach the end of their operational life, while the nature created or restored during their operation will remain as a lasting positive legacy. Within Phase 2, we distinguish between new offshore wind farms, decommissioned and repowered offshore wind farms, and existing offshore wind farms, recognizing that each combination of



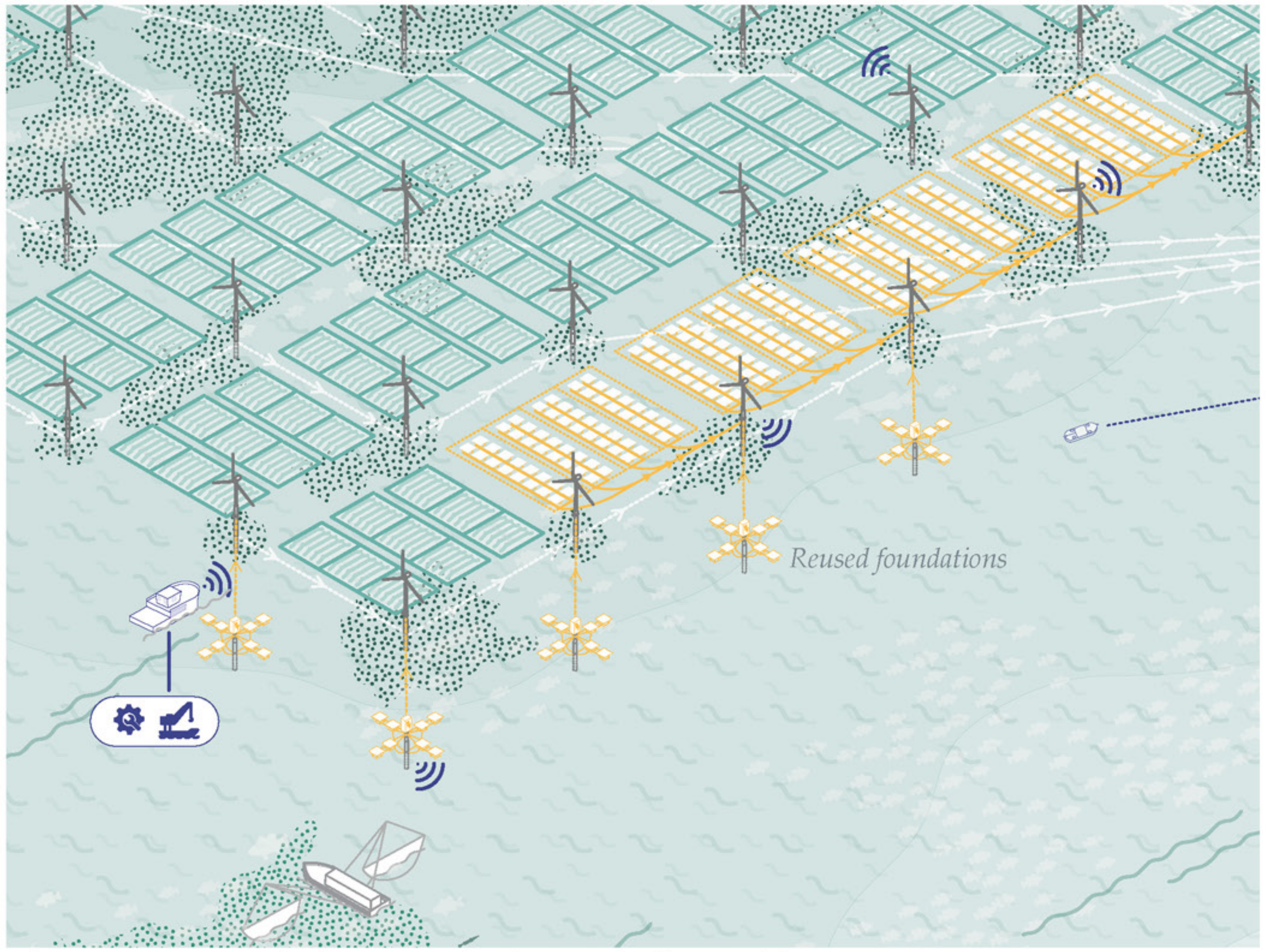
Schematic representation of an offshore wind farm and offshore aquaculture in phase 2 of a maripark

functionalities interacts differently depending on the site and context.

Nearshore: Aquaculture farms located close to shore will be removed at the end of their operational lifespan and replaced with offshore wind farms, optimizing the use of space. The nature created or restored at the former aquaculture sites will remain, strengthening the ecosystem.

Offshore:

- Within offshore wind farms, all rock revetments are designed to be nature inclusive and suitable for sea ranching.
- Military operations utilize existing sensors and drone platforms.
- Aquaculture is installed in offshore wind farms to meet market demand, either through collocation in existing farms or synergetic integration in new farms, with wind turbine foundations used for anchoring.
- Floating photovoltaics (FPV) are integrated into both existing and new offshore wind farms, leveraging the offshore wind farm substation and export cable, the turbine transformer, and potentially the turbine foundation for anchoring. These FPV farms cover 3–10% of the offshore wind farm area.
- Operation & Maintenance is handled by a multifunctional vessel equipped with sleeping facilities, aquaculture processing and storage, and drone launch capabilities.
- Drones (aerial or marine) can be launched from the substations or the hub vessel.
- Storage and flexibility solutions are fully integrated within the substation, which also incorporates vessel refueling or charging stations, an aerial drone port, and other multifunctional infrastructure.
- Inside the wind farm a dedicated area for nature development is allocated.



Schematic representation of a decommissioned and repowered offshore wind farm

Variant: Decommissioned and Repowered Offshore wind farm

- Approximately 10% of the existing foundations will be retained and used to support small-scale floating photovoltaics
- The remaining wind turbines and foundations will be removed to avoid conflicts with the new offshore wind farm layout.
- A new offshore wind farm will be established by shifting the layout by 100 meters (assumption).
- The jacket structure of the existing substation will be repurposed for the new substation.
- The export cable to shore will be reused until the end of its lifespan, and interarray cables from decommissioned turbines may be repurposed for FPV, provided their remaining lifespan is sufficient.

Variant: Existing Offshore wind farm

- Aquaculture and FPV are collocated within the offshore wind farm, leveraging the existing substation and export cable, and potentially using the turbine transformer and turbine foundations for anchoring, assuming the same developer manages both wind and solar assets.

Photo credit: www.orgpermod.com

V. Recommendations for advancing Multi-Use and realising systemic mariparks

The research findings outlined above formed the input for the fourth and final workbench: "What can we learn from the earlier pragmatic exploration? And what can we subsequently advise our policymakers?"

This fourth workbench confirms a clear conclusion: Multi-Use at sea should not stop at co-location of activities. Europe must raise the ambition.

Mariparks should become the framework through which Multi-Use contributes to systemic sustainability — delivering measurable ecological benefits, societal gains, and long-term resilient economic value.

Based on the development and testing of scenarios, we recommend the following priority actions:

1. Position Mariparks as a systemic sustainability tool

Multi-Use should be developed not as an end in itself, but as a mechanism to shift offshore development from single-use exploitation to regenerative system design.

Every Maripark must demonstrate potential for measurable net-positive impact: ecological, social, and economic.

2. Anchor economic drivers to a North Star: net-positive ecological goals

Mariparks should stimulate economic activity and long-term return on investment to emerge from synergies across uses, while the ultimate benchmark (the 'North Star') is ecological improvement ('net positive') aligned with the Biodiversity Strategy, MSP Directive, Ocean Pact, and broader (cf. recommendation 4).

3. Enable controlled experimentation through regulatory "sandboxing"

The EU should offer a structured framework for time-bound, monitored experimentation, reducing administrative barriers while safeguarding ecological integrity. This will accelerate innovation and evidence-based policymaking.

4. Develop EU-aligned metrics and frameworks for "Net-Positive"

Dedicated European frameworks and shared indicators are needed to define, quantify, and verify net-positive performance — including ecosystem restoration, climate resilience, and circular resource flows.

5. Maripark zones

National MSP processes can be designated as innovation zones as stepping stones toward integrated Maripark areas, where synergies, shared infrastructure, and ecological regeneration are enabled from the outset.

6. Move to basin-scale coordination of Mariparks

Establish EU-level guidance for sea-basin strategies (North Sea, Baltic, and others) to ensure connectivity, cross-border coherence, and ecosystem-scale impact. A shared EU planning template will support harmonised adoption.

7. Introduce minimum standards for Multi-Use zones

Create EU-level minimum requirements for permitting, monitoring, restoration obligations, environmental assessments, and operational compatibility—ensuring predictability for investors and administrations.

8. Promote flexible governance models

A Maripark should adopt the governance structure best suited to its context. Port-based or port-partnered entities may provide an effective operational backbone for logistics, monitoring, and long-term system maintenance.

9. Design for robustness and adaptive capacity

Mariparks should be built as dynamic platforms for interaction, not as fixed single-technology zones. Initial efficiency losses should be understood as strategic investments enabling scalable and resilient Multi-Use.

10. Design for systemic scale and interconnection

Pilot projects must be conceived with potential for scaling and interlinking. Only networked Mariparks operating at sea-basin level will generate meaningful ecological and socio-economic impact.

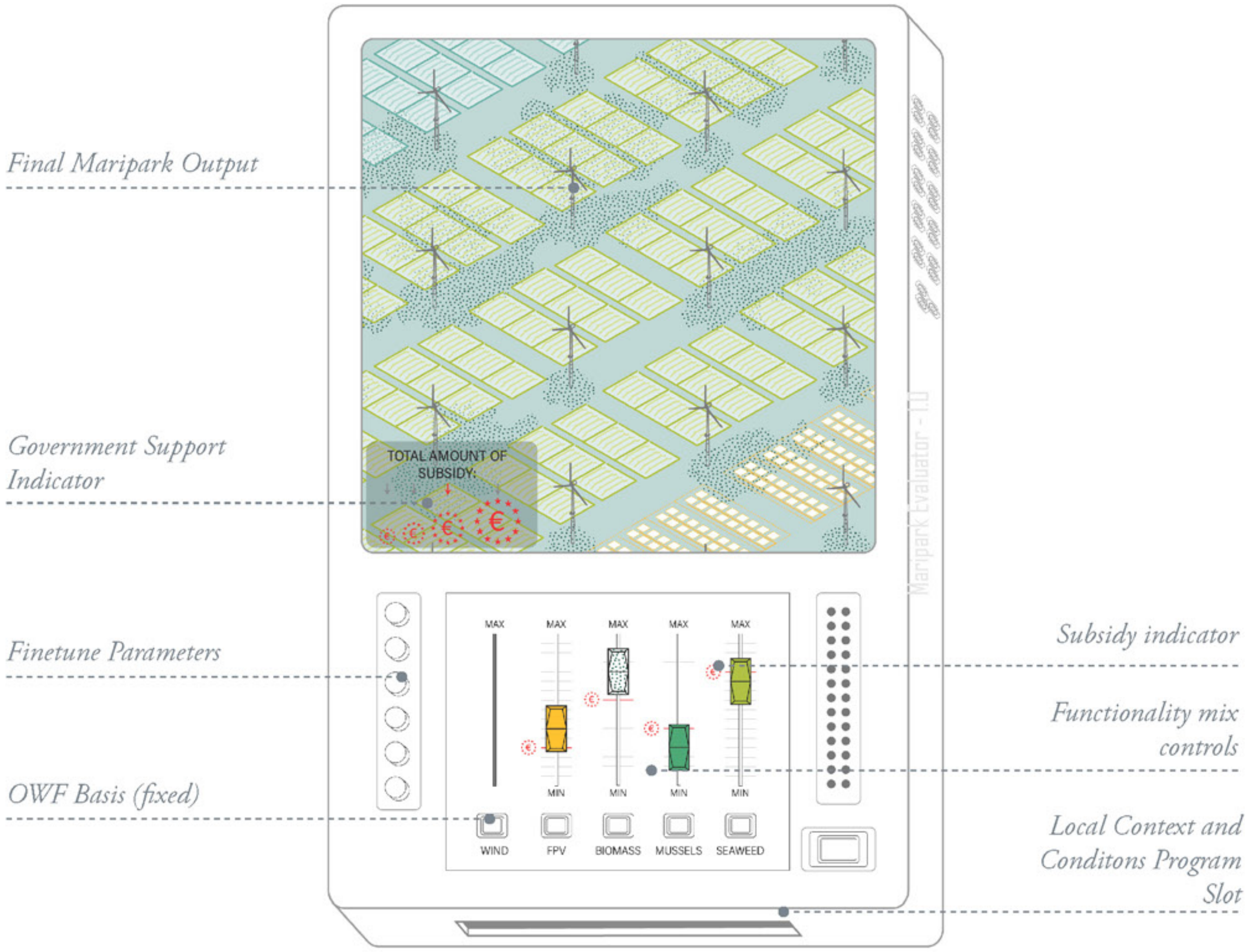
11. Require shared offshore infrastructure in new developments

Energy, logistics, monitoring, data, and communication systems should be interoperable and multi-use-ready. Access to EU funding and sea-basin plans should be conditional on this requirement.

In summary

Multi-Use is not optional — it is a necessary transition. But to deliver true value, Europe needs to pursue systemic Mariparks, not simply spatial co-location of activities. The next phase is not to ask whether Multi-Use is feasible, but to ensure it meaningfully contributes to Europe's ecological, societal, and economic future.

"Through North C Neutral, we have the tools to co-create a resilient master plan for our seas together with key stakeholders"



The Maripark Evaluator

Within the Mariparks concept, there are endless possibilities and combinations to explore. The final form and business case of each project will depend on the specific context and circumstances at the time of its development.

This study shows that not every combination of functions will result in a commercially viable business case, and may need government subsidies. Supporting certain activities or not is ultimately a social and political choice.

We symbolize this with the Maripark Evaluator: stakeholders can design a tailor-made scenario with a given mix of functions. The Evaluator will indicate what is economically viable and what would require public funding — and how much. This assessment is based on a set of assumptions and boundary conditions (political, economic, technical, etc.) that apply to the specific project in question.

Going offshore is always the more expensive and challenging option. Who ultimately pays for these additional costs — the public or the private sector — should be the subject of a public and political debate, in order to make balanced and well-founded choices for our future. Scaling up may help cover part of the additional costs. However, this too must be weighed carefully against the need for a sustainable and livable future for our seas.

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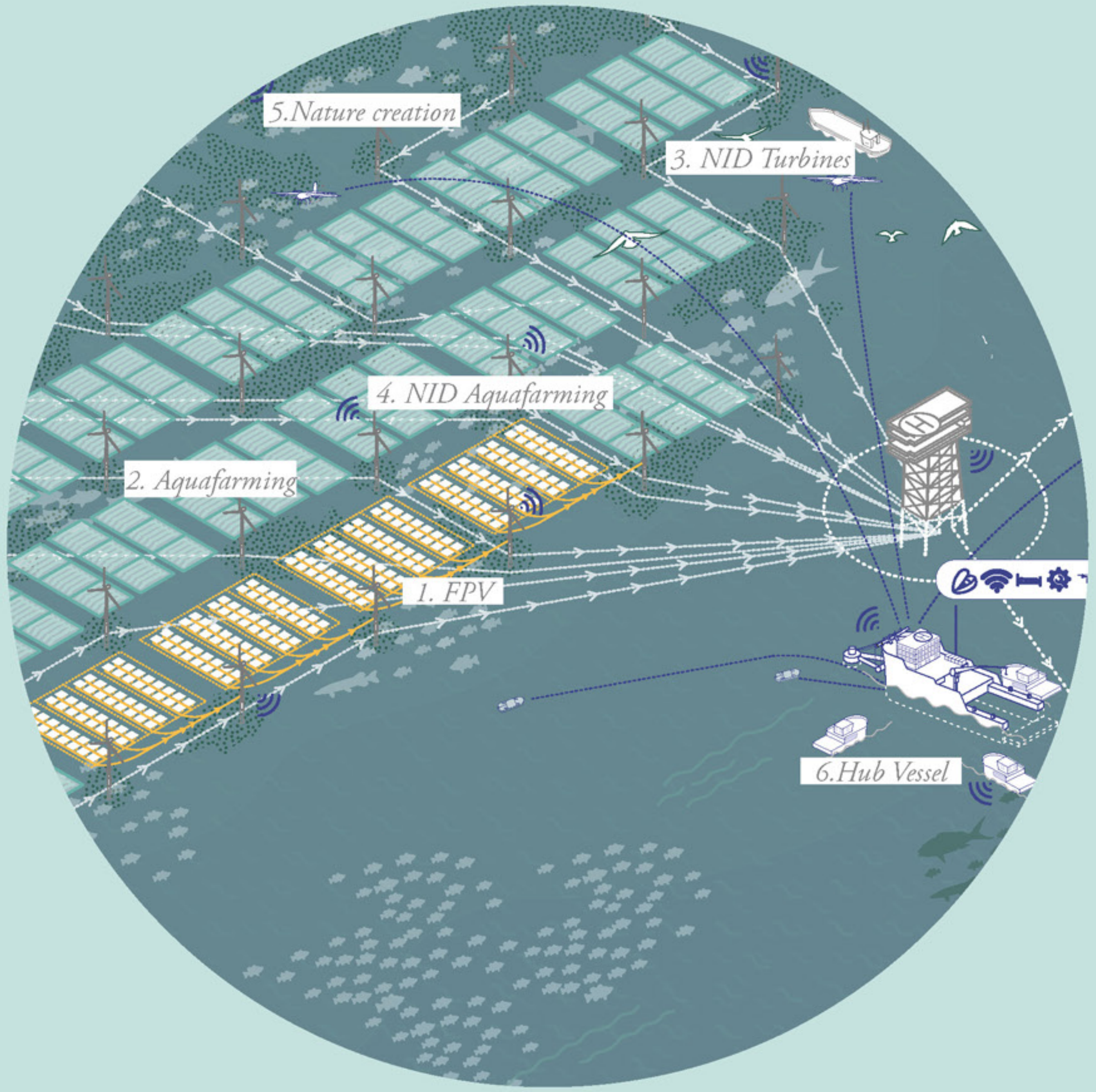
APPENDIX: Building blocks for Multi-use



To substantiate and enrich the different scenarios, we have examined the various constituent elements (described above) and the underlying spatial logic. And we briefly zoom in on nature creation (& sea ranching), decommissioning of wind turbines and multifunctional O&M vessels. Future research can add more functionalities to increase the overall performance of the multi-use concept.

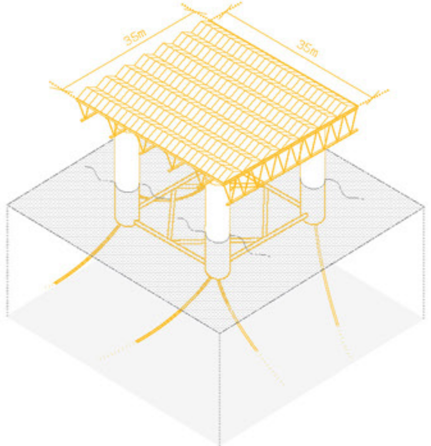
Floating Photovoltaics
Building Blocks

Design Assumptions

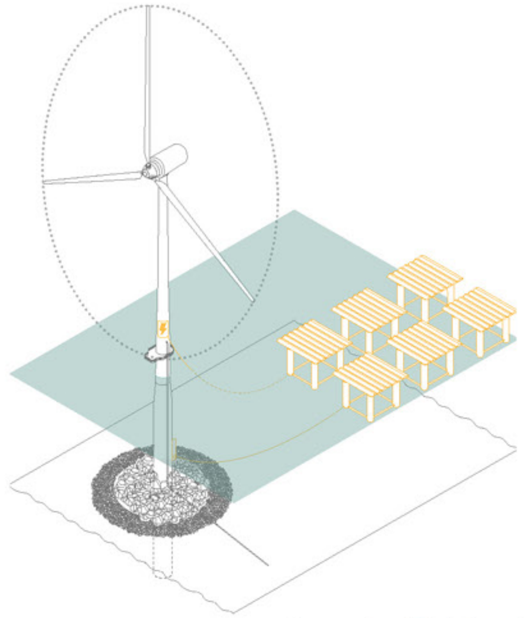
- Standard FPV module = ca 35 x 35 m

- Arrays of FPV keep ca 63 m of open space for service and maintenance

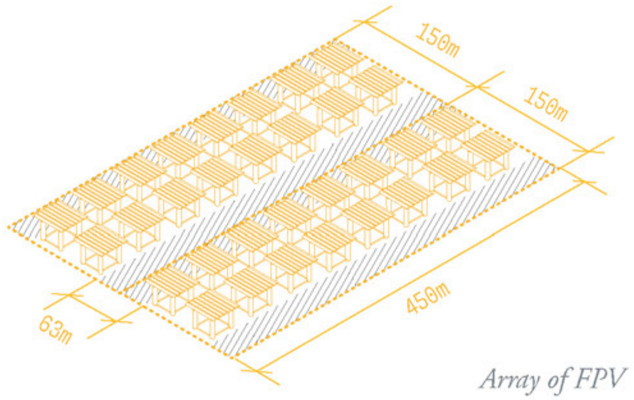
- FPV's in OWF's are placed outside the the shipping lanes for service and maintenance, and outside the safety perimeter around the turbine



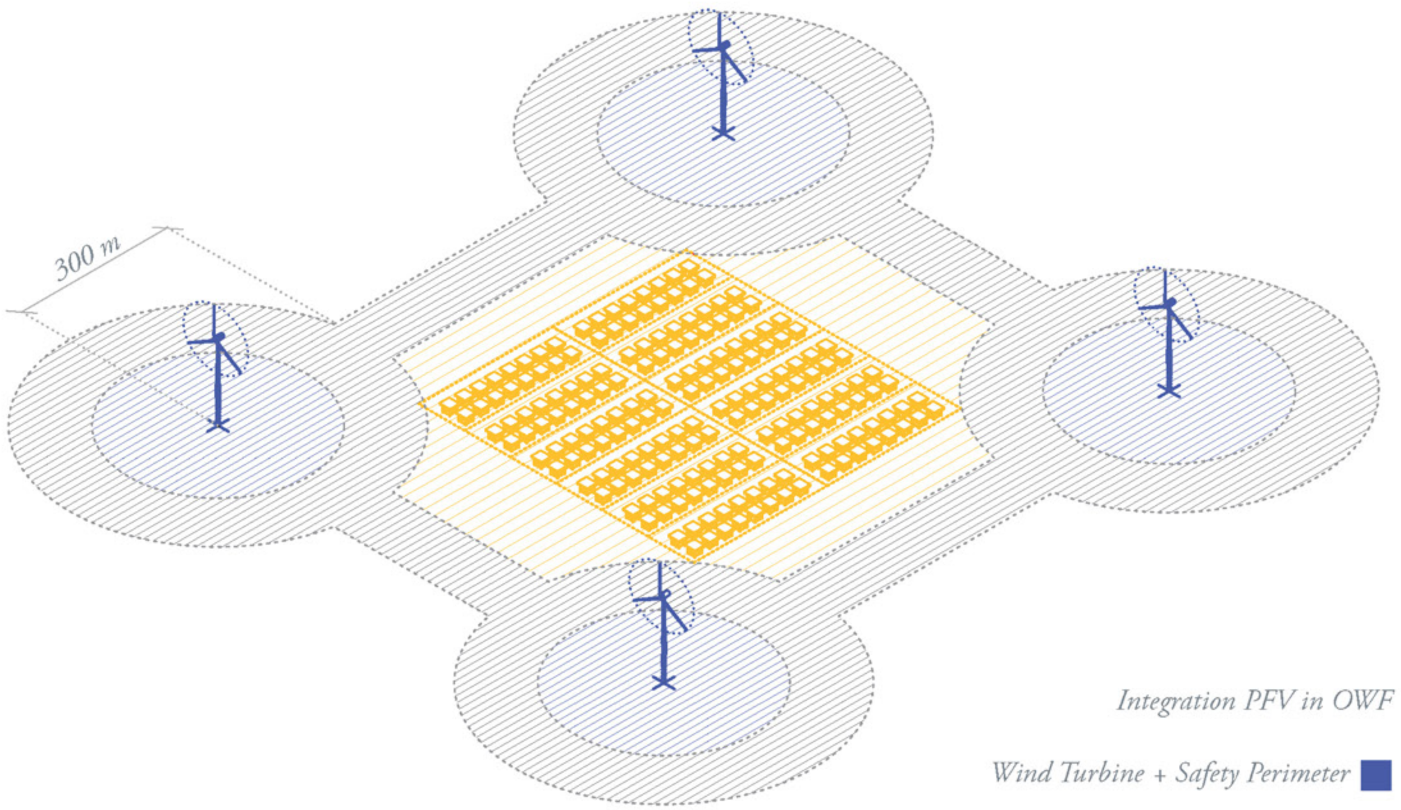
Standard Module



Connection Turbine - FPV



Array of FPV



Integration PFV in OWF

Wind Turbine + Safety Perimeter

Zone for FPV

Maintenance Lanes

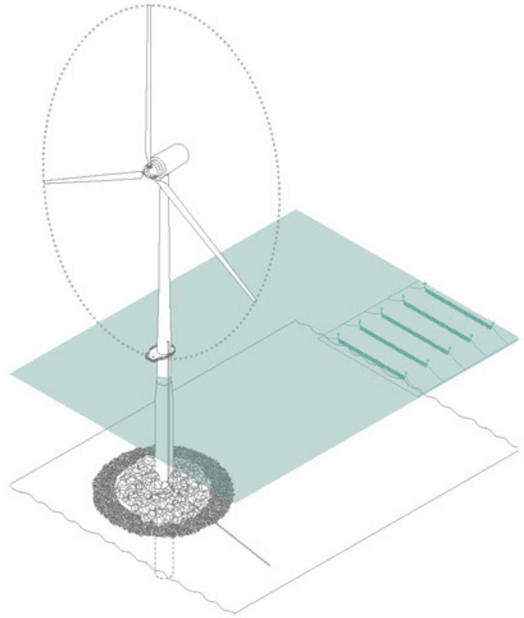
Aquaculture
Building Blocks

Design Assumptions

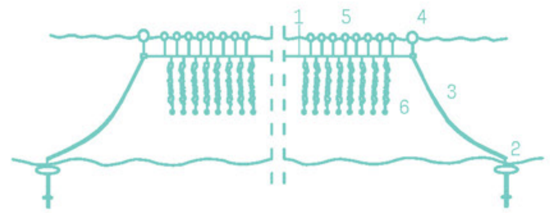
- Standard farming module = ca 200 x 250 m

- Backbone = 100-120 m long with Every 1.5 m a mussel line of each 6m (dropper lines) à 70 ropes per backbone

- Farms in OWF's are placed outside the the shipping lanes for service and maintenance, and outside the safety perimeter around the turbine

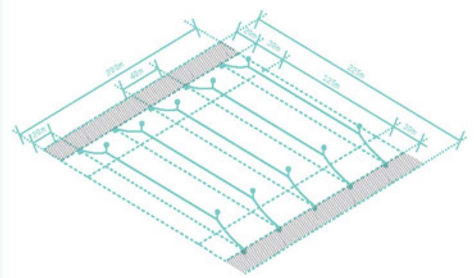


Connection Turbine - Aquafarm

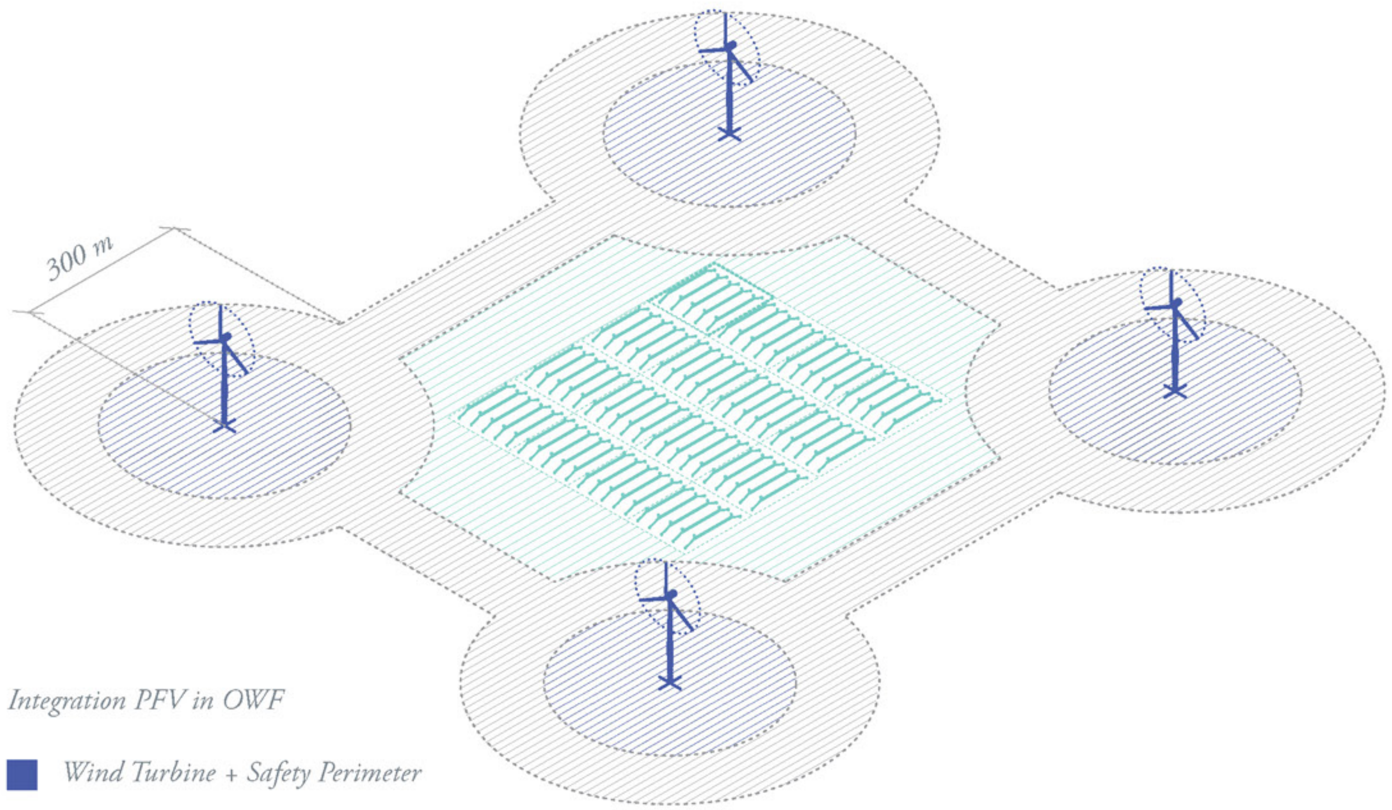


1. Backbone
2. Anchor
3. Mooring Line
4. Corner Buoy
5. Buoy
6. Dropper Lines

Typical section



Standard Module



Integration PFV in OWF

Wind Turbine + Safety Perimeter

Zone for aquafarming

Maintenance Lanes

Nature Inclusive Design (NID)
Building Blocks

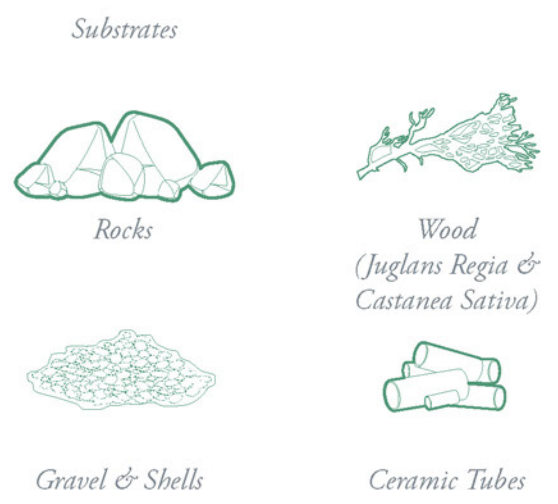
NID Strategies and Elements

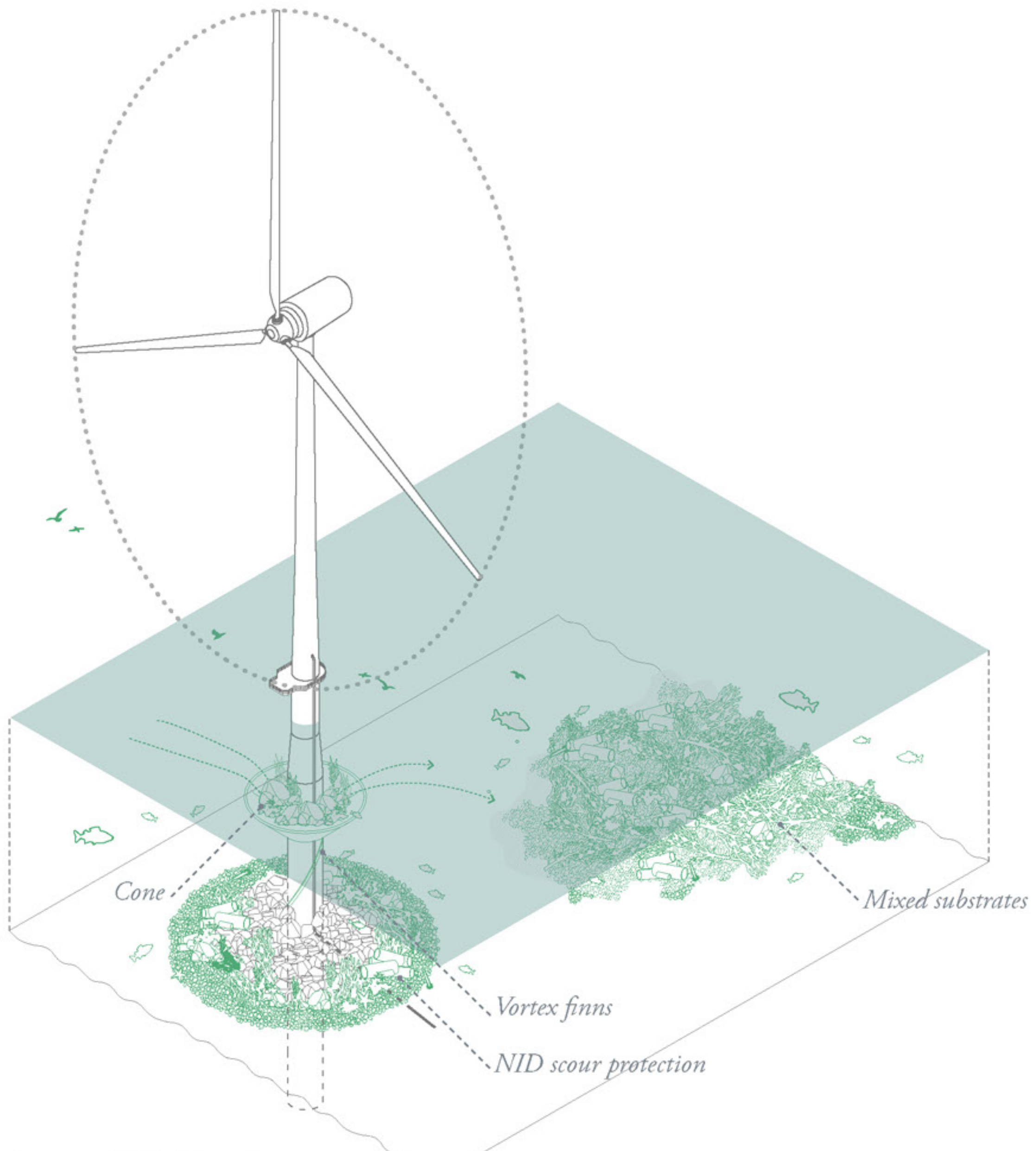
- Nature inclusive scour protection

-Apply a mix of hard substrates such as gravel, rocks, ceramic tubes and shells around and in between all infrastructure

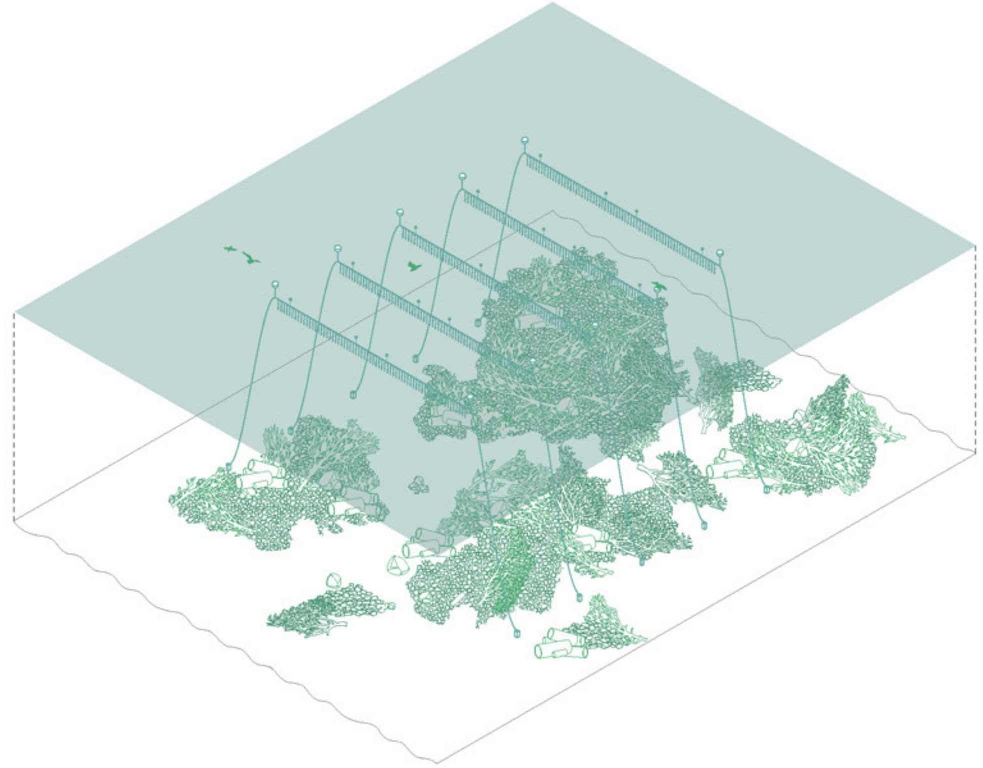
- Organic substrates (wood)

- NID subtidal cone and vortex fins on the foundation (Turbines only)

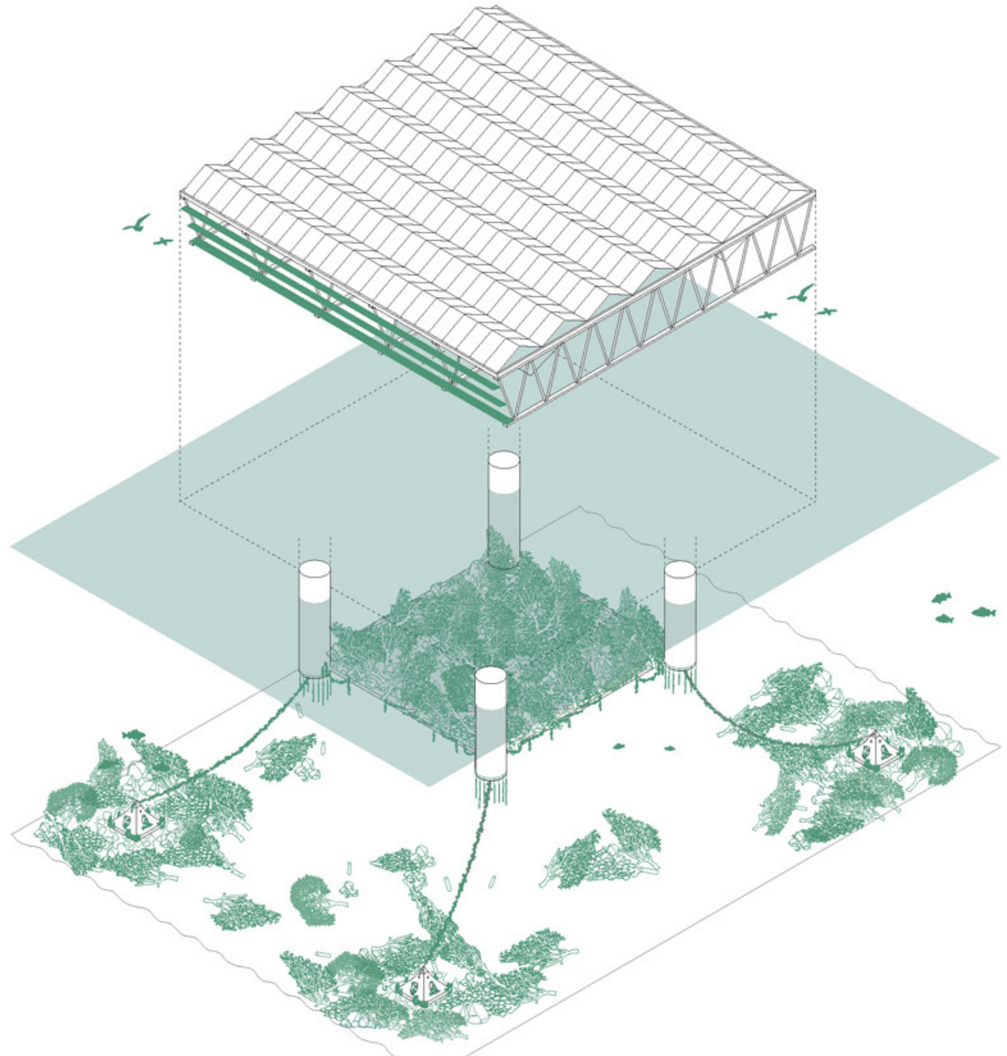




Integrated NID Monopile



NID aquafarming



NID Floating PV

Aquafarming and Nature Restoration
Building Blocks

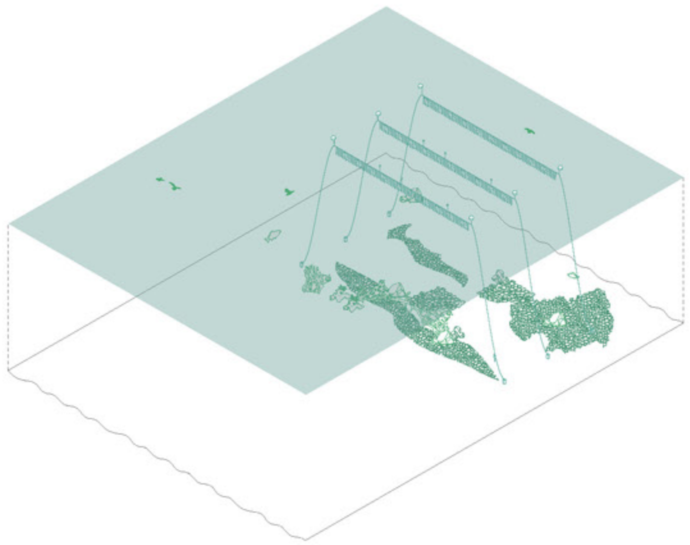
Design Strategy - Building with Nature

Aquafarming can be used to restore natural reefs in degraded areas and enhance biodiversity.

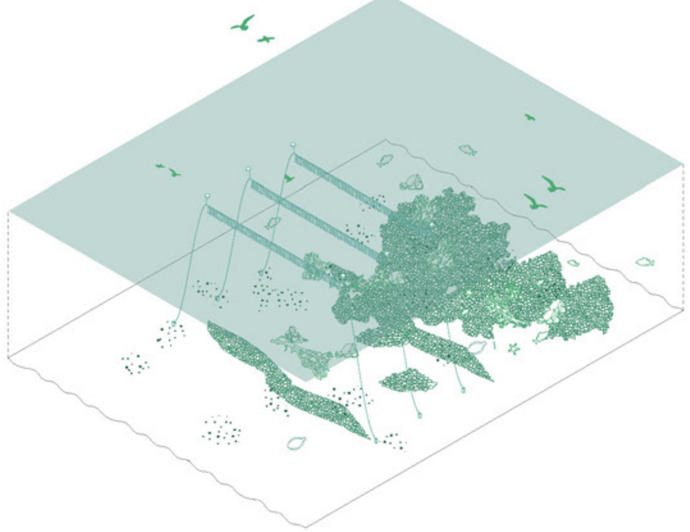
Step 1: Biodeposits from the dropper lines fall onto the seabed. Over time, these biodeposits — a mix of faeces, pseudofaeces, and shell material — can accumulate and form a hard substrate that mimics the natural reef-like structures mussels or oysters create in the wild.

Step 2: Move the farm to a location nearby to repeat the process. Nature in the 1st area will continue to develop naturally.

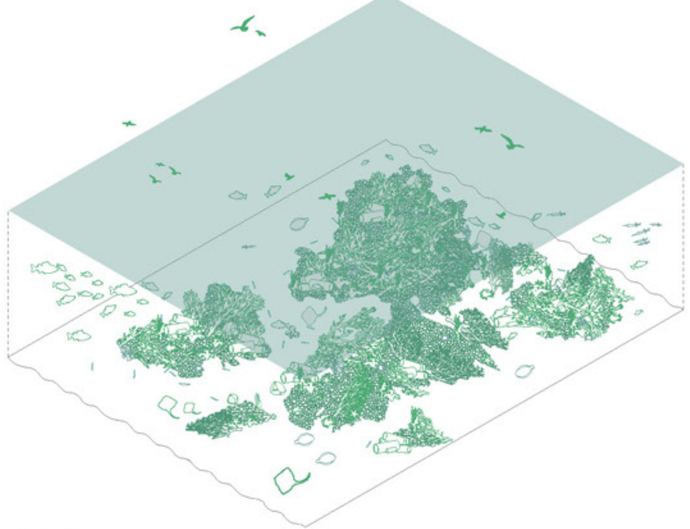
Step 3: Remove all aquafarming from the area and protect the newly created nature area from any harmful activities.



Step 1



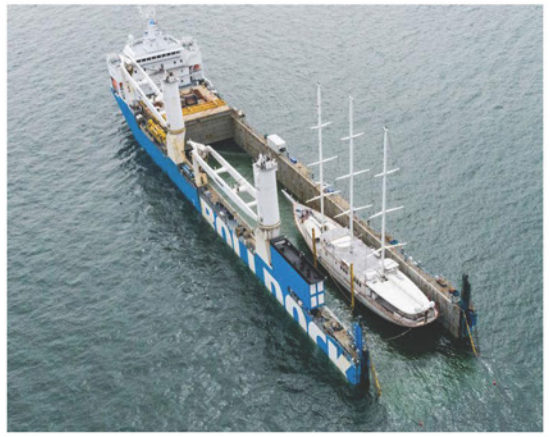
Step 2



Step 3

Multifunctional Operation & Maintenance Vessels & Floating Hubs
Building Blocks

Example of a multifunctional vessel developed by Zeevisserijbedrijf Brands (source: https://projectoctopus.nl/)



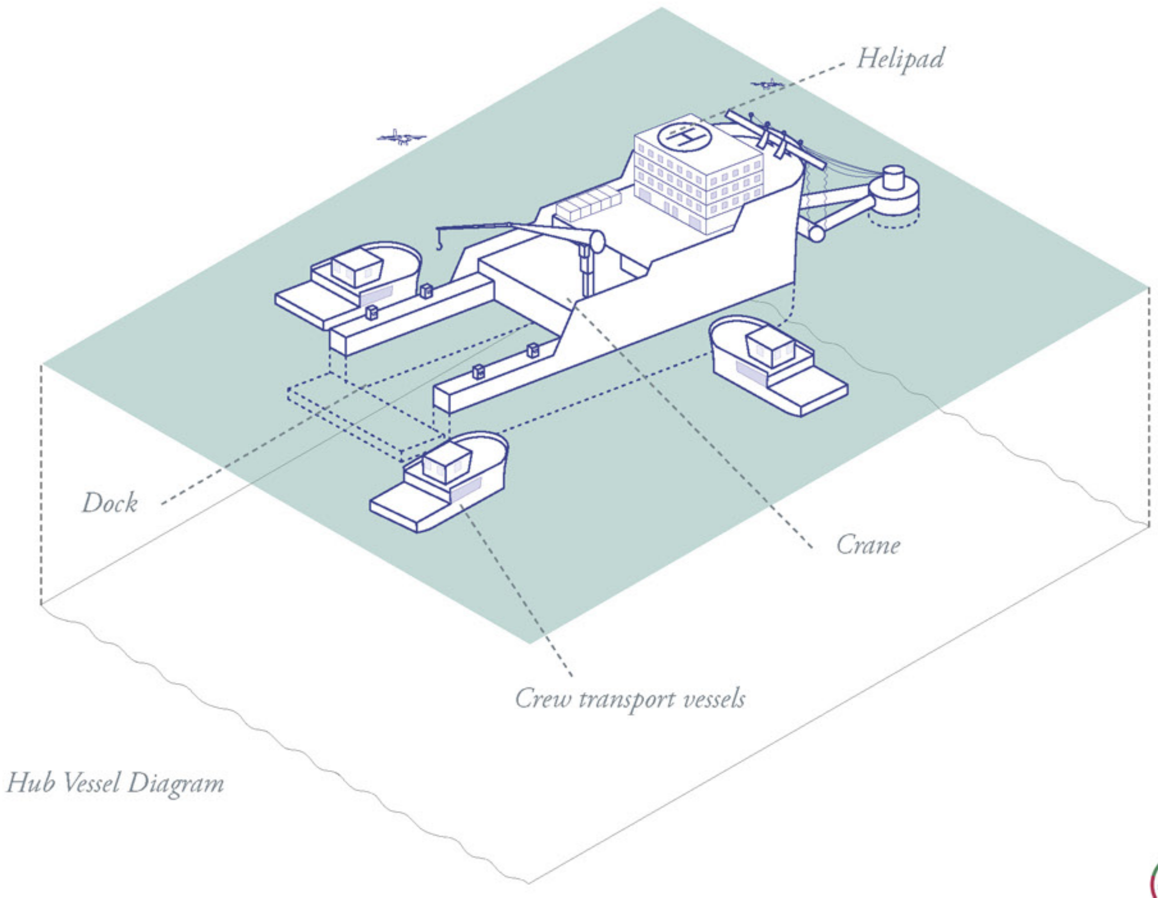
Example of an open dock vessel (source: CONCEPTONTWERP HUB IN HET MARIPARK, Marin)

Description

-Multipurpose hub vessel for offshore operations, maintenance and processing

-Functions:

- staff accomodation
- hospital
- generators
- container decks
- workshops and storage
- dock
- CTV, shuttles
- Crane



Hub Vessel Diagram

This report is the account of a search for feasible mariparks, based on potential business cases and master planning. The report concludes with policy advice and positions mariparks as a lever in the greening of the blue economy towards a systemic approach.

Co-funded by the European Union

https://vasab.org/project/nesbp/

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