Road 2 SID

Full report

Advancing multi-use in offshore wind farms

Roadmap for the Dutch North Sea

a grow initiative

Advancing multi-use in offshore wind farms

a Roadmap for the Dutch North Sea

Prepared by:

Stichting Deltares
Natalia Aleksandrova; Luca van Duren; Antonios Emmanouil

Stichting Maritime Research Institute Netherlands (MARIN)
Jorrit-Jan Serraris; Floor Spaargaren

TNO
Joep Breuer; Anthony Vitulli; Jan-Willem Wagenaar

Checked by:

Boskalis Offshore Contracting B.V.
Paul Peters; Sander Steenbrink

Stichting Deltares
Sharon Tatman

RWE Renewables GmbH
Arjen Schultinga

Seaway 7 Offshore Contractors B.V.
Mark Bloemsma

Shell Global Solutions International B.V
Eldina Salkanovic

TenneT B.V.
Annemiek Hermans; Erik-Jan Kok; Garnt Swinkels

Approved by:

Stichting Deltares
Jan-Joost Schouten

Stichting GROW
David de Jager

The project has been carried out with a subsidy from the Dutch Ministry of Economic Affairs and Climate, National Schemes EZK-subsidies, TKI Offshore Energy - part of energy innovationNL, as taken care of by RVO (Netherlands Enterprise Agency).

Please cite this document as:
GROW (2023) Advancing multi-use in offshore wind farms
Roadmap for the Dutch North Sea (Road2SID report)

Stichting GROW, November 2023

Foreword from GROW

The offshore wind sector, as represented in the GROW consortium, recognises the importance of making multi-use in future offshore wind farms a reality. Still, neither the direction nor the end goals that governments may require in future tendering procedures are clear. The sector needs a roadmap for multi-use, or better formulated, towards a true symbiosis of wind energy and other activities at sea. As both technical and institutional innovations will be required to make such a symbiosis a success, and as both types of innovations take time, it is important to start working on this roadmap with relevant actors in the offshore domain as soon as possible. The GROW consortium hence initiated the preparation of this *Roadmap for technological advancements needed for Symbiosis Inclusive Design in offshore wind (Road2SID)*. The roadmap has been prepared by several GROW consortium partners in close collaboration with various stakeholders.

It is noted to the reader that the project's original ambition was to get directions for technological innovations that the industry partners in GROW partners could embrace and support. How could technical innovations in the design of offshore wind energy systems facilitate the mutually beneficial development and deployment of other technologies and/or offshore activities? How could this symbiosis be realised? The conclusion from the Road2SID process is that it is too early to formulate such directions, as the boundary conditions for Symbiosis Inclusive Design (SID) are not agreed upon yet. It was hence decided to make a start with the process of establishing these boundary conditions. As will be seen when reading this document, these boundary conditions concern predominantly regulatory, business case and governance aspects. Technology and innovation are then expected to be tailored to these preconditions. The GROW partners are eager to contribute to the further design and implementation of this roadmap that hopes to contribute to a truly sustainable use of – and partnership with – the seas.

Utrecht, November 2023

David de Jager
Director of GROW
www.grow-offshorewind.nl

Executive Summary

Background on multi-use in wind farms

The Netherlands has made its ambitions clear to position itself as a leader in Europe for renewable energy generation, green production of sustainable fuels, and further electrification of industry to meet the corresponding European targets. The government has established a roadmap to increase the total installed capacity of offshore wind to 22 GW by 2030 as part of the North Sea Programme 2022-2027, surpassing the current national energy and climate plans. It is foreseen that up to 70 GW of offshore wind will be installed in the Dutch North Sea by 2050. The area required for this development is vast and competing for space with traditional fisheries, nature protection areas, shipping and other activities (see Figure 0.1).

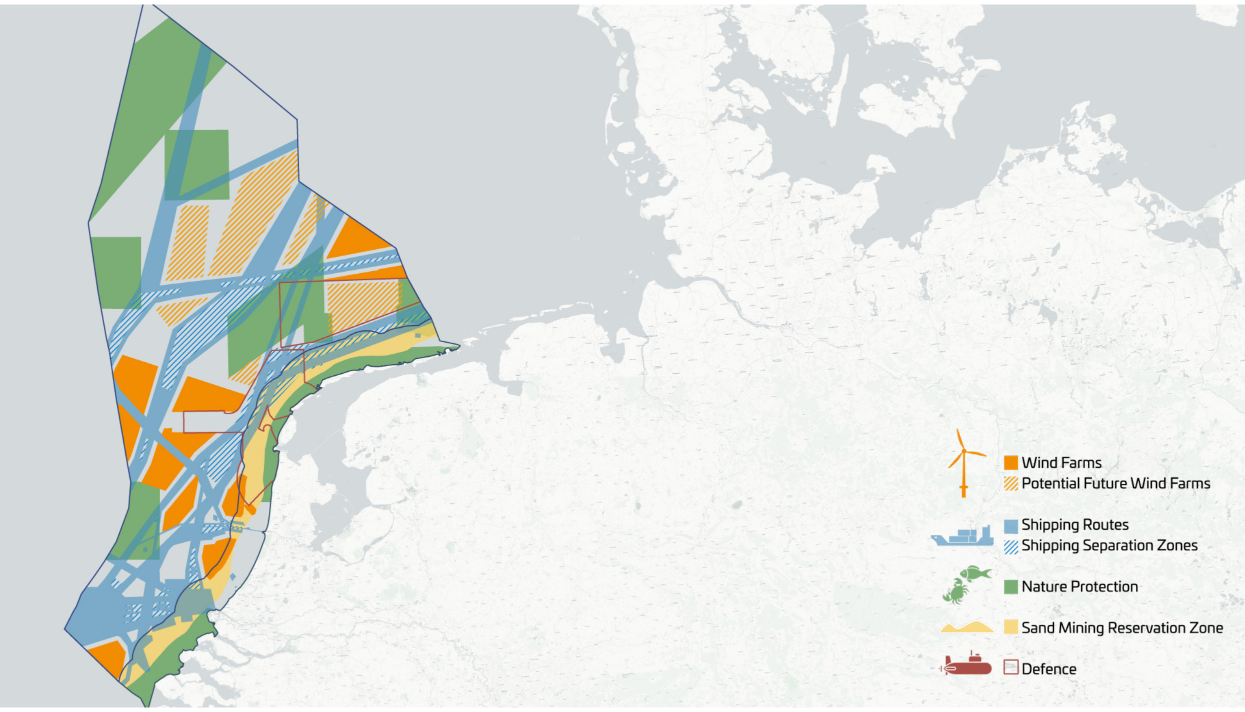

Figure 0.1 Use of space in the Dutch North Sea. This map represents the estimated future spatial use based on 'Programma Noordzee 2022-2027'. Please note that the space used by Oil & Gas infrastructure and cable routes is not shown. The map also does not include future uses that are still uncertain in their location, e.g., hydrogen infrastructure and aquaculture.

The Netherlands is one of the leading countries on the topic of shared use of marine space (later also referred to as *multi-use* or *symbiosis* in this document), primarily driven by the scarcity of space and long-term experience with the marine economy. However, the field of symbiosis between functions inside wind farms is relatively young, with many unknowns. The knowledge and practical experience are still lacking on many fronts. Fortunately, some developments are underway in all three types of multi-use. Therefore, this Roadmap defines the key challenges and proposes actions for advancing the multi-use of space in offshore wind farms in the Dutch North Sea.

Shared use in offshore wind farm zones can be facilitated through appropriate choices in the planning and design. A non-exhaustive overview of current practices and focus areas in the Dutch North Sea is presented in Figure 0.2.

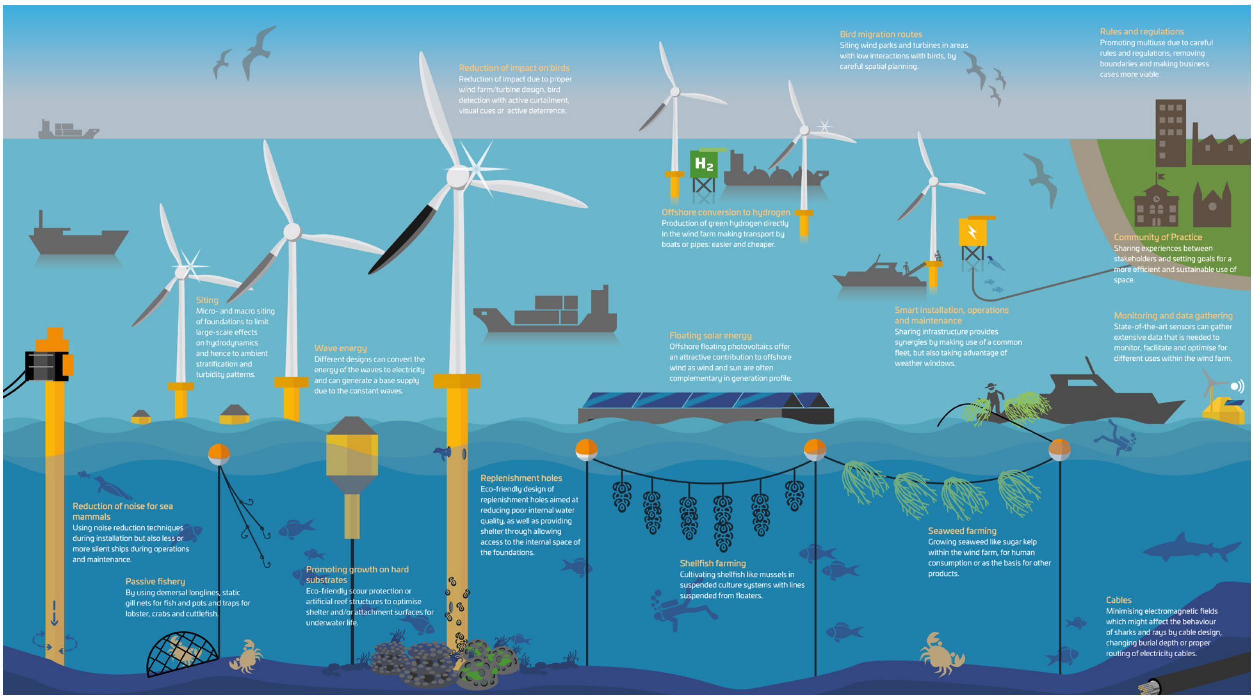

Figure 0.2 Available practices for the symbiosis of nature, energy and food production at sea

Shared use in offshore wind farm zones can be facilitated through appropriate choices in the planning and design. In this study, multi-use approaches are discussed along three types of multi-use within offshore wind farms, which correspond to major transitions taking place in the North Sea:

- nature transition – nature protection and ecosystem strengthening
    - with activities related to nature-inclusive design of offshore wind farms
- food transition – sustainable production of food in the marine environment
    - with activities related to passive fishing, shellfish and seaweed farming
- energy transition – generation, conversion and storage of sustainable energy
    - with activities related to solar, wave, tidal energy and hydrogen production

Stakeholder perspectives

The symbiotic design of offshore wind farms involves a large number of stakeholders whose interests need alignment. Therefore, we have asked various stakeholders about their perspectives on the individual themes of Nature, Food and Energy and their feedback on the opportunities they see, the challenges they face and the responsibilities they feel.

There are ongoing developments underway on multi-use: both policy and technology are developing at a fast pace, especially in the case of energy generation (technology) and nature & ecosystem strengthening (policy). In the framework of this study, a wide group of stakeholders was interviewed to understand the range of perspectives for all three types of multi-use (Figure 0.3). Stakeholder groups were the following: offshore wind farm developers, Offshore installation contractors, NGOs, regulating bodies, multi-use innovator companies, and research organisations. It is noted that certain stakeholders, like bottom trawling fisheries, were not involved in this research, given that offshore wind farms form a priori exclusion areas for such activities in the Netherlands.

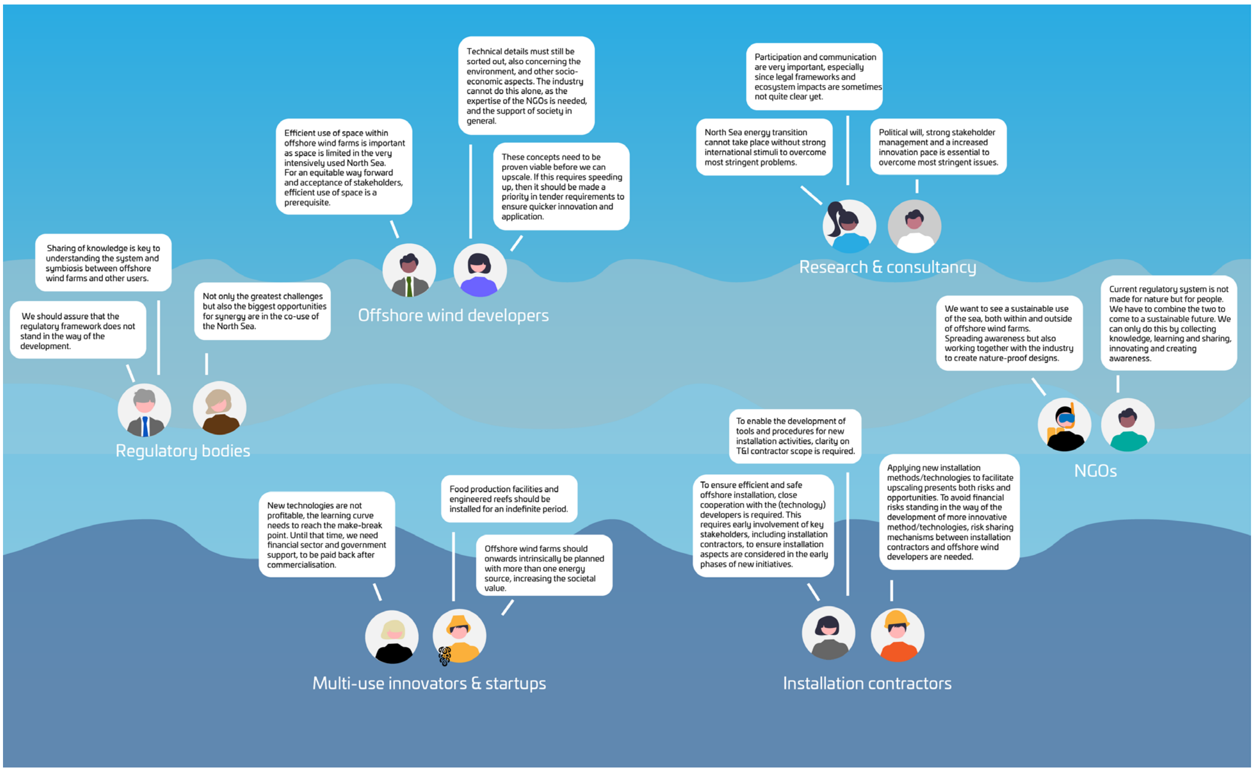

Figure 0.3 Exploring stakeholder perspectives on symbiosis: challenges and opportunities

The key conclusions from the stakeholder consultation are summarised below:

Opportunities

Most stakeholders believe that combining offshore wind with other activities creates opportunities for utilising marine space more efficiently. On a technology level, the stakeholders see opportunities in relation to sharing infrastructure and mooring systems, as well as for optimisation of offshore operations. For example, equipment for ecological monitoring can be integrated with offshore wind infrastructure.

Challenges

In terms of challenges, many stakeholders pointed out that legislation concerning permitting and decommissioning is currently either unclear or underdeveloped. In terms of financing, they indicated that the costs of realising multi-use projects are very high due to high insurance costs, offshore operations costs and lack of business case and track record for new technologies. A complex stakeholder field adds to the challenges. Lastly, the stakeholders identify the additional safety risks as an additional challenge.

Responsibilities

Most stakeholders see it as their own responsibility to advance innovation in the field of multi-use for the benefit of natural ecosystems and future energy systems. They are also open to collaboration with other parties and to raising awareness concerning the need for symbiosis. Most stakeholders identify offshore wind farm developers as key stakeholders and action owners for advancing symbiosis, but all stakeholders acknowledge the need for a proper regulatory framework to be provided by the government. Exploring and facilitating the business case of various multi-use activities is a prerequisite for advancing symbiosis in offshore wind farms. Finally, across all themes, a long-term vision of multi-use offshore wind farms is deemed necessary to be developed primarily by the government in collaboration with the industry.

Action driven roadmap

Based on the state of the art and the stakeholder feedback, we have formulated specific actions that have the potential to accelerate the development of multi-use offshore wind farms (Figure 0.4). These actions are proposed by the Road2SID consortium to be undertaken by 2030. The proposed timeline reflects a compromise between ambition and realism, while the exact order of actions and main action owners are indicative and based on common sense.

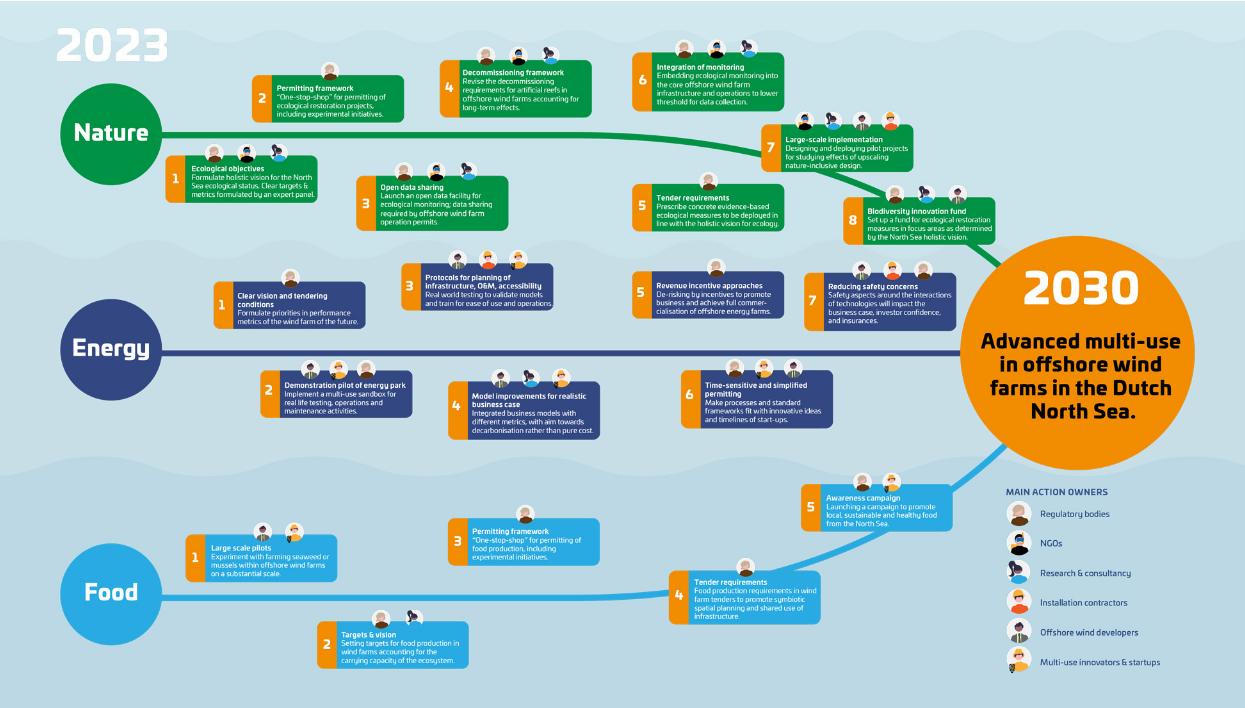

Figure 0.4 Key actions to advance symbiosis towards 2030. Assigned priority, timeline and main action owners are indicative.

Comparing the different themes, we see that there are overlapping actions. The most common action in all three themes is performing pilots. Besides this, most actions are defined in the governmental areas and specifically on an integrated vision, resulting in tender requirements for multi-use. In this respect, improvements in permitting procedures are seen as an important action in the near future. Lastly, increasing business cases through technological advancement and sharing capacity with offshore wind farm infrastructure is a common action across all themes. To explore how some of these actions were or can be undertaken in practice, three case studies have been executed addressing the past, present and future of symbiotic offshore wind farms.

Case study 1 – Experiences from symbiosis in Borssele

The aim of this case study was to investigate how the organisations involved in multi-use are looking at the Borssele wind farm site in setting up a multi-use business case for sustainable energy (wave, solar), aquaculture and nature restoration and strengthening. To that end, Road2SID reached out and held interviews with various multi-use innovators.

Since 2020, an area passport has been in place, assigning a preferred multi-use option to the various plots of the Borssele offshore wind farm and a legal framework in which multi-use developers can submit a permit application. Three years later, the status of multi-use activities in wind farms is that there is one initiative in place related to mussel farming from OOS[1]. A summary of the interviews is presented in Figure 0.5.

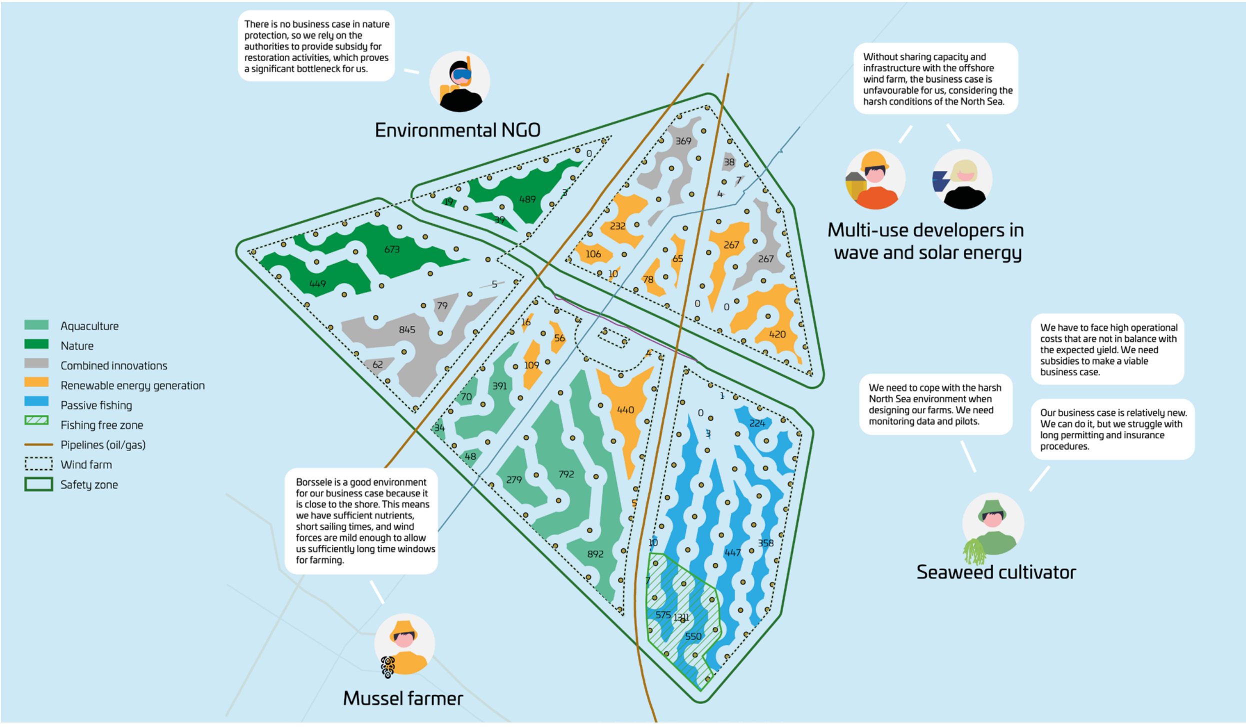

Figure 0.5 Experiences from symbiosis in Borssele

In general, it is mentioned by all parties that developing a business case is challenging. The main reason behind this is the North Sea's physical conditions (strong currents, waves and wind), which leads to the need for a technically robust design and suitable vessels. It is mentioned that since some of the multi-use initiatives are fairly new, this leads to a longer permitting process, getting towards a complete admissible permit application.

Case study 2 - Making information systems symbiotic at present

One contribution to stimulate and optimise multi-use activities at present is to develop an Operational Information System (OIS). The goal would be to make present and upcoming multi-use operations more efficient and safer by sharing information and thereby increasing multi-use business case potential. This case study gives a blueprint for such an OIS that details and provides metrics for multi-use activities within the wind farms (Figure 0.6).

[1] Permission to install the OOS Cees Leenaars mussel farm in the North Sea - OOS International

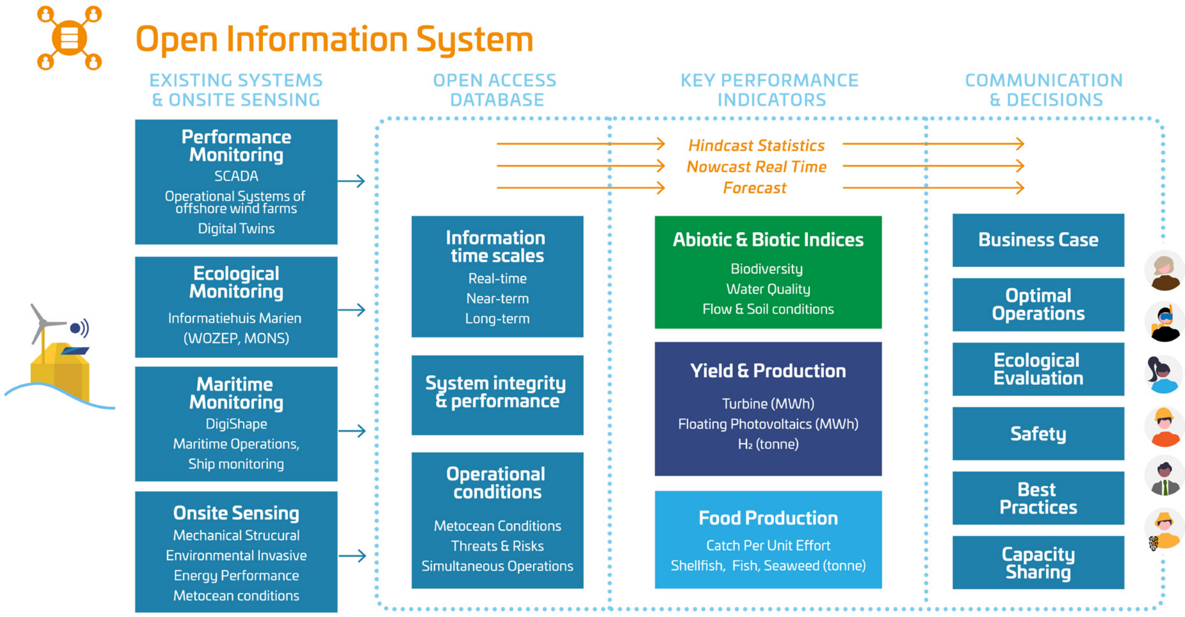

Figure 0.6 A blueprint for an Open Information System to be used in symbiotic offshore wind farms

The basic questions the OIS needs to address directly relate to the required operations and assets in a symbiotic offshore wind farm. For example, these include inspections and maintenance of the infrastructure, harvesting periods, wave and wind restrictions for food and energy assets, as well as for vessels that will tend to them. The OIS needs to ensure that multi-use operators can base their activities and actions on a reliable time-based operations and monitoring system. The system allows retrieval of various depths of information depending on the interest of the various users. The OIS will be used by:

- contractors for real-time weather data and forecasts during installation
- wind farm operators to store and retrieve SCADA[2] data as an O&M planning tool.
- multi-use operators for monitoring of harvest (food) and system status (energy); operational planning and risk warnings
- research institutes for advising and authorities for monitoring the ecosystem's biotic status and maritime operations' safety towards and inside the wind farm

Case study 3 – Integrated vision for symbiosis in 2050

In this case study, we attempt to describe our vision for symbiotic offshore wind farms by 2050 in the following quote:

"By 2050, a revolutionary era of Dutch Offshore Wind Farms has emerged. Through harmonious integration, ecological measures, alternative forms of renewable energy generation, conversion and storage, as well as food production within offshore wind farms have fully matured to the maximum of their potential and are the standard, ushering in a new era of holistic, inclusive, and transboundary spatial planning that respects the carrying capacity of the North Sea. In this new era, symbiotic Offshore wind farms act as the catalyst to achieve the climate and biodiversity targets set by the Dutch and European policymakers."

[2] Supervisory Control And Data Acquisition

In the pursuit of a sustainable future, the adoption of Symbiosis Inclusive Design (SID) as the standard for developing offshore wind farms has become imperative. This visionary approach focuses on three essential pillars, which collectively ensure the successful implementation of SID in offshore wind farms:

(1) Holistic international integration

It is essential to establish an interconnected network of wind farms, a joint European area dedicated to SID for offshore wind with a comprehensive governance structure that oversees the equitable distribution of responsibilities.

(2) Data

Data will play a central role in the offshore wind industry, particularly in the context of SID initiatives, where extensive data gathering will be necessary to learn, monitor, facilitate and optimise. The implementation of efficient communication systems between different users will ensure seamless data integration throughout the entire wind farm, which is especially important for the state-of-the-art sensors and monitoring systems that will be operating across the entire wind farm.

(3) Innovation

All wind farm infrastructure and planning and operation will be designed with symbiosis in mind. In this way, offshore wind farms will facilitate shared use of space by fully integrated design and capacity sharing. In addition, in this vision of the future, all components of wind farms, from foundations to turbine blades, will be constructed using fully re-useable or recyclable materials, promoting circularity and minimising waste. Furthermore, wind farms will operate with zero emissions throughout their entire lifespan.

This visionary scenario for the implementation of SID in offshore wind farms by 2050 highlights the importance of holistic international integration, data-driven decision-making, and innovation. By adopting a unified approach, harnessing the power of data, and embracing innovative solutions, offshore wind farms of the future will not only contribute to global sustainability but also serve as harmonious (artificial) infrastructure ecosystems that thrive in symbiotic coexistence with nature and facilitate food production. To that end, an integrated toolbox is developed that aims at fully symbiotic offshore wind farms and is relevant across all three main transitions of the North Sea, i.e., nature, energy and food.

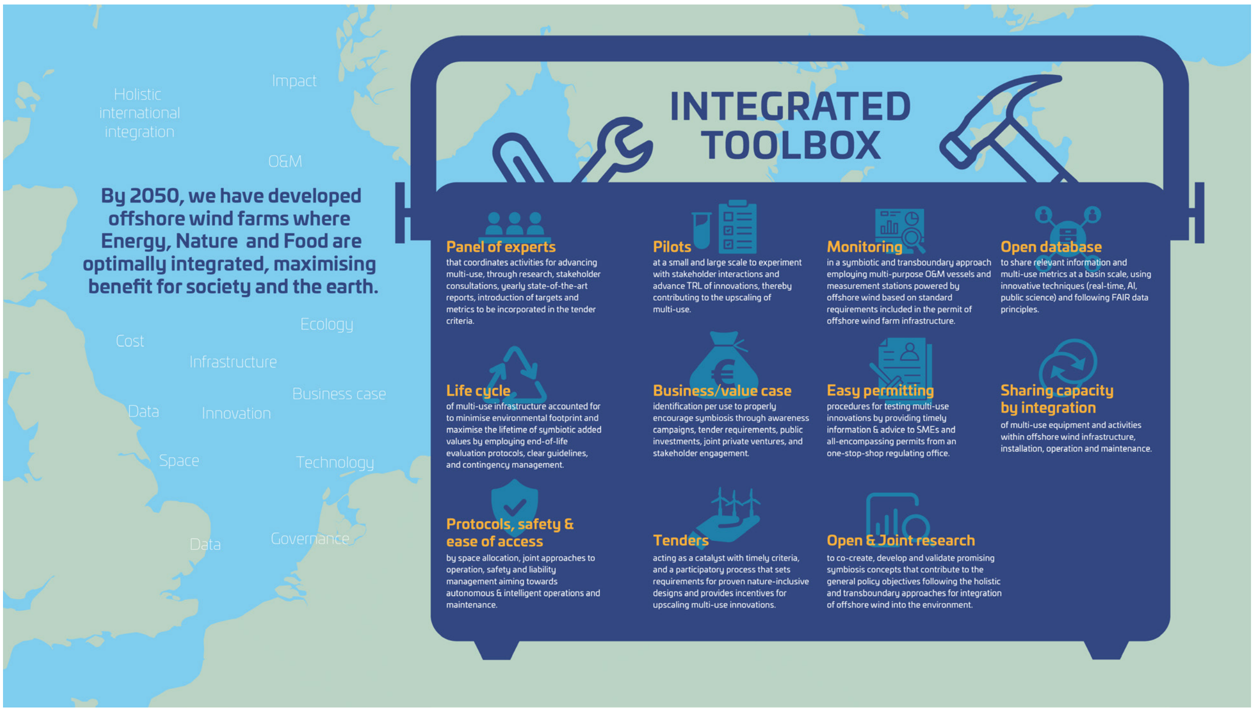

Figure 0.7 Integrated toolbox for achieving symbiotic offshore wind by 2050

Table of Contents

List of abbreviations

A

AWE	Airborne wind energy

B

BRUV	Baited remote underwater video

C

CAPEX	Capital expenditure
CTV	Crew transfer vessel

D

E

EEZ	Exclusive economic zone
EZK	Dutch Ministry of Economic Affairs and Climate (Economische Zaken en Klimaat)

F

G

H

I

I&W	Dutch Ministry for Infrastructure and Water (Infrastructuur en Waterstaat)

J

K

KEC	Framework for Assessing Ecological and Cumulative Effects

L

LCOE	Levelised cost of energy
LNV	Dutch Ministry for Agriculture and Food (Landbouw, Natuur en Voedselkwaliteit)

M

MONS	Dutch governmental North Sea monitoring programme
MU	Multi-use

N

NGO	Non-governmental organisation
NID	Nature-inclusive design

O

O&M	Operation and maintenance
OTEC	ocean thermal energy conversion
OWF	Offshore wind farm

P

PEM	Proton exchange membrane electrolysis
PV	Photo Voltaic

Q

R

ROV	Remotely operated vehicle
RVO	Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland)
RWS	Executive agency of the Dutch Ministry of Infrastructure and Water Management (Rijkswaterstaat)

S

SID	Symbiosis Inclusive Design

T

TRL	Technology readiness level
TSO	Transmission System Operator

U

V

W

WEC	Wave energy converters
WOZEP	Dutch governmental offshore wind ecological programme (Wind Op Zee Ecologisch Programma)
WT	Wind turbine

X

Y

Z

1. Introduction

1.1. Motivation

The North Sea is one of the most used seas worldwide and is home to various functions such as nature, energy, shipping, recreation, and fishing (see figure 1.1). Due to the expected enormous expansion of offshore wind farms in the coming decades, we will be facing major challenges to achieve an efficient use of space in the North Sea. To ensure the optimum use of the North Sea, recently regulations and frameworks for agreements have been drawn up recently between governments and stakeholders, like the North Sea Agreement[3] and the National Environmental Vision (NOVI)[4]. These schemes aim to promote wind energy generation in combination with other functions that do not compromise the reliability and safety of renewable energy production at sea. In practice, developers of wind farms will then have to meet additional requirements.

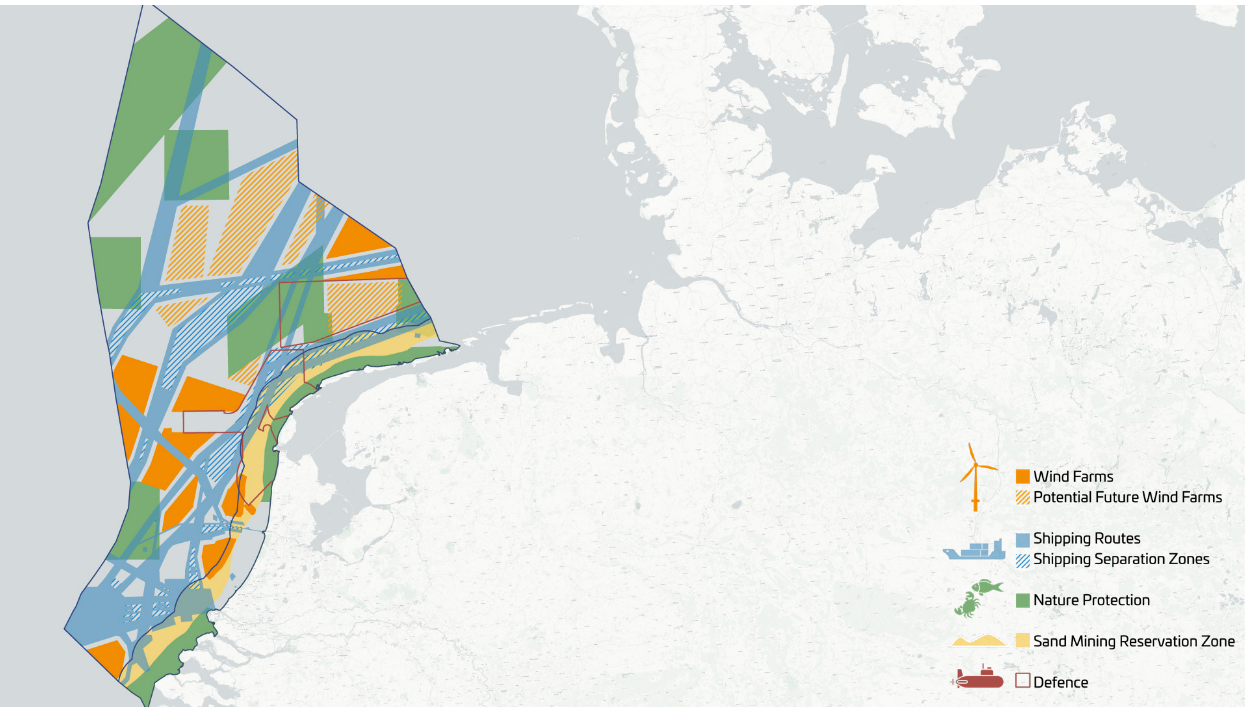

Figure 1.1 The use of space in the Dutch North Sea. This map represents the estimated future spatial use based on 'Programma Noordzee 2022-2027'. Please note that the space used by Oil & Gas infrastructure and cable routes is not shown. The map also does not include future uses that are still uncertain in their location, e.g., hydrogen infrastructure and aquaculture.

Several concepts exist that aim to integrate other functions, such as floating solar energy, aquaculture, nature and passive fishing with offshore wind. Until now, these concepts have been developed as additions to existing offshore wind farm infrastructure. One step further is to fully integrate multiple functions into the early design stages of offshore wind farm developments.

To date, operators have gained little experience in combining functions within their wind farms. Therefore, additional knowledge is needed regarding both the required technological developments and

[3] https://www.noordzeeloket.nl/publish/pages/184533/the_north_sea_agreement.pdf
[4] https://novistukken.nl/english/default.aspx

the evolving regulatory framework to stimulate optimal symbiosis between the several sea users and offshore wind farms.

Therefore, GROW partners have initiated the ‘Roadmap for Technological Advancements for Symbiosis-Inclusive Design in Offshore Wind’ (Road2SID project), in which we explore the possibilities for technological progress to achieve better symbiosis and well-integrated designs for offshore wind farms. Based on brainstorming sessions and interviews with various stakeholders, we assess the integration potential of various functions, such as nature-inclusive design, aquaculture, and floating solar energy, while considering spatial requirements, technological readiness levels, regulatory challenges and potential risks and opportunities. Based on this exploration, we identify opportunities, bottlenecks and requirements for technological advancement. We use the findings to develop a roadmap towards future symbiosis included in the design of offshore wind developments.

1.2. Terminology

Regarding the terminology used in this document, it is important to note that we have used the terms *shared use of space, multi-use* and *symbiosis* interchangeably in this project. For this research, a symbiotic offshore wind farm is an area where multiple activities and functions related to the three core transitions of the North Sea (nature, food, energy) are taking place simultaneously. In this way, Symbiosis Inclusive Design (SID) is then the design of offshore wind farm’s installation, operation and/or infrastructure in a way that shared use of space between different functions is facilitated.

Shared use in offshore wind farm zones can be facilitated through appropriate choices in the planning and design. In this study, we chose to discuss three types of multi-use activities and shared functions within offshore wind farms which correspond to major transitions taking place in the North Sea:

- nature transition – nature protection and ecosystem strengthening
  - with activities related to the mitigation of negative ecological impacts and nature-inclusive design of offshore wind farms
- food transition – sustainable production of food in the marine environment
  - with activities related to passive fishing, shellfish and seaweed farming but excluding bottom trawling fishing as this is a priori excluded within Dutch offshore wind farms
- energy transition – generation, conversion and storage of sustainable energy
  - with activities related to solar, wave, tidal energy and hydrogen production

1.3. Research objective

This Roadmap defines the key challenges and proposes actions for advancing symbiosis in offshore wind farm zones in the Dutch part of the North Sea. Our roadmap discusses ecological, technological, regulatory and economic aspects of achieving symbiosis of functions in the offshore wind farm areas.

The objectives of the roadmap are:

- To summarise the current knowledge on the symbiosis of functions.
- To identify the perspectives of various stakeholders on the future of symbiotic offshore wind farm.
- To propose actions for advancing the co-use of marine space in offshore wind farms.

This research focuses on the context of the Netherlands, although the outcomes of this research can be useful for other contexts. It should be noted that the project's original ambition was to get directions for technological innovations that GROW partners, i.e., the industrial sector, could embrace and support. The conclusion from the Road2SID process is that it is too early to formulate such directions, as the boundary conditions for Symbiosis-Inclusive Design (SID) are not agreed upon yet. It was hence decided to make a start with the process of establishing these boundary conditions.

1.4. Reader's guide

The document first describes the current knowledge and practice for multi-use in offshore wind farms within each of the three themes separately in chapter 2. The literature review is guided by a set of research questions about the technological, governance and business case aspects of the given type of multi-use. In answering these research questions, knowledge gaps are identified.

An overview of risks, challenges and opportunities for each type of co-use is made based on interaction with stakeholders described in chapter 3. Stakeholder research is performed by means of questionnaires and interactive workshops. The stakeholders' responses are used to formulate priority actions needed to realise the ambitions for the future development of multi-use offshore wind farms in the Dutch North Sea. These priority actions are presented in chapter 4.

To make the proposed actions more tangible, three case studies of co-use in offshore wind farms are created in chapter 5. These case studies provide (practical) examples of how multi-use can effectively be put into practice by looking into past, present and future implementation of symbiosis in offshore wind farms.

The document concludes with chapter 6, which provides a concise synthesis of the roadmap outcomes.

2. State of the art on shared use of space in offshore wind farms

2.1. Introduction

The North Sea plays a major role in several transitions towards a more sustainable economy: the energy transition, food transition and nature transition. At the same time, the North Sea is already in intensive use in a variety of sectors (shipping, fishing, sand mining, military, tourism), and its ecosystem is already under stress. The development of multi-use strategies is motivated by the lack of marine space that intensified with the large-scale roll-out of offshore wind.

The North Sea Agreement (Noordzeeakkoord) and the National Strategy on Spatial Planning and the Environment (NOVI) form the basis for the current policies in the Netherlands on the use of the North Sea. There, the challenge of the scarce marine space is described, and the first steps are made to enable the use of marine space by multiple functions. The plans are further detailed in the North Sea Programme 2022-2027 (I&W, 2022) and in the more recent policy letter on multi-use in the North Sea (I&W, 2023a).

The Dutch Government has made its ambitions clear to position itself as a leader in Europe for renewable energy generation, green production of sustainable fuels, and further electrification of industry to meet European energy and climate targets. The government has established a roadmap to increase the total installed capacity of offshore wind to 22 GW by 2030 as part of the North Sea Programme 2022-2027. Furthermore, in 2023, the Netherlands, together with other European countries bordering the North Sea, signed the Ostend Declaration on the North Sea as Europe's Green Power Plant, pledging to work towards a more interconnected North Sea energy system and raise the ambitions for the installed energy capacity. Considering this agreement, it is foreseen that up to 70 GW of offshore wind will be installed in the Dutch North Sea by 2050 (Tweede Kamer, 2022).

The area required for this development is vast and is competing for space with traditional fisheries, nature protection activities and the space needed for future energy infrastructure other than wind energy. Multi-use of offshore wind farm areas is broadly recognised as a (partial) solution to this challenge.

This chapter contains a description of three types of activities concerning shared use of space in combination with offshore wind: nature (ecosystem protection and strengthening), sustainable food production and energy generation & storage. An overview of the current state of knowledge is given, guided by a set of research questions formulated by the Road2SID consortium to explore the aspects of governance, technological and ecological knowledge base and economics. These research questions are listed in Appendix A.

2.2. Nature – mitigation of impacts and strengthening of the marine ecosystem

Offshore wind farms can be designed to minimise their negative environmental impact. In addition, measures can be taken to contribute to the strengthening of the marine ecosystem and habitat restoration. With the latter goal in mind, the term Nature-Inclusive Design (NID) is generally used to refer to wind farm design choices which integrate measures aimed at ecosystem strengthening.

There is currently an active debate on which measures are the most appropriate for nature & ecosystem protection and strengthening in combination with offshore wind farms and on which scale they need to be deployed. Terms such as “nature protection”, “habitat restoration”, “nature enhancement”, and “nature-inclusive design” are used in this discourse to describe a variety of approaches to this complex problem. In this study, we use the terminology of “nature and ecosystem strengthening” in accordance with the term “natuurversterking” (in Dutch). Should the natural ecosystem simply be protected by limiting local negative impacts and left to develop by itself? Or should habitats of native species be actively restored, and if so, by what means? And what should happen to the infrastructure at its end-of-life if it has become part of the habitat as an artificial reef?

It should be noted that the topic of ecology in the context of multi-use within wind farms may be open to different interpretations, given the various ecological measures and activities that are typically practised in the Dutch North Sea. Relevant policy documents on multi-use refer specifically to activities that are focused on strengthening the ecosystem (I&W, 2023a). At the same time, measures that focus on the mitigation of negative impacts may not perceived as multi-use of wind farms but rather as requirements in offshore wind farm design.

Since nature protection, mitigation of adverse impacts and ecosystem strengthening are typically considered jointly in relation to offshore wind farm development (for example, in tender requirements), in this roadmap, we are not specifically excluding measures that focus on mitigation of adverse ecological impacts. After all, according to the description of multi-use of marine space by the Dutch government[5], attention shall be paid to ensure that multi-use developments remain within the ecological carrying capacity of the North Sea, which obviously depends also on mitigating any negative impacts on the ecosystem.

Overall, many unknowns remain: the effectiveness and the desirability of different ecosystem protection and strengthening measures still need to be determined through research and pilot studies. As a starting point, the current state of the knowledge and practice for such measures in offshore wind farms are described in the sections below.

2.2.1. Options for impact mitigation and strengthening of ecosystem

When considering the relationship between human activity in the North Sea and the ecosystem health & biodiversity, it is useful to apply the logic of the "mitigation hierarchy” - a cross-sectoral tool for limiting negative impacts from development projects (CSBI, 2015). The mitigation hierarchy states that the mitigation actions should be structured along a sequence of four steps:

1. anticipate and avoid impacts on biodiversity and ecosystem services
2. where avoidance is not possible, minimise the impacts
3. when impacts occur, rehabilitate or restore
4. where significant residual impacts remain, offset

[5] https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/kamerstukken/2023/06/08/verdere-uitwerking-beleid-medegebruik-in-windparken-op-zee/verdere-uitwerking-beleid-medegebruik-in-windparken-op-zee.pdf

Offshore wind farms invariably have an impact on the surrounding environment, and measures can and should be taken to minimise this impact as much as possible – this minimisation has the highest priority in the mitigation hierarchy.

Measures that are aimed at minimising the negative impacts of wind farms on the environment are, for example:

- Avian species: painting one of the wind turbine blades in a contrasting colour to allow active collision avoidance; active deterrence of avian species via sound or light; allowing for bird migration corridors; bird detection and species identification with the possibility to stop or slow down the turbine (curtailment).
- Marine life: eco-friendly construction, operation and maintenance – selecting optimal installation windows and/or minimising noise, soil disturbance, light, and vibrations; minimising electromagnetic fields from cables.

However, poor ecosystem health of the marine environment and the decline of biodiversity are caused by a wide range of anthropogenic activities in the North Sea (historical and present). Offshore wind development projects can play a positive role in implementing the next step of the mitigation hierarchy – ecosystem restoration.

In addition, nature-inclusive design (NID) typically refers to design choices which integrate measures for ecosystem strengthening in the wind farm design (i.e. increasing suitable habitat for native species). Nature-inclusive design, therefore, goes one step further than the minimisation of negative impacts and attempts to contribute to ecosystem restoration (but naturally, it does not replace mitigation measures).

Ecosystem strengthening measures usually take the form of add-ons or optimisations of existing infrastructure elements in the offshore wind farm designs. There is already a multitude of available concepts for integrating ecosystem-strengthening measures within offshore wind farms (Hermans et al., 2020). New concepts emerge as new ecological challenges become better understood and new regulations are introduced. The various concepts and measures differ in terms of target species, level of integration with the core infrastructure and methods.

Nature-inclusive design approaches for the benefit of marine life can be:

- eco-friendly scour protections – through the choice of materials, shapes and dimensions to provide optimised shelter and/or attachment surfaces
- artificial reef structures (e.g., reef balls, oyster cages) attached to the core infrastructure or at rock protections (monopiles or cables) aimed at providing shelter and/or attachment surfaces
- eco-friendly design of replenishment holes, aimed at reducing poor internal water quality, as well as providing shelter and/or nurseries by allowing access to the internal space of the foundations for certain species

Determining optimal conditions for ecological measures

Preferred approaches will differ between offshore wind farms depending on site conditions and key species to protect. The suitability of artificial hard substrate and habitat requirements for different marine target policy species for the North Sea are described in several studies (Van Duren et al., 2016; Smaal et al., 2015; Van den Bogaart et al., 2019; Lengkeek et al., 2017). Besides water depth, temperature, salinity, oxygen content, and food availability, local abiotic factors such as bottom shear stress, sediment/substrate type and seabed mobility determine the habitat suitability for settling species. For example, dynamic areas with soft sediment are usually more suitable for polychaete[6] reefs, whereas shellfish such as the flat oyster can thrive in areas with low dynamics and hard substrates (Herman and van Rees, 2022).

Around the world and especially in the North Sea with the Rich North Sea program, successful pilots with nature-inclusive concepts have been conducted (TRL 7-9). This includes several types of artificial reefs and oyster reintroduction methods, and it is crucial that new concepts can be tested in relevant offshore environments and that data about the functioning of artificial reefs and other NIDs are shared efficiently. In Hermans et al. (2020), the TRL for different options is provided.

Opportunities for scalable nature-inclusive design

Next to pilot studies, a key challenge currently is to scale up the practical implementation of measures. Nature-inclusive designs can potentially be integrated into core infrastructure, as opposed to being an add-on, possibly leading to more cost-effectiveness, gains in logistics and scaling-up potential.

Integration of ecological functions into offshore wind farm designs at the right scale and in the right place would benefit from active governmental coordination via the regulatory framework, for example, through being prescribed in Site Decisions (steering on predefined measures) or in tenders (steering on desired outcomes while leaving room for innovation).

It should be noted that the choice of the most appropriate NID measures is highly dependent on the location, making standardisation challenging. Evidence for this is found in the literature (Langhamer et al., 2012; Degraer et al., 2022; Glarou et al., 2020). Geomorphological seabed conditions and local ecology influence the range of options in a specific location. For add-on measures, such as artificial reefs (Hermans et al., 2020), the modularity of artificial reef products is not a direct advantage towards implementing them in offshore wind farms. The limiting factor for these modular designs is likely the installation process, where effective standard approaches are yet to be developed.

Technical risks posed by the nature-inclusive design

Successful implementation of nature-inclusive design in offshore wind farms is only possible if the ecological measures do not pose unacceptable levels of technical risk to the functioning of the traditional offshore wind farm infrastructure. An example of such technical risks is when artificial reef (add-on) elements are placed next to core infrastructure (cables, support structures) and may become unstable under storm events, with a risk of damage to this infrastructure (Emmanouil et al., 2023). This risk can be mitigated by appropriate design choices concerning hydraulic stability.

Monitoring: strategies, scale and synergies

Monitoring the local ecology during the operation of the wind farm is crucial to understanding and proving the effectiveness of nature-inclusive design measures that are in place. A fit-for-purpose monitoring strategy needs to be developed in each project. Next to that, monitoring considerations are a subject of research in government programmes such as MONS, WOZEP and the KEC for cumulative effects (OFL, 2020).

---

[6] Polychaeta is a paraphyletic class of generally marine annelid worms, commonly called bristle worms or polychaetes.

In theory, a synergy between the offshore wind farm operation and maintenance (O&M) activities and the monitoring of local ecology may be desirable (to reduce costs), but it often appears challenging to make this synergy work in practice. The main reasons for that are the difficulty of matching time windows and operational systems (matching requesting party and operational party) as well as the challenge of having appropriate vessels that are fit for auxiliary purposes. However, there are some positive examples, such as the bird observers from Waardenburg Ecology that sail on the CTV from TenneT to make observations at the Borssele platforms. Integrated ecological monitoring is also being considered in the MIVSP project[7].

Examples of ecosystem-strengthening measures in the field

In the Netherlands, The Rich North Sea (*de Rijke Noordzee*) organises pilots in the Offshore Test Site (1 km^2), which is used to test artificial reefs designed for (among other species) oysters, mussels and cephalopod eggs. Other shellfish reef restoration pilots are carried out in the Voordelta and Borkum Reefs (Didderen et al., 2018; 2020). Examples of relevant initiatives are oyster restoration pilots in Gemini offshore wind farm, artificial reef structures at Luchterduinen offshore wind farm, and eco-friendly scour protections at Hollandse Kust Zuid offshore wind farm and Borssele offshore wind farm.

Nature-inclusive design of offshore wind farms is also gaining attention outside the Netherlands. In the greater North Sea, for example, flat oyster restoration pilot studies are being done in Belgian and German offshore wind farms (Smaal et al., 2017; Kamermans et al., 2018). In Germany, the approach to nature-inclusive design differs from the Dutch approach: the goal of these developments is not the overall enhancement of biodiversity but nature restoration in affected areas.

In Taiwan, offshore wind turbines are designed to support the introduction of coral larvae (Ørsted, 2022), and on the east coast of the United States, where significant growth of offshore wind is expected in the coming decades, research is now initiated for monitoring the ecological baseline and for methods to promote biodiversity enhancement.

2.2.2. Policy and governance for ecological measures in wind farms

The global guidelines for artificial reefs are the London Convention and London Protocol guidelines (IMO & UNEP, 2009). The OSPAR guidelines on Artificial Reefs in relation to Living Marine Resources (OSPAR, 2013) focus on the Northeast Atlantic region. European legislation and policy most relevant for the North Sea is the Marine Strategy Framework Directive (MSFD) (2008/556/EC), which required member states to achieve "Good Environmental Status" in the European seas by 2020. The European Habitats Directive (1992/43/EC) is important for the protection and restoration of biodiversity in Natura2000 areas and can aid in selecting target species. In addition, the Convention on Biological Diversity (CBD) and the EC Biodiversity Targets (to meet the International Biodiversity Convention) should be kept in mind when considering nature-inclusive design (Naylor et al., 2012). The relevant global and European guidelines and their applicability to the offshore wind context are described in more detail in the ecological framework by Vergouwen & Van Duren (2023).

[7] Maritime Information Provision Service Point https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/maritime-information-provision-service-point/

Regulations for applying ecological measures in offshore wind farms in the Dutch North Sea

Within the Exclusive Economic Zone (EEZ) of the Netherlands, the state has the jurisdiction to grant permits for offshore wind farm construction. The decision-makers must take into consideration environmental obligations under international law. First, the Netherlands has various general legal and political duties that apply to all stages of the life cycle of an offshore wind farm and artificial reefs related to environmental protection and prevention of pollution. Furthermore, before any intervention can be taken in the natural system, the State must apply the precautionary principle as part of nature legislation and only apply the best available environmental practices. The North Sea Programme (2022-2027) contains the measures that are taken to ensure a good environmental status of the Dutch sector of the North Sea.

Prior to opening a new wind farm area to development, the Dutch government draws up an Environmental Impact Assessment (EIA) and a Wind Farm Site Decision (in Dutch k*avelbesluit*), which includes technical and non-technical regulations applicable to the wind farm in question, including environmental aspects. After making a definitive decision about the construction of an offshore wind farm at a particular wind farm site, an Area Passport (in Dutch *gebiedspaspoort*) for the area is made, describing the natural properties of the location, the current users, and the possibilities for future combined use. An area passport indicates exactly how a wind farm area is set up, where the wind turbines and cables will be located, where there is room for passage of vessels, and where there is still room for other (multi-use) activities.

For realising nature-inclusive design in the primary infrastructure of the wind farm (e.g., scour protection), no separate permit is required. The operator of the offshore wind farm is allowed and can even be obliged to design the scour protection using a nature-inclusive approach. However, separate structures on the seabed in between wind turbines are not allowed to be placed without an additional permit. The Water Act permitting procedure for artificial reefs includes an assessment regarding safety, liability, and lifecycle duration[8].

In order to facilitate offshore wind farm development and the permitting process, the government has put in place several knowledge development programs, including MONS[9] (Nature Strengthening and Species Protection Monitoring Survey) and WOZEP[10] (Offshore Wind Ecological Programme).

Current practice in offshore wind farm tenders

For the recently constructed Borssele offshore wind farm as well as Hollandse Kust Zuid offshore wind farm, the Wind Farm Site Decisions already included regulations for nature-inclusive design, stating that a nature-inclusive design plan must be submitted, but without prescribing specific target species or implementation methods (Hermans et al., 2020).

However, the later issued Wind Farm Site Decision for Hollandse Kust West VI (HKW) wind farm zone describes specific measures “to increase the suitable habitat for species naturally occurring in the North Sea”. The measures are related to the design of scour protection for wind turbine foundations, including

[8] www.noordzeeloket.nl/medegebruik/
[9] https://www.noordzeeloket.nl/en/network/north-sea-consultation-0/mons-research-monitoring-programme/
[10] https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/ecology/offshore-wind-ecological-programme-wozep/

the installation of artificial structures. In the HKW tender criteria concerning permitted materials, construction techniques, pollution and ecological monitoring were also included.

Next to the requirements in the Wind Farm Site Decision, tender scoring criteria for nature-inclusive aspects of offshore wind farm design have also been introduced. The most recently completed tender of Hollandse Kust West VI contained MEAT[11] criteria for ecological innovation. These criteria are supplementary to the measures included in the Wind Farm Site Decision. The tender includes criteria concerning allowed materials/construction techniques, pollution, and ecological monitoring. The latest tender for IJmuiden Ver offshore wind farm Site Alpha contains criteria for habitat provision and restoration measures to be deployed on a large scale, with specific umbrella species and examples of measures being prescribed. In this tender, it is required to submit a substantiation of the ecological measures along with even more specific data management and collaboration plans. There are also additional criteria concerned with environmental stress mitigation, such as avoidance of collision casualties and light- and noise disturbance.

Ecosystem strengthening efforts and umbrella species

When considering the ecological impact on marine species and possible ecosystem-strengthening options, assessing ecological impacts cannot feasibly be carried out for all marine species, and there is a lack of information on the habitat requirements of all individual species (Lengkeek et al., 2017). Therefore, so-called “umbrella species” are chosen for their keystone function (affecting a multitude of other organisms, maintaining the structure of their ecological community) to represent groups of species with similar habitat requirements. As such, measures to enhance umbrella species will also benefit other species. The selection of umbrella species is described, for example, by Lengkeek et al. (2017), where it is based on key policy species. In offshore wind farm tender criteria, the focus has so far been placed on species protected through the EU Birds Directive and Habitats Directive, the IUCN NL Red List and species listed in the MSFD species list (Hermans et al., 2020).

Decommissioning frameworks

There is a wide discussion at the moment concerning the removal of potentially successful artificial reefs developed over the lifetime of a wind farm at various parts of the introduced infrastructure, for example, scour protections that have turned into a habitat. The different regulatory frameworks for the decommissioning of artificial offshore constructions in the North Sea are described by Vergouwen and Van Duren (2023). The United Nations Convention on the Law of the Sea 1982 (UNCLOS, 1982) and the IMO guidelines for the removal of offshore structures (IMO, 1989) state that abandoned or disused structures must be removed to ensure the safety of navigation and that adverse effects on the marine environment should be avoided. The IMO Resolution A.672 (IMO, 1989) provides a general removal requirement for abandoned or disused offshore installations or structures on any continental shelf or in any EEZ, except where non-removal or partial removal is consistent with outlined guidelines or standards. Within this resolution, a standard exists for the enhancement of living resources through the placement of material from removed installations or structures on the seabed (e.g., forming artificial reefs); these should be located well away from customary traffic lanes and should adhere to standards relevant for maintaining maritime safety.

[11] Most Economically Advantageous Tender, Dutch: *EMVI*

2.2.3. Value creation and business case

Especially nature-inclusive design measures create additional environmental value in an offshore wind farm development project. However, the maintenance and financial responsibilities that come with these measures are considerable, and it is not entirely clear who should finance the implementation and take on the operational risks. This makes the implementation of nature-inclusive design in offshore wind farms more challenging within the traditional business case of wind farm development.

Nature-inclusive design is the core part of the business case for companies that offer ecological add-on products (e.g., reef elements), supplying them to wind farm developers and offshore contractors. However, there is a struggle for these companies to support their business case with data demonstrating the successes of their products. To obtain this data, field experience and monitoring are required. Pilot projects with dedicated monitoring programs can generate such data.

The business case for nature-inclusive design for marine contractors and offshore wind farm developers is largely linked to the tender requirements set by the government. There is no direct return on investment for NID. Quantification of initial and operational costs is also not straightforward due to limited knowledge and experience with the appropriate scale on which the measures should be implemented. An approach of costs per reef element is made in the catalogue by Witteveen and Bos and Wageningen University and Research (Hermans et al., 2020). However, the quantification of the ecological effects of artificial reefs is not possible at the moment. The currently ongoing Costs and Biodiversity of Nature-Inclusive Energy (KOBINE) project aims to further quantify the nature gain in relation to construction/maintenance costs (Bos et al., 2022).

Ecological measures form the necessary bridge between the energy transition on the one hand and the mitigation of biodiversity loss on the other. At a time when the need to mitigate climate change is rising sharply, and biodiversity loss is accelerating, the offshore industry has the opportunity to address both issues. Nature-inclusive design practices can create business involvement in the biodiversity discourse and encourage new collaborations. An indirect business case for nature-inclusive design in offshore wind farms is its contribution to the Corporate Social Responsibility (CSR) policy of developers or marine contractors, as it adds environmental value to their projects and knowledge export potential.

2.3. Food production

In this section, the state of the art concerning food production within offshore wind farms is described from a governance, technological, ecological and business case perspective. Offshore food production does not necessarily need to be placed within offshore wind farms; however, on the crowded North Sea, it is expected that this will be the only option in terms of use of space. The paragraphs on technological and ecological aspects are divided between different types of food production.

2.3.1. Policy and governance on food production in offshore wind farms

The Gemeenschappelijk Visserijbeleid (GVB)[12] defines the allowable fishing and aquaculture activities for the European Union. The GVB aims to protect the fish stock by setting the maximum allowable fishing quota and facilitating access for fishermen to the EU fishing grounds. The GVB aims to support

[12] https://www.europarl.europa.eu/factsheets/nl/section/197/gemeenschappelijk-visserijbeleid

the fishing and aquaculture industry to offer ecological, economic and socially sustainable food from the sea to the citizens of the EU. Standards for aquaculture[13] are included in the GVB as well.

Vistikhetmaar – Regels-op-zee[14] describes the regulatory framework: the European framework for fishing activities is worked out in the GVB. The European Commission defines the Total Allowable Catch (TAC) per species and area. The Dutch government subdivides the quota, or contingent, amongst the fleet; product organisations (POs) redistribute the quota amongst the fleet. The Visserijwet 1963 *(VW)*[15] defines the fishing activities in the Netherlands. The Dutch regulatory framework distinguishes *MFL1* and *MFL2* fishing activities. *MFL1* includes active fishing of restricted species (e.g., herring, mackerel, haddock, sole, cod, etc.) by means of (bottom-) trawl nets. *MFL2* covers other species and techniques.

The regulatory framework and possibilities for aquaculture and passive fishing within offshore wind farms are described in the study by Mulder (2022). It explains that the present offshore wind farms are not yet designated areas for food production. This report also describes the process to embed the goals of the North Sea Agreement in the regulatory framework.

A study by Kusters (2020) aims to identify regulatory barriers and enablers to the implementation of multi-use in Dutch offshore wind farms. The study warns of "institutional void" or "destabilising controversies" between formal laws and regulations and informal institutionalised practices and suggests the need for greater regulatory involvement by the government. To overcome this void, adaptive regulatory management is required.

For each wind farm, "area passports" are prepared to detail which types of co-use (including food production) will be given precedence in which part of the wind farm. The first one for which such a passport is drafted is wind farm Borssele[16]. In this wind farm, Site 3 is designated for mariculture, including shellfish and seaweeds; Site 2 is designated for passive fishing. A study by Putter (2020) attempts to identify national and international business partners related to multi-use within Borssele offshore wind farm.

Fish farming is a type of aquaculture and is thereby covered by the GVB. According to the Dutch Noordzeeloket[17], a seaweed farm would need to apply for a permit via the Waterwet. No specific rules or laws are applicable to seaweed at the moment. Regarding passive fishing, the regulatory framework is also described in Vistikhetmaar – Regels-op-zee[18]. The possibilities of fishing in Dutch offshore wind farms depend on EU regulation, the Visserijwet, the Waterwet, MFLs and track records. This combination of regulations makes it complex to determine which methods and catch of which species are allowed.

Longline fishing is not practised in the Dutch waters. In the UK, it is still practised by local fisherman nearshore. The Netherlands does not hold EU permits for longline fishing. Because of the absence of EU permits and lack of track record for longline fishing, it is not foreseen to be applied in offshore wind farms.

[13] https://www.europarl.europa.eu/factsheets/nl/sheet/120/aquacultuurproductie-in-de-europese-unie
[14] https://vistikhetmaar.nl/onderwijs/lesmodules/regels-op-zee/
[15] https://wetten.overheid.nl/BWBR0002416/2019-01-01/
[16] https://www.noordzeeloket.nl/publish/pages/188385/handreiking-gebiedspaspoort-borssele.pdf
[17] https://www.noordzeeloket.nl/functies-gebruik/windenergie/doorvaart-medegebruik/infographic/stap-3-vergunningaanvraag/
[18] https://vistikhetmaar.nl/onderwijs/lesmodules/regels-op-zee/

The Netherlands does possess licenses for gill net fishing. Gill net fishing is generally practised along the shore. The regulatory framework would need to be adjusted to facilitate gill net fishing in offshore wind farms. Fishing with pots and traps within the offshore wind farms is allowed within the present regulatory framework.

In other countries around the North Sea, the possibilities for fishing in offshore wind farms can be different. In the UK, fishing activities in offshore wind farms are allowed, but practices are limited because of the insurance policy and fees. In Denmark, the offshore wind farm operators have to agree with local fishermen during the permitting procedure. This typically results in buyouts.

2.3.2. Technological aspects

An outline of the feasibility of offshore aquaculture and its potential for multi-use in the Dutch North Sea is given in a study by Jansen et al. (2016). The work lists technical, ecological and economic boundary conditions for aquaculture of fish, mussels and seaweed. Furthermore, it lists risks and synergies resulting from combining aquaculture with other industries, including offshore wind. The work concludes that the potential for fish cultivation is limited, but seaweed cultivation is likely to gain popularity when challenges related to processing are overcome. Mussel culture has the highest potential in the near future.

In a coarse assessment by Bolman et al. (2019), it is estimated that roughly 25% of the total surface area within a wind farm can be used for other types of development, including food production. The technology readiness levels (TRLs) of the aquaculture techniques inside and outside wind farms are estimated to be as follows:

	Outside offshore wind farms	*Inside offshore wind farms*
Seaweed Farming	*TRL 7*	*TRL 2*
Exposed shellfish farming	*TRL 8*	*TRL 3*
Exposed fish farming	*TRL 8*	*TRL 2*
Active fishing techniques	*TRL 9*	*TRL 2*
Passive fishing techniques	*TRL 9*	*TRL 3*

Technical advantages of food production multi-use are the co-sharing of mooring infrastructure and synergies in the operational phase (integrated operations with support vessels). Aquaculture infrastructure could, in theory, be moored to the offshore wind turbine foundations. This is, however, not likely to be done in the near future because of the safety zones around turbines. Pre-installed mooring points for multi-use activities inside offshore wind farms do provide some benefits: reduced safety risks to offshore wind farms during mooring installation in case mooring structures are installed prior to the offshore wind farm operation, reduced risk of anchoring inside the offshore wind farms, lower CAPEX when mooring structures are installed by offshore wind farm installation vessels during offshore wind farm installation, lower CAPEX for aquaculture operators when mooring structures are pre-installed available infrastructure.

The technical aspects differ depending on the type of food production. Below, these are described for seaweed, shellfish, active and passive fishing, and aquaculture.

2.3.2.1. Seaweed

Examples of offshore seaweed production can be found in Tullberg et al. (2022). From the mentioned techniques, only the longline system of Ocean Rainforest described by Bak et al. (2018) is still in operation today.

Endresen et al., 2019 conducted towing tests on growing lines of sugar kelp to find a relation between drag forces, measured size, weight of the kelp and current velocity. The results show that there is an adaptation to the current flow in the lines of kelp, which reduces the experienced loads. This results in a power function with an exponent smaller than 2 for the modelling of drag forces. Similar results were found in Vettori and Nikora (2019) for individual seaweed blades. This illustrates the difficulty in modelling organic matter such as seaweed since it does not behave as expected in conventional offshore structures.

Large-scale offshore seaweed production in a wind farm has not been tested full scale, but exploratory research in an Offshore basin[19] showed it is possible (Spaargaren and Otto, n.d.). Several pilots have been tested offshore in the United Horizon 2020 project and the Wier&Wind project. This last project included an automated harvesting machine, as described by Murre[20].

2.3.2.2. Shellfish

Traditionally, the Dutch shellfish sector has been based on culture and fishery on bottom plots. Since the last decade, suspended culture systems (Seed Mussel Collectors – SMCs) have been applied to relieve fishing pressure on natural seed beds. SMCs are mainly floating buoys and tubes on which a collector substrate is deployed (Rosland et al., 2011; Oirschot et al., 2017). Kamermans et al. (2011) give an overview of SMC techniques applied in exposed seas in other countries and conditions for the Dutch North Sea. Drag loads on strings of mussels and seaweed have been measured in several studies. In particular, seaweed can incur quite a lot of drag when it is close to harvest size (Gaylord et al., 2008).

Constructions and mooring need to be robust to avoid failure. Fixed anchors (piled or screwed) are more reliable than gravity based and drag anchors. However, installation of these involves higher costs (Lagerveld et al., 2014).

Long lines should not touch the seabed to avoid loss of the harvest to starfish. This requires sufficient buoyancy, especially when the harvest is fully grown. However, large buoyancy floaters are more susceptible to wave and wind loads. This will need to be taken into account in the design of offshore long-line structures.

Having lines oriented perpendicular to the tidal flow may cause undue stress on anchors and lines and incur damage. Particularly in areas with relatively high tidal currents, orientation parallel to the main current direction is likely essential. If infield cables are oriented perpendicular to the main current, this will restrict the maximum length lines can have. Having a layout of infield cables parallel to the main current offers the best options for this type of aquaculture. Further restrictions imposed by the infield cables are the safety zones, which do not allow any anchoring or crossing of cables in the water column.

The design for the semi-submersible mussel farm from the company OOS, which is intended to be placed in wind farm Borssele, has circumvented this problem by developing a system where lines are

[19] Spaargaren, F., and O. William. Model Testing of a Multi-Use North Sea Farm.
[20] https://www.murre.nl/en/successful-seaweed-harvest-operation-on-the-north-sea/

suspended in a radial pattern from a central location[21]. This design measures 76 by 32 meters and should easily fit between infield cables.

Pilot projects with offshore mussel and flat oyster cultivation are being conducted in Belgium (Zeeboerderij Westdiep[22]; UNITED The Belgian Pilot[23]). Although not yet applied within offshore wind farms, these pilot projects do demonstrate the feasibility of mussel and flat oyster cultivation near the Dutch North Sea.

Other types of shellfish cultivation, such as European oysters or scallops, can take place in stacked baskets (Laing, 2002). This is not practised currently in the Netherlands, but it has fewer restrictions on farm layout. The optimum depth for scallop cultivation is given as 15-30 m (Laing, 2002), which means that most current wind farms qualify.

2.3.2.3. Active fishing

Active fishing is currently not allowed in Dutch offshore wind farms, although the possibility is being explored. Active fishing consists of moving mobile gear through the water by means of a trawl vessel. Active fishing consists of pelagic and demersal fisheries. Pelagic fisheries target species which swim in schools in surface waters; nets do not interact with the seabed.

Demersal active fishing targets for species living on the seafloor by means of beam trawls. Demersal fishing on sole and place is the most popular and traditional in the Dutch North Sea. In all the current wind farms, dynamic sand waves occasionally cause buried cables to become exposed. Demersal fishing is, therefore, presently not allowed within within offshore wind farms (Beleidsnota Noordzee 2016-2021[24]). ECORYS (2019) and Primo Marine (2019) investigate the risks and costs of mitigation of demersal fishing activities in future offshore wind farms. The studies conclude that sea-bed fishery in future offshore wind farm shall affect all stakeholders and increase the cost of energy produced by affected offshore wind farms. Demersal fishing in offshore wind farms is therefore not foreseen to be allowed in the foreseeable future and therefore not taken into account further in the present research.

Flyshoot methods can potentially be applied in offshore wind farms. Flyshoot nets are installed from a fishing vessel at zero speed and pulled in towards the vessel. The present Dutch flyshoot fishing nets are too large to be used within offshore wind farms, but smaller-scale flyshooting can potentially be applied. Experiments within small-scale flyshoot methods in offshore wind farms take place in Sweden and Denmark (Steenbergen et al., 2020). In order to realise small-scale flyshoot methods in Dutch offshore wind farms, the risks of floating, non-moored nets and operations of the fishing vessels within the offshore wind farm operation need to be investigated.

[21] https://www.oosinternational.com/permission-to-install-the-oos-cees-leenaars-mussel-farm-in-the-north-sea/
[22] https://www.colruytgroup.com/nl/duurzaam-ondernemen/initiatieven/zeeboerderij
[23] https://www.h2020united.eu/images/Workshops/WS2/WS2_Belgian_Pilot_17May2022.pdf
[24] https://www.noordzeeloket.nl/publish/pages/123283/ontwerp_beleidsnota_noordzee_2016-2021_3916.pdf

2.3.2.4. Passive fishing

Passive fishing techniques are methods where fishing gear is left in place for a certain time before retrieval. Passive fishing techniques that can be applied in Dutch offshore wind farms are described in Steenbergen et al. (2020). These consist of hand line fishing, longline fishing, jigging, and fishing with pots and traps and gill walls.

Figure 2.1 Illustration of Pots and traps, Gill netting, Jigging, Handline Source https://www.seafish.org

Rockmann et al. (2015) describe the risks of passive fishing in offshore wind farms to cables, turbines and foundations, divers, birds and sea mammals. Anchoring in wind farms can carry risks of snagging behind exposed cables. This risk does depend on the type of anchoring and environmental loads on the gears. Not much information is available in this field; further research is required. In general, fixed foundations will mitigate this risk.

Demersal longline fishing can be technically feasible in offshore wind farms. Longlines will have to be positioned parallel to the infield cables to avoid interference with the safety zones around the cables. Demersal long lines and their anchoring (by chain on the seabed) might cause a risk for (unburied) cables.

Static gill nets or gill walls have leadlines on the seabed and floatlines at the top, keeping the net ‘standing’ vertically in the water[25]. In stronger flows, lines are best kept parallel to the main current to avoid excess drag; in weak flows, they are most effective if placed perpendicular to the current. Gill nets can be left for over 12 hours (Minns & Hurley, 1988), so these will likely not be allowed to cross infield cables. The maximum length of gill nets in the Netherlands is 25 kilometers per vessel[26]. It is unclear to what extent wind farm design needs and can be optimised to better accommodate gillnet fishing. It is also unclear if gill nets are going to be allowed in wind farms.

Fishing with pots and traps is less common in the Netherlands than, for example, in the UK. These gears are generally used to catch lobster, crabs and cuttlefish. There seem to be little design optimisations in wind farms applicable to pots. The research programme Win-Wind[27] has investigated the feasibility (ecological, technical, regulatory and commercial) of fishing on crab with pots in PAWP.

2.3.2.5. Aquaculture

So far, nearly all open-water fish farms are in sheltered locations. The Norwegian Development License scheme[28] stimulates aquaculture outside the fjords in more exposed areas. SINTEF has established the EXPOSED Aquaculture Centre[29] to enhance research and the industry towards aquaculture in more exposed and harsh environments. Research topics consist of ecology, safety, engineering, operations,

---

[25] https://www.fao.org/3/x6935e/x6935e00.htm; Seafish.org - Gill Nets

[26] article 84, “Uitvoeringsregeling Zeevisserij”; https://wetten.overheid.nl/BWBR0030288/2021-08-01

[27] https://www.wur.nl/nl/project/Win-Wind.htm

[28] https://thefishsite.com/articles/what-is-on-salmon-aquacultures-tech-horizon-norway-development-license

[29] https://www.sintef.no/en/ocean/initiatives/sfi-exposed/

monitoring and autonomy. DNV has developed technical guidance and classification rules for fish farming (DNV, 2020; 2022). Few offshore fish farms are yet in operation offshore Norway. The Norwegian trend towards offshore, exposed conditions might offer technical solutions for offshore aquaculture in the Dutch North Sea in offshore wind farms as well. For multi-use developments in offshore wind farms, these systems will need to be adapted to shallow water and confined space between the WTs.

2.3.3. Ecological aspects

Food production in offshore wind farms can pose general risks, such as over-exploitation of the marine environment by overstocking areas with extractive aquaculture (Vilmin et al., 2021). Next to that, there may be ecological risks due to the interactive effects between, e.g., significant amounts of mussels and other filter feeders on the support structures (Degraer et al., 2013) and relatively high stocking densities in aquaculture sites. The combination may lead to reduced carrying capacity for other ecosystem components. At the same time, Stichting De Noordzee[30] acknowledges the positive effect of shellfish cultivation can have on the ecosystem and nature in offshore wind farms.

Both the transport of live biota, as is likely to occur in aquaculture, as well as the availability of alien hard substrate, can be conducive to the establishment of non-native or invasive species. (Naylor et al., 2001, Bracewell et al., 2012; 2013). The combined risks are not yet known.

For fish farming, there is the risk of escape and interbreeding between wild and cultivated species. This is a major concern in Norwegian fish farming by open net pens. Limited literature and knowledge are available about the risks and effects of the escape of cultivated fish in the Dutch North Sea since offshore fish farming does not take place and is not likely in the Dutch North Sea.

Within wind farms, wind speeds are reduced, as is wave generation (Boon et al., 2018). Large-scale aquaculture may intensify this wake effect. To what extent this affects the ecosystem is currently unclear.

A special approach that exploits the extractive properties of bivalves and seaweed is Integrated Multi Trophic Aquaculture (IMTA). In IMTA systems, the extractive species are introduced to remove the excess nutrients discharged from fish cage aquaculture, to create a more sustainable production system and simultaneously increase economic profitability. In open seas, IMTA fits with the concept of 'ecosystem-based management' as each activity is placed in a wider ecosystem context and managed so that it contributes to sustainable development. However, commercial fish culture in the North Sea seems unviable at this moment due to the types of commercial fish available, as described in Jansen et al. (2016), which takes away the principal basis for the IMTA approach in this area (that is, having a fed component).

There are also food safety risks to consider. Extractive types of aquacultures (seaweed and shellfish) are the most likely forms of aquaculture. Such species may take up materials either leached from the support structures or elevated levels of contaminants in the seabed.

Wind farms in seasonally stratified areas may boost primary production (van Duren et al., 2021; Zijl et al., 2021). This may be positive, but it can also have negative effects on promoting Harmful Algal Blooms

[30] Noordzee.nl

(HABS). In such areas, HABS can threaten food safety for mussels. The added risk is unknown, and for the near future (next 10 years), shellfish cultivation in these areas is unlikely.

Large distances to port may incur a reduction in quality during transport of fresh or live products. Processing at sea allows to maintain the quality but will influence the business case.

2.3.3.1. Seaweed

For seaweed production, the farmers are looking for locations that have moderate nutrient conditions combined with high current velocities, resulting in a high flux of nutrients. Areas with high local nutrient concentrations appear to get quickly overgrown with Bryozoans and other epifauna, making the seaweed difficult to sell and also reducing light availability and, hence, growth (Walls et al., 2017). The best wind farm fitting these conditions is Borssele. Flow velocities are high, and numerical models indicate maximum growth in these areas (Vilmin et al., 2021). Note: seaweed's impact on nutrients and primary production can occur quite some way downstream (Vilmin et al., 2021). The assessment by Onderz. Form. B. et al. (2019) did not take any potential presence of aquaculture in the Belgian wind farms bordering the Borssele site into account. At present, such presence is limited, but the suitability of Borssele may change with developments there.

2.3.3.2. Shellfish

Mussels require chlorophyll from phytoplankton to grow. They benefit from areas with high nutrient concentrations that generally coincide with areas of high phytoplankton availability. This condition is mainly available near the Dutch coast and less far offshore. The best wind farms for mussel cultivation are in the Holland Coast area (HKZ, HKN). The farms with intermediate yields are areas such as Borssele and HKW), while farms further afield (IJmuiden Ver, TNvW, Zee-energie) are likely to produce less. One exception is the Gemini wind farm Buitengaats, where conditions are also deemed intermediate, possibly because this farm may benefit from the nutrient input from the Elbe River (van den Bogaart et al., 2019; 2020). Note that in these analyses, the newer search areas have not been taken into account. However, as these are all located in areas where nutrient and chlorophyll concentrations are low, it is not to be expected that these areas will be more productive. Also, for mussels, the potential presence of aquaculture in neighbouring countries (e.g., Belgium) has not been taken into account.

Van den Bogaart et al. (2019, 2020) have also analysed the designated wind farm areas known at that time for suitability to cultivate other species. Regarding the flat oyster, the best locations appear to be Borssele and TNvW (including Gemini). Other locations in the Holland Coast (HKN, HKZ) are also likely to yield high production. However, this applies to off-bottom cultures. These locations are characterised by mobile sand waves, and bottom cultures (as well as natural bottom reefs) are not likely to develop there due to smothering.

NGOs acknowledge that shellfish cultivation can have a positive effect on the ecosystem and nature in offshore wind farms. Monitoring at a longline mussel farm in the UK (Bridger et al., 2022) showed an increase in crab and lobster around the farm.

An ecological and/or business risk of mussel cultivation is starfish. When mussels are on the seabed, large amounts of the harvest are eaten by starfish. Long-line cultivation can avoid this when systems are designed with sufficient buoyancy to carry the harvest.

2.3.3.3. Passive fishing

Not much information is available about the qualitative and quantitative fish stock in Dutch offshore wind farms. There is currently not enough data to indicate which areas would be most suitable for which species. offshore wind farms might function as a refugium for sea life. The ecosystems might be delicate, especially in the first years after the construction of the offshore wind farms. The carrying capacity and stock of both restricted (MFL1) and unrestricted (MFL2) species will need to be monitored during fishing activities in offshore wind farms. Passive fishing activities are small-scale and could serve as a monitoring method.

2.3.3.4. Aquaculture

Fish farming in the Netherlands is restricted to onshore sites for species such as eel, Tilapia, catfish, yellowtail kingfish and turbot[31]. Fish farms in open water are currently absent in the Netherlands. Salmon and seabass farms are common in surrounding countries, but the Dutch North Sea is not suitable for these species. Reijs et al. (2008) show that for commercially interesting fish species, the temperature was either too high in summer (e.g., for species like salmon or cod) or too low in winter (e.g., for species like seabass) and the relative shallowness of the Dutch North Sea does not allow cages to be submerged to compensate for sub-optimal temperature conditions. They conclude that the economic and technological advancements are not considered well enough to overcome the biological boundaries for the growth and production of fish in the Dutch North Sea. Furthermore, for fish farming of non-native species, the risk of escape and contamination with native species should be considered as well. Offshore aquaculture of native demersal species is not widely considered yet, but there are ideas to cultivate and discard them till they are matured.

2.3.4. Value creation and business case of food in offshore wind farms

The existing analyses for seaweed and mussel business cases often do not take into account the distance to ports. This is clearly an issue that will contribute to the business case. Mussels are a product that needs to be brought to the market alive. So, once they are harvested, they need to be at the processing plant the next day at the latest. Distance to ports with facilities is possibly even more essential than yield. Mussel farmers indicate a maximum sailing time of 1.5 hours[32]. This may change in the future if mussels are cultivated for, e.g., augmenting animal feed. Such mussels may be frozen on-site, and travelling times may become less essential. However, this is a development that is uncertain and not expected in the next 5 years or so.

There is a knowledge gap in the suitability of offshore wind farms based on operational conditions. Experiences with operations & maintenance in the offshore wind industry show maximum sailing times of 1.5 hours for voyages by small vessels (CTVs), leaving and returning to port on a daily basis. When voyage time is longer than 2 x 1.5 hours, larger accommodation (SOV) vessels are used, which allows them to stay offshore overnight and return to port on a (bi)weekly basis.

2.3.4.1. Seaweed

Mass balance calculations, as well as the first model exercises, have indicated that the carrying capacity of the North Sea for seaweed cultivation is limited (van Duren et al., 2019 and; Zijl et al., 2021). Although

[31] https://www.nevevi.nl/viskweek-in-nederland/
[32] https://magazines.wur.nl/european-research-en/futuremares

there is certainly a larger market for seaweed, the maximum amount that can be cultivated (without fertilisation, which carries large risks) is limited – which in turn limits the market potential.

Seaweed can be used for food or feed. Seaweed for fresh human consumption needs to be brought to the consumers fresh (within a day after the harvest), which increases OPEX and is likely impossible for offshore seaweed production. Like other foods from the sea, such as shellfish or fish, seaweed does need to be handled quickly to avoid decay. Seaweed can be kept and consumed fresh for a few days; seaweed can be dried or fermented for long-term conservation.

2.3.4.2. Shellfish

Lagerveld et al. (2014) present background and regulatory, technical, ecological, and economic considerations of the potential combination of offshore wind energy production and large-scale mussel farming in offshore areas in the North Sea. The project studies the feasibility, concludes there is potential for large-scale mussel farming in offshore wind farms and gives a scenario and roadmap of such a combination in the Dutch North Sea.

Van den Burg et al. (2017) give a detailed risk and economic assessment for mussel farming in offshore wind farms and conclude that mussel aquaculture is an appealing commercial model for increased returns in offshore wind farms, although synergies are limited to O&M activities. The study identifies the challenge of implementing mussel aquaculture in offshore wind farms: the wind sector is not likely to take this initiative, while the mussel sector is significantly smaller, and it is questionable if they have the financial and organisational resources to take this step.

Stakeholders from the mussel industry acknowledge the (business) potential of mussel farming in offshore wind farms. The mussel sector sees potential to double its current production (mainly from the Oosterschelde) on the North Sea[33]. Initiatives towards mussel farming in offshore wind farms are being undertaken: PO Mossel, together with other partners, is undertaking pilots in the near-shore Voordelta; in Belgium, pilots are undertaking with longlines in the offshore Zeeboerderij[34] and within research programme UNITED[35], OOS is targeting to facilitate the infrastructure for mussel aquaculture in Borssele[36].

2.3.4.3. Passive fishing

The business potential for passive fisheries seems limited. Passive fishing is labour-intensive and not considered suitable for scale-up. At present, the plots in Borssele Site 2 do not offer a viable business case. For offshore wind farms further away from the coast, the business case will be even more challenging due to longer sailing times. Incomes of passive fishing could offer a viable business to a few fishermen or serve as additional income besides other business activities.

2.3.4.4. Aquaculture

Fish farming by means of open net pans is a big industry in Norway, Chile and Southeast Asia. However, due to the ecological (non-availability of suitable species) and technological (harsh environments)

[33] Schelpdierconferentie 2022 - BlueDeal
[34] https://core.ac.uk/download/pdf/333623515.pdf
[35] https://www.h2020united.eu/images/Webinar_Reports/UNITED-2020-06-03-Webinar_PRESENTATION_BELGIAN_PILOT_NEVEJAN.pdf
[36] Schelpdierconferentie 2022 - News - OOS

conditions, fish farming does not seem to be a viable business case within offshore wind farms on the Dutch North Sea.

2.4. Energy generation, conversion, and storage

The large-scale roll-out of offshore wind brings with it the challenge of integrating intermittent renewable energy supply into the energy system. The variability of the offshore wind, along with the planned phasing out of traditional fossil-based power plants, can lead to problems in providing the necessary electricity consumers require at the right point in time. To address this, the integration of renewable assets along with storage or conversion solutions within offshore wind farms can provide synergies to reduce supply-side variability and develop the maturity level of emerging technologies. These efforts can further help reach the decarbonisation targets on both national and European levels.

From this perspective, the multi-use of offshore wind farms with other renewable technologies is explored, with the aim of identifying the existing state of the art for such combinations of technologies.

2.4.1. Policy and governance of energy generation and storage

The rules and regulations regarding energy generation at sea are detailed in the Energy Act. There is currently no regulatory framework for connecting parties other than permit holders of offshore wind farms (Dutch Government, 2022). When the Energy Act enters into force (2024 or 2025), these alternative forms of generation will still not be able to have their own connection to the offshore grid. The explanatory memorandum (p. 87) does recognise that a connection can be shared with a wind farm permit holder (Tweede Kamer, 2023).

Currently, each technology that is installed in the water must file for individual permits and conduct separate environmental impact assessments. At the moment, there is no harmonised approach for integrating technologies in the same space to assess cumulative effects on nature and the environment.

Only a few examples of integrated wind farms with alternative technologies have been proposed. Most recently, the Holland Kust West VII tendering programme aimed to encourage the integration of wind farms into the Dutch Energy system, allowing for winning tenders to promote and include alternative technologies within the wind park design, such as floating solar PV, electrolysis, batteries, etc. However, no explicit targets or metrics concerning the level of integration were specified, leaving guidelines vague and open to interpretation. At the same time, moving forward, it is clear that proposing a wind farm with the integration of other sources will be more and more common. This tendering round could spark a trend for further integration and more detailed requirements for the future.

2.4.2. Technological aspects

The available space within offshore wind farm development lease areas provides an interesting pathway to integrate and operate other renewable energy sources, storage systems, and conversion technologies (such as hydrogen), with examples mentioned in Horschig et al. (2022) and Ibrahim et al. (2022). Integrated systems can also bring about the creation of energy hubs or islands which facilitate and improve interconnection, transportation, and energy security between countries (Durgesh et al., 2022). These technologies have been developed over the past decades, with some having matured faster than others. They are now starting to emerge as integrated development projects alongside new wind farms (Buljan, 2022) but also as standalone demonstration projects, as shown in Ziar (2021) and Oliveira-Pinto & Stokkermans (2020). This will push technology readiness and allow further understanding of individual and integrated systems.

2.4.2.1. Technological readiness level of various alternatives

Offshore Wind is now established as a maturing technology, with floating wind also entering demonstration phases[37] and soon will reach commercial scale (TRL8-9) (Ibrahim et al., 2022). Complementary resources are entering demonstration pilot projects, with different concepts ranging in TRL 4-8. The complementarity of other resources within wind farms can lead to a multitude of new partnerships and concepts[38], as mentioned in Buljan (2022) and (IRENA, 2021).

The status quo of alternative offshore energy devices is as follows:

- Tidal energy converters can provide co-use of shoreline space, with the most developed being the barraged concept (TRL 9) and the newest concepts considering vertical axis and Archimedes screw concepts (TRL 5) (IRENA, 2020). Several tidal converters have been deployed in the past decades. They have demonstrated to provide a robust energy supply, but operations and maintenance costs of the underwater mechanical structures jeopardise the business case.
- Wave Energy Converters (WEC) have been developed over the past decades, ranging from oscillating water column and attenuator concepts (TRL 8) to overtopping devices (TRL 5) (IRENA, 2020). These designs have demonstrated it to be a challenge to develop a robust and cost-efficient design. The absence of commercially viable solutions after decades of research and design indicates that a viable business case is challenging.
- Floating solar/photovoltaic (FPV) is applied successfully on sheltered inland waters, mainly in Asia. Designs and developments for exposed offshore conditions are maturing rapidly (Horschig et al., 2022; Buljan, 2022; Ziar, 2021; Oliveira-Pinto & Stokkermans, 2020; and TNO, 2022). In the past years (2018-2023), designs have matured from TRL 3 to 6. FPV offers an attractive addition to offshore wind production. As for WECs, the challenge lies in the development of a sufficiently robust and cost-effective design of the FPV system.
- Other offshore energy converters are ocean thermal energy conversion (OTEC) and salinity gradient concepts. But these need deep waters and will be difficult to combine with offshore wind, even floating wind.
- Airborne wind energy (AWE) is slowly maturing for onshore, off-grid applications (Skysails, Kitepower). Initial tests have been done offshore (Makani), but the systems need increased reliability and a larger scale for application offshore. They do offer promise as they use much less material (90%) than conventional wind turbines and possibly operate in lower wind regimes[39].

Storage technologies such as hydraulic systems developed by FLASC[40] and Ocean Grazer[41] have entered piloting phases (TRL 4) and can prove indispensable to regulating the timely distribution of variable renewable energy sources to shore.

[37] https://www.equinor.com/energy/hywind-tampen
[38] https://www.floatingpowerplant.com/
[39] Task 48 Airborne Wind Energy Systems Task 48 | IEA Wind TCP (iea-wind.org)
[40] Subsea 7 and FLASC secure UK BEIS Funding for Offshore Energy Storage Technology.https://www.offshoreenergystorage.com/subsea-7-and-flasc-secure-uk-beis-funding-for-offshore-energy-storage-technology/
[41] https://oceangrazer.com/

Conversion technologies for Power-to-X applications (conversion technologies that turn electricity into carbon-neutral synthetic fuels) are also under pilot and demonstration stages, with hydrogen production from offshore wind achieving TRL 5 (IEA, 2022). PEM technologies (proton exchange membrane electrolysis), presently most suitable for variable renewable hydrogen production, are reaching TRL 7-8 (Ibrahim et al., 2022). Production of green hydrogen and transformation into downstream products can open new ventures. Revenues and expanded possibilities for hybrid power plants.

Lastly, numerous configurations and spatial planning of energy hubs and islands are being developed by many countries, especially those in the North Sea, with examples such as Durgesh et al. (2022) and Danish Energy Islands[42]. The development of energy hubs is still at a low TRL level (TRL3). Bottom-founded islands have the potential to increase to higher TRL levels quickly since they are based on existing technologies and industry knowledge.

Electric charging buoys are considered a solution towards emission-free maintenance of offshore wind farms. They can deliver power from the wind park directly to (diesel) electric vessels and, as such, reduce the power on the export cable. Development of such buoys is at a TLR 5 with examples such as Stillstrom by Maersk[43] and Bluewater (2022).

Challenges for charging buoys that are to be addressed in the coming years include:

- Ownership of the infrastructure: Who will own and operate the charging buoy? Can this be facilitated by the TSO (Transmission System Operator)?
- Power transformation from the wind park (66kV AC) through the buoy (11kV) to the charging vessel (DC) and integration with the vessel's power management infrastructure.
- Hgh dynamic motions of the buoy and associated equipment

2.4.2.2. Changes in offshore wind farm design, integration and operations

Emerging alternative energy sources described above will need to share space in between or around the rows and arrays of wind turbines of an offshore wind farm. The arrangement of these technologies brings a variety of possible integration concepts, where sharing common infrastructure and connection points becomes increasingly complex.

In the simplest of connections, a large area of space can be designated for the entire technology type, essentially acting as its own asset alongside the wind farm. There could be a common connection at the central substation before exporting the energy to land, or each technology could have its own export cable to shore.

More integrated concepts could also distribute the technologies such as wave converters or floating solar panels into combined arrays, sharing available infrastructure of specific wind turbines, further making use of existing cables and platforms, and even utilising the turbine tower itself to house components with numerous examples provided in Pérez-Collazo et al. (2015), Waqas Ayub et al. (2023), Astariz et al. (2015), and in the United Project[44]. Different inverters and transformers can also be considered depending on the configurations, with the possibility of having them on a fixed infrastructure or floating platform as well. The complementarity of different sources, such as wind and

[42] Denmark's Energy Islands. Retrieved from Danish Energy Agency: https://ens.dk/en/our-responsibilities/energy-islands/denmarks-energy-islands
[43] https://stillstrom.com/
[44] https://www.h2020united.eu/

solar, for example, shows a considerable amount of anti-correlation. Hence, cable pooling (the utilisation of the existing export cables for different technologies) is indeed possible. This can lead to reduced infrastructure costs and more consistent generation transported to shore with little curtailment, as highlighted in López et al. (2020) and Golroodbari et al. (2021).

Sharing infrastructure and making use of space could also provide synergies to O&M strategies (Astariz et al., 2018), making use of the common fleet but also taking advantage of weather windows. Designs have even been proposed to create entirely new hybrid concepts across multiple technologies relying entirely on shared infrastructure support (Solomin et al., 2021).

In an offshore wind farm, turbine spacing and cable routing are optimised for energy yield and CAPEX. At the ocean surface, 500-meter zones around offshore structures need to be maintained while on the seabed; however, 250-meter corridors around cables are needed. Offshore wind farms may also have shipping lanes that may pass through them. This leaves an irregularly shaped patchwork of areas available for other users within an offshore wind farm. One example of designated zones for a different form of multi-use while respecting existing wind turbine and cable infrastructure is the “Handreiking gebiedspaspoort Borssele”[45].

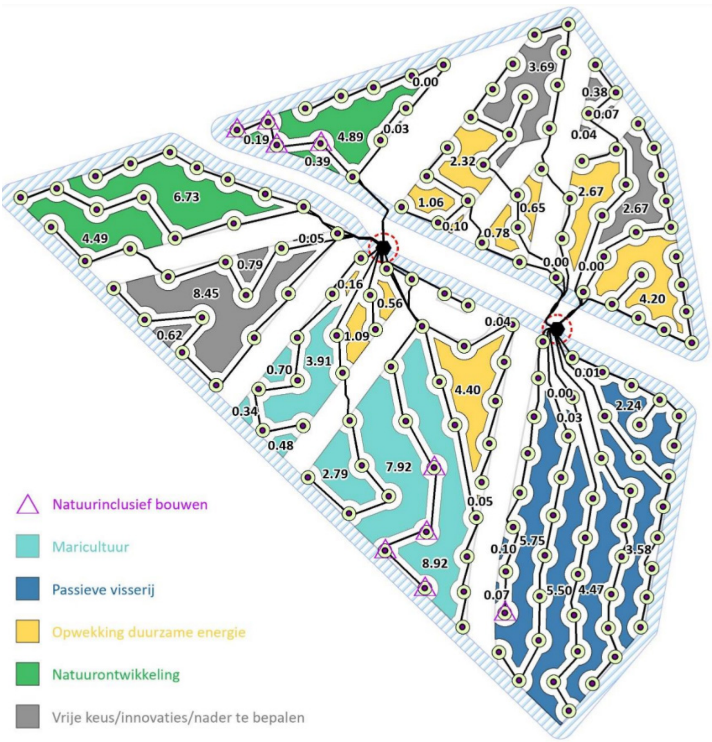

Figure 2.2 Zoning map of preferred areas per shared use activity in the Borssele wind energy area.

With offshore wind farms being the primary purpose of future development areas in the Dutch North Sea, other users are currently expected to operate within the constraints dictated by the offshore wind farm layout. Note that any new structures placed within offshore wind farm will also have their own safety plans, operations, and required access corridors. It is interesting to note that other approaches to spatial planning can be applied. For example, in the United States, BOEM has come under pressure from

[45] https://www.noordzeeloket.nl/publish/pages/188385/handreiking-gebiedspaspoort-borssele.pdf

fishermen and, therefore, increased the space available for other users by increasing the distance between wind turbines to 1 nautical mile.

Furthermore, the degree of impact that technologies can have on other systems' production levels is not well known. Dynamic shading, for example, caused by the rotational frequency of wind turbine blades over the surface of floating PV panels, could cause disturbances at certain times of the day and year and hence limit the generation output. Similarly, large floating structures around wind turbines could impact the roughness conditions and, therefore, influence the incoming wind flow conditions for the turbine (TNO, 2022).

2.4.3. Value creation and business case

Energy consumption and location will play a key role in determining the spatial and infrastructure planning of the future energy system. As more offshore electricity becomes operational and green molecule production technologies mature towards commercialisation, the dispatch of energy to consumers needs to become robust and resilient. Several studies (e.g., Berenschot Kalavasta, 2020; Netbeheer Nederland, 2023 and; Gasunie & Tennet, 2019) have assessed the infrastructure requirements, costs, and energy flows for electricity, hydrogen and methane coupling for present and future time horizons for 2030 and 2050. Given increased targets from European initiatives[46], a large effort will be placed on decarbonisation and further electrification of the industry with works from TKI Energie en Industrie (2021) and CE Delft & TNO (2022). This implies more renewables in the energy system and more flexible demand assets to consume this energy, be it from hybrid boilers, data centers, electric vehicles, and electrolyses. Therefore, the integration of multiple technologies, both for production and conversion, should be located in the closest vicinities possible. This would reduce transport and efficiency losses, help alleviate bottlenecks, and make use of an existing or limited electrical infrastructure.

Household demand is situated primarily around the large cities of the Netherlands, mainly in north and south Holland. Industrial demand is predominantly situated in the west (Randstad region) for chemicals and refining and northeast of the country for chemicals and paper (European Commission Joint Research Centre, 2022). Import and export connections to Germany, Belgium and other countries in the North Sea are situated in the North and South.

The Netherlands is already one of the main producers of ammonia, high-value chemicals, and fertilisers in Europe and will need an increased supply of hydrogen and green gas production under new climate policy regulations introduced by the European Commission and renewable energy directives (CE Delft; TNO, 2022). It also aims to be a key industrial hub for hydrogen production (Guidehouse, 2021) and part of a larger backbone for European green hydrogen supply and distribution.

2.4.3.1. Synergies for production, operations, and maintenance

Combining the offshore wind farm with other forms of energy generation, energy conversion, or energy storage technologies can add value by providing higher overall energy yield from the offshore area as well as optimising the use of the (export) infrastructure of the offshore wind farm and stabilisation of the electricity grid. This is possible by supplementing power generated from the wind with additional energy from another source (s) during periods of reduced generation due to low windspeeds or

[46] Delivering the European Green Deal [Delivering the European Green Deal (europa.eu)]

curtailment. There is also the possibility of converting electrons to molecules and storing the energy during periods of low demand and high production.

Furthermore, it is also possible to have efficient installation and O&M procedures (both from a cost and environmental impact perspective) when the same transport assets and technicians can be used to install or service the infrastructure offshore. Operations and maintenance on alternative energy converters can be performed by the same type of vessels as used for offshore wind turbines, such as CTVs and SOVs for small repair campaigns.

O&M strategies and procedures for alternative energy converters will benefit from the advancements of O&M by the offshore wind industry, i.e., in terms of port infrastructure, vessels, adaptive scheduling and the development of autonomous techniques for inspection and simple maintenance tasks.

Opportunities for combined maintenance of offshore wind turbines and alternative energy converters seem evident. However, conflicts could arise in determining the prioritisation of maintenance. Sometimes, it is contractual when it comes to who is responsible for carrying out or planning the offshore works; therefore, it is contractual between client and contractor. The need for optimisation in using vessels is therefore apparent. Priority might be given to the assets with the highest loss of revenue (i.e., the offshore wind turbine). This increases downtime of the alternative energy device in the wind park, which would result in higher LCOE and can ultimately jeopardise its business case. Combined maintenance and prioritisation need to be well arranged between the wind farm operator and multi-use owner. In some cases, these entities can be one and the same and would cause fewer barriers for arrangements on combined maintenance.

Within the community of practice (CoP), options are being explored to create a so-called "Maripark", which aims to create common interests for all invested parties and users of the space offshore as currently done for land-based industrial estates such as the organisation of roads, and infrastructure (internet, electricity, etc.).

Overall, an optimised, integrated system combining the various energy generation, storage and conversion methods and the associated export solutions will result in a system where the various components are used most efficiently. This will result in an overall lower cost per unit of energy delivered and improved (e.g., higher, stabilised) revenue streams.

2.4.3.2. Insurance, permitting, spatial footprint

The spatial footprint of an energy park is based on the level of co-usage in the designated space. While nature-inclusive design can have minimal impact (as nature is ever-present in and around the wind farm), the integration of more infrastructure on the water or below it disturbs the environment and other surrounding technologies. Presently, the area passport approach leaves an irregularly shaped patchwork of areas available for other users of the space. With offshore wind farms being the primary focus of the development area, other users of the space are currently expected to operate within the constraints dictated by the existing layout. Note that any new structures placed within offshore wind farm will also have their own safety and operation access corridors. These corridors need to be accounted for to ensure clear and accessible spacing for operations and safety.

This poses a conflict as most multi-use solutions use catenary mooring, which requires a lot of space below the surface (along with the regulatory restriction that no anchors are allowed in the offshore wind farm). This limits the space for actual energy generation. Hence, alternative mooring and anchoring need further investigation. Furthermore, increasing operational activities of different technologies will increase the risk of incidents in the wind farm and should be optimised in great detail.

The integration of different technologies could increase insurance costs significantly. For example, the installation of a solar farm within a wind farm also increases the risk of vessel collision with one of the structures or objects detaching and posing a risk to the wind farm, which, of course, must be prevented. Due to a lack of experience with these integration cases, there is also no guideline on how to insure these multi-use projects. The insurance to cover the operation and installation activities of technologies that are near each other in the North Sea can be complicated and require proper planning and consideration. Upfront agreements and clear guidance ensure proper insurance (and associated business costs) along with proper management.

Regarding permitting, there is presently no clear guidance on which permits will exactly be needed to integrate different energy generation technologies. It is currently assumed that a separate permit must be obtained under the Water Act Nature Protection Act, including a separate Environmental Impact Assessment for integrating technologies other than offshore wind (Overheid.nl, 2020; 2021; 2023). This approach and process are not well streamlined, and it would be necessary to have a harmonised and simplified permitting landscape for integrated technologies. This, of course, requires an additional assessment of cumulative effects.

2.4.3.3. Sharing of risk, cost and revenue

The decision to allocate costs and distribute revenue will depend on whether the multi-use offshore energy farm is operated by one sole entity or a collection of partners for each technology. In the case that a large wind farm developer also develops and operates other renewable assets, then they would most likely be interested in operating the whole site. This would simplify the decisions concerning costs and revenue dispatching. It would also alleviate the risk of potential insurance and permitting consequences that may stem from combined operations when performing installations and maintenance procedures.

A more decentralised approach may bring added value that more parties can bring forward their shared experience and knowledge about each particular asset to be responsible for its performance. Within this, it could be possible to still have one central command of operations and ownership and subcontract the parties with relevant expertise.

This remains to be seen and explored in real life, as recently awarded tenders with multiple technologies and providers involved will have to establish a clear and defined set of roles and contract agreements between them. It may be the first learning experience of its kind in offshore conditions.

2.5. Concluding remarks

The overview of current knowledge and practice on multi-use in offshore wind farms was presented above for the context of the Dutch North Sea.

There are many developments underway concerning all three transitions linked to multi-use: nature, food and energy. Both policy and technology are developing fast, especially in the case of energy generation (technology) and nature (policy). The Netherlands is one of the leading countries on the topic of marine multi-use, primarily driven by the scarcity of space and long-term experience with the marine economy. However, the field of symbiosis between functions inside wind farms is relatively young, with many unknowns. The knowledge and practical experience are still lacking on many fronts.

Symbiotic projects involve a large number of stakeholders whose interests need to be aligned. The overview in this chapter already indicates some challenges faced by the different stakeholders. These and other challenges, as well as opportunities, are explored further through stakeholder consultations in chapter 3.

3. Stakeholder perspectives

In this chapter, the results of the stakeholder consultation process are described. The stakeholder consultation is done to establish a range of views on the current challenges and opportunities with regard to multi-use. Early response was gathered during several meetings and workshops in the form of interactive presentations and breakout sessions. On the basis of this input, the questions of the questionnaire were formulated. The questionnaire consisted of some general questions on the organisation the respondents are affiliated with and detailed questions on the 3 topics: Nature, Energy and Food. Depending on the choices of the respondents within the questionnaire, they were asked for input on one or more of the 3 topics. More than 60 stakeholders were approached to fill in the questionnaire from a wide range of stakeholders.

In total, 41 responses to the questionnaire were received, coming from 33 different stakeholder organisations. The stakeholders come from 6 different categories of organisations. The regulating bodies, research organisations and NGOs included in this survey are all based in the Netherlands. The offshore contractors, offshore wind farm developers and multi-use innovators (manufacturers of multi-use elements and technologies complementary to offshore wind) are either based in the Netherlands or internationally (Belgium, Norway, Denmark, Germany) but are involved in the field of multi-use offshore wind energy in the Dutch waters.

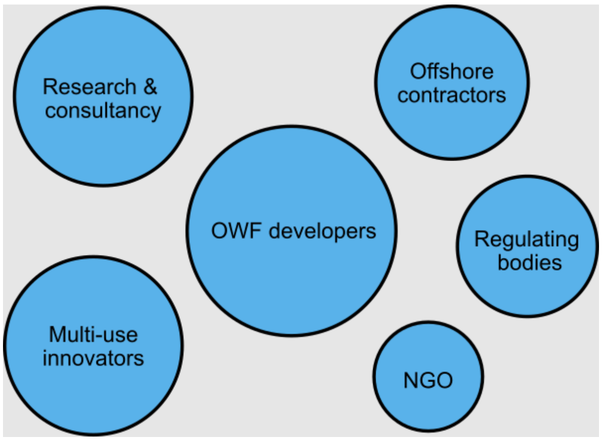

Figure 3.1 Types of stakeholder organisations that submitted responses to the questionnaire. The size of the circle indicates the number of responses from this type of stakeholder.

From the questionnaire and the general stakeholder outreach, it became clear that although there are many technical solutions (e.g., design of offshore wind farm, NIDs) for multi-use in offshore wind farm, the main bottlenecks come from governance (e.g., legislation is unclear) and economy (business cases and financing) (see section 3.4)

Overall, this questionnaire sheds light on the stakeholder perspectives concerning opportunities, challenges, own responsibilities and requirements from others for advancing symbiosis-inclusive design of offshore wind farms. The insights are specific to each of the three symbiosis themes, discussed in section 3.1 (nature protection & ecosystem strengthening), section 3.2 (food production) and section 3.3 (alternative energy generation, conversion and storage). More details around the questionnaire can be found in appendix A, B and C.

3.1. Stakeholder perspectives on multi-use with nature & ecosystem strengthening

3.1.1. Opportunities

When asked about opportunities in developing multi-use with ecosystem strengthening and impact mitigation measures, stakeholders most often highlighted:

- utilising marine space more efficiently
- opportunities for enhanced nature monitoring
- obligatory tender requirements

Efficient use of space was highlighted by nearly all parties as a benefit. Large areas are necessary for effective nature protection in the North Sea, and multi-use activities are seen as an option to alleviate some pressure on spatial planning. Nature protection zones can be partially combined with wind farm areas, although exclusive nature protection zones will still be required elsewhere. Existing synergies between offshore wind and nature protection were highlighted that have to do with restrictions on fishing activities in the offshore wind farm areas, leading to less pressure on nature within these wind farms.

Enhanced nature monitoring was, in particular, highlighted as an opportunity by the regulating bodies and research institutes. Monitoring of biodiversity and ecosystem health is important for decision-makers and researchers as an input into effective future marine spatial planning. Monitoring within wind farms can be made easier by utilising synergies with the offshore wind farm infrastructure and operations.

To multi-use innovators and wind farm developers, in turn, obligatory tender requirements are seen as a major driver of multi-use developments. Provided that clear and specific offshore wind farm tender requirements on ecosystem strengthening are available, then a more straightforward business case would exist for these parties to carry on the development of this type of multi-use.

3.1.2. Challenges

A wide range of challenges was indicated by the stakeholders for the implementation of multi-use with ecosystem-strengthening measures. The most frequently highlighted challenges by the stakeholders are:

- unclear legislation for permitting & decommissioning
- lack of a traditional business case
- complex field of stakeholders and conflicting interests
- lack of well-proven concepts and track record

Unclear legislation was named as a major factor by offshore wind farm developers, multi-use innovators, NGOs and researchers. offshore wind farm developers highlight the need for consistent guidelines from the tender criteria and area passports. Unclear decommissioning policy is a concern for both multi-use innovators and NGOs; this has been highlighted as hampering development.

The lack of traditional business cases is recognised as an issue by a broad group of stakeholders. Especially for installation contractors, this can be a showstopper, as the design choices are often guided by optimising costs, which leaves little space for innovative solutions. Clear financial incentives are needed to enable multi-use developments.

The complex field of stakeholders surrounding the multi-use of offshore wind farms with ecosystem strengthening is named as a major challenge by offshore wind farm developers, installation contractors, multi-use innovators and regulating bodies, although different parties highlighted different impacts of this complexity. To offshore wind farm developers, the many stakeholders and activities co-located in one area are perceived as a source of increasing risks. The decision-making procedure on which ecosystem strengthening measures are appropriate is also named as a challenge by developers. There are conflicting claims by different uses on the seabed inside the offshore wind farms, which is also named as a challenge encountered by multi-use innovators. To policymakers and regulating bodies, the complexity of the stakeholder field and conflicts between marine space users lead to slower policy- and decision-making, which hampers the development of enabling multi-use policies.

The lack of well-proven concepts and track records hinders the large-scale application of known concepts, as the long-term effects are still unknown. This can only be tackled by a stepwise approach with sufficient monitoring and modelling. A balance should be found between the risk of making a wrong decision and waiting too long to strengthen the ecosystem on a large scale.

3.1.3. Responsibilities and requirements

Most stakeholders see it as their responsibility to advance innovation in the field of multi-use: this was a common response among offshore wind farm developers, multi-use innovators and installation contractors. Most of the stakeholders also saw it as their responsibility to engage with other stakeholders to arrive at solutions.

Regulatory bodies naturally see their responsibility in advancing regulatory frameworks; however, other parties also indicated to see a role for themselves in this process. All types of stakeholders saw a role for themselves in advancing stakeholder engagement and awareness. offshore wind farm developers and research institutes, in particular, are concerned with developing system understanding and sharing knowledge with other parties. All in all, it is seen from the responses that each type of responsibility is spread widely across stakeholders. This may be an indication that stakeholders do not see a single clear role for themselves but are trying to fulfil multiple roles with increasing complexity. This might call for a general framework to align responsibilities and dependencies.

In terms of requirements, by far, the majority of stakeholders have indicated that they require advancements in regulatory frameworks. These advancements are mostly needed to make multi-use solutions economically feasible and to provide clear guidelines and recommendations for all steps of multi-use development. Stakeholders from regulatory bodies, in turn, require insights into the business case of developers, contractors and innovators, as well as improvements in system understanding in order to draw up holistic regulatory frameworks.

Other commonly named requirements are the support in stakeholder engagement and making available the currently missing knowledge on system understanding. Better information on how “to do it right” is needed by the developers and contractors, but also by NGOs. It is vital to have reliable knowledge of the short- and long-term impacts of both wind farms themselves and the ecosystem-strengthening measures.

3.1.4. Vision for multi-use with nature & ecosystem strengthening measures

Stakeholders were asked to formulate their definition of success when it comes to the symbiosis between nature and offshore wind. Most parties have responded that their vision of successful implementation is improved biodiversity and ecosystem health, as well as an abundance of target species, more broadly formulated as a positive impact on marine nature on a large scale. The indicators of this impact can be, e.g., the presence of self-sustaining oyster reefs or increased biodiversity of mobile species.

Installation contractors added that an indicator of success would be the presence of consistent industry stimulus for nature-inclusive design, i.e. incorporating multi-use solutions in their business case. According to the research institutes, success would be defined by an improved understanding of both negative and positive impacts of offshore wind farms on nature and by this knowledge being used for improved decision-making by designing clear guidelines and metrics for measuring ecosystem health inside offshore wind farms.

3.1.5. Governance aspects

When asked about who should ideally coordinate the implementation of co-use between nature and offshore wind, the universal response from the questionnaire respondents was that it should be coordinated by the government through the use of laws, site decisions and tender requirements. Efforts taken by offshore wind farm developers are driven by such guidance from the regulating bodies, while efforts by installation contractors are driven by both the regulations and the directions from offshore wind farm developers. Research parties highlight the importance of basing the regulations on state-of-the-art research provided by applied institutes. In the Netherlands, the Noordzeeoverleg (NZO) has a role to play in the coordination of best practices for ecosystem strengthening.

3.1.5.1. Upcoming regulatory changes

Another question was posed to the regulating authorities and NGOs regarding the expected steps that the Dutch Government is already planning to take to stimulate offshore wind farm multi-use with ecosystem strengthening. The main planned actions in the short term are to modify the tendering procedures for new offshore wind farms. Tenders with requirements for nature-inclusive design elements will become the new norm. Instead of scoring extra points for nature-inclusive design measures, the tendering parties will need to comply with pre-defined requirements for protecting and restoring marine nature. Documents in relation to the tendering for the IJmuiden Ver wind farm describe the new tendering procedure.

3.1.5.2. Suggestions for policy improvements

Respondents were asked to formulate suggestions on what can be improved in the current governance framework for enabling nature-inclusive design in offshore wind farms, i.e. which incentives, coordinating actions and knowledge sharing do they see necessary? Below, the suggestions by different stakeholder groups are summarised:

Offshore wind farm developers expressed the need for the following:

- a clear vision from the side of the regulations on what they should be focusing on for effective NID deployment. Requirements for nature-inclusive design should best be included in the tenders, with explicit expectations on how and which NID measures to implement. This could lead to direct requirements in the permit.
- NID measures should be designed with upscaling in mind and should be possible to integrate with normal offshore wind farm operations (monitoring and maintenance).

- Knowledge sharing between owners of pilot studies should be stimulated, not only on completion but also during the pilot operation process (intermediate results).
- Rules regarding decommissioning need to be changed to provide an option of keeping the scour protections and NID elements in place after decommissioning of the wind farm.

offshore wind farm installation contractors stressed the importance of including all stakeholders in the NID design process from the beginning in order to avoid conflicts later on when certain design decisions have already been made. A good way to arrive at standardised designs would be to set up joint industry projects (JIPs) to identify the most promising NID solutions, which can later be picked up by regulators in the tender requirements. This would guarantee a structured approach to how the innovative concepts are selected (instead of each party working on it separately).

Multi-use innovators indicated that they would like more clarity on the Dutch fisheries law, which is relevant to active ecosystem-strengthening efforts.

Research institute representatives expressed a wish for a more long-term vision from the side of the regulators and more effective central coordination.

Environmental NGO respondents suggest the creation of a nature restoration fund to enable the improvement of the ecological status of the North Sea, to which all users of the sea would need to contribute. Next to that, a critical look at the decommissioning rules is needed: when do the remaining structures really contribute to a healthier habitat, and when can they best be removed?

Regulators, in turn, highlighted that better knowledge sharing with the industry needs to be organised to get an overview of NID design options. Also, there is value in gathering all NID design ideas that were submitted to offshore wind farm tenders, including those that did not win the tender. It is possible that valuable designs are being lost by not considering the proposals of parties that did not win a tender. But it would be against the direct interest of those parties to share the ideas as they might want to use these to win the next tender.

3.1.5.3. Permitting and decommissioning

Respondents were asked to share their experiences with permitting and decommissioning. According to the majority of respondents, current decommissioning rules are very unclear in terms of what can remain and what needs to be removed. Long-term impacts are not taken into account in this decision.

offshore wind farm developers express an urgent need for clearer NID permitting and decommissioning rules. An example from Belgium is given where the Government is effectively working on clarifying decommissioning rules. Some of the multi-use innovators refer to the example of Portugal, where they experienced quick decision-making combined with wide stakeholder engagement when licensing NID applications.

Research parties highlight that the current permitting and decommissioning legislation is not suitable for deploying standardised NID solutions and would need to be simplified for a faster roll-out.

3.1.6. Technology aspects

Several questions were posed on technical aspects of offshore wind farm design and operation: design approaches and monitoring strategies.

Firstly, the stakeholders were asked broadly to provide their opinion on what is the best strategy for designing offshore wind farms to support marine ecosystems. Different stakeholders highlighted different aspects of the design:

- Offshore wind farm developers called for local focus on which measures are appropriate, based on site-specific knowledge and local targets, which nevertheless need to fit in the bigger picture of North Sea ecosystem preservation.
- Offshore wind farm contractors suggest that the best way to arrive at a good design is "learning by doing", i.e. extensive monitoring of a range of solutions.
- Research institutes suggest that a vision of a desirable ecosystem should be central to the design as a starting point. When a vision is formulated, available scientific and practical knowledge can be used to bring the current situation closer to this vision. It is best not to just focus on increasing biodiversity but also to think of which kinds of species are most desirable at the location. It is also of great value to work together with environmental protection organisations and fisheries, as they possess valuable knowledge of the local ecosystem and its problems.
- Environmental NGOs express the need for tendering requirements based on clear national and international vision. It is important not to forget about the value of passive restoration in offshore wind farms and to minimise the negative environmental impacts of offshore wind farm foundations and scour protections.

Setting up a proper monitoring strategy is an essential component of deploying innovative nature-inclusive designs. A good monitoring framework should accurately reflect the positive and negative impacts of offshore wind farm on ecology, including the potential positive impacts of NID measures. Respondents were asked to reflect on the current monitoring practices and frameworks. The following answers were received:

- Offshore wind farm developers and installation contractors are generally not aware of any present standardised monitoring frameworks. Developers expressed the need to better understand in advance the monitoring programmes mentioned in the new offshore wind farm site decisions, which are currently only described on a high level.
- A positive example of a monitoring programme development from abroad was given by one of the respondents – the WinMon study from Belgium (Degraer et al., 2013).
- According to the offshore wind farm developers, the current monitoring practices are focused on the negative impacts of offshore wind farms and still need to be tailored to NID measures by including positive impacts as well. A good monitoring framework would need to entail coordinated public sharing of resulting data and should have a standardised approach across wind farms.
- According to researchers, it is important to approach monitoring frameworks with a long-term strategy in mind, considering also the necessary innovations in monitoring techniques. It would be beneficial to set up an integrated digital replica of offshore wind farm ecology. Currently, the MONS framework is in development, which should support monitoring practices in offshore wind farms (Noordzeeoverleg, 2021).
- Environmental NGOs highlight the importance of integrated monitoring over the entire EEZ area and potentially across borders, where coordination with neighbouring countries is key. For effective monitoring of birds, the MOTUS network (MOTUS Wildlife Tracking System. https://motus.org/) should be expanded.

- Multi-use innovators added that there is a need to develop new monitoring methods that are appropriate for large-scale nature restoration and ecosystem-strengthening projects. Artificial reef elements are small in size, so these methods should be able to cover large areas with high resolution in a cost-effective manner.

3.1.7. Business case aspects

Commercial stakeholders (developers, contractors and innovators) were asked to elaborate on how NID measures are expected to fit in the business case. Both offshore wind farm developers and installation contractors see NID as a strategy to help increase the social acceptance of large-scale offshore wind to help build relationships with local stakeholders. Nature-inclusive design developments are seen as part of the corporate social responsibility (CSR) efforts by these companies.

For multi-use innovators, the business case is self-evident, and it is made stronger when NID measures become an obligatory part of offshore wind farm design in tenders. These tenders can then help leverage funding for nature-positive infrastructure.

3.2. Stakeholder perspectives on multi-use with food production

A questionnaire on stakeholder perspectives on multi-use with food production activities was shared with relevant stakeholders, among which are (the number between the () indicates the number of questionnaire submissions received from this type of stakeholder):

- offshore wind developers and utility companies (5)
- offshore wind installation contactors (0)
- multi-use innovators & start-ups (2)
- non-governmental organisations (2)
- regulating bodies (1)
- research institutes (3)

3.2.1. Opportunities

The opportunities identified by most stakeholders in food production multi-use in offshore wind farms are the following:

1. Efficient use of space
2. Combined mooring opportunities
3. Sharing capacity of operating vessels within offshore wind farms
4. Efficiency gains in environmental impact assessment

Efficient use of space is also identified as the most promising by both other themes. Combined mooring and efficiency in environmental impact assessment are also considered promising opportunities by the nature stakeholders, whereas the opportunity of sharing vessels is also seen by alternative energy generators.

3.2.2. Challenges

In terms of challenges identified by the food stakeholders, the top challenges identified are:

1. Safety issues and technical risks
2. Lack of well-proven concepts and track record in the field

3. Unclear legislation concerning permitting
4. No traditional business case
5. Large costs (insurance, monitoring etc.)

There are no challenges that stand out specifically for food production. The concern for safety and technical risks is shared with energy, which is to be expected since they are also introducing new floating infrastructure to the site. The lack of a traditional business case is shared with nature, with the difference that nature will not sell anything, so there is no commercial sense of a business case; whilst the offshore-produced food market does have the potential to be a commercial market, it is, however, nonexistent now.

3.2.3. Responsibilities and requirements

Nine out of 21 stakeholders who replied to be active in food production see their main responsibility in advancements in stakeholder engagement & awareness. This is interesting since stakeholder engagement and awareness were not identified as a challenge for the food theme in the stakeholder responses to the questionnaire. Both advancements in innovations, technology and advancement in system understanding & knowledge sharing had four replies, and lastly, advancements in business cases and advancements in regulatory framework both have two.

3.2.4. Timing and lifetime

When asked about the ideal moment to integrate food production in the offshore wind farm development, different opinions are posed about the subject; three stakeholders agree that food production should be integrated into the design phase before construction:

Now, it is better to integrate it from the start to get the most profit out of a certain area. In this way, the offshore wind farm can be designed in such a way that makes food production feasible within the area.

However, another three stakeholders have the opposite opinion and state that aquaculture should be added after installation. These stakeholders do not provide a more elaborate view on why they think so:

The tender could already require this option. However, permitting and installation should happen after the wind farms have been built.

Different stakeholders agree there is a possible showstopper in the difference in lifetime between a food production facility and a wind farm, and therefore, it needs to be determined what this impact is. One stakeholder mentions that the permitting of all multi-users is as long as the wind farm is in operation. Another stakeholder obviously disagrees with this policy:

Food production facilities and/or engineered reefs should be installed for an indefinite period, which automatically indicates that these systems should not face any impact of activities during and after.

3.2.5. Business case and consortia

There are some divergent insights from stakeholders on what types of food production would have a viable business case. One stakeholder specifically mentions low trophic marine aquaculture, i.e., seaweeds and shellfish, possibly in co-cultivation. Another stakeholder notes that most of them are promising but not fully understood or developed yet. While a third thinks there are almost none today.

Seaweed, mussel farming, passive fishing. (Everything with a maximum area within the carrying capacity of the ecosystem). Active fishing is now not allowed for various reasons, which can be made viable for fishing, but with a price for other forms of use, so the Netherlands does not want to focus on that now. Fish farming is not profitable in the Netherlands.

When asked about the ideal future consortia, different combinations of wind industry, installation contractor, seafood producer, developer and research parties are mentioned.

That depends entirely on the location of the wind farm. Not everything is equally interesting everywhere. This also applies to the other forms of shared use.

The food production party will have a business case separate from the offshore wind farm operator. It is possible to share the costs of the seabed lease and share O&M operations with the wind farm operator. Income is based on the production of functional proteins for human consumption.

Not many replies are received on the question of what foundations would be possible for multi-use food production structures in offshore wind farms. One stakeholder is firm in their preference for permanent mooring. It is mentioned by another stakeholder that modules from nature enhancement can be designed to facilitate multi-use

3.3. Stakeholder perspectives on multi-use with energy generation

The questionnaire on perspectives of multi-use with alternative energy activities was shared with relevant stakeholders, among which are (the number indicates total questionnaire submissions received from this type of stakeholder):

- offshore wind developers and utility companies (7)
- offshore wind installation contactors (5)
- multi-use innovators that design and manufacture artificial reef structures (2)
- non-governmental organisations active in environmental protection of the North Sea (2)
- regulating bodies of the Dutch government (2)
- research institutes (3)

3.3.1. Opportunities

From investigating the responses of various stakeholders, the most impactful opportunities in regard to energy multi-use are:

1. Efficient use of space
2. Sharing capacity of infrastructure
3. Sharing capacity of operating vessel fleet

These opportunities are also expected, for integrated designs of offshore wind farms could achieve lower CAPEX and OPEX for higher yield, higher energy density per unit area, and more utilisation of the existing export cables to connect to the national grid. This translates to making the levelised cost of energy cheaper.

3.3.2. Challenges

Challenges are generally more abundant and equally weighted amongst stakeholders with an interest in alternative energy technologies. However, distinctions can still be seen, with the most pressing ones highlighted as:

1. Unclear legislation concerning permitting and decommissioning
2. Immature or non-existing business case
3. Safety and technical risks
4. Large costs (insurance, monitoring, etc.)

These challenges are all interrelated, but the need for better legislation criteria can help overcome these challenges (including the tendering criteria challenge itself). The business case for more early-stage renewable energy generation technologies such as PV and hydrogen is still costly, and de-risking is further required. If there is no clarity about the intent of the government criteria to deploy these technologies offshore, then there is a risk of a lack of incentive to take on these risks.

Furthermore, challenges pertaining to a lack of well-defined concepts were also mentioned, and this can put a strain on the technological aspects of integration. Missing well-proven technology leads to risk in the business case; hence, feed-in tariffs and demonstration projects are needed to promote these synergies.

From the table, there is common agreement amongst stakeholders concerning opportunities, as previously mentioned, and they are mainly technology and business case-related opportunities. Challenges are more varied; the majority fall under challenges to governance (lack of interest, vision, legislation) and business case (immature or non-existent, conflict of interest and high costs).

Stakeholders within the energy theme place their core responsibility mainly on:

1. Advancing technology
2. Advancing the business case

and require:

1. Advancements in regulatory framework
2. Advancing technology
3. Advancing the business case

It is interesting to note which stakeholder type was most sought after to partner with to further develop offshore wind farms. Across all stakeholders responding to the energy theme, multi-use innovators and developers were most sought after, followed closely by regulators.

Stakeholders were also asked to respond to energy-specific questions. Their responses are summarised and aim to provide a further understanding of the issues regarding alternative energy production within offshore wind farms. These are the opinions of the stakeholders who contributed to the survey.

3.3.3. Technology aspects

Stakeholders expressed that the risks of integrating different technologies within offshore wind farms will present themselves in the form of installation and operation activities, leading to performance impacts on other systems. The addition of new technologies will modify the layout and the execution planning regarding their integration, installation constraints, and electrical architecture deeply as well. For efficient use of space, careful consideration needs to be given to corridors for transport.

Furthermore, the integration of cables and substations transformers will also require changes to accommodate more power flow. If other forms of energy are produced, such as hydrogen, pipelines will lead to design considerations of the whole wind farm to reduce the cost for installation and O&M.

On a larger scale, the up-scaling of newer technologies will also have an impact on the space taken up by development areas that still need to be assigned in the North Sea; hence, earlier integrations into the design of these lease areas are important.

3.3.4. Governance aspects

Stakeholders were in consensus that proper governance and clear vision in tendering criteria along with legislation is an important driver to develop hybrid power plants on the North Sea. The need for European energy independence due to the most recent threats to supply and ensuring a more stable supply from renewables (hence reducing variability in the system) are ongoing themes that need to be considered for future development. Therefore, the opportunity to impose obligatory tendering requirements is necessary. It is still not to the wind farm owner's benefit to add additional energy devices since offshore wind is a well-proven technology with a sharply declining LCOE. To realise the integration of alternative energy technologies, strict and clear goals need to be added to the tender requirements.

Multi-use should, therefore, be part of the early design phase. The current lack of clarity about who should decide, when, and what is allowed in the park is a hindrance to moving forward.

Furthermore, guidelines and standards for innovative alternative energy solutions are too high and need to be lowered to give these solutions a chance.

Another large requirement would be amendments to the existing Offshore Wind Act, which currently only allows for offshore wind energy to be transported to shore by the TSO. This will need to change to allow for other renewable energy sources to plug into the grid. The new energy act (*Minister voor Klimaat en Energie (2022)*) does allow this, but the primary goal is still to connect offshore wind energy to the grid.

3.3.5. Business case aspects

Future consortia will still involve long-standing industry leaders, but diversity should be included to make way for innovators and research institutions to facilitate the development of offshore parks from the beginning. The emphasis moving forward should prioritise the opportunities identified above, such as sharing space, infrastructure capacity, vessel fleet, and ensuring collaboration.

The sharing of risks in regard to curtailments depends mainly on the type of ownership (singular or co-ownership) and the offtake contract structure (such as a power purchase agreement). Ultimately, closer cooperation is needed between parties. The easiest way forward is if energy assets are owned by the same developer or operator. Therefore, having a central command of the ownership would be most efficient. However, this should not discourage the co-ownership of offshore energy parks, given the complexity of possible technologies that could be present.

3.4. Conclusions on stakeholder perspectives

Of course, we have asked the stakeholders about their perspectives on the individual themes of Nature, Food and Energy and their feedback, in closed and open form, is presented above. However, if we look at the overall picture, conclusions can be drawn on a general level.

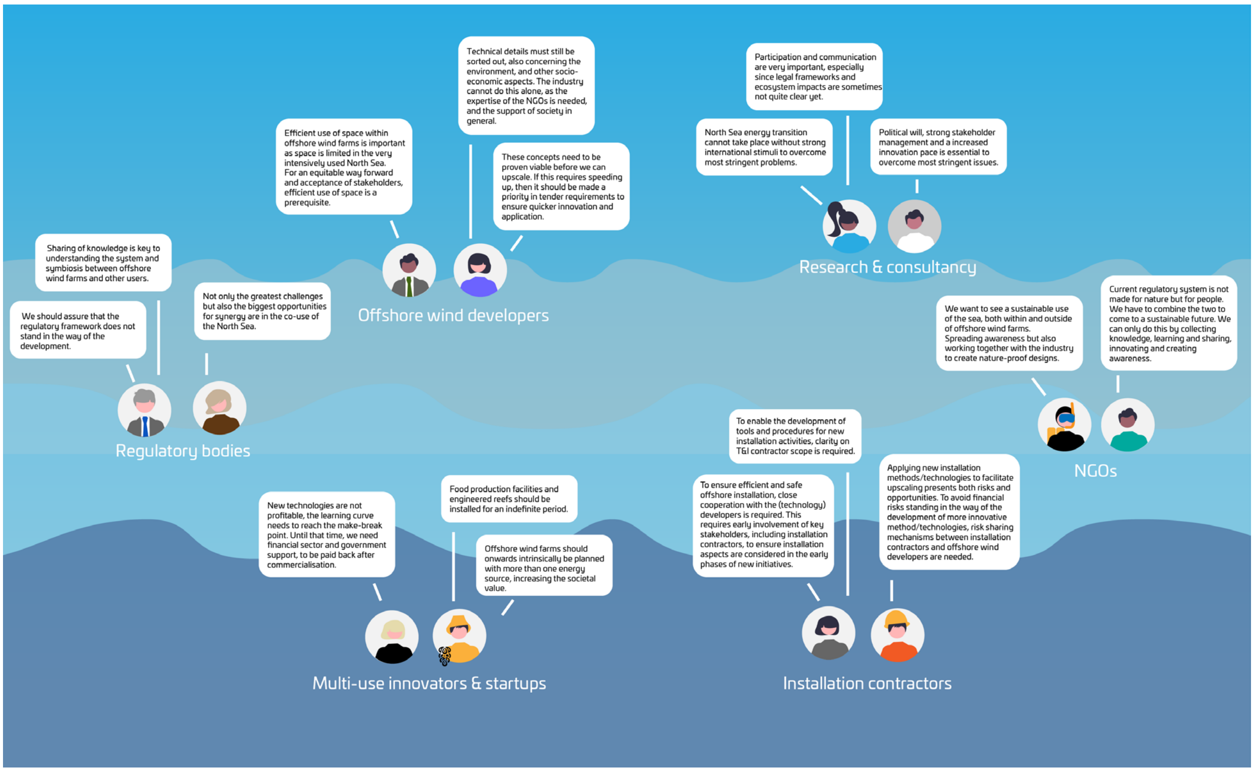

Figure 3.2 Exploring stakeholder perspectives on symbiosis: challenges and opportunities

Opportunities

For instance, we see that the stakeholders believe that combining offshore wind with nature, food, or other energy aspects creates opportunities for utilising the marine space more efficiently. On a technical level, the stakeholders see opportunities in shared infrastructure, mooring and operating the vessel fleet. Specifically, the infrastructure offers opportunities for enhanced nature monitoring.

Challenges

In terms of challenges, the stakeholders identify that legislation concerning permitting and decommissioning is unclear. In terms of finance, they see that the costs of multi-use are high, with high insurance costs, high offshore operation costs and a lack of business case and/or track record of technologies. In that sense, the complex field of stakeholders and conflicting interests will definitely not help. Last, the stakeholders identify risk as a challenge, considering, among others, the increased (shipping) activity within wind farms.

Responsibilities and Requirements

Most stakeholders see it as their responsibility to advance innovation in the field of multi-use, both in terms of nature as well as energy. With respect to the former, the stakeholders saw a role for themselves in advancing stakeholder engagement and awareness, and they expect action from developers and even more from the government in terms of a regulatory framework. With respect to energy, the stakeholders see a responsibility to advance technology and advance their business cases. This is also a requirement to make alternative energy happen in offshore wind farms.

To elaborate on the governance of multi-use (energy) offshore wind farms, the stakeholders were in consensus that proper governance and clear vision in tendering criteria along with legislation is an important driver to develop hybrid power plants on the North Sea. Interestingly enough, the 'energy' stakeholders claim that multi-use should be part of the early design phase, whereas the 'food' stakeholders seem to have contradicting viewpoints given the next two quotes:

"Now, it is better to integrate food production in wind farms from the start to get the most profit out of a certain area. In this way, the offshore wind farm can be designed in such a way that makes food production feasible within the area."

"The tender could already require this option. However, permitting and installation of food production in wind farms should happen after the wind farms have been built."

Clearly, a long-term vision of multi-use offshore wind farms is necessary.

4. Roadmap of actions to enable multi-use

In the previous chapters, various aspects of multi-use in offshore wind farms are investigated by means of a literature review and stakeholder consultation. This resulted in a better understanding of opportunities, risks and challenges associated with the three different types of multi-use activities in wind farms: nature, food production and alternative energy generation. Subsequent stakeholder interactions in the format of a survey and workshops were used to collaboratively formulate specific actions that have the potential to accelerate the development of multi-use offshore wind farms. Some of these actions are related to policy modifications, and some are related to technological or knowledge development.

The actions are presented below per type of multi-use. This division is kept because the different types of multi-use are generally facing different challenges. A reflection on the possible common (integrated) roadmap of actions beneficial for multi-use, in general, is further discussed in case study 3 (section 5.4).

4.1. Actions to enable multi-use with nature & ecosystem strengthening measures

Different stages of implementing nature-inclusive design solutions in offshore wind farms are facing different types of challenges. The overall difficulty in creating effective NID solutions is exacerbated by the lack of a holistic vision for nature protection and restoration in the North Sea on different spatial scales. The main challenges in implementing these solutions are related to legislation and permitting aspects. Next to that, a lack of traditional business case and established best practices in the design are hindering the development by market parties. Possible technical risks to offshore wind farm infrastructure and lack of open knowledge-sharing procedures between the developers are additional factors slowing down the process.

The challenges listed above are multi-faceted and diverse in terms of their scale and the responsible stakeholders. In an attempt to untangle this complex set of challenges and to find solutions for going forward, a set of actions was formulated together with stakeholders. These actions are described below. The order in which these actions are presented reflects the time horizon at which these actions should ideally be realised, ranging from immediate actions to long-term, more complex actions, but remains indicative. Main responsible stakeholders are also suggested as a first indication for each action, although in most cases, it can be argued that a wider group of stakeholders needs to be involved in the execution.

Actions to enable multi-use with nature:

1. Formulate a vision for achieving the good ecological status of the North Sea
   (Regulatory bodies, NGOs, Research & consultancy)
2. Simplify permitting framework
   (Regulatory bodies)
3. Enable data sharing through an open data facility
   (Regulatory bodies, NGOs, Research & consultancy)
4. Develop a decommissioning framework
   (Regulatory bodies, NGOs, Research & consultancy)
5. Develop effective tender requirements and procedures
   (Regulatory bodies)
6. Integrate ecological monitoring with infrastructure

(Regulatory bodies, NGOs, Research & consultancy)

7. Design and deploy large-scale pilot projects
   (NGOs, Research & consultancy, offshore wind farm Developers, Installation contractors)
8. Establish a biodiversity innovation fund
   (Regulatory bodies, Research & consultancy, offshore wind farm Developers)

4.1.1. Action 1: Formulate a vision for achieving the good ecological status of the North Sea

A holistic vision for the ecology in the North Sea would need to be formulated, accompanied by clear targets and metrics for ecosystem strengthening and nature protection. This vision is necessary to create focus regarding nature restoration and ecosystem-strengthening activities and support the decision-making in nature-inclusive design. The lack of such a vision currently has been indicated as a major challenge to the offshore wind farm developers, NGOs and policymakers. The ecosystem-strengthening activities within a single wind farm must be harmonious with the efforts outside of the wind farms and, ideally, throughout the rest of the (basin-scale) region to achieve a net positive impact. This vision must provide an answer to what constitutes success in marine ecosystem strengthening.

To formulate this vision, an independent (inter)national expert panel could be formed, consisting mainly of experts from the fields of (system) ecology who are also experienced with interfaces between ecology, policy and technology. This panel would be tasked with developing a vision for the (Dutch) North Sea based on the best available scientific information and international policy. Importantly, this panel would then need to review upcoming tender criteria and evaluate planned measures in order to make a practical interpretation of this vision.

The expert panel can be assembled already in the short term. We recognise that a holistic vision for the ecology in the North Sea can likely not be formulated fully in the short term due to many uncertainties that exist, but as a first step, this panel can define the main, practically applicable criteria for a good ecological status of the Dutch North Sea, and create an understanding of how a potential intervention can be assessed on its ecological value. This expert panel should work in close contact with stakeholder panels (such as the Community of Practice North Sea – CoP Noordzee).

4.1.2. Action 2: Simplify permitting framework

The current permitting procedures and rules for installation and decommissioning of artificial reefs and reef-like structures are complex and are perceived by many stakeholders (developers, installation contractors, wind farm operators/owners, and especially innovators) as hindering development. Permitting procedures would need to be simplified and streamlined by creating a “one-stop-shop" for permitting nature-inclusive design elements and associated experimentation. These procedures would need to be designed with the goal of facilitating ecosystem-strengthening initiatives.

The new permitting structure would need to be a joint initiative by all relevant governmental parties. This could be facilitated by forming a panel representing the Netherlands Enterprise Agency (RVO), the Ministry for Agriculture, Nature and Food Quality (LNV), the Ministry for Infrastructure and Water (I&W), the Ministry of Economic Affairs and Climate (EZK) and Rijkswaterstaat (RWS). This initiative could be integrated with the existing interdepartmental North Sea initiative of the Dutch Government, IDON (Interdepartementaal Directeuren Overleg Noordzee[47]).

This action is deemed independent from other actions and should be initiated in the short term.

4.1.3. Action 3: Enable data sharing through an open data facility

Continuous ecological monitoring would be needed to map out and monitor the ecological state of the North Sea to design appropriate ecosystem-strengthening measures and assess their effectiveness. Monitoring offshore is complex, and data is usually scarce, which makes it even more important to make the monitoring data that is available open and accessible. We strongly recommend creating an open data facility or making use of an existing facility (e.g., InformatieHuis Marien[48], which would serve as a monitoring database for ecological research.

This data facility would need to follow the FAIR principle (Findable, Accessible, Interoperable, Reusable). The database would have to be accompanied by a framework for collecting, maintaining and accessing the data. The requirement to share monitoring data could become part of offshore wind operation permits. The recommendation on which parameters are important to monitor and in what way (accuracy, duration, spatial, depth and time resolution) should be informed by science and be linked to the overall ecological objectives for the North Sea (see action 1).

Such a data facility could be set up by the Dutch government in the short term, e.g., through the MONS Program[49].

4.1.4. Action 4: Develop a decommissioning framework

Part of the complexity of designing and permitting nature-inclusive design, particularly for artificial reef-like structures, lies in the uncertainty regarding the future decommissioning requirements. Decommissioning rules for artificial reefs inside wind farms, including those that are integrated into scour protections or foundations, would need to be reviewed such that they would be stimulating for new artificial reefs to be built with a net positive effect on ecology. The revised framework would need to give developers, installation contractors and innovators more certainty in NID projects and, at the same time, ensure that the possible artificial reef effect of infrastructure is not used to justify leaving the infrastructure in place when it is, in fact, harmful to marine life.

A successful decommissioning framework would need to be linked to the holistic vision of the ecology of the North Sea (see action 1) and consider the positive and negative impacts of structures at various scales. Naturally, negative short-term and long-term effects of the remaining infrastructure should be carefully considered (e.g., risks of marine pollution).

This action is linked to action 2 (permitting framework) and could also be enacted by an interdepartmental collaboration, e.g., through the IDON panel.

[47] https://www.colruytgroup.com/nl/duurzaam-ondernemen/initiatieven/zeeboerderij rleg-noordzee/
[48] https://www.informatiehuismarien.nl/
[49] https://www.noordzeeoverleg.nl/noordzeeoverleg/mons-programma/default.aspx

4.1.5. Action 5: Develop effective tender requirements and procedures

Ecological tender criteria for offshore wind farms are currently the main driver of nature-inclusive design in offshore wind farms. There is no traditional business case for ecosystem-strengthening measures, yet they require a considerable investment in terms of finances, planning and knowledge development. Clear and scientifically informed ecological tender requirements could be used to incentivise the desired NID development.

In an upcoming offshore wind tender, the ecological requirements are specified further (e.g., the tender criteria for IJmuiden Ver Alpha offshore wind farm are more specific than those for Hollandse Kust West VI offshore wind farm). Although the new tender criteria include a significant ecological component, they are not providing a baseline of ecological measures to all bidding parties: each party must come up with their solutions by consulting relevant experts. This may lead to a large spread in proposed measures and fragmentation of knowledge development, and thus, inefficient use of resources in the offshore wind farm industry.

Further development of tender procedures would need to be in concretising the appropriate measures that need to be deployed in a specific offshore wind farm zone beforehand to reduce the competitive character of developing ecological knowledge and practice and focus on utilising and generating open information and research. To provide ecological requirements and boundary conditions for future wind farms, a lot more cooperative approaches are needed.

This action would need to be realised by the EZK and LNV ministries in the Dutch Government, with input from the knowledge panel on the holistic ecological vision for the North Sea (see action 1).

4.1.6. Action 6: Integrate ecological monitoring with infrastructure

Ecological monitoring includes measurements of both biotic (e.g., biodiversity) and abiotic (e.g., flow and seabed) parameters. Monitoring using dedicated equipment and vessels is at present quite costly and not feasible to do frequently and over large areas, although it is necessary. In the future, ecological monitoring could best be embedded in the offshore wind farm operation by using the core infrastructure of wind farms and maintenance vessels as a basis; such integration would help lower the financial threshold for monitoring and increase the amount of data available to researchers significantly. The monitoring infrastructure could be supplemented by unmanned and automated measurement techniques. As part of the MONS programme research, the availability of new, innovative monitoring technologies for ecological monitoring within/near offshore wind farm will start in 2023. This research will be carried out in close collaboration with the offshore wind farm industry so any ‘low-hanging fruit’ technologies can be implemented directly.

Some level of integration monitoring processes in the current infrastructure and operations could be achieved in the short term within wind farms currently under construction. Deep structural integration of monitoring practices in the offshore wind farm infrastructure could best be done from the start and embedded in the offshore wind farm design using novel monitoring techniques.

This action would need to be stimulated by tender requirements in upcoming offshore wind farms, where guidelines on the monitoring methods and required parameters would need to be provided. This action is linked to the development of overall ecological objectives for the North Sea (action 1), and it is closely interrelated with the proposed open monitoring data facility (action 3).

4.1.7. Action 7: Design and deploy large-scale pilot projects

Pilot projects are essential for accelerating knowledge development about effective ecosystem-strengthening measures. Pilots can be set up on different spatial and temporal scales, depending on the objective, e.g., testing an artificial reef structure around a single turbine foundation or monitoring solutions deployed across a wind farm to assess the cumulative effects. Existing wind farms could also be used as testing sites for nature-inclusive design. New wind farms can best be used as test sites for the development of measures concerning the ecologically oriented design of the core infrastructure itself since adjusting existing assets will be, in most cases, impossible. Pilot studies for new concepts with low TRL could even be performed at test sites outside wind farms.

The goal of offshore pilots would be to explore concepts and lower the risks by "learning by doing", addressing the issue of the lack of well-proven concepts. In addition, pilots can be used to develop a business case that supports innovators, especially SMEs (small & medium-sized enterprises). Insights from pilot studies, if made publicly available, contribute to public knowledge development and information sharing amongst stakeholders. Synergies between different stakeholders can be explored in these pilots to develop management practices for future wind farms.

Small-scale pilots are already ongoing at test sites in the North Sea, mostly at test sites outside of offshore wind farms or at small test sites within existing offshore wind farms. However, pilots who assess the effects of upscaling various NID designs are also needed in the short term. Considering that setting up such pilots relies on ecosystem understanding and a basin-scale holistic vision, preparation should start as soon as possible. It is important that such pilots are initiated before most new wind farms are built (by 2030) so that learnings can be implemented from the start.

This action depends on the progress of other actions related to permitting (action 2), tender requirements (action 5), and the development of a holistic vision (action 1). The results of pilots and ecological monitoring within offshore wind farms could be shared through an open monitoring database (action 3). The development of the large-scale pilots is an action that would need to be implemented through a collaboration between offshore wind farm developers, offshore contractors, ecological restoration innovators and environmental NGOs.

4.1.8. Action 8: Establish a biodiversity innovation fund

One of the struggles in deploying ecosystem-strengthening measures in the North Sea is the lack of dedicated funding for nature restoration and ecosystem strengthening. An ecological biodiversity innovation fund could contribute to the solution of this problem, and it could be made mandatory for new offshore wind farm projects to contribute to this fund. The first steps in this direction are already being taken in the tendering process for the development of the IJmuiden Ver offshore wind farm. The resources from the fund would need to be spent on targeted ecological measures that are judged most effective and urgent based on the holistic vision for nature in the North Sea (see action 1). This way, a financial instrument will be created to enable the right ecological measures to be applied in the right places, as opposed to fragmented efforts within separate wind farm areas.

In order to deploy this initiative effectively, there are a few crucial questions that would need to be answered. Who should be responsible for the implementation of ecological measures? How to finance the most effective measures towards the holistic, basin-scale vision of the ecology in the North Sea? Which stakeholders and which actions should be best financed by this fund?

4.2. Actions to enable multi-use with food production

The main opportunity for food production within offshore wind farms is an efficient use of space; since fishing grounds are reduced with wind farms, there is space for other food production in these areas. Pilots have shown technical feasibility. Mussel farming, seaweed farming and passive fisheries are proven technology outside of wind farms. However, this was mainly near- or inshore. Ecological opportunity is there in the form of aquaculture locations forming habitats for other species. Sharing of infrastructure and facilities with the offshore wind farm could be an economic opportunity in the future.

Food production within wind farms is not without its risks. Increased (shipping) activity within wind farms increases the risk of collisions. Next to that, there are other safety concerns associated with technical risks. These risks lead to high(er) insurance costs.

The main identified challenges (knowledge gaps on design parameters; processing of food from offshore; unclear regulatory framework; limited carrying capacity North Sea; lack of viable business case; large cost of offshore operations; insecure sales market; lack of well-proven concepts and track record in the field) could be tackled by a set of actions as described below. The order in which these actions are presented reflects the time horizon at which these actions should ideally be realised, ranging from immediate actions to long-term, more complex actions, but remains indicative. Main responsible stakeholders are also suggested as a first indication for each action, although in most cases, it can be argued that a wider group of stakeholders needs to be involved in the execution.

Actions to enable multi-use with food production:

1. Design and deploy large-scale pilot projects
   (Offshore wind farm developers, Multi-use innovators & start-ups)
2. Develop a vision and define targets for offshore aquaculture in policies
   (Regulating bodies, Research & consultancy)
3. Integrate food production in offshore wind tenders
   (Regulating bodies)
4. Launch an awareness campaign to increase the market potential of North Seafood
   (Offshore wind farm developers, Multi-use innovators & start-ups)

4.2.1. Action 1: Design and deploy large scale pilot projects

Large-scale pilots would need to be developed within offshore wind farms. These pilots could focus on farming either mussels or seaweed on a substantial scale.

All aspects of the shared use thus could be tested since a pilot would involve the entire operation. A pilot within an offshore wind farm would make efficient use of space as it is within the wind farm, and the associated challenges could be better identified and understood. Efficiency gains in combining vessels, mooring and environmental impact assessments may be explored to understand the viability of these synergies for future projects. A pilot would increase the industry experience with these offshore structures and, therefore, lessen the technical risk and increase the track record of the developers. Pilots are expected to have large costs associated with it. The pilots can be realised in the short term; the first pilots are already in planning.

4.2.2. Action 2: Define targets for offshore aquaculture in policies

If aquaculture in offshore wind farms is to be realised on a large scale, there would need to be targets in (Dutch) policy. This could be done in the form of a roadmap for food from the North Sea. In these targets, the desired food type and quantity to be produced should be defined. This should take into account the ecological production limits locally and system-wide. Next to ecosystem limits, rules and regulations for safety criteria to enable insurance would need to be implemented. With these targets, food production might also be part of the tendering of an offshore wind area.

Progress towards these targets would need to be facilitated through the regulatory framework to ease food production project development and permitting within offshore wind farms. This action would enable the reduction of risks in terms of uncertainty for developers and investors. With clear targets, investing in offshore food production will become more interesting.

Before well-founded targets can be defined, more knowledge would need to be gained on the potential market opportunities, carrying capacity of the ecosystem and the techno-economics of the cultivation systems. Part of this knowledge would be developed in the pilots; for other topics (subsidised), research would be required.

4.2.3. Action 3: Integrate food production in offshore wind tenders

Food production targets could be integrated into offshore wind tenders, with a focus on achieving efficient use of space. Taking food production into account from the tendering phase would enable the integration of food production in the design of the wind farm. For instance, design choices could be made in the spatial layout: mussel longlines are best installed in the direction of the current to reduce drag loads. Other possible synergy advantages could be standardised anchorage systems or sharing of vessels.

This action can be realised based on targets of offshore food production (need to be defined as described in action 2).

4.2.4. Action 4: Launch an awareness campaign to increase market potential of North Sea food

An awareness campaign could be launched to promote sustainable, local and healthy food from the North Sea. This campaign is aimed at increasing the market potential of offshore seafood that is sustainably produced. This would help to increase the business case and reduce the insecurity of the sales market. Before this campaign can be launched, more clarity is required on which foods can actually be produced at a reasonable cost in the North Sea.

We emphasise that while strengthening the business case for offshore food production, it is important to keep in mind the need to alleviate the pressure on spatial planning in the North Sea and to produce this food sustainably. There is a risk that a vastly improved business case could lead to more competition for space outside of offshore wind farms.

4.3. Actions to enable multi-use with energy generation, conversion and storage

As described in the previous sections, stakeholders with an interest in multi-use energy generation saw opportunities in more efficient use of space, sharing of infrastructure and operating capacity, where the incentives could come from obligatory regulations and requirements in the future offshore wind farms.

These opportunities, however, do come with their set of challenges, stemming mainly from immature business cases for newer technologies, unclear regulations to permitting, and an overall lack of interest to take on the risk of combined assets (especially if tender and regulatory requirements are not clearly stipulated). On top of these challenges, risks to safety and insurance costs due to the installation and operations of offshore energy parks need to be addressed.

Actions aiming to address these key opportunities, risks and challenges were formulated, informed by consultations with stakeholder representatives and the knowledge of the present and the upcoming energy landscape of the Netherlands. The order in which these actions are presented reflects the time horizon at which these actions should ideally be realised, ranging from immediate actions to long-term, more complex actions, but remains indicative. Main responsible stakeholders are also suggested as a first indication for each action, although in most cases, it can be argued that a wider group of stakeholders needs to be involved in the execution.

Actions to enable multi-use with energy generation, conversion and storage:

1. Formulate a clear vision and tendering conditions
   (Regulating bodies)
2. Implement a demonstration pilot of an energy park
   (Offshore wind farm developers, Multi-use innovators & start-ups, Regulating bodies)
3. Develop protocols for planning of infrastructure, O&M and accessibility
   (Offshore wind farm developers, Installation contractors, Multi-use innovators & start-ups)
4. Develop realistic integrated business case models
   (Offshore wind farm developers, Research & consultancy, Multi-use innovators & start-ups)
5. Develop an approach to financial incentives
   (Regulating bodies)
6. Develop time-sensitive and simplified permitting procedures
   (Regulating bodies, Multi-use innovators & start-ups, Offshore wind farm developers)
7. Reduce safety concerns
   (Offshore wind farm developers, Installation contractors, Regulating bodies)

4.3.1. Action 1: Formulate a clear vision and tendering conditions

The utmost priority is the need for a clear vision of offshore energy parks of the future. This implies setting the criteria as to what an offshore wind farm should prioritise in terms of performance metrics to be considered a winning bid. This could take shape in promoting a more reliable and stable source of power flow to the energy system or to maximise the energy density of allocated development space. In essence, simply valuing the levelised cost of energy (LCOE) as the driving force for feasibility is an impediment to multi-use, at least in the state of the current timeframe.

Furthermore, ensuring that energy from different technologies can land to shore requires an amendment to the existing energy act, where presently, TenneT is only instructed to transport offshore wind energy to shore. This change would help guide the vision for integrated energy parks and future tenders.

At the moment, multi-use is facilitated through the area passports after the wind park is built. This is not optimal since multi-use activities should not conflict with the ongoing businesses of the wind park, and thus, it makes the business case more difficult. An alternative strategy would be to include multi-use during the park design and construction. This would result in a more viable business case.

This action is paramount as it would allow all other cascading actions to fall into place. It addresses unclear tendering criteria and lack of a vision and would also impose on developers and partners the need to cooperate to be considered, thus taking on the risk to advance technologies in a more integrated way. This would also increase the maturity of emerging technologies through demonstration.

This vision must be established in the short term (in the next few years) to encourage partnerships and speed up the maturity of technologies and business cases.

4.3.2. Action 2: Implement a demonstration pilot of an energy park

A demonstration park can take the shape of any mix of technologies and help create a sandbox for real-life testing, operations, and maintenance activities to be conducted. While promoting new technologies, it can also demonstrate synergies in production, complementarity of resources, and sharing of infrastructure within offshore wind farm zones. Not only are the technological and business opportunities realised, but business and government challenges can also be explored here by de-risking immature technologies and ensuring confidence for future development areas.

This action, therefore, addresses the challenges due to the lack of well-proven concepts, lack of cooperation, and safety and insurance risks because it promotes at the same time the opportunities of sharing of infrastructure, capacity, vessel fleet, and validating methods. It can also help to explore the potential business case for infrastructure synergies.

This action requires softer permitting and regulatory frameworks that can be prioritised with a proper vision and structure in place. It, therefore, relies on the existence of a vision framework as described in the previous action.

The timeframe for such a pilot demonstration site can be realised through the most recent tenders, and hence, they can be fully established by 2030. The earliest upcoming example of alternative floating solar energy in a wind park is expected by 2025 in the Hollandse Kust Noord offshore wind farm.

4.3.3. Action 3: Develop protocols for planning of infrastructure, O&M, accessibility

Models can be developed to simulate the necessary costs, impacts, and synergies between closely spaced technologies, but eventually, this needs to be translated to safety and ease of access in real-world conditions. Real-world testing of such protocols helps validate models and provides training for ease of use and operations. This could be achieved through pilot demonstration, where risks of failure are expected and can be worked upon for further refinement.

This action helps address synergies of sharing infrastructure and vessel fleet while also refining cost savings, de-risking and thus lowering costs. Like the need for pilots, this can be part of their realisation for 2030.

4.3.4. Action 4: Develop realistic integrated business case models

Integrated business case models are currently being developed in industry and academia, ranging from investigations into power utilisation, dispatching to markets, revenue stacking and value assessments. These models, much like the previous actions above, would require testing under real-world conditions. The value added by integrated technologies should also be measured by different metrics than we have today and should align with our values towards electrification and decarbonisation rather than pure cost. This action aims to address the current immaturity of the business case.

To enable this action, both clarity of vision for offshore energy parks and hubs, along with regulatory criteria to adhere to, can influence the impact of such models. Pilot demonstrators or early rollouts of integrated farms from the most recent tenders can be the testing ground for new strategies and validation.

This action can be realised in the forthcoming years and further validated with pilot demonstrations or recently awarded tenders by 2030.

4.3.5. Action 5: Develop approach to financial incentives

The multi-use of offshore wind farms can be de-risked, given the proper framework and space to demonstrate. Models can be validated, and costs can be reduced over time. Eventually, to stimulate further development, incentives would need to be provided to promote business interest in multi-use and to achieve full commercialisation of integrated offshore energy parks. They can be in the form of subsidies, contracts for difference, rewards for baseload generation, etc.

Cost is the driving factor in investment decisions and is the path of least resistance to a minimum viable product. However, the motivation for developing offshore energy multi-use comes not just from cost but also from energy transition and decarbonisation efforts, which would need to be incentivised.

Incentivisation approaches can be further developed once the demonstration phases have produced commercially viable results and are ready for expansion to full-scale roll-out. Hence, timelines after 2030 might be more suitable for the action to take place.

4.3.6. Action 6: Develop time sensitive and simplified permitting procedures

An efficient way to simplify the permitting process of new technologies operating in the same space is needed. This would remove one of the biggest hurdles for innovative ideas, as they mostly do not fit within a standard framework. Permitting processes can easily go beyond the runway available to start-ups. Currently, it is assumed that separate permits under the Water Act, Nature Protection Act, and other regulations are needed for integrating other energy technologies in the offshore wind farm zones. The proper protocols to assess the impact on other technologies also need to be defined and tested.

This action would address the main challenge towards permitting and decommission regulations, along with safety concerns. It is dependent on amendments to regulations and, thus, a holistic vision for proper and clear regulation. This action would most likely be first tested in the recently awarded tenders and can further be explored in future pilot-scale offshore energy demonstrations to simplify the process. Hence, a realisation of 2030 is indeed realisable to set the stage for the next decade.

4.3.7. Action 7: Reduce safety concerns

Safety aspects around the unmanned interactions of different technologies will impact the business case, investor confidence, and insurance. Hence, proper pilot demonstrations, permitting consideration, and developing protocols for planning, installation, and operations are all crucial in realising such an action. This is of paramount importance to human health, but also performance, and should be the ultimate end goal along with providing other performance metrics.

This action will need iterative designs, testing and validation, and hence can only ever be fully realised with the existence of pilots under real-world conditions before certification of the offshore parks can be granted.

4.4. Concluding remarks

The actions defined in this chapter per type of multi-use display some general suggestions common to all three types, although differences can be found in the focus points. In terms of timeline, nature & ecosystem strengthening is most advanced, and installing pilots is a common action between all three themes.

Next to the pilots, most actions are defined for the policy domains. A common action is related to permitting: all desired methods for multi-use need a clear permitting framework - an important action for the near future. Reducing risks and improving the business case by technical advancement is an action for all themes.

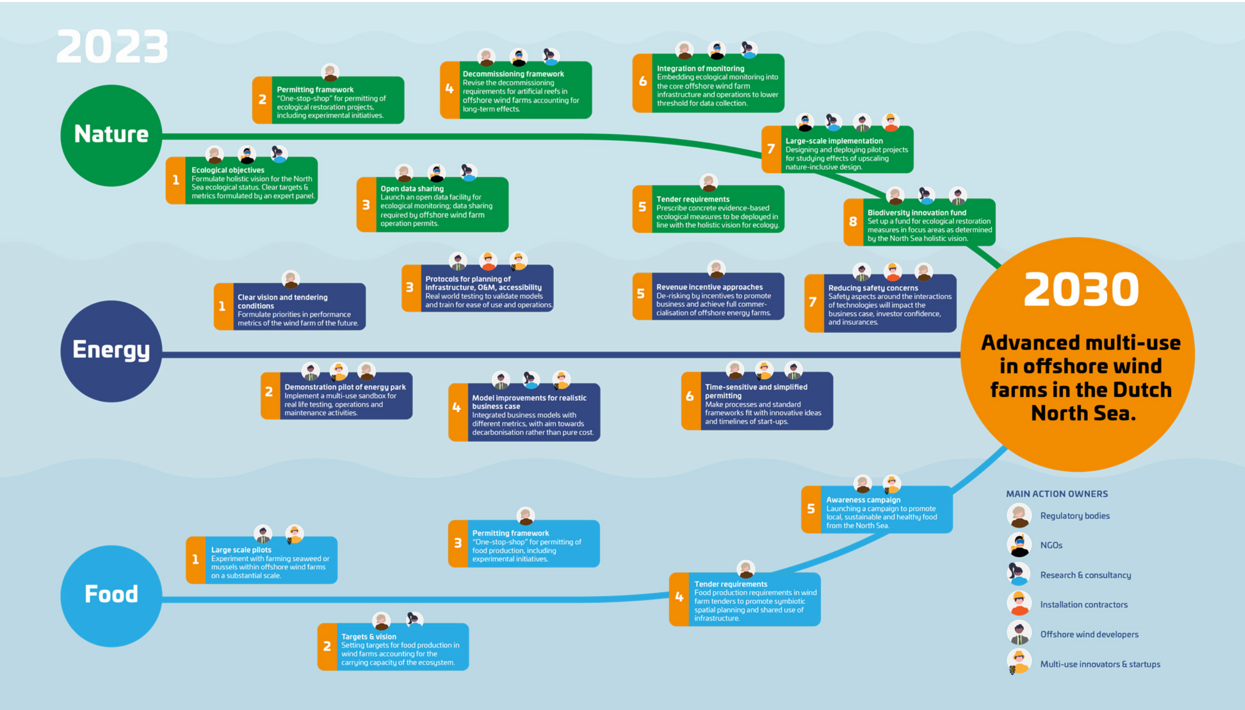

Figure 4.1 Key actions to advance symbiosis towards 2030

An integrated action roadmap that accounts for all themes towards fully symbiotic offshore wind farms in the far future is elaborated in case study 3, "The symbiotic offshore wind farm of the future".

5. Case studies

5.1. Introduction

The case studies have been selected such that they build upon the actions defined in the previous chapter and summarised below. They explore how these actions have been undertaken in the past, how these can be realised in the present and how they can lead into the future. Three different examples are used for this, in the form of three different Dutch wind farms: Borssele in case study 1, a present-day wind farm for case study 2 and finally, a theoretical wind farm in one of the search areas announced in the North Sea Programme, to be built by 2050 in case study 3.

5.2. Case study 1: Learnings from previous SID wind farms

5.2.1. Background and methods

This is the Symbiosis Inclusively Designed wind farm of the past or the lack thereof. This use case mainly focuses on giving input for the actions indicated in the previous chapter. The logic is that the actions are necessary because they were lacking or not in place for Borssele. This case study aims to investigate how the innovators involved in multi-use are looking at the Borssele wind farm site in setting up a multi-use business case for:

- sustainable energy (wave, solar)
- mariculture
- nature protection/restoration

For the Borssele wind farm, there is an "area passport" (gebiedspaspoort in Dutch) in place[50]. The area passport describes the areas with the preferred multi-use option. Together with the "area passport", there is a legal framework in place in which the multi-use developers are able to submit a permit application. The current status of multi-use activities in the wind farm is that there are only a few initiatives in place, such as the OOS mussel farm[51] and passive fishing experiments.

The research question of this case study is formulated as follows:

"What are the circumstances (enablers and showstoppers) that the areas being mentioned and available are not totally filled in/are covered (yet)? What is the background(s) of this? What might be the lessons to change things/make it happen either in wind farm Borssele itself or in the other wind farm already built or being built in the future?"

Road2SID reached out to various multi-use developers, and interviews were held with:

- multiuse developers Sustainable energy (2 parties)
- multiuse developers Food production (3 parties)
- multiuse developer Nature - environmental NGO (1 party)

The results of these interviews are summarised in the sections below per theme.

[50] Borssele wind farm zone - Noordzeeloket UK
[51] Permission to install the OOS Cees Leenaars mussel farm in the North Sea - OOS International

5.2.2. Results

Energy generation within offshore wind farms - Wave & solar

Concerning multi-use options of renewable energy generation (wave and solar in this case) within offshore wind farms, the perspectives are somewhat aligned between the two parties interviewed:

- There is no standalone business case due to relatively high costs in relation to expected revenues due to the harsh North Sea environment (waves, wind, current).
- Business case of energy multi-use activities can improve if:
  - multi-use assets are combined with wind farm (hook on, on the end of the string)
  - infrastructure (power outlet) at sea becomes available to plug in

Food production within offshore wind farms - Seaweed

The perspectives on seaweed cultivation within offshore wind farms differ between various parties:

1) No business case is available:
   - Footprint linked to fuel use is too high in relation to yield (per kilo yielded product)
   - There is a high-cost price anticipated linked to the required:
     - Operating ships with DP2[52]; certification, insurances
     - Design of seaweed farms is difficult in the North Sea's harsh environmental conditions (strong currents, unfavourable waves and wind conditions)
2) Business case is likely available:
   - Seaweed production is fairly new for authorities and insurance companies, which leads to numerous questions and challenges, eventually ending up in:
     a) Longer process towards a complete (“*ontvankelijke in Dutch*”) permit application for the Water Law related to Safety:
        - having an installation certified
        - no technical standards yet in place
     b) Longer process towards a complete (“*ontvankelijke in Dutch*”) permit application for the Nature Conservation Law:
        - need for describing the effects on nature. Since seaweed production is new, these results are not yet known from practical experience
     c) Longer time is needed to have the initiative insured
        - risks
        - potential damage to wind farm assets

Overall, this leads to relatively high costs to have the permits in place.

Recommendations mentioned were:

- need for a subsidy to have these costs covered
- monitoring should be part of the WOZEP programme of the authorities

[52] Dynamic Positioning navigation system.

Food production within offshore wind farms - Shellfish

Currently, OOS has a multi-use installation in place in the Borssele wind farm area. In general, the 5 drivers that determine whether shellfish production takes place are:

1) Suitable areas are coastal zones (nearshore) and Borssele, from the perspective that the right amount (many) of nutrients are present there.
2) Sailing time is a strong determining factor. Wind force 4 (Beaufort scale) is the limit to being able to work. At greater distances, this will become a factor in the number of workable days available. This affects the cost side of the business case.
3) Installations are known from abroad and have proven themselves there. However, the need to be maintained/managed on a weekly basis. A method (to be developed) with remote monitoring/sensors will bring this frequency down.
4) Wind farm owners formulate necessary (offshore) conditions. OOS has knowledge and experience with this in the offshore environment, has certificates and is insurable.
5) The OOS installation is relatively expensive and, therefore, a bottleneck for the business case.

Drivers 1 and 2 are deemed to be the dominant factors.

Ecosystem strengthening and impact mitigation within offshore wind farms

There is currently no investment or subsidy programme available to support new activities related to ecological measures within Borssele. As a result, except for experiments focused on oyster restoration,[53] there are no other initiatives within Borssele plots designated for nature-strengthening measures. NGOs are expected to come up with plans and investments, which proves a bottleneck (in terms of resources, time and money), given the lack of traditional business case when it comes to nature strengthening.

Food production within offshore wind farms – Passive fishing

Currently, LNV has contracted Wageningen Marine Research (WMR) to execute passive fishing experiments to address the ecological, financial and operational opportunities and risks of passive fishing in the Borssele wind farm. General observations are:

1. A Wind farm provides a safe location for passive fishing and opportunities due to the absence of active fishing.
2. The possibilities for passive fishing are limited due to fishing regulations and additional wind farm requirements defined in BAS.
3. Challenging business case due to far distance to shore, associated sailing time and costs
4. Scattered space for positioning nets and cages. Borssele wind farm layout is not optimal for positing nets.

[53] The Netherlands Joint Project – Blauwwind and The Rich North Sea Oyster Pilot – NORA (noraeurope.eu)

5.2.3. Summary

The various perspectives explored from the interviews are summarised below.

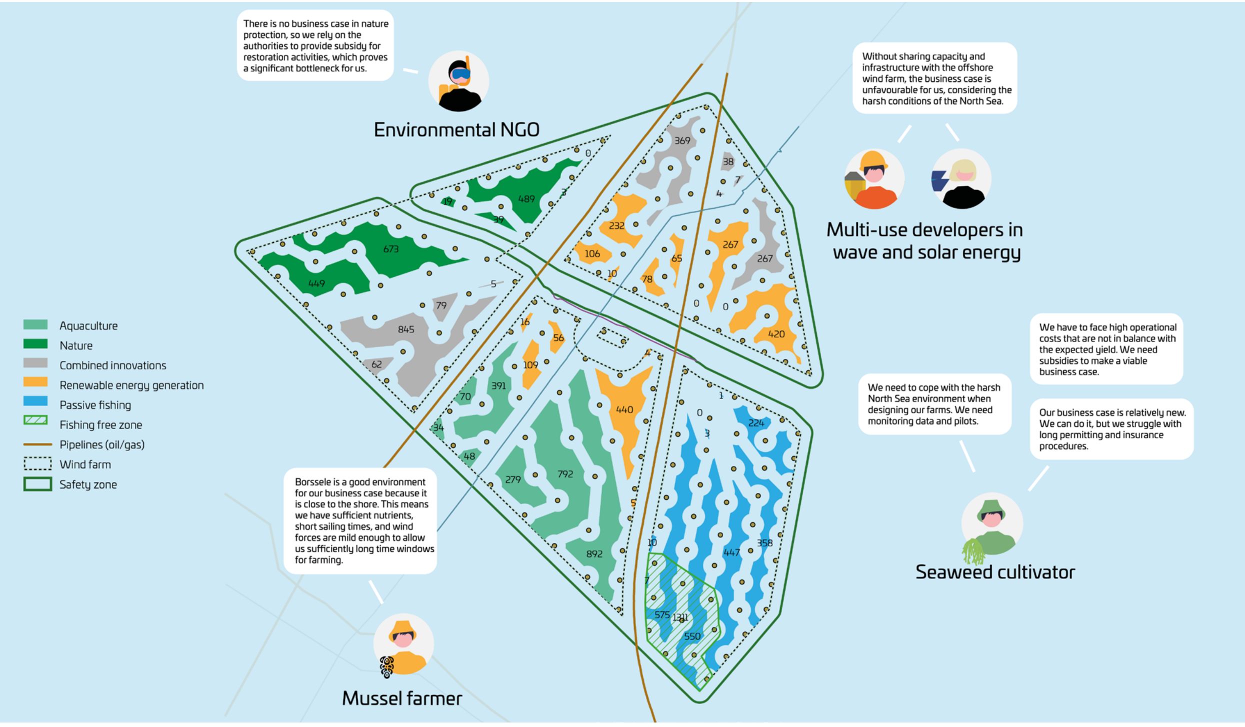

Figure 5.1 Summary of interviews with (potential) multi-use operators in the Borssele offshore wind farm

5.3. Case study 2: The present (or next) SID wind farm

5.3.1. Background and methods

Borssele wind farms have been in operation since 2021; however, multi-use activities are still limited. Case study 1 reveals the reasons behind this. In this case study, we want to take the learnings from case study 1 and focus our attention on what could be done in offshore wind farms that are now being built, or that will be built in the near future to stimulate multi-use in order to achieve SID. As such, it is a building block towards the last case study, i.e. the SID offshore wind farm of the future.

One contribution to stimulate and optimise multi-use activities is to develop an Operational Information System (OIS). The goal would be to make present and upcoming multi-use operations more efficient and safer by sharing information and thereby increasing multi-use business case potential. Therefore, this case study gives a blueprint for such an OIS that details and provides metrics for multi-use activities within wind farms.

Such an OIS is best developed for a wind farm that will be built, like Hollandse Kust West and Ijmuiden Ver, such that it is possible to incorporate specific OIS requirements already in the wind farm planning and design phase. However, an OIS can still be developed and implemented in the Borssele offshore wind farm and wind farms that are being built at the time of writing in 2023, I.e. HKZ and HKN. HKZ Wind Farm has been licensed with regulations for food production and nature conservation and could be more geared to food and nature-inclusive design. Plans have recently been made to develop an area passport for sharing the existing space between turbines in a similar manner to the Borssele Wind

Farm[54]. In HKN, the focus is more on energy asset infrastructure, where the Crosswind consortium has committed to demonstrating a floating solar pilot, along with battery and hydrogen conversion and storage.

For this case study, the following activities are foreseen in the offshore wind farm:

1. Energy assets comprising wind turbines, floating solar, and hydrogen offshore.
2. Food aquaculture in the form of seaweed and mussel farms.
3. Passive fishing activities.
4. Pilot demonstration facility for testing and research.
5. Nature-conscious monitoring and operations.

5.3.2. Objectives of the Operational Information System (OIS)

The goal of the OIS is to make present and upcoming multi-use operations more efficient to increase the business case potential by providing information. This efficiency can be achieved in different ways. Information can be collected and shared between users through an open-access information system and consists of system performance information and operational information tailored to the multi-use operator's needs. A proposed flow of information between the various users is illustrated in the following figure:

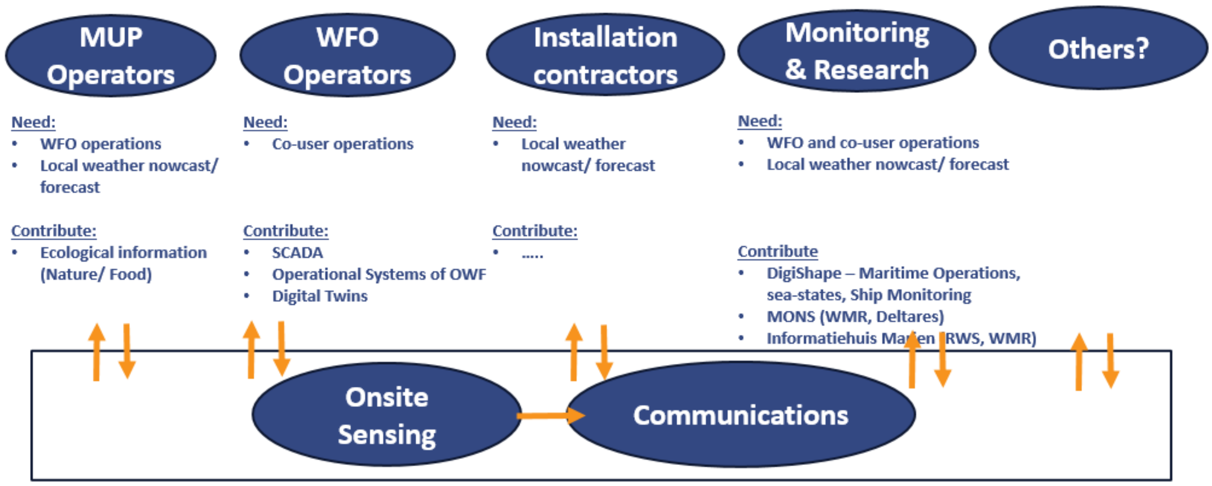

Figure 5.2 Flow of information between the various users of a symbiotic offshore wind farm.

Not all data and information can be collected and used by each user since the information provided by the OIS can cover various time scales, which are not all relevant to all users. There are different types of data and information depending to a large extent on the type of monitoring performed and the sensors that are used (left part of the figure below, as well as the way the information that is provided is used in decision-making (right part of the figure below).

The basic questions the OIS needs to address concern the required operations: inspections and O&M of the structures, harvesting periods, wave and wind restrictions for food and energy assets and for the vessels that will tend to them, etc. The OIS needs to ensure that the multi-use operator can base their

[54] Windenergiegebied Hollandse Kust (zuid) inclusief windpark Luchterduinen (LUD) - Wind op zee

operational activities and actions on a reliable time-based operations and monitoring system. So, the global purposes of the system are to:

- provide yield and production: energy and food
- provide system integrity and performance (long term): WT, FPV or aquaculture structure
- provide operational conditions (near term; real-time)
- provide safety and incident status (real-time)

It is acknowledged there are several information systems available already. Examples are:

- Informatiehuis Marien (abiotic and biotic information; long term statistics; open access)
- SCADA (WTG system status; long term and real-time statistics; private access)
- DigiShape (maritime and abiotic information; long term statistics; open access)
- MarineTraffic (maritime information; real-time; open access)
- Weather forecasts (real-time and forecast; open access)
- UNITED Decision Support System (real-time and forecast; open access)
- Wind op Zee[55] (publicly available, long-term wind measurements across the North Sea)

These systems demonstrate the need for open-access information on biotic and abiotic metrics; the plurality of systems demonstrates the lack of one central system.

For operational decisions, to optimise the operations, real-time information and short-term forecasts are vital. This requires bringing information in real-time from the wind farms to the decision-makers onshore. RWS has the ambition to facilitate the infrastructure that is necessary to transmit large amounts of information at high speed. In the framework of the above, the Road2SID consortium strongly supports this ambition, particularly in the realm of this use case.

The system could be facilitated by a governmental body, such as RWS. This ensures independence and Dutch North Sea coverage. Contributions to the system could be enforced by the tender criteria of new infrastructure projects in the North Sea. Contributions include both financial contributions for the development and maintenance as well as contributions by adding open access information. RWS is, in fact, already undertaking activities to facilitate better digital connectivity for collecting data, which will ease the development of the OIS. See, for example, the Connectivity Fieldlab North Sea project[56] and the DigiShape open innovation platform where RWS, industry, and research institutions are working together on projects, experimenting with data innovations for water applications.

The system allows the retrieval of various depths of information depending on the interest of the specific users. The OIS will be used by:

- WFOs to store and retrieve SCADA data and as an O&M planning tool.
- multi-use operators for monitoring of harvest (food) and system status (energy); operational planning and risk warnings
- installation contractors for real-time weather data and forecasts during construction
- research institutes for advising and authorities for monitoring the biotic status (nature and food) and safety of maritime operations towards and inside the wind park

[55] www.windopzee.net
[56] https://www.noordzeeloket.nl/functies-gebruik/scheepvaart/digitale-connectiviteit-noordzee/

5.3.3. Blueprint

Having set the objectives above, the next questions are how the system should look like and what quantities need to be measured and/or gathered. The blueprint, from a functionality perspective, of the Operational Information System is given below.

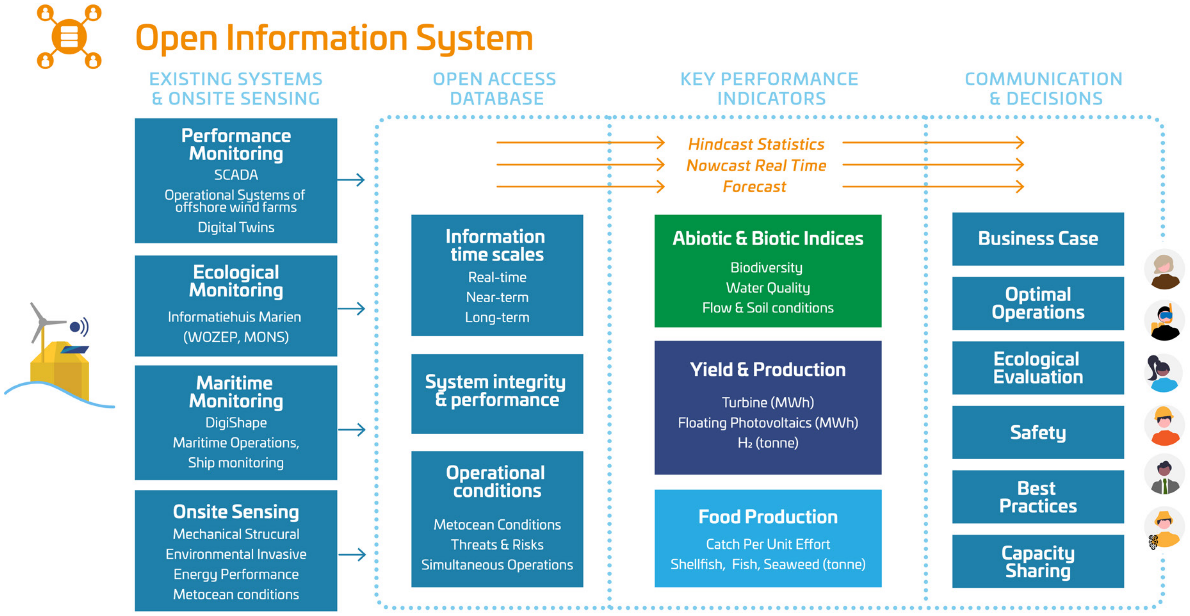

Figure 5.2 A blueprint of the Open Information System from a functionality perspective

Here, we identify the main functionalities of the system to be:

- Sensors to measure onsite conditions (i.e. Performance Monitoring). The Operation Information System (OIS) collects information relevant to multi-use activities. It is acknowledged that there are several information platforms, yet we propose that the information from these different measurement and monitoring platforms is plugged into the system. The system will integrate and offer the following (integrated) information:
  - mechanical/structural
  - energy performance (OWT, FPV)
  - met ocean conditions
  - biotic conditions of the ecosystem
  - maritime operations
  - environmental hazardous information

  These sources of data and information tend to mostly provide (near) real-time information for the decision-making process of short-term operational multi-use (e.g., harvesting or O&M planning). The details around these quantities are indicated in the figure below and the text underneath.

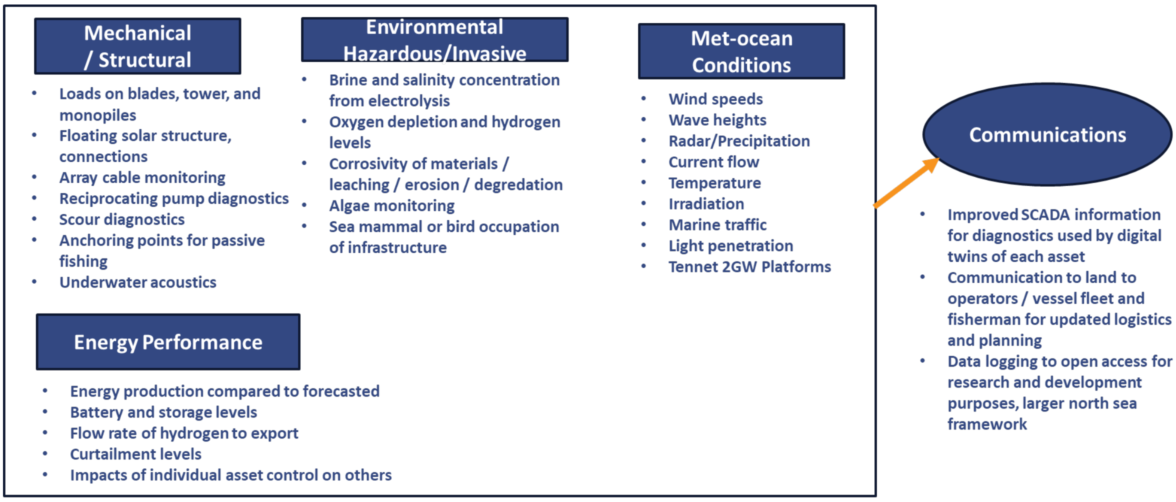

Figure. 5.4 A detailed but not exhaustive breakdown of various monitored parameters to be uploaded to the Open Information System

- Ecological monitoring: This type of monitoring consists of 1) hypothesis-driven field research that allows us to gain a better understanding of crucial processes, thereby improving models and their formulations; the data obtained also forms the basis for improving data collection in subsequent monitoring, and 2) field observations that are repeated systematically and over a long period of time as part of a structured programme. With this latter type of data, knowledge about the state of the marine system can be developed in order to gain insight into how the system functions. This is the information that is/will be monitored in the research programmes of MONS[57] and is currently disseminated through the Informatiehuis Marien[58] and potentially can feed into the Ecological Evaluation of the decision-making process. This type of information tends to have the form of long-term statistics.
- Maritime monitoring: This type of data tends to be midterm forecasting and real-time. This includes the marine traffic of all vessels in and around the wind park from AIS and Marine Traffic[59]. Real insight into this information reduces risks of collisions and interference. Long-term statistics allow us to perform quantitative risk analyses on the risks of multi-use operations, which feed decision-making for future wind farms.
- Communication and coordination of maritime activities within the offshore wind farm. The system is an open, accessible platform with live communication between the wind park and the shore. Live communication (through 4G or 5G) is vital for operational decision-making to optimise operational activities.
- Operational decision support. The goal of the OIS is to support decision-making. This does not only require data and open access but also indicators, metrics and stakeholder/end-user co-creation of the OIS. Examples of the information the system could provide: maximum allowable operational criteria for ships in order to determine whether to sail out or not. Another example is a prediction of revenues (for energy and food) in order to determine how to harvest and bring the products to the market. The OIS also facilitates co-shipping to reduce voyages between the wind farm and the shore.

[57] https://www.noordzeeloket.nl/omgeving/noordzeeoverleg/mons-onderzoeks-monitoringprogramma/
[58] https://www.informatiehuismarien.nl/
[59] www.marinetraffic.com

So, the blueprint indicates what kind of information is being gathered and for what purpose. However, that does not yet give the operational support that the OIS is supposed to do. The last part of the chain is decision support, which translates the information into metrics upon which the operator can make decisions. In order to do that, we have to close the chain and relate the OIS information to the goals of its users. Below some key examples of metrics are given:

- provide yield and production
    - energy: Wind speed, solar irradiation, WT power, FPV power, H2 kg, etc.
- food: Catch per Unit Effort (CPUE), Landings per Unit Effort (LPUE) :
    - shellfish kg, Fish kg, Seaweed kg, etc.
- provide system integrity and performance
    - measured load vs critical load, fatigue damage, stage of crack development, etc.
- provide operational conditions
    - operational status from SCADA system, status of maintenance tasks, location of service vessels and crew
- provide safety and incident status
    - method statements, EHS procedures, inspection reports, incident reports, etc.

Remarks and recommendations for the next tenders

The intended users of the OIS platform are the multi-use operators. They can best learn from the platform if they also provide information to the system. In this way, they learn from each other. Of course, this also requires the sharing of sensitive information. Here, the purpose is not to reveal the company's intellectual proprietary but, again, to learn as a multi-use industry. In mature industries, this is already quite common, as it is also quite common in safety environments to share incidents and the learnings from them. Also, independent institutes know quite well how to treat confidential data and only share aggregated or processed data. The government could support the sharing of (confidential) data by putting such requirements in the tender criteria. It is recommended to encourage applicants to actively participate in defining the area passport, ensuring that it aligns with their specific needs and goals. This approach can enhance engagement and ownership in the learning process. To ensure the success of operations and monitoring, it is essential to thoroughly assess the complexity of integration and scalability early in the process. This will enable proactive planning and resource allocation to address potential challenges effectively.

5.4. Case study 3: Symbiotic offshore wind farm of the far future

5.4.1. Background and methods

This case study treats the Symbiosis-Inclusively Designed wind farm of the far future. Unlike the other case studies, no specific offshore wind farm is used here as a reference case because this case study relates to (Dutch) offshore wind energy as a whole by 2050 and hence includes offshore wind farms that are currently commissioned under construction, but to a large extent also the ones planned between 2030 and 2050.

With this case study, we attempt to envision a fully symbiotic offshore wind production grid. This grid is a network of offshore wind farms that are harmoniously integrated with - and take into account - the environment and carrying capacity of the North Sea. This harmony is achieved by simultaneously accommodating all possible additional uses related to ecology, food production and alternative forms of renewable energy generation and storage next to the production of offshore wind energy.

The objective of this case study is to produce a visualisation that describes an ideal situation for the Dutch North Sea in terms of multi-use within offshore wind farms, to be realised by 2050. To this end, the following research questions were developed:

(i) What would be an ideal situation for fully symbiotic offshore wind farms in the far future?

(ii) What are the overlapping actions between all three themes, and what are the related ideal outcomes to achieve such a vision?

(iii) Which actions need to be realised by the offshore wind industry and which by the regulators?

The case study is executed through brainstorming sessions and design workshops held within the Road2SID consortium.

5.4.2. Vision statement

First, a vision statement is formed as part of this case study. A concise description of this vision towards symbiotic offshore wind farms follows:

"By 2050, a revolutionary era of Dutch Offshore Wind Farms has emerged. Through harmonious integration, ecological measures, alternative forms of renewable energy generation conversion and storage, as well as food production within offshore wind farms have fully matured to the maximum of their potential and are the standard, ushering in a new era of holistic, inclusive, and transboundary spatial planning that respects the carrying capacity of the North Sea. In this new era, symbiotic offshore wind farms act as the catalyst to achieve the climate and biodiversity targets set by the Dutch and European policymakers."

In short, realising this vision means achieving maximum efficiency in offshore spatial use by supporting as much renewable energy, food and abundance of target species as possible, with the minimum additional investments, effort and operational costs.

In larger detail, this ambitious vision for the symbiotic offshore wind farms in 2050 is built and can be evaluated upon the following four indicators:

(i) achieving maximum optimisation of offshore wind farm core infrastructure (i.e., WTG, foundations, substation platforms, IAC and export cables) to support secondary uses (*min. additional CAPEX for symbiotic offshore wind farm*);

(ii) achieving maximum optimisation in shared O&M activities (*min. additional OPEX for symbiotic offshore wind farm*);

(iii) achieving a viable business case for secondary commercial alternative uses next to offshore wind, such as floating solar or aquaculture (*max. kWh or calories per* km^2);

(iv) achieving a Net Positive Impact (NPI) on climate (*tonnes GHG per kW per* km^2) and biodiversity and abundance (*max. number of native target species per* km^2).

In the remainder of this chapter, we present priority actions, ideal outcomes and the necessary technological and regulatory pillars to realise this vision.

5.4.3. An integrated toolbox for symbiotic offshore wind farms by 2050

Based on an integration of the actions described in chapter 4 across all three transitions taking place in the North Sea (nature, food, energy), the ideal outcomes are hereby defined to establish fully symbiotic wind farms by 2050. The toolbox of ideal outcomes is summarised in this section.

Panel of experts

A multi-disciplinary panel of experts is formed, responsible for updating the holistic vision for symbiosis, consulting stakeholders and providing yearly reports with metrics and tender criteria.

Tenders

Tenders for symbiotic projects have minimum requirements for established concepts, scoring for innovation and system integration. The planning and duration of the tenders are such that they do not continuously hamper the free exchange of knowledge and ideas by having short lead times and large intervals. Criteria are communicated in advance, whilst feedback cycles ensure improvements. As a moonshot, tenders demand fully symbiotic offshore wind farms.

Easy permitting

The focus is on facilitating permitting processes with easy access and streamlined procedures. A one-stop-shop approach provides timely information and advice to small and medium enterprises (SMEs). Regular bi-annual reviews ensure permitting guidelines stay up-to-date. As a moonshot, the aim is to achieve a single, all-encompassing permit system.

Open database

An open database and open-source platform operate at a North Sea basin scale. The data, including biotic, abiotic, and energy-related information, is linked to metrics, following the FAIR principles. Site characterisation studies on symbiosis by RVO contribute to the database. The moonshot objective is to update the database in real-time, utilising, where possible, artificial intelligence and involving public science.

Monitoring

Monitoring activities are conducted by multi-purpose O&M vessels and by utilising the infrastructure of offshore wind farms. These activities are integrated into the permitting of the infrastructure and adhere to standardised requirements. A development and ownership framework is established to support these efforts. The moonshot aspiration is to achieve an international, EU-level approach to monitoring practices.

Open and joint research

Open research initiatives are established, closely linked with the multi-disciplinary panel of experts. A dedicated research fund is created, supported by both the government and industry, specifically focusing on SID. Joint Industry Projects (JIPs) are encouraged, even for future offshore wind farms. The core ideas of bids, with regard to their alignment with SID, are made public, promoting transparency. Additionally, the scoring motivation behind the selection process is also made public, ensuring accountability and fairness.

Sharing capacity by integration

Capacity sharing is achieved through the integration of infrastructure, including foundations, cables, and more, for the installation and operations of multi-use activities. Maintenance activities also benefit from this integrated approach. The moonshot is to achieve a net positive impact on biodiversity and climate, ensuring that these activities contribute to the overall sustainability and conservation efforts.

Protocols, safety and ease of access

Protocols are established to ensure safety and ease of access for all stakeholders involved. Space allocation mechanisms are put in place to effectively manage the use of resources. Ways of working and coexistence among different entities are defined to promote collaboration. Safety protocols and liability management frameworks are implemented to mitigate risks and ensure accountability.

As moonshot goals, digitalisation plays a key role in transforming operations, while autonomous and intelligent monitoring and maintenance systems are developed to enhance efficiency and effectiveness in the industry. These advancements aim to revolutionise the sector and contribute to a safer, more sustainable, and technologically advanced future.

Life cycle

The life cycle of projects ensures no risks to ecology and safety, with a focus on recyclable structures. Guidelines are established for typical infrastructure in the National Energy and Climate Plans (NECPs). End evaluations are conducted, and contingencies are defined to provide clarity on policy. The moonshot objective is to extend the lifetime of projects, maximising their long-term positive impact and sustainability in the use of resources.

Business/value case

The development of a strong business and value case is emphasised, considering factors such as export potential and creating awareness about the benefits of symbiotic projects. Tenders are steered to align with the overarching goals and criteria set for symbiosis. Subsidies and investments play a crucial role in supporting these initiatives, while joint ventures foster collaboration and shared expertise. Furthermore, Corporate Social Responsibility (CSR) is integrated into the Most Economically Advantageous Tender (MEAT) criteria. CSR points are awarded, which, in turn, reduce the tender bid price. This approach incentivises bidders to prioritise social and environmental responsibility in their proposals, ensuring a comprehensive evaluation that encompasses sustainability aspects alongside financial considerations.

Pilots

Pilots encompass technology and governance, progressing from Technology Readiness Level (TRL) 4 to 7. The focus is on wind farm scale projects that thoroughly understand the individual and cumulative effects. The clustering of offshore wind farms considers ecological and operational environmental factors. Collaborations between industry and SMEs are fostered. The moonshot ambition is to achieve fully symbiotic pilots, pushing the boundaries of sustainable innovation and validating concepts which are subsequently effectively implemented in future offshore wind farms.

5.4.4. Pillars of fully symbiotic offshore wind farms

In the pursuit of a sustainable future, the adoption of Symbiotic Inclusive Design (SID) as the standard for developing offshore wind farms has become imperative. This visionary approach focuses on three essential pillars:

(1) Holistic International Integration
(2) Data
(3) Innovation

These pillars collectively ensure the successful implementation of SID in offshore wind farms. In this section, we will delve into each pillar and explore how they contribute to the successful realisation of SID by 2050 and beyond.

5.4.4.1. Holistic international integration

The implementation of SID in offshore wind should transcend geographical boundaries, extending beyond individual regions and focusing on the basin scale. For instance, when considering offshore wind developments in the North Sea, it is crucial to involve all neighbouring countries whose coastal borders touch this vast body of water. Collaboration among European Union (EU) countries is particularly vital in achieving the ambitious carbon emission reduction targets set for 2050. Therefore, it is essential to establish an interconnected network of wind farms that seamlessly spans across all North Sea countries. This connectivity fosters collaboration, transparency, and a unified approach to offshore wind farm management and operation.

To further promote this holistic international integration, the establishment of a joint European area dedicated to SID for offshore wind is recommended. Such an area would encourage contributions and collaborations from all North Sea countries, thereby enhancing SID initiatives. To facilitate effective monitoring and ensure compliance with SID requirements, the appointment of a designated authority, such as a Minister of the North Sea, could be considered. Moreover, the holistic international integration necessitates the establishment of a comprehensive governance structure that oversees the equitable distribution of responsibilities among all North Sea countries involved in offshore wind farm development.

To emphasise the importance of the holistic approach, it is crucial that society fully embraces green renewable energy by 2050. In addition, encouraging the consumption of local seafood can further reduce individual carbon footprints. Education initiatives aimed at informing the public about offshore wind developments in the North Sea can play a vital role in achieving these objectives. Lastly, until there is clarity about the long-term impact, a commitment to decommissioning offshore wind turbines should be in place, considering the ongoing debates surrounding this topic and its potential implications for the marine ecosystem.

5.4.4.2. Data

In the future, data will play a central role in the offshore wind industry, particularly in the context of SID. As SID initiatives related to nature, energy and food become fully operational, extensive data gathering will be necessary to monitor, facilitate and optimise the system. This data will be sourced from various technological applications, including drone-based monitoring (above and below the sea), which minimises ecological impacts. The implementation of efficient communication systems (e.g., OIS) between these technologies will ensure seamless data integration throughout the entire wind farm. This is especially important for the state-of-the-art sensors and monitoring systems that will be operating across the entire wind farm.

By 2050, well-established and standardised metrics will exist to quantify the benefits of SID in offshore wind farms. These metrics will enable evaluation and continuous improvement of co-use system setups. Additionally, metrics that assess the economic advantages of implementing SID will provide detailed insights into the financial benefits associated with co-use in offshore wind farms.

5.4.4.3. Innovation

Innovation will be a critical element for the success of SID in future offshore wind projects. In 2050 and beyond, Governments will play a pivotal role by providing the necessary infrastructure, such as vessels, aircraft, technical equipment, etc., to streamline SID implementation. Wind farms will embrace a creative mindset, incorporating the best available techniques for nature restoration and strengthening. In this vision of the future, all components of wind farms, from foundations to turbine blades, will be constructed using fully recyclable materials, promoting circularity and minimising waste. Furthermore, wind farms will operate with zero emissions throughout their entire lifespan.

This visionary scenario for the implementation of SID in offshore wind farms beyond 2050 highlights the importance of holistic international integration, data-driven decision-making, and innovation. By adopting a unified approach, harnessing the power of data, and embracing innovative solutions, offshore wind farms of the future will not only contribute to global sustainability but also serve as harmonious (artificial) infrastructure ecosystems that thrive in symbiotic coexistence with nature.

5.4.5. Summary

A concise summary of case study 3 is presented in the figure below, where the focus is paid to the integrated toolbox for advancing symbiosis in offshore wind farms towards 2050.

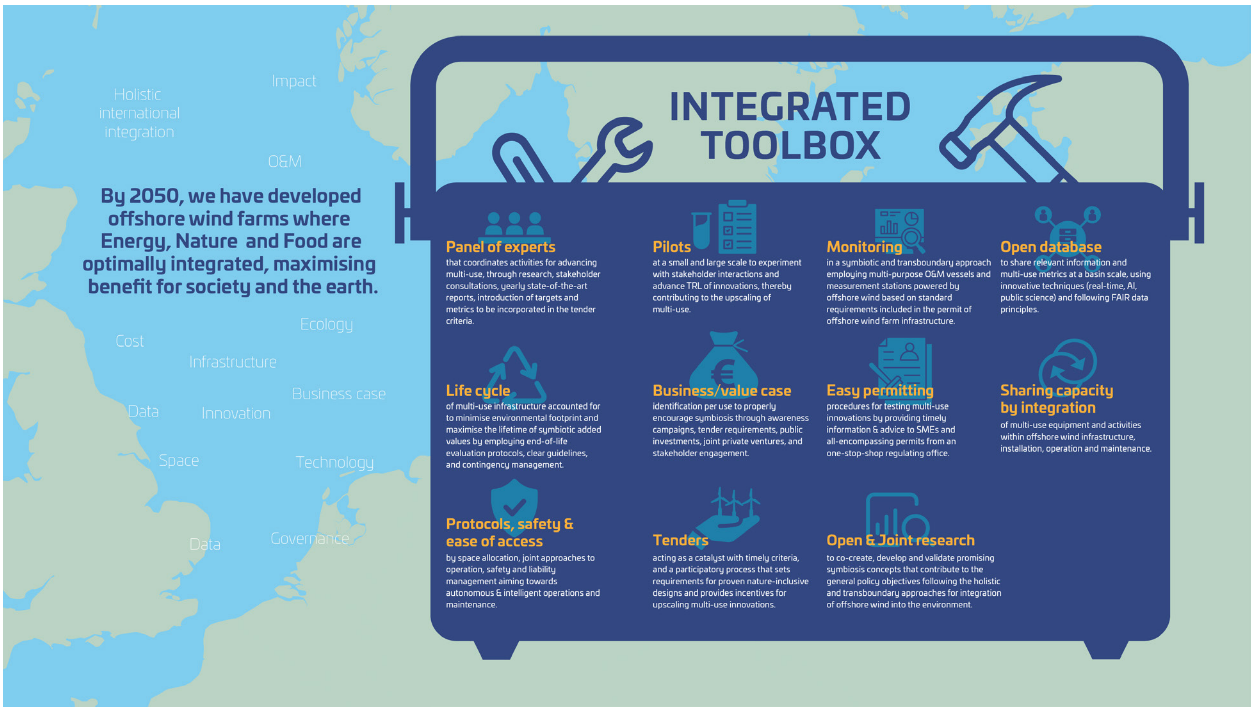

Figure 5.5 A summary of the integrated toolbox that can be used to advance symbiosis towards 2050

6. Synthesis

The Netherlands is one of the leading countries on the topic of marine spatial planning with a specific focus on shared use of marine space, typically also referred to as multi-use. This is primarily driven by the scarcity of space combined with the high ambitions for offshore wind energy production and long-term experience with the marine economy. Since offshore wind farms are foreseen to take up most of the space within the Dutch North Sea, it is logical to consider designing them so that shared use of space is not excluded but facilitated instead. This is what we call the symbiosis-inclusive design of offshore wind farms.

The knowledge and practical experience are still lacking on many fronts, but fortunately, some developments are underway in various types of multi-use. In this project, we focused on the multi-use activities and considered options that fall under the three main transitions taking place in the North Sea, namely energy, food and nature transition in the context of climate change. A review of existing initiatives and best practices shows that there is a plethora of options to be explored for integrating more functions within existing, planned and future offshore wind farms.

For example, multi-use approaches can be followed to store, convert and even increase the energy yield within offshore wind farms, e.g., by using the space between turbines for floating solar, wave and/or tidal energy generation. In addition, offshore wind farms can be designed in a way that they minimise adverse impacts on the environment during the operational lifetime, and nature-inclusive design options also exist to use offshore wind infrastructure and space to even support the restoration of keynote species and strengthen the ecosystem. Last but not least, offshore wind farms may be used as hubs for sustainable food production at sea, for example, breeding, rearing, and harvesting of fish, shellfish and seaweed.

The field of symbiosis between functions inside offshore wind farms is relatively young, with many unknowns. Through stakeholder consultations, uncertainties are identified with respect to the developing regulatory framework, for example, concerning decommissioning of artificial reefs. Conflicting interests but especially a complex field of stakeholders is another challenge that relates to governance. Knowledge gaps are also present. These relate to the required technological advancements and upscaling of novel concepts towards large-scale deployment. Linked to this, a question remains concerning the extent to which certain multi-use activities fit within the carrying capacity of the North Sea ecosystem. Finally, the economic viability of certain forms of multi-use developments is challenged by the harsh North Sea conditions that limit operating windows and increase installation costs.

Of course, not only challenges but also opportunities are identified for advancing multi-use development within offshore wind farms. For example, the exclusion of bottom trawling fishing within Dutch offshore wind farms increases the chances for successful restoration of historic oyster reefs. In addition, the business case of certain activities is deemed to improve drastically once capacity is shared with offshore wind farm infrastructure, for example, by means of shared use of grid connection system and by means of synergies in planning and operations. It becomes apparent that the offshore wind industry has an important role to play in advancing symbiosis. However, at the moment, there is still no governance and regulatory framework, albeit that first attempts have been made. There are also no incentives for the offshore wind industry to assist in accelerating certain forms of multi-use. Fortunately, there is openness for collaboration and a shared sense of responsibility across various stakeholders to advance technology specifically on this topic.

What is clear across various stakeholders is that the regulatory framework should be leading in advancing symbiosis in offshore wind farms over technological advancements. Any technological advancements required to take symbiosis to the next level are largely inspired by and eventually tailored to the requirements set for offshore wind farms and multi-use in general by the government. Therefore, further improvements to this regulatory framework should be prioritised. This also highlights the leading role of the government towards a successful rollout of multi-use in the North Sea. The development of this regulatory framework requires as a starting point a long-term and holistic vision by the government in collaboration with the industry that extends even further from the Dutch borders. The development of this vision may, however, be challenged by limitations in available knowledge and a lack of well-proven approaches. It follows that a "learning-by-doing" approach is also necessary here to inform such a vision.

The proposed short-term actions for the coming decade vary to some extent across different types of multi-use, since available practices, technical requirements and readiness levels, as well as the maturity of the business cases, vary amongst those too. Nevertheless, for all themes, the typical sequence of proposed actions involves setting targets, solving permitting and regulatory bottlenecks, and finally experimenting with technology development through large-scale pilots to minimise technical risks and assess environmental impacts. Naturally, each action can be best undertaken by a specific (combination of) stakeholders depending on associated requirements, although it is clear that due to interfaces, input is required across the board of stakeholders.

It should be mentioned here that offshore wind farm tender requirements set by the Dutch government are widely acknowledged as a catalyst in stimulating multi-use developments so far, for example, concerning nature strengthening and system integration. These are very likely necessary in the future, too, although improvements in the procedure are possible. For example, improvements could be made in the timing of publishing requirements, in the description and substantiation of certain scoring criteria upon release, and in feedback rounds with the industry and research institutes. Especially for topics related to nature protection and strengthening, improvements are needed for the optimal use of the limited human resources amongst the scientific community, as well as for the build-up of knowledge and communication among various stakeholders.

Looking at recent experiences with the multi-use of space, even with a relatively well-developed regulatory framework set by the government, activities within allocated areas in the Borssele offshore wind farm have not yet been sufficiently picked up, except for one initiative on mussel farming. For activities related to nature strengthening, there is no business case, and environmental organisations rely fully on financial support from the government. Certain multi-use innovators that focus on energy or food production attribute the slow response to a lack of a business case for their activities, given the high costs required to operate in a harsh environment like the North Sea. Provision of financial tools and/or subsidies for testing and developing their designs further are typically seen as a first step to resolve this. However, most gains are expected from sharing capacity with future offshore wind farms, for example, in terms of shared use of infrastructure and operating vessels.

Furthermore, there are actions that can be taken now or in the short term to stimulate shared use of space. An open information system will be necessary for the various multi-use stakeholders operating in the same area, including the wind farm owners. This is currently missing. To that end, and starting from existing information, data can be gathered in an open-access database. This open information system will translate data into information and key performance indicators relevant to the various uses. Based on this information, different multi-use operators can communicate and decide on planning of (common) operations, coordinated actions for mitigation of safety incidents ecological concerns or coordination of any other actions that are needed to improve their business case.

Finally, given the numerous uncertainties we are dealing with at present, it has proven hard to anticipate the far future of symbiosis in offshore wind farms. It is clear, though, that if climate change is to be addressed in a way that facilitates a sustainable energy, nature and food transition in the North Sea, we rely on offshore wind farms that will have harmoniously integrated by 2050 ecological measures, alternative forms of renewable energy generation and storage, as well as food production, with the right balance of activities that serve society and remain within the carrying capacity of the North Sea ecosystem.

To that end, several moonshots need to be taken within the coming years that will help stakeholders to overcome challenges and explore opportunities in regulatory, economic and technological aspects. As an indication, these moonshots can, for example, involve a "one-stop-shop" for permitting innovations, joint private ventures between different multi-use operators and wind farm owners and finally, joint and open research initiatives for the development of technology.

Ultimately, the development of fully symbiotic offshore wind farms in the future will largely depend on actions taken in at least three overarching pillars. First, a holistic and transboundary vision with a comprehensive governance structure that oversees the equitable distribution of responsibilities at a basin scale. Second, extensive data gathering to learn, monitor, facilitate and optimise through the implementation of efficient communication systems between different users. Third, technological innovations to design all wind farm infrastructure, planning and with symbiosis in mind.

References

Astariz, S., Perez-Collazo, C., Abanades, J., & Iglesias, G. (2015). Co-located wave-wind farms: Economic assessment as a function of layout. Renewable Energy,Volume 83,ISSN 0960-1481,https://doi.org/10.1016/j.renene.2015.05.028., 837-849.

Astariz, S., Vazquez, A., Sánchez, M., Carballo, R., & Iglesias, G. (2018). Co-located wave-wind farms for improved O&M efficiency. Ocean & Coastal Management,Volume 163,ISSN 0964-5691,https://doi.org/10.1016/j.ocecoaman.2018.04.010., 66-71.

Bak, U.G., Mols-Mortensen, A., & Gregersen, O. (2018). Production Method and Cost of Commercial-Scale Offshore Cultivation of Kelp in the Faroe Islands Using Multiple Partial Harvesting. *Algal Res. 2018,*.

Berenschot Kalavasta (2020). Scenariostudie ten behoeve van de integrale infrastructuurverkenning 2030-2050. Berenschot Kalavasta.

Bluewater (2022). E-buoy Brochure. Retrieved from bluewater.com: https://www.bluewater.com/wp-content/uploads/2022/05/Leaflet_E-buoy.pdf

van den Bogaart van den, L., Poelman, M., Tonk, L., Neitzel, S., van der Wal, J. T., Coolen, J. W. P., Machiels, M., Rozemeijer, M., de Boois, I., Vergouwen, S., & van Duren, L. (2019). Geschiktheid zeewindparken voor maricultuur en passieve visserij: Een kwalitatieve beoordeling van geschiktheid van windparklocaties voor voedselproductie. (Wageningen Marine Research rapport; No. C044/19).

Bolman, B., Boon A.B., Maarse M., Roetert T., Schouten J., & S. Vergouwen. (2019). Quick-scan co-use of future offshore wind farms (in Dutch with English summary). doi: 10.13140/RG.2.2.33257.93284.

Bos O., Kingma E., van Onselen E., Olie R., van der Endt J., Hermans A., & J. Kwakkel. (2022). Costs and Benefits of Nature-Inclusive Energy (KOBINE). Poster presentation. https://edepot.wur.nl/581712

Bridger, D., Attrill, M. J., Davies, B. F., Holmes, L. A., Cartwright, A., Rees, S. E., Cabre, L. M., & Sheehan, E. V. (2022). The restoration potential of offshore mussel farming on degraded seabed habitat. Aquaculture, Fish and Fisheries, 2(6), 437-449.

Buhagiar, D., Sant, T., Farrugia, R., & Farrugia, D. (2019). Increasing the Value of Offshore Wind by Integrating On-Board Energy Storage. Journal of Physics: Conference Series,1222, DOI 10.1088/1742-6596/1222/1/012038.

Buljan, A. (2022). RWE Wins Dutch Subsidy-Free Offshore Wind Tender with 760 MW Project Including Green Hydrogen and Floating Solar. Retrieved from offshoreWind.biz: https://www.offshorewind.biz/2022/11/11/rwe-wins-dutch-subsidy-free-offshore-wind-tender-with-760-mw-project-including-green-hydrogen-and-floating-solar/

van den Burg, S. W. K., P. Kamermans, M. Blanch, D. Pletsas, M. Poelman, K. Soma, & G. Dalton. (2017). “Business Case for Mussel Aquaculture in Offshore Wind Farms in the North Sea.” *Marine Policy* 85:1–7. doi: 10.1016/j.marpol.2017.08.007.

CE Delft & TNO (2022). 50% green hydrogen for Dutch industry: Analysis of consequences draft RED3. Delft: CE Delft.

CSBI (2015). A cross-sector guide for implementing the Mitigation Hierarchy. http://www.csbi.org.uk/our-work/mitigation-hierarchy-guide/

Degraer, S., Brabant, R., & B. Rumes. (2013). Environmental impacts of offshore wind farms in the Belgian part of the North Sea: Learning from the past to optimise future monitoring programmes. Royal Belgian Institute of Natural Sciences.

Degraer S., Brabant R., Rumes B., & L. Vigin. (2022). Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea - Attraction, Avoidance and Habitat Use at Various Spatial Scales.

Didderen, K., van der Have, T. M., Bergsma, J. H., van der Jagt, H., Lengkeek, W., Kamermans, P., van den Brink, A., Maathuis, M., & Sas, H. (2018). Shellfish bed restoration pilots Voordelta, Netherlands. Annual report 2018. Wageningen University & Research, Bureau Waardenburg, SASCON.

Didderen, K., Lengkeek, W., Bergsma, J. H., van Dongen, U., Driessen, F. M. F., & Kamermans, P. (2020). WWF & ARK Borkum Reef Ground oyster pilot. Active restoration of native oysters in the North Sea—Monitoring September 2019 (p. 40). Bureau Waardenburg Report no.19-227. Bureau Waardenburg, Culemborg.

DNV (2020). *DNVGL-OTG-24. Offshore Technical Guidance; Fish Escape Prevention from Marine Fish Farms.*

DNV (2022). *DNV-RU-OU-0503. Rules for Classification; Offshore Units; Floating Fish Farming Units and Installations.*

Doropoulos, C., Elzinga, J., ter Hofstede, R., van Koningsveld, M., and Babcock, R. C. (2019). *Optimizing industrial-scale coral reef restoration: comparing harvesting wild coral spawn slicks and transplanting gravid adult colonies. Restor. Ecol. 27, 758–767.*

Van Duren, L. A., Gittenberger, A., Smaal, A. C., Van Koningsveld, M., Osinga, R., van der Lelij, J. C., & De Vries, M. B. (2016). Rijke riffen in de Noordzee: verkenning naar het stimuleren van natuurlijke riffen en gebruik van kunstmatig hard substraat. Deltares.

Durgesh, K., Aravind, S., van der Veer, E., Yeshambel, M., Hajonides van der Muelen, T., van Zoelen, R., & Kee, J. (2022). North Sea Energy 2020-2022 Energy Hubs & Transport Infrastructure.

Dutch Government (2016). Kavelbesluit I windenergiegebied Borssele. Accessed at: https://wetten.overheid.nl/BWBR0037794/2016-04-09

Dutch Government (2022). Kavelbesluit VII windenergiegebied Hollandse Kust (west). Accessed at: https://wetten.overheid.nl/BWBR0046414/2022-04-01

ECORYS (2019). *Kansen, Risico's En Kosten Voor de Visserij Bij Toestaan Sleepnetvisserij in Windenergiegebieden*.

Emmanouil, A., Aleksandrova N., & van Duren, L.A. (2023), Scale model testing of eco-friendly scour protections for offshore foundations and cables. *11th International Conference on Scour and Erosion 2023 proceedings, based on JIP HaSPro (Handbook Scour and Cable Protections).*

Endresen, P. C., Norvik, C., Kristiansen, D., Birkevold, J., & Volent, Z. (2019). Current induced drag forces on cultivated sugar kelp. In International Conference on Offshore Mechanics and Arctic Engineering (Vol. 58837, p. V006T05A007). American Society of Mechanical Engineers.

European Commission Joint Research Centre (2022). Energy and Industry Geography Lab. Retrieved from joint-research-centre: https://joint-research-centre.ec.europa.eu/scientific-tools-databases/energy-and-industry-geography-lab_en

Fox, A. & I.K. Petersen (2019). Offshore wind farms and their effects on birds.

Gasunie & Tennet (2019). Infrastructure Outlook 2050. Gasunie and Tennet.

Glarou, M., Zrust, M., & Svendsen, J. C. (2020). Using artificial-reef knowledge to enhance the ecological function of offshore wind turbine foundations: Implications for fish abundance and diversity. Journal of Marine Science and Engineering, 8(5), 332.

Golroodbari, S., Vaartjes, D., Meit, J., van Hoeken, A., Eberveld, M., Jonker, H., & van Sark, W. (2021). Pooling the cable: A techno-economic feasibility study of integrating offshore floating photovoltaic solar technology within an offshore wind park. Solar Energy,Volume 219,ISSN 0038-092X,https://doi.org/10.1016/j.solener.2020.12.062., 65-74.

Guidehouse (2021). European Hydrogen Backbone: Analysing future demand, supply, and transport of hydrogen. Utrecht: Guidehouse.

Herman, P. M. J., & F. F. Van Rees. (2022). Mapping Reef forming North Sea Species. 11207716-000-ZKS-0001, Deltares, Delft.

Hermans, A., Bos, O. G., & Prusina, I. (2020). *Nature-Inclusive Design: a catalogue for offshore wind infrastructure: Technical report*. (Technical report; No. 114266/20-004.274). Witteveen+Bos. https://edepot.wur.nl/518699

Hofstra, J., van de Leun, K., Brosschot, S., & Smit, E. (2023). Integratie van duurzame bronnen op zee. Retrieved from Invest-NL: https://www.invest-nl.nl/business-development/publicaties/integratie-duurzame-bronnen-op-zee?lang=nl

Horschig, T., Hammer, H., Hordvik, T., Pettersen, S., & Tagliapietra, M. (2022). The Future of Floating Solar: Drivers and barriers to growth. Arnhem.

Ibrahim, O. S., Singlitico, A., Proskovics, R., McDonagh, S., Desmond, C., & Murphy, J. D. (2022). Dedicated large-scale floating offshore wind to hydrogen: Assessing design variables in proposed typologies. Renewable and Sustainable Energy Reviews, 160, 112310.

IEA (2022). ETP Clean Energy Technology Guide. Retrieved from ETP Clean Energy Technology Guide: https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide?selectedSector=Hydrogen

IMO & UNEP (2009). Guidelines for the Placement of Artificial Reefs: London Convention and Protocol/UNEP. London: International Maritime Organization.

IMO (1989). Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone. IMO Res. A.672(16).

IRENA (2020). Innovation outlook: Ocean energy technologies. Abu Dhabi: International Renewable Energy Agency.

IRENA (2021). Offshore renewables: An action agenda for deployment. Abu Dhabi: International Renewable Energy Agency.

I&W (2022). Programma Noordzee 2022-2027. Ministry of Infrastructure and Water of the Netherlands.

I&W (2023a). Kamerbrief verdere uitwerking beleid medegebruik in windparken op zee. Ministry of Infrastructure and Water of the Netherlands. Date: 08.06.2023.

I&W (2023b). Kamerbrief Partiele Herziening van het Programma Noordzee 2022-2027. Ministry of Infrastructure and Water of the Netherlands. Date: 17.05.2023.

Jansen, H. M., Van Den Burg, S., Bolman, B., Jak, R. G., Kamermans, P., Poelman, M., & Stuiver, M. (2016). The feasibility of offshore aquaculture and its potential for multi-use in the North Sea. Aquaculture international, 24, 735-756.

Kamermans, P., Schellekens, T., & Beukers, R. (2011). Verkenning van mogelijkheden voor mosselteelt op Noordzee (No. C021/11). IMARES.

Kamermans, P., Walles, B., Kraan, M., Van Duren, L. A., Kleissen, F., Van der Have, T. M., & Poelman, M. (2018). Offshore wind farms as potential locations for flat oyster (Ostrea edulis) restoration in the Dutch North Sea. Sustainability (Switzerland), 10, 308.

Kusters, J. (2020). A monoculture of wisefarms or a sea of possibilities? Exploring multi-use implementation as a solution for efficient ocean planning in the Dutch North Sea (Doctoral dissertation).

Lagerveld, S., Rockmann, C., Scholl, M.M., Bartelings, H., Burg, S.W.K. van den, Jak, R.G., Jansen, H.M., Klijnstra, J., Leopold, M.F., Poelman, M., Smith, S.R., Stavenuiter, J., Veenstra, F.A., Veltman, C. & Westra, C. (2014). Combining offshore wind energy and large-scale mussel farming: background & technical, ecological and economic considerations (No. C056/14). IMARES.

Langhamer, O. (2012). Artificial reef effect in relation to offshore renewable energy conversion: state of the art. The Scientific World Journal, 2012.

Lengkeek, W., K. Didderen, M. Teunis, F. Driessen, J.W.P. Coolen, O.G. Bos, S.A. Vergouwen, T.C. Raaijmakers, M.B. de Vries, & M. van Koningsveld (2017). Eco-Friendly Design of Scour Protection: Potential Enhancement of Ecological Functioning in Offshore Wind Farms. http://edepot.wur.nl/411374.

López, M., Rodriguez, N., & Iglesias, G. (2020). Combined Floating Offshore Wind and Solar PV. Journal of Marine Science and Engineering. 2020, 8(8), 576; https://doi.org/10.3390/jmse8080576.

May, R., Nygård, T., Falkdalen, U., Åström, J., Hamre, Ø. & B.G. Stokke (2020). Paint it black: Efficacy of increased wind turbine rotor blade visibility to reduce avian fatalities. Ecology and evolution, 10(16), 8927-8935.

Minns, C. K., & D. A. Hurley. (1988). "Effects of Net Length and Set Time on Fish Catches in Gill Nets." doi: https://doi.org/10.1577/1548-8675(1988)008<0216:EONLAS>2.3.CO;2.

Mulder, J. (2022) "Herstel Onderwaternatuur En Bevorderen Passieve Visserij/Aquacultuur in Windparken Op Zee."

Naylor, L. A., Coombes, M. A., Venn, O., Roast, S. D., & Thompson, R. C. (2012). Facilitating ecological enhancement of coastal infrastructure: The role of policy, people and planning. *Environmental Science & Policy*, *22*, 36-46.

Netbeheer Nederland (2023). Het energiesysteem van de toekomst: de II3050-scenario's, Integrale energiesysteemverkenning 2030-2050. Netbeheer Nederland.

Noordzeeoverleg (2021). Monitoring en Onderzoek Natuurversterking enSoortenbescherming (MONS). Report.

OFL (2020). Het Akkoord voor de Noordzee. Extra mijlen voor een gezonde Noordzee.

Oliveira-Pinto, S., & Stokkermans, J. (2020). Assessment of the potential of different floating solar technologies – Overview and analysis of different case studies. Elsevier, Energy Conversion and Management, Volume 211.

van den Bogaart, L., Poelman, M., Tonk, L., Neitzel, S., van der Wal, J. T., Coolen, J. W. P., Machiels, M., Rozemeijer, M., de Boois, I., Vergouwen, S., & van Duren, L. (2019). Geschiktheid zeewindparken voor maricultuur en passieve visserij: Een kwalitatieve beoordeling van geschiktheid van windparklocaties voor voedselproductie. (Wageningen Marine Research rapport; No. C044/19). Wageningen Marine Research. https://doi.org/10.18174/475934

van den Bogaart, L., van der Wal, J. T., Tonk, L., Bos, O., Coolen, J., Poelman, M., Vergouwen, S., van Duren, L., Janssen, H., & Timmermans, K. (2020). *Geschiktheid zeewindparken voor maricultuur en passieve visserij : een kwantitatieve beoordeling van de kansrijkheid van de gebieden voor de potentiële productiviteit van een selectie aan commercieel interessante soorten*. (Wageningen Marine Research report; No. C127/19A). Wageningen Marine Research. https://doi.org/10.18174/509196

Ørsted (2022). ReCoral: A new safe haven concept. Using Wind Turbines to Support Coral Restoration. https://orsted.com/en/sustainability/our-priorities/nature/recoral

Overheid.nl Besluit milieueffectrapportage (2020) wetten.nl - Regeling - Besluit milieueffectrapportage - BWBR0006788 (overheid.nl)

Overheid.nl Wet Natuurbescherming (2021) wetten.nl - Regeling - Wet natuurbescherming - BWBR0037552 (overheid.nl)

Overheid.nl Elektriciteitswet 1998 (2022) wetten.nl - Regeling - Elektriciteitswet 1998 - BWBR0009755 (overheid.nl)

Overheid.nl Waterwet (2023) wetten.nl - Regeling - Waterwet - BWBR0025458 (overheid.nl)

Pérez-Collazo, C., Greaves, D., & Iglesias, G. (2015). A review of combined wave and offshore wind energy. Elsevier, Renewable and Sustainable Energy Reviews, Volume 42,, 141-153.

Primo Marine (2019). *TRA-1 Consequences of Possible Sea-Bed Fishery in Future Offshore Wind Farms*.

Putter, L. V. (2020). The Identification of Business Partners Related to Multi-Use within Wind Farm Borssele.

Reijs, Th.A.M., Oorschot, R.W.A., Poelman, M., & Kals, J. (2008). *Aquacultuur Op Open Zee. TNO Rapport 2008-D-R1048/A*.

Rijksoverheid (2022). THE ESBJERG DECLARATION on The North Sea as a Green Power Plant of Europe. Retrieved from rijksoverheid.nl: https://www.rijksoverheid.nl/documenten/publicaties/2022/05/18/the-esbjerg-declaration-on-the-north-sea-as-a-green-power-plant-of-europe

Rockmann, C., Lelij, A.C. van der, Duren, L. van & Steenbergen, J. (2015). "VisRisc - risicoschatting medegebruik visserij in windparken." 46.

RVO (2022). Plans 2030-2050. Retrieved from www.rvo.nl/: https://english.rvo.nl/information/offshore-wind-energy/offshore-wind-energy-plans-2030-2050

RVO (2023). Hollandse Kust (west) Wind Farm Zone. Retrieved from rvo.nl: https://english.rvo.nl/information/offshore-wind-energy/hollandse-kust-west-wind-farm-zone

Smaal, A., Kamermans P.,Kleissen F.,van Duren L.A. and T. van der Have (2017). "Platte Oesters in Offshorewindparken (POP)." Yerseke: Wageningen Marine Research, Deltares, Bureau Waardenburg. http://edepot.wur.nl/412950.

Smaal, A. C., Kamermans, P., Van der Have, T. M., Engelsma, M. Y., & Sas, H. (2015). Feasibility of Flat Oyster (Ostrea edulis L.) restoration in the Dutch part of the North Sea (No. C028/15). IMARES.

Solomin, E., Sirotkin, E., Cuce, E., Selvanathan, S., & Kumarasamy, S. (2021). Hybrid Floating Solar Plant Designs: A Review. Energies 2021, 14(10), 2751; https://doi.org/10.3390/en14102751.

Steenbergen J., S. Neitzel & P. Molenaar (2020). *Visserij in Windparken; een verkenning van mogelijkheden*.

TKI Energie en Industrie (2021). Routekaart Elektrificatie in de Industrie. Retrieved from Rijksoverheid: https://www.rijksoverheid.nl/documenten/rapporten/2022/09/19/routekaart-elektrificatie-in-de-industrie

TNO (2022). Challenges and potential for offshore solar. TKI Wind Op Zee.

Tullberg, R. M., Nguyen, H. P., & Wang, C. M. (2022). Review of the Status and Developments in Seaweed Farming Infrastructure. Journal of Marine Science and Engineering, 10(10), 1447.

Tweede Kamer (2022). Structuurvisie Windenergie op Zee. Brief van de minister voor klimaat en energie. Brief 33 561-54.

Tweede kamer (2023) Energie wet. Memorie van toelichting 36378-3 Regels over energiemarkten en energiesystemen (Energiewet) | Tweede Kamer der Staten-Generaal

UNCLOS (1982). "United Nations Convention on the Law of the Sea." https://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

Vergouwen S., & L.A. Duren (2023). Ecological framework for nature-inclusive design. Accessible from Deltares JIP HaSPro.

Vettori, D., & Nikora, V. (2019). Flow-seaweed interactions of Saccharina latissima at a blade scale: turbulence, drag force, and blade dynamics. *Aquatic Sciences, 81, 1-16.*

Waqas Ayub, M., Hamza, A., Aggidis, G., & Ma, X. (2023). A Review of Power Co-Generation Technologies from Hybrid Offshore Wind and Wave Energy. Energies 2023, 16(1), 550; https://doi.org/10.3390/en16010550.

Ziar, H. (2021). Floating solar stations. *10 breakthrough ideas in energy for the next 10 years*, (2), 30-43.

Appendix A: State of art on multi-use in offshore wind farms

The review of the state of the art of multi-use in offshore wind farms, presented in chapter 2, was guided by a set of research questions per theme (nature, food, energy). These questions were formulated by the Road2SID consortium to explore the governance, technological & ecological knowledge base and economic aspects of this type of symbiosis.

Research questions – nature

Questions related to governance

- What are the different approaches to nature protection in offshore wind farms?
- What are the regulations that you need to account for in developing nature-inclusive design in offshore wind farms in the Dutch North Sea?
- What are the most important insurance, liability and permitting considerations?
- What is the existing regulatory framework with respect to decommissioning?
- What kind of criteria have been put forth in offshore wind farm tenders so far?
- What umbrella species are the focus of restoration efforts?

Questions on the technological and ecological knowledge base

- What kind of options exist for nature-inclusive design in offshore wind farms?
- What are the optimal conditions for applying nature-inclusive design?
- What is the Technology Readiness Level (TRL) of the existing concepts?
- To what extent is it possible to standardise nature-inclusive design for wide applicability?
- What are the operational synergies for maintaining and monitoring of nature-inclusive design solutions?
- Can nature-inclusive designs pose any extra technical risks to offshore wind farm infrastructure?
- How is monitoring of nature protection in offshore wind farms organised and what are the opportunities and challenges?
- Who should perform monitoring and at what scale?
- Is it possible to differentiate between the effects of different ecological restoration measures?
- What ecological pilot studies exist in offshore wind farms in the Dutch North Sea?
- What are the examples of nature protection and restoration measures from abroad?

Questions on value creation and business case

- How can nature-inclusive design be integrated into traditional business cases?
- For which stakeholders is nature-inclusive design part of the business case?

Research questions - food production

Questions related to governance

- What is the existing regulatory framework?
- How will the government (EZK) evaluate food production in the tenders of new offshore wind farms?
- What are the ecological risks & advantages of integration design?

- Are there food safety risks?
- What are the other risks & advantages of integration design?
- What are the regulatory disadvantages & advantages of integration design?
- What will be the role of the government (LNV) in food production?
- Who owns/is responsible for the assets?
- What would be the ideal moment to integrate multi-use in the offshore wind farm development?
- Are there priorities in the co-use of the space in offshore wind farms?
- Are these priorities different for each offshore wind farm?

Questions on the technological knowledge base

- What are the existing technologies for offshore food production? What is the TRL?
- Which further technologies are foreseen?
- What is the level of integration with the offshore wind farm?
- What is the impact of differences in lifetime on the installation, O&M and decommissioning?
- What are the typical environmental loads on various structures?
- What design codes/factors are applicable to multi-use structures?
- What are the technological risks & advantages of integrating food production in the offshore wind farm design?
- What is the optimum offshore wind farm layout for food production?
- What foundations are required for multi-use structures?
- What foundations are possible for multi-use structures in offshore wind farms (permanent, temporary)?
- How and when to install?
- Which offshore wind farms (present & upcoming) are most suitable for food production?
- How will the future consortia look like? What would be the ideal future consortia construction from an integrated design point of view?

Questions on value creation and business case

- Which foods can be produced in Dutch offshore wind farms?
- What are the relevant features of the markets for various types of food?
- What will be the CAPEX and OPEX for various types of foods?
- What is the potential market size?
- Who will finance food production in offshore wind farms? Developers/industry/government (subsidies).
- What are the business cases for various types of food? Seaweed, shellfish, active fishing, passive fishing, fish farming
- Which business cases are viable?

Research questions - alternative forms of renewable energy generation

Questions related to governance

- What is the existing regulatory framework?
- What regulatory framework changes will be necessary?

- How is the electrical integration and curtailment facilitated?
- How is the operation of the combined assets handled? Who decides how to operate them?
- Who will own the assets?
- How will/should space allocation change?

Questions on the technological knowledge base

- What are the integration options and technology Readiness Levels (TRL)?
- What are the levels of integration with the offshore wind farm?
- What are the main drivers in the optimisation of integration?
- What are the technological risks for integration within the offshore wind farm?
- How will the integrated technologies (energy production, conversion, storage) change the offshore wind farm design and layout?
- What are the additional impacts of integrated new technologies on offshore wind farm?

Questions on value creation and business case

- Where are the (main) consumers located? What form of energy do they require?
- What are the potential synergies for O&M activities?
- What are the added benefits of sharing equipment/infrastructure for integrated design?
- What are the insurance and permitting considerations?
- How can space impact (spatial footprint) in the offshore wind farm be optimised?
- Who is responsible for the decision of revenue and cost distribution?
- How will the value of lost energy due to curtailment be shared with the stakeholders?
- How and to what extent can we standardise technology integration design solutions?
- What will/should future consortia look like?

Appendix B: Open questions to stakeholders

For the stakeholder consultation of which the results are described in chapter 3, the following open questions were asked. The questionnaire was done in an online form, and depending on the choices of the respondents, they were requested to answer a larger or smaller set of questions.

General questionnaire

Nature specific questions

1. Who should coordinate the enabling of co-use between nature and offshore wind?
2. What is defined as 'success' when it comes to symbiosis between nature and offshore wind? Which indicators of success would you use and monitor, and why?
3. What value, from a business perspective, does the application of nature-inclusive design bring?
4. A good monitoring framework should accurately reflect the positive and negative impacts of offshore wind farms (incl. any NID measures) on ecology. How do you reflect on the current monitoring framework (e.g., WOZEP or MONS)? What can be improved in this framework?
5. What can be improved in the current governance framework to better enable nature-inclusive design applications in offshore wind farms? What kind of coordination, incentives and knowledge sharing are needed?
6. What is the best strategy for designing offshore wind farms in relation to preserving and supporting the local marine ecosystem?
7. What actions do the Dutch Government plan to take in order to move forward with enabling nature-inclusive measures in the offshore wind farms, specifically on 1) continuing the auction approach of tendering and 2) other measures?
8. What is your experience with permitting and decommissioning of nature-inclusive design elements (artificial reefs, oyster cages, etc.) in the North Sea? (both in and outside of offshore wind farms). How do you think these topics will develop in the future?

Food

1. What would be the ideal moment to integrate food production into the offshore wind farm development?
2. What is the impact of differences in lifetime between the wind farm and food production facilities on the installation, O&M and decommissioning of both?
3. Which types of food production have a viable business case? (Seaweed, shellfish, active fishing, passive fishing, fish farming) What do you need to be viable?
4. What would be the ideal future consortia construction from the point of view of an integrated design of offshore food production within wind farms?
5. How will food production in offshore wind farms be financed? How can this be realised?
6. What foundations are possible for multi-use food production structures in offshore wind farms (permanent, temporary)?

Energy

1. What are the main drivers in the optimisation of the integration of different types of energy technology/sources?
2. What will future consortia for energy projects look like?
3. What regulatory framework changes will be necessary for the facilitation of multi-use design?

4. What are the technological risks for the integration of different/complementary renewable technologies/storage within the offshore wind farm?
5. How will the integrated technologies (energy production, conversion, storage) change the offshore wind farm design and layout?
6. How will space allocation change for additional renewable energy co-use?
7. How is the electrical integration and curtailment facilitated? How will the value of lost energy due to curtailment be shared with the stakeholders?
8. Who will own the energy assets? How is the operation of the combined assets handled?

Appendix C: Results of the questionnaire to stakeholders

Answers to generic closed questions included in the shared questionnaire are presented here in larger detail. These concern the stakeholder group that the respondents affiliate with and identified opportunities and challenges concerning multi-use in offshore wind farms. These are also presented in the context of a specific type of symbiosis (in the themes of nature, food and energy transition) with offshore wind farms.

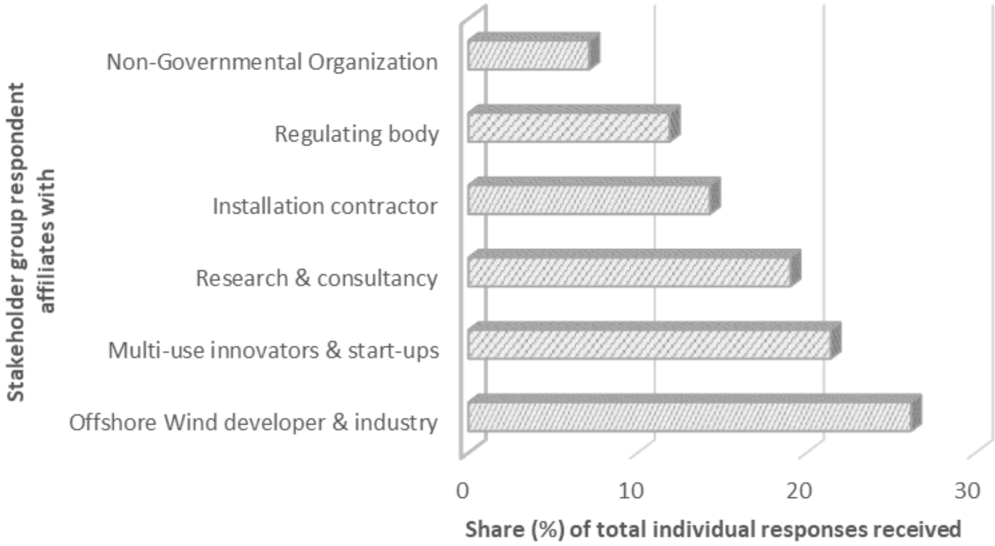

Figure C.1 Affiliation of questionnaire respondents. Research & consultancy includes research institutes, programs, universities, and engineering companies. Regulating body includes ministries and implementation agencies. Multi-use innovators & start-ups include multi-use technology developers, operators, and umbrella organisations enabling multi-use developments.

More than 40 questionnaires were filled out by various respondents who were affiliated with a certain stakeholder group. To start with, we asked what are the most important opportunities and challenges that the organisation of the respondents identifies in relation to symbiotic-inclusive design of offshore wind farms specifically and separately for Nature (e.g., strengthening and protection), alternative forms of renewable energy production (e.g., floating wind, wave, tidal) conversion and storage, and Sustainable Food production (e.g., shellfish and seaweed cultivation, passive fishing).

The lists included a number of prescribed possible answers that were gathered based on input received from stakeholder interaction sessions in the preceding months of the survey. Respondents were given the chance to elaborate on their top identified opportunities and challenges and to mention other possible challenges and opportunities that were not included in the list. Insights from these responses are presented in chapter 3.

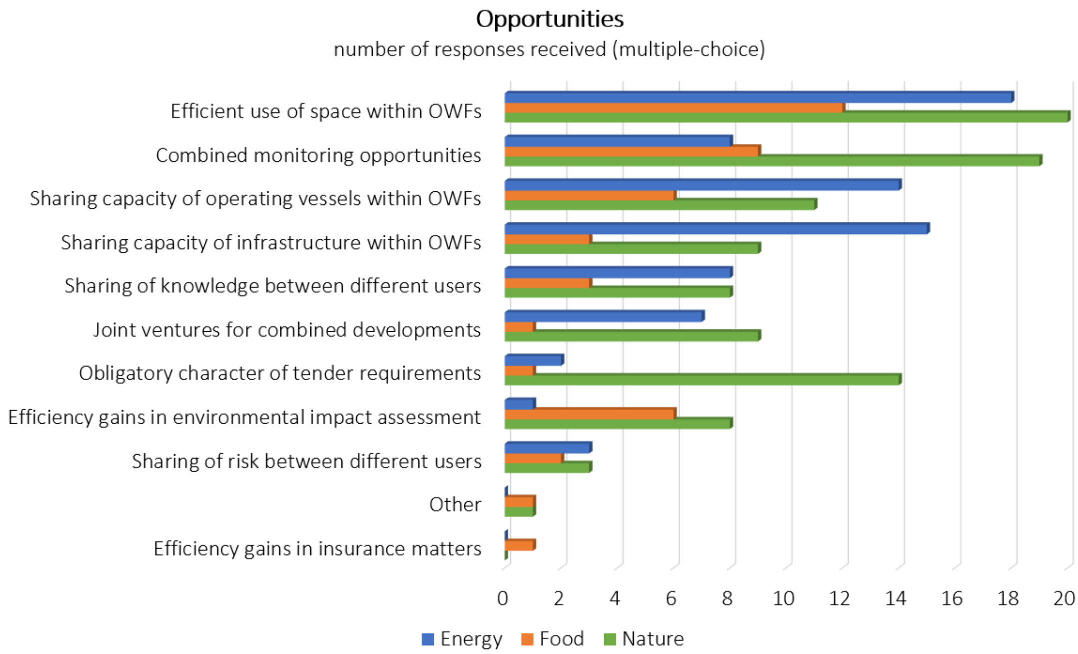

Figure C.2 Most important opportunities identified per theme of symbiotic offshore wind farm design

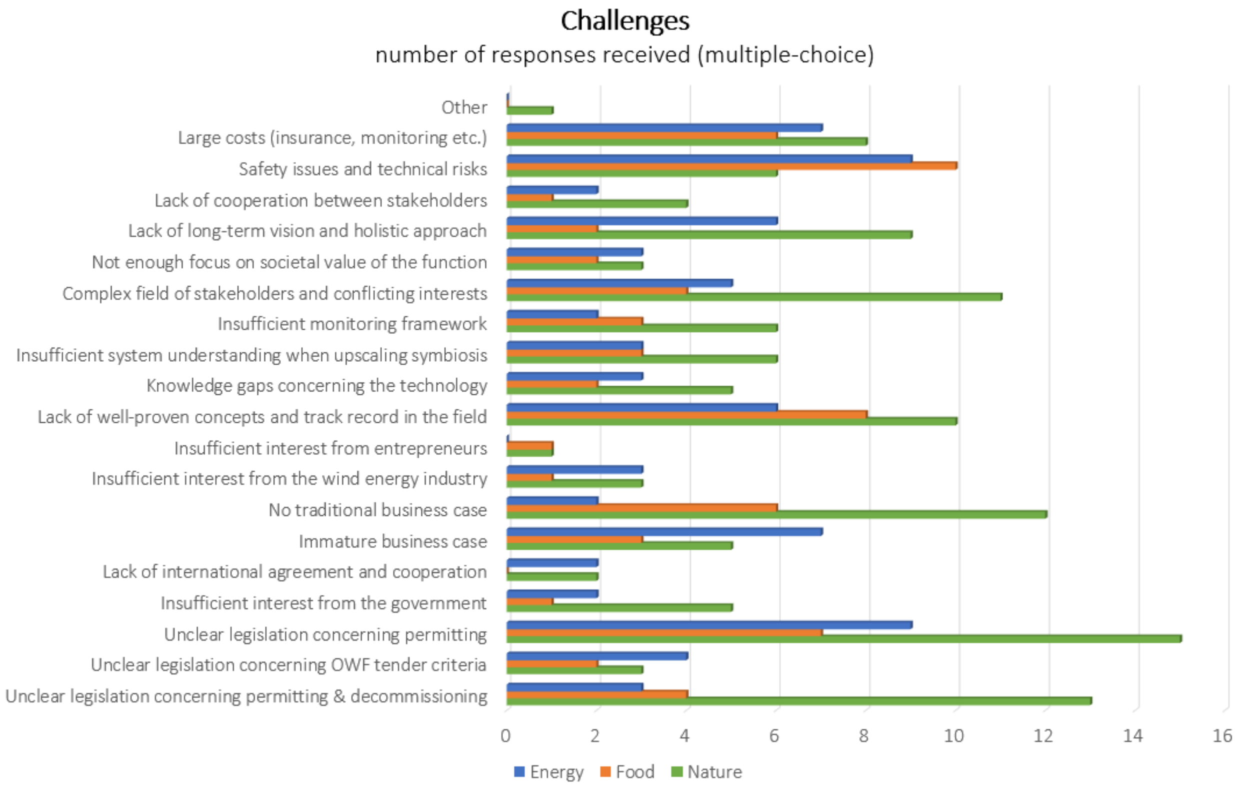

Figure C.3 Most important challenges identified per theme of symbiotic offshore wind farm design

Stakeholders were then asked what their role was and what they foresee as the immediate need (from others) to further advance the integration of multi-use options within offshore wind farms. The following plots show the distribution of responsibilities and requirements identified from each stakeholder group.

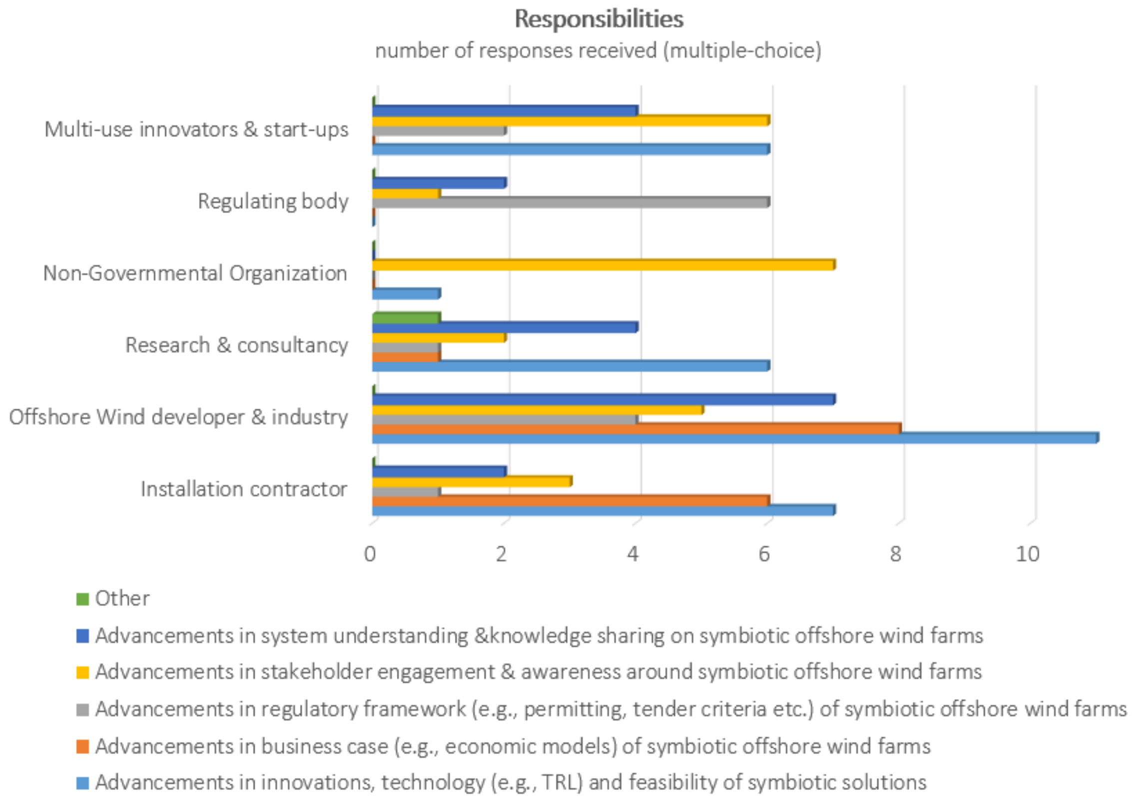

Figure C.4 Top responsibilities for needed advancements in symbiosis identified from each stakeholder group

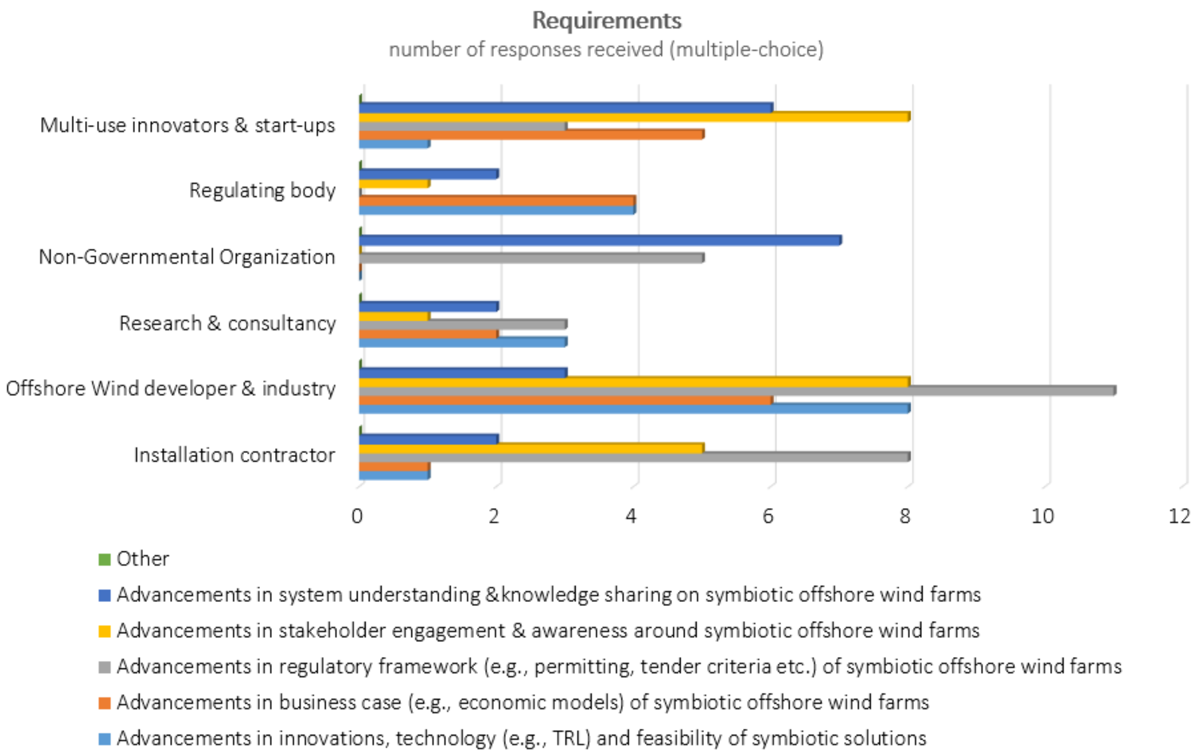

Figure C.5 Top requirements for needed advancements in symbiosis identified from each stakeholder group

Partners

Deltares
MARIN
TNO
Boskalis
RWE
Seaway7
Shell
TenneT
Van Oord

Funding

The project has been carried out with a subsidy from the Dutch Ministry of Economic Affairs and Climate, National Schemes EZK-subsidies, TKI Offshore Energy (part of energy innovationNL), as taken care of by RVO (Netherlands Enterprise Agency).
In addition, the GROW Common Fund has contributed financially to the project.

Contact

Deltares
Antonios Emmanouil
Antonios.Emmanouil@deltares.nl

More information on the
GROW/Road2SID project webpage
grow-offshorewind.nl/project/road2sid

a grow initiative