North Sea Energy
offshore system integration

D6.4
WHITE PAPER

North Sea Energy 2023-2025

Towards a Synergistic Multi-Use in the North Sea

North Sea Energy offshore system integration

D6.4 WHITE PAPER

North Sea Energy 2023-2025

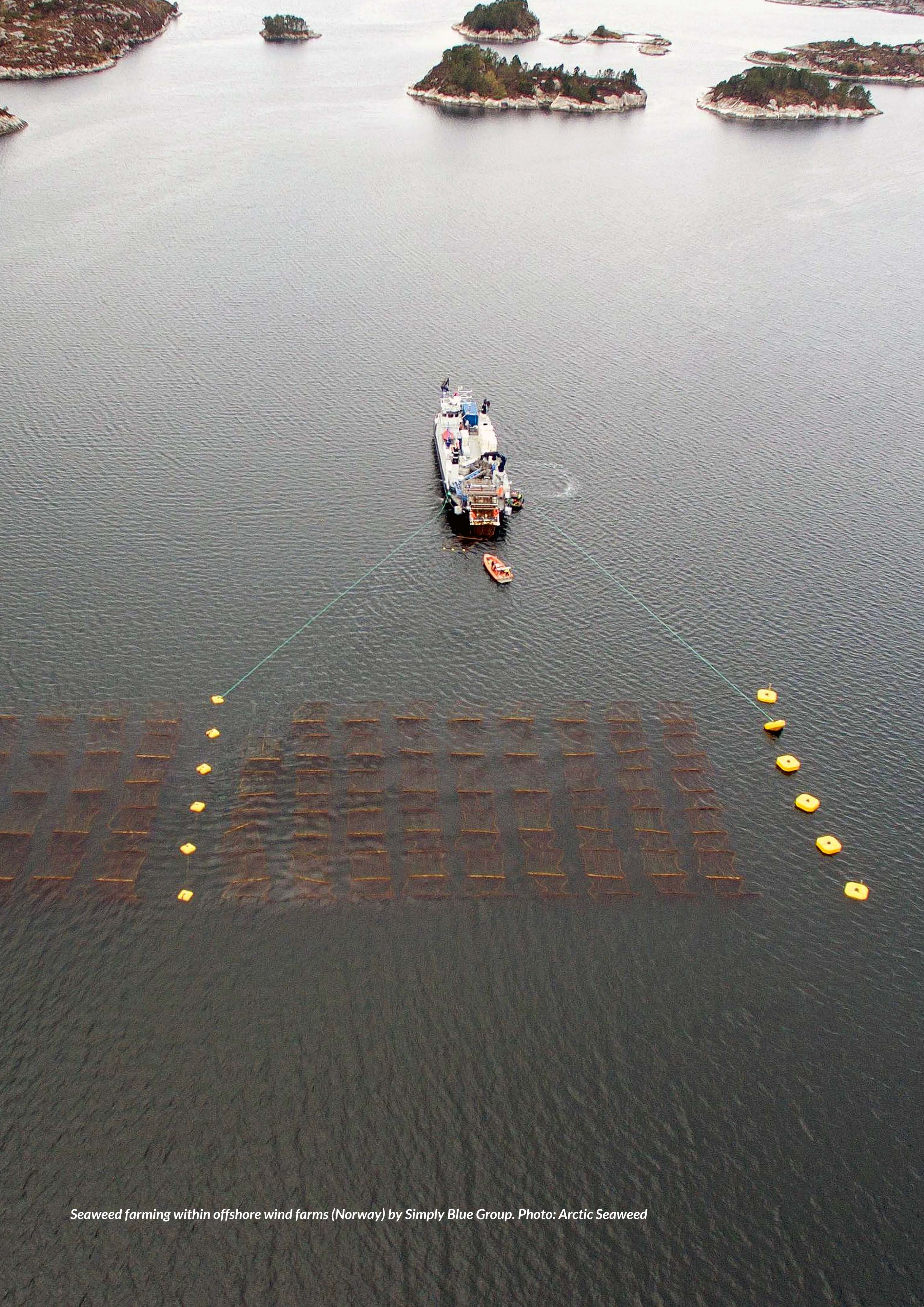
Towards a Synergistic Multi-Use in the North Sea

Authors:
Aravind Satish (TNO)
Moreno de Respinis (Arcadis)
Joep Breuer (TNO)
Ouassim Khatraoui (Arcadis)
Pascal Marcus (Arcadis)

Reviewers:
Sander des Tombe (DMEC)

Cover page design:
Ferry Streng (Arcadis)

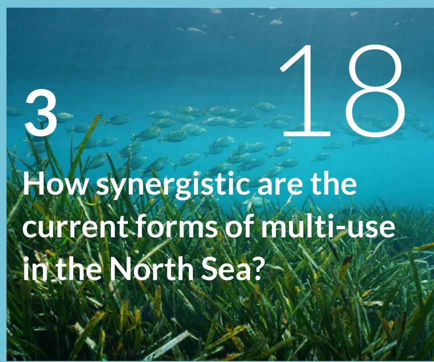
The project has been carried out with a subsidy from the Dutch Ministry of Economic Affairs and Climate, National Schemes EZK-subsidies, Top Sector Energy, as taken care of by RVO (Rijksdienst voor Ondernemend Nederland)



Seaweed farming within offshore wind farms (Norway) by Simply Blue Group. Photo: Arctic Seaweed

Contents


2
13
What is the North Sea's current state of offshore multi-use?


3
18
How synergistic are the current forms of multi-use in the North Sea?


4
21
What Would happen if the North Sea's Current Multi-use Patterns are Projected into the Future?


1
8
What is offshore multi-use of space?


5
31
How can synergistic multi-use become a norm in the North Sea ?

Executive summary

Introduction

The North Sea offers numerous opportunities and resources, yet both physical and ecological space are limited. Additionally, the distribution of resources for various activities is uneven. These constraints lead to competition among different activities for the same space. The aim of this paper is to investigate how the various offshore human activities and marine protected areas can coexist within the same space, a concept referred to as 'offshore multi-use'. When there is a symbiotic relationship among the various sectors of offshore human activities or among the human activities and marine protected areas involved, this paper has called it synergistic multi-use. This paper addresses the following questions to examine multi-use in the North Sea:

- What is the current state of multi-use in the North Sea?
- How synergistic are the current multi-uses in the North Sea?
- What would happen if the North Sea's current multi-use patterns are projected into the future?
- What are some examples of synergistic multi-uses in the North Sea and what can we learn from them?
- How can synergistic multi-use become the norm in the North Sea?

The spatial data obtained from the North Sea Energy Atlas were used to analyze the degree of multi-use in the North Sea. The (in)compatibility of co-located activities and assets was assessed through literature review and expert interviews, enriched with examples of marine spatial conflicts from demonstration and commercial projects.

What is the current state of multi-use in the North Sea?

Multi-use of offshore space is indeed present in the North Sea, with a higher density of such activities in its southern regions with shallow waters. A detailed examination of the Dutch, German, and Belgian exclusive economic zones reveals that approximately two-thirds of this area is shared by either two or more human activities, or by marine protected areas along with one or more human activities—double the proportion found in the North Sea. In the North Sea, most multi-use occurs between fishing grounds and marine protected areas or one or more activities related to shipping, offshore grids, and military areas.

How synergistic are the current multi-uses in the North Sea?

The multi-use between the following offshore activities were analyzed

- wind farms and obstacle-free zones around oil and gas platforms,
- wind farms and shipping lanes,
- Marine protected areas and fishing,
- Marine protected areas and offshore grids

These forms of multi-use were selected based on the common spatial overlaps of human activities and marine protected quantified through the methods described earlier. Additionally, some forms of multi-use were examined due to their significance in ongoing political discussions on maritime spatial planning. Among the identified challenges in the North Sea's current state of multi-use is the overlap of ecological protected areas with human activities such as fisheries, shipping, oil and gas, wind farms, pipes and cables. The expansion of offshore wind farms also poses a challenge as they can provide physical hindrance to large-scale fishing. The analysis revealed that the multi-use of offshore space is complex, with overlapping interests among the different stakeholders. The absence of synergy among the co-located activities has led to spatial conflicts, safety hazards, and environmental concerns.

What would happen if the North Sea's current multi-use patterns are projected into the future?

It isn't sustainable to extend current multi-use patterns in the future. The North Sea will see many more wind farms after 2030. Portions of the designated areas for future wind farms in the Dutch North Sea overlap with several obstacle-free zones around oil and gas platforms. Avoiding wind turbines in these zones will substantially reduce wind energy production in this region. Conversely, placing wind turbines in these zones poses risks to helicopter movements to and from the platforms. The installation of new wind turbines will also increase the shared area with marine protected areas and fishing grounds.
Both hydrogen and CO_2 transport and storage will be accompanied by new infrastructure. Therefore, after 2030, geological storage formations and new hydrogen and CO_2 pipes to enable this storage and transport will claim additional seafloor space to the benefit of energy system integration. These geological formations will also require monitoring which will be difficult when the storage sites are located beneath offshore wind farms.

Shipping activity is also expected to increase in the future. Re-routing shipping lanes is a time-consuming process that can take up to 10 years, making it a challenging task to alter shipping lanes to accommodate other human activities.
There is also growing momentum to recognize nature as a legitimate stakeholder and to increase obligations to restore nature in the North Sea. The European Union has adopted a Nature Restoration Law, which will also impact obligations to restore nature in the North Sea.

Current and planned synergistic multi-use projects in the North Sea

The several projects examined in this paper illustrated that there is a growing trend towards synergistic multi-use in the North Sea. They combined several technological innovations as well as environmental responsibility to maximize the potential of offshore spaces for diverse economic and ecological benefits.

How can synergistic multi-use become the norm in the North Sea?

The insights gathered suggests the following list of recommendations to make synergistic multi-use a norm in the North Sea:

- Co-locate human activities in a way that reduces their cumulative pressure on the marine ecosystem.
- Ensure that diverse sectors of offshore human activities and marine protected areas are included in the North Sea's maritime spatial planning. This can be achieved by engaging stakeholders from various sectors in the planning phase
- Encourage the sharing of marine data and knowledge important for maritime spatial planning. Such relevant data can aid maritime spatial planning by helping to understand cross-sectoral impacts, and thereby find opportunities for multi-use and avoid it if necessary
- Strive for synchronized legislations on multi-use among the North Sea countries and ensure that multi-use of offshore space is treated as a norm in the legislations where they provide net positive impacts.
- Support multi-use research and demonstration projects to advance these initiatives to commercial readiness. Prepare adequate funding to support these efforts.

In conclusion, the North Sea's current multi-use environment is characterized by a delicate balance of competing interests and human activities. However, there is a trend towards synergistic offshore multi-use. By learning from successful examples of synergistic multi-use and prioritizing nature restoration, the North Sea can continue to be a vital and productive maritime region. Effective planning is crucial to make such synergistic multi-use a norm in the North Sea.

1 What is offshore multi-use of space?

The North Sea is one of the busiest maritime regions in the world [1]. It harbors vast fishing grounds. Ships navigate through these international waters. Offshore wind farms use the area to produce renewable electricity. The seabed houses electricity cables that transport this electricity, as well as telecommunication cables and pipelines. These pipelines transport oil and gas produced from beneath the seabed to various ports in the countries surrounding the North Sea. Several companies in these neighboring countries have offshore assets, such as platforms, allowing them to explore and produce oil and gas. Besides this, the North Sea ecosystem is one of the most productive in the world and home to many (protected) species. The multitude of uses in the North Sea is visualized in *Figure 1* and *Figure 2*.

The opportunities and resources may seem abundant, but space – physical as well as ecological space - is a limiting factor. Furthermore, the resources related to the activities above are not uniformly spread. These limitations drive different activities to compete for the same space. **The goal of this paper is to explore how these activities might be able to share the same space[1], which will be referred to as 'offshore multi-use' here.**

With the highly industrialized countries surrounding the North Sea adopting transition strategies towards sustainable economies, the North Sea is facing a transformative challenge. There are three transitions mentioned in the Dutch North Sea Agreement: the energy transition, from fossil-based to renewables-based, including CO_2 storage in the subsurface; the food transition, from wild catch with a relatively large impact on the marine ecosystem towards new forms of protein production with a lower impact; and the nature transition, from a moderately limited protection of North Sea nature to recommended percentages of Marine Protected Areas (MPAs), areas closed to bottom-disturbing fishing practices while effective measures are taken to protect species that are now under heavy pressure. Nature-inclusive development of new infrastructure and active nature restoration efforts are also part of the nature transition. The contribution of the nationally protected areas to the target is to be confirmed, recent information suggest a 30% Marine Protected Areas (MPAs) in each of the EU27 countries [2] and 15% of the Dutch North Sea being closed for bottom-trawling [3] by 2030. The three transitions are synchronized in their goal to create sustainable blue economies in line with the Maritime Spatial Planning (MSP), which is defined by the European Union (EU) Maritime Spatial Planning (MSP) Directive [4] as :

"Maritime spatial planning (MSP) is the tool to manage the use of our seas and oceans coherently and to ensure that human activities take place in an efficient, safe and sustainable way. "

While the ambition is clear, synchronizing the strategies on how to use the available space and resources of the North Sea poses challenges. For example, the energy transition requires space to construct offshore wind farms, energy islands[2] and lay pipelines and cables. Simultaneously, the nature transition might necessitate that certain areas remain completely undisturbed. This may call for synergistic multi-use of space among offshore human activities MPAs—multi-use where there is a symbiotic relationship among the various sectors of offshore human activities as well as with MPAs.

Absence of synergistic multi-use has consequences. An example is the displacement of activities, such as fishing, exploitation of nature and disruption of shipping routes as well as energy production activities. Inability to find compatibility within multi-use will likely lead to spatial conflicts between

Space is a limiting factor in the North Sea. This calls for synergistic multi-use of space among offshore human activities as well as with MPAs.

1 In this research, 'sharing the same space' does not necessitate that the activities need to be performed in the same geographic spot; it also refers to activities that are performed adjacent to each other.

2 An energy island is an offshore large-scale infrastructure functioning as a central location for collecting, generating, storing, and distributing renewable energy, primarily from offshore wind farms

stakeholders' interest and delays in decision making; slowing down all the three transitions.

The topic of synergistic multi-use has previously been explored in several projects such as the MERMAID [5] which focused on combining food and energy production in multi-purposed offshore platforms; ROAD2SID [6] investigated the coexistence of nature, food and energy; EU-SCORES [7] explored the combination of offshore wind with wave and offshore solar energy, and eMSP NBSR [8] supported coherence of maritime policy and maritime spatial plans in North and Baltic Sea Regions. A comprehensive overview of projects can be found in the Maritime Spatial Planning library [9].

Building on these insights, this whitepaper will discuss the following questions:

- What is the current state of multi-use in the North Sea?
- How synergistic are the current multi-uses in the North Sea?
- What would happen if the North Sea's current multi-use patterns are projected into the future?
- What are some examples of synergistic multi-uses in the North Sea and what can we learn from them?
- How can synergistic multi-use become a norm in the North Sea?

To address the research questions, spatial data from the North Sea Energy Atlas [10] was utilized to analyze the extent of multi-use in the North Sea. The compatibility of co-located activities and assets was then assessed through a combination of literature review, expert interviews, and references to documented marine spatial conflicts. Following this, reports on demonstration and commercial projects that successfully resolved these incompatibilities and conflicts were examined to illustrate examples of synergistic multi-use. In this way, this paper seeks to provide an academic perspective on offshore multi-use of space.

The geographical scope of the spatial-calculations as well as examples of marine spatial conflicts and synergistic forms of multi-use is the North Sea (i.e., the Greater North Sea excluding the English Channel, Skagerrak and Kattegat). Additionally, the paper provides insights into policies and regulations affecting offshore multi-use, primarily focused on the Netherlands and the European Union (EU).

It is important to note that the spatial data used in this analysis, which represents various marine spatial activities, may be incomplete and subject to updates.

North Sea Energy Atlas

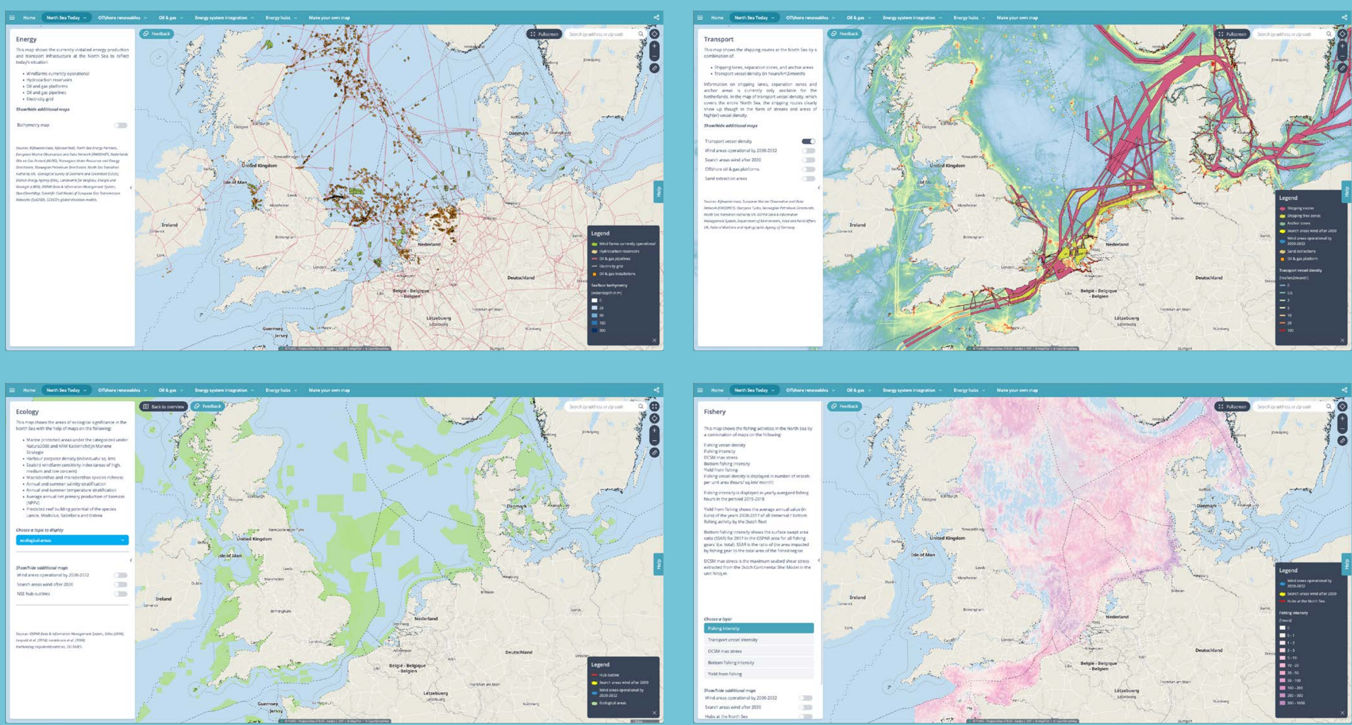


Figure 1: Current uses of the North Sea (as of 2023)

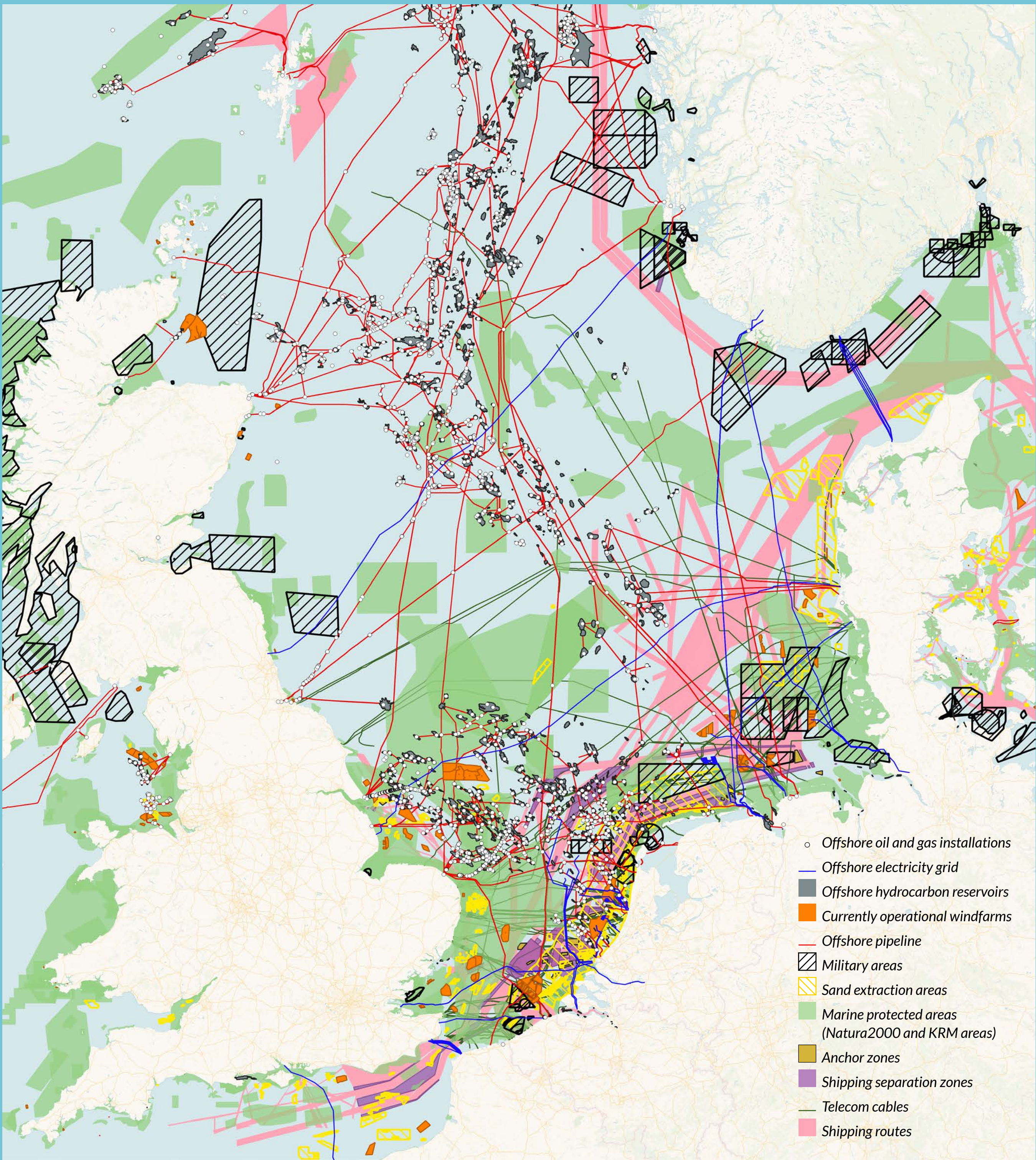
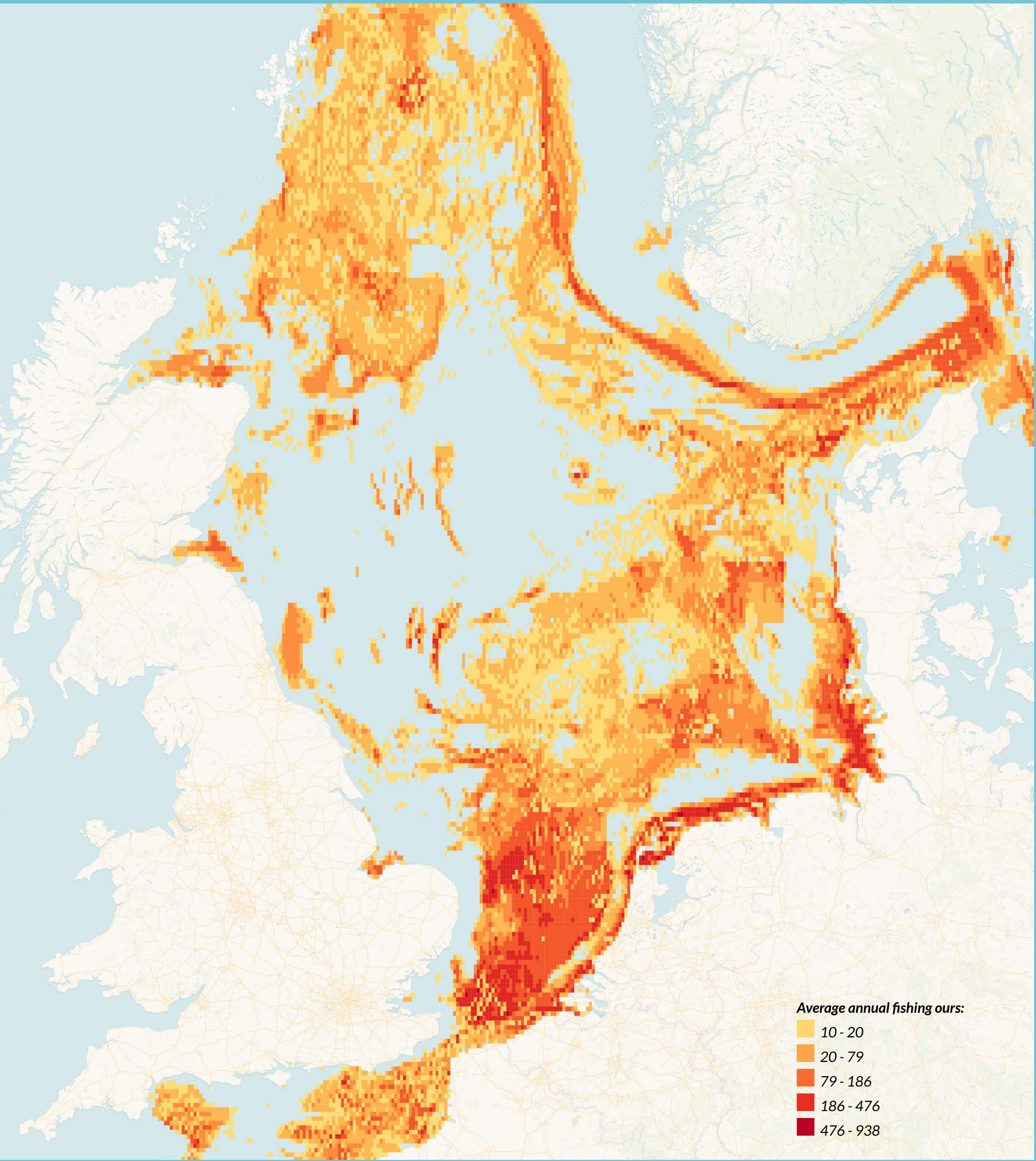
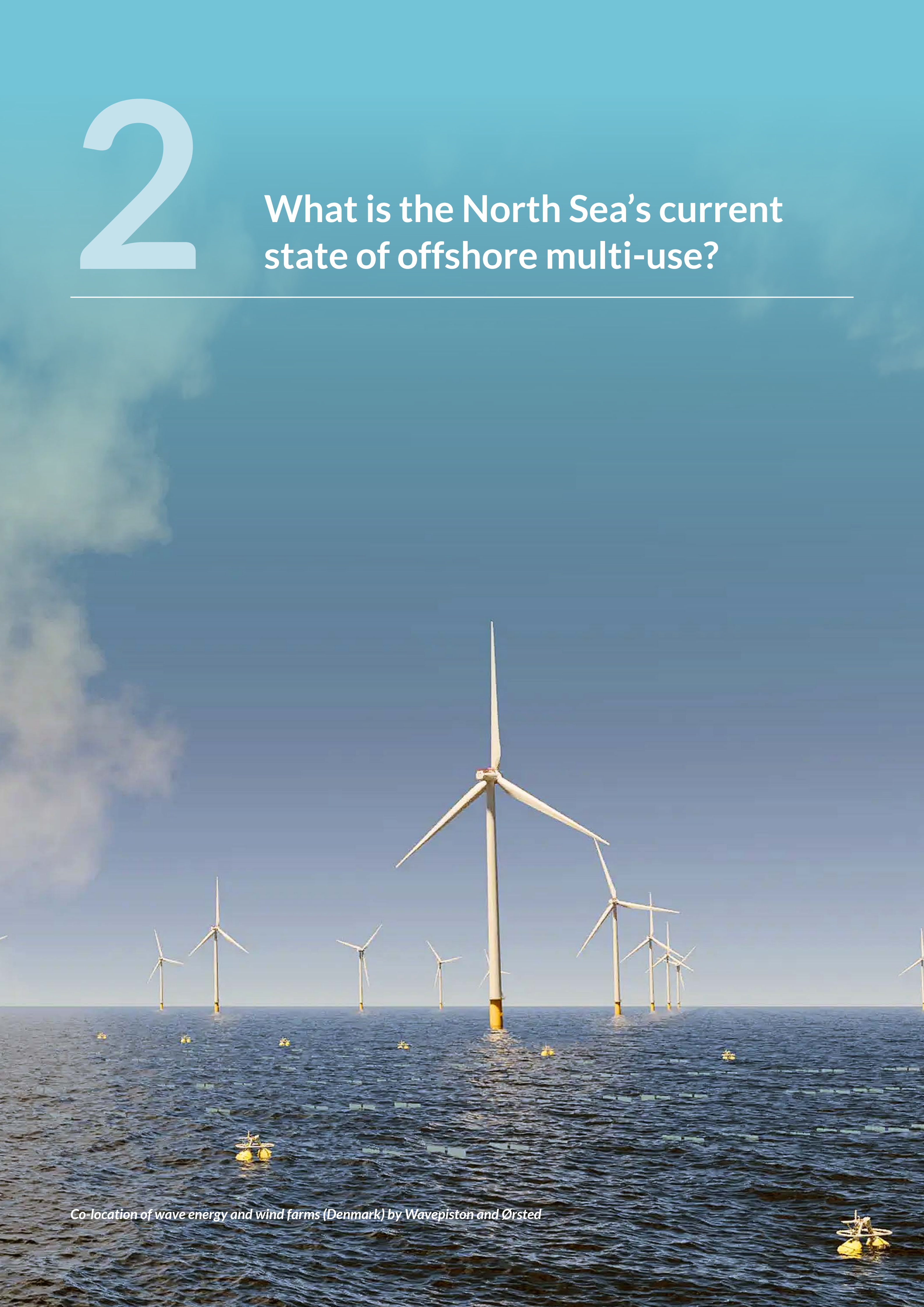


Figure 2: Intensity of annual fishing hours in the North Sea. Areas fished less than 10 hours annually have been excluded



2 What is the North Sea's current state of offshore multi-use?



Co-location of wave energy and wind farms (Denmark) by Wavepiston and Ørsted

The North Sea is no stranger to multi-use of offshore space. As of 2023, an offshore human activity is co-located with a MPA or at least one other human activity in approximately a third of the area of the North Sea. This is explained in *Figure 3* by dividing the area of the North Sea into rectangular grid cells of 2-3 km^2 area and counting the number of activities claiming each cell[3]. *Figure 3* also shows the area, in km^2, occupied by each category of grid-cells in the North Sea where all grid cells having the same set of activities (such as fishing, shipping, wind energy production etc.) is said to fall in the same category. Each rectangular block in *Figure 3* represents a type of grid-cell and the block's size is indicative of the cumulative area occupied by its grid-cells. *Figure 4* represents the same analysis for the German, Dutch and Belgian North Sea.

The density of multi-use is unequal and is skewed towards the southern parts of the North Sea . A close examination of Figure 1 shows that several human activities and MPAs are clustered in the Exclusive Economic Zones (EEZ) of the Southern North Sea countries. Closely examining the Dutch, German, and Belgian EEZs through Figure 4 shows that approximately two-thirds of that space is shared by either two or more human activities, or by MPAs along with one or more human activities s—twice that of the North Sea. *Figure 4* was obtained by repeating the analysis conducted for *Figure 3*, but for an area covering only the Dutch, German and Belgian EEZ.

Most of the observed multi-use is between fishing grounds and one or more of the activities associated with MPAs, shipping, offshore grids and military areas. Fishing is a unique activity in the respect that it is the most widely spread activity as shown in *Figure 2*. The North Sea has some of the busiest shipping lanes in the world with about 260,000 ship movements annually [11] as it connects the top three major European seaports along its coast (Rotterdam, Antwerp and Hamburg). Based on the data collected in this study, at least 13% of the North Sea's area (~72,000 km^2) is reserved for shipping lanes, shipping separation zones and anchor zone. A large part of the North Sea's surface area also falls under ecological protection; almost 25%. While this represents a considerable portion of the North Sea, almost all of these are open to various kinds of fisheries (including bottom-trawling), shipping, oil and gas production and other activities. Tracing the path of the routes of oil and gas pipelines, electric cables or telecom cables in Figure 1 will show that many of them coincide with ecologically protected areas too.

As of 2023, the geographical boundaries of wind farms cover nearly 1 % (~4500 km^2) of area in the North Sea and these are expected to increase in the future. **And nearly 35% of these wind farm areas are shared either with fishing grounds, ecologically protected areas or both** based on the analysis

3 Note that these activities either claim the same geographic spot or are adjacent to each other within 2-3 km^2

To prepare *Figure 3* and *Figure 4*, the North Sea area was divided into rectangular grid-cells of size 2-3 km2 and the number and type of human activities and MPAs occurring in 2023 in each grid was determined. The publicly available spatial data used here and their sources is listed in Table 2. Since the data used was collected in 2023, and any updates to this public data after 2023 are not reflected in Figures 3 and 4. If there were multiple activities occurring in a cell, it was considered to have multi-use. Note that this analysis does not make a distinction between activities in close proximity and those sharing the same geographic spot within a 2-3 km2 area . A list of human activities and MPAs were inspected in each cell—presence of shipping (shipping lanes, shipping separation zones and anchor zones), fishing (if there is more than 10 hours of fishing in the grid-cell annually. Even though almost all regions of the North Sea are used for fishing, it is not conducted to the same degree in all parts of the North Sea. The maximum number of annual fishing hours in any North Sea region was ~900. To account for only those regions that are frequently used for fishing, only regions with more than 10 hours of annual fishing is considered used for fishing activities), ecology-protection (Natura2000 and Kaderrichtlijn Mariene Strategie (KRM) protected areas), offshore grid (pipes, electricity cables or telecom cables and their respective inclusion zones; both offshore pipes and offshore electric cables have an inclusion zone of 0.5 km on either side of the pipe/cable where further human activities on the seabed is limited. The inclusion zone is 0.75 km for an offshore telecom cable), obstacle free zones (5 nautical mile caution radius assumed around all offshore production platforms), identified hydrocarbon fields (to account mainly for the exploration and monitoring for hydrocarbons, CO2 or H2 storage), military areas (for training exercises, aerial maneuvers, equipment testing, restricted navigation areas) designated areas for sand and seashell extraction and areas designated for currently operational wind farms. All grid-cells with identical lists of activities occurring inside are assumed to be grid-cells of the same type.

conducted to construct *Figure 3*. Other usages of the North Sea include sand and sea shell extraction reserve areas and military areas used both for naval exercises and low flying; these occupy 4% and (~24,000 km²) and 7% (~42,000 km²) of the North Sea respectively.

North Sea's subsurface also holds oil and gas reservoirs from where vast amounts of hydrocarbons have been extracted. The offshore platforms used to produce the oil and gas from the reservoirs have a 500 m safety zone, in which no other activities are allowed without permission from the operator, and an obstacle free zone of 5 nautical mile radius around them for helicopters to arrive and depart from these platforms. **Tall structures such as wind turbines within the obstacle free zones are a safety risk. Instances where obstacle free zones and designated wind farm areas necessitated meticulous planning** [12].

Thus, one can see that multi-use is indeed present. Most of the observed multi-use is between fishing grounds and one or more of the activities associated with MPAs, shipping, offshore grids and military areas. The density of multi-use is unequal and is skewed towards the southern parts of the North Sea. However, it is yet to be determined whether these multiple uses are truly synergistic.

Most of the observed multi-use is between fishing grounds and one or more of the activities associated with MPAs, shipping, offshore grids and military areas


Wave energy converter by Mocean Energy

Figure 3: Quantifying the current degree of multi-use in the North Sea. The figure shows the area, in km², occupied by each category of grid-cells in the North Sea where all grid cells having the same set of activities (such as fishing, shipping, wind energy production etc.) is said to fall in the same category. Each rectangular block in the figure represents a type of grid-cell and the block's size is indicative of the cumulative area occupied by its grid-cells

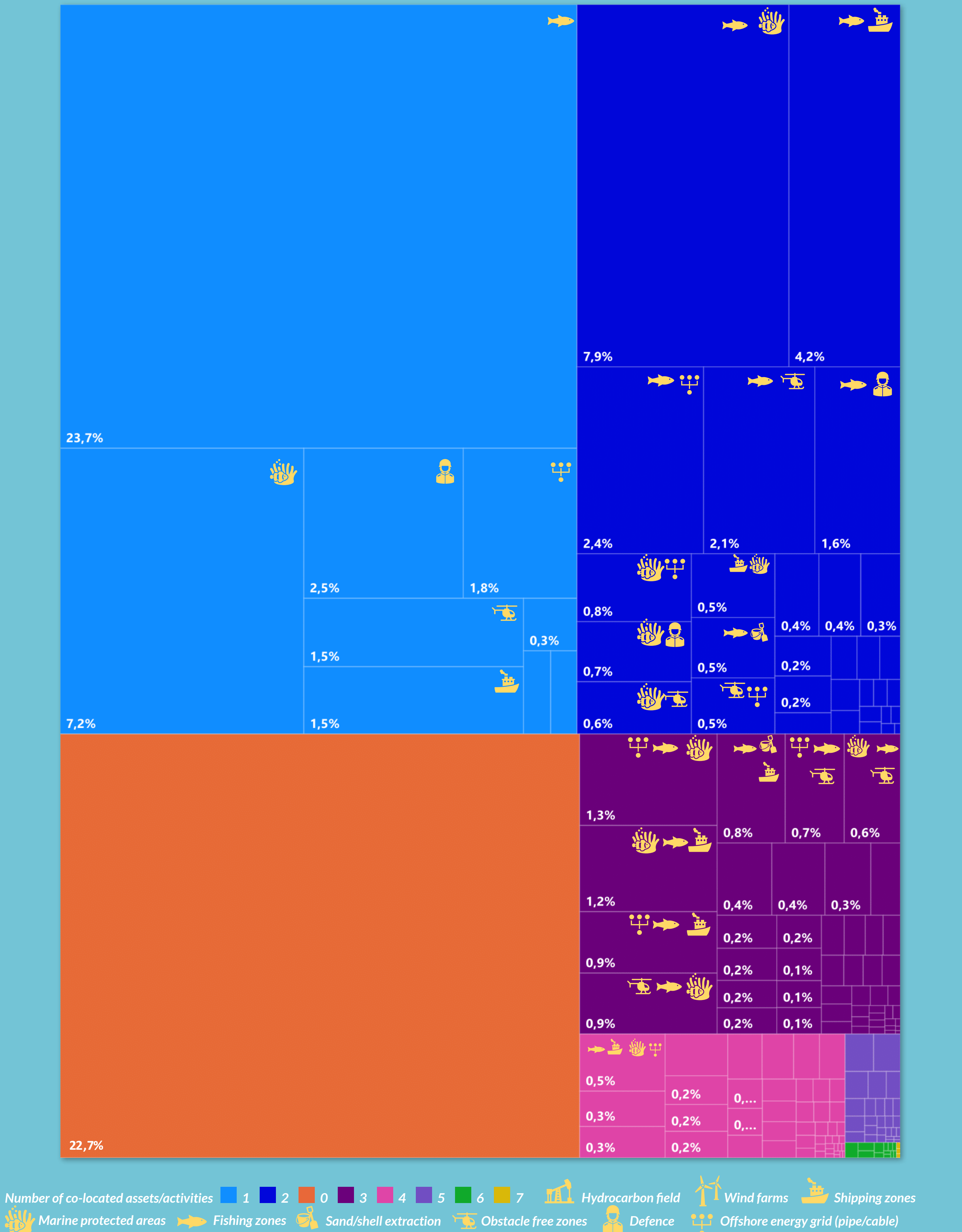
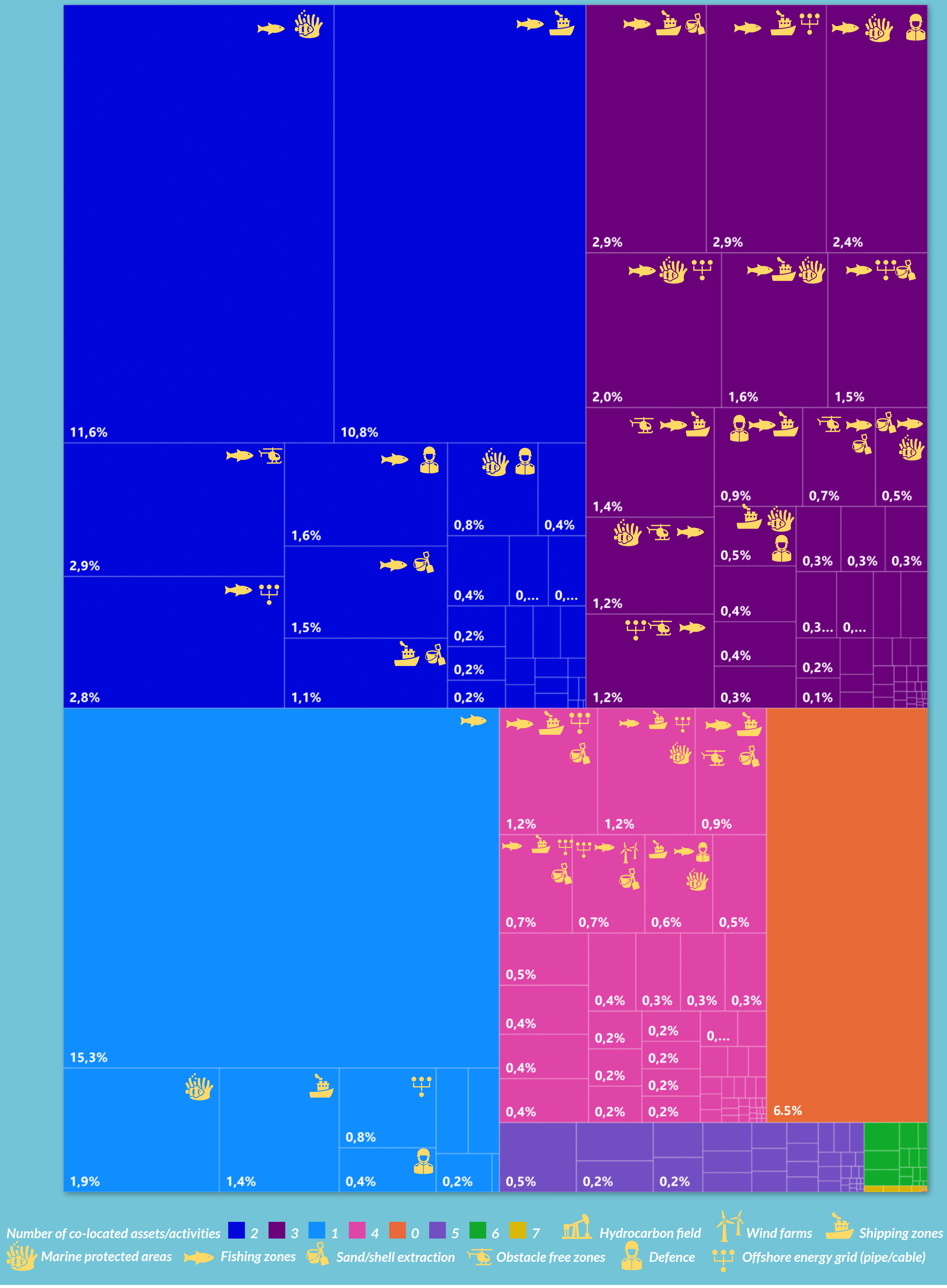


Figure 4: Quantifying the current degree of multi-use in the German, Dutch and Belgian North Sea.



3

How synergistic are the current forms of multi-use in the North Sea?

Seagrass—a vital habitat for ocean wildlife

The following forms of multi-use have been examined in this section. They are between:

- wind farms and obstacle free zones
- wind farms and shipping lanes
- wind farms, MPAs and fishing
- MPAs and offshore grids.
- These forms of multi-use have been chosen based on observed popular spatial overlap of human activities and MPAs from Figures 1-4. Some forms of multi-use were also examined due to the significance of their spatial overlaps in ongoing political discussions on MSP[4][13, 14]. The purpose of this examination was to check if those overlaps indeed caused any spatial conflicts of interest or harmed the activities.

Wind farms and obstacle free zones

As of 2023, the area of overlap between existing wind farms and obstacle free zones was nearly 230 km^2. Based on this study's spatial analysis. Even though this number might seem small compared to the area co-used by fishing and marine protection, their shared use of space has been debated often. For example, the obstacle free zones around oil and gas (O&G) platforms for helicopters has proven to be a constraint for planning offshore wind, calling for meticulous planning between wind farm developers and oil and gas operators. Furthermore, three other wind farms were reduced by 8GW due to similar spatial conflicts [15]. Challenges appear also when looking from the perspective of the other side of the coin (the helicopter-movements). In the Dutch North Sea, an area of 5 nautical miles (NM) is established as the obstacle free zones around a platform or rig with a helideck. The purpose of the obstacle free zones is to safeguard helicopter departures and arrivals, so objects within the 5 NM radius are a potential obstacle. Wind turbines represent one such obstacle. For instance, the overlap of the Hollandse Kust Noord wind farm with the obstacle free zones in its vicinity was assessed to have a major impact on the helicopter-movements. Under conditions of low visibility, the platforms would not be accessible. Furthermore, during good visibility conditions, corridors for the helicopters to pass and measures to stop the turbines was deemed necessary [12]. This conflict between wind farms and obstacle free zones could provide opportunities for other forms of renewable energy (i.e. offshore solar or wave energy) that are closer to sea level than the high wind turbines.

4 Read more about the spatial conflicts between wind area 6/7, oil and gas production, underground hydrogen storage and carbon capture and storage in the Dutch North Sea at ebn.nl/wp-content/uploads/2024/12/2023-EBN-Memo-Mijnbouwactiviteiten-Zoekgebied-Windenergie-6-7.pdf

Wind farms and shipping lanes

Figure 1 shows that several existing wind farm areas are in the close vicinity of existing shipping lanes; in some cases, almost completely islanded between shipping lanes. The installation of these wind farms can interfere with established shipping lanes, requiring rerouting and potentially increasing the risk of maritime accidents [13]. To avoid such risks, a 264 km^2 area reserved for electricity production from wave, currents or wind in the Belgian North Sea had to be reduced to 238 km^2 [16]. This adjustment was made due to the presence of major shipping routes to the north and south of the reserved area.

Wind farms, MPAs and fishing

A large part of the North Sea falls under ecological protection (25%). However, the ecological state of the North Sea is not good according to the 2023 OSPAR Quality Status report. Most of the MPAs are open to a range of human activities, including oil and gas production and wind farms (in the UK), with special permission. Shipping is allowed everywhere in MPAs and also fisheries (including bottom-trawling) is generally allowed for. Increasingly, the stricter management of MPAs to protect

Overlapping interests of different stakeholders has led to many instances of spatial conflicts, safety hazards and environmental concerns instead of a symbiotic relationship

marine biodiversity e.g. from the impact of bottom-trawling, leads to tensions between nature conservation goals and fishing communities.

Figure 3 and *Figure 4* show that almost 35% of the existing wind farm areas are shared either with fishing grounds, or MPAs or both. This situation raises concerns about synergistic effects of these types of multi-use. First of all, construction and operation of wind farms can lead to the displacement of mobile species and damage to sessile species, both affecting ecological values and fisheries [17]. For under-water nature, there is relief in knowing that the foundations and scour protection of wind-turbines may also help new habitats to develop and may facilitate long-term growth of certain fish species by providing some shelter from fishing. On the other hand, the expansion of offshore wind farms limits access to traditional fishing grounds and provides physical hindrance for bottom-trawling and other types of large-scale fishing. In the Netherlands, only passive fishing techniques are allowed for in wind farms. Also, wind farms form a major barrier and risk to many seabirds and to migratory birds crossing the North Sea. This leads to increasing disputes over space and the potential displacement of fishing activities.

Offshore grid and MPAs

Observation of Figure 1 will show that a large portion of offshore pipelines and cables pass through MPAs. There is research that suggests that installed pipelines may offer a habitat supporting benthic species [18]. However, the installation and maintenance of pipelines and cables can also damage sensitive marine habitats and disrupt conservation efforts. Cables in the operational phase may also have a negative impact on sharks and rays through the electric fields surrounding them. A thorough understanding of all the effects of installed pipelines and cables and their decommissioning on marine nature is not available at present.

These examples illustrate that **the multi-use of offshore space is complex due to overlapping interests of different stakeholders. In many instances, that has led to spatial conflicts, safety hazards, and environmental concerns as opposed to a symbiotic relation between them.** Addressing these issues requires further research to determine how these activities can coexist more harmoniously, ensuring that the needs of all stakeholders are balanced while minimizing harm to the marine environment.

CorPower Ocean (Ireland)'

4 What Would happen if the North Sea's Current Multi-use Patterns are Projected into the Future?

Bird hotels in wind farms (UK) by Ørsted

Electricity and natural gas make up the majority of the energy commodities that is produced from the North Sea currently. According to the European Green Deal, the EU's Energy System Integration Strategy aims to produce electricity from renewables, produce clean hydrogen and facilitate carbon capture and storage. Considering the EU's 2050 climate-neutral goals, that implies that hydrogen and captured CO_2 would be added to the existing commodity-mix of the North Sea in the years between 2030 through 2050. The vast space in the North Sea provides many opportunities for large scale green hydrogen production and CO_2 storage; but in order to circumvent the limitations posed by space the energy system would need to pave way for system integration and sector coupling between power and hydrogen production from offshore wind as well as gas transportation in form of hydrogen and CO_2.

The installed offshore wind capacity in the North Sea was 28 GW in 2023. This number is expected to increase to 120 GW by 2030, and to 300 GW by 2050 [19]. This increase in energy infrastructure will consequently occupy a significant amount of space in the North Sea as seen in Figure 6. Accordingly, additional electric cables and associated infrastructure that transport the electricity to shore needs to be accounted for. A key area of interest is the offshore wind sector. The expansion in this domain is notable: the designated area for offshore wind is set to increase from ~4,500 km² in 2023 to over 40,000 km² by 2050 based on the wind farm boundaries sketched in the national plans of the North Sea countries. Consequently, additional electric cables and associated infrastructure that convey the electricity to shore also needs to be accounted for.

Previous sections of this study have already explained the consequences of locating wind turbines within the obstacle free zones around oil and gas platforms [20]. Large parts of the designated areas for developing future wind farms in the Dutch North Sea also interfere with several such obstacle free zones. Examples can be found in wind area 6/7 in the Dutch North Sea[5]. Avoiding wind turbines to make way for obstacle free zones in wind area 6/7 will reduce wind energy production significantly [21]. On the other hand, expanding wind energy production could compromise accessibility to prospective oil and gas reservoirs present in wind area 6/7 (along with geological formations with potential for H_2 and CO_2 storage).

The installation of new wind turbines to meet the 2050 energy transition goals will also increase the area shared with MPAs and fishing grounds. Within these fishing grounds, if the fish concentrate in wind farms where they are safe from fishing, certain types of fishing will have to be ceased until new methods of fishing are developed that can be used within the wind farms. This could result in potential spatial conflicts. Figure 5 displays the significance of the choice between sharing of space with fishing and its cessation. Figure 5 compares the multi-use of human activities as well as MPAs in 2023 and after 2030 in areas of the North Sea planned to be occupied by offshore wind farms. The figure shows how approximately 12,500 km² (in light blue) and 3,000 km² (in pink) of offshore area currently used solely for fishing and MPAs respectively will overlap with areas designated for offshore wind farms in the future if the former two activities are to remain in their respective locations.

Besides wind energy targets, the EU strategy on offshore renewables has a target of 40 GW of installed capacity for ocean technologies such as wave, tidal and solar [22]. Furthermore, the Dutch government has also set a target of installing 3 GW of offshore solar by 2030 [23]. However, without sharing of space, (potentially that which is available between wind turbines) more space might need to be allocated for renewable energy production and their operation and maintenance.

Technology to produce green hydrogen using offshore wind energy are also being examined. The produced hydrogen is expected to feed into an international grid of offshore hydrogen pipelines in the North Sea. Blueprints of this international hydrogen grid have been proposed by gas network operators for the hydrogen and gas produced at the North Sea [24] [25] as shown in Figure 6. Parts of the grid may repurpose existing gas pipelines and parts of it will be new; and new pipelines indicate that they will have to claim new space on the seafloor.

The presence of depleted gas fields and saline aquifers in the North Sea also provides opportunities for CO_2 storage. Either ships or existing and new pipelines can transport the captured carbon dioxide through the North Sea. For example, the Northern Lights program plans to transport CO_2 captured and collected at various ports of the North Sea countries and plans to inject it into depleted gas fields in the Norwegian part of the North Sea. Denmark, Project Greensand and Bifrost are moving fast, with shipping and/or pipelines. Transport of CO_2 through pipelines is also planned within the Porthos and Aramis carbon capture and storage (CCS) projects expected to start CO_2 injection in 2026 and 2028 respectively. Porthos and Aramis will lay new pipelines to transport CO_2 to offshore depleted gas fields approximately 20 and 230 km away

5 Read more about the spatial conflicts between wind area 6/7, oil and gas production, underground hydrogen storage and carbon capture and storage in the Dutch North Sea at ebn.nl/wp-content/uploads/2024/12/2023-EBN-Memo-Mijnbouwactiviteiten-Zoekgebied-Windenergie-6-7.pdf

respectively. Just like in the case of pipelines used to transport hydrogen, new CO_2 transport pipelines will also claim space on the sea floor.

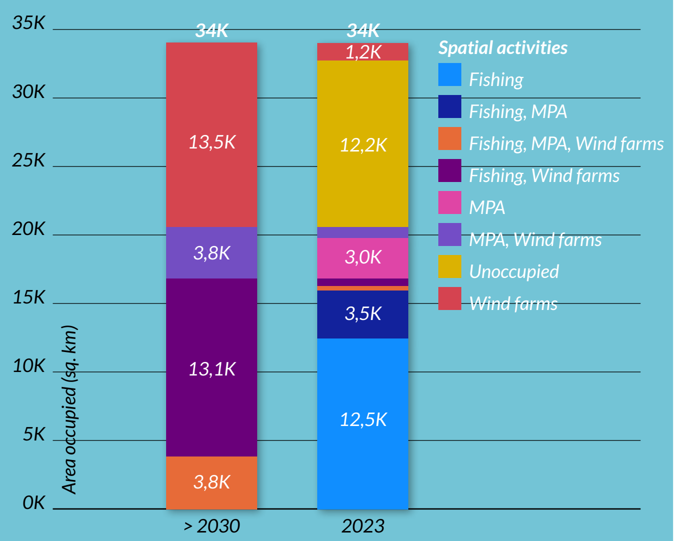
Propositions of Underground Hydrogen Storage (UHS) and CO_2 storage offshore will necessitate extensive monitoring of the subsurface storage throughout its operational lifetime to ensure safety and efficiency. CO_2 storage will also require monitoring even after operation has stopped and CO_2 injection has ceased. This monitoring can become particularly challenging when the storage reservoirs are situated beneath offshore wind farms or near oil and gas platforms. The presence of wind turbines, obstacle free zones, and vessels in these areas complicates the deployment and operation of monitoring ships, making it difficult to conduct necessary surveillance and maintenance activities. The installation of new pipelines required to transport the CO_2 and H_2, not only for storage, but also for import and exports, might also interfere with MPAs as mentioned in previous sections.

The European Union aims to import 10 Mton/year of renewable H_2 from non-EU origin by 2030. Assuming this hydrogen is to be transported in the form of ammonia, this would be equivalent to 185 ships/yr, assuming ammonia tankers of capacity 80.000 cubic meters6 7. To put it in scale, this represents 0.5 % of the current movements. Part of it will be then replace existing fossil energy carriers. While perhaps not substantial, it is in line with the North Sea Agreement, which also mentions that shipping is an activity that is projected to increase in the future [26]. Interestingly, re-routing shipping lanes is a time-consuming procedure and can take up to 10 years. Combining all these insights, it can be a cumbersome task to alter shipping lanes to accommodate other human activities or have them overlap shipping lanes.

There is also momentum to recognize nature as a rightful stakeholder and increase obligations to restore nature in the North Sea. For example, nature-inclusive designs for offshore energy infrastructure such as wind farms are increasingly being implemented, in particular in the Netherlands and the UK. On request from the Dutch National North Sea Agreement, Witteveen+Bos [27] has published a set of best practices for nature-inclusive construction of offshore installations. Permissions for certain types of fishing activities are being revised in MPA Areas by the Dutch Government. Moreover, the EU adopted a Nature Restoration Law, which will also impact obligations to restore nature in the North Sea [28].

6 ANALYSIS | Are there enough ships to carry exports of hydrogen as ammonia? | Hydrogen Insight
7 World's largest ammonia carriers for Naftomar Shipping to be built by Hanwha Ocean and classed by Bureau Veritas | Marine & Offshore

Figure 5: Comparison of spatial activities in 2023 and in post-2030 in areas where wind farms will be present/planned after 2030



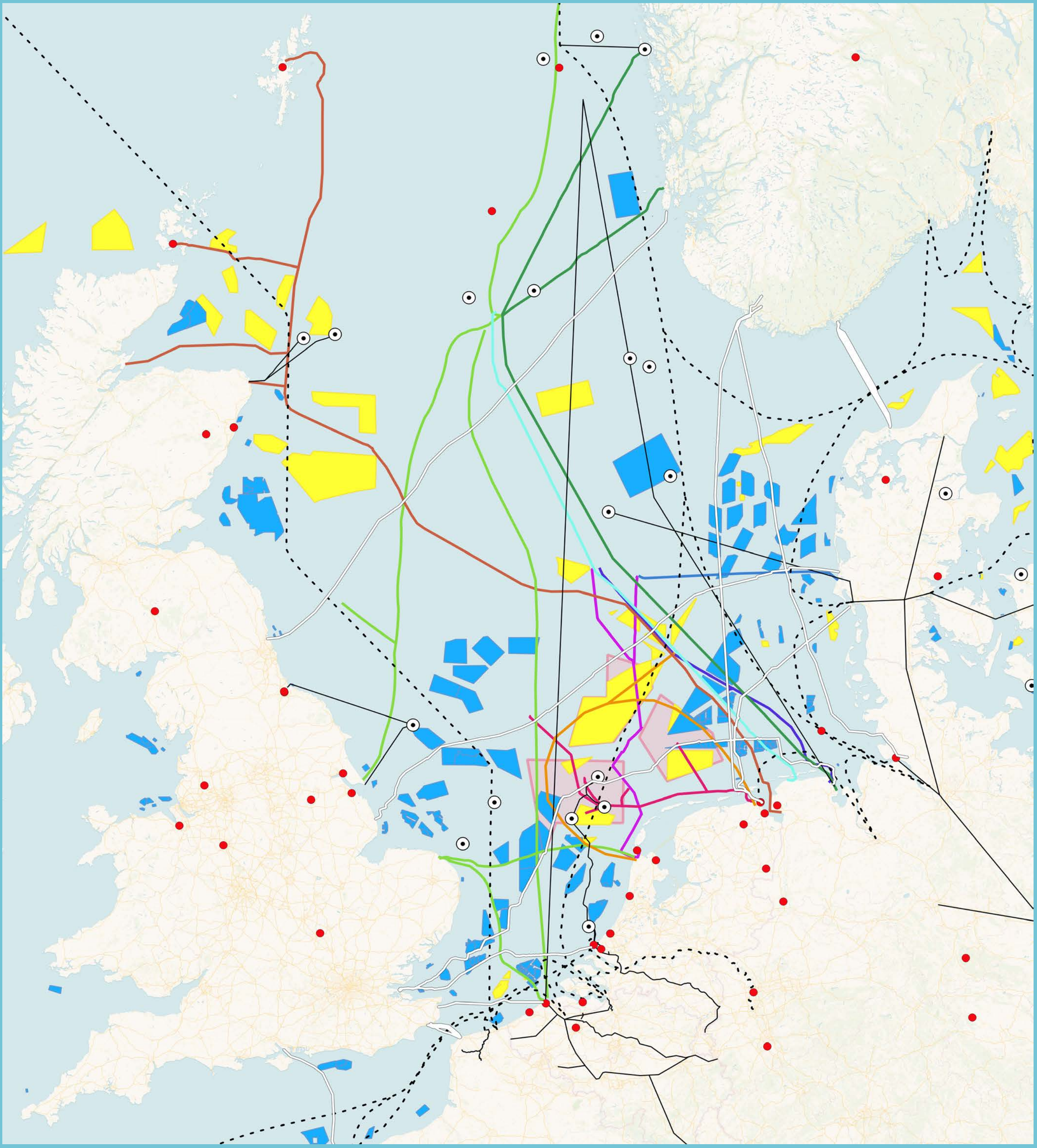
In the areas of the North Sea where offshore wind farms are expected to be present after 2030, Figure 5 compares the state of multi-use of offshore activities in 2023 and after 2030. The goal of Figure 5 is to cast a spotlight on the potential growth in overlap of MPAs and fishing grounds with offshore wind farms in the future if the former two activities are to remain in their respective locations. Therefore, only areas (in km^2) of fishing, offshore wind farms and MPAs and their overlaps with each other were analyzed to make Figure 5. The areas corresponding to fishing and MPAs in 2023 considered here are the same as those used to construct Figure 3. To represent offshore human activities for the years post 2030, the only change in claimed areas considered is that due to the growth in wind farm development. The post-2030 wind farm areas considered for this calculation is shown in Figure 6. All other activities are assumed to claim the same area as in 2023 due to the lack of data about their future states.

Figure 6: Post 2030 energy infrastructure outlook in the North Sea (based on data available in 2023). The maps shows an outlook of potential new offshore energy infrastructure and projects that will add to the current offshore activities in the North Sea. These include existing and planned wind farms, planned H_2 and CO_2 transport routes and storage projects, and future energy hubs envisioned by the North Sea Energy Program

- Potential CO_2 capture/transport/storage projects
- Potential H_2 production/transport/storage projects
- Potential CO_2 transport routes with ships
- Potential CO_2 transport routes with pipelines
- Windfarms operational by 2030-2032
- Windfarm search areas after 2030
- Boundary of potential energy hubs envisioned by the NSE program
- Electricity interconnectors

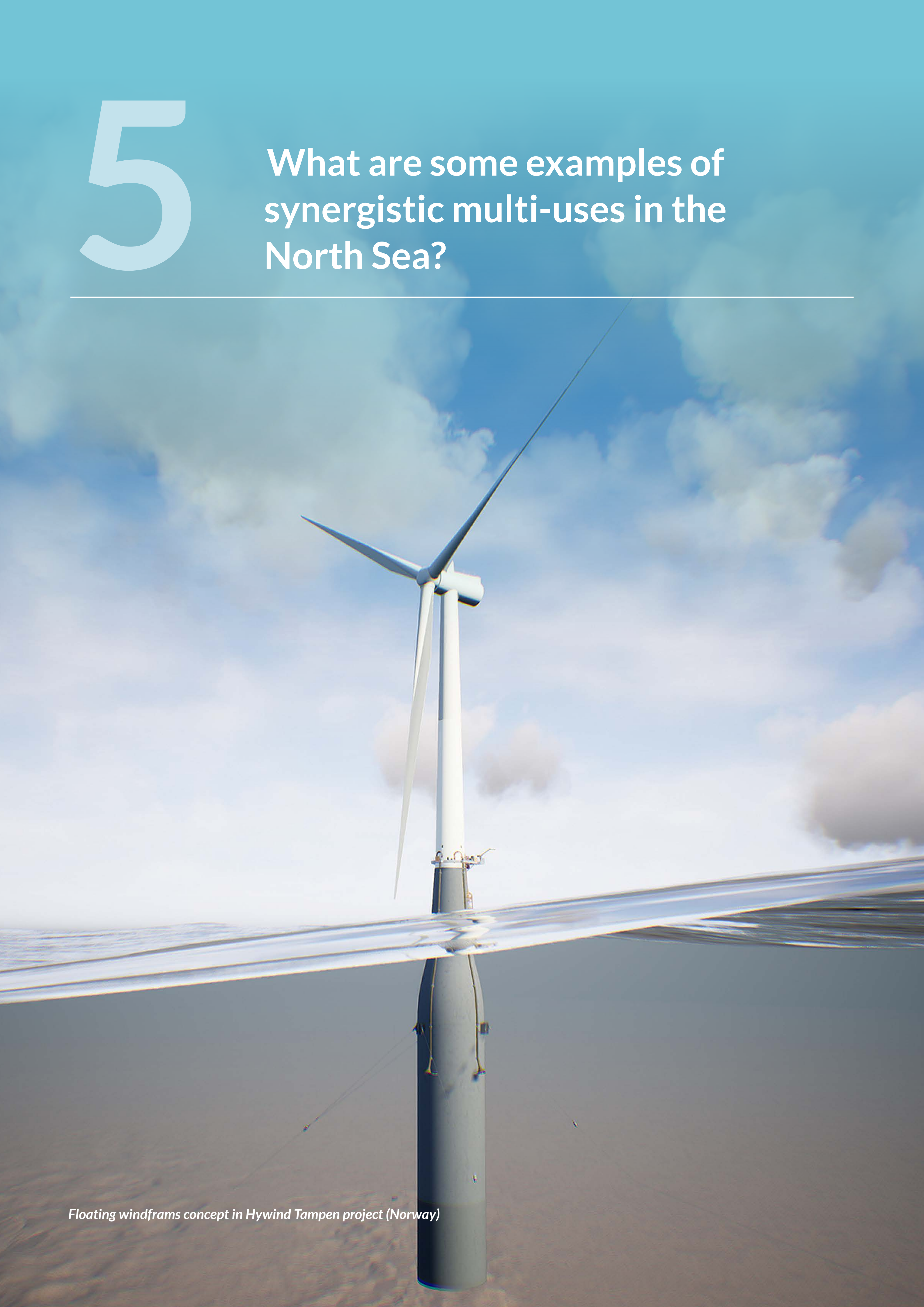
Hydrogen backbone initiatives in the North Sea:

- Aquaductus
- CHE (Clean Hydrogen to Europe)
- EHB (European Hydrogen Backbone)
- European Hydrogen Backbone Link
- Europipe
- HyONE
- NGT
- NOGAT
- Tyra-Nybro



5

What are some examples of synergistic multi-uses in the North Sea?



Floating windframs concept in Hywind Tampen project (Norway)

There are already quite some interesting examples of multi-use in existence or planned in the near future within the North Sea area. The list below indicates some of them which can be used as inspiration for future multi-use.

Each of these projects offers valuable insights into the practicalities and potential of multi-use applications in marine environments. They demonstrate how different uses, such as energy generation, environmental conservation, marine protein production and recreation, can coexist and even benefit from each other. **These projects pave the way for replicable and scalable synergistic multi-use solutions that align with both industrial and environmental goals.**

Hywind Tampen floating offshore wind farm exemplifies the diverse utilization of offshore space, showcasing advancements in renewable energy production, oil and gas production. Situated in the Norwegian North Sea, Hywind Tampen features an 88 MW floating wind farm with turbines placed in deep waters exceeding 100 meters. Hence renewable energy production need not be concentrated near the shore [40]. This project not only supplies 35% of the power demand for nearby oil and gas platforms but also pioneers renewable energy production away from traditional shallow waters near shore.

Within the Dutch Offshore wind farm Hollandse Kust Zuid the first commercial offshore seaweed farm is planned, combining offshore wind and aquaculture. In other parts of the North Sea already pilots are developed to explore this option. For example, the UNITED H2020 project and its successor ULTFARMS, which focus on combining aquaculture—specifically blue mussel and seaweed cultivation—with offshore wind farms located at various locations in the Baltic and North Seas up to 80 kilometers offshore. This initiative aims to prove the feasibility of multi-use in extreme offshore conditions, potentially setting a precedent for similar applications worldwide. If the pilot successfully *demonstrates this multi-use in such extreme conditions*, it would imply its application in several other offshore locations [41]. Figure 8 displays an innovative approach to seaweed cultivation employed in the Kriegers Flak offshore wind farm in Denmark where seaweed is grown in lines inside the perimeter of the windfarm

In the Netherlands, the Borssele and Hollandse Kust Zuid offshore wind farms exemplify a policy shift towards shared offshore space. They cover surface areas of approximately 344 and 214 km^2 respectively. These initiatives allow for the cohabitation of wind farms with activities such as marine aquaculture, other renewable energy sources like solar and tidal, and projects aimed at enhancing marine biodiversity [42]. Area passports provide detailed guidelines for synergistic activities within different regions of the wind farms, alongside designated passages for through-shipping [43] to ensure safety and accessibility. These area passports are visualized in *Figure 7*.

The PosHYdon project integrates offshore wind energy with offshore green hydrogen production and oil and gas extraction, testing the integration of these energy systems in the Dutch North Sea. Similarly, **the Endurance project plans to integrate CCS activities with wind farms,** focusing on mitigating collision risks and optimizing offshore space utilization. In the Endurance project, there is a 110 km^2 overlap of space on the sea floor between the BP-led Endurance

Table 1: Examples of projects addressing offshore multi-use

Project Name	Description	Multi-Uses
Princess Elisabeth Island (Energy Island Belgium, 2024) [29]	Grid Extension in North Sea	Grid Cables, Offshore Wind
Hywind Tampen (Floating Wind, Norway, 2022) [30]	First Floating Wind Farm for Oil & Gas Power	Oil & Gas, Offshore Wind
Endurance/Hornsea (CCS and Wind, UK) [31]	Overlap of Wind Farm and Carbon Storage	Wind, CO_2 storage
Hollandse Kust West VI (Ecowende, Netherlands, 2026) [32]	Minimal Impact Wind Farm Design	Wind, Nature
Hollandse Kust West VII (OranjeWind Power II, Netherlands, 2026) [33]	Offshore Wind with Energy Storage Integration	Wind, Energy Storage, floating solar
PosHYdon (Hydrogen, Netherlands, 2024) [34]	First Fully Electrified Offshore Platform to produce hydrogen and transport to shore.	Oil & Gas, Hydrogen, Wind
North Sea Farm 1 (Borssele, 2024) [35]	Commercial offshore Seaweed farm	Wind, Aquaculture
Hywind Scotland [36]	Passive fishery in floating offshore wind farm	Wind, Fishery
Borssele [37]	Passive fishery in floating offshore wind farm	Wind, Fishery
OOS International Project [38]	Mussel farming within offshore wind farms	Wind, Aquaculture

Figure 7: Zonal planning of Hollandse Kust Zuid [39]

project for carbon capture and storage and Oersted-led Hornsea-4 wind farm. In the overlapping area, there was the risk of boats used to monitor CO_2 leaks colliding into the Hornsea's wind turbines. Through a commercial agreement, this issue was resolved. However, the details of this agreement is currently limited and hence offers limited insights at this time.

In terms of environmental stewardship, projects like Hollandse Kust West VI [44] prioritizes nature conservation alongside wind farm development. The project implements innovations such as taller turbines to reduce bird collisions and employ bird-recognition systems to curtail rotor operation during critical migration periods. Progress is also being made in the field of bird monitoring elsewhere; for instance, the firm Spoor employs software that uses advanced computer vision and artificial intelligence to identify, track, and categorize birds within wind farms, as shown in Figure 9.

Meanwhile, the wind farm **Hollandse Kust West VII** [45] **incorporates energy system integration in its plans by proposing floating solar plants and subsea energy storage technologies** to maximize energy generation efficiency and complement wind energy production. Complementary research is also validating the economic and environmental synergies (such as sharing maintenance activities) of co-locating a floating solar park and the wind farm [46]. The companies RWE and SolarDuck are collaborating to develop the use of floating solar parks in Hollandse Kust West VII. An example of a floating solar park within an offshore wind farms conceptualized by SolarDuck is shown in Figure 10.

The Hywind Scotland project addresses the challenge of multi-use by conducting trials to integrate static fishing with floating wind turbines [47] , demonstrating effective spatial management alongside existing oil and gas platforms. Similar trials are conducted in the Dutch Borssele offshore wind farm [48]. Interestingly, fishing might also provide other services such as environmental monitoring and site inspection of offshore structures, especially if fishermen spend longer times between wind turbines. [49].

Overall, these projects illustrate a growing trend towards sustainable offshore development, combining technological innovation with environmental responsibility to maximize the potential of offshore spaces for diverse economic and ecological benefits.

Figure 8: Seaweed sowing at the Kriegers Flak offshore wind farm; Photos: T. Boderskov

Figure 9: UK-bird behavior monitoring in project Spoor AI

Figure 10: Offshore solar concept by SolarDuck

6 How can synergistic multi-use become the norm in the North Sea?

Co-locate human activities in a way that their cumulative pressure on the marine ecosystem is reduced. Simply using offshore multi-use to fit as many human activities as possible in the North Sea could deteriorate an already degraded ecosystem [50]. Therefore, to ensure a net positive impact on the North Sea ecosystem with the energy, protein and nature transition pathways, it is important to study the cumulative impacts of the present and future human activities.

Ensure that diverse sectors of offshore human activities and MPAs are included in the North Sea's MSP. This can be achieved by engaging stakeholders from various sectors in the planning phase. By doing so, the North Sea ecosystem can benefit from cumulative positive impacts of cross-sectoral human activities which would not have been identified if a wide array of sectors were not consulted. Here are some examples of cross-sectoral positive impacts:

- Integrating renewable energy production with existing offshore operations can lead to cleaner, more sustainable energy solutions. For instance, the PosHYdon project, which produces hydrogen from renewable electricity generated by wind, showcases how renewable energy can be effectively harnessed offshore. Similarly, the HyWind Tampen floating wind farm, is expected to meet about 35% of the power demand for five oil and gas platforms and so it demonstrates the potential for reducing of carbon emissions with wind energy.
- Combining aquaculture farms with wind farms in the North Sea allows for coordinated maintenance trips, reducing the number of commutes required for operations and maintenance (O&M) activities [51]. This integration can streamline logistics, ease financial burdens, lower emissions and other environmental impacts and improve the efficiency of the involved sectors.

Encourage the sharing of marine data and knowledge important for MSP. Such relevant data can aid MSP by helping to understand cross-sectoral impacts, and thereby find opportunities for multi-use and avoid it if the cumulative impacts prove harmful. However, not all knowledge and data is easily accessible or open to the public and several are proprietary. This paper's research also faced challenges in finding relevant data required to quantify multi-use (as performed in chapters 2 and 4). Particularly to map the future MSP in the North Sea; aside from the planned offshore wind farm areas, there is limited information available.

Strive for synchronized legislations on multi-use among the North Sea countries. Synchronized legislations will make it easy to utilize the data and knowledge shared between the North Sea countries from its various sectors of human activities [52]. To accomplish that, dialogues between the public institutions from all North Sea countries is required, especially to address regulatory, safety and legal challenges along the way [53]. Furthermore, ensure that multi-use of offshore space is treated as a norm in the legislations where they provide net positive impacts. This also necessitates a level of uniformity in how impacts of human activities in the North Sea ecosystem are perceived.

To support multi-use research and demonstration projects, and to advance these initiatives to commercial readiness, it is essential to prepare adequate funding. Chapter 5 lists several examples of synergistic multi-use projects. Understanding their impacts on the North Sea basin would be valuable. If the impacts of these projects prove beneficial, the best practices identified can be further researched, implemented in demonstration projects, and, if successful, brought to commercial readiness. This approach will help establish multi-use as a standard practice in the North Sea. Financial support, possibly through government incentives or mixed funding sources, is crucial for these initiatives. Without such support, early developers may need to face significant costs [52].

Consider centralizing decision-making to resolve spatial conflicts on a strategic level within Marine Spatial Planning (MSP) and permitting.

A way forward could be found in recommendations from Kusters et al [54]. on spatial conflict resolution. This paper suggests that decision-makers should focus on the strategic level of marine spatial plans. For the Dutch North Sea, this could involve establishing measures to prioritize activities over others. Centralizing decision-making can help resolve conflicts by facilitating discussions on trade-offs between maritime activities and bringing together all sectoral considerations and individual measures, allowing a more proactive approach to conflict resolution. Additionally, there is a need for initiatives that promote intensified international collaboration, which should pro-actively include spatial issues in their discussions (e.g. via new initiatives such as the GSNBI).

7 Concluding Remarks

The North Sea offers numerous opportunities and resources, yet both physical and ecological space are limited. Additionally, the distribution of resources for various activities is uneven. These constraints lead to competition among different activities for the same space. The aim of this paper was to investigate how the various offshore human activities and MPAs can coexist within the same space, a concept referred to as 'offshore multi-use'. And when there is a symbiotic relationship among the various sectors of offshore human activities or among the human activities and MPAs involved, this paper has called it synergistic multi-use.

Multi-use of offshore space is indeed present in the North Sea, with a higher density of such activities in its southern regions. A detailed examination of the Dutch, German, and Belgian EEZs reveals that approximately two-thirds of this area is shared by either two or more human activities, or by MPAs along with one or more human activities—twice the proportion found in the North Sea. In the North Sea, most multi-use occurs between fishing grounds and one or more activities related to shipping, offshore grids, military areas and MPAs. Among the identified challenges in the North Sea's current state of multi-use is the overlap of ecological protected areas with human activities such as fisheries, shipping, oil and gas, wind farms, pipes and cables. The expansion of offshore wind farms also pose a challenge as they can provide physical hindrance to large-scale fishing.

Co-locate human activities in a way that reduces their cumulative pressure on the marine ecosystem.

It was found that multi-use of offshore space is complex, with overlapping interests among the different stakeholders. The absence of synergy among the co-located activities has led to spatial conflicts, safety hazards, and environmental concerns. The ambitions of the protein, energy and nature transition pathways will result in increased spatial claims in the future and synergistic multi-use is crucial to meet those ambitions sustainably.

To make synergistic multi-use a norm in the North Sea, the following measure are recommended:

- Co-locate human activities in a way that reduces their cumulative pressure on the marine ecosystem.
- Ensure that diverse sectors of offshore human activities and MPAs are included in the North Sea's MSP. This can be achieved by engaging stakeholders from various sectors in the planning phase
- Encourage the sharing of marine data and knowledge important for MSP. Such relevant data can aid MSP by helping to understand cross-sectoral impacts, and thereby find opportunities for multi-use and avoid it if necessary
- Strive for synchronized legislations on multi-use among the North Sea countries and ensure that multi-use of offshore space is treated as a norm in the legislations where they provide net positive impacts.
- Support multi-use research and demonstration projects to advance these initiatives to commercial readiness. Prepare adequate funding to support these efforts.

In conclusion, the North Sea's current multi-use environment is characterized by a delicate balance of competing interests and human activities. However, there is a trend towards synergistic offshore multi-use, aiming to maximize the potential of offshore spaces for a variety of economic and ecological benefits. By learning from successful examples of synergistic multi-use and prioritizing nature restoration, the North Sea can continue to be a vital and productive maritime region. Effective planning is also crucial to ensure that human activities as well as MPAs can coexist sustainably.

Data used

Table 2: Summary of spatial data used

	Spatial data	Source
1	Shipping zones	North Sea Energy Atlas [10]
2	Shipping separation zones	
3	Anchor zones	
4	Intense fishing areas	
5	Offshore wind farms operational as of 2023	
6	Offshore wind farms operational by 2030-2032	
7	Search areas for offshore wind farms after 2030	
8	Marine protected areas (Natura2000 and KRM areas)	
9	Boundary of potential energy hubs[8] envisioned by the NSE program	
10	Oil and gas pipelines along with a safety inclusion zone of 0.5 km on either side of pipe	
11	Identified hydrocarbon fields	
12	Electricity cables along with a safety inclusion zone of 0.5 km on either side of cable	
13	Telecommunication cables along with their safety inclusion zone 0.75 km on either side of the cable	
14	Sand extraction zones	
15	Military zones	
16	Fishing areas in the North Sea	
17	Potential CO_2 capture/transport/storage projects	
18	Potential H_2 production/transport/storage projects	
19	Potential CO_2 transport routes with pipelines	European Commission -projects of common interest & projects of mutual interest transparency platform [55] Clean Air Task Force [56]
20	Potential CO_2 transport routes with ships	
21	Hydrogen backbone initiatives in the North Sea	The European Hydrogen Backbone Initiative [57], Gasunie [58], AquaDuctus [59], Clean Hydrogen to Europe (CHE) Pipeline [60], Noordgastransport (NGT), Norther Offshore Gas Transport (NOGAT) [61]

8 Energy hubs are defined as offshore energy systems where production, conversion and/or storage of energy commodities (electricity, natural gas, hydrogen) and CO_2 are co-located. Transport of energy commodities and CO_2 to and from shore takes place via national transport corridors and/or via international interconnections. In this way, energy hubs are search areas for offshore system integration opportunities, i.e., where activities such as electricity production, CO_2 transport and storage, offshore hydrogen production and platform electrification for (green-field) natural gas production can be combined.

References

[1] M. Quante and F. Colijn, "North Sea Region Climate Change Assessment," Springer, 2016, p. 528.

[2] European Commission, "EU Biodiversity Strategy Dashboard," 13 March 2023. [Online]. Available: https://dopa.jrc.ec.europa.eu/kcbd/EUBDS2030-dashboard/?version=1#Target%201.

[3] Overlegorgaan Fysieke Leefomgeving, "The North Sea Agreement," 2020.

[4] E. Commission, "Maritime Spatial Planning," 2007. [Online]. Available: https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/maritime-spatial-planning_en. [Accessed 19 12 2024].

[5] European Commission, "Innovative Multi-purpose off-shore platforms: planning, Design and operation," [Online]. Available: https://cordis.europa.eu/project/id/288710/reporting.

[6] "ROAD2SID," [Online]. Available: https://www.marin.nl/en/jips/road2sid.

[7] "EU-SCORES," [Online]. Available: https://euscores.eu/.

[8] "eMSP NBSR," [Online]. Available: https://www.emspproject.eu/.

[9] European Commission, "MSP Projects," [Online]. Available: https://maritime-spatial-planning.ec.europa.eu/msp-practice/msp-projects.

[10] Program, North Sea Energy, "North Sea Energy Atlas," [Online]. Available: https://north-sea-energy.eu/en/energy-atlas/.

[11] Wadden Sea Board, "Shipping safety," 2019. [Online]. Available: https://www.waddensea-worldheritage.org/system/files/wsb-29-5-5-1_shipping_safety.pdf.

[12] To70, "Helicopter accessibility of oil & gas platforms near the offshore wind farm sites Hollandse Kust (zuid and noord)," 2017.

[13] European MSP Platform, "Conflict fiche 7: Maritime transport and offshore wind".

[14] P. J. Stephenson, "Maritime Spatial Planning in Europe. Discussion Paper on," Berlin, Germany.

[15] "Kamerbrief over ruimtelijke samenhang windparken en mijnbouwactiviteiten op zee," 17 May 2023. [Online]. Available: https://www.rijksoverheid.nl/documenten/kamerstukken/2023/05/17/ruimtelijke-samenhang-windparken-en-mijnbouwactiviteiten-op-zee.

[16] S. Degraer, R. Brabant, B. Rumes and L. Vigin, "Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Attraction, avoidance and habitat use at various spatial scales. Memoirs on the Marine Environment," Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, Brussels, Belgium, 2021.

[17] European MSP Platform, "Conflict fiche 5: Offshore wind and commercial fisheries".

[18] C. N. Lacey and P. Hayes, "Epifauna associated with subsea pipelines in the North Sea," ICES Journal of Marine Science, p. 1137–1147, 2019.

[19] "More port capacity needed for European offshore wind targets 2030," [Online]. Available: https://www.agro-chemistry.com/news/more-port-capacity-needed-for-european-offshore-wind-targets-2030/.

[20] Nederlands Lucht- en Ruimtevaartcentrum, "Offshore windturbinezog en veilige helikopteroperaties," 2016.

[21] "Brieven Regering – Nationale Omgevingsvisie (Government Letters – National Spatial Strategy," [Online]. Available: https://www.tweedekamer.nl/kamerstukken/brieven_regering/detail?id=2023Z08744&did=2023D20940.

[22] "Offshore Marine Energy: Solar, Wave, Tidal," [Online]. Available: https://northseaenergyroadmap.nl/offshore-marine-energy.

[23] "Multi-source offshore energy parks can play an important role in our future renewable electricity system," [Online]. Available: https://euscores.eu/multi-source-offshore-energy-parks-have-an-important-role-to-play-in-our-future-renewable-electricity-system/.

[24] Gasunie, "Gasunie to develop international hydrogen network in German North Sea," 2023. [Online]. Available: https://www.gasunie.nl/en/news/gasunie-to-develop-international-hydrogen-network-in-german-north-sea.

[25] Fluxys, "Aquaductus," [Online]. Available: https://www.fluxys.com/en/projects/aquaductus.

[26] "Import of hydrogen," [Online]. Available: https://www.portofrotterdam.com/en/port-future/energy-transition/ongoing-projects/hydrogen-rotterdam/import-of-hydrogen.

[27] "Samenvattend verslag van het Noordzeeoverleg," 25 10 2023. [Online]. Available: https://www.noordzeeoverleg.nl/nieuws/2577097.aspx.

[28] "Nature restoration law: Council gives final green light," 17 June 2024. [Online]. Available: https://www.consilium.europa.eu/en/press/press-releases/2024/06/17/nature-restoration-law-council-gives-final-green-light/.

[29] "The Princess Elisabeth Island," [Online]. Available: https://www.elia.be/en/infrastructure-and-projects/infrastructure-projects/princess-elisabeth-island.

[30] "Hywind Tampen," [Online]. Available: https://www.equinor.com/energy/hywind-tampen. [Accessed 2024].

[31] "BP, Orsted reach deal over overlap of UK Endurance CCS, Hornsea windfarm sites," [Online]. Available: https://www.reuters.com/business/energy/bp-orsted-reach-deal-over-overlap-uk-endurance-ccs-hornsea-windfarm-sites-2023-06-20/. [Accessed 2024].

[32] "The most ecological wind farm yet," [Online]. Available: https://ecowende.nl/en/. [Accessed 2024].

[33] "RWE participates with unique concepts in Dutch offshore wind tender for Hollandse Kust West sites," [Online]. Available: https://www.rwe.com/en/press/rwe-renewables/2022-05-16-rwe-participates-in-dutch-offshore-wind-tender-hollandse-kust-west/. [Accessed 2024].

[34] "Poshydon," [Online]. Available: https://poshydon.com/en/. [Accessed 2024].

[35] "World's first seaweed farm on North Sea wind farm," Deltares, [Online]. Available: https://www.deltares.nl/en/news/worlds-first-seaweed-farm-on-north-sea-wind-farm. [Accessed 2024].

[36] "Hywind Scotland," Equinor, [Online]. Available: https://www.equinor.com/energy/hywind-scotland. [Accessed 2024].

[37] "Passive fishing in Borssele," 31 May 2024. [Online]. Available: https://www.rijksoverheid.nl/documenten/rapporten/2024/06/26/passive-fishing-in-borssele. [Accessed 2024].

[38] O. International, “Launch of test OOS-SMF)pilot),” 11 April 2024. [Online]. Available: https://www.oosinternational.com/launch-of-test-oos-smf-pilot/. [Accessed 2024].

[39] Dutch Ministry of Infrastructure and Water Management, “Hollandse Kust (zuid) Wind Farm Zone including Offshore Wind Farm Luchterduinen (LUD),” [Online]. Available: https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/free-passage-shared-use/hollandse-kust-zuid-wind-farm-zone-including/. [Accessed 2024].

[40] C. Dupont , F. Herpers and . C. le Visage, “Recommendations for positive interactions between offshore windfarms and fisheries,” European Commission, 2020.

[41] “Blue mussels, seaweed and offshore wind energy in Germany,” H2020United, [Online]. Available: https://www.h2020united.eu/pilots/2-uncategorised/40-blue-mussels-seaweed-and-offshore-wind-energy-in-germany. [Accessed 2024].

[42] Rijkswaterstaat, “Borssele wind farm zone,” Noordzeeloket, [Online]. Available: https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/free-passage-shared-use/borssele-wind-farm-zone/. [Accessed 2024].

[43] Rijkswaterstaat, “Programma Noordzee 2022-2027,” Noordzeeloket, [Online]. Available: https://www.noordzeeloket.nl/beleid/programma-noordzee-2022-2027/. [Accessed 2024].

[44] Ecowende, “The most ecological wind farm yet,” Ecowende , [Online]. Available: https://ecowende.nl/en/. [Accessed 2024].

[45] RWE, “Offshore wind farm OranjeWind,” RWE, [Online]. Available: https://benelux.rwe.com/en/locations-and-projects/oranjewind-offshore-wind-farm/. [Accessed 2024].

[46] DMEC, “DMEC Projects,” DMEC, [Online]. Available: https://www.dutchmarineenergy.com/about-dmec/projects. [Accessed 2024].

[47] Equinor, “Floating wind,” [Online]. Available: The Hywind Scotland project combines floating wind and (passive) fishery. Moreover, it addresses the challenge of spatial multi-use by conducting trials to integrate static fishing with floating wind turbines , demonstrating effective spatial management a. [Accessed 2024].

[48] “Exploring co-use of offshore wind farms by passive fisheries in Borssele wind farm, the Netherlands: An experimental study on the technical, ecological, economic and safety considerations of fishing with handline, gill nets, pots and jigging machines,” Wageningen University& Research, [Online]. Available: https://research.wur.nl/en/publications/exploring-co-use-of-offshore-wind-farms-by-passive-fisheries-in-b. [Accessed 2024].

[49] Omroep Flevoland, “Nieuwe toekomst voor Urker vissers: de boswachters van de Noordzee,” 25 Juli 2024. [Online]. Available: https://www.omroepflevoland.nl/nieuws/389766/nieuwe-toekomst-voor-urker-vissers-de-boswachters-van-de-noordzee#:~:text=Urker%20vissers%20kunnen%20de%20’boswachters,mogelijk%20ook%20de%20molens%20onderhouden.. [Accessed 2024].

[50] “eMSP NBSR,” [Online]. Available: https://www.emspproject.eu/. [Accessed 27 12 2024].

[51] C. Röckmann, S. Lagerveld and J. Stavenuiter , “Operation and Maintenance Costs of Offshore Wind Farms and Potential Multi-use Platforms in the Dutch North Sea,” in Aquaculture Perspective of Multi-Use Sites in the Open Ocean, Springer, 2017, pp. 97-113.

[52] A. Schultz-Zehden and e. a. , “Ocean Multi-Use Action Plan,” MUSES Project, Edinburgh, 2018.

[53] R. Santjer and e. a. , “UNITED Final Report 10.7,” European Commission, 2023.

[54] J. E. Kusters, F.M. van Kann, and C. Zuidema. “Spatial conflict resolution in marine spatial plans and permitting procedures for offshore wind energy: an analysis of measures adopted in Denmark, England and the Netherlands.” Frontiers in Marine Science 12, 2025

[55] European Commission, “PCI-PMI Transparency platform,” [Online]. Available: https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer/main.html. [Accessed 2024].

[56] T. Lockwood, “Europe’s cross-border CO_2 networks start to take shape,” Clean Air Task Force, 21 February 2023. [Online]. Available: https://www.catf.us/2023/02/europes-cross-border-co2-networks-start-to-take-shape/. [Accessed 2024].

[57] European Hydrogen Backbone, “European Hydrogen Backbone initiative,” [Online]. Available: https://ehb.eu/. [Accessed 2024].

[58] Gasunie, “Gasunie investigates hydrogen network in North Sea,” 12 October 2022. [Online]. Available: https://www.gasunie.nl/en/news/gasunie-investigates-hydrogen-network-in-north-sea. [Accessed 2024].

[59] AquaDuctus, “Hydrogen Infrastructure in the North Sea,” [Online]. Available: https://aquaductus-offshore.de/. [Accessed 2024].

[60] Gassco, “PMI – CHE pipeline,” [Online]. Available: https://gassco.eu/en/about-us/what-we-do/low-carbon-value-chains/pmi-che-pipeline/.

[61] NGT, “Offshore hydrogen transportation through re-used natural gas pipeline on the North Sea,” 24 November 2022. [Online]. Available: https://noordgastransport.nl/offshore-hydrogen-transportation-through-re-used-natural-gas-pipeline-on-the-north-sea/. [Accessed 2024].

North Sea Energy
offshore system integration

Design: www.knoeff.nl

North Sea Energy

offshore system integration