North Sea Energy
offshore system integration

D4.1

North Sea Energy 2023-2025

Designing Nature-Inclusive Energy Hubs

Methodology, design and comparative impact assessment for Hub North

Navigating the North Sea transition!

For centuries, the North Sea has been a source of economic strength, ecological richness, and international cooperation. Always subject to change, yet steadfast as a connector of nations, cultures, and economies. Today, it once again takes center stage—this time as a lighthouse region for the transition to a sustainable, affordable, and reliable energy system. The North Sea Energy program marks an important step in this development.

North Sea Energy is a dynamic research program centered around an integrated approach to the offshore energy system. Its aim is to identify and assess opportunities for synergies between multiple low-carbon energy developments at sea: offshore wind, marine energy, carbon capture and storage (CCS), natural gas, and hydrogen. At the same time, the program seeks to strengthen the carrying capacity of our economy, society, and nature.

The offshore energy transition is approached from various perspectives: technical, ecological, societal, legal, regulatory, and economic. Our publications provide an overview of the strategies, innovations, and collaborations shaping the energy future of the North Sea. They reflect the joint efforts of companies, researchers, and societal partners who believe in the unique potential of this region as a hub for renewable energy and innovation.

What makes this program truly distinctive is not only its scale or ambition, but above all the recognition that we are operating in a dynamic field of research. The energy transition is not a fixed path, but a continuous process of learning, adapting, and evolving. New technologies, a dynamic natural environment, shifting policy frameworks, and changing societal insights demand flexibility and vision. Within this program, we work together to ensure that science and practice reinforce one another.

This publication is one of the results of more than two years of intensive research, involving over forty (inter)national partners. This collaboration has led to valuable insights and concrete proposals for the future of the energy system in and around the North Sea. All publications and supporting data are available at: https://north-sea-energy.eu/en/results/

We are deeply grateful to all those who contributed to the realization of this program. In particular, we thank our consortium partners, the funding body TKI New Gas, the members of the sounding board, the stakeholders, and the engaged public who actively participated in webinars and workshops. Their input, questions, and insights have enriched and guided the program.

At a time when energy security, climate responsibility, and affordability are becoming increasingly urgent, this work offers valuable insights for a broad audience—from policymakers and professionals to interested citizens. The challenges are great, but the opportunities are even greater. The North Sea, a lasting source of energy, is now becoming a symbol of sustainable progress.

With these publications, we conclude an important phase and look ahead with confidence to the next phase of the North Sea Energy program. In this new phase, special attention will be given to spatial planning in the North Sea, European cooperation, and the growing importance of security in the energy system of the future.

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Designing Nature-Inclusive Energy Hubs

Methodology, design and comparative impact assessment for Hub North

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Executive summary

The North Sea is a pivot in accelerating the energy transition towards implementing European climate goals. The North Sea Energy program (NSE) aims to identify and assess opportunities for synergies between multiple low-carbon energy developments offshore with optimal value for society and nature. Work package 4a of NSE works on the nature-inclusive design of offshore energy hubs. Its objective is to explore the potential negative and positive impacts of the NSE energy hubs on the marine ecosystem and identify measures for a nature-inclusive spatial design (NISD) of one particular hub.

In this report, we describe the results of our work on an NISD for Hub North and our assessment of its potential impacts on the marine ecosystem. The design and the impact assessment are the results of desk research as well as the collaboration with a large group of NSE partners as well as ecological experts and stakeholders from a variety of organizations and backgrounds.

The Hub North area is currently characterized by relatively low intensity of human activity and high biodiversity, including long-living, protected species. The seabed is a deep somewhat soft-bottom environment with low seabed dynamics, there is a high level of seasonal (summer) stratification, in particular in the northeastern part, and the area functions as an important corridor for seabirds between the Dogger Bank and the Frisian Front. The studied energy hub would introduce 14 GW of wind farms with 7 GW of hydrogen production and the associated infrastructure into this environment. Also, we expect to see a role for offshore photovoltaics (OFPVs), i.e. floating solar panels, in order to stabilize the electricity delivery to the electrolysers and make as efficient use of space as possible. However, with the current level of knowledge about OFPVs, we are unable to make a proper assessment of what would be a good balance between offshore wind and OFPVs or a preferred location of OFPVs from an economic as well as an ecological perspective. With regard to OFPVs we therefore only discuss some general considerations that should play a role in a final NISD. In the 'standard design’, infrastructure is spread out over the area. **In the NISD, it is located so as to 1) avoid areas with the strongest summer stratification, 2) avoid areas of high ecological value and create areas with a minimum of human activities, 3) maintain connectivity for birds and mobile species, 4) and concentrate noise and vibrations from hydrogen production near shipping lanes. Additionally, the NISD includes active native oyster restoration in the west and passive nature restoration zones throughout the area as well as the introduction of artificial reefs and resting areas for birds. Finally, the NISD proposes to reduce turbine blade speeds and include a start/stop mechanism for wind turbines responding to bird migrations across the area.**

The energy hub is expected to have a significant impact on the ecology of the area through increased disturbance in the form of active disturbance of the seabed (in the construction and decommissioning phases) and noise, emissions of heat and brine, increased mixing of stratified waters, benthic habitat degradation and change in substrate, the creation of electromagnetic fields, barriers, collision risks for migratory birds and loss of foraging area for local birds. The focus of the NISD lies more on avoiding and reducing than restoring and compensating these impacts, at least partially. A cumulative assessment of all potential impacts is not feasible due to uncertainties of how different types of impacts add up and the

difficulties of predicting how currently existing impacts will be influenced by hub developments in the area.

The possible development of the Hub North area is expected to mostly take place between 2030 and 2040, in environmental conditions and future technologies that may substantially differ from current conditions and best available technologies. Hence, our main recommendation is to revise and expand the NISD development on Hub North again in parallel with the development of the government Roadmap Offshore Wind beyond 2032 and the site decisions for wind area 6/7. In the meantime, we recommend addressing several knowledge gaps that are crucial for a refined NISD. These include bat migration, the ecological impacts of OFPV (especially on abiotic factors and higher trophic levels), the effect of concentrating activities such as noise production and brine release, the cumulative impact of all renewable energy production (combining offshore wind, floating solar and hydrogen production), and the impact of this transition on the ecological carrying capacity of the North Sea. Also, we recommend making use of existing infrastructure in the area to explore how implementing additional hard substrate may impact ecology in this location, and of planned pilot projects to improve our understanding of potential impacts and mitigation measures related to hydrogen production.

1 Introduction

1.1 Aim of the program

The North Sea is a pivot in accelerating the energy transition towards implementing European climate goals and hence the targets of the Paris climate agreement. Deployment of offshore renewables and implementation of carbon capture and storage (CCS) offer opportunities for accelerated growth of a low-carbon, sustainable energy supply that is reliable and affordable. In the North Sea Energy program 35+ public and private organisations from different North Sea countries collaborate to identify and assess opportunities for synergies between multiple low-carbon energy developments offshore.

For decades, the North Sea has been an important location for energy production in the form of oil and gas. More recently, the ambitious target of rolling out 260 GW of offshore wind by 2050 has been set in the North Sea Energy Cooperation (NSEC). Also, the European Commission has set targets with regard to production and import of renewable hydrogen 20 GW (combined onshore and offshore) by 2030, with further expansion towards 2050 and CO_2 transport and storage offshore in the North Sea.

The projected strong build-up of offshore energy infrastructure in the next decades comes with several challenges such as reducing costs, understanding and reducing negative impacts on marine ecosystems and minimizing spatial claims by reusing existing infrastructure and seeking synergy with other use functions (multi-functional use). But also, managing, transporting and integrating offshore wind energy in the energy system at acceptable system cost for society and with high energy security is an important challenge.

The North Sea Energy program (NSE) aims to identify and assess opportunities for synergies between multiple low-carbon energy developments offshore with optimal value for society and nature.

Earlier results of the North Sea Energy program show that without (1) large-scale deployment of offshore wind and (2) the implementation of carbon capture and storage, an accelerated growth of a low-carbon, sustainable energy supply for North Sea households and industry is difficult and costly to achieve. Also, earlier NSE-phases show that the creation of energy hubs, in which a range of different energy technologies are combined, existing energy infrastructure is reused and connectivity between North Sea energy markets is created, is key to an economically and spatially efficient transition towards a low-carbon energy system. Exploring the development of North Sea Energy Hubs as important stepping-stones for large-scale system integration is at the heart of the program. In previous phases, three offshore energy hub areas in the Dutch North Sea were conceptually developed and various aspects of energy hubs were explored (see *Figure 1*)

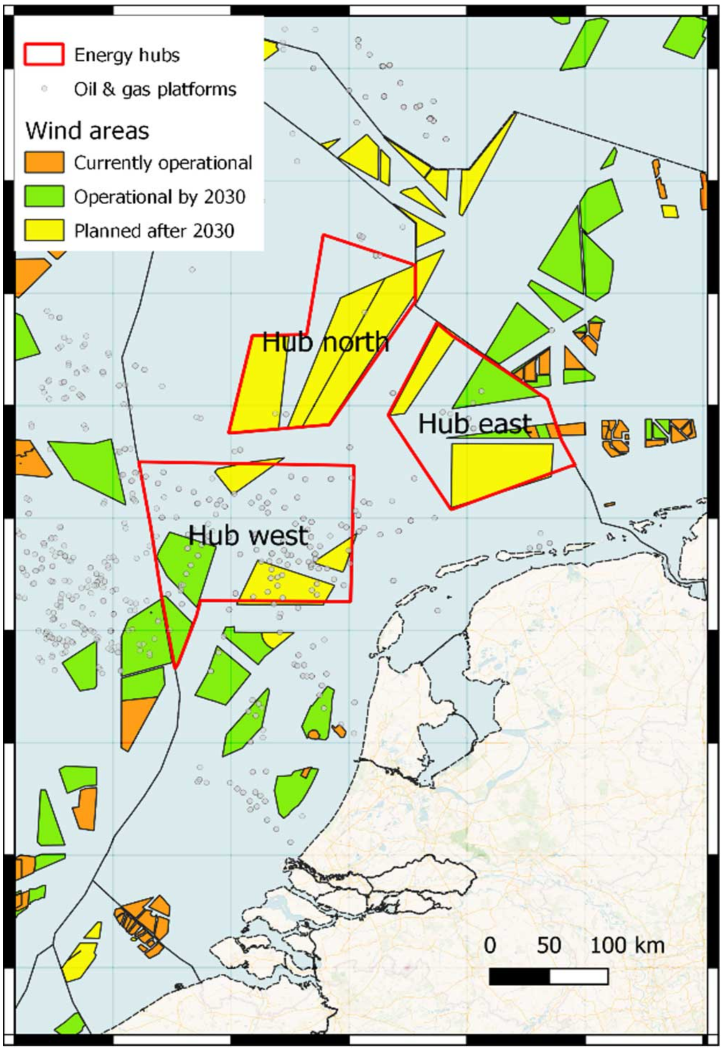

Figure 1. Potential energy hubs identified by NSE in 2022.

This phase of the NSE program aims to design Offshore Energy System blueprints towards 2050 for these three offshore energy hubs areas. This includes all relevant perspectives: technical, environmental, ecological, societal, legal, regulatory and economic feasibility. This work will generate insights for informed decision making by industry and policy makers. In the short term for decisions on pilot, demonstration and early commercial projects that involve offshore system integration. In the long term for decisions on new and adapted policies needed to facilitate and stimulate optimal system integration and spatial planning of energy infrastructure.

1.2 Work package 4a

Work package 4a works on the nature-inclusive spatial design of offshore energy hubs. Its objective is to explore the potential negative and positive impacts of the NSE Energy Hubs on the marine ecosystem and identify measures for a nature-inclusive (spatial) design of one particular hub that would mitigate negative impacts and maximize positive impacts. To this end, the work package aims to develop and apply principles to include ecology and nature in the design of the offshore energy system. The focus is on adding to existing work being performed in this field on nature-inclusive design of offshore wind and focus on new offshore energy technologies (i.e., offshore hydrogen, energy storage, solar and other marine energy options). To determine the effectiveness of the nature-inclusive energy hub design, it is compared to a technical design without nature-inclusive considerations. The results of this work package feed into the iterative design of the offshore energy hubs being developed within work package 1 of the NSE5 program.

Work package 4a focuses on four research questions:
- What are the expected impacts (negative and positive) on the marine ecosystem from the proposed NSE Energy Hubs?
- What measures could be taken, learning from best practices inside and outside the North Sea area, that would be expected to mitigate negative impacts and maximize positive impacts?
- What would a ‘maximum nature-positive’ (nature-inclusive spatial design) energy hub look like? This is to be explored and designed for one of the proposed energy hubs.
- What is the expected environmental gain from a nature-inclusive design energy hub as compared to the original conceptual design?

1.3 Reading guide and terminology

This report describes a large-scale nature-inclusive spatial design for Hub North and compares this with a ‘standard design’ for this area. As ‘standard design’, we use a sketch provided by NSE-WP1 in March 2024, which means that the ‘standard design’ presented here may significantly deviate from the designs/Blueprints presented at the end of this phase of the NSE Program. The intention is that those designs/Blueprints will incorporate some of the recommendations in this report and consequently may resemble the nature-inclusive design.

The following terminology is often used in the report:

Standard Design		The technical design sketched by NSE WP 1 in March 2024
Nature Inclusive Design (NID)	NID	Nature inclusive design at asset level
Nature Inclusive Spatial Design	NISD	NID at the spatial level of the entire hub
Asset		One turbine, hydrogen platform or solar panel

In **Chapter 2**, we first describe the research process that we have gone through in order to develop a nature-inclusive design, based on the ‘Seawilding approach’ developed by ARK Rewilding. Next the ‘standard design’ and the nature-inclusive design are presented in **Chapter 3**. In **Chapter 4** we describe the potential impacts of the ‘standard design’ as compared with the nature-inclusive design. First, paragraph **4.2** describes the potential impacts of the different asset types that are projected within Hub North, with a focus on wind turbines and electrolysers for hydrogen production. The resulting large-scale effects are then described for the ‘standard design’ and the nature-inclusive design in terms of abiotic parameters (**4.3**), pelagic habitats (**4.4**), benthic habitats (**4.5**) and bird habitats (**4.6**). Finally, the comparison between the nature-inclusive design and the standard design will be summarized in chapter **4.7**.
In our comparative assessment, we focus on the potential impacts of the hub-related infrastructure in the operational phase, as this is the phase in which you would see the

difference between different designs of a hub lay-out. In **Chapter 5**, we also provide some more general recommendations regarding the preparatory phase, the construction phase and the decommissioning phases. Unless otherwise mentioned, these recommendations would equally apply to a 'standard' as well as a nature-inclusive design.
In **Chapter 6**, we finally discuss aspects considering cumulative impacts, main drivers of change, ecosystem components and carrying capacity.

2 Research process

The research and design process has combined desk research with a survey and two workshops with experts in North Sea ecology and in the various technologies involved in the hub-design. During the design process, the NSE team collaborated with ARK Rewilding, using their 'Seawilding approach' as design methodology.

2.1 ARKs Seawilding approach

The Seawilding approach is based on the principles set out in the handbook ['Process-Oriented Nature Conservation'] and aims to create the conditions for 'self-willed', wild and robust nature, including positive feedback loops with socio-economic systems. It takes nature – the marine ecosystem – as its starting point, describing its current condition and exploring its potential condition considering current and future constraining and enabling factors. The methodology is based on the rewilding framework as presented by Perino et al., (2019), that targets trophic complexity, natural disturbances, and dispersal as interacting ecological processes that can improve ecosystem resilience and maintain biodiversity. Furthermore, the methodology considers humans and their activities, as part of nature and attempts to create as much space for natural processes as possible by reducing constraining and strengthening enabling factors.

The Seawilding approach consists of seven steps, which we have gone through in our research & design process:

1. **Seascape scope definition:** What is the scope of the seascape, in terms of geographic scale, ecological complexity and human use? The scope was defined in a process before, during and after workshop 1. The geographic scope was set to the area of Hub North. In collaboration with WP1, we defined which technologies to include in the design, what technical parameters to use for the various technologies/assets and how to deal with the potential impacts from other users. Also, we decided to focus on the operation phase and the final design as it would presumably be in 2050.
2. **Describing the current ecological state.** In preparation for workshop 2 we developed a fact sheet describing the current state of the Hub North area in terms of ecology and human use. The factsheet is available in Appendix A.
3. **Defining constraints.** How do humans constrain natural processes, thereby limiting the ecological state? In workshop 2, participants discussed the constraints on natural processes that current and future human activities, incl. the construction and operations of energy-hub infrastructure, (would) impose through interacting infrastructure, environmental triggers and human-wildlife interactions.
4. **Exploring enabling conditions.** How can we create enabling conditions for natural processes? In workshop 2, participants discussed what conditions the nature-inclusive design might create that would facilitate natural processes creating a robust ecosystem.
5. **Defining potential future state.** Given constraining and enabling conditions, what is the potential future state? In workshop 2, participants explored what future ecological state could be feasible in the hub North area, with or without an energy hub.
6. **Selecting interventions.** What are executable interventions to create the conditions for a desirable future state? In workshop 2, participants discussed what interventions might result in a more complex and robust ecological state. After the workshop, the WP4 team

has made a further selection of interventions to form a consistent design. Also, the team has added interventions known from desk research, current practise and input from WP1 to the suggestions provided by the workshop participants.

7. **Connecting the dots.** Considering a selection of executable interventions, the final question is what is needed to create the conditions for actual implementation of these interventions, in terms of policy, collaboration, incentives, innovations, etc. In this report, we only include some general recommendations with regard to this step, that were mentioned in the workshops. A further discussion of this question forms part of WP7.

2.2 Desk research and expert survey

We started out by inventorying existing information, identifying relevant stakeholders and experts within and outside of the NSE program. NSE partners provided input during a scoping session. External experts were asked to provide input through a survey. These experts were identified from the research network of the WP4 team, based on the experts' involvement in North Sea ecology and offshore energy infrastructure.

Questions in this phase focused on the advantages and disadvantages that each of the three NSE energy hubs would have as a study area (see paragraph 1.1). Additionally, input was collected on design criteria for a nature-inclusive design (such as a focus on zero impact versus aiming for positive impacts).

2.3 Scoping

To facilitate choosing a hub and formulating design specifications, we gathered basic information on each of the three NSE hubs. This included the general characteristics of the technical design from the previous phase of NSE, as well as ecological information and information on current and planned uses of the areas. Additionally, a matrix was developed linking energy technologies (such as wind farms, centralised hydrogen production and subsurface CO_2 storage) to their related activities (such as cable laying and discharge of oxygen) and these activities to ecological impacts (such as changes of seabed levels and underwater noise).

The hub characteristics and impact matrix were discussed during a workshop with 29 of the identified stakeholders and experts on November 14th 2023 (Workshop 1). The participants of this and the subsequent workshop were experts on North Sea ecology and offshore energy invited from green non-governmental organizations (NGOs), energy companies, marine contractors and research organizations. Representatives from government bodies were also invited to participate in the workshops but preferred not to participate in order to avoid any potential misunderstandings with regard to differentiation between their personal (expert) opinion and official government policy. The full report of Workshop 1 can be found here.

Based on the results of Workshop 1, the WP4 team decided to choose Hub North as the study area for the nature-inclusive design. The following considerations formed the main drivers of this decision:

- **Hub North is relatively far from shore and planned to contain very large amounts of renewable energy production.** This makes it the most logical hub in which to include large-scale offshore hydrogen production. The combination of projected amounts of hydrogen production and offshore wind also offers opportunities to discuss scale effects of large volumes of wind and hydrogen production.
- **Hub North is planned in an ecologically sensitive area, with relatively low intensity of existing activity and high biodiversity, including long-living, protected species.** This means that any developments taking place here will have to be nature-inclusive in design, in order to make a chance of staying within the limits of what is acceptable in terms of ecological impact. At the same time, the area also offers opportunities for interventions that may help restore/strengthen processes that may contribute to a complex and robust ecological state.
- **Developments within Hub North are planned after 2030**. Therefore, decision making regarding energy developments in this area are at a stage that allows us to have an impact by contributing to the process of the Partial Revision of the North Sea Programme 2022-27, which is to be finalised in 2025. Moreover, this timeline provides sufficient room for filling some of the many knowledge gaps that still exist with regard to (the impact of energy infrastructure on this particular part of) the North Sea ecosystem, allowing for an adaptive management approach.

2.4 Design generation

Based on the facts sheet, a large number of maps regarding abiotic factors, ecological functions and current use of the Hub North area, ideas for a nature-inclusive (spatial) design were generated during a second workshop, on 19 March 2024 (Workshop 2). The participants were split in four groups and were given the task to come up with design interventions, following steps 3 to 6 of the Seawilding approach. Two groups were requested to focus on large-scale spatial and temporal design interventions, and the other two groups were requested to focus on 'local' interventions relating to specific types of infrastructure. The groups were provided with a technical sketch, a set of assumptions as standard (not nature-inclusive) design (see paragraphs 3.2 and 3.3), a fact sheet containing information on the ecology of the Hub North area and preliminary illustrations of the potential impacts of wind turbines and electrolysers for hydrogen production (earlier versions of figures 6 and 7).

To facilitate developing designs that could feed the research process, a few rules were established. First, participation in this workshop and the process of exploring nature-inclusive design options for the Hub North area explicitly did ***not*** imply that participants endorsed the idea of an energy hub in this particular area. In fact many of the participants fundamentally disagreed with the idea of placing an energy hub in the area, because of the sensitivity and the relative ecological richness of the area. The focus was not on *whether* the energy infrastructure should be realised, but on *how* it could best be realised *if* that were to happen. Conversely, the designs should not result in much lower energy production, as that would lead to more infrastructure (and ecological impacts) elsewhere. Finally, while other users of the area and their impacts are important to take into account, the designs focus primarily on interventions related to energy infrastructure.

The full report of Workshop 2 can be found here.

2.5 Design definition

Based on the outcomes of the workshop, the WP4 team developed a single, coherent nature-inclusive design. This included selecting from the results of the four workshop groups a coherent set of interventions, as some of the interventions targeted the same impacts in different ways or made other interventions technically unfeasible. Interventions were selected aiming to maximise the potential positive outcome of the nature-inclusive design, compared to the standard design, and to minimise the potential negative impacts on the Hub North area. This was done based on the 'Mitigation Hierarchy', which offers an effective framework to limit negative ecological impacts of development projects as much as possible (Ekstrom et al., 2015). The Mitigation Hierarchy highlights prioritization of four types of practices to minimise the negative impacts of human interventions on the ecosystem:

1. **Avoidance**, e.g. site selection, design and scheduling;
2. **Minimalization**, i.e. partial mitigation of impacts, through physical, operational and abatement controls;
3. **Restoration or rehabilitation**, facilitating re-establishment of habitat types, biodiversity values and/or ecosystem services; and
4. **Compensation**, measurable conservation outcomes outside the area domain compensating for significant adverse impacts that cannot be avoided, minimized or restored.

This framework highlights that aiming for preventive measures (avoidance and minimalization) should always be prioritized over remediation measures (restoring and offsetting). There are a few things to note about the NISD in relation to this hierarchy:

- As a result of working within the boundaries of Hub-North, the options for avoidance are automatically limited to avoiding areas within the Hub, and compensation measures elsewhere are not considered.
- As the quality of the ecosystem as a whole is degraded, mitigation measures, when effective, could lead to a better system compared to the baseline and potentially have restoring capacities.
- The NISD starts out looking at the spatial layout of human activities, in order to avoid or minimize impacts in areas in which natural processes are particularly sensitive to human activities and to explore opportunities for locating specific infrastructure elements in a way that may facilitate restoration/rehabilitation of natural processes within the area as a whole.
- Enhancing positive effects logically occurring from placing infrastructure, such as the addition of hard substrate habitats or the exclusion of bottom trawling fisheries, is also considered as a restoration/rehabilitation measure.
- The NISD aims to mitigate and restore to such a level that compensation elsewhere does not need to be looked at. Combined with the spatial constraints and the aim to do a qualitative comparison, in practice compensation (and the need to compensate), is not explicitly discussed in this report.

In parallel, the technical design parameters were refined in collaboration with WP1. During this phase, we reduced the volume of energy production to be included in the design. The original values from NSE4 were 28 GW of wind energy and 18 GW of hydrogen production. The spatial claim of this amount of energy production left very little freedom to make choices for the spatial design. During this phase, WP1 defined two refined scenarios for Hub North. We decided to use the electron-heavy scenario (DEC), as it includes large volumes of energy production while still leaving enough space to make meaningfully different choices in the NISD.

2.6 Assessment

A comparative assessment between the nature-inclusive design and the standard design was made to assess to what extent the nature-inclusive design reaches the aims of mitigating negative impacts and maximizing positive impacts on the marine ecosystem (see chapter 4). The assessment was made based on biotic and abiotic criteria relevant for the marine environment.

Information from the impact matrix (see figures 6, 7 and 8) was used to visualize the impacts of the various technologies planned in Hub North on the abiotic conditions. Abiotic conditions were categorized in hydrodynamics, sediment dynamics and other abiotic conditions. The current state of the Hub North area, the effects of the planned developments under the standard design on this state, and the effects of the measures taken under the nature-inclusive design were described for each of the abiotic conditions. A comparative conclusion is presented on the difference between the standard design and the nature-inclusive design for the respective condition. Similarly, the effects of the nature-inclusive design on biotic conditions, categorized by pelagic habitats, benthic habitats and bird and bat habitats was assessed, by describing the current situation in the Hub North area and the resulting state after installation of the standard design and the nature-inclusive design of Hub North based. The comparative summary provides an overview of the nature-inclusive design measures and their effects (direct or through abiotic changes) on the biotic groups.

2.7 Review and revision

After workshop 3 we received a number of recommendations from NSE partners and workshop participants that have been processed in this report:

- What we now call NISD was called NID up until the workshop. But as it really is a high-level spatial design, reviewers felt it would be more appropriate to differentiate between NID at asset level and NISD at the larger level of this hub.
- To aid the reader and clearly define point 1 we have also added a terminology overview in 1.3.
- We clarified the maps further. This included
  - Marking out all areas that are deliberately designated for nature and/or kept free of structures, meaning the oyster restoration zones and the stratification zones. These were already part of the design, but not yet included on the map.
- Moving the bird corridor east for a better overlay with the relatively deep silty part of the hub, which has a particularly high value for birds and as a natural carbon storage. To make space for this, we moved 2 GW of the wind farms from the eastern to the western side of the corridor.
- Whereas in workshop 2 we started out with the aim of fitting in 28GW of offshore wind in the Hub-North area, this was significantly modified after sprint 2 of the NSE programme as work package 1 decided to focus on two different scenarios: an electron-

heavy design with 14GW of offshore wind and a molecule-heavy design with 24GW of offshore wind. As it was clear already from workshop 2 that 24GW would not realistically fit into a nature-inclusive spatial design, we decided to focus on the electron-heavy scenario for the standard design as well.
    - We split the hydrogen production capacity between the two wind farm areas, as this seems a more likely scenario from a technical perspective. As a result, both areas have gas and electricity infrastructure.
- We adjusted the tables in the comparative summaries for the abiotic conditions (in 4.3.4) and biotic components (4.7), making them more coherent and comparative.
- We addressed specific minor comments made by the partners throughout the document.
- After the external review by Witteveen + Bos we made a number of text improvements and clarifications regarding underlying assumptions and scope of this report. Also, we added a number of potential effects to the asset flow charts in Ch. 4 and improved the description of and reasoning behind the NISD.

3 Nature-inclusive design of Hub North

In this chapter, we describe the characteristics of the NISD we developed during the research process. We first describe the current characteristics of the part of the North Sea where the energy hub would be located (3.1). We then describe the terms of reference for the design, the types and volumes of energy technologies included (3.2). These terms of reference form the basis for both the standard design (3.3) and the nature-inclusive design (3.4). In the next chapter, we compare the ecological impacts of these two designs.

3.1 Current characteristics of the area

The most recent OSPAR QSR (2023) concluded that the cumulative pressures from human activities affect North Sea marine ecosystems and biodiversity in significant and measurable ways, that all pressure are (too) high with quite a few increasing and hardly any of them decreasing. Though the net effect of cumulative pressures have resulted in a 'not good' status for many protected and common species, Hub North is located in an area with relatively low intensity of existing activity, including fishing activities, and high biodiversity, including long-living, protected species. Due to the eradication of oyster banks in the 19th century, the Central Oyster Grounds, which include the Hub North area, are currently in an "alternative stable state" of other types of biogenic structures formed by burrowing organisms such as mud shrimp (*Upogebia* sp.) instead of oyster banks. The seabed in the area is a deep somewhat soft-bottom environment: water depth ca. 30 – 50m with a silty and fine sand seabed and relatively low seabed dynamics with no suitable substrate for sessile epifauna. However, relatively high densities of vulnerable benthic species are found in the area, including the ocean quahog (*Arctica islandica*), which only starts reproducing at the age of 6 to 13 years, making the population very vulnerable to disturbances (de Bruyne et al., 2013). Although flat oyster (Ostrea edulis) reefs are no longer present in the area, it is characterized by conditions that indicate suitability for the development of flat oyster populations (P. M. J. Herman & van Rees, 2022; van Duren et al., 2022).

Due to the soft-bottom environment and relatively low seabed dynamics changes to morphology of the ecosystem may have severe impacts on the currently existing ecosystem. There is a high level of seasonal (summer) stratification of the waters in the area (temperature as well as salinity), in particular in the northeastern part of the hub area. Also, wave height is relatively high in the northeastern part of this area as compared to the rest of the Dutch North Sea. This implies a relatively high risk of accidents with ships potentially colliding with wind turbines and offshore installations in the area. At the level of the seabed, however, wave energy is moderate, because of the depth.

The hub area is surrounded by three **Marine Protected Areas (MPAs) (see figure 25)**:

- Cleaver Bank. This area is a Natura2000 area installed with the aim of maintaining the size and improving the quality of existing reef habitat (H1170) in the area and maintaining population size, size and quality of habitat for harbour porpoise (H1351), grey seal (H1364) and common seal (H1365).
- Oyster Grounds. This area is protected on the basis of the Marine Strategy Framework Directive (MSFD) with the aim of enhancing seabed integrity (i.e. benthos in general).

- Frisian Front. This area is a Natura2000 area installed with the aim of maintaining the size and quality of habitat for guillemots (A199) with a focus on the habitat function as a resting location.

The Hub North area is characterized by a deeper, siltier zone (below the South-Eastern corner of the Oyster Grounds MPA) with a high organic carbon storage potential in addition to (benthic) ecological value (see https://www.noordzee.nl/hoe-de-zee-een-cruciale-rol-kan-spelen-in-het-compenseren-van-onze-co2-uitstoot/). For seabirds, this area functions as an important corridor between the Dogger Bank and the Frisian Front, and particularly for guillemots, auks and northern gannets. For underwater species, the precise connectivity and role of the area in the distribution of organisms are not yet known. However, the supply of benthic larvae to the Central Oyster Grounds is expected to be from the northwest direction (Jongbloed et al., 2013).

Primary production in the hub area is relatively low compared to parts of the Dutch North Sea closer to the coast. In the most recent OSPAR QSR, chlorophyll concentrations, used as a proxy for phytoplankton biomass, are estimated to be in a good status (i.e., not too high). With rising sea temperatures caused by climate change, there is a concern that stratification may be disturbed (see e.g. Desmit et al., (2020))

For more detailed information on the ecological state of the area, see Chapter 4.

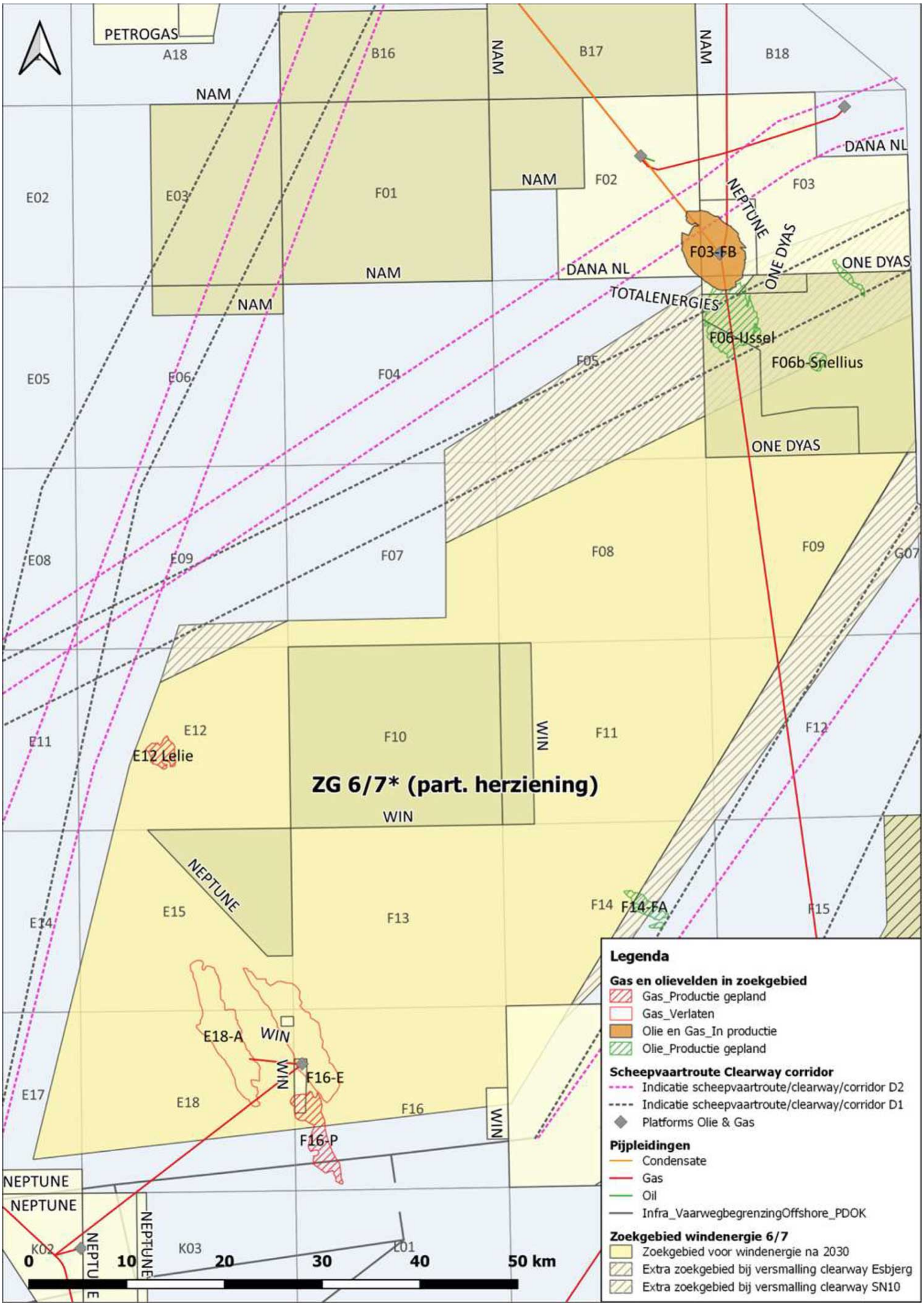

Figure 2. Map of Hub-North area with existing energy-related activities and (future) shipping lanes (internal NSE document).

Current human use of the area is relatively limited (see *Figure 2*) Shipping is the most intensive activity, and the hub area is bordered by the Kattegat shipping route on the east side and the Northern Sea Route and the clearway Esbjerg–Hull in the north-west. These shipping routes are expected to continue to be at least as intensively used in the future. Within the area itself, shipping activity is currently relatively limited. Also, there is limited fishing activity in the area, primarily focused on lobsters.

Some nine oil and gas production or exploration licenses have been granted for the area, some of which are continuing until 2047. Currently there are five production platforms in the area: three in the northern part in the F3 and F6 Blocks and two in the southern part in the F16 Block. The F16 platforms are expected to be decommissioned before 2040. Underneath the area, there is space that may be suitable for CO_2 storage and hydrogen storage (salt caverns and some hydrocarbon fields). It is highly uncertain whether such storage will be developed, but this will certainly not happen before 2030. Through the area runs a number of major hydrocarbon pipelines: NGT, WGT and NOGAT. These may possibly be reused for hydrogen transport after cessation of their function for gas transportation.

3.2 Terms of reference for the hub design

For the design of Hub North, we developed terms of reference describing the types and amounts of energy infrastructure in the hub. This includes renewable energy production, conversion, storage and transport. These terms of reference are primarily based on intermediate results of work package 1 of NSE5, as we have tried to achieve a certain amount of consistency in the underlying assumptions made within the programme. The ToR for offshore wind turbines differs from the assumptions made in WP1: whereas WP1 works with wind turbines with a 21 MW capacity, we assume 15 MW capacity per turbine. This is a conservative assumption, which may not seem to match our more optimistic assumptions for the size of offshore electrolysers. We decided to stick to the 15 MW as this corresponds with the 'North Sea standard' suggested by the Dutch wind industry association NedZero for the period until at least 2034. Though it might be feasible to achieve 21 MW capacity within this standard, we wanted to make sure that we did not underestimate the ecological impact by being over-optimistic with regard to the number of wind turbines needed. For electrolysers, on the other hand, it is considered unlikely that electrolysers smaller than 0.5 GW per platform will be economically feasible so far offshore as Hub North is.

The aim of these terms of reference is to enable an accurate comparison of the nature-inclusive design and the 'standard design'. Reducing the amount of infrastructure in Hub North could benefit local ecology but would also likely result in displacement of infrastructure to other locations. As our scope is limited to the Hub North area, this would lead to an unfair comparison of the designs.

These terms of reference should not be understood as an assessment of what amount of activities is possible in the Hub North area. At the time of the research, it was not possible to assess the realism of the terms of reference in any further detail than what is mentioned above. Given the limited ecological knowledge about the area and the fact that energy developments are expected to take place relatively far in the future, there are large uncertainties regarding what energy infrastructure will fit in the physical and ecological space. There are also uncertainties about the types of activities that will be feasible and sufficiently attractive offshore (for instance in the case of offshore hydrogen production and storage), as well as the spatial claims from other human uses, which are not considered here. Work package 1 of NSE has studied these aspects in more detail.

The terms of reference for the design are:

- **Renewable energy production**. We assume that 14 GW of wind turbines and some level of offshore floating photovoltaic (OFPV) will be installed in wind area 6/7. 14 GW corresponds with the electron-heavy (DEC) scenario of NSE work package 1. For the type of wind turbines, we base our analysis on a relatively conservative assumption of 933 monopiles with 15 MW capacity each, being placed with a distance of minimum 1200 m between them. Based on current regulations, as described in Programma Noordzee 2022-27, we assume that the only forms of co-use in wind farms allowed are: active nature restoration, food production (passive fishing, aqua- and mariculture), and other forms of renewable energy production, i.e. OFPVs in this case. According to current Dutch regulations, no ships or other objects are allowed without permission from the operator within 150 m of a wind turbine. Also, specific lanes for thoroughfare of ships are created where these forms of co-use are not allowed. For the sake of practicality, we assume that 1 GW of OFPVs may also be included in the wind farm area. So far, it is impossible to say whether this is a realistic assumption.
- **Oil and gas production**. We assume that oil and gas production in the area will be almost phased out before 2050. Thus, no production is included in the design.
- **Hydrogen production**. Of the 14 GW of installed electricity production capacity, we assume that 7 GW will be used for hydrogen production within the hub. This also corresponds with the electron-heavy (DEC) scenario. The electrolysers for this production can be built on different types of infrastructure. We assume that the electrolysers will be placed on so-called power to gas (P2G) platforms with a capacity of 0.5 GW each, which would result in a total of 14 P2G platforms. Platforms are surrounded by a safety zone of 500 m in which no activities are allowed without permission of the operator. Through innovation, it might be possible to build larger P2G platforms with more than 0.5 GW capacity, or to locate electrolysers within the wind turbines. Also, electrolysers might theoretically be stationed on an artificial island. As none of these options are currently deemed feasible, however, we did not include them in our terms of reference.
- **Hydrogen storage**. It may be necessary and feasible to store hydrogen in the underground in salt caverns or former gas fields. Such storage was not included in this design, as too little is currently known about the need for and the spatial and environmental impacts of such storage.
- **CO_2 storage.** In order to reduce complexity, we assumed that the potential for CO_2 storage in the area will not be developed. If this is developed, this would potentially have a significant impact on the space available for offshore wind, depending on the extent to which related infrastructure needs to be accessible by helicopter and on the technology used for seismic monitoring of the storage reservoirs.
- **Electricity transport**. In our scenario, we assume that produced electricity will be transported to shore via 4 high-voltage direct current (HVDC) cables of 2 GW each.
- **Hydrogen transport.** P2G platforms will have (new) hydrogen pipelines connecting to a compressor platform. One compressor platform can service four P2G platforms (or 2 GW of capacity). These compressors connect to a larger transport pipeline transporting the hydrogen to shore, which will be either re-used or new.

- **Timeline**. It is expected that the wind farm and related infrastructure will be mostly developed in phases between 2030 and 2040. By 2050 all infrastructure should be in place to contribute to the climate goals as planned. The Dutch government currently assumes that wind turbines are placed with at least 1km between them and with a safety zone of 150m around each turbine where no ships or other objects are allowed without permission from the operator.

These and additional details regarding technical specifications of the Hub North Area are summarized in Table 1.

Table 1. Technical specifications for Hub North infrastructure and activities.

Infrastructure part/activity	Number and capacity	Characteristics
14 GW offshore wind	933 turbines of 15 MW	Technical characteristics (reference: IEA 15 MW reference wind turbine (Gaertner et al., 2020)): • Monopile foundation diameter: 10 m • Rotor diameter: 240 m • Maximum tip height: 270 m above mean sea level (MSL) • Minimum tip clearance: 30 m above MSL Spatial and use characteristics: • 150 m safety zone around each turbine (sea level and below) • Minimum distance between turbines: 1.2 km • Assumed power density: 10 MW/km^2 (resulting spatial footprint: 1400 km^2) Maintenance: • 1 service operations vessel (SOV) stationed at location and transiting back to port every 14 days
1 GW offshore floating photovoltaic (OFPV)	Number of installations depending on technology	• Sun blocking area of 5 – 5.5 km^2 depending on technology. References: (Vlaswinkel et al. 2023 and Schneider et al., 2023. Review. Box 1. p. 20.)
7 GW hydrogen production	14 P2G platforms of 500 MW electrolysis	• 80 x 40 m footprint • 500 m safety zone • Normally unmanned (no helicopter circle) • Shipping: 1 service operations vessel (SOV) stationed at location and transiting back to port every 14 days
7 GW electricity transport	4 substation (transformer) platforms of 2 GW	• 105 x 77 m footprint • 500 m safety zone
	4 HVDC cables of 2 GW	• 4 m deep trench, covered with sand • 50 m safety ‘corridor’ on each side
7 GW hydrogen transport	4 compressor platforms of 2 GW	• Similar to P2G platforms
	Pipelines	• Semi-buried, placed on top of seabed and ‘sinking’ down by their own weight • 50 m safety ‘corridor’ on each side

3.3 Standard design

A standard hub design was formulated as a point of reference for the nature-inclusive design. This standard design is a relatively simple design based on intermediate results of work package 1 of NSE5. It should be noted that it does not match their final design, which has been refined and has a higher level of detail. The standard design is intended as a reference for the assessment of the ecological impacts, not as an optimized technical design.

Figure 3 the standard design. Characteristic of the design is that:

- Around 1,400 km^2 is used for wind farms, based on the assumed power density (10 MW/km^2). This is 30% of the total wind search area 6-7 (shown in yellow). We assume that the wind farms are 2 GW in size and spread evenly over the search area. *Figure 3* shows an example of how they could be located, with the size of each wind farm based on an average power density.
- Hydrogen production takes place at the wind farms in the northeastern part of the hub. Here, transport to shore is longest and the existing NGT pipeline may offer opportunities for reuse. P2G platforms and compressors are located close to the wind farms.
- Energy from the wind farms in the southwestern part of the hub is transported as electricity. Substation (transformer) platforms are located here. These are connected to a power cable leading out of the wind farm area and towards shore (the part outside of the hub area is not fully included in the design).

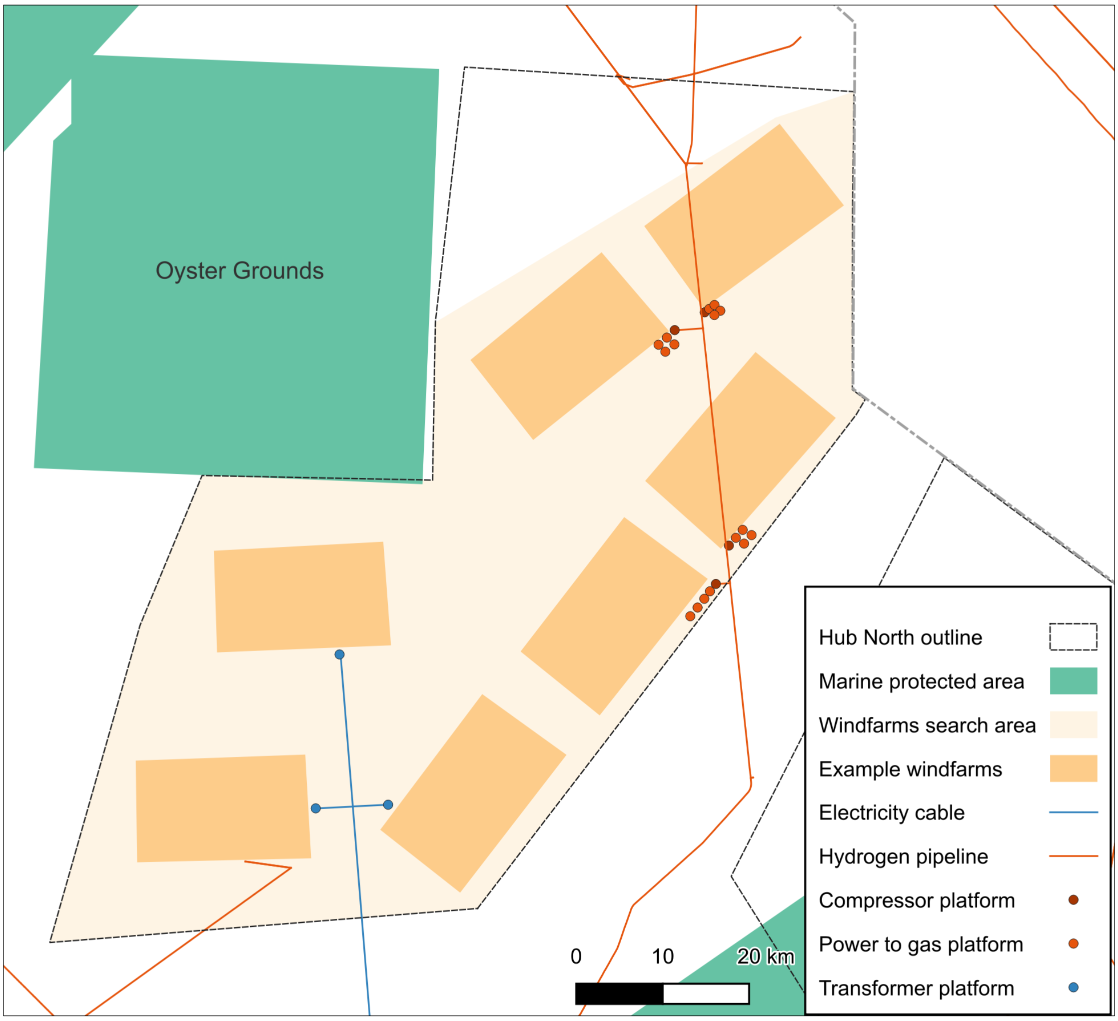

Figure 3. Map of the standard design of Hub-North. Note that the exact placement of example wind farms, platforms, and pipelines and cables is illustrative and not used in the impact assessment.

3.4 Nature-inclusive Spatial Design

The aim of the NISD is to design an energy hub for Hub North that has a minimum of negative impacts on the surrounding ecosystem and a maximum positive impact, while still allowing for renewable electricity and hydrogen production as described in paragraph 3.2.

Throughout the research process described in Chapter 2, recommendations were gathered for the individual asset level interventions as well as for the spatial design. The recommendations for the NISD in the first place seek to avoid and mitigate a number of constraints on natural processes (also framed as pressures on the ecosystem) and in the second place to create enabling conditions for certain natural processes that are expected to lead to a more biodiverse and robust ecosystem (see paragraph 2.1). During the workshops the general feeling of the experts was that while the importance of repeating small-scale interventions many times over should not be underestimated when mitigating or avoiding impacts, interventions on a larger level were found to be more promising and impactful. Due to the scale of the hub area it also proved impossible to show both small and larger scale interventions in the same map, and therefore the NISD Map has more focus on large scale interventions. The focus of both the NID and the NISD is on constraints and enabling conditions in the operational phase that will affect the final resulting ecosystem. In Chapter 5, we also discuss a number of recommendations regarding the preparatory and construction phases and for the decommissioning phase.

The following factors influencing natural processes in the area have been considered in relation to the planned Hub North developments (in no particular order) and form the basis for the NISD interventions described in this paragraph:

- continuous noise and vibrations from wind turbines and hydrogen compressors
- vessel movements
- habitat disturbance
- brine disposal from hydrogen production
- oxygen release from hydrogen production
- light blocking by platforms and offshore solar panels
- collision and barrier effects, both above and below water
- habitat loss (of foraging areas)
- changes in stratification
- introduction of hard substrates
- induction of electromagnetic fields by cables
- cooling water intake and outlet by hydrogen production
- pollution
- heat release

An important note to be made is that the ecological effects of many of the potential influences are poorly understood, especially when occurring at a large scale. This, in combination with significant knowledge gaps regarding the functioning of the current ecosystem in the Hub North area, makes it difficult to assess which influences could be seen as constraints and which ones might (also) function as enabling conditions. In our design, we regularly suggest measures that may seem ‘excessive’ - e.g. avoiding the placement of infrastructure in particular locations, whereas it is still highly uncertain how much damage a certain activity will cause in those locations. We do so, as application of the Precautionary Principle is the formal standard for handling uncertainties with regard to environmental impacts: that means that measures should be taken to avoid a potential impact in cases of uncertainty. In particular if potential impacts may be non-reversible.

The specific effects of a final design will eventually need to be subject to an environmental impact assessment in a much later state. A baseline assumption throughout this document is that if such an assessment proves that pressures from an energy hub will exceed the ecological carrying capacity and/or regulatory limitations on e.g. the impact on birds, the hub will not be built, or the design will have to be altered. Regulators are responsible for making this decision in line with policies stipulated in Programma Noordzee and the Dutch North Sea Agreement. In Ch. 7 Conclusions & Recommendations, we discuss the difficulties of determining ‘ecological carrying capacity’ in more detail.

3.4.1 Overall spatial design

Considering the mitigation hierarchy (1. Avoidance, 2. Minimization, 3. Restoration/Rehabilitation, 4. Compensation), a proper NISD starts out looking at the spatial layout of human activities, in order to avoid or minimize impacts in areas in which natural processes are particularly sensitive to human activities and to explore opportunities for locating specific infrastructure elements in a way that may facilitate restoration/rehabilitation of natural processes within the area as a whole.

The NISD for Hub-North is shown in *Figure 4*. This design should be taken as an indication of the location and planning of Hub North activities, which has not yet been modelled or tested for practical feasibility and economics.

Figure 4. Map of the NISD of Hub North. Note that the exact placement of platforms, pipelines and cables is illustrative and not used in the impact assessment.

Considering the current ecological state and abiotic characteristics of the Hub North area (see paragraph 3.1), the following spatial interventions in the NISD aim to **avoid or minimize negative impacts**:

- **Avoid areas with strongest summer stratification**. Based on model outputs with regards to summer stratification these areas are in the northeastern corner and, to a lesser extent, the northwestern corner of the hub area. In these areas, the NISD would neither have wind turbines nor P2G-platforms.
- **Avoid areas of high ecological value and create areas that are closed for (all) human activities.** Considering the high ecological value of the Hub North area, it is key that nature restoration should be the primary form of 'co-use' in the entire area. This implies

that certain parts of the area would be left undeveloped, while best available nature-protecting and -strengthening practises would be applied in construction and design in all infrastructure developments, as agreed within the North Sea Agreement (Hermans, et al., 2024; Overlegorgaan Fysieke Leefomgeving, z.d.). Forms of co-use with a negative impact on nature should be avoided in the entire area considering the already high impact of energy-related developments. The northeastern part of Hub North is an area where infrastructure developments should be limited, and nature restoration promoted. This area is ecologically particularly valuable due to its relatively high diversity of (long-living) benthic organisms, its importance for harbour porpoises and its proximity to the Oyster Grounds and the Dogger Bank. Next to the northeastern part and specific hotspots with long-living benthic species, that would need further site-specific research to avoid, it is also recommended to keep as much of the silty, deep zone in the middle of the hub area free from infrastructure and other bottom-disturbing activities. This way, a significant amount of presumed benthic hotspots are avoided, the carbon storage potential of that area kept intact, and turbidity is reduced. In areas that are left undeveloped, including the corridor mentioned below, we assume that other human activities, such as fishing or shipping, will also not be allowed for. This would imply a decrease of human pressures in those areas. This might be seen as a kind of compensation for the increase in energy-related pressures on the ecosystem in the area as a whole.

- **Maintain connectivity for birds and mobile species** (pelagic species and marine mammals) by establishing a corridor between the marine protected areas in the north (Central Oyster Grounds, Dogger Bank) and the south (Frisian Front). As shown in *Figure 5* below, the construction of wind farms and other energy-related infrastructure in Hub North, in combination with wind farms planned in neighbouring countries, will create a serious barrier for birds and mobile species that tend to avoid noise and wind farms: for these species, safe migration from the western and Northern part of the North Sea to the Frisian Front, the Wadden Sea and the Dutch coast will be made almost impossible for these species. Therefore, maintaining a corridor with minimum disturbance from human activities is key. This corridor could overlap with the silty, deep zone in the middle, but would probably need to be at least some 40 km wide (as guillemots densities are significantly reduced within Offshore Windfarms (OWF) and within a radius of 19,5 km of an OWF) in order to allow common guillemots to pass through, without feeling hindered by wind turbines (Grundlehner et al., 2024; Peschko et al., 2024). This corridor should be a limited-use area. It is free of structures and other disturbing activities such as fishery, but can potentially be used for shipping. For the best potential, this limited-use area should be extended into the borders of the MPAs around Hub North, thereby effectively creating a continuous protected area between the Frisian Front and the Dogger Bank. With the shipping lane passing between Hub North area and the Frisian Front, however, a certain level of disturbance will remain in that part.
- **Place P2G platforms (electrolysers) and compressor platforms in a location where noise disturbance is already significant.** Though we currently do not know exactly how much noise is produced by electrolysers and compressors, we suggest to locate them along the shipping lanes, preferable in the southern and eastern part of the hub. These areas are already impacted by the large amount of vessel movements through the adjacent seaways and we expect that noise from electrolysers and compressors will not add significant pressures in this area. Additionally, this location would allow for relatively easy access for maintenance ships and for a good pipeline connection to the NGT and NOGAT

pipelines. Like in the 'standard design' these pipelines could then be reused for hydrogen transport or – if that turns out to be unfeasible – at least the same routing can be followed, limiting disturbance of the seabed along the route. Whether these locations are suitable also from the perspective of e.g. brine emissions would need to be explored, but with the current state of knowledge, there is no reason to assume that brine emissions would be ecologically more damaging in these areas than elsewhere in the Hub North area.

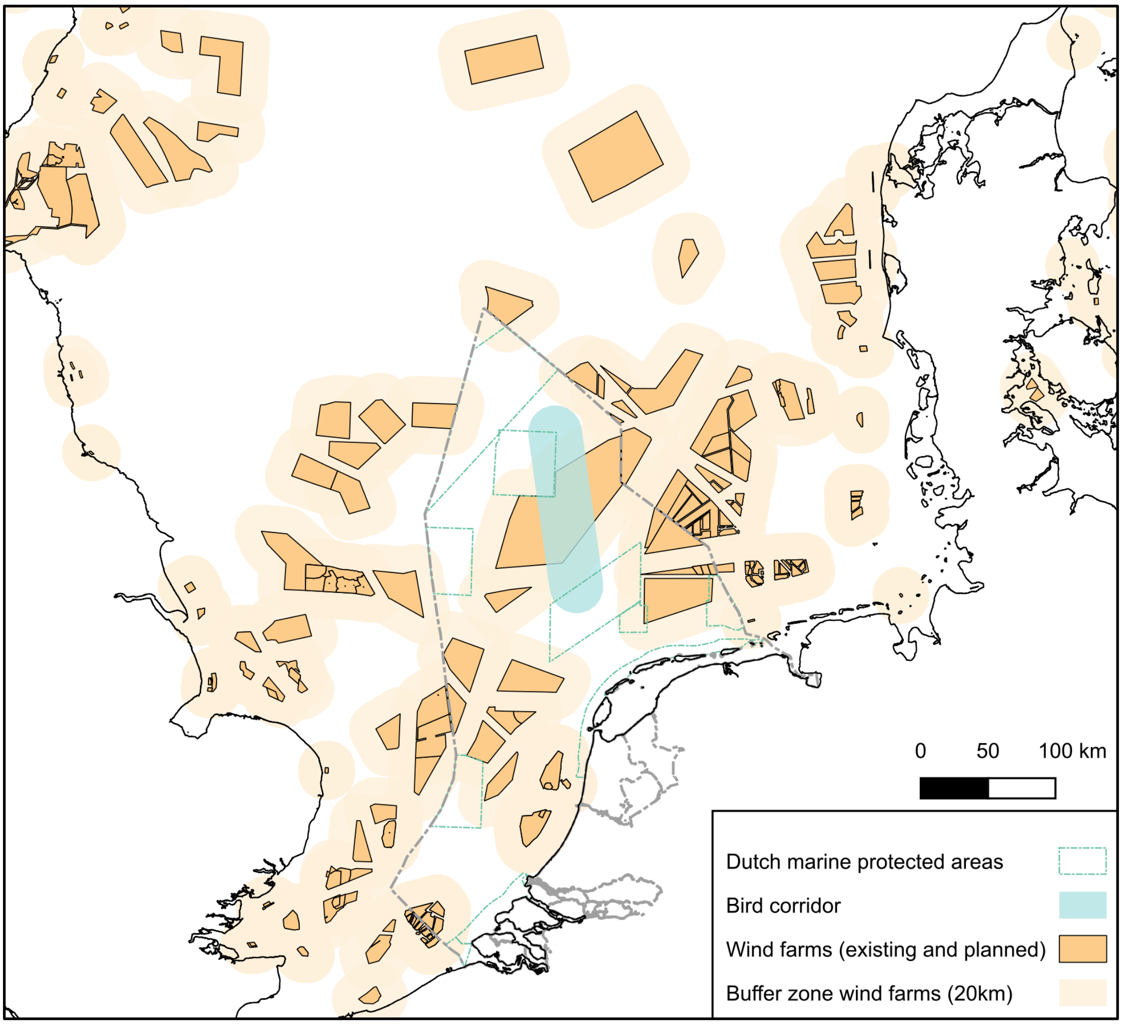

Figure 5. The bird corridor in Hub North (blue fill) in relation to Dutch MPAs (blue outline) and possible future barrier effects of OWFs, based on current OWFs and search areas and a 20 km radius of disturbance. This corridor is free of structures and other disturbing activities such as fishery and shipping.

Also, a number of interventions were included aiming to **facilitate restoration/rehabilitation of natural processes**, in particular the restoration of native oyster reefs and/or other reef building species:

- **Active native oyster restoration.** Considering that the area is characterized by conditions that indicate high suitability for the development of flat oyster populations (see paragraph 3.1) and the predominantly eastward current, it is suggested to start experimenting with flat oyster restoration measures in the western part of Hub North already in an early phase. Oyster restoration efforts could take place within the wind farms. In addition, active restoration measures, providing habitat for flat oysters as well as other species could be integrated in all wind farm developments in the area, thereby enhancing biodiversity locally as well as regionally by creating stepping stones and interconnectivity over the larger area. To preserve the effort care should be taken when decommissioning (see chapter 5.3). Further investigation is needed to include the productivity and seasonal stratification partners of the area into the oyster suitability analyses.

- **Create passive nature restoration zones throughout Hub North**. Passive restoration zones are relatively small no-use areas between wind turbines and other infrastructure where nature can run its course. Passive nature restoration zones are a potentially effective measure adding value to the larger nature corridor by strengthening connectivity within the hub area. As not much has been published about the effectivity of such measures in this type of environment, there are currently no areas within the hub thought to be more suitable than others.

A location for **offshore floating photovoltaic** (OFPV) was not specified within the 'standard design'. Because of this, in combination with the lack of knowledge currently available on the impacts of OFPV, the decision was made not to deviate from this. We therefore do not specify a location of OFPV activity in the nature-inclusive design. Regarding space allocation for 1 GW of OFPV, this is relatively small anyhow, approximately 5 km², with a similarly small impact compared to other infrastructure in the hub area. It should be noted that new insights into the impacts of OFPV can and should be applied to improve the design, as this might significantly affect the cumulative impact of renewable energy production in the area on the ecosystem. For example, increasing the total amount of energy generated by OFPV, instead of offshore wind, may significantly increase the role of potential negative ecological impacts of OFPV, such as the decrease in light availability in pelagic habitats and the introduction of hard structures at the water surface. On the other hand, it might also help counterbalance certain negative impacts of offshore wind, such as the impact on stratification (see Ch. 4). Ideally, the two technologies should be combined and placed in such a way that the cumulative (negative) impact on the ecosystem is minimised and the energy yield optimised. A deliberate trade-off of positive and negative impacts of OFPV in combination with offshore wind, however, is not possible with the currently available information.

The NISD concentrates wind farms, locating 8 GW in the western and 6GW in the eastern part of the hub . The exact spatial claim of these wind farms depends on the power density. The wind farms as shown in *Figure 4* require a power density of 10 MW/km^2. Should this prove unfeasible, more space to the north would need to be included, in what is currently indicated as stratification area empty of structures.

3.4.2 Asset-level interventions

In addition to the spatial design, asset-level interventions (also framed as NID options) were were proposed with the aim of reducing negative impacts (constraints) and maximizing potentially positive impacts (enabling conditions), while considering the mitigation hierarchy. In principle, these interventions could be applied in the standard design as well, but as they are costly measures, we assume them to be applied only or at a larger scale in the NISD. (1. Avoidance, 2. Minimization, 3. Restoration/Rehabilitation, 4. Offsets). In principle, these interventions could occur in the standard design as well, but as they are costly measures, we assume the scale of artificial reefs to be bigger in the NISD.

- Artificial reefs on the seafloor (at a larger scale in the NISD)
- Reduce speed of turbine blades when birds are detected, add a start/stop mechanism (exclusive for NISD) and increasing tip height of the turbines

Artificial reefs on the seafloor

To facilitate fish and benthic species attracted to hard substrates, artificial reefs are placed on the seafloor and scour protection around the structures, incl. pipelines and cable crossings. Within the NISD this will include bigger/more structures particularly in the area designated to active oyster restoration. The primary function of these artificial reefs is to increase the ecological functioning of the local hard substrate ecosystem, by providing habitat and substrate for various species, including oysters. Also using specially designed scour protection that facilitates the growth of a biodiverse species community is recommended.

Reduce speed of turbine blades and add start/stop mechanism

To decrease collision risk, the speeds of the blades of wind turbines are lowered when an increase in bird numbers is expected. Furthermore, a start/stop mechanism is implemented which can instantly shut down wind turbines to avoid collisions during migratory periods for birds. Finally, an increase in tip height is implemented which decreases the collision risk for birds.

Measures that have not been elaborated in spatial designs

It should be noted that a number of nature enhancement measures that work for different asset types have not been elaborated in the spatial design. Based on current knowledge, these are no-regret nature enhancement measures and should be applied wherever possible both in the standard design and in the NISD. These include:

- fish hotels
- aggregate cables and bury them deeper
- adjustments to scour (e.g. varying size, material and structure)
- nature-enhancing cable crossings
- water replenishment holes to benefit (targeted) organisms.

For these measures, it is important to consider the decommissioning phase of the hub already at the design stage: further discussions on this topic are provided in Chapter 5 (General recommendations and mitigation measures in the construction and decommissioning phases).

Furthermore, there are measures that are still being researched and might be worth considering as no-regret in the future if they prove effective, such as painting one rotor blade black. Or measures that would be beneficial to a nature inclusive design such as different monopile/tower shapes that reduce drag, or changing hard substrate for soft. Such measures are not specifically addressed in this study, as most of them are still in their infancy and knowledge about what really works and what would work in this particular area is very limited. Hence, with regard to the application of such measures, it is key to make good use of learnings from (pilot) projects elsewhere.

Additionally, intermediate level scale options, including variations in turbine height, density and spacing as well as routing or burial of cables, have not been incorporated into the nature inclusive spatial planning design, as the scale of the design was considered not to be appropriate for this level of detail. Moreover, the specific effects of such interventions are also insufficiently understood. Developments and recommendations on these aspects should be monitored in the coming years with an eye to emerging best-practices

In order to get an impression of what might be the potential in this area, it might also be worthwhile setting up research on already existing man-made structures in the area such as oil & gas platforms and shipwrecks.

3.4.3 Process-related recommendations

In this paragraph an overview is given of the process-related interventions that were brought forward during workshops 2 and 3. These recommendations are not included within the NISD, because they do not have clear spatial and ecological implications, making them unsuitable for a comparison. However, they should not be overlooked and are considered highly important for the effective realisation of a nature inclusive (spatial) design Hub. These interventions aim to make sure that decisions made in preparation for and during the construction process make good use of new knowledge about the ecosystem itself as well as about the effects of various types of infrastructure and related measures to protect and strengthen nature:

- Implement adaptive management.
- Continuous, standardised monitoring and adaptation
- Education
- Governance
- Data sharing

Adopting an adaptive management approach to develop the Hub informed by continuous, standardised monitoring results is of crucial importance. By combining adaptive management with continuous strategic and mandatory monitoring efforts, best practices can continuously be reassessed based on new information regarding impacts on ecological components. This allows for adaptations in the spatial design based on new information and enables the implementation of innovative measures that may increase the efficiency of renewable energy generation and/or the efficacy of impact mitigation and nature-enhancement. In terms of scheduling and using an adaptive management approach, it is suggested to start the rollout of developments in Hub North in the South-West and work towards the north-east. This way, active oyster restoration can be started as soon as possible, and the most sensitive area will be avoided for a longer time span. While rolling out developments in the South-West, it is advisable to already start limiting other human activities in the rest of the hub area, in order to allow nature to get a chance of restoring itself to some extent, before further developments take place, and to start improving baseline knowledge of the ecosystem in the middle and northeastern part of the area. Such efforts will be needed to ensure that spatial designs and nature-protective and -enhancing measures in the northeastern part will be effective.

To fill the knowledge gaps related to interventions and their effectiveness, a monitoring roadmap should be created and integrated into a national monitoring programme, e.g.

MONS or Wozep. This national monitoring programme needs to help future decision making and make it mandatory to monitor in a standardised manner when implementing new projects in the North Sea so the system knowledge is improved, and knowledge gaps can be filled. Monitoring of the current state of the ecosystem (the baseline), impacts of various human activities and infrastructure and of nature restoration should be prioritized. This way the actors can adapt on the way. In the short term, monitoring efforts on existing gas platforms in the Hub North area and on H_2 production pilots elsewhere in the North Sea could provide valuable information on what kind of impacts are to be expected from the introduction of hard substrate in the area and from the process of offshore H2 production. For example:

- Using existing gas platforms (F16, F15, F2, F3) to research/monitor potential for biodiversity on/around platforms in the area and start experimenting with nature-enhancing measures within their safety zones. If the platforms turn out to be able to support ecosystem restoration, it might be considered to leave parts of them in place as artificial reefs.
- Use H_2 production pilots 1 and 2 to monitor potential impact on birds, in particular guillemots and their predators, and to experiment with different solutions for disturbances caused by brine and heat emissions.

Additionally, to promote monitoring efforts and facilitate efficient use of results, data-sharing between offshore wind farm operators, fishermen, oil- and gas operators and other users or stakeholders needs to be mandatory. This could help steepening the learning curve, preventing stagnation and optimizing the use of human resources. Finally, to ensure that positive impacts are not limited to the short-term, more research needs to be done on the decommissioning phase. By doing this, new, nature-friendly ways of decommissioning could be developed that maintain any potential positive effects of nature-inclusive design measures and related infrastructure. During the workshops the importance of education and governance was also mentioned and is reported in the workshop notes (workshop 1, workshop 2 and workshop 3).

4 Resulting ecological state from large scale design options

4.1 Assumptions

In this chapter we discuss the impact from the different design options in Chapter 3 on different abiotic and biotic conditions of the ecosystem. This will be done on a high level and based on the ecological information in the fact sheet (Appendix A). The resulting state is a result of a 'best case' scenario in which some 'best case' assumptions have been made:

- The entire design including all nature enhancement measures has been built and realised within the ecological carrying capacity and within all applicable laws and regulations
- All placed infrastructure is operational and is being properly maintained
- All nature enhancement measures are successful
- Some asset-level interventions are included in the NISD, see paragraph 3.4.2.
- No construction and demolition impacts are taken into account and are considered in Chapter 5.

4.2 Asset type impact description

4.2.1 Turbines

The large-scale impact of wind turbines in the marine environment is summarised in *Figure 6* where it is presented for a single turbine, however, describing the situation of large-scale roll-out. E.g. the effect of a single turbine on the mixing of the water column will be very limited, but when 2000 turbines are installed in the marine environment the cumulative impact can be significant. The impacts in *Figure 6* will be described in more detail in the next paragraphs.

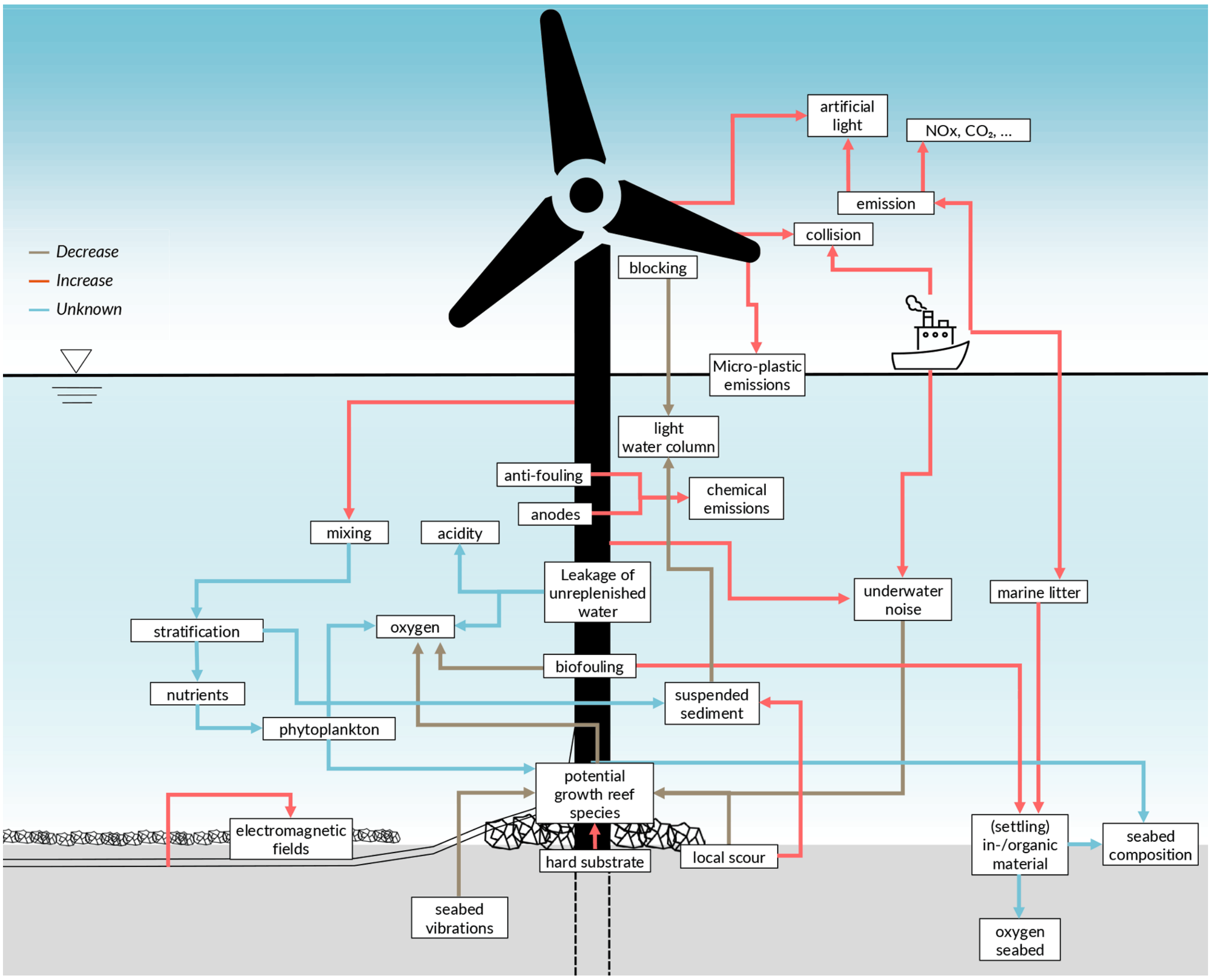

Figure 6. Turbine specific impacts on the marine environment. This specifies the impact when large scale implementation is put in place. Green arrows indicate an increase; red arrows indicate a decrease; blue arrows indicate an unknown change.

4.2.2 Hydrogen production

As for turbines, the large-scale impact of hydrogen production on the marine environment is described in *Figure 7*. Also, here the impact becomes more significant when multiple P2G-platforms are installed, and these impacts are described in more detail in the following paragraphs.

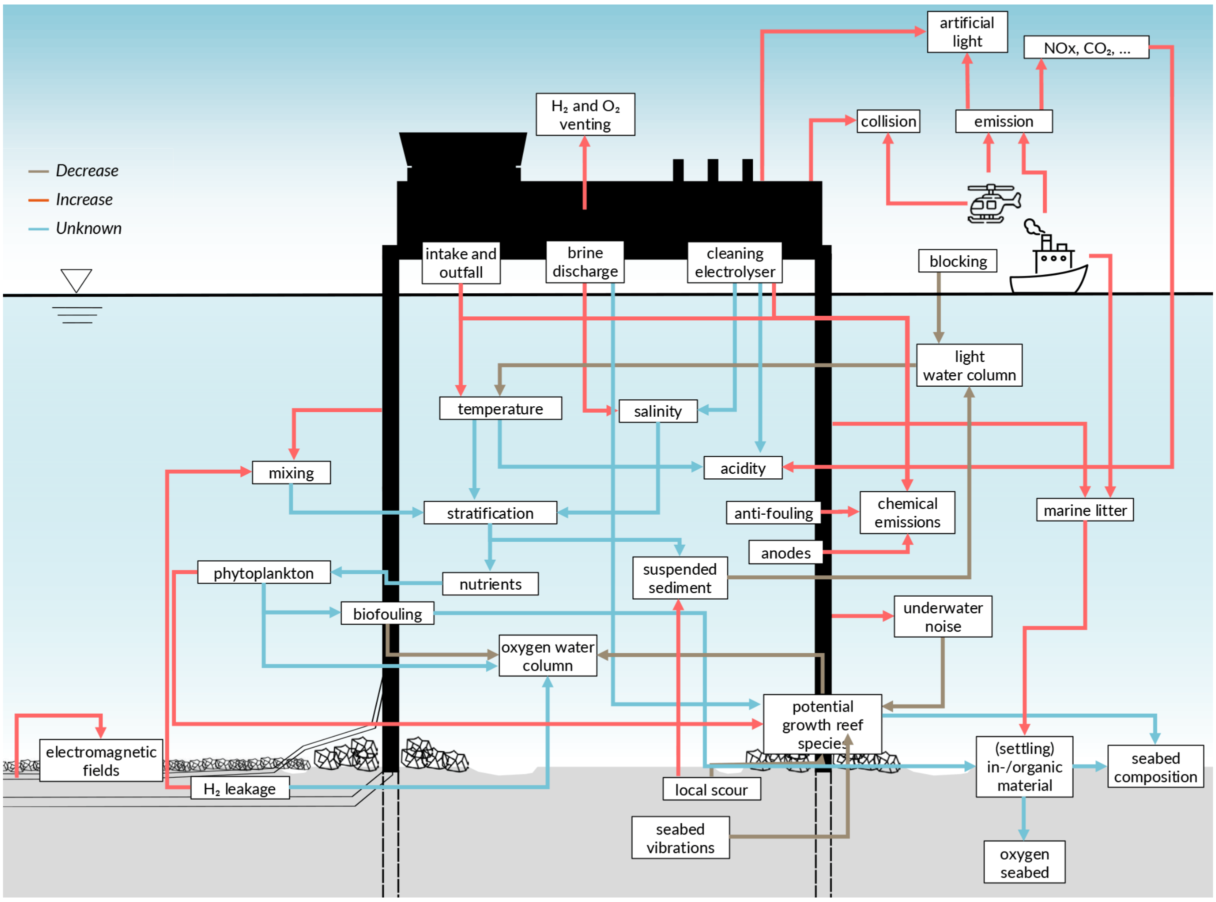

Figure 7. Power to Gas (P2G) platform specific impacts on the marine environment. This specifies the impact when multiple P2G-platforms are implemented in the marine domain. Green arrows indicate an increase; red arrows indicate a decrease; blue arrows indicate an unknown change.

4.2.3 Offshore floating photovoltaic

For offshore floating photovoltaic activities, the impact is described in *Figure 8*, which considers these floating devices to be directly on top of the sea surface. Knowledge on the impacts of inland floating photovoltaics is emerging, but insight is not readily transferable to marine environments as they are unbounded, tidal, saline, highly ecologically diverse, and generally experience stronger winds, waves, and currents (Hooper et al., 2021). The impacts in *Figure 8* will be described in more detail in the next paragraphs.

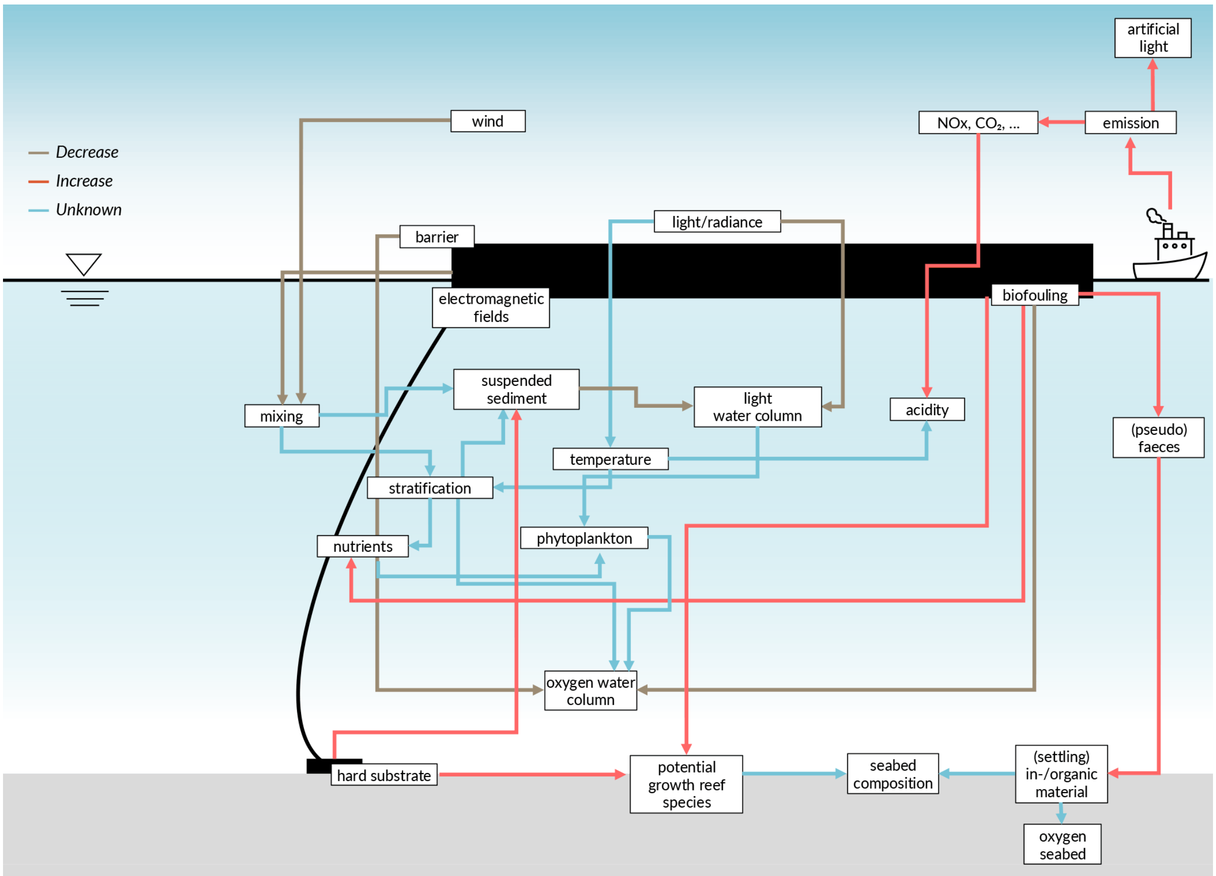

Figure 8. Offshore floating photovoltaic impacts on the marine environment. This specifies the impact when floating solar devices are implemented in the marine domain. Figure modified from Schneider et al. (in progress).

4.3 Abiotic conditions

This paragraph focuses on the difference between the impact of the base design and the NISD on the abiotic conditions. It concludes with a comparison of all abiotic impacts.

4.3.1 Hydrodynamics

4.3.1.1 Wind and waves

Current state
Area with larger significant wave heights compared to other parts of the Dutch North Sea. The shallow Dogger Bank borders Hub North.

Standard design
Offshore wind farms harvest wind energy and thereby slow down the wind velocity at sea surface level (momentum sink), which directly affects the wave growth and indirectly the wave propagation, dissipation and interactions. This happens downstream of the turbine(s) displaying a local wake effect. Other local wind effects can be increased mixing of the atmosphere and air flow amplification by the turbines; both potentially increasing the wind speed at the sea surface (Boon et al., 2018). Zijl et al., (2023) models the effect of OWF's on waves by reducing the wind speed by 10% in the OWF area, resulting in a decrease in significant wave height inside and downstream of the OWF areas, see *Figure 9*. Other local wave effects can be present due to blockage by offshore structures (e.g. offshore wind, or P2G-platforms) and local changes in bathymetry and bed roughness due to the structures and scour protection.

Floating solar panels, on the other hand, as modelled by Karpouzoglou et al., (2020), cause friction, which leads to reduced current velocities both beneath and downstream of the floating farm, establishing a quieter hydrodynamic regime with reduced mean wave heights and reductions in turbulence and vertical mixing (Benjamins et al., 2024).

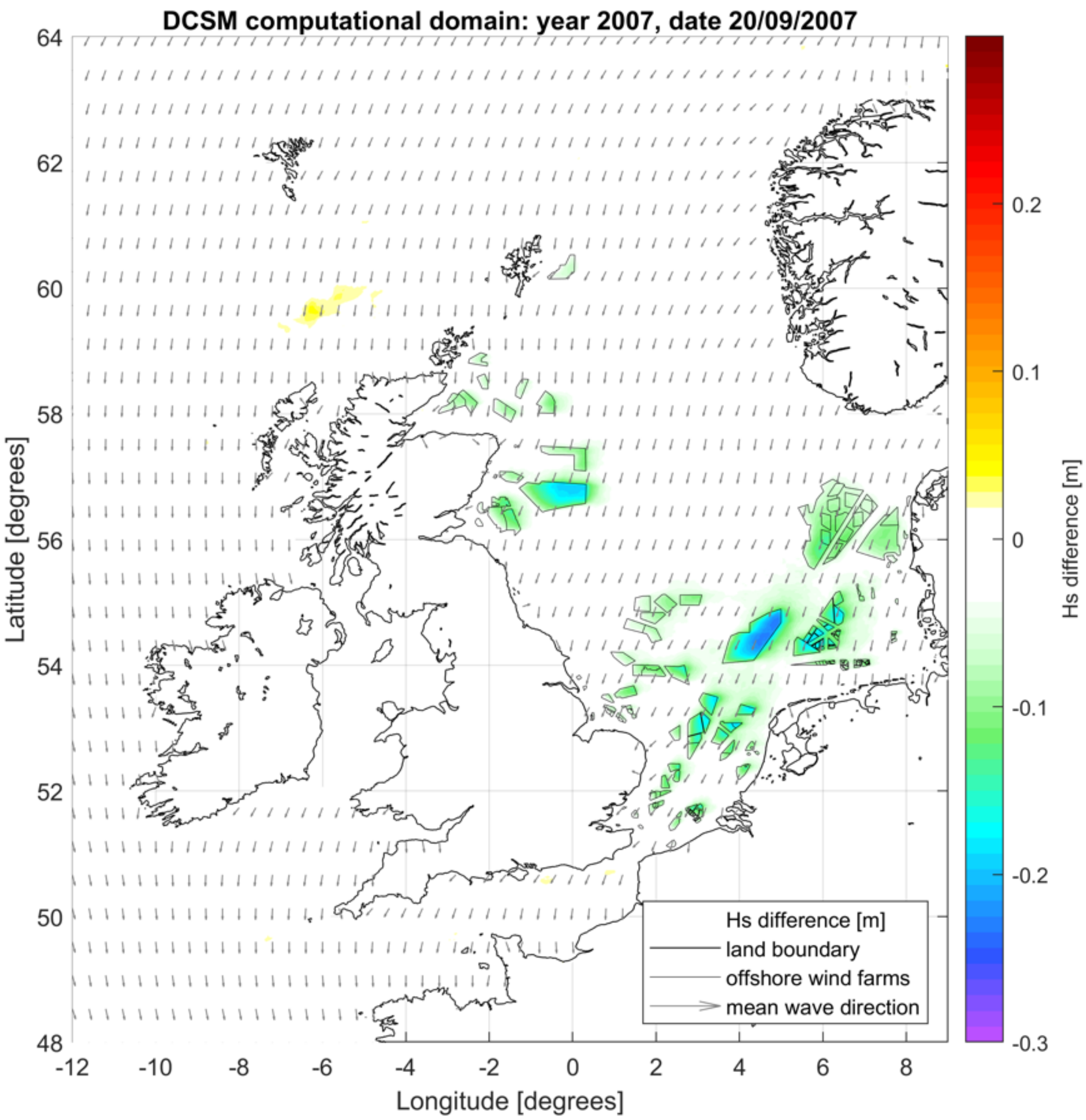

Figure 9. Absolute difference in significant wave height between a reference scenario without OWFs and a future scenario with OWF's (Zijl et al., 2023).

Nature-Inclusive Design
NISD does not account for wind/waves changes (on a local or on a larger scale) directly. While successful active oyster restoration may reduce wave dynamics by altering bathymetry and bed roughness, this effect has only been demonstrated for relatively shallow water depths. It is uncertain if this results in significant wave attenuation at the considered depths and scales (Jiang et al., 2025) .

Comparative conclusion
The impact of the presence of the energy infrastructure on the wave dynamics remains equal in both designs: for both a decrease in wave height is expected. Potential effects of wave attenuation by restored (oyster) reefs through changes in the bathymetry and bed roughness in the area are uncertain.

4.3.1.2 Tides and currents

Current state
In the area of Hub North, the residual current flows in an (north)easterly direction, driven by the residual M2 tidal current to the east and predominant wind patterns from the southwest. *Figure 10* shows a stronger residual current at the surface than at the bottom.

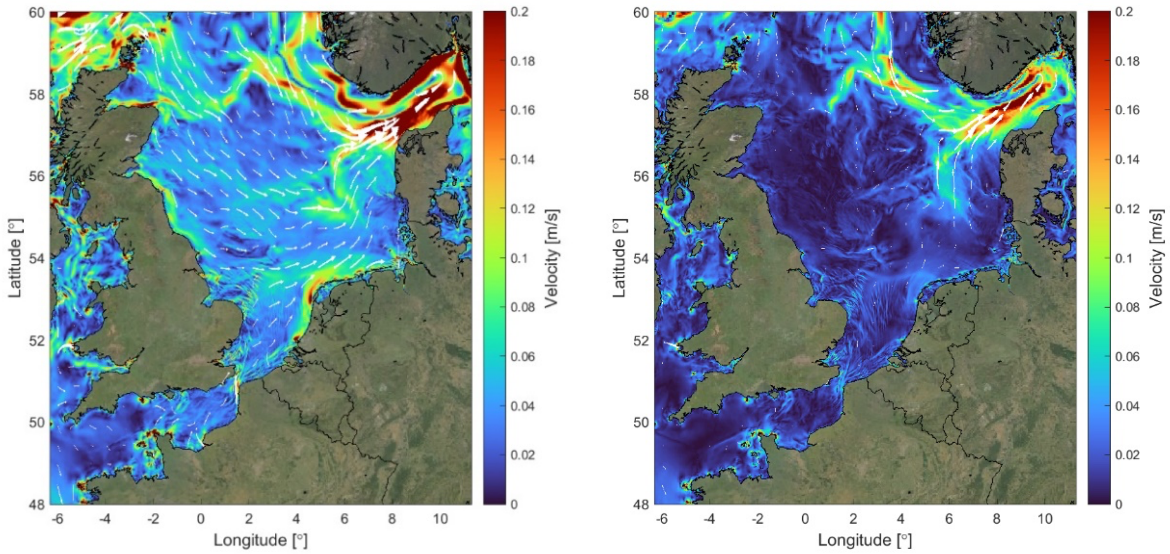

Figure 10. Modelled annual mean residual current velocity (2007) at the surface (left) and bottom (right) (Zijl et al., 2023).

Standard design
Zijl et al., (2023) shows that the installation of monopiles and turbines in Hub North will likely result in a smaller residual current velocity at the surface locally (inside the Hub), see *Figure 11*. Residual current velocities both increase and decrease in magnitude outside OWF areas, especially along the borders of Hub North changes in velocity are expected. The expected changes near the bottom are rather small. The main cause for changing flow patterns is the obstruction of flow by the structures, which changes the local flow velocities and leads to an increase in vertical mixing and tidal energy dissipation.

As the P2G-platforms, and the pillars carrying this platform, have similar effects on the mixing of the water column as monopiles, the effect expected by Zijl et al., (2023) will be similar for the P2G-platforms. The brine and cooling water outfall plumes can alter the existing flow patterns.

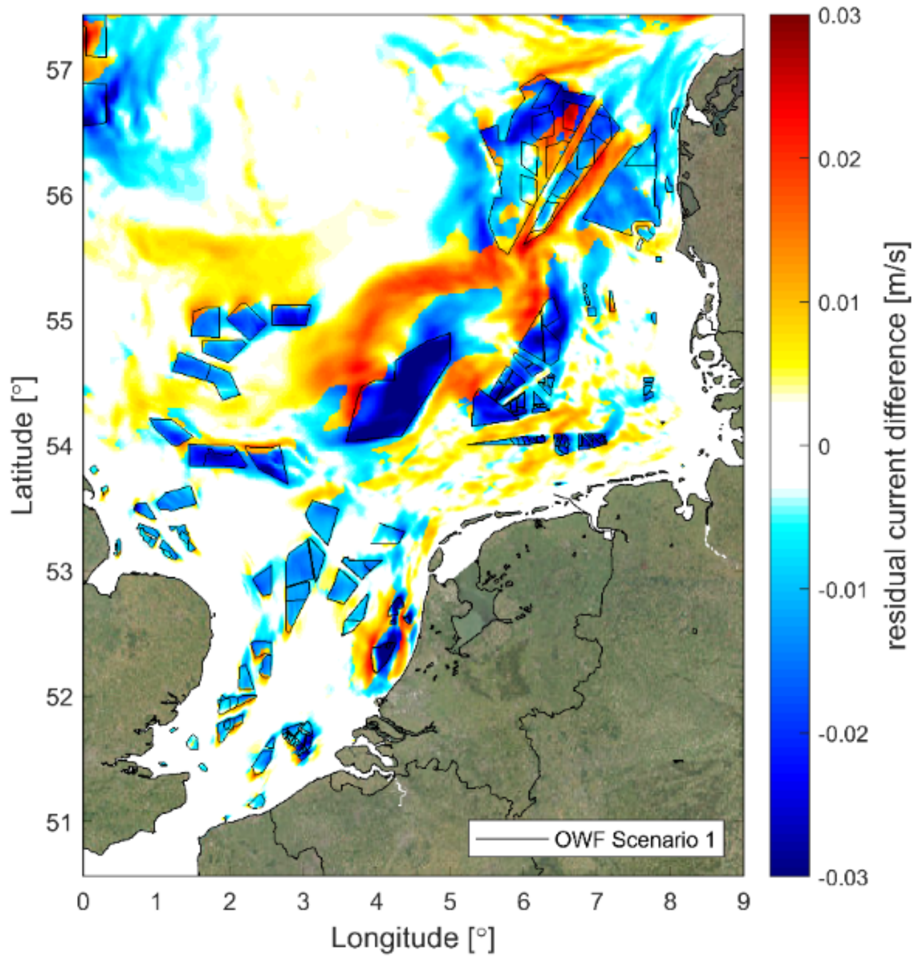

Figure 11. Absolute change in annual residual velocity in the top layer (2007) (Zijl et al., 2023).

Nature-Inclusive Design

In the NISD, the developments are restricted to a different area within Hub North, potentially decreasing the effect on the residual current velocities locally. It is unclear to what extent the corridor will have an effect on mitigating the effects on the currents. In general, the effects of the NISD compared to the SD on the residual currents are expected to be very similar.

Since all P2G-platforms are placed along the eastern boundary of Hub North, some of the effects on the (residual) current velocity may be translocated outside the Hub North area.

The restoration of (oyster) reefs can further change the flow velocities in and around Hub North. It is unclear in what order the (residual) current velocities will change because of potential reef forming.

Comparative conclusion

There are no NISD measures directly tailored to mitigate changes in flow patterns. The restriction of developments to a smaller area rather than using the entire area of Hub North can potentially decrease the change in (residual) current velocities. However, reef formation can enhance changes in flow patterns, as well as the placement of P2G-platforms in one line along the boundary of Hub North. The net difference in current velocities between the design options is unclear.

4.3.1.3 Temperature, salinity and nutrients

Current state

Due to high interannual variability in stratification regimes in Hub North the area cannot be classified as one stratification regime (van Leeuwen et al., 2015). Hub North is located between a seasonally stratified region in the North and an intermittently stratified region in the South. *Figure 12* indicates a northward increasing gradient in summer temperature stratification in Hub North. During summer, increased atmosphere temperatures and solar radiation lead to warmer sea surface layers compared to cooler bottom layers and their different densities keep the layers separated. Salinity stratification is rather small if not negligible in this area. The exchange of (suspended or particulate (in)organic) substances between different layers within stratified water is limited.

The concentration of nutrients in the North Sea follows a seasonal pattern. Concentrations are highest in winter and decrease in spring, when algae start to bloom. After summer, when the hours of daylight decrease, algae decline in numbers and nutrient concentrations increase again. Within the North Sea, in the region surrounding around the Dogger Bank, close to Hub North, lowest nutrient concentrations are measured (Topçu & Brockmann, 2004).

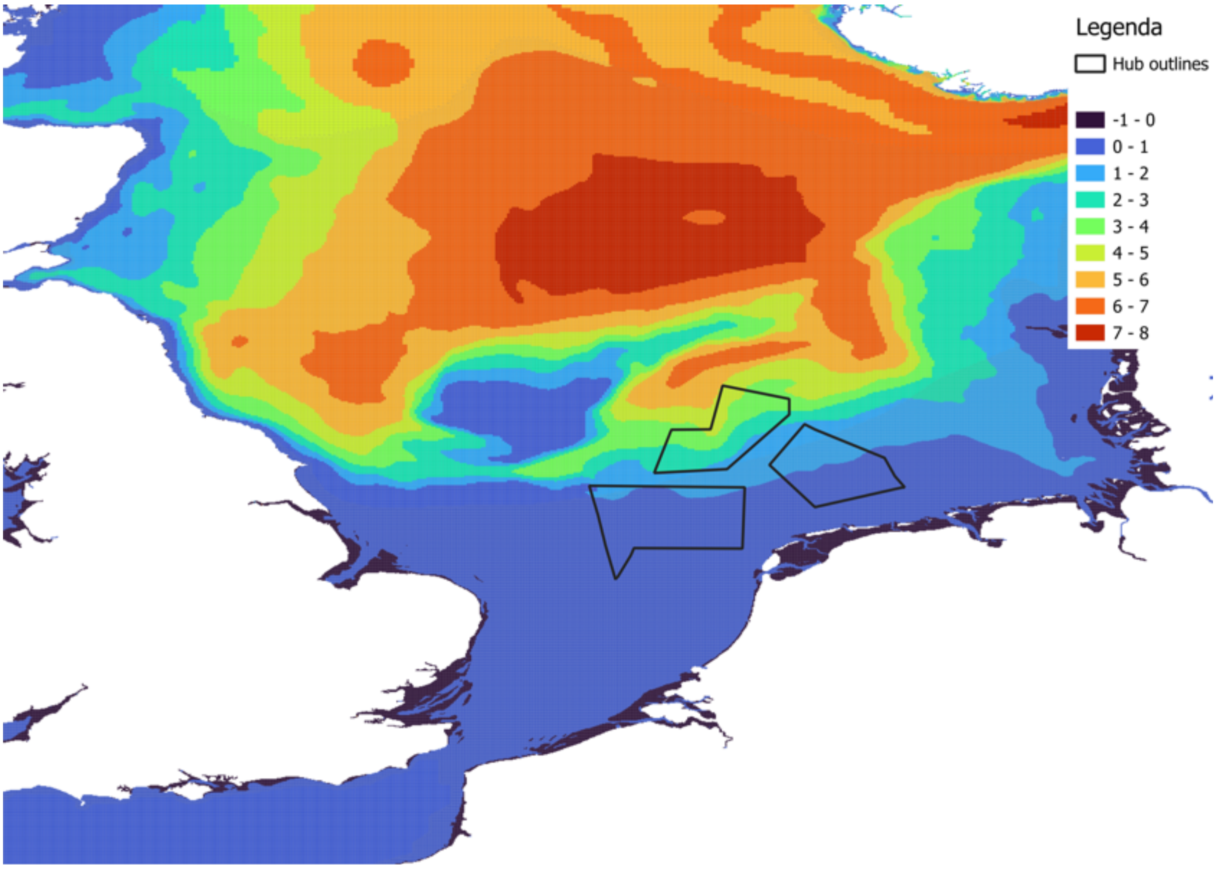

Figure 12. Modelled summer temperature stratification in the North Sea in 2007. The numbers indicate the temperature difference (°C) between the top and bottom water layers. Figure based on data from (Zijl et al., 2023).

Standard design

The presence of offshore structures induces an increase in mixing of the water column and a subsequent decrease in stratification. As Hub North is subjected to summer temperature stratification, this effect might be most notable during summer. *Figure 13* shows the absolute and relative change in the annual mean of the vertical temperature difference. Zijl et al., (2023) expects that the effects of changes in vertical salinity differences, due to the construction of wind farms in Hub North, is negligible compared to changes in temperature stratification.

The discharge of cooling water and the brine discharge from the P2G-platforms form effluent plumes that are positively buoyant (cooling water effluent) and negatively buoyant (brine discharge). The dilution and dispersion of these plumes need to be modelled to understand the effects of these discharges on the environment. A first modelling study by van der Linden, (2024) on brine discharge in the North Sea from P2G-platforms, showed a significant local increase in salinities but with use of brine diffusers these effects can be minimized further away from the discharge location. The amount of cooling water effluent will be substantial, still requiring detailed modelling of the plume dispersion and dilution. The cooling water effluent potentially increases stratification, but also affects nutrient distribution and oxygen levels. Another numerical model study by (van der Hagen, 2024) investigated 14 scenarios changing the electrolyser capacity and discharge characteristics during summer and winter conditions. The study finds that the direct effects of brine discharge on marine ecosystems are minimal due to only small increases in salinity. However, the sinking behavior of brine effluent, especially in worst-case scenarios, needs further consideration as it could form density currents affecting nutrient cycling and benthic communities. The thermal plume is largely confined to the top 5 meters of the water column but extends into the far-field of the domain.

Inland studies of OFPV systems (such as those in lakes and reservoirs) have demonstrated localized cooling of the water beneath the panels due to decreased solar heating. The extent of this cooling effect can vary based on the coverage area and the levels of vertical mixing and horizontal water movement. This cooling may be significant on a local scale. However, in offshore environments, the cooling effect is likely minimal, with negligible to minor impacts on biological communities (Benjamins et al., 2024). The combined effect of reduced solar irradiance, wind shielding and increased hydrodynamic drag on stratification is dependent on the stratification regime at the OFPV location. Increased stratification is likely to be most noticeable when deploying OFPV systems in areas that naturally experience strong (seasonal) stratification (Karpouzoglou et al., 2020).

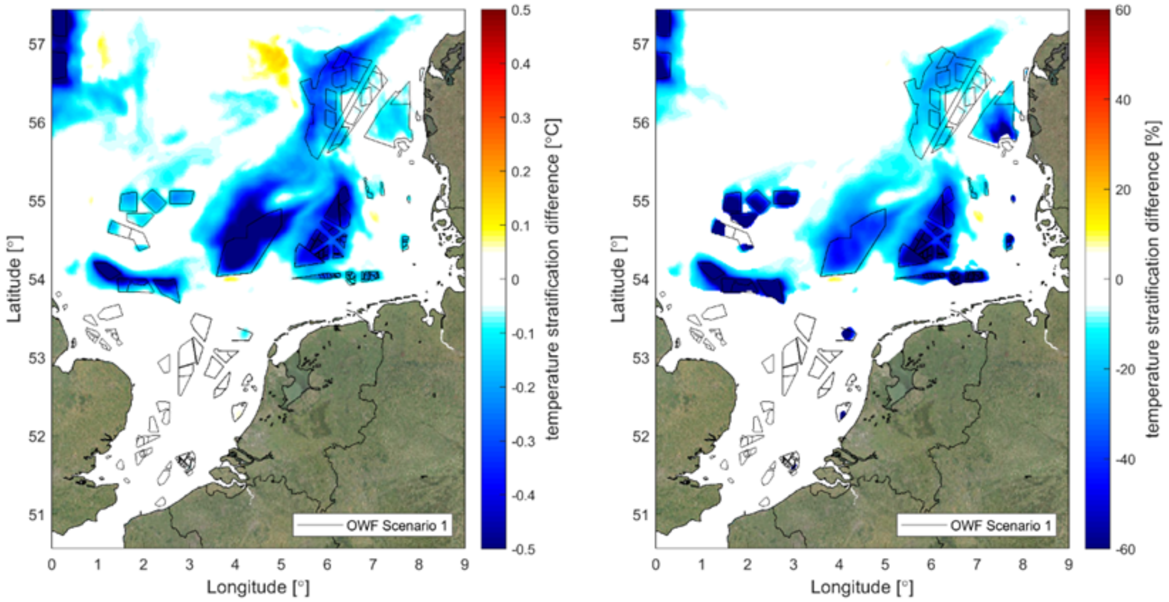

Figure 13. Modelled absolute change (left) and relative change (right) in the annual mean of vertical temperature difference (scenario 1). Mean stratification differences <0.5 °C are not shown in the right chart. (Zijl et al., 2023).

Nature-Inclusive Design

In Hub North, despite interannual variability, a northward increasing gradient in summer stratification can be assumed. In the NISD option, refraining from development of offshore wind farms in the northernmost tip of Hub North, has the most impact in decreasing the magnitude of the disruption of the natural occurrence of stratification within the Hub North area.

P2G-platforms are placed along the eastern border of Hub North, as this is already bordering a busy shipping lane area and further away from most ecologically relevant areas. Cooling water and brine discharge will therefore mainly be coming from the eastern border of Hub North. Modelling of the plumes dispersion and dilution will be required to assess the difference in effect between the two designs, e.g. the effect of discharging throughout the water column or over a larger area.

Further investigations are required to determine whether a closed-loop cooling water intake and outfall system is beneficial for the marine environment. Such a system, where heat is disposed through the seabed or through air, could limit the effluent plume of cooling water into the North Sea. However, biofouling might counteract this heat release to the environment. Other recommendations for further research include the extraction of rest heat for lithium recovery process (creating a loop) and the extracting the salt for other purposes.

Comparative conclusion

The NISD partially mitigates the effect of the energy hub on the stratification patterns by limiting the energy infrastructure to the least stratified areas within Hub North. Strategic placement of P2G-platforms within the NISD reduces the effects of cooling water and brine discharge on the increase of temperature and salinity in the Hub North area.

4.3.2 Sediment dynamics

4.3.2.1 Suspended sediment concentration

Current state
The amount of suspended particle matter (SPM) in the water column or turbidity depends on the local hydrodynamics (e.g. bed shear stress, mixing) and the seabed composition. Turbidity of the North Sea is generally high compared to other regions (Shi & Wang, 2010). The highest turbidity can be expected in the southern North Sea, including (part of) the Hub North area, because of input of particles from various riverine systems (Wilson and Heath 2019). The modelled current situation for Hub North indicates a low yearly averaged bed shear stress and a relatively high yearly-averaged near-bed and surface total inorganic matter (TIM), as shown for the year 2007 in the left panels in *Figure 14*, *Figure 15* and *Figure 16* (Zijl et al., 2023).

Standard design
Together with the bed shear stress, the foundation-induced turbulence affects the vertical distribution of SPM. The absolute changes in year-averaged bed shear stress resulting from energy developments are expected to be small for Hub North (see *Figure 14*). The relative changes in the near-bed and surface TIM, however, are rather high (*Figure 15* and *Figure 16*). Up to 20% increase of near-bed TIM is demonstrated for the western part of Hub North, whereas a relatively large decrease (up to -20%) is shown for the north-east part of the wind farm. The surface TIM follows the same pattern but shows a bit smaller decrease of TIM in the northeastern part of Hub North.

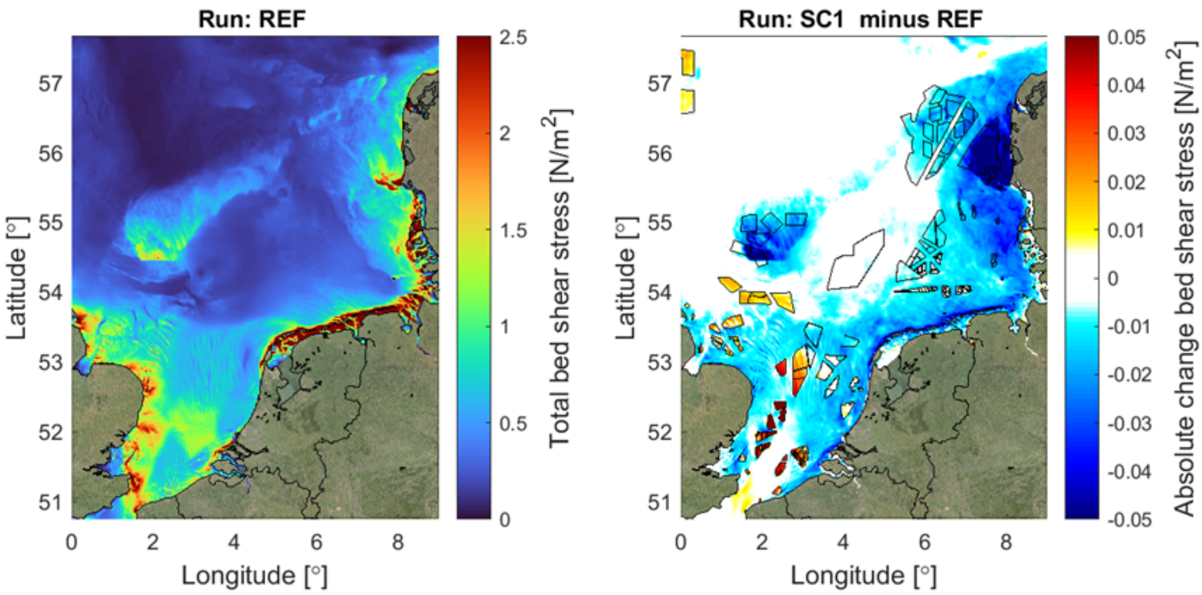

Figure 14. (Left) Modelled yearly averaged total bed shear stress in the reference scenario without offshore wind farm developments and (right) the absolute changes in total bed shear stress for a future wind farm scenario (Zijl et al., 2023).

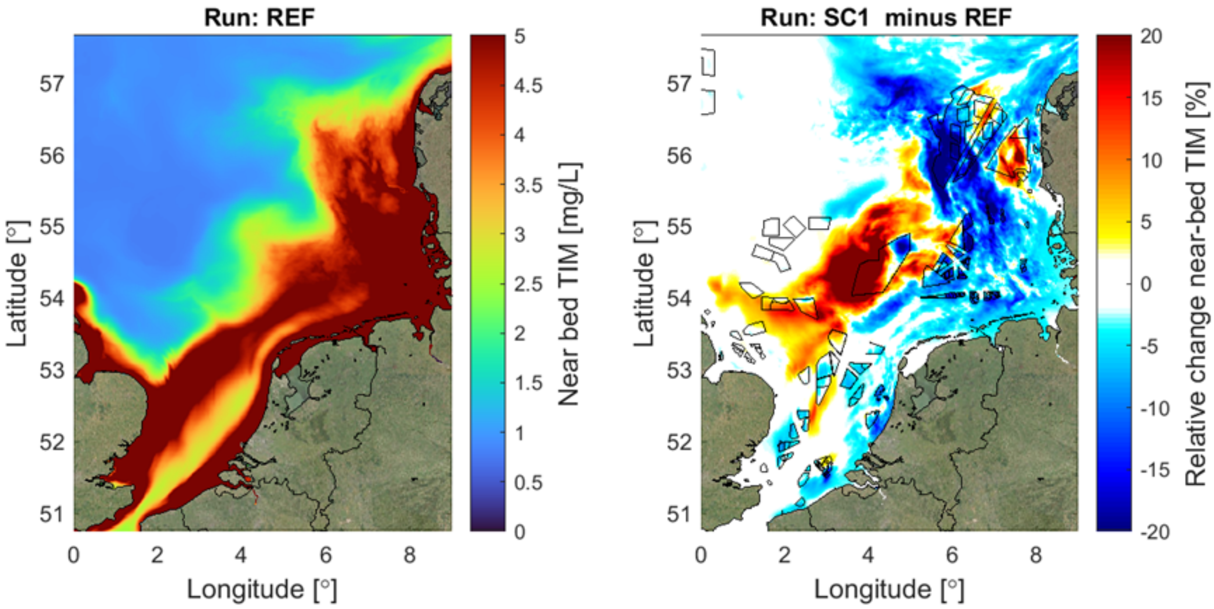

Figure 15. (Left) Modelled yearly averaged near-bed total inorganic matter in the reference scenario without offshore wind farm developments and (right) the relative changes in near-bed total inorganic matter for a future wind farm scenario (Zijl et al., 2023).

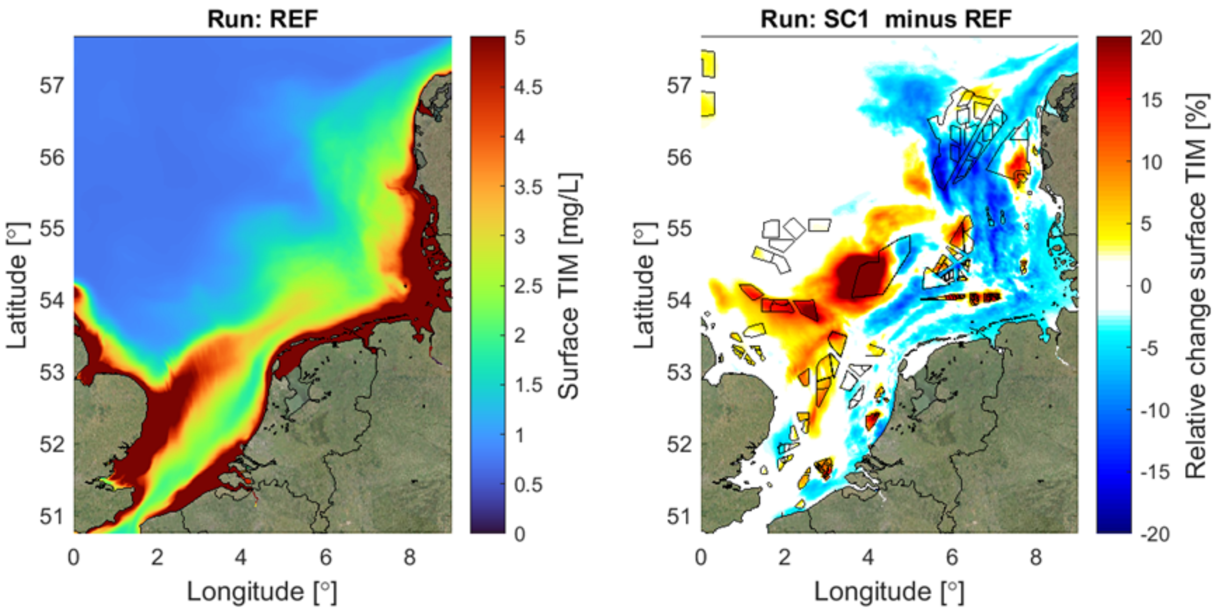

Figure 16. (Left) Modelled surface total inorganic matter in the reference scenario without offshore wind farm developments and (right) the relative changes in surface total inorganic matter for a future wind farm scenario (Zijl et al., 2023).

NISD

The northeastern part of Hub North, where a decrease in TIM is expected for the standard design will be left undisturbed in the NISD. For the rest of the Hub North area, the direct effects of the developments result in an increase of TIM, similar to the standard design (see *Figure 15* and *Figure 16*), but opposing indirect effects might be caused by oyster reefs. Restored oyster reefs can reduce the amount of TIM near the bed by filtering the water, increasing water quality locally. Several studies highlighted the benefits of oyster restoration projects in relation to ecosystem services provided by these oyster reefs (Chambers et al., 2018; Coen et al., 2007; Dame et al., 1984; Peterson et al., 2003). The filtration of suspended material is seen as one of these ecosystem services. However, a study by Grabowski & Peterson (2007) pointed out that yet localized effects of oyster filtration (e.g. reduced turbidity) has been observed, the effects of oyster restoration on water quality in large water bodies are still difficult to quantify. Further studying of the effect of oyster restoration on turbidity reductions, especially in wind farms, is required to quantify this.

Comparative conclusion

The impact of turbines in the northeast on the Hub North area, leading to a local reduction in TIM, is minimized in the NISD where this area remains undisturbed. The area where the strongest increasing effects of turbines on TIM is expected coincides with the area subject to the highest restoration efforts in the NISD. Oyster restoration might therefore mitigate a part of the turbine-induced increase in TIM in this area. The contribution of the effects of oysters on TIM is not quantified and depends on the effectiveness and scale of oyster restoration, but is unlikely to match the modelled increase in near-bed TIM of 20%.

4.3.2.2 Seabed morphodynamics

Current state

Hub North is not an area with sand wave dynamics as is the western part of the Dutch North Sea. With a relatively low bed shear stress the seabed is more static and has a finer seabed composition than the western sand wave dominated Dutch North Sea. Current sediment maps of the area show that the bottom (*Figure 17*) of Hub North is mainly dominated by (gravelly) muddy sand, where the southwestern and northeastern part of the domain has a (gravelly) sand seabed (Dabekaussen et al., 2023).

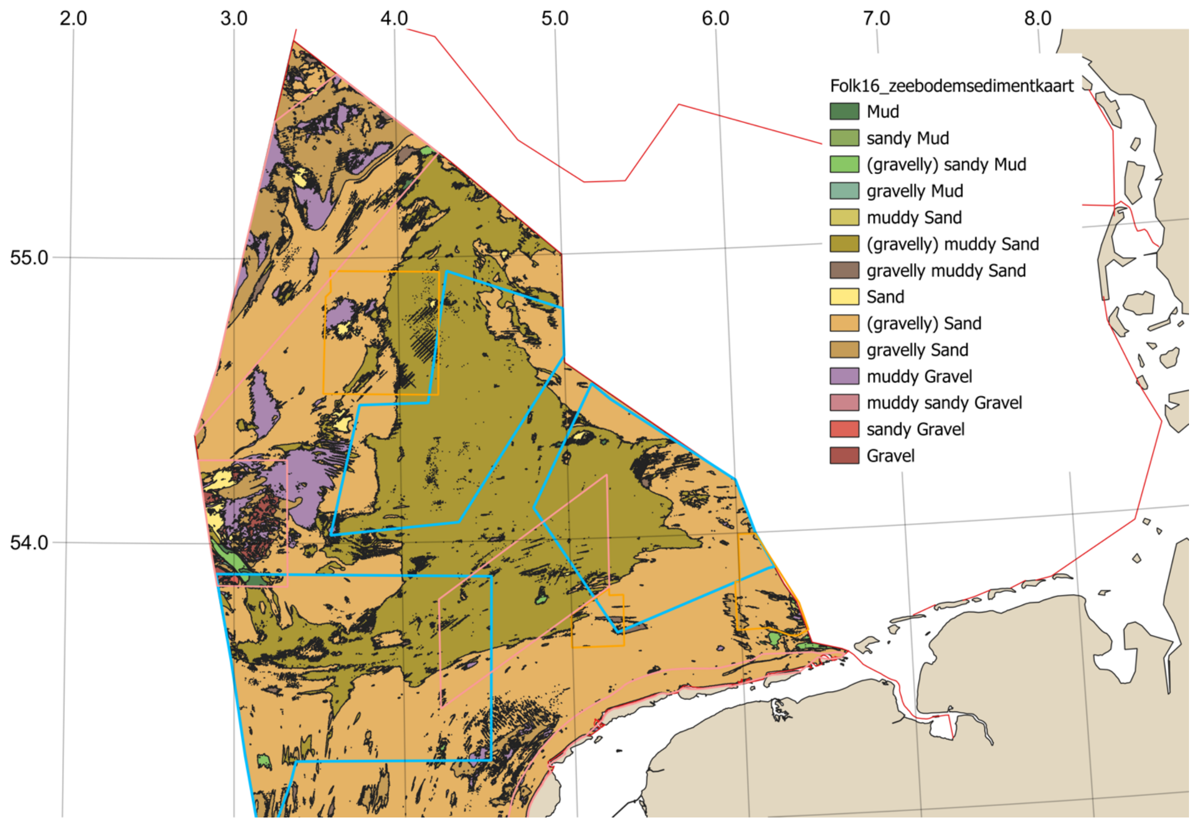

Figure 17. Folk 16 classification map (Kaskela et al., 2019) of the sea bottom for the northern section of the Dutch North Sea. Blue shapes indicate the NSE hub contours and thin pink/yellow shapes indicate the marine protected areas. Figure created from TNO seabottom sediment map (Dabekaussen et al., 2023).

Standard Design

Bed shear stress impacts the erosion and deposition processes near and in the seabed, affecting bed forms and sedimentology. In areas with relatively low bed shear stress, as is the case in Hub North, OWF's or other platforms can significantly influence this stress (increasing tidal currents around foundations), causing resuspension of SPM and sediments that otherwise would remain near or in the seabed (Boon et al., 2018). Coarsening of the seabed can be a result in the long term.

Nature-Inclusive Design

NISD-measures are not considered for the morphodynamics.

Comparative conclusion

It is not adequately known what the effects of large-scale implementation of energy infrastructure is on the (long-term and large-scale) morphodynamics. Because the area has no sand waves and does not show very strong seabed dynamics, the effect of the SD or NISD on the morphodynamics is not considered in the design process or comparative impact assessment.

Without such a model-based approach, quantification is dangerous as both concentration-enhancing and concentration-reducing effects play a role and the resulting net effect varies in space and time, depending on which effect is dominant at a given time and position. In addition, not only the present and local conditions determine this, but also the ambient conditions and the conditions in the past, as SPM dynamics typically are not in instantaneous equilibrium with hydrodynamic conditions but may show important lag (i.e. memory) effects (Boon et al., 2018).

4.3.3 Other abiotic conditions

4.3.3.1 Chemicals

Current state
The chemicals added to the environment due to activities taking place in hub North considers mainly potential pollutants used or released during offshore green hydrogen production. The current state is that these pollutants should be absent or close to being absent. The description of the standard design and NISD discusses what those pollutants might be and how this release can be mitigated.

Standard design
Potentially hazardous substances may be released into the North Sea during the production of offshore green hydrogen. Specifically, the possibility of contaminants in cooling water, and contaminants in electrolyser membranes are considered.

Several pollutants are used or released during the production of offshore green hydrogen, with potentially serious environmental consequences. Major pollutants include biocides such as chlorine (Cl_2), sulfuric acid (H_2SO_4) and various halogens found in cooling water that can harm aquatic life when released into the marine environment, i.e. acidification of seawater, bioaccumulation in the food chain, changing the chemical composition of water and formation of hazardous byproducts (Gohil & Suresh, 2017; Maeda, 2022; Matin et al., 2011).

During the Reverse Osmosis (RO) desalination process, there is a risk of releasing substances, such as heavy metals, due to corrosion and the use of certain chemicals for maintenance. For example, harmful chemicals such as antiscalants and detergents that are highly acidic or alkaline (Zhang et al., 2022). In addition, corrosion can cause the release of toxic heavy metals into the environment (Missimer & Maliva, 2018).

Perfluorinated compounds (PFCs), including PFAS (per- and polyfluoroalkyl substances), are used in PEM electrolysers (Di Virgilio et al., 2023). These substances can bioaccumulate in the marine ecosystem and are toxic to organisms, with the potential for non-degradation, which is dangerous. In addition, electrolyser membranes and components contain heavy metals that can harm marine life if leaked into the environment (Becker et al., 2023; Giancola et al., 2019).

Risks of chemical pollution are limited in well-maintained OFPV systems (Benjamins et al., 2024). Unlike terrestrial PV arrays, where chemical dust suppressants are often used to maintain panel efficiency with various negative environmental impacts, the presence of water will generally reduce the requirement for such substances. However, the use of antifoulants on submerged surfaces can result in pollution, and the ramifications of their use should be carefully considered; recent advances in this field also offer potential for non-chemical antifoulant alternatives.

Nature-Inclusive Design
The placement of P2G-platforms along the eastern border of Hub North might reduce the environmental impact of chemicals being released as the P2G-platforms are bordering a busy shipping lane area and further away from most ecologically relevant areas. The earlier suggestion of investigating the use of a closed-loop system for the intake and outfall system of cooling water and whether this is beneficial for the marine environment applies also for chemicals and pollutants. The use of a closed-loop system could limit the effluent plume of pollutants into the North Sea.

The release of pollutant plume dispersion on the eastern border of Hub North and the effect of a closed-loop system must be modelled to assess the difference in impact between the designs.

Comparative conclusion
Strategic placement of P2G-platforms within the NISD could reduce the effect of pollutant on a larger area in Hub North, however, since these pollutants are transported through the water avoiding release is advised.

4.3.3.2 Ambient sound

Current state
The natural ambient sound, composed of elements like wind, rain and ocean waves, is a constant presence in the marine environment. However, these natural sounds are relatively soft compared to sounds (or noise) from human activities, especially shipping activities, with the result that the natural noise gets drowned out. Excluding these anthropogenic noises, the background underwater sound levels across the North Sea for the 125 Hz frequency band are approximately 90 dB re 1 µPa median sound pressure level (SPL). During winter these levels are slightly higher, approximately 5 dB higher than summer values, due to windier conditions in winter (OSPAR, 2023). The southern part of the North Sea and major shipping routes are impacted by the highest level of anthropogenic noise. Here, anthropogenic noise often exceeds the background noise by 20dB (OSPAR, 2023).

Standard design
Anthropogenic noise, which can be either impulsive or continuous, leads to an increase in the sound levels of the North Sea. Sources for continuous underwater noise are shipping, recreational boating, fishing, oil and gas activities, and offshore wind turbines. As demonstrated in *Figure 18* the combined sound pressure around Hub North, without plans for offshore energy activities, are relatively low compared to other areas of the North Sea. However, note that in and around Hub North there are several shipping lanes (planned for).

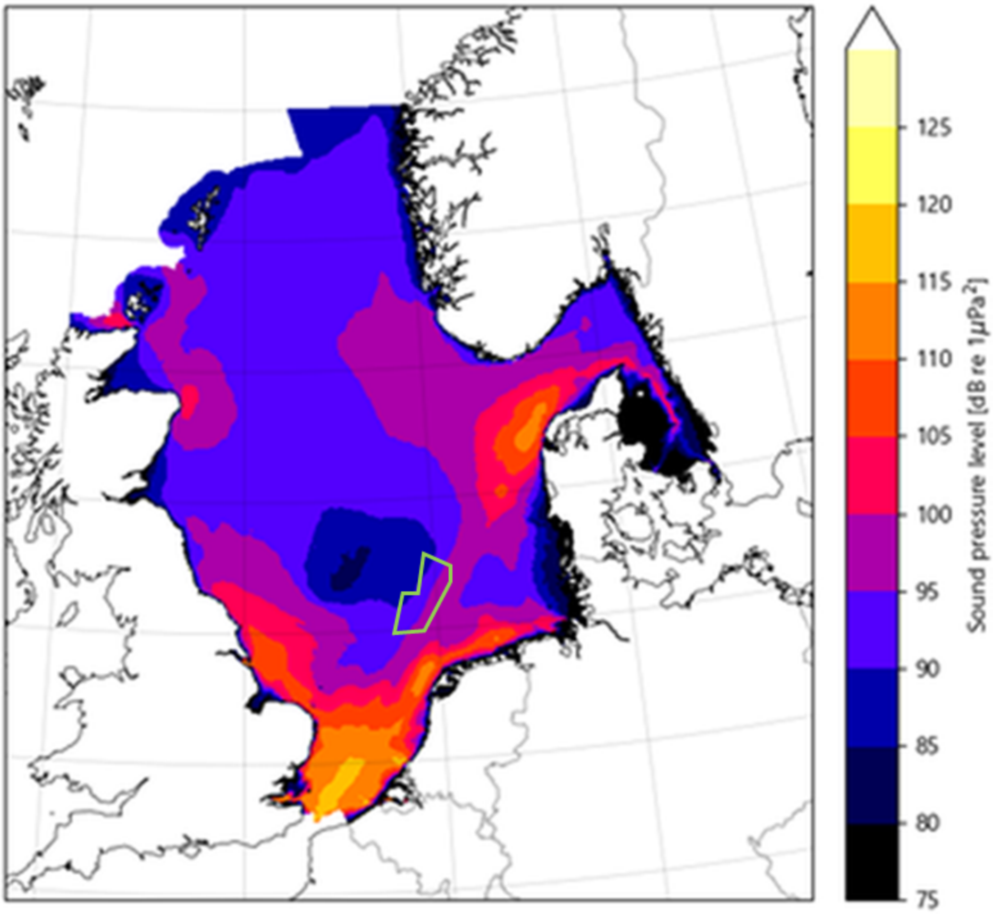

Figure 18. The overall median sound pressure level across 2019, from natural and anthropogenic sources combined. Figure from (OSPAR, 2023).

In the design of Hub North, impulse underwater noise will mainly occur during the construction phase. However, continuous noise will be present during the operational phase, too. Available measurements of underwater noise from different wind turbines during operation are reviewed to show that source levels are at least 10–20 dB lower than ship noise in the same frequency range. Cumulative noise levels could be elevated up to a few kilometers from a wind farm when the ambient noise levels are very low. In contrast, the noise is well below ambient levels unless it is very close to the individual turbines in locations with high ambient noise from shipping or high wind speeds (Tougaard et al., 2020). A wind farm is less detectable in intense ship traffic areas (Bergström et al., 2013), although tonal components can often be detected at tens of kilometers (Tougaard et al., 2020). Hydrogen production, and all activities related to it, can be a significant contributor to continuous sound production. The rotating equipment in pumps, compressors (to deliver hydrogen to shore), and electrolysers all produce a certain amount of continuous noise (pers. Comm. With the experts from work package 1). In addition to wind turbine and P2G-platform noises, vessels servicing the turbines and platforms/stations add frequent noise as well. Since wind farms typically require daily maintenance, this results in increased noise from vessels compared to before construction (Tougaard et al., 2020).

Nature-Inclusive Design
During the operational phase anthropogenic noise will be produced by different structures (e.g. wind turbines, P2G-platforms) and vessels as in the standard design. This will lead to noise disturbance in all of Hub North. However, in the NISD the placement of various assets allows for concentrating the effect to a smaller area. The main outcome of this placement is localizing the hydrogen production to the eastern side of the hub (*Figure 3*), to coincide with the sound production for the existing shipping lane and therefore decrease sound production in the remaining area of Hub North. Other spatial design choices are leaving part of hub North free from activities so that no structures are placed in the Northern part of the Hub as well as in the north-south corridor. These areas will also receive limited continuous sound produced by wind turbines. That way the sound impact on surrounding MPAs and ecologically particularly valuable parts of the Hub North area is reduced.

On asset level little mitigation options exist for operational noise (i.e., the vibrations from the turbine transmitted through the foundation out into the water). Current acoustic mitigation methods, such as bubble curtains for pile driving, are not appropriate given the long operational times and relatively low noise levels (Tougaard et al., 2020). Some noise from maintenance vessels may be reduced by making use of vessels, including staff, being stationed in the area for longer periods of time rather than sailing back and forth from the coast. Possibly, operating permits might also include specific demands regarding the use of particularly silent, hybrid vessel types.

Comparative conclusion
By placing the main contributors to continuous sound production in an already relative highly disturbed area (i.e. sound production by shipping lane) and thereby localizing, the impact of sound might be reduced by the NISD design. However, the cumulative contribution from the many turbines as well as P2G-platforms may be considerable and should be included in future research.

4.3.3.3 Electromagnetic fields

Current state
In the current North Sea electromagnetic fields coming from natural sources are low, with the earth magnetic field ranging between 25 and 70 µT (Nyqvist et al., 2020).

Standard design
With the addition of the developments in the area a significant increase in the number of electric cables is expected. These cables produce electromagnetic fields (EMFs) that extend towards the area around the cables, by producing a locally changed electric and magnetic environment.

Nature-Inclusive Design
Options for the Nature-Inclusive Design are to look further into eco-friendly routing and burial of cables. More on these options is highlighted in the paragraph on demersal fish, sharks and rays (4.5.3).

Comparative conclusion

There are no specific interventions in the NISD to mitigate the impacts of developments on electromagnetic fields within the Hub North area, compared to the standard design.

4.3.3.4 Light climate

Current state

Light attenuates with water depth, so light is mostly available in the upper water layers. Light attenuation increases with the concentrations of SPM in the water column and is usually lowest in winter (e.g. Capuzzo et al., 2015; Luo et al., 2022). In the North Sea, an increase in SPM concentrations has led to a decrease in water clarity during the last century (Capuzzo et al., 2015; Thewes et al., 2021). Secchi depth is currently below 5m on average for most of the southern North Sea (Capuzzo et al., 2015). In general, light availability is higher in the northern North Sea, compared to the southern North Sea (*Figure 19*).

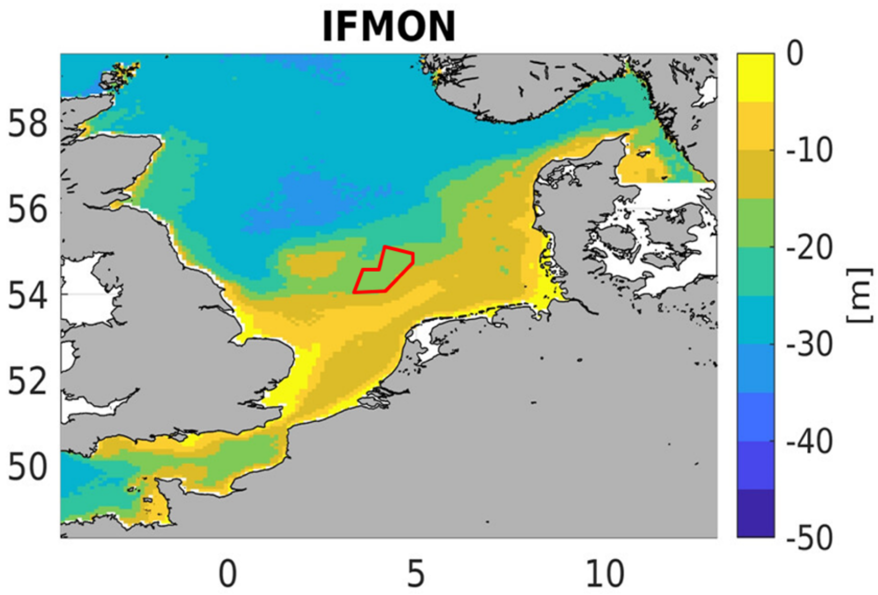

Figure 19. Modelled z10 (depth at which light intensity is 10% of surface intensity) in the North Sea increases northwards (from Thewes et al., 2021). Hub North location indicated with red outline.

Standard design

With the addition of the developments in Hub North the light availability is impacted both directly and indirectly. Indirect impacts are related to mixing, turbulence, sediment dynamics and stratification and are discussed in earlier paragraphs. However, direct impacts on light availability comes from the blocking of light by offshore floating photovoltaic (OFPV) and to a lesser extent by P2G-platforms and turbines.

Nature-Inclusive Design

Potential differences in light availability between the standard design and the NISD result from effects related to stratification and SPM mentioned in previous paragraphs. For the areas where turbines are absent in the NISD, the effects of the mixing-induced increase in SPM in the water column will be reduced. This may result in higher light availability in the northern part of the Hub, although the light availability is relatively high already in this area. Effective restoration of oysters can also decrease the SPM and potentially increase the light availability, although this effect is expected to be minimal. There are no differences between the location or the total area of OFPVs between the Nature-Inclusive design and the standard design.

Comparative conclusion

There are no specific interventions in the NISD to mitigate the impacts of developments on light availability within the Hub North area, compared to the standard design. Light availability is expected to increase slightly because of the decrease in mixing effects and the effects of oysters on SPM concentrations.

4.3.4 Comparative summary

The resulting effects from offshore activities on the abiotic environment are often interrelated and complex to estimate. Abiotic variables were divided in three categories: hydrodynamic conditions, sediment conditions and other abiotic conditions. Some abiotic variables are expected to show considerable differences between the standard design and the NISD. By refraining from development of wind energy in the northern part of the Hub North area in the NISD, the effects on stratification will be reduced within this seasonally stratified area. This mitigates the effects on temperature, salinity, nutrients, suspended/inorganic matter and light availability induced under the standard design. By placing P2G-platforms along the southern and eastern side of the Hub North area within the NISD, effects of cooling water and brine discharge on temperature and salinity in the Hub North area are reduced, as are the potential effects of the introduction of chemical substances. Some abiotic variables are expected to show only minor differences between the standard design and the NISD. This is the case for the decrease in wave height and the decrease in sound. For some abiotic variables no differences are expected, or differences are unclear, between the standard design and the NISD. This is the case for the residual current, morphodynamic changes and electromagnetic fields. Table 2 contains a comparative overview for the abiotic conditions, assuming a standard and nature-inclusive design generating 14GW of offshore energy.

Table 2. Comparative table for the abiotic conditions. The table describes 1) the abiotic conditions, 2) a brief description of the current state in the Hub North area, and main outcomes for each condition regarding the 3) expected resulting state of the standard design (comparative to the current state), 4) the NISD measures (see 3.4.1) that influence the abiotic condition, and 5) the resulting state of the NISD (comparative to the standard design). Outcomes and measures that are unknown, uncertain, or expected to be negligible are described in grey font.

Abiotic condition	Current state	Standard design (vs current state)	NISD Measures	NISD (vs standard design)
Waves and currents	High waves and wind Residual current towards the east	Decrease in wind speed and wave height by OWFs; Decrease in wave height by OFPV Decrease in residual current velocity; Difference in flow patterns by P2G intake and outfall	Active oyster restoration P2G platform strategic placement; Active oyster restoration	Decrease in potential difference in flow patterns by P2G effects translocated outside Hub area; Potential effect of active oyster restoration on current velocity
Temperature, salinity and nutrients	Influence of summer stratification in the North of the Hub	Mixing effects in naturally stratified areas by OWFs; Increase in temperature and salinity by P2G cooling water effluent and brine discharge; Decrease of temperature caused by OFPV	Avoid stratified and sensitive areas; P2G platform strategic placement	Decrease of mixing effects by avoiding areas with strongest stratification; Localize the effects of P2G platforms on temperature and salinity increase, thereby decreasing harmful effects throughout the Hub area
Suspended sediments	Relatively high turbidity	Increase of TIM in the largest part of the west and centre of Hub North; Decrease of TIM in the northeast	Avoid stratified and sensitive areas; Active oyster restoration	Smaller effect of decrease in TIM in the northeast; Opposing effects of OWFs and oyster restoration in the west of the hub
Morphodynamics	Muddy sand bottom, not very dynamic, low bed shear stress	Increase in bed shear stress	None	Unclear
Chemicals	Low concentrations of chemicals	Potential introduction of hazardous substances, mainly by P2G activities and OFPV	P2G platform strategic placement	Localize the effects of P2G platforms on chemical concentration increase, thereby decreasing harmful effects throughout the Hub area. and increasing negative impacts in local area due to higher local pressure
Ambient noise	Noise levels not very high	Increase in noise from OWFs and P2G in operation, increased shipping and (maintenance) vessel activities	P2G platform strategic placement	Localize (minor) part of the noise increase close to already noisy shipping lanes
Electro-magnetic fields	Weak	Increase by introduction of electricity cables	None	None
Light climate	Intermediate light availably (increasing northward)	Increased in light availability in west and centre of the Hub; Decrease in light availability in northeast	Avoid stratified and sensitive areas; Active oyster restoration	Smaller increase in light availability in the northeast; Opposing effects of OWFs and oyster restoration in the west of the hub

4.4 Available pelagic habitats

4.4.1 Current situation

Pelagic habitats are open-water environments occupied by phyto- and zooplankton, diving birds (see paragraph 4.6.4), fish and marine mammals, all of which occur within Hub North. Planktons occupy the lowest tiers of the food web and are the main source of marine production. Changes in plankton communities can directly or indirectly affect higher food web levels, such as fish and marine mammals. Plankton abundance, distribution and biomass fluctuate throughout the year and are mainly affected by nutrient-, light availability and stratification. Currently there are little to no activities which have large scale effects on the nutrient- light availability and stratification within Hub North.

According to OSPAR, Hub North is located within the pelagic shelf habitat, see *Figure 20*. The status for shelf habitats within the Greater North Sea is not good due to changes in phytoplankton and zooplankton communities, phytoplankton biomass and zooplankton abundance. In southern areas of the Greater North Sea, warming has led to nutrient limitation due to increased stratification, driving a decline in diatom abundance (Edwards et al., 2022). However, these changes are not specific for Hub North.

Small to mid-sized pelagic fish play a central role in marine ecosystems, channelling energy and nutrients between lower trophic levels like plankton and top predators (Frederiksen et al., 2006). Large pelagic fish such as large adult tuna, which have been re-observed in the Dutch North Sea since 2015, are top predators which feed on other smaller fish (Mariani et al., 2017).

There is not much specific information available about the distribution of pelagic fish within Hub North. According to the MONS-program common pelagic fish in the North Sea are herring, sprat, small sand eel, Raitt's sand eel, horse mackerel, mackerel, pilchard, greater sand eel, anchovy, sand smelt, sea bass, three spined stickleback and transparent goby. On the Dutch Continental Shelf around twelve of these species are common to very common. All these pelagic species can move rapidly through the area - the Northeast Atlantic area, the North Sea, and the European coasts. Spatial and temporal distribution of fish is for a large part determined by the presence of food and suitable habitats. A suitable habitat is a complex combination of biotic and abiotic factors, which differ per species and per life stage within species.

Like large pelagic fish, marine mammals (seals and harbour porpoise) are also top predators of the food web within the North Sea and they feed predominantly on fish. The harbour porpoise (*Phocoena phocoena*) is the smallest and by far most common cetacean species in the North Sea and is often used as an indicator species for marine mammals. Being described as a continental shelf species, it is distributed throughout the shallow North Sea, from coastal waters up to the Dogger Bank in the central North Sea, see *Figure 21*.

In the current situation fishery is allowed throughout the whole area of Hub North. The assumption is made that for both the standard design and NISD a no-fishing zone is implemented. This will have a positive impact on fish communities and marine mammals.

Reduced fishing leads to improvements in habitat quality due to an increase in prey biomass/abundance and a reduction in bycatch (Calderan & Leaper, 2019).

Below the impact of the standard- and NISD-design on the three groups (plankton, fish and marine mammals) are explained.

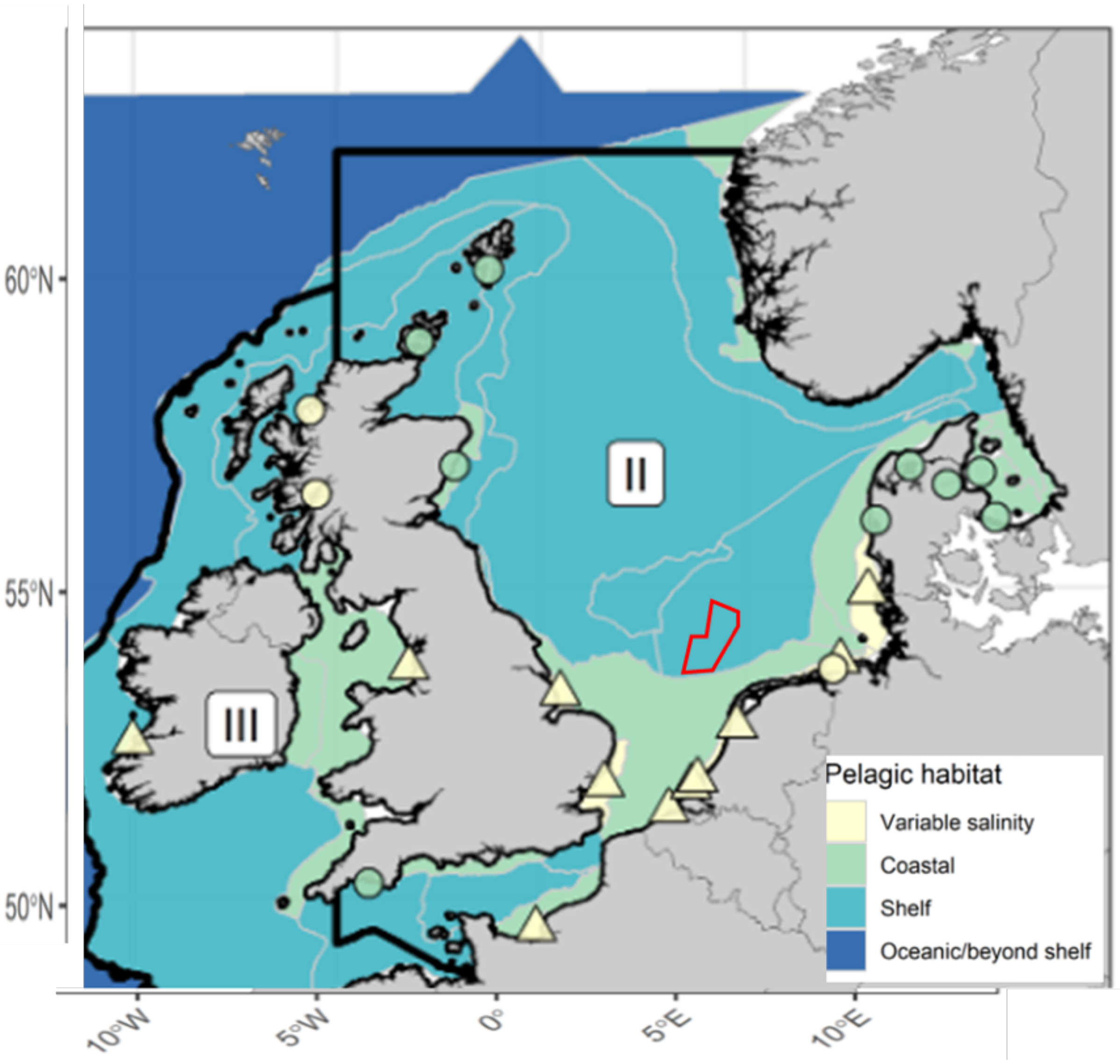

Figure 20. Pelagic habitats according to OSPAR.

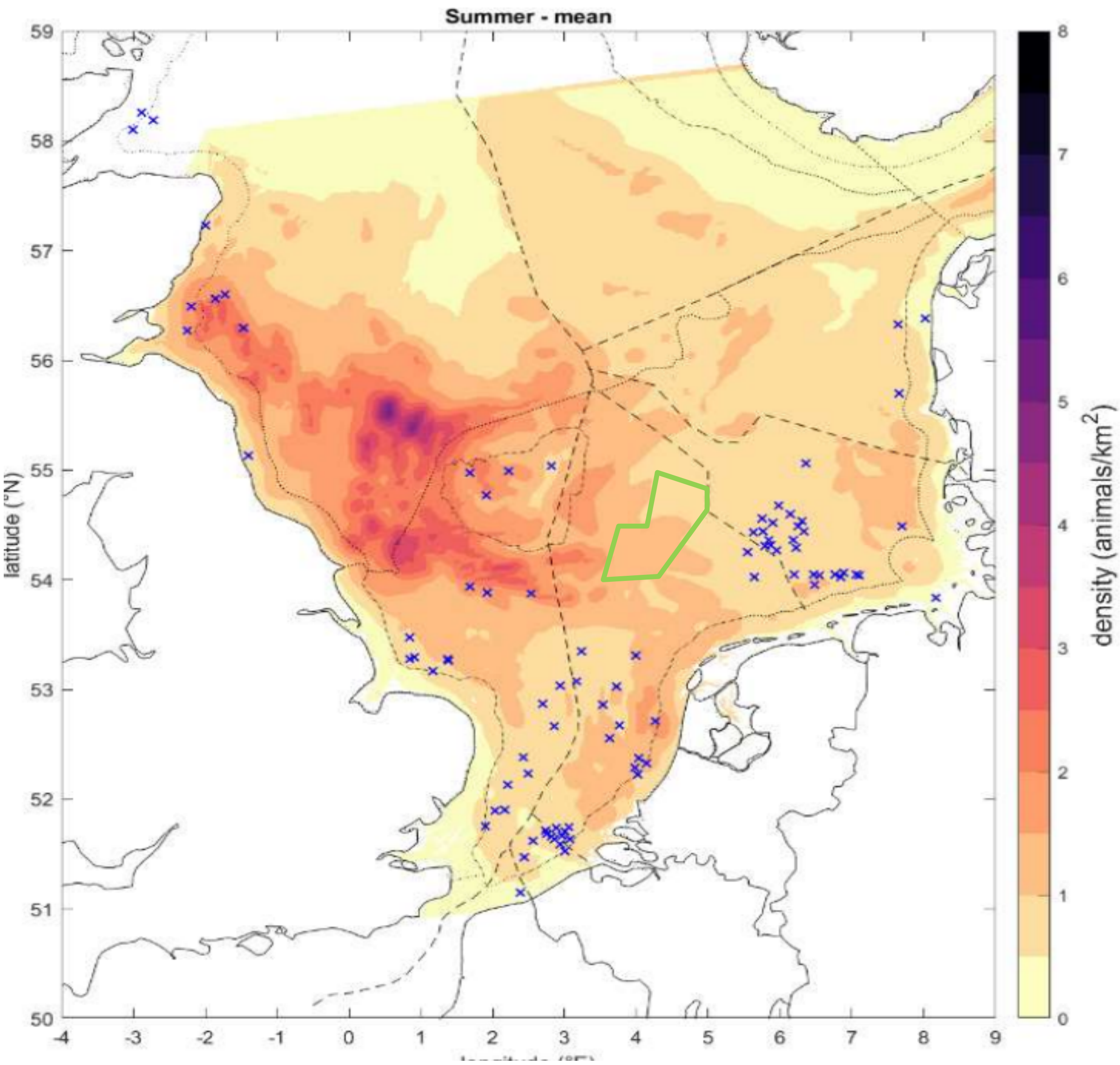

Figure 21. Modelled harbour porpoise mean summer densities in the North Sea during the period 2014-2019 (Heinis et al., 2022). Blue crosses show the selected sites in each wind farm/wind energy

area for which calculations were made.

4.4.2 Resulting state lower trophic levels

After installation of Hub North (Standard Design)
Installing many structures within Hub North changes the hydrodynamics and increases vertical mixing. Increased vertical mixing leads to an increase in nutrient availability at the surface and therefore to increased primary production, which can mean an increase in phytoplankton. At the same time, changes in sediment dynamics lead to an increase in pelagic inorganic matter concentrations, leading to a decrease in primary production due to the deterioration of the light climate. The combined effect of changes in hydrodynamics and sediment dynamics is highly variable between locations. In some OWFs a significant increase in primary production is found while in others a decrease is found. A change in vertical mixing can lead to a change in summer stratification, which can lead to a change in the

phytoplankton community (Edwards et al., 2022). According to Zijl et al., (2023) effects on primary production by OWFs within search area 6/7, in which Hub North is located, can be significant, with local increases relative to the scenario without OWFs of more than 40%. Concordantly with the clear increase in primary production in search area 6/7, near-surface chlorophyll-a concentrations also increase.

OFPV can have various impacts related to shading, impacts on hydrodynamics and water-atmosphere interchange, energy emissions, impacts on benthic communities, and impacts on mobile species. The interplay of the reduced irradiance, wind shielding and increased hydrodynamic drag due to OFPV systems might impact organisms reliant on photosynthesis and mixing, including phytoplankton (Benjamins et al., 2024). According to Karpouzoglou et al., (2020), OFPV-driven shading effects on marine phytoplankton communities were potentially important, at local scales, and widespread deployment could have significant effects, depending on the tidal and stratification regime at the location of installation.

Structures, such as wind turbines and platforms provide a habitat for species such as the blue mussel (*Mytilus edulis*). The increasing number of structures alters the functioning of the surrounding pelagic ecosystem by restructuring the biological communities at and around the submerged foundations and pile structures (Joschko et al., 2008; Krone et al., 2013). Filter feeders, such as the blue mussel, have been shown to significantly reduce the ambient concentration of phytoplankton and zooplankton (Dolmer, 2000; Maar et al., 2007). By changing phytoplankton biomass, epifaunal filtration can be expected to affect primary productivity and thus the very basis of the marine food web and biogeochemical cycling locally above mussel beds and around offshore wind turbines (Slavik et al., 2019). However, according to recent findings effects of mussel growth on pillars within OWFs on yearly average primary production and chlorophyll-a concentrations could be at least one order of magnitude smaller than the effects resulting from changes in hydrodynamics (e.g. residual currents, vertical mixing) and sediment dynamics (Zijl et al., 2023).
According to Slavik et al., (2019) the impact of OWFs on annual primary productivity is predominately local. However, at short timescales there is a larger regional effect on biomass and productivity, which can extend up to several 100s of km beyond the bounds of the OWF area or Hub North.

Zooplankton often forage on phytoplankton and are therefore directly impacted by changes in the phytoplankton community. Potential changes in the phytoplankton community due to the presence of structures will therefore also impact the zooplankton community.

NISD

Options for the NISD are a 40 km wide connectivity corridor from the Dogger Bank MPA to the Frisian Front MPA and avoiding areas with strongest summer stratification (northern part). In the NISD, similar effects occur as described under the standard design. The placement of structures leads to changes in hydrodynamics and vertical mixing. However, there are several measures in the NISD which may reduce the changes in hydrodynamics and leave portions of the hub area undisturbed. By implementing these measures, the effects on hydrodynamics and the impact on stratification are reduced. The north-south corridor weakens the cumulative wake effect of the structures in the Western part of the hub, compared to the standard design, because no structures are placed within a corridor of 40 km wide. By not constructing any structures in the Northern part of the hub the most vulnerable area with regard to stratification might be excluded from impacts. Implementing these measures can thus reduce the potential impacts on phytoplankton and zooplankton communities.

Impacts caused by OFPV are similar to the standard design because the NISD isn't different from the standard design. Similar to the standard design, the structures (e.g. wind turbines and platforms) in the NISD provide habitat for benthic species such as blue mussels. If oyster reef restoration succeeds in the NISD there might be competition between oysters and other species such as blue mussels. However, this does not diminish the positive impact of the NISD. The impact described under the standard design is similar for the NISD.

Comparative conclusion
Similar effects occur in the NISD and the standard design. However, the NISD leaves portions of the hub undisturbed, reducing the effect on hydrodynamics and the impact on stratification. By reducing the impacts, the potential change in phytoplankton and zooplankton communities will be smaller. In both designs filter feedings organisms are present. In the NISD active oyster reef restoration occurs and no active oyster restoration occurs in the standard design. This difference in oyster restoration has likely no effect on the filter feeding capacity, as other filter feeding organisms, such as blue mussels will fulfill the role of filter feeder in the standard design. There is no difference on the filter feeder effect on plankton and OFPV-effect between the standard design and NISD.

4.4.3 Resulting state pelagic fish

After installation of Hub North (Standard Design)
Placing structures within an offshore environment has both positive and negative impacts on pelagic fish communities. OWFs and platforms seem to be targeted by certain fish for food and/or refuge and profit from the ecological changes that take place following their installations. Atlantic horse mackerel (*Trachurus trachurus*), Atlantic cod (*Gadus morhua*) and pouting (*Trisopterus luscus*) predate on the local epifauna community as revealed from diet studies and combined diet–stable isotope studies (Degraer et al., 2020; Mavraki et al., 2021; Reubens et al., 2013, 2014; Van Berkel et al., 2020). Other species such as the Atlantic mackerel (*Scomber scombrus*) use offshore structures for shelter.

However, according to Espinosa et al., (2014) highly migratory fish such as tuna (*Thunnus spp*.) may be disturbed by the operational sounds of OWFs and platforms. Continuous sound can have an impact on fish and marine mammals as it may interfere with key life functions of fish and marine mammals (e.g., foraging, mating, nursing, resting, migrating) by impairing hearing sensitivity, masking acoustic signals, eliciting behavioural responses, or causing physiological stress (Popper & Hawkins, 2019). In areas with low natural ambient noise and low levels of ship traffic the noise produced by new energy developments is possibly large enough to raise concern for negative effects on species of fish, however, especially large-scale cumulative effects are still largely unknown.

Placing structures in Hub North will have food-web effects. For example, changes in zooplankton abundance and community, caused by changes in phytoplankton, see paragraph

4.4.2, can have an impact on planktivorous fish species, such as clupeids (Floeter et al., 2017). Species that forage on fish such as birds and mammals can in-turn be affected by changes in fish communities.

Studies noted an increase in the encounter rate of large predatory fish along the edges of similar large floating structures (floating piers), but a decline in overall fish abundance and diversity in more deeply shaded areas beneath the piers (Benjamins et al., 2024). These observations suggest that areas of deep shade beneath large floating or standing structures may be suboptimal habitat for many fish species. It is questionable if deeply shaded areas underneath OFPV will occur as they often assemble individual modules, with light gaps in between. For fish, the presence of shade caused by OFPV's and platforms can even be desirable, as it could make them more difficult to spot compared with adjacent sunlit parts of the water column or from above. However, exact effects of shading caused by OFPV or other platforms on fish communities remains a knowledge gap and requires further research.

NISD

Options for the NISD are the creation of a 40 km wide connectivity corridor from the Dogger Bank MPA to the Frisian Front MPA, avoiding areas of high ecological value, the creation of passive restoration zones and suitable P2G--platform placement (alongside shipping lanes). No structures are placed in MPAs, corridor and passive restoration zones, leading to a decrease of ambient sound within these areas increasing the surface of unaffected areas, both during construction and operation. However, continuous sound from ships or wind turbines or P2G-platforms can travel for multiple kilometres. So, it is likely that the ambient sound levels are still increased within the aforementioned areas, but this increase will be less than in the standard design. Furthermore, ambient sound levels throughout Hub North can be reduced by concentrating the P2G-platforms near the shipping lane which will allow for reduced noise in the rest of Hub North. Overall, the decrease in habitat quality due to added ambient sound will be smaller in the NISD than in the standard design.

Impacts caused by OFPV are similar to the standard design because the NISD isn't different from the standard design.

Comparative conclusion

Similar effects occur in the NISD and the standard design. However, the NISD leaves portions of the hub undisturbed and reduces the impact of increased ambient noise. By reducing the impacts, the quality of the pelagic habits for fish will decrease less compared to the standard design. There is no difference in the OFPV-effect between the standard design and NISD.

4.4.4 Resulting state marine mammals

After installation of Hub North (Standard Design)

The creation of Hub North will have negative impacts on marine mammals. Post installation the amount of disturbance in the area will be larger than before due to human impacts such as the presence of electromagnetic fields and anthropogenic noise. Research by Teilmann et al., (2002) shows that porpoises still swim through areas where wind farms have been built and where power cables are located. This shows that there is no complete barrier effect due to electromagnetic fields.

In areas with low ambient noise levels OWF-related noise reaches several kilometers far. In contrast, in areas with high ambient noise the noise is well below ambient levels unless it is very close to the individual turbines. The chance that a seal or porpoise will suffer hearing damage is negligible given the levels that occur in practice. After construction of OWF and platforms harbour porpoise return to the area. (Todd et al., 2023) found that within five months, porpoise detections per day had returned to pre-platform levels.
However, within Hub North the number of wind turbines and P2G-platforms is large. It is unknown what the cumulative impact of Hub North will be on marine mammals. The cumulative contribution from the many turbines may be considerable (Tougaard et al., 2020). Available measurements of underwater noise from different wind turbines during operation showed that source levels are at least 10–20 dB lower than ship noise in the same frequency range. Furthermore, it's known that habituation to sound occurs within marine mammals (Tougaard, 2021). In the standard design a reduction of habitat quality occurs due to the presence of added OWF-related noise.

NISD
Options for the Nature-Inclusive Design are the creation of a 40 km wide connectivity corridor from the Dogger Bank MPA to the Frisian Front MPA, avoiding areas of high ecological value, the creation of passive restoration zones and suitable P2G-platform placement (alongside shipping lanes). No structures are placed in the corridor and passive restoration zones, leading to a decrease of ambient sound within these areas increasing the surface of unaffected areas, both during construction and operation. However, continuous sound from ships or wind turbines or P2G-platforms can travel for multiple kilometres. So, it is likely that the ambient sound levels are still increased within the aforementioned areas. However, this increase will be less than in the standard design. Furthermore, ambient sound levels throughout Hub North can be reduced by concentrating the P2G-platforms near the shipping lane, which will allow for less noise in the rest of Hub North. Overall, the decrease in habitat quality due to added ambient sound will be smaller in the NISD than in the standard design.

Comparative conclusion
Similar effects occur in the NISD and the standard design. However, the NISD leaves portions of the hub undisturbed and reduces the impact of an increase in ambient noise. By reducing the impacts, the quality of the pelagic habits for marine mammals will decrease less compared to the standard design.

4.5 Available benthic habitats

4.5.1 Current situation

The area around Hub North is part of what used to be the Central Oyster Grounds, which contained extensive flat oyster reefs until these were destroyed by excessive (oyster) fishing in the beginning of the 19th century. Despite the name, Oysters are no longer the predominant species in the area, in fact almost no sessile epifauna is found in the area. The area is dominated by biogenic structures formed by burrowing organisms (such as mud shrimp; *Upogebia* sp.). The area is relatively undisturbed by human impact pressures such as fisheries and relatively high densities of vulnerable species are found in the area, including the ocean quahog (*Arctica islandica*). One of the other reasons why the area is suitable for the ocean quahog is the high sedimentation level (Herman & Witbaard, 2023).This species only starts reproducing between the age of 6 to 13 years, making the population very vulnerable to disturbances (de Bruyne et al., 2013). Other benthic species found in the area are green sea urchins (*Psammechinus miliaris*), sea potatoes (*Echinocardium*), lesser cylinder anemones (*Cerianthus lloydii*), starfish (*Astropecten irregularis*) and Norwegian Lobster (*Nephrops norvegicus*) (Witbaard et al., 2013). The exact locations and densities of various benthic species in the area are unknown.

In 2021, Van Der Reijden et al. published a study that divided geographical locations of the North Sea seafloor based on the benthic characteristics of the entire North Sea, *Figure 22*. Based on these geographical areas, the most common species in the benthic zone are:

- Epifauna (organisms living on the seafloor)
    - EF-10. *Corbula gibba* (Bv)/common basket-shell; *Turritella communis* (Ga)/common tower shell; *Amphiura chiajei* (Op)/brittle star; *Echinocardium cordatum* (Ech)/sea potato; *Flustra foliacea* (Br)/bryozoa
    - EF-11. *Ophiura albida* (Op)/ serpent's table brittle star; *Ophiura ophiura* (Op)/ serpent star; *Alcyonidium diaphanum* (Br)/ sea-chervil (*bryozoa*); *Flustra foliacea* (Br)/*bryozoa*; *Euspira nitida* (Ga)/common necklace shell
    - EF-12. *Ophiura albida* (Op)/ serpent's table brittle star; *Flustra foliacea* (Br)/ bryozoa; *Alcyonium digitatum* (An)/ dead man's fingers (*cnidarian*); *Psammechinus miliaris* (Ech)/green sea urchin; *Ophiura ophiura* (Op)/serpent star
- Endobenthos (organisms living IN the seafloor)
    - EB-5. *Bathyporeia elegans* (Cr)/amphipod; *Amphiura filiformis* (Op)/brittle star; *Myriochele* (Pc)/ polychaete worm; *Bathyporeia tenuipes* (Cr)/amphipod; *Magelona* (Op)/annelid worm
    - EB-7. *Kurtiella bidentata* (Bv)/ bivalve mollusc; *Amphiura filiformis* (Op)/brittle star; *Scalibregma inflatum* (Pc)/T headed worm; *Ophiura* (Op)/ brittle star; *Eudorellopsis deformis* (Cr)/ hooded shrimp
    - EB-10. *Amphiura filiformis* (Op)/brittle star; *Diastylis lucifera* (Cr)/ crustacean; *Myriochele* (Pc)/ polychaete worm; *Lumbrineris latreilli* (Pc)/annelid; *Chaetopterus* (Pc)/parchment worm
- Demersal fish
    - DF-2. Limanda limanda/ Dab; Pleuronectes platessa/ Plaice; Hippoglossoides platessoides/ Long rough dab; Buglossidium luteum/ Solenette; Arnoglossus laterna/ Mediterranean scaldfish

○

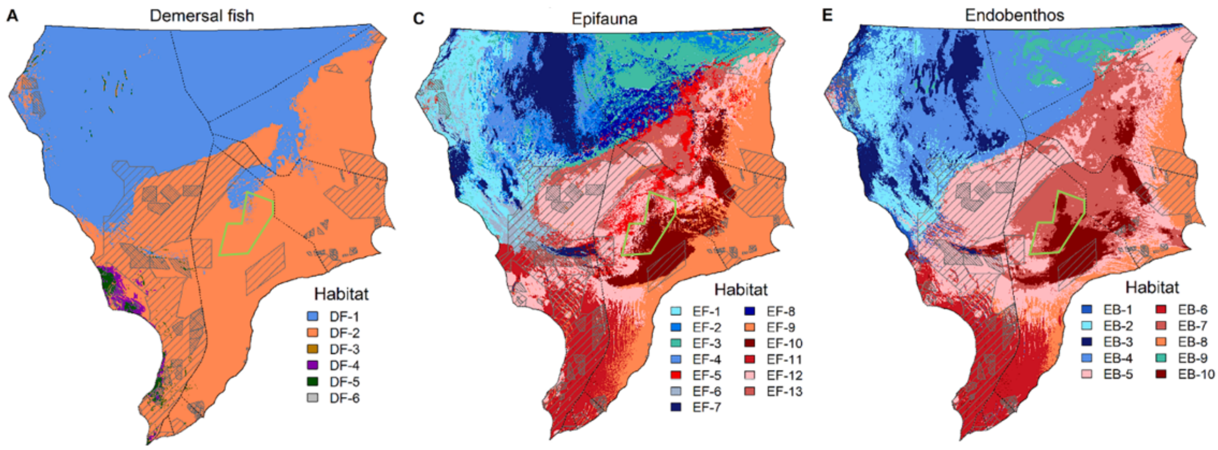

Figure 22. Benthic maps derived from Van Der Reijden et al., 2021. In Appendix C of this paper a description of the habitat codes and species description per habitat code is provided, relevant species per habitats for this report are listed in the text above. The green outline indicates the position of hub North.

4.5.2 Resulting state Benthos

After installation of Hub North
Post installation, the amount of general disturbance in the area will be larger than before for benthic organisms. Introduction of infrastructure and green hydrogen production will result in changes in currents, salinity and near-bed TIM. The latter is expected to increase by 20% in the western part of the Hub, and decrease by several percent in the north (see 4.3.2) based on model results. Around the turbines the amount of organic matter will increase due to the presence of artificial reefs (Degraer et al., 2020). This includes organisms attached to the infrastructure higher up in the water column and their waste products (debris, faeces, detrital matter). This area will change from almost exclusively muddy and sandy to a mix of mud sand and patches of hard substrate. This could lead to a decline of habitat for currently present species that are typical for soft-bottom environments such as polychaete worms (e.g. mud worms) and the ocean quahog, although these soft-bottom habitats will still constitute the majority of habitats in the Hub North area.

With the introduction of hard substrate patches, a new type of habitat will be introduced to the area, see also pelagic habitats. This offers opportunities for hard substate species such as anemones, barnacles and mollusks (including mussels and oysters) to grow on the turbine and scour protection (see for instance: Bouma & Lengkeek, 2013). Also, OFPV may function as catalysator for the formation of natural reefs on the seabed, due to mussels settling underneath the panels and falling down in mounds on the seabed underneath. This would increase the amount of sessile epifauna in the Hub North area. Some of these species are known to benefit biodiversity as they are endemic and provide food to other ecosystem levels. Furthermore, the hard substrate can be used as a basis for settlement and recruitment of reef building species (e.g. mussels and oysters), after which these reefs can grow towards more sandy parts. This in turn, provides for more dispersal for other species towards these parts. In this process, there is a risk of creating settling opportunities for invasive species that compete with species that are part of the current balance. Based on current research, this is thought to occur less often than theorized (Degraer et al., 2020).

In the areas between the hard substrate patches the species currently present, such as mud worms and ocean quahog, could still thrive, but their development might be limited by factors such as a local increase in salinity and temperature from the P2G-platforms (brine and cooling water discharge) or the increased amount of suspended inorganic matter. Thermal stress from a 5 GW electrolyser operating at full capacity could significantly impact marine organisms near the discharge point, stressing or harming species not adapted to rapid temperature changes (van der Hagen, 2024). Also these species will remain sensitive to human disturbances such as cable maintenance and anchoring. As the hub, including wind farms, covers a large area and the impacts are distributed across the whole hub, all habitats are near an impacted zone. A question that comes to mind is if this could lead to a shift in the ecosystem. This could provide opportunities for new or other native species to develop in the area; it is for instance known as a high potential area (to the north) for the development of sand mason worms (*Lanice conchilega*) and deemed suitable for flat oysters. However, the time over which such a shift takes place is uncertain. When the change occurs gradually species have time to adapt to changes. If the change does not happen gradually species, such as the sensitive long living ocean quahog, could lose their habitat entirely. This would have significant effects on their dispersal throughout the North Sea. Most likely this negative outcome can be avoided by careful (micro)spatial planning and an improved understanding/modeling of the Hub North Area.

NISD

The NISD leaves portions of the hub undisturbed, increasing the survival chances for the populations of species currently living in those parts of the area. Through dispersal from the unaffected areas, areas affected by habitat loss could then recover faster. However, the overall improvement in recovery time will probably be limited considering the scale of operation and the fact that most areas affected by habitat loss will be a different habitat than before, even after ‘recovery’.

Active oyster restoration is proposed in the Western part of the hub, to allow oysters to actively disperse downstream from there. This is also the part of the hub where an increase in SPM is expected. A functional oyster reef could counter this and help filter the water. To gain a functional oyster reef the NISD proposes installing oysters early or attaching oyster spat directly to structures, perhaps even pre-construction. A downside to this might be that already adapted oysters will need to deal with (heavily) increased SPM during the construction phase and will need to adapt to the permanent increase later. The upside is that in general functional, stable reefs are more resistant to stressors. It takes between 10-15 years for a stable functional oyster reef to develop. The sooner active oyster restoration happens the better the outcome of this measure will be. If this measure is implemented too late (< 10 years before construction) it is unlikely that a functional stable oyster reef will develop. Also, further investigation is needed to include the productivity and seasonal stratification partners of the area into the oyster suitability analyses.

Active oyster restoration can contribute to getting a desired stepping stone effect and kickstarting biodiversity development compared to the original design. The same goes for all enhancement measures taken on asset level such as providing reef blocks and optimizing scour protection.

Offshore solar installations inherently provide functional seafloor protection.. As observed by Mevraki et al., (2023), offshore solar platforms host a mussel community attached beneath the floaters. Shell drop-off from mussels attached on renewable energy devices could create secondary habitat on the seafloor and attracts multiple epifauna species (Krone et al., 2013). However, first sedimentary observations underneath OFPVs did not reveal an organic matter enrichment (Vlaswinkel et al., 2023), but possibly this could happen after longer periods of time, underneath larger farms, or at other, less dynamic locations and eventually lead to creation of mussel beds. This potential creation of such mussel beds could increase benthic heterogeneity and, therefore, local biodiversity on the seafloor. Additionally, the mussel beds could become settlement places where even oyster larvae (dispersing from the western zone) can attach and grow, forming a natural oyster bed. It is however not certain whether this will be the case.

Finally, concentrating the P2G-platforms near the shipping lane will allow for less noise and brine disturbance in the rest of Hub North. This could increase the chances for sessile species such as the ocean quahog to thrive in the sandy habitat between the turbines.

Comparative conclusion
The hub area would shift from a relatively undisturbed area with sandy or muddy biogenic structures, to a more disturbed (for a time) area with a larger coverage of hard substrate. However, the NISD leaves space for vulnerable species to remain undisturbed while also giving room for new biodiversity impulses.

4.5.3 Resulting state Demersal fish, sharks and rays

After installation of Hub North
Post installation, the amount of general disturbance in the area will be larger than before. Introduction of infrastructure and green hydrogen production will result in changes in currents, salinity and near-bed TIM. The latter is expected to increase by 20% in the western part of the Hub, and decrease by several percent in the north (see 4.3.2) based on model results. Around the turbines the amount of organic matter will increase due to the presence of artificial reefs (Degraer et al., 2020). This includes organisms attached to the infrastructure higher up in the water column and their waste products (debris, faeces, detrital matter). This area will change from almost exclusively muddy and sandy to a mix of mud sand and patches of hard substrate.

As shown in paragraph 4.5.1 multiple demersal fish reside within the area. The loss of sandy substrate might result in a loss in habitat for some demersal fish but also result in an increase of rocky habitat for demersal fish. However, there is a lot of uncertainty of the effect of wind turbines on demersal fish. Some demersal fish, such as plaice have been known to benefit from wind turbines (Buyse, 2023). The extra sedimentation will most likely not affect the survivability of the fish. Flatfish, specifically, are generally very tolerant of high concentrations of suspended sediment. Studies of plaice with suspended sediment concentrations of 3 g l^{-1} showed no effect after a 14-day exposure (Moore, 1991; Van Berkel et al., 2020).

The disturbances due to noise of demersal fish are uncertain, but mostly have no effect on population dynamics. A study done by Stenberg et al., 2015, showed that there were no significant changes in the abundance or distribution patterns of pelagic and demersal fish in acoustic surveys done during wind farm construction, neither between a control site and the wind farm site nor inside the impact area between foundations. However, there was already a significant temporal variation and patchiness in the distribution patterns of fish densities and biomass, and individual responses were not included in that data. Noise due to the usage of the wind farm might still influence individuals.

Electromagnetic fields due to the electric cabling within the park and connecting to the coast might influence some of the flatfish. Halibut (*Hippoglossus hippoglossus*) was shown to have a stunted growth and development after exposure to high electromagnetic fields(Woodruff et al., 2012). Even though halibut is not a common species in the area, it shares a lot of traits with dab and plaice, which can be found in the Hub area.

The sharks and rays (elasmobranchs) in the North Sea might, similarly to the other demersal fish species, lose some habitat. Especially rays can use sandy substrates to hide and bury themselves. Concomitantly, oviparous elasmobranchs need specific substrates to attach their eggs to, for which the new hard substrates from the wind farm might be used (Carrier et al., 2004).

Elasmobranchs generally use a variety of senses, such as smell, sound and electroreceptors, to sense prey and do not need to hunt by sight. An increase in SPM is therefore not a problem for the foraging strategies of elasmobranchs (Kalmijn, 1971). The effects of an increase in ambient sound are a largely unknown factor for bottom-dwelling elasmobranchs, as little research has been done. However, with the current knowledge, it is known that benthic species of elasmobranchs have a smaller hearing range than those that dwell in pelagic habitats, indicating that pelagic sharks and rays might use sound more to hunt or navigate (Mickle & Higgs, 2022).

Elasmobranch species can be sensitive to both electric and magnetic or electromagnetic fields (EMFs) (Anderson et al., 2017; Keller et al., 2021; Meyer et al., 2004) since they rely on their ability to detect electromagnetic signals for various behaviours such as orientation, navigation (Newton & Kajiura, 2020), avoiding predation (Kempster et al., 2013) and finding both their conspecifics/mates and prey buried beneath the substrate (Collin et al., 2015; Kajiura & Holland, 2002; Kempster et al., 2013; Sisneros & Tricas, 2002). The proposed behavioural impacts can be organized into three types: 1) disruptions in embryonic development, 2) behavioural changes of local-dwelling animals and 3) influences on migratory patterns. The potential consequences associated with each behavioural category are illustrated in *Figure 23* (Hermans et al., 2024). Especially the first type of impact could prove problematic, as elasmobranchs might attach their eggs to the wind farm pylons (being hard substrate) which would result in larger exposure to EMFs, which might impact the embryogenesis.

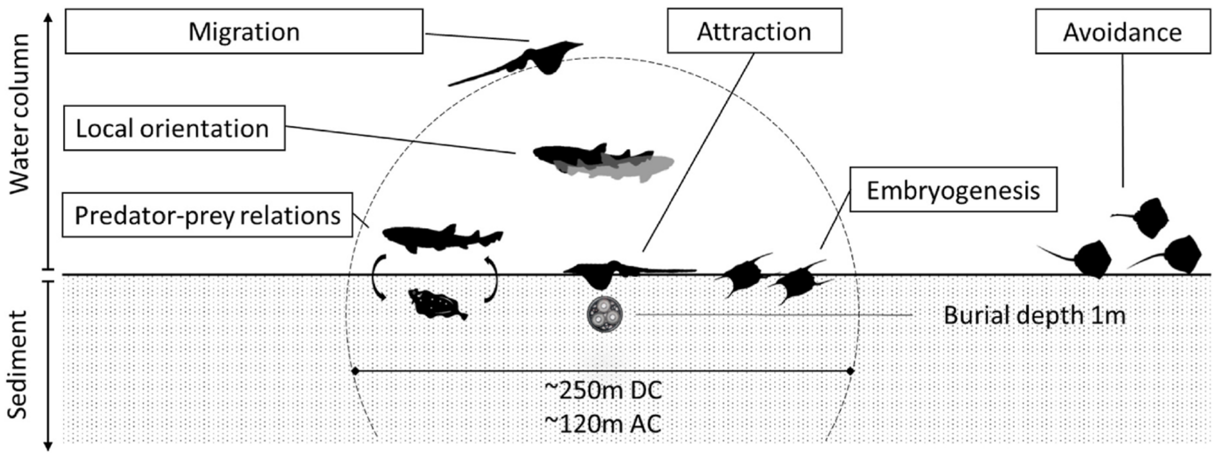

Figure 23. Schematic overview of possible elasmobranch responses exposed to modelled magnetic fields (Figure from Hermans et al., (2024)). Potential impact range based on a perception level of 0.005 µT, modelled levels for the OWF export cable Ijmuiden-Ver (2 GW direct current subsea power cable) and Borssele (700 MW alternating current subsea power cable) transporting maximum amount of power is indicated by dotted line. AC = Alternating Current; DC = Direct Current.

NISD

The NISD leaves portions of the hub largely undisturbed by energy-related activities and the entire hub area undisturbed by fishing. As both demersal fish and elasmobranchs benefit from undisturbed sandy areas, the NISD could benefit these fish species. Additionally, through the dispersal from the unaffected areas, demersal fish species affected by habitat loss could recover faster. Moreover, the addition of hard structures in the form of fish hotels or other substrates away from cabling and the monopiles could provide a place for oviparous elasmobranchs to attach their eggs, without influence of the electromagnetic fields in the area. In general, for EMF, eco-friendly routing should be considered, avoiding certain areas with large and diverse number of species of the highly sensitive elasmobranchs and demersal flatfish. The map overview from Hermans et al., (2024) demonstrates higher diversity of elasmobranchs species in certain parts of the Hub (*Figure 24*). Avoiding these areas as much as possible with cable routing and potentially investigating deeper burial of cables, as well as marking areas as specific biodiversity hotspots, to reduce the EMF transmitted to the aquatic environment and to reduce the effects of cable biting or uprooting of the cables, is recommended.

Both elasmobranchs and other demersal fish face heavy pressures from fisheries both directly and indirectly due to bycatch and habitat degradation. Especially viviparous (but potentially also oviparous) elasmobranchs are sensitive to bycatch, as even if they survive when released, their fecundity might be lowered due to survival techniques where they abort any potential offspring (Wheeler et al., 2020). The addition of passive restoration areas in the NISD could provide a safe haven for these groups. The addition of fish hotels or other structures could also provide a nursery function for benthic fish, shark and skate fry.

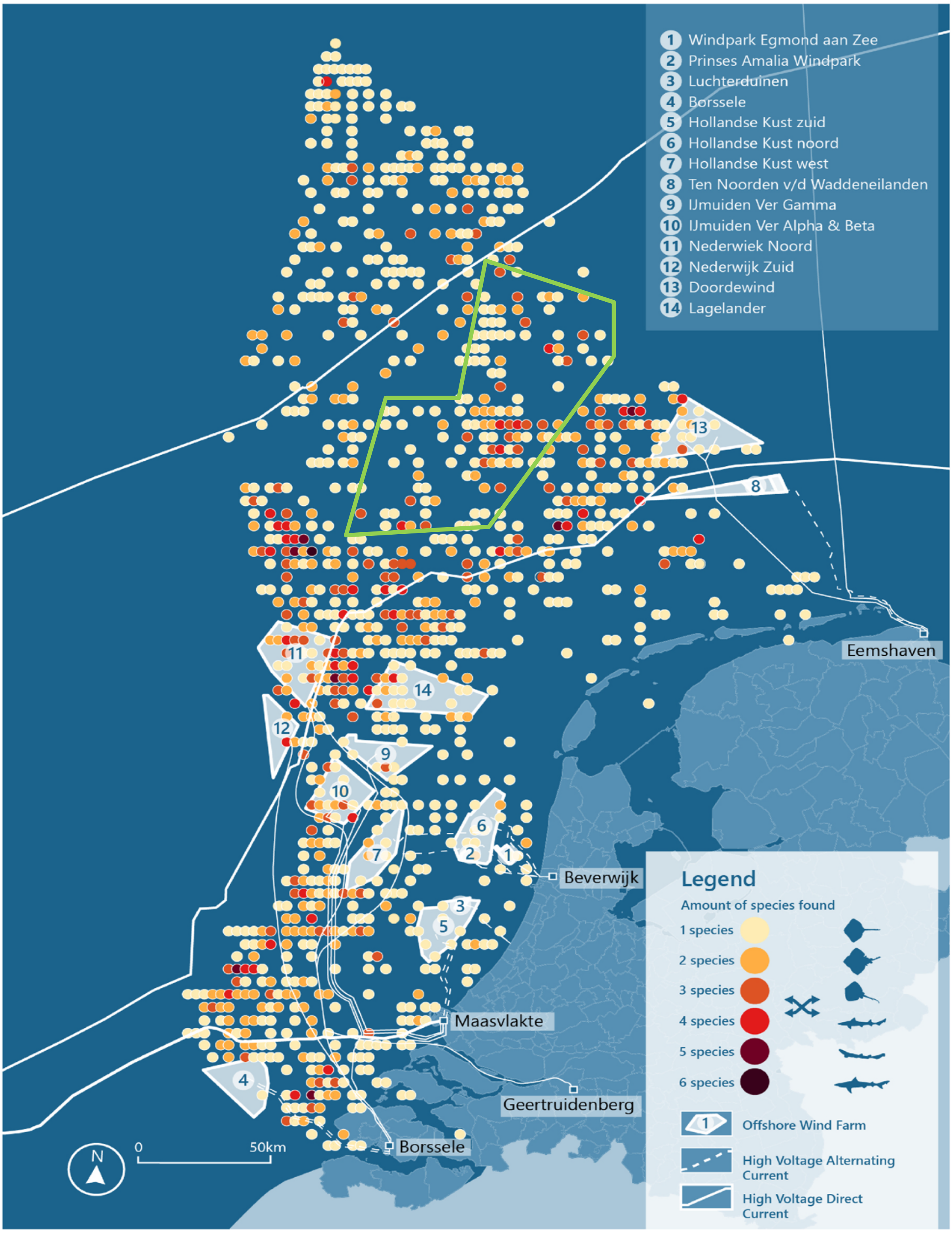

Figure 24. Overview from Hermans et al., (2024) of offshore wind farm export cables and interconnect cables built and planned until 2030 on the Dutch Continental Shelf in relation to the catch data of elasmobranch species. Solid lines indicate direct current cables, dashed lines indicate alternating current cables, data obtained from Informatiehuis Marien Open data viewer. Species richness indicates number of elasmobranch species caught based on Frisbe (1980–2019) and DATRAS (ICES) fisheries database. Figure shows overlap between cable routes and habitat use of Elasmobranchs. Green contour represents the area of Hub North.

Comparative conclusion
Energy developments in Hub North will increase stressors on the habitat of demersal fish and elasmobranchs, mainly through habitat degradation and the addition of EMF. In the NISD, the electric cables will be rerouted to reduce the effects of EMF on benthic species, and the addition of a passive restoration zone will provide the demersal fish with less disturbed habitat.

4.6 Bird and bat habitats

Wind farms and other energy infrastructure placed in the North Sea have various effects on birds and bats. For birds, the energy infrastructure forms barriers in their migration routes (paragraph 4.6.1), occupies foraging areas (paragraph 4.6.2), creates collision risk (paragraph 4.6.3) and has indirect effects (paragraph 4.6.4) (effect of wind farm on pelagic life impacts birds as well). Impacts on birds are divided into migratory – and local seabirds. These impacts are described in the four sections of this paragraph, respectively.

We currently lack sufficient knowledge on bat migration patterns to accurately assess the potential impact of Hub North on bat populations. The limited observations of bats in the area do not provide enough data to draw conclusions about effects on any specific population.

4.6.1 Barrier to movement

Local seabirds
Hub north is situated between areas of ecological importance such as the Dogger Bank, the Frisian front and the central oyster grounds (A, C and G in *Figure 25*). These areas are considered ecologically important as they are crucial feeding grounds for a variety of “local” bird species. Primarily guillemots, razorbills, puffins, fulmars, kittiwakes, gannets and greater black backed gulls can be found here (Bemmelen et al., 2023, 2024; Fijn et al., 2022; van Bemmelen et al., 2024).

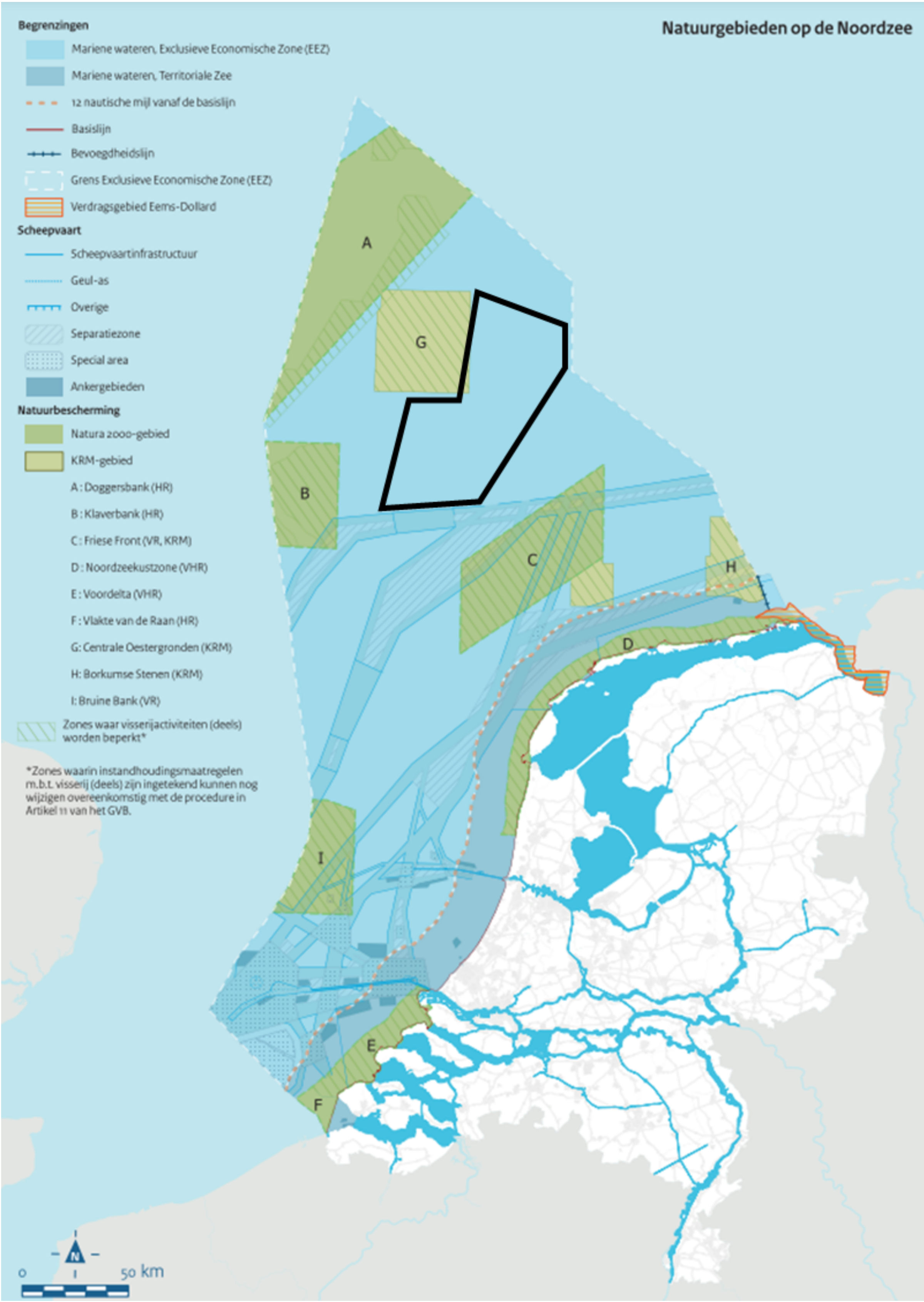

Figure 25. Areas of ecological importance in the Dutch part of the North Sea. The dark outline indicates the area in which hub north is situated (Noordzeeloket, z.d.).

Migratory birds
On a larger scale, several migratory bird species, like swans, geese, waders and some songbirds, can be prone to a barrier effect by OWFs. Although the routes are roughly the same, factors like weather, habitat, barriers, and food availability can influence the flight paths (La Sorte & Fink, 2016). Scientific literature identified the North Sea as a migration route. *Figure 26* shows the migratory route of a Bar-tailed godwit. However, due to the factors described above, the specific route can vary from year to year (Bradaric et al., 2020). It is therefore hard to pinpoint which exactly species migrate through the area of Hub North.

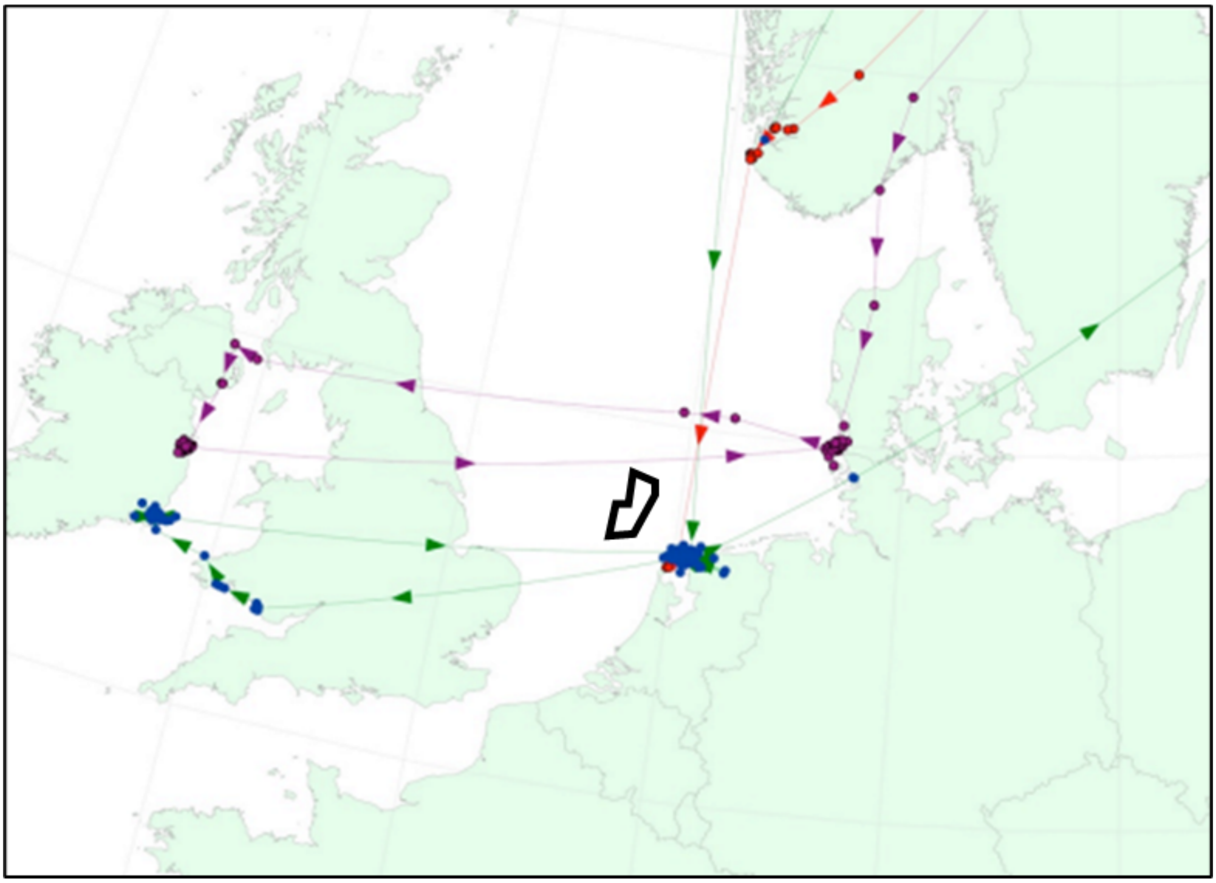

Figure 26. Migratory movements of Bar-tailed Godwits tagged in Norway. Shows an indication of migratory movements. These movements are similar to that of other bird species (Gyimesi et al., 2017).

After installation of Hub north

Local seabirds
The presence of structures in the Hub North area will likely hinder migration between the foraging areas for birds that are sensitive to visual disturbance and use the area of Hub North to forage (see paragraph 4.6.2). Effects can be expected for gannets, common guillemots and razorbills, as these birds experience disturbance from 3 up to 19,5 km away (Peschko et al., 2024; Vanermen & Stienen, 2023).

Migratory birds
Similarly, birds that migrate over long distances can experience a barrier effect caused by the presence of turbines. *Figure* shows the pathways of migrating waterbirds through, but mostly around Nysted OWF in Denmark. For this wind farm in particular it was concluded that the additional distance travelled by eiders is unlikely to impact populations negatively (Masden et al., 2009). Hub North is a lot larger than Nysted OWF, so birds need to fly a long additional distance if they want to avoid Hub North. It is unclear if Hub North negatively affects migrating bird populations through a barrier effect by itself. However, this hub will contribute to the cumulative effect of the multitude of OWFs that will be present in the North Sea. With the growing amount of OWFs in the North Sea it becomes increasingly unlikely that bird populations can migrate over the North Sea relatively undisturbed. Hence, Hub North will substantially contribute to the increased distances that migrating birds will have to travel over the North Sea with increased energetic costs to individual birds as a result. This could very well have a significant impact on certain populations.

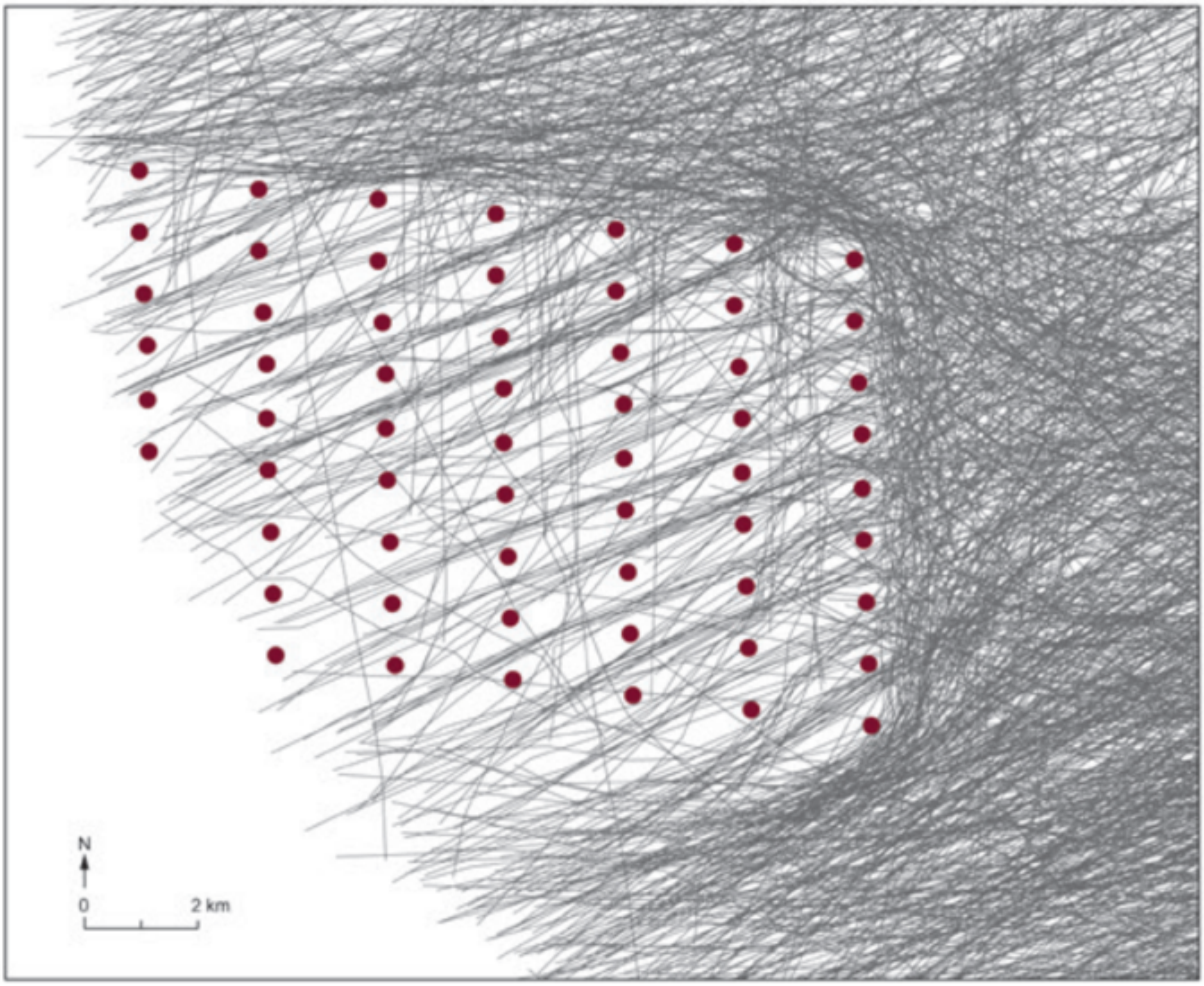

Figure 27. Bird migration through and around Nysted OWF (Denmark) (Desholm & Kahlert, 2005).

NISD

Local seabirds
The NISD leaves a 40 km wide corridor in the middle of Hub North with a north to south orientation that is a limited use area. The corridor width is based on Peschko et al., (2024) which demonstrates that guillemots densities significantly decrease within a radius of 19,5 km from an OWF. It is free of structures and other disturbing activities such as fisheries, but can be potentially used by shipping. This corridor means that theoretically, birds can travel (swim/fly) through the area of Hub North relatively undisturbed and that the connectivity between crucial foraging habitats (Frisian Front, Central Oyster grounds and Dogger Bank) is ensured, see *Figure 5*. However, the validity of this statement hinges on two key assumptions:

1. Birds figure out that they need to travel in a longer, Z pattern between the Dogger Bank and the Frisian front rather than swim or fly in a straight line.
2. Birds have a tolerance to disturbance that is less than the width of the corridor or get accustomed to the existing disturbances within the corridor.

Here we assume that marine bird species that reside on open sea for large amounts of time are able to grow accustomed to the presence of turbines and other structures. Being present regularly in the area of Hub North means that individual birds are confronted with turbines and other structures on a regular basis. Several marine species, mainly cormorant and gull species, have shown attraction to OWFs or are showing strong signs of habituation (Dierschke et al., 2016). This suggests that individual birds could grow accustomed to the new situation after construction is completed.

Migratory birds
Dierschke et al. (2016a) have not included migrating bird species in their research, nor do we think that migrating species grow accustomed to OWFs or are able to figure out how to use the corridor in the NISD. Migration routes vary each year (Vardanis et al., 2011) so the chance that a migrating individual will encounter Hub North regularly is relatively small. Even though the corridor creates a link between Natura 2000-area Frisian Front, the Central Oyster Grounds and Natura 2000-area Dogger Bank, most birds that migrate over large distances have a north-east or south-west flight orientation, and not north-south (like the orientation of the corridor).

Comparative conclusion
Both the NISD and the standard design will form an obstruction to migration of birds. To local migration between important feeding grounds as well as to international migration between summer and winter habitats. The obstruction to local migration is mitigated to some extent by leaving a corridor free of structures, but it is expected that this is primarily beneficial to bird species that are able to grow accustomed to disturbance by wind turbines. The corridor creates a link between Natura 2000-area Frisian Front, the Central Oyster Grounds and Natura 2000-area Dogger Bank. Without the corridor, Natura 2000-area Frisian Front is closed in by offshore wind farms and no pathways without OWF disturbance are present in the Dutch North Sea. The corridor is beneficial for local birds, in particular guillemots, that forage and migrate in the North Sea and move from the Frisian Front to the Dogger Bank.

The effect of Hub North on international bird migration is likely to be more profound when assessing the cumulative effect of OWFs in the entire North Sea. For these birds it is expected that there is no difference between and standard design.

4.6.2 Loss of foraging area

Local seabirds

In a recent report published by SOVON (Vogel et al., 2024), the area in which Hub north is situated has been identified as important habitat for common guillemots (*Figure 28*). Common guillemots can be found in the Dutch EEZ all year round, but highest abundance is in the autumn and winter season. During these months guillemots are usually found floating in large groups on the open sea where they forage mainly on fish. Besides guillemots, fulmars, kittiwakes, gannets, puffins, and razorbills are frequently observed in the area of Hub North during the late autumn and winter months (Bemmelen et al., 2023, 2024; Fijn et al., 2022; van Bemmelen et al., 2024).

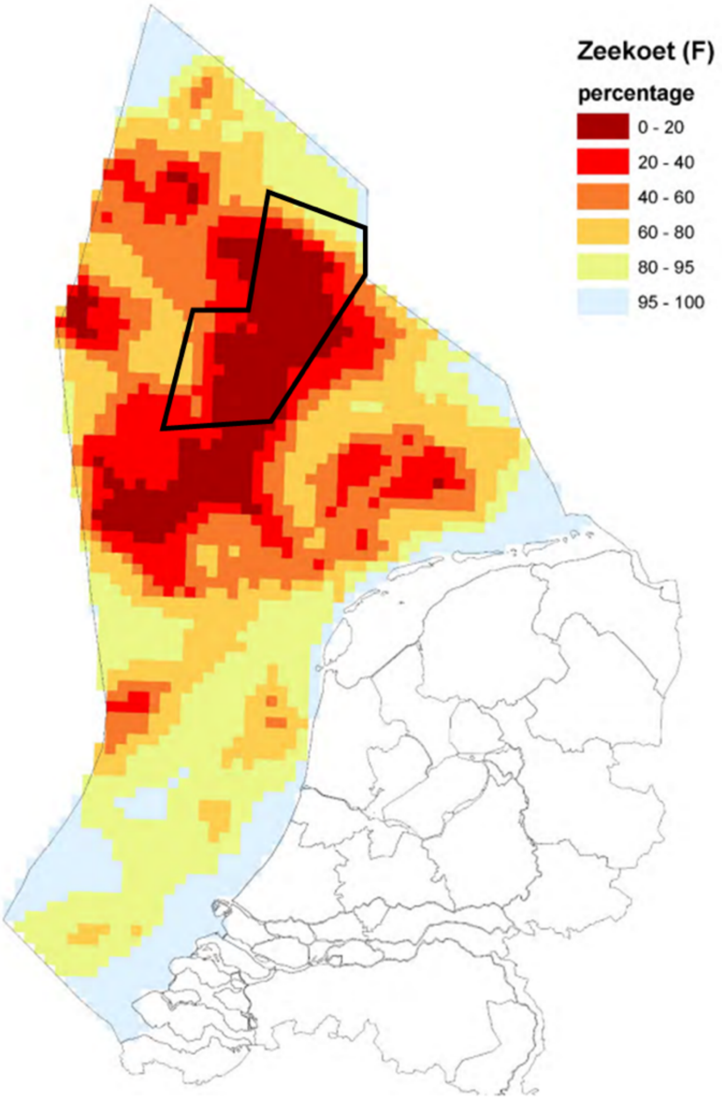

Figure 28. Guillemot abundance within the Dutch exclusive economic zone of the North sea (Vogel et al., 2024). The blue frame indicates roughly in which area Hub North is located.

After installation of Hub north

Local foraging birds
Research has shown that especially guillemots are highly sensitive to visual disturbances (Peschko et al., 2024). Guillemot density in the German part of the North Sea was significantly reduced up to a radius of 19.5 km around operational OWFs. Disturbance distances of the other species found in the area of Hub north differ between 1 and 5 km (Vanermen & Stienen, 2023). Of the other aforementioned species, fulmar, gannet and razorbill show avoidance behaviour to wind parks to some extent (Dierschke et al., 2016; Grundlehner et al., 2024). Based on the behaviour of guillemots and razorbills, puffins are likely to avoid wind parks as well as they belong to the same taxonomic family and share a similar life history. Dierschke et al. (2016) think that avoidance behaviour is stronger when the wind turbines are rotating and is therefore stronger on windy days.

On the other hand, several gull species, red-breasted merganser and great cormorants have shown attraction to OWFs. This is most likely due to the increased availability of food within the OWFs as fish reside near the man-made structures (Dierschke et al., 2016) or, specifically for the great cormorant, the possibility to rest on the structures within Hub north.

NISD

Local seabirds
The NISD does not specifically aim to compensate the loss of available habitat of species that show avoidance to wind farms. Several low disturbance zones, including the corridor, have been created within the NISD that can be utilized by birds as well. But it is most likely that only birds that have low sensitivity to disturbance will utilize these areas (Dierschke et al., 2016).

Comparative conclusion
Within the NISD there is more surface area that is left free of structures. Therefore, assuming that the intensity of the disturbance caused by the layout of structures is similar between the NISD and the standard design, more acreage is left available for foraging birds.

4.6.3 Collision risk

Migratory and local seabirds
The collision zone within wind farms has been determined at between 20 and 120 meters high (Johnston et al., 2014), or higher at 25 to 250 meters high (Krijgsveld et al., 2015) depending on factors such as rotor height. Victims of collision can be roughly divided into two categories: seabird species and migratory species. Seabird species reside on or above the sea surface and are found on the open sea in various periods through the year. Various gull species, skuas, terns and gannets are common victims of collisions with turbine blades. Migratory bird species do not reside on or above the open sea, but several species cross the North Sea in large flocks each spring and autumn when traveling between their breeding and wintering areas. Swans, geese, waders and some songbirds are common victims of collision (Potiek et al., 2022).

After installation of Hub north

Migratory and local seabirds
As with the barrier to movement effect, Hub North by itself will probably not negatively affect bird populations through collisions, but Hub North will contribute to the cumulative effect of the multitude of OWFs that are present in the North Sea. With the increasing amount of OWFs in the North Sea it is increasingly likely that individual birds collide with turbine blades. Hub North will thereby contribute to the cumulative number of collision victims.

NISD

Migratory and local seabirds
The NISD does not aim to prevent seabird collision victims directly. As with the barrier to movement effect, Hub North by itself will probably not negatively affect bird populations through collision victims, but Hub North will contribute to the cumulative effect of the multitude of OWFs that will be present in the North Sea. For migratory species the NISD uses reduced tip speeds when birds are detected and a start/stop mechanism during bird migration. A mathematical model in combination with renowned bird experts predict the migration of large flocks 2 days in advance after which the turbines can be stalled until the migration has passed (Noordzeeloket, 2022). Increasing the tip height will lead to a reduction in bird collisions (Schaub et al., 2024).

There are indications that improving blade visibility will reduce collision victims in several bird species (May et al., 2020). However, the research of May et al., (2020) was carried out with a land-based wind farm and thus, land associated bird species. There is some overlap between the species that collided with the turbines in the research of May et al., (2020) and species that migrate over the North Sea. But it is not clear yet if improved blade visibility will also reduce the number of collision victims of marine bird species. However, improving the blade visibility will probably lead to a larger visual barrier for species. If research indicates that improved blade visibility will reduce collision victims in offshore wind farms as well, it makes sense to include this in the NISD.

Comparative conclusion
The chance that a bird will encounter a turbine blade will be similar between the NISD and the standard design. As the energetic output of both the designs is equal, only the layout of where the turbines will be placed will differ from the standard design, but we assume that the number of turbines will be equal. However, the layout of the OWFs has an effect on the amount of collision victims. Thus, choosing the right areas for the OWF and staying clear of important migration routes is important. The NISD does lower the amount of collision victims by deploying a full stop of the turbines when chances of large-scale bird migration are high.

4.6.4 Indirect effects

Migratory and local seabirds
Changes in species interactions (indirect interspecific interactions) or non-equilibrium dynamics (like in food webs) can disturb populations or impact ecological functioning (Ouro et al., 2024). This paragraph aims to qualify the potential indirect effects of an energy hub to

birds and bats. These potential indirect effects occur in standard design and NISD. As a lot is unclear about these indirect effects, no distinction is made between the standard design and NISD in potential effects. It points to the urgent need for further research into the indirect effects of offshore energy infrastructure on higher trophic levels.

Some potentially indirect impacts on birds in areas of offshore energy infrastructure developments are identified by (van de Bilt et al., 2018) and primarily relate to the changes in food supply. Firstly, the exclusion of fishery in the hub area can either increase or decrease the number of fish locally. No fish are caught, but this coincides with a decrease in bycatch, which functions as a food supply for scavenger birds. (van de Bilt et al., 2018) furthermore states that fishing intensity will not decrease and just relocates, increasing the fishing intensity in other areas. A second aspect is the underwater noise during construction, and during the operational phase, that affects the pelagic species distribution and subsequently the bird populations. Thirdly, reef formation on the introduced hard substrate can increase the food availability, working its way up from hard substrate colonizers to birds (Degraer et al., 2020; Raoux et al., 2017; van de Bilt et al., 2018). Lastly, the possible change in stratification and turbidity can alter the primary production and, in the end, also higher trophic levels such as birds. In case certain bird populations grow, the risk of collision becomes larger, especially if population growth is concentrated in wind farm areas. Whether the result on bird populations is positive, neutral of negative remains to be seen.

Van de Bilt et al., (2018) also identified potential indirect effects on bats in offshore wind farms. The larger concentrations of insects that are found around wind turbines and construction/maintenance vessels are attractive to bats, which feed on insects. This could lead to an increase in bat numbers but might also increase collision risks as well. Construction or maintenance vessels do not impose this collision risk and can act as foraging and resting spaces. Jongbloed et al., (2020) classifies the effect of energy infrastructure on bats in Hub North as unclear.

4.7 Comparative summary

In this paragraph a comparative summary is given for the different habitats (benthic, pelagic and bird). In Table 3 an overview of the impacts on the groups and the NISD measures to reduce these impacts are shown. These measures include both large-scale and small-scale options.

Pelagic habitats
The expected effects of the standard design of Hub North on lower trophic levels include changes in primary production due to vertical mixing, sediment disruption, an increase in the abundance of filter feeders, and shading. These effects are highly specific to offshore wind farms.

The presence of structures may benefit some fish species by providing shelter or increasing food availability, while other species may experience disturbances from noise pollution. Fish populations may be influenced by changes higher or lower in the food web, such as alterations in the abundance of phytoplankton (an indirect food source), marine mammals (predators), and birds (predators). Like lower trophic levels, the NISD will have a lower impact than the standard design because portions of Hub North remain undisturbed.

Marine mammals are expected to experience disturbances primarily from underwater noise pollution caused by maintenance vessels, turbines, and P2G-platforms. They may also be indirectly affected by changes lower in the food chain. Once again, the NISD will have a less profound impact than the standard design, as it leaves parts of Hub North undisturbed.

Benthic habitats
The standard design of Hub North will impact the benthic habitats mainly through the introduction of infrastructure, habitat degradation, substrate shift, increase in EMF and ambient noise. These effects impact benthos such as crustaceans, bivalves and urchins, demersal fish (e.g. flatfish), rays and sharks.

Impacts caused by the standard design also occur in the NISD. However, in the NISD many of these impacts are reduced compared to the standard design (for example, the electric cables will be rerouted to reduce the impact of EMF on benthic). Furthermore, the NISD leaves space (e.g. passive restoration zones) for vulnerable species to remain undisturbed whilst also giving more room for new biodiversity impulses.

Bird habitats
Hub North will impact bird habitats through the barrier effect, loss of foraging area, collision risks and indirect effects on species interactions and the food-web. These effects impact migratory birds and local birds that forage within and around Hub North. Impacts caused by the standard design also occur in the NISD. In the NISD these impacts are reduced with measures, such as creation of a bird corridor and a start/stop system.

Table 3. Comparative table for the biotic components. Tabel describes 1) the biotic component, 2) a brief description of the current state in the Hub North area, and main outcomes for each condition regarding the 3) expected resulting state of the standard design (comparative to the current state), 4) the NISD measures (see 3.4.1) that influence the biotic component, and 5) the resulting state of the NISD (comparative to the standard design). Outcomes and measures that are unknown, uncertain, or expected to be negligible are described in grey font.

Biotic component	Current state	Standard design (vs current state)	NISD Measures	NISD (vs standard design)
Pelagic habitats – Phytoplankton and zooplankton	Plankton community composition changing with unknown impacts on the marine food web	Increased mixing in OWFs results in increase of phytoplankton (and indirectly, zooplankton); Potential impacts of OFPV on plankton; Increase of hard-substrate benthic organisms results in decrease in plankton	Avoid stratified and sensitive areas; Active oyster restoration	Effects on plankton avoided in stratified areas, where effects are most prominent; Negative effects of oysters and other hard-substrate organisms on plankton
Pelagic habitats – fish	Various common pelagic fish species can be found in Hub North	Increase in fish biomass by fishing ban; Pelagic fish attraction to offshore structures; Potential barrier effect on pelagic fish migration; Negative impact of operational OWF noise on pelagic fish; Potential effects of OFPV on fish	Avoid stratified and sensitive areas; Bird corridor; Passive nature restoration; P2G platform strategic placement	Undisturbed areas and reduced impact of noise; Increase of fish connectivity by corridor; Increase of fish connectivity and decrease of disturbance in passive restoration locations;
Pelagic habitats – marine mammals	Porpoise habitat	Increase in noise from operational OWF	Avoid stratified and sensitive areas; Bird corridor; P2G platform strategic placement	Undisturbed areas with reduced impact of noise
Benthic habitats - benthos	Relatively undisturbed bottom, especially in the north, with little sessile epifauna and predominantly benthic organisms associated with soft sediment habitats, including long-living and sensitive species	Increased disturbance (bed shear stress, inorganic matter); Loss of soft sediment habitat; Increase in hard substrate; Potential effects of P2G; Increase food availability at seafloor by OFPV	Avoid stratified and sensitive areas; Active oyster restoration; P2G platform strategic placement	Northern area, rich in benthic species remains undisturbed; Increase in reef building hard-substrate benthos (associated with higher biodiversity and ecosystem functioning and potentially effective in opposing OWF increasing effects on SPM);

				Decrease in soft-sediment benthic organisms; Reduced impact from brine and cooling water effluent
Benthic habitats – demersal fish, sharks and rays	Present throughout the Hub North area	Loss of soft-sediment habitat (sandy); Disturbance from electromagnetic fields; Potential increase in demersal fish such as plaice, Increase suitable locations for attachment of shark and ray eggs	Avoid stratified and sensitive areas; Passive nature restoration	Less disturbance in avoided and passive restoration areas
Bird habitats – Foraging birds	Hub North is situated between multiple crucial feeding grounds for a variety of bird species; Various bird species, including guillemots frequently forage in the Hub North area	Loss of foraging area; Increase in collision risk; Hinder movement between foraging area	Bird corridor; Avoid stratified and sensitive areas; Reduced tip speeds	Increased connectivity between crucial feeding areas; Less disturbance in avoided areas; Lower collision risk
Bird habitats – Migratory birds	Various bird species migrate over the Hub North area	Increase in collision risk; Potential barrier effect	Reduced tip speeds and start/stop mechanism; Bird corridor	Lower collision risk; Decrease in barrier effect

5 General recommendations and mitigation measures in the construction and decommissioning phases

During the workshops several general process recommendations (paragraph 3.4.3) and recommendations to minimize the ecological impact of construction and decommissioning activities were provided. The specific construction impacts from a final design will of course need to be subject to an environmental impact assessment in a much later state. A baseline assumption throughout this document is that the entire design, including all nature enhancement measures, has been built and realised within the ecological carrying capacity and within all applicable laws and regulations. If construction cannot be carried out within the ecological carrying capacity and regulatory limitations, the hub will not be built, or the design will be altered.

This chapter is purely meant to emphasise the need to consider construction and decommissioning impacts already in the design phase.

5.1 Impacts in the construction phase

Anthropogenic noise during construction
Impulsive noise is produced by seismic air gun surveys, pile driving for offshore wind turbines and other construction, explosions, military activities, and some acoustic deterrent devices (OSPAR, 2023). Impulsive sound only occurs during the construction phase and not during the operational phase. Impulsive sound sources are capable of causing permanent hearing damage and blast injuries and have been observed to cause temporary displacement of small cetaceans (e.g., harbour porpoise), increased physiological stress in some fish species (Duarte et al., 2021), and developmental abnormalities in invertebrate larvae (McCauley et al., 2017). While effects on individual animals have been shown for a number of species, there is uncertainty regarding whether and how the effects of sound on individuals are translated to the population or ecosystem scale. However, it is shown that noise can also affect species interactions, thereby altering food web dynamics (Simpson et al., 2016). Many of these disturbances can be partially mitigated. By using new techniques (e.g. suction buckets, gentle driving of piles (GDP)) to install wind turbines the amount of impulsive noise can be reduced. Currently, these techniques are still in the developing stage, but they may be promising construction methods in the future.

Cables during construction
The primary environmental impacts in the construction phase include disturbance of the seabed impacting benthic species, through habitat loss, turbidity along the cable corridor and vessel noise.

Hydrogen construction
The primary environmental impacts of P2G-platforms in the construction phase include disturbance of the seabed, impacting benthic species and turbidity, and noise from vessels and piling.
The primary environmental impacts of hydrogen pipelines in the construction phase include disturbance of the seabed and vessel noise.

Turbines during construction
The primary environmental impacts of wind turbines in the construction phase include disturbance of the seabed impacting benthic species and turbidity, and noise from piling and vessels.

5.2 Mitigation by optimizing construction periods?

Impulse underwater noise is the most profound driver of disturbance during OWF and platform construction and is produced in different phases in the construction process during pile driving, seismic surveys and UXO clearances.

Amongst the wildlife occurring in the area of Hub North especially harbour porpoises and alcid species (Puffins, guillemots and auks) are sensitive to this kind of disturbance as both harbour porpoises and alcid species are (1) present almost year-round in the area of Hub North, (2) spend a large amount of time underwater and (3) have sensitive ears.

Various technologies exist and are being developed, which substantially reduce the amount of noise made by pile driving. Currently, the most applied mitigation measure is the use of bubble curtains, but also more innovative methods using vibration techniques are being developed (see https://grow-offshorewind.nl/newsitem/alternative-methods-for-installing-monopiles-for-offshore-wind-energy for a short animation of various technologies). Considering the significant impact pile driving has on marine life, the implementation of best practices for minimizing this source of noise is absolutely crucial. Next to such no-regret measures, we explore the possibilities for limiting construction activities to optimal time periods in order to minimize all forms of disturbance of harbour porpoises and alcid species.

Abundance of alcid species
Alcid species use their hearing to locate prey underwater (McGrew et al., 2022; Zeyl et al., 2022). Impulse underwater noise can disrupt this process, potentially causing birds to miss out on food and, consequently, energy. As far as is known, some species have hearing sensitivity comparable to that of certain seals and toothed whales. The auditory organ of a bird is quite similar to that of mammals, featuring hair cells that transmit signals to the brain. However, birds possess the unique ability to regenerate damaged hair cells within a few weeks to a few months (Zeyl et al., 2022), something that mammals cannot do.

Less is known about the impact of impulse underwater noise on birds or any associated hearing damage, but there are examples where this disturbance can be significant. For instance, a seismic survey off the coast of South Africa led to a shift in the foraging location of African penguins. African penguins that foraged within 100 km of the seismic sparker foraged an average of 12 kilometres further from their nest location compared to when the sparker was turned off (Pichegru et al., 2017). These observations were made in waters much deeper than the North Sea (up to 100 meters). In deeper water, sound propagates more effectively than in shallow water. Therefore, it is expected that the disturbance would be less extensive in the shallow waters of the North Sea.

Auks, common guillemots and puffins spend most of their lives on open sea, but crucially, most individuals will return to shore during breeding season. Population density of these species therefore, is lowest during the months June and July, see *Figure 29* (Ministerie van LNV, 2014; van Bemmelen et al., 2024). Concentrating construction activities so that they take place in the summer months would hence disturb the smallest amount of alcid individuals.

Abundance of harbour porpoise
As described in paragraph 4.4.4 impulse underwater noise can also cause physical damage to harbour porpoises. Harbour porpoises are present year-round in the area of Hub North, but not always in the same quantity. Harbour porpoise density in the North Sea has been studied by Gilles et al. (2016). Gilles et al. (2016) gives an average harbour porpoise density for the whole Dutch North Sea in spring, summer and autumn season. *Figure 30* shows seasonal fluctuations in harbour porpoise population size in the North Sea (Gilles et al., 2016). The highest population is in spring (0.91 ind./km^2) and the lowest is in autumn (0.56 ind./km^2). Directing construction activities such that seasons with high harbour porpoise densities can be avoided, would minimize the disturbance to the harbour porpoise population.
We did not account for the disturbance caused by impulse underwater noise during different stages of the harbour porpoise's breeding season, because it is challenging to distinguish the effects across various seasons. Harbour porpoises have both a long gestation period and a long lactation period (Ecomare, 2017). Therefore, the choice is between causing disturbances while harbour porpoises are still suckling or while females are pregnant. Disturbing suckling individuals might lead to the separation of mother and calf, whereas disturbing pregnant females could result in a higher incidence of infertile offspring (Heinis et al., 2022). Both situations can be disastrous to the population if occurring frequently.

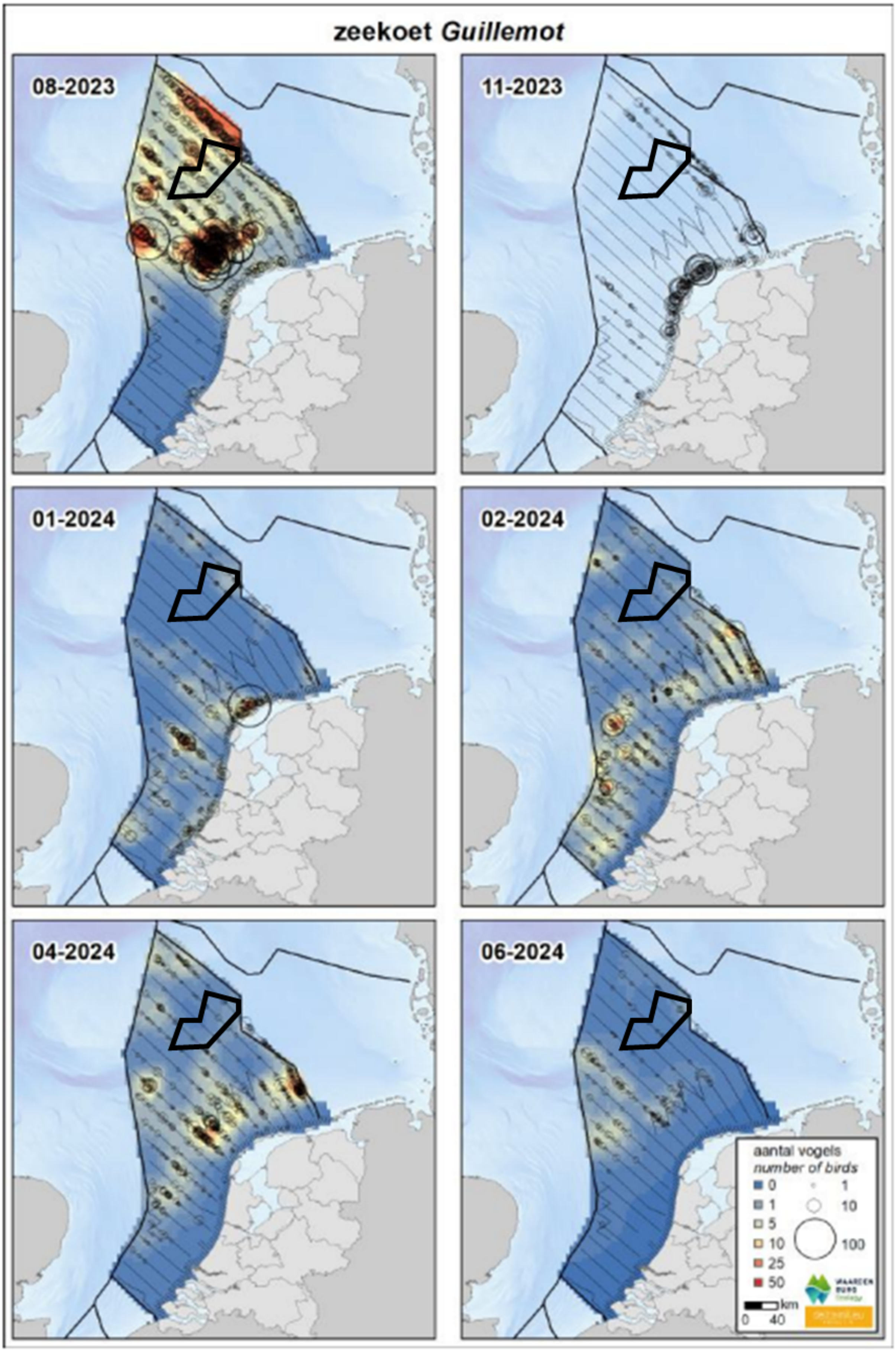

Figure 29. Abundance of common guillemots in the Dutch EEZ (van Bemmelen et al., 2024).

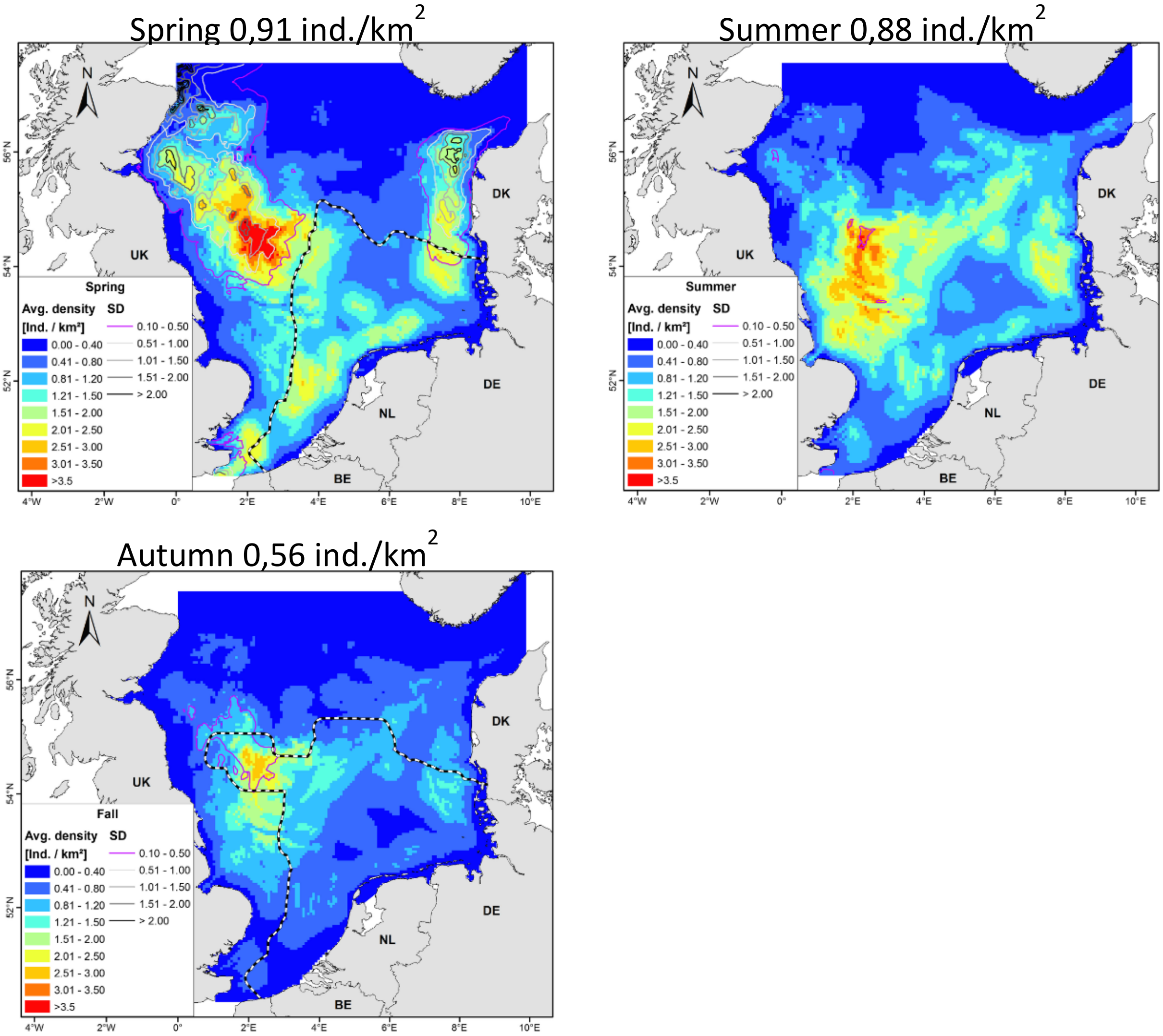

Figure 30. Seasonality in harbour porpoise population density (individual per km²) in the North Sea (Gilles et al., 2016).

Optimal period considering construction activities

Based on the duration of some construction activities - pile driving for a wind farm can take up to a year or more - it will be impossible to only select a few months where construction activities can take place. However, there are certain activities that will only take a few weeks to complete, which are easier to direct to a certain season, such as UXO scanning/clearing, seismic surveys and pile driving for platforms. With the densities of harbour porpoises and alcid species, as shown in *Table 4*, it is possible to select periods during the year when these animals are present in low numbers. Given the sensitivity of harbour porpoises, we prioritize reducing disturbance to this species. However, it is advisable to also implement additional measures to prevent disturbance to alcid species. The life cycle of harbour porpoise and alcids also need to be considered during the operational phase of Hub North.

Table 4. Summary of the presence of harbour porpoises and alcid species throughout the year.

Month	Harbour porpoise density	Alcid density
January	-	high
February	-	high
March	high	medium
April	high	medium
May	high	medium
June	medium	low
July	medium	low
August	medium	medium
September	low	high
October	low	high
November	low	high
December	-	high

5.3 Decommissioning considerations

Currently, all infrastructure that is placed in the Dutch North Sea (with the exception of pipelines and a few old, concrete installations) has to be fully removed to shore at the end of its economic lifetime, unless there is a clear potential for reuse (Dutch Mining Law and Dutch Offshore Wind Energy Law and Water Law). For wind farms and other forms of renewable energy, however, decommissioning regulations are currently being discussed within OSPAR, which so far only has an agreed policy for the decommissioning of oil- and gas installations (OSPAR Decision 98/3).
From a nature-inclusive design perspective, it is important that at least objects that are deliberately designed and placed with the aim of strengthening nature, and which are successful in developing the desired ecological value, will not have to be removed at the end of the economic lifetime of the surrounding infrastructure. In some cases, this might imply that also parts of the asset structures to which the nature-inclusive measures are attached (scour protection, cable crossings, monopile/tower or platform legs) may have to be left in place, too. If leaving in place parts of the asset infrastructure is not allowed for, it is crucial that nature-enhancing measures are placed in a way that allows for them to stay intact after decommissioning. There are several options for this: locating nature-enhancing objects at a safe distance from asset infrastructure, using natural materials so there is no need for removal, or only removing the asset structure once the ecosystem is robust enough to handle this.

For the asset infrastructure itself, incl. any nature-enhancing measures that are attached to it, it is key to consider how to (facilitate) design of infrastructure in a way that allows for (re)use of various parts, e.g. scour protection, foundations, pipelines and cables over much longer time periods, incl. repowering. Probably, this will demand a higher level of standardisation of infrastructure and substantial regulatory changes and incentives, as (designing for) reuse is often more expensive and complicated for the individual asset owner than new-build. Another measure to reduce the impact from decommissioning would be to facilitate designs and technologies that allow for relatively easy removal with minimum disturbance of the seabed. Also, the use of natural materials may reduce the need for removal of nature-strengthening elements.

We would like to note that to facilitate the continuity and protection of ecological values developing on and around man-made structures, local, and possibly also international law- and regulation, will have to be adapted, allowing for more exceptions from the full-removal principle and ensuring very clear arrangements with regard to the transfer of (long-term) responsibilities to new owners or a permanent institution such as the State. This, however, goes beyond the scope of the current report.

6 Cumulative impacts discussion

All of the previously described impacts are focussed on particular impacts of a single activity, or a few impacts from different activities combined. However, the cumulative impact assessment of all activities and added structures in Hub North is still missing. The reason for that is the uncertainty of adding up impacts and the difficulties of predicting how currently existing impacts by e.g. fishing or shipping, will be influenced by hub developments in the area. For example, the impact of noise production and electromagnetic fields can be added up relatively easily. Both impacts negatively affect species groups and mitigating one or both impacts with an NISD, e.g. burial of cables, localizing noise production, rerouting of cables, will certainly reduce the combined impact. This becomes more complex for indirect impacts, such as the increased water column mixing due to monopiles, which changes the amount of nutrients and SPM at the surface and might result in different primary production rates of phytoplankton. This impact chain goes even further when looking at higher trophic levels, e.g. which species depend on phytoplankton for their food source and to what extent does increased production at the surface result in an increase in fluxes of organic matter to the seabed? These complex interactions vary over space and time and need further investigation before a clear statement can be made about the final outcome of this impact chain. For other activities, such as offshore floating photovoltaic and hydrogen production, still little is known about the direct effects of large-scale application. Consequently, even less is known about the cumulative impact of solar, wind and hydrogen production combined – in particular as some effects, for example on mixing of the water column, may weaken each other, while other effects may reinforce each other.

Assessing the cumulative impact of hub North is therefore not feasible in this study. However, an earlier study assessed the cumulative impact of all human activities on biodiversity of the North Sea (Jongbloed et al., 2023). This study showed a decrease in the cumulative Impact Risk (cIR) for the majority of ecological components to a long list of activities taking place by 2040. Especially for fish and deep seabed there was a decrease of >3.5% in cIR (2040 vs. 2022; Table 5 on the next page). For other ecological components, such as birds, an increase in this cumulative Impact Risk of ~3% is expected, primarily caused by offshore wind. Important note is that activities considered in this study include the main activities planned on the North Sea for 2040: Fishing (Benthic trawling, nets, pelagic trawls); Aquaculture; Mining; Oil and Gas; Shipping; Telecoms and Electricity; Wind farms and 27 other human activities (e.g. military, flood defence, and tourism). The list does not include floating photovoltaic and hydrogen production. A follow-up study on the potential of multi-use to reduce cumulative impacts in the marine environment highlighted that the calculated cIR in multi-use is often lower than in single-use and in any case never higher. The integration of multiple offshore activities in this assessment includes renewable energy, aquaculture, nature restoration and tourisms activities (in different combinations) and compared these to single-use. In this study renewable energy includes wind farms, export cables and solar platforms. The lower cumulative impact of multi-use scenarios in the study is based on the assumption that multi-use leads to reductions in the spatial extent and/or the duration of activities. This especially leads to a smaller impact risk in the installation phase. (Tamis et al., 2024). Using multi-functionality as a means of reducing cumulative impacts depends on a highly optimized, integrated design process and on what happens to the 'left-over' space: if multi-functional use does not lead to a reduction in the total spatial extent and/or duration of all human activities, the cumulative impact will also not be reduced.

Assessing cumulative impact may not always be feasible, but it is extremely relevant to take into account when developing the lay-out and spatial planning of future wind farms. As an example, in this project we suggested adding the 40 km bird corridor to accommodate migration of guillemots that can be influenced by OWFs up to 19,5 km. In *Figure 5* all planned OWF's were drawn, with a 20 km buffer around them. Although this is a very simple method, the figure provides insight in the importance of (cross-border) spatial planning and the scale of impact from OWFs for sea birds. By implementing this corridor in the NISD, the connectivity between important bird feeding areas significantly improves. **We therefore recommend roughly drawing out ecological impacts and taking measures such as the bird corridor into account when doing spatial planning.**

Table 5. Change in cumulative impact risk (%) of human activities on ecological components in two future scenarios (2030, 2040) relative to the baseline (2022). An increase is shown in bold. Table from Jongbloed et al. (2023).

Ecological component	Change in impact risk (%; 2030 vs 2022)	Change in impact risk (%; 2040 vs 2022)
Birds	0.4%	2.9%
Mammals	-0.3%	-0.4%
Fish & Cephalopods	-1.7%	-3.7%
Pelagic water column	-0.8%	-1.7%
Littoral sediment	0.0%	0.2%
Littoral rock and other hard substrata	0.0%	0.2%
Sublittoral sediment	-0.6%	-1.6%
Circalittoral rock and other hard substrata	-0.2%	0.0%
Infralittoral rock and other hard substrata	-0.2%	0.0%
Deep-seabed	-1.6%	-3.6%

7 Conclusions and recommendations

It is evident that all conclusions in this report are heavily reliant on assumptions surrounded by a substantial amount of uncertainty, as the report covers spatial developments up to 2050. When (and if) this hub will be built both scientific insights and technological developments will have developed and evolved. It will therefore not surprise anyone that we would like to do some recommendations for further research.

Knowledge gaps

Several knowledge gaps still exist in the ecological impact assessment of hub North, or in general. If we look at the unknowns in our study a division can be made into content related knowledge gaps and innovation/technology related knowledge gaps.

Some of the most relevant content related knowledge gaps are:

- (effects of energy infrastructure on) bat migration,
- the effect of floating photovoltaic on higher trophic levels (e.g. birds and mammals) and on abiotic factors when applied at large scale,
- the effect of concentrating activities: e.g. placing all noise production related activities in a more compact area, and thereby also concentrating all other impacts related to that activity, e.g. brine production and chemical pollution.
- the cumulative impact of all renewable energy production (i.e. wind, solar and green hydrogen and possible counterbalancing effects of wind and floating solar), including the associated effects on other human activities with a (potentially) high impact such as bottom-trawling and shipping (accidents).
- the impact of the energy transition on the ecological carrying capacity of the North Sea.

With regard to this last knowledge gap, in paragraph 4.1 it was stated that we assume that the ecological carrying capacity issue is resolved before final decisions are made to actually start constructing the various infrastructure components of hub North. Whether the specific designs analyzed here, both standard and NISD, are feasible within the ecological carrying capacity is not something that this study can answer. First of all, this depends on the level of pressures from human activities elsewhere in the North Sea and how they develop. Secondly, more information (e.g. monitoring), data analysis, modelling and assessments are required to fully understand how the different activities impact the North Sea ecosystem. And to what extent negative impacts could be mitigated through innovative measures without creating new negative impacts. At the same time, we realise that not all knowledge gaps will be filled and new ones will arise in the process of filling knowledge gaps as research (programs) and technology developments continue. We therefore recommend to keep doing cumulative impact studies at regular intervals to stay up to speed with the state of affairs and planning in the North Sea. This should be part of an adaptive management strategy. With regard to the NSE program and developments in Hub North, we specifically recommend revisiting this study around 2030 and maybe even once again five years after that to keep adding knowledge and progress into the development of Hub North.

Spatial planning

We found that with the current state of planning for Hub North, and the current technological knowledge (many planned technologies have never been implemented on this scale), executing a full and fair comparative study between a 'standard' and nature-inclusive design proved challenging. On the positive note, because of this lack of fair comparison the technical team (work package 1) has been very willing to listen and take ecological suggestions for the design into account. Consequently, the final spatial blueprints or designs from work package 1 incorporates many elements of what is here the NISD. That implies that the 'standard' design used here has not been further elaborated later in the NSE project process and therefore does not necessarily reflect what would be a preferred design seen from a technical perspective. A major difference between our NISD and the designs presented by work package 1 is that where we have based our design and analysis on 15MW wind turbines, which are already being used in practice, work package 1 has decided to base their design on a more forward-looking assumption using 21MW turbines. This difference might have substantial consequences also for the ecological impacts, as larger turbines imply that they are located with greater distance between each other (leading to lower power density and hence a need for more space for wind farms to produce the same amount of energy), have larger rotor blades (larger tip height and/or smaller distance between the water surface and the lower tip) and need to be piled deeper into the seabed or be designed with a different type of tower. All these differences are likely to result in different effects on various species as well as on abiotic factors such as mixing of the water column. The current consensus between ecologists is that larger turbines, by an OWF of a fixed amount of MW, lead to less disturbance for species.

A first recommendation on spatial planning was already made in chapter 6: we recommend roughly drawing out ecological impacts and taking spatial measures in order to be on the safe side, i.e. applying the precautionary principle in situations where effects are highly uncertain but could have a very significant impact. Maintaining a bird corridor and minimizing activities in areas with strong stratification and/or sensitive species are examples of such measures. If solid monitoring shows that ecological impacts are smaller than first expected, plans can be adapted and infrastructure or other activities may gradually be (re)introduced later in areas that were at first avoided. This is what we call adaptive management.

To elaborate on this, we recommend to start up more detailed research into the ecological values in the Hub North area as soon as possible, including micro-siting in the South-Western part, where infrastructure is to be rolled out first. This research should be followed by a solid monitoring programme for the full area in combination with modelling of potential effects of wind farms in combination with offshore solar panels andH2-production. For the latter, good environmental monitoring of impacts from pilot projects on offshore H2 production – in the Dutch North Sea as well as elsewhere, e.g. in Germany - is key. Based on improved knowledge from monitoring and pilots, the NISD development and comparative assessment on Hub North could be repeated and expanded towards 2030, leading to a more certain assessment of impacts and potential mitigation and nature-enhancing measures. In parallel, technological innovation should be stimulated that could help reduce some of the major impacts of large-scale roll-out of wind farms such as the mixing of the water column and the barrier effects on birds.

Conclusion

The objective of this report is to explore the potential negative and positive impacts of the NSE Energy Hubs on the marine ecosystem and to identify measures for a nature-inclusive (spatial) design that would mitigate negative impacts and maximize positive impacts. To this aim, four research questions were introduced in paragraph 1.2. Below the conclusions for each one of these research questions are summarized.

- What are the expected impacts (negative and positive) on the marine ecosystem from the proposed NSE Energy Hubs?

The NISD and standard design impact have the same disturbance effect chains and impact the same species. However, in the NISD the disturbance is often less for the impacted groups as compared to the standard design. An overview of all the (a)biotic impacts for the NISD and standard design are discussed in chapter 4 and summarized in **Fout! Verwijzingsbron niet gevonden.**.

- What measures could be taken, learning from best practices inside and outside the North Sea area, that would be expected to mitigate negative impacts and maximize positive impacts?

The measures for the NISD in the first place seek to avoid and mitigate a number of constraints on natural processes and in the second place to create enabling conditions for certain natural processes that are expected to lead to a more biodiverse and robust ecosystem. While the importance of repeating small-scale interventions many times over should not be underestimated, interventions on a larger level were found to be very promising and impactful. An overview of the large-scale measures can be found in paragraph 3.4.1 and the small-scale measures paragraph 3.4.2.

- What is the expected environmental gain from a nature-inclusive design energy hub as compared to the original standard design?

Compared to the standard design the measures taken in the NISD in combination with the generally recommended measures, are expected to lead to:

- Maintenance of larger foraging areas for birds
- Maintenance of migratory bird exchange between MPA's that are of major importance to various species of sea birds
- Protection of natural carbon storage capacity of the deep, silty area in the middle of the hub area.
- An increase in biodiversity mass for native oysters and other reef building species that can kickstart natural processes
- Enhancement of native oyster and other forms of reef restoration through stepping stones and protection against seabed disturbing activities.
- Potential increase in competition for nutrients between oysters/filter feeders and other species.
- Potential decrease in impacts by structure on stratification. Followed by a change in primary production.
- The presence of additional structures may benefit some fish species by providing shelter or increasing food availability.

- Decreased negative impacts on demersal fish and elasmobranchs due to avoidance of important areas and deeper burial of EMVs. Positive impacts from the creation of opportunities for attaching eggs away from EMVs and other disturbances.
- A more gradual and well-designed roll-out of infrastructure making it easier for the ecosystem to adapt to new circumstances.

Once again, the NISD will have a less profound impact than the standard design, as it leaves parts of Hub North undisturbed.

- What would a 'maximum nature-positive' (nature-inclusive spatial design) energy hub look like? This is to be explored and designed for one of the proposed energy hubs.

A 'maximum nature-positive' energy design contains small-scale and large-scale measures. For Hub North the NISD is shown in paragraph 3.4.1 and *Figure 31* below.

Figure 31. Map of the NISD of Hub North. Note that the exact placement of example wind farms, platforms, and pipelines and cables is illustrative and not used in the impact assessment.

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Appendix A: Ecological fact sheet Hub North

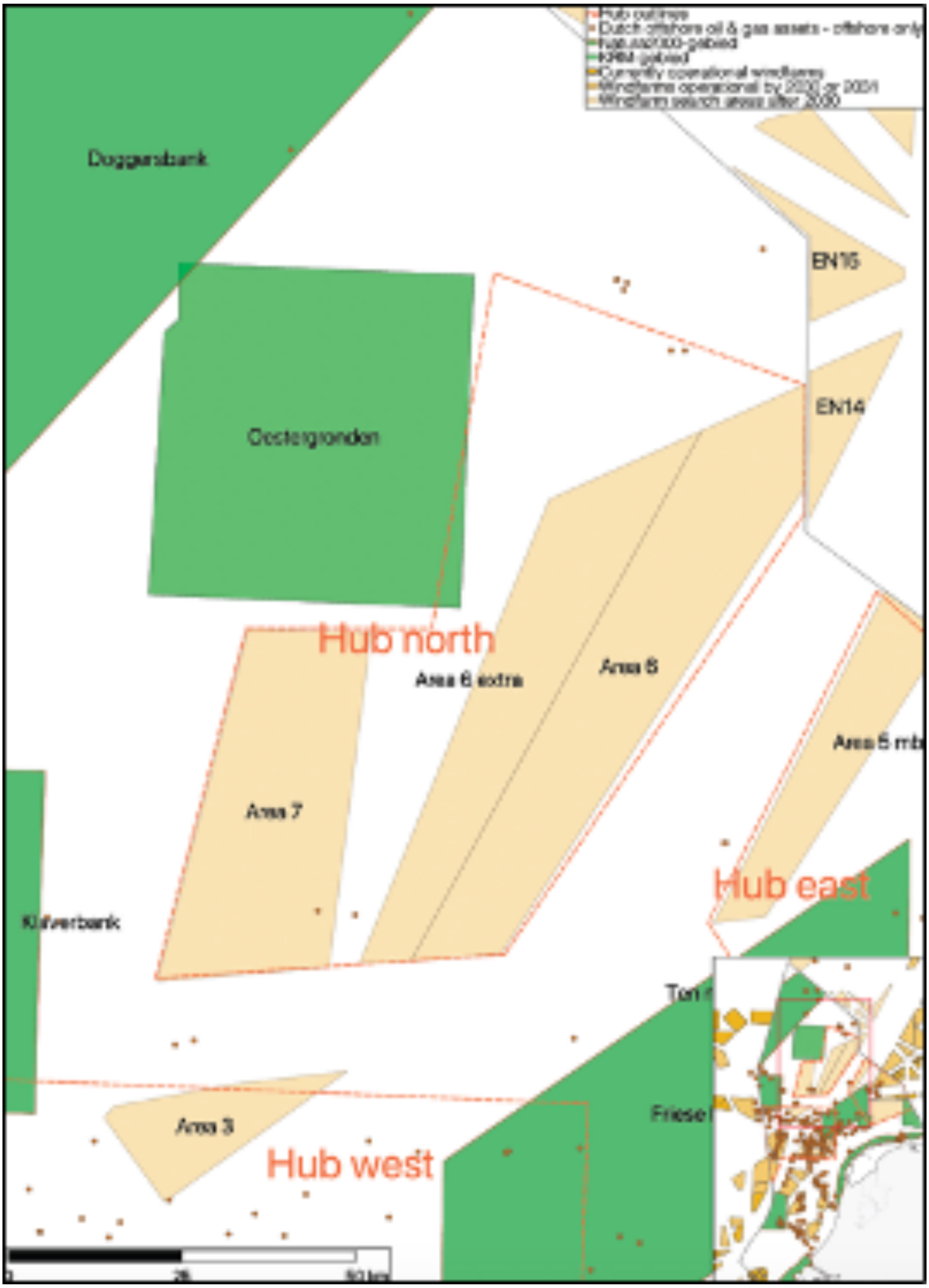

Figure A1. Hub North is defined as the area just south and east of the Central Oyster Grounds MPA bordering the German EEZ. The outline of the hub area should be seen as a preliminary 'search area' with soft borders that may very well be adapted.

Ecological characterization of the area

Abiotic factors

- The seabed in the area is a deep somewhat soft-bottom environment: water depth ca. 30 – 50m with a silty and fine sand seabed and relatively low seabed dynamics. Changes to morphology of the ecosystem may therefore have severe impacts on the currently existing ecosystem.
- There is a **high level of seasonal (summer) stratification of the waters** in the area (temperature as well as salinity), which is very likely to be significantly disturbed by large-scale developments of wind turbines and platforms (e.g. for hydrogen production). So far, it is unknown how disturbance of stratification will impact the functioning of the wider ecosystem and food chain.
- **Wave height is relatively high in the northeastern part of this area** as compared to the rest of the Dutch North Sea. This implies a relatively high risk of accidents with ships potentially colliding with wind turbines and offshore installations in the area. At the same time the long distance to shore means longer traffic movements and limited ability to respond to incidents and calamities. **At the level of the seabed, however, wave energy is moderate,** because of the depth.
- **Interconnectivity** with surrounding MPAs (and other ecologically relevant locations). For **seabirds**, the area functions as an important corridor between the Dogger Bank and the Frisian Front, and particularly for auks and northern gannets migrating to the Frisian Front in autumn. For **underwater species**, the precise connectivity and role of the area in the distribution of organisms are not yet known. However, the supply of **benthic larvae** to the Central Oyster Grounds is expected to be from the northwest direction (Jongbloed et al., 2013). The area between the Dogger Bank and the Frisian Front may also be used as a corridor for underwater animals moving between these areas.
- **Primary production** in the area is relatively low compared to parts of the Dutch North Sea closer to the coast. In the most recent OSPAR QSR (Prins & Enserink, 2022), chlorophyll concentrations, used as a proxy for phytoplankton biomass, are estimated to be in a good status (i.e. not too high). Over the past years, there is no significant trend of change. With rising sea temperatures caused by climate change, there is a concern that phytoplankton production may increase in the area over time, leading to a lack of oxygen, and that stratification may be disturbed (Desmit et al., 2020).

Important species and habitats

- Hub North is located between three **Marine Protected Areas (MPAs):**
  - **Cleaver Bank.** This area is a Natura2000 area installed with the aim of maintaining the size and improving the quality of existing reef habitat (H1170) in the area and maintaining population size, size and quality of habitat for harbour porpoise (H1351), grey seal (H1364) and common seal (H1365).
  - **Oyster Grounds.** This area is protected on the basis of the Marine Strategy Framework Directive (MSFD) with the aim of enhancing seabed integrity (i.e. benthos in general).
  - **Frisian Front.** This area is a Natura2000 area installed with the aim of maintaining the size and quality of habitat for guillemots (A199) with a focus on the habitat function as a resting location.

- Hub North is located in an **area with relatively low intensity of existing activity and high biodiversity, including long-living, protected species.** The area (south of the MSFD MPA (Oyster Grounds)) is very valuable in itself – high biodiversity and long-living species - and different from the MSFD MPA. Although flat oyster (*Ostrea edulis*) reefs are presumably no longer present in the area, it is characterized by conditions that indicate high suitability for the development of flat oyster populations (P. M. J. Herman & van Rees, 2022; van Duren et al., 2022). A report from an expert workshop of WMR and NIOZ and Witbaard et al., 2013) suggest that the southern part of the Central Oyster Grounds (i.e. the Hub North area) is different from the northern part, which is now an MPA and that the central, deeper part of this area is different from the eastern and western parts.
- **Benthic species:** Due to the removal of oyster banks, from which the area derives its name, the Central Oyster Grounds are currently in an "alternative stable state" of other types of biogenic structures formed by burrowing organisms (such as mud shrimp (*Upogebia sp.*)) instead of oyster banks. Almost no sessile epifauna is found, the cause of which is unclear. However, it is striking that relatively high densities of vulnerable species are found in the area, including the ocean quahog (*Arctica islandica*), which only starts reproducing at the age of 6 to 13 years, making the population very vulnerable to disturbances (de Bruyne et al., 2013). Other benthic species found in the area are green sea urchins (*Psammechinus miliaris*), sea potatoes (*Echinocardium*), lesser cylinder anemones (*Cerianthus lloydii*), starfish (*Astropecten irregularis*), Norwegian Lobster (*Nephrops norvegicus*) (Jongbloed et al., 2013).The exact locations and densities of various benthic species in the area would need to be further explored in order to make well-informed decisions about infrastructure locations.
- **Flat Oyster:** When characteristics such as seabed composition, depth, and shear stress in the seabed are considered, the area between the Frisian Front, the Cleaver Bank, and the Central Oyster Grounds has potential for restoration (P. M. J. Herman & van Rees, 2022; van Duren et al., 2022). This could make the area ecologically even more valuable.
- **Sand mason worm:** although the sand mason worm (*Lanice conchilega*) is not found abundantly in the area, there are indications that the northern part of the Hub North area has a relatively good suitability for this species (P. M. J. Herman & van Rees, 2022).
- **Fish:** Certain flatfish such as plaice, dab, and turbot have spawning grounds in the area and the area between the Dogger Bank and the Frisian Front may be used as a corridor for underwater animals. In the area, large schools of tuna have been sighted in recent years. Little is known about the presence of sharks and rays in the area. These species are considered to be sensitive to electromagnetic fields and need some level of hard substrate to lay their eggs.
- **Marine mammals:** harbour porpoise are present in the area, but not at particularly high amounts.
- **Birds and bats:** For some critical seabirds, such as northern gannets, common guillemots, and black-legged kittiwakes, the area is very important. As part of the work on wind search area 6/7 Waardenburg Ecology has conducted an analysis based on available bird data, which included common guillemots, northern gannets, and great black-backed gulls, among others (not yet published). This analysis shows that the deeper, siltier middle part of the area shows the highest bird counts. Biodiversity on the seabed is also high in this part. This zone is also a crucial passage for auks and northern gannets migrating to the Frisian Front in autumn. The importance of this area to (migrating) bats

is unknown, but it is not expected to play a major role as it is located outside known migration routes.

- **Blue Carbon (organic carbon storage potential):** The Central Oyster Grounds are characterized by a deeper, siltier zone with a high organic carbon storage potential in addition to (benthic) ecological value (see https://www.noordzee.nl/hoe-de-zee-een-cruciale-rol-kan-spelen-in-het-compenseren-van-onze-co2-uitstoot/). Capturing organic carbon is an important natural measure against climate change. By protecting the seabed and leaving it undisturbed, more carbon can be sequestered.

Current users of the area and potential developments

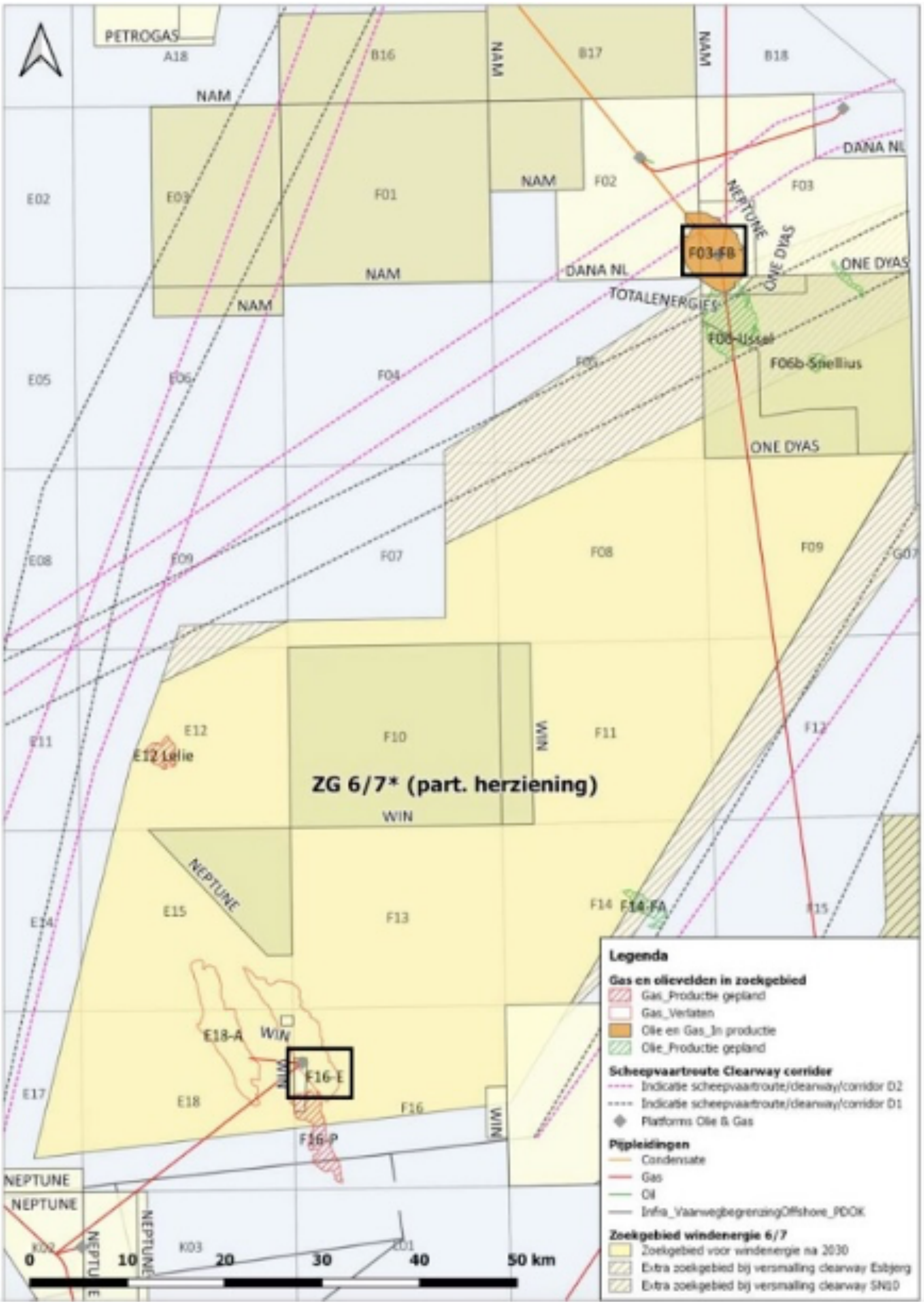

Figure A2. Map of Hub-North area with existing energy-related activities and shipping lanes.

- **Shipping** is the most intensive activity in the area, which is bordered by the Kattegat shipping route on the east-side and the Northern Sea Route and the clearway Esbjerg – Hull in the north-west. These shipping routes are expected to continue to be at least as intensively used in the future (see https://www.marinevesseltraffic.com/NORTH%20SEA/ship-traffic-tracker#gotomap for a live-picture of shipping intensity). The Northern Sea Route is expected to be increasingly used in the future as climate change leads to longer ice-free periods around the North Pole. Within the area itself, shipping activity is currently relatively limited. Due to the combination of the shipping route and the wave intensity, there is a relatively high risk of environmental disasters resulting from collisions of ships with wind turbines and offshore installations in a future energy hub setting. Also, intensive energy production in the area is likely to significantly increase the amount of underwater noise from shipping in the area, which may impact a range of marine species.
- Currently, there is limited **fishing activity** in the area primarily with otter-mix and, to a lesser extent, beam trawling (for Sole). It is uncertain whether fishing activities might move toward this area as other areas further south are being (partially) closed for fishing/bottom-trawling activities. However, the distance to shore, depth and seabed characteristics are likely to be naturally limiting factors on fishing activity and in particular on bottom-trawling.
- Some nine **oil & gas production or exploration** licenses have been granted for the area, some of which are continuing until 2047. Currently there are five production platforms in the area: three in the Northern part in the F3 and F6 Blocks and two in the southern part in the F16 Block. The platforms in the northern part are expected to be able to play a key role in a future energy hub, whereas the F16 platforms are expected to be decommissioned before 2040. Underneath the area, there are aquifers, which may be suitable for CO2-storage (zone 1: blocks F10/F11/F13 and F14, zone 2: blocks F04, F05 (within the Oystergrounds MPA), F07 and F08. It is highly uncertain whether these areas will be developed, but certainly not before 2030. Through the area runs a number of major oil & gas pipelines: NGT, WGT and NOGAT. These may possibly be reused for hydrogen transport after cessation of their function for gas transportation.
- According to EMODnet several telecom cables lay within Hub North (https://emodnet.ec.europa.eu/geoviewer/#). It is our impression that these are no longer in use, but this would need to be checked.

Energy Hub North: Description of plausible energy-related activities by ff2050

Category	Activity	Existing	Hub scenario
Energy Production	Offshore wind	-	
	Natural gas		
	Offshore solar	-	-
Offshore conversion & storage	Electrolysis	-	
	CO_2 storage	-	-
	Energy storage	-	?
Transport infrastructure	Electricity – cables and substations	-	
	Gas – pipelines and compressors		

Figure A3 This figure summarizes current energy-related activities in the Hub-North Area and assumed activities in 2050 (Hub-scenario).

- For Hub North, we currently assume that the max. potential of 28 GW of wind will be installed in wind area 6/7. Of this 28 GW, we assume that 18 GW will be used for hydrogen production and 10 GW for electricity. The final size and design of the wind farm and the timeline for development has not yet been decided upon by the government, so the assumptions here are surrounded by significant uncertainty.
- In our scenario, produced **electricity** will be transported to shore via 5 HVDC cables (5 x 2GW) (see yellow dotted lines in the map below, *Figure A4*). Cables may be laid in trenches and/or covered with scouring protection to keep them in place. Cables are lined with a safety zone, where fishing and anchoring is limited. The primary **environmental impacts** in the construction phase include disturbance of the seabed along the cable corridor and vessel noise. During operations, the electromagnetic fields around the cables may have an impact on certain fish species, in particular sharks and rays. Scouring protection adds hard substrate to the area.
- For **hydrogen production**, it is assumed that electrolysers will be placed on platforms with a capacity of 0.5 GW each, i.e. 36 platforms in total. Each platform will have one (new) hydrogen transport pipeline connecting to a larger pipeline (see green dotted lines on the map below). Through innovation, it might be possible to build larger platforms with more than 0.5 GW capacity, but so far, this is deemed unfeasible. The primary **environmental impacts** in the construction phase include disturbance of the seabed, impacting benthic species and turbidity, and noise from vessels and piling. During operations, potential environmental impacts are primarily caused by large amounts of water extraction for desalinisation and cooling, discharge of water with increased salinity (1.3%), emissions of heat, impacts of antifouling chemicals used for cleaning, noise from maintenance vessels (it is assumed that a small number of service operations vessels will be stationed in the area, transiting back to port every 14 days), vibrations from compressors and other machinery, and light disturbance. The platforms themselves will

create new habitats for species above and under water and may, on a large scale, have an impact on abiotic factors such as stratification. Platforms are surrounded by a 500m safety zone where no ships are allowed without permission from the operator.

- **Construction of an island is currently deemed unfeasible** in this area: it is relatively deep, which means that huge amounts of sand would be needed and there is not enough suitable sand nearby. With innovative techniques construction of an island might be possible if this is deemed sufficiently valuable in terms of economics or ecological impact.
- **Hydrogen transport** to shore(s) will take place with re-used and new pipelines. As part of the work on the hub blueprints in WP 1, NSE5 is investigating scenarios for transport of hydrogen to shore, taking into consideration the potential for re-use of existing pipelines in combination with newly constructed pipelines. It may be needed and feasible to also store hydrogen in the underground in salt caverns or former gas fields. The primary **environmental impacts** of pipelines in the construction phase include disturbance of the seabed and vessel noise. During operations, scouring protection adds hard substrate to the area. In case of damage, hydrogen could leak from the pipeline. Pipelines are lined with a safety zone, where fishing and anchoring is limited.
- It is expected that the **wind farm** and related infrastructure will be mostly developed in phases between 2030 and 2040. By 2050 all infrastructure should be in place in order to contribute to the climate goals as planned. The Dutch government currently assumes that wind turbines are placed with at least 1km between them and with a safety zone of 50m around each turbine where no ships or other objects are allowed without permission from the operator. The primary **environmental impacts** of wind turbines in the construction phase include disturbance of the seabed and noise from piling and vessels. During operations potential environmental impacts are primarily caused by the risk of collisions of birds and bats with the blades, impacts of antifouling chemicals used for cleaning, noise from maintenance vessels and light disturbance. The presence of the turbines themselves, plus scouring protection, will create new hard substrate and may, on a large scale, have an impact on abiotic factors such as stratification.
- In the NSE5 scenario's, it is assumed that **oil and gas production** in the area will be almost phased out before 2050. In case of successful explorations in block F06/F10, new platforms for gas production may be installed. In that case also the platform in the F3 block will continue to play a role for evacuating produced oil from gas production in the area. Other existing platforms are assumed to be decommissioned in the period 2030 – 2050.
- Underneath the area, there are aquifers, which may be suitable for CO2-storage (zone 1: blocks F10/F11/F13 and F14, zone 2: blocks F04, F05 (within the Oystergrounds MPA), F07 and F08. It is highly uncertain whether these areas will be developed, but certainly not before 2030. **In the NSE5 scenario's for Hub North, CO2-storage is currently not included.**

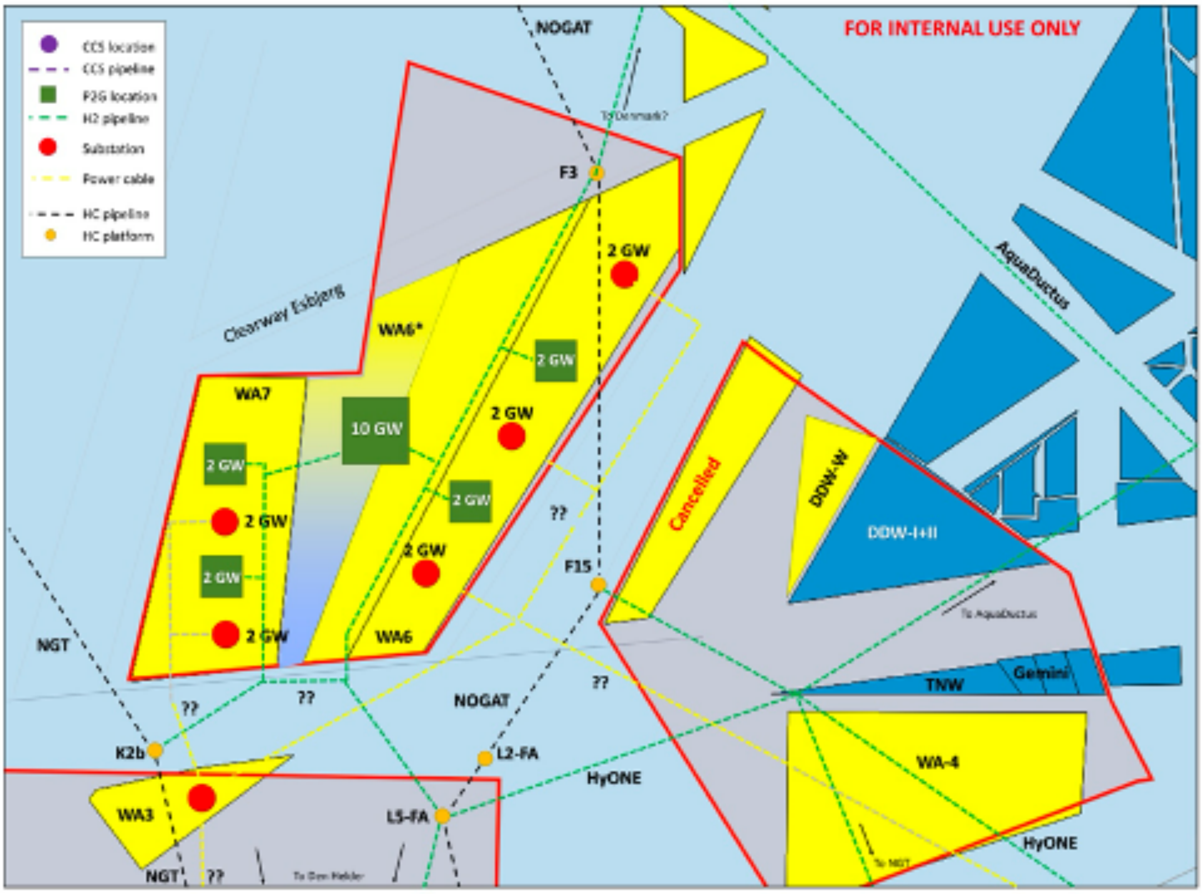

Figure A4. Map of Hub-North and Hub-East with the infrastructure that is assumed to be present in 2050 within the NSE scenarios. The blue areas are existing wind farms and the yellow areas are wind search areas, as defined in Programma Noordzee 2022-27.

Considerations for nature-inclusive design - interventions

- Due to the current relatively low intensity of existing activity and high biodiversity with long-living species, a nature-inclusive hub design in this area would in the first place have to **consider mitigation measures to minimize negative impacts/disturbance of the seabed and abiotic factors like stratification**.
- In the first place, the **exact location of infrastructure will be a key factor determining impact on the ecosystem:** avoiding sensitive areas where possible and designing infrastructure as potential resting places, foraging locations and stepping stones for key species might play an important role. Also **well-considered timing of construction activities** will be an important measure to help reduce impact.
- **Minimizing seabed disturbance** would demand thorough surveys of benthic habitats and species in the area, before construction is started, and avoiding construction activities in particular areas (probably in the middle of the area, but still to be defined in further detail). Minimizing the number of cables and pipelines in/across the area should be a consideration to reduce seabed disturbance as well as minimizing electric fields. Reuse of existing infrastructure would present a clear advantage above new construction activities. Also, innovations may be needed to minimize seabed disturbance during construction and the phasing of (construction) activities might have to be planned in a way that allows a disturbed area to 'come to rest' before new activities begin in order to control turbidity. During operations, energy installations may help to keep the area closed to bottom-disturbing fishing practises.
- In order to **minimize impacts on abiotic factors like stratification**, innovations will be needed in wind farm construction and lay-out as well as for platforms to be used for hydrogen production. Due to the seabed conditions and depth the location does not seem suitable for islands as an alternative to platforms.
- Potential **impacts from large-scale hydrogen production will have to be considered and dealt with in a manner that avoids negative impacts**: What amounts of brine would be produced by the large-scale hydrogen production and could it be injected into former gas fields, transported to shore or at least be pre-mixed before it is released into the sea? How will cooling water effluents impact water temperatures in the area and how will this interact with stratification and climate change impacts? And what are the best options to deal with oxygen resulting from hydrogen production?
- **For seabirds the area functions as an important corridor for migration between the Dogger Bank and the Frisian Front.** Potential risks of collision for seabirds will have to be considered as well as the risk of increased predation on Guillemot (father-)chick combis migrating to Frisian Front. The latter might be caused by large numbers of platforms in the area acting as nesting and foraging spots for large gulls. The choice of location of platforms in relation to wind turbines might help reduce the risk of collisions of turbines and birds attracted by the riches of the area.
- Opportunities for strengthening nature in the area might focus on:
  - Flat Oyster restoration and protection of the Central Oyster Grounds.
  - Creating/protecting gravel spots where skates and sharks can safely lay their eggs.
  - Nature-inclusive measures to protect benthos environment/improve benthos community.
  - Increasing fish biomass available for tuna (and other predatory species, incl. marine mammals) in the area.

- Designing platforms to house breeding birds or act as resting place for migrating birds.

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