North Sea Energy
offshore system integration

D4.1
WHITE PAPER

North Sea Energy 2023-2025

Designing Nature-Inclusive Energy Hubs

Whitepaper on General Recommendations and Outcomes for Hub North

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Whitepaper on General Recommendations and Outcomes for Hub North

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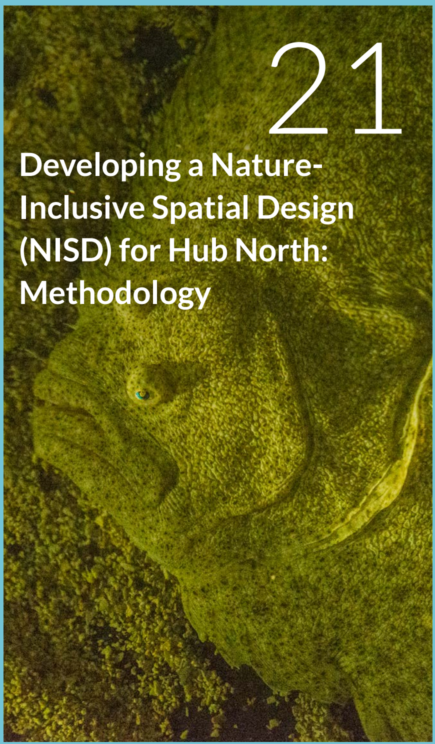
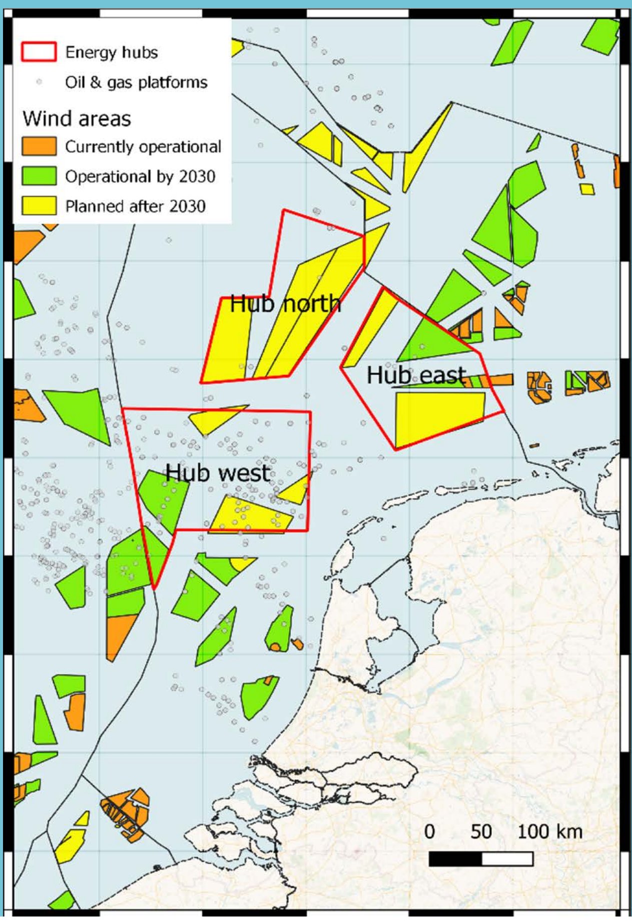


Introduction

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 focuses on the nature-inclusive design of offshore energy hubs. Its objective is to explore the potential impacts of NSE energy hubs on the marine ecosystem and to identify measures for a nature-inclusive spatial design (NISD) of one particular hub.

In this whitepaper, we share a number of general recommendations for the design of nature-inclusive energy hubs in the North Sea, based on our learnings working on a NISD for Hub North *(see Figure 1)*. In addition, we present a nature-inclusive spatial design (NISD) for Hub N   orth and our assessment of its potential impacts on the marine ecosystem as compared to a 'standard' design. The design and the impact assessment are the results of desk research as well as a number of workshops with a group of NSE partners, ecological experts and stakeholders from a variety of organizations and backgrounds.

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



The full report, of which this whitepaper is a summary, can be found here.

Gather information… zooming in and zooming out.

Designing a nature-inclusive energy hub: general recommendations

The installation of large-scale energy infrastructure is highly likely to have significant effects on the functioning of nearby marine ecosystems across various levels. By altering abiotic conditions, creating physical barriers for certain species, and providing extensive new habitats for others, large developments influence the fundamental dynamics of ecosystems at a regional scale. Local marine environments may be substantially affected by disturbances from construction activities, shipping, other forms of noise, electromagnetic fields (EMFs), chemical emissions, and changes in abiotic conditions. In this paragraph, we offer several general recommendations for nature-inclusive energy hub (spatial) design, which are partly derived from process-related suggestions made by experts and stakeholders during workshops and partly based on insights gained from the nature-inclusive design process outlined below.

Developing Nature-Inclusive (Spatial) Designs as a spatial planner or developer

In the current regulatory context, infrastructure developers generally do not have the possibility to decide about the development of a full energy hub area. The permitting procedures of OWFs and sub-surface activities like oil and gas production and CO_2 or hydrogen storage widely differ and decisions are made separate from each other. In some cases, OWFs are now tendered in combination with hydrogen production, nature restoration or passive fishing, but more extensive multi-use permitting is not yet being implemented in the Dutch North Sea. This means that the recommendations provided below may in the first place seem relevant to spatial planners, i.e. policy makers. However, the principles, we believe, may just as well be applied to smaller areas forming part of an energy-hub and, maybe most importantly, may be seen as an invitation to developers to look beyond their own specific assets and seek collaboration with other energy developers and users of space in their surroundings.

- **Gather information on the current, past and expected future ecological state.** Take the necessary time to gather all relevant information about the current ecological status of the area where the development is planned. This should include data on particularly sensitive species and habitats, as well as information on how the area is connected to protected nature areas and nearby man-made structures. Additionally, investigate the historical state of the

ecosystem (prior to industrialization and intensive fishing) and the projections for changes in fundamental conditions due to climate change. This knowledge is essential for implementing a nature-inclusive design at both the spatial and asset levels. ARK's Seawilding approach described in the next chapter may help you do this in a systematic way.

- **Zoom in and zoom out.** Infrastructure developments may affect local ecosystems and species that depend on a very specific habitat in a very specific location. Minimizing negative impacts of such sensitive species may demand micro-siting and very specific location planning. On the other hand, infrastructure may also affect mobile species at a regional level, e.g. by creating barriers for birds or migrating fish or by impacting the availability of food for species foraging in the area. In order to understand and mitigate regional impacts it is crucial to look beyond your own area of development. Seeking collaboration with neighbouring developers and coordinating measures to reduce negative impacts at a regional scale is key.

Strategically concentrate or disperse ecological impacts.

- **Take into account other current and potential future uses of the area.** The North Sea is one of the busiest seas in the world. Hence, multi-functional use of space is crucial. On the other hand, not all uses of space can be combined without hindering each other, creating safety issues or excess cumulative pressures on the ecosystem. Exploring current and potential future uses of the area and engaging in a dialogue will help identify synergies and manage risks. Beware: as energy infrastructure moves further offshore, it also enters areas that are currently not being heavily used by humans. In those areas mitigating negative impacts on the marine environment will be even more important than in areas that are already subject to heavy pressure from human activities.

- **Apply the mitigation hierarchy.** Avoiding or minimizing negative impacts should remain the top priority, especially in sensitive areas that are currently in a relatively good ecological state. In areas that are in a degraded ecological state, restoration and rehabilitation may have significant added value. If all else fails compensation of ecological values that will be disturbed or lost as a result of the development should be considered. However, in many cases it is difficult to find a location that really compensates for the same habitats and species and compensation will often involve trade-offs with other users who will have to reduce their impact on the compensation-area.

- **Strategically concentrate or disperse ecological impacts.** The cumulative impact of energy infrastructure may be highly dependent on the distance between structures/ activities with a particular effect, e.g. noise, (chemical, heat or brine) emissions or impact of the water flow. For example, concentrating electrolysers and other noise producing infrastructure near a shipping lane may help reduce noise in other parts of the hub area. Concentrating emissions in a few areas may increase impact on the local environment, while decreasing the impact at a larger scale. Whether concentration or dispersion is the better option may vary depending on the ecological characteristics of the area and the types of impact.

- **Position active restoration projects so as to strengthen the regional ecosystem.** Active restoration of habitats is a popular action for developers as it combines well with construction activities. Planning for active restoration first of all demands a very good understanding of the ecological conditions in the area: what habitats and species are likely to be able to develop in that area? And how will such developments impact the wider regional ecosystem? Secondly, it is key to position active restoration projects in locations, where they can disperse and grow with the aid of natural water flows. Isolated habitats are highly vulnerable and larvae being transported by currents need to arrive in places with the right conditions for them to settle.

- **Engage marine ecologists and other experts to identify potential constraints and enabling conditions** for creating a resilient ecosystem through the infrastructure you plan to develop. Their expertise will help you explore what ecological state you could aim for and what measures could guide you in the right direction.

- **Plan the development allowing for learning cycles of experimentation, data gathering and adaptation.** While optimism and ambition are key in the design process, it is equally important to recognize that our understanding of marine ecosystem dynamics is still limited. As a result, predicting the outcomes of various interventions with certainty is not yet possible. Experimentation and unexpected results - both positive and negative - are inevitable.

- **Establish a robust monitoring program** to track the ecological development of your infrastructure over time and facilitate the sharing of data and insights to accelerate learning. In the short term, this may appear to be an unnecessary expense, but in the long term, it could prove valuable by demonstrating that the measures taken have resulted in significant ecological benefits. This could improve public support for energy developments and potentially reduce the risk of having to invest substantial funds in removing infrastructure or artificial reefs that actually do have ecological value.

- **Make good use of available catalogues and toolboxes with nature-protecting and -enhancing design measures and decision-making frameworks.** Examples of a decision-making framework that is widely recognised in The Netherlands is “Hermans, A. et al. 2024. Onderzoek naar natuurbeschermende en natuurversterkende maatregelen voor energie infrastructuur op de Noordzee” (see https://www.noordzeeoverleg.nl/nieuws/2679673.aspx) This report also contains a catalogue of best practise measures, which will be regularly updated as part of the research programme (MONS Programme) associated with the Dutch North Sea Forum. Another example is the “Toolbox to nature enhancement in offshore wind farms” developed by The Rich North Sea.

Embedding Nature-Inclusive (Spatial) Design in policy

In order to facilitate an ecologically safe roll-out of offshore energy production, we recommend that policy makers take an **adaptive management approach to spatial planning and site development, including the following measures:**

- **Preliminary Ecological Impact Assessment:** In the early stages, it is essential to roughly outline potential ecological impacts and implement spatial measures to err on the side of caution, applying the precautionary principle in cases where effects are highly uncertain but could have significant consequences. In the Netherlands, this is done for wind farms within the Kader Ecologie en Cumulatie (KEC). However, this process currently only considers the impacts of wind farms and not the broader energy hub activities such as hydrogen production. For Hub North, examples of measures based on such an initial assessment would include maintaining a bird corridor and minimizing activities in areas with strong stratification or sensitive species.

- **Prioritizing Detailed Ecological Research:** It is crucial to prioritize and speed up more detailed research into the ecological values and potential for improvement in areas designated for large-scale energy infrastructure development. This includes micro-siting in areas that are anticipated to be particularly sensitive. For Hub North, this would involve micro-siting in the southwestern part of the area, where infrastructure is to be deployed first, as well as modelling the potential cumulative effects of wind farms in combination with offshore solar panels and hydrogen production, particularly with respect to abiotic conditions like stratification. Testing initiatives such as native oyster restoration and other nature-enhancing measures in the area could also be beneficial, including utilizing the 500-meter safety zones around oil and gas platforms (F16, F15, F2, F3), and modelling the spread of larvae across the region.

- **Environmental Monitoring and Reporting:** A solid and continuous environmental monitoring and reporting program should be established to assess the impacts of pilot projects on offshore hydrogen production and offshore solar panels, both in the Dutch North Sea and elsewhere (e.g., Germany). This should extend to full-scale developments of wind farms and related infrastructure. For Hub North, a monitoring roadmap should be created and integrated into a national monitoring program, such as MONS or Wozep. This program should make standardized monitoring mandatory for new energy projects in the North Sea, improving system knowledge and filling knowledge gaps. By doing so, stakeholders can adjust strategies accordingly. In the short term, monitoring efforts for hydrogen production pilots 1 and 2 could focus on potential impacts on birds, particularly guillemots and their predators, and experiment with solutions for disturbances caused by brine and heat emissions.

Schedule Roll-out based on Ecological Sensitivity and Knowledge.

- **Scheduling Rollout Based on Ecological Sensitivity and Knowledge:** The rollout of energy infrastructure should be scheduled to align with the level of ecological knowledge and the potential sensitivity of an area. Specifically:
  - Start with areas in a relatively poor ecological state that could benefit from reduced bottom disturbance and increased hard substrate associated with energy infrastructure.
  - Prioritize areas where we already have substantial knowledge about ecosystem dynamics, while avoiding areas where further research is needed to minimize negative impacts.
  - For Hub North, this would mean beginning development in the southwestern part and moving towards the northeastern part. This approach allows for the early initiation of active oyster restoration and delays disturbance in the most sensitive areas. During development in the southwestern part, it would be advisable to limit other human activities in the remainder of the hub area to allow nature to begin restoring itself before further development, and to improve baseline ecological knowledge in the middle and northeastern parts. Such measures are necessary to ensure the effectiveness of spatial designs and nature-protecting and enhancing strategies in the northeastern area.

- **Adaptation of Plans Based on Monitoring Results:** If solid monitoring reveals that ecological impacts are smaller than initially expected, plans could be adjusted, and infrastructure or other activities may gradually be reintroduced into areas that were initially avoided. With improved knowledge from monitoring and pilot projects, the nature-inclusive spatial design (NISD) development and comparative assessment for Hub North could be revisited and expanded toward 2030, providing a more reliable assessment of impacts and potential mitigation or nature-enhancing measures. If, on the other hand, research and monitoring reveals that ecological impacts are larger than expected, policy-makers also need to allow for downwards adaptation of targets for the development and use of an area.

- **Data Sharing:** To support monitoring efforts and maximize the efficiency of data usage, data-sharing between offshore wind farm operators, fishermen, oil and gas operators, and other users should be mandatory. Facilitating a collaborative approach will help accelerate learning, prevent stagnation, and optimize the use of human resources.

- **Incentivizing Nature-Inclusive Design:** It is essential that tendering procedures and permitting processes for other energy-related activities, such as hydrogen production, continue to provide strong incentives for nature-inclusive design, construction, and decommissioning (in line with the Dutch North Sea Agreement). Procedures and incentives should increasingly focus on the energy hub infrastructure as a whole, rather than individual assets (e.g., wind farms, electrolysers, solar panels), to facilitate integrated hub development that minimizes ecological impacts, optimizes use of space, and creates synergies between nature-enhancing measures across various asset levels.

- **Promoting Technological Innovation:** Concurrently, technological innovations should be stimulated to reduce the major impacts of large-scale hydrogen production, such as heat and chemical emissions, and wind farm deployment, such as water column mixing and bird barrier effects. Additionally, to ensure that positive impacts are sustained in the long term, further research and innovation are necessary to identify new, nature-friendly decommissioning methods that could preserve any positive effects of nature-inclusive design measures and related infrastructure.

Adapt plans based on monitoring results Incentivize Nature-Inclusive Design.

Developing a Nature-Inclusive Spatial Design (NISD) for Hub North: Methodology

In close cooperation with a group of external experts and stakeholders participating in three workshops, we have developed an NISD specifically for Hub North. This group of experts also provided input via a review of the resulting report describing the NISD, comparative assessment of the NISD and a 'standard' design and some general recommendations (see [link to full report]). The group consisted of experts on North Sea ecology and offshore energy 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.

Aiming for a design that would have a maximum positive impact on the marine ecosystem – and a minimum negative impact - we made use of the 'Seawilding approach' developed by ARK Rewilding for the NISD. This 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:

1. **Seascape scope definition:** What is the scope of the seascape, in terms of geographic scale, ecological complexity and human use? The geographic scope for our NISD is Hub North as indicated in *figure 1*. In collaboration with NSE 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 operational phase and the final design as it would presumably be in 2050.

2. **Describing the current ecological state.** Based on desk research, we developed a fact sheet describing the current state of the Hub North area in terms of ecology and human use. In the workshops, expert input added further details to this description.

3. **Defining constraints.** How do humans constrain natural processes, thereby limiting the ecological state? In the workshops, 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 the workshops, participants discussed what conditions the Nature-Inclusive (Spatial) 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 the workshops, 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 the workshops, participants discussed what interventions might facilitate a robust ecological state. After the workshops, the WP4 team made a further selection of interventions to form a consistent design and added interventions known from desk research, current practise and input from WP1.

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 and is reflected in D7.2 and D7.3.

The NISD essentially reflects the choices made in step 6, and the qualitative assessment of impacts of the standard design as compared with the NISD reflects the process and outcomes of steps 2 to 5.

In addition to the Seawilding approach, we based our nature-inclusive design on the mitigation hierarchy with regard to (negative) impacts:

1. Avoidance,
2. Minimization
3. Restoration/Rehabilitation
4. Compensation

Energy Hub North: current characteristics

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):**

- **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 of the full report.

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.

Future human use: Terms of reference for the hub design

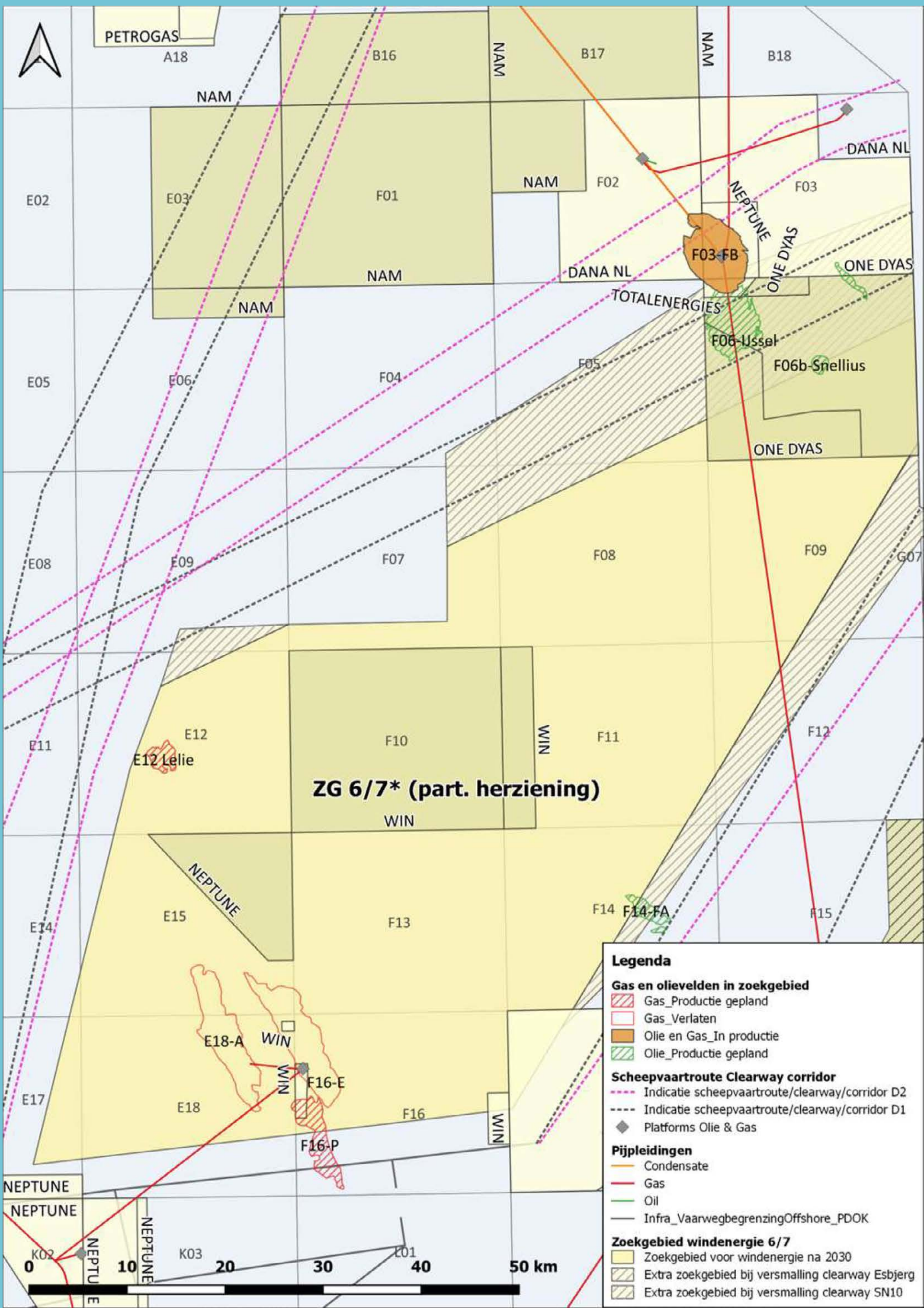
For the design of Hub North, we developed terms of reference describing the types and amounts of energy infrastructure to be considered. **This includes 14GW of offshore wind, 1GW of offshore floating photovoltaic (OFPV), conversion of 7GW of renewables into hydrogen, whereas the rest will be transported to shore via 4 high-voltage direct current (HVDC) cables of 2 GW each.** This corresponds with the electron-heavy (DEC) scenario used in work package 1 of NSE. 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. The Dutch government currently assumes that wind turbines are placed with at least 1 km 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. Also, specific lanes for thoroughfare of ships are created where the above-mentioned forms of co-use are not allowed. No oil and gas production is included in the design, as we assume that this will be almost phased out before 2050.

The electrolysers for **hydrogen production** can be built on different types of infrastructure. We assume that they will be placed on 14 so-called power to gas (P2G) platforms with a capacity of 0.5 GW each. 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. However, as none of these options are currently deemed feasible, we did not include them in our terms of reference. 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.

In our terms of reference, we assume that produced **electricity will be transported** to shore via 4 high-voltage direct current (HVDC) cables of 2 GW each. 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. *Table 1*, summarizes the terms of reference in full detail.

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. The terms of reference do not reflect an assessment of what amount of activities is feasible in the Hub North area. 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 and about the types of activities that will be economically feasible offshore.

Figure 2. Map of Hub-North area with existing energy-related activities and (future) shipping lanes. Source Memo Mijnbouwactiviteiten Zoekgebied Windenergie, EBN 2023)



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 assessment of the impacts of the design focus on the operational phase of the hub as it would be in 2050.

Potential effects of introducing energy infrastructure in the Hub North area

Introducing the projected amount of infrastructure into the Hub North area certainly will have a major impact on the marine ecosystem. In the process of developing the nature-inclusive design and assessing the potential impacts of a the 'standard design' versus the nature-inclusive design, we based our work on the assumptions regarding the potential impact of different types of assets summarized below.

Table 1. Terms of reference for Hub North infrastructure and activities.

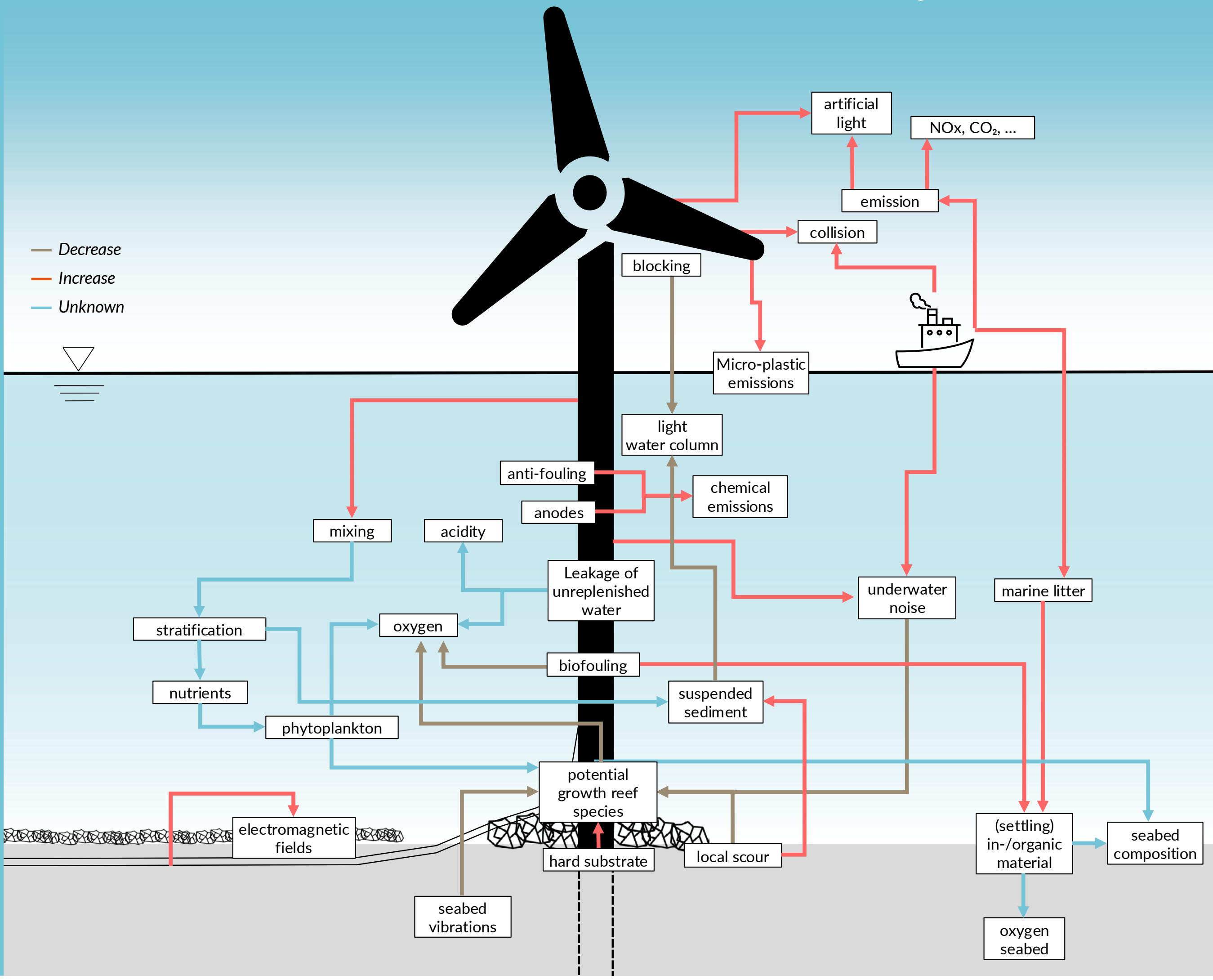
Infrastructure part/activity	Number and capacity	Characteristics
14 GW offshore wind	933 turbines of 15 MW	Technical characteristics (reference: IEA 15 MW reference wind turbine (Gaertner et al., 2020)): • Monopile foundation diameter: 10 m • Rotor diameter: 240 m • Maximum tip height: 270 m above mean 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/km2 (resulting spatial footprint: 1400 km2) 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 km2 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

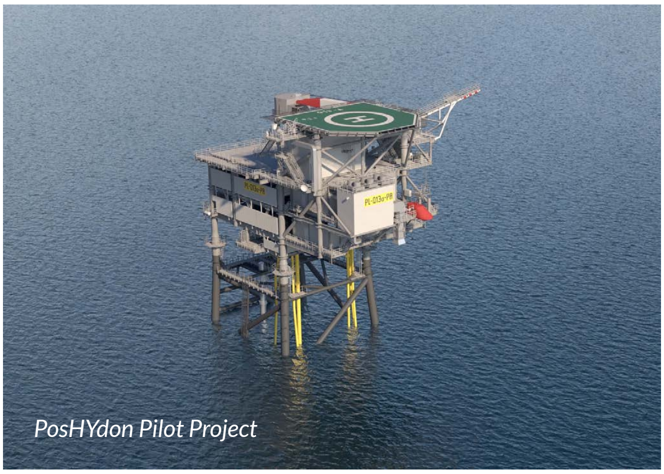
The large-scale impact of **wind turbines** in the marine environment is summarised in *Figure 3* where it is presented for a single turbine, however, describing the situation of large-scale roll-out. For example, the effect of a single turbine on the mixing of the water column will be very limited, but when 2000 turbines are installed in the marine environment the cumulative impact can be significant. The impacts in *Figure 3* are described in more detail in Chapter 4 of the full report.

The large-scale impact of **hydrogen production** on the marine environment is described in *Figure 4*. Also, here the impact becomes more significant when multiple P2G-platforms are installed, and these impacts are described in more detail in Chapter 4 of the full report.

For offshore **floating photovoltaic activities**, the impact is described in *Figure 5* 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 4* are described in more detail in Chapter 4 of the full report.

Figure 3. 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.

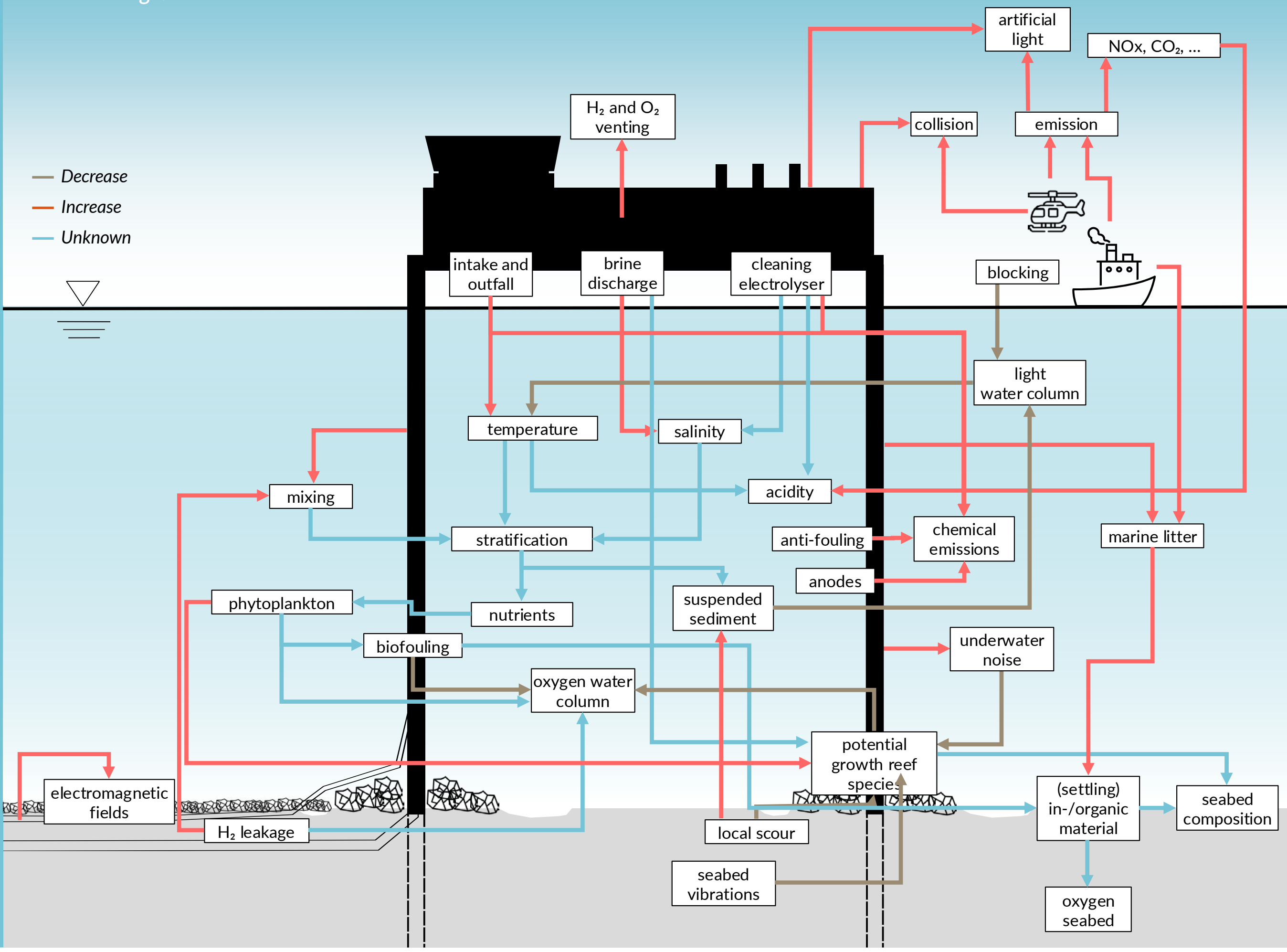




The following factors influencing natural processes in the area have been considered in relation to the planned Hub North developments (in no particular order) and form the basis for the NISD interventions:

- 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

Figure 4. 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.



- 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. The specific effects of a final design will eventually need to be subject of an environmental impact assessment in a much later state. A baseline assumption throughout our work is that if such an assessment proves that the infrastructure needed for the hub cannot be constructed within regulatory limitations or the carrying capacity of the North Sea ecosystem, the hub will not be built, or the design will have to be altered.

Standard design of Hub North

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 5. 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).

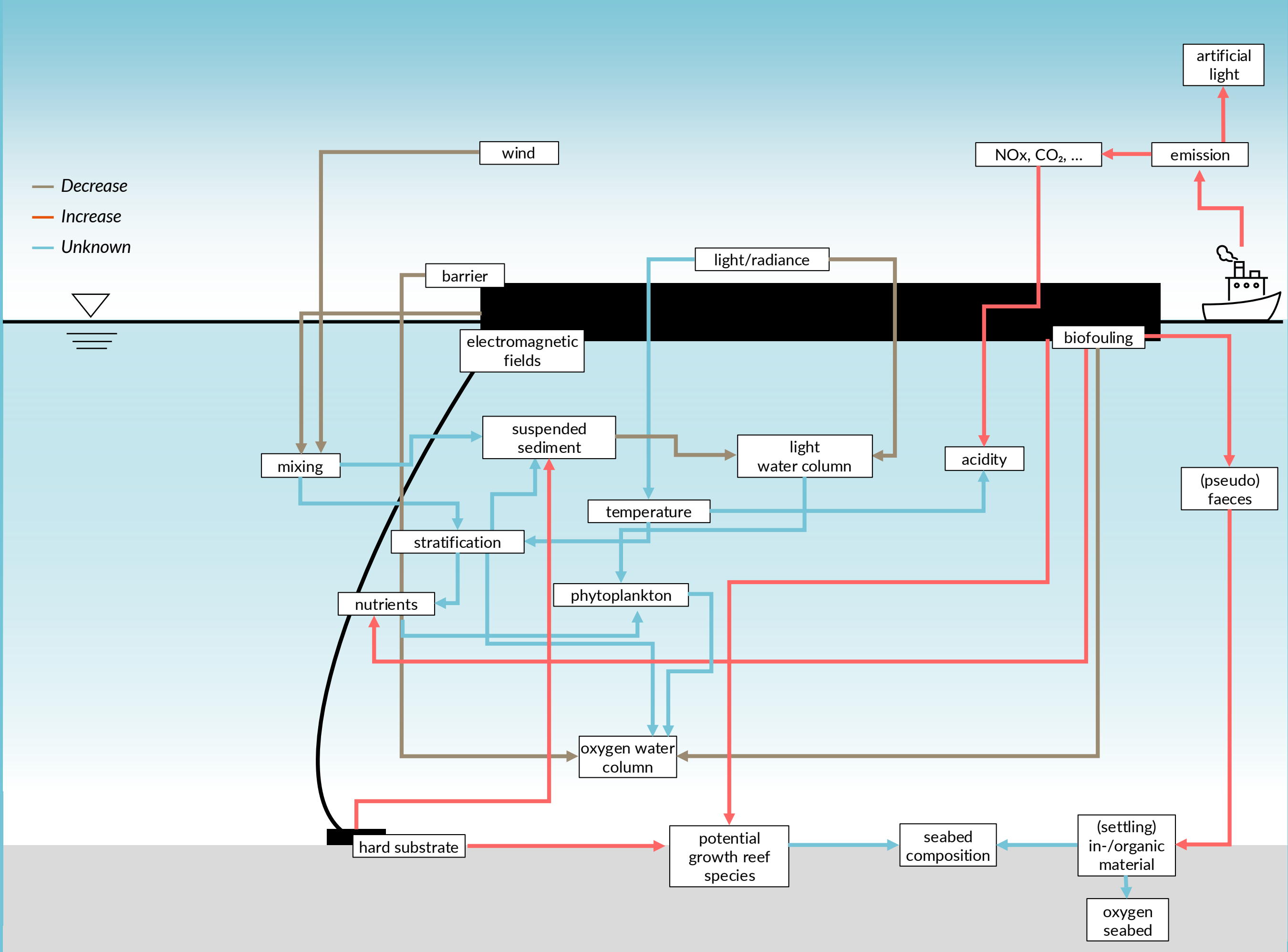


Figure 6 shows the standard design. Characteristic of the design is that:

- 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).

Nature-inclusive Spatial Design (NISD)

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 our terms of reference.

The recommendations for the NISD are primarily based on input from the experts and stakeholders participating in the workshops. In the first place the design seeks 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

Figure 6. 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.

that are expected to lead to a more biodiverse and robust ecosystem. 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 our general recommendations (above and Chapter 5 in the Full Report), however, we also discuss some recommendations for the preparatory and construction phases and for the decommissioning phase.

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 7 and 8*. 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.

Considering the current ecological state and abiotic characteristics of the Hub North area, the following spatial

Figure 7. 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.

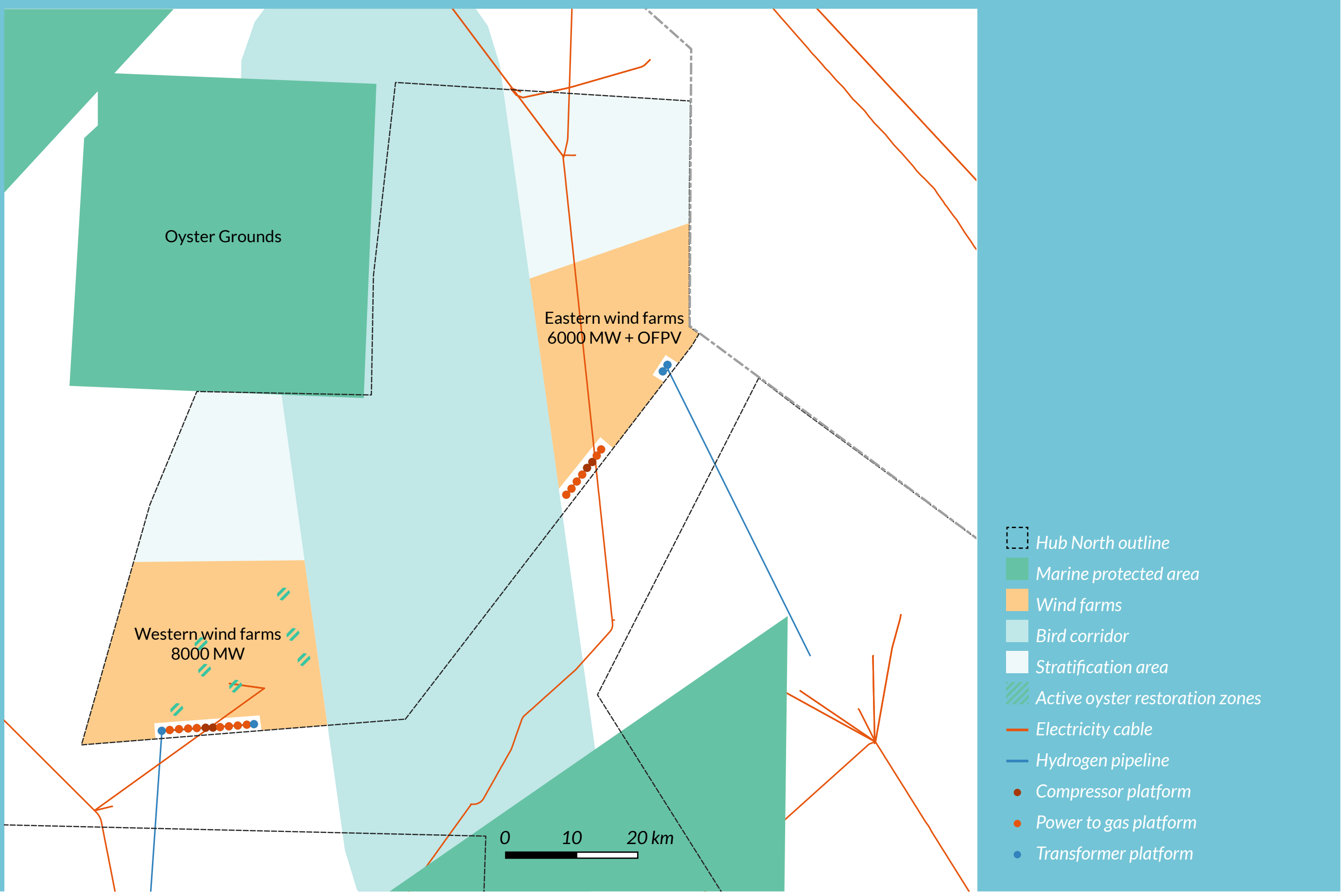
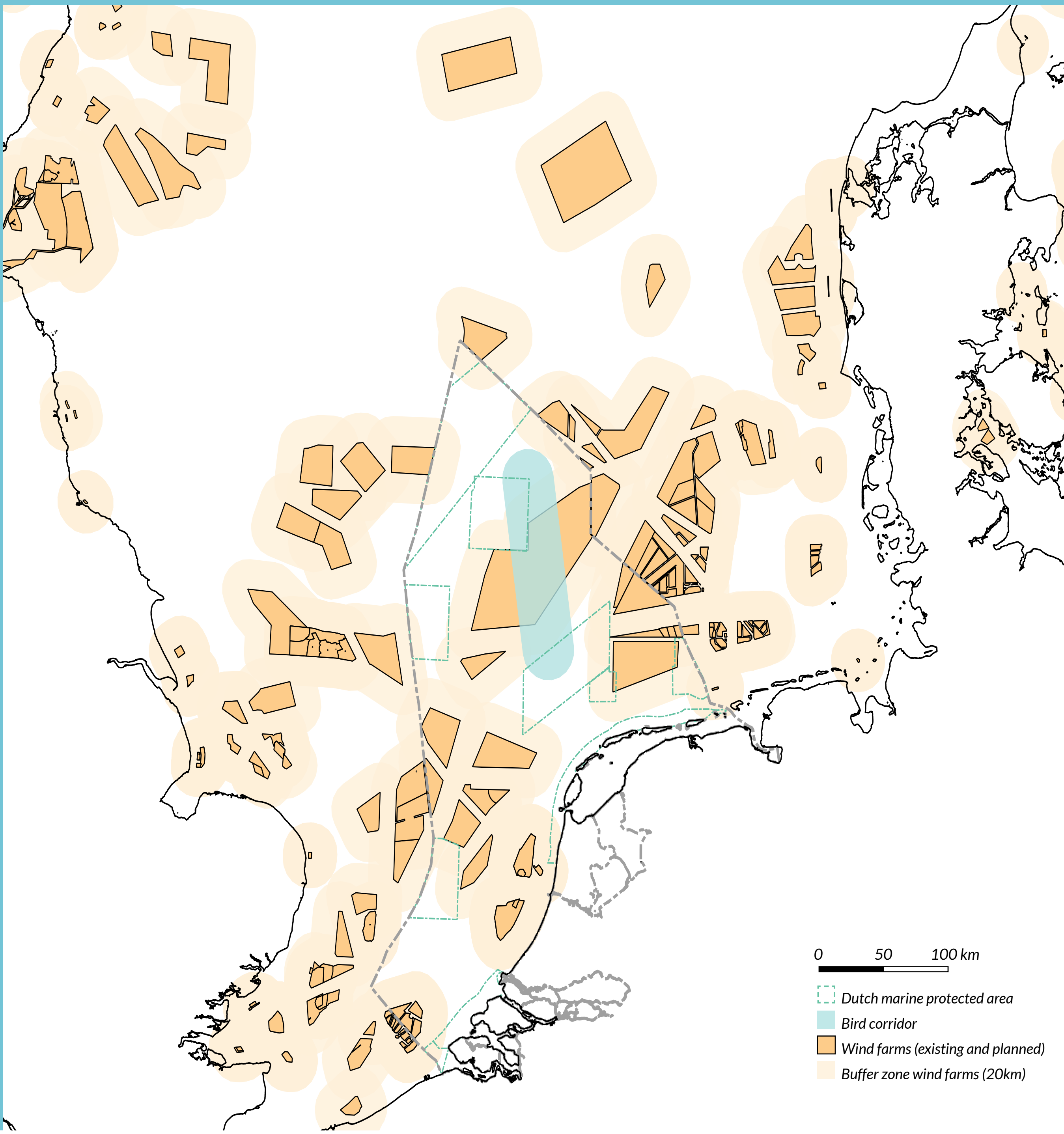


Figure 8. The bird corridor in Hub North (blue fill) in relation to Dutch MPAs (blue outline) and possible future barrier effects of OWFs, based on current OWFs and search areas. The light yellow areas around the (planned) OWFs indicate a 20 km radius of disturbance that may function as a barrier to certain bird species, in particular guillemots. The figure illustrates the severe impact cumulative OWF developments may have on birds migrating from the West and North to the Dutch Coast and the Wadden Sea. The bird corridor is meant to be free of structures and other disturbing activities such as fishery and shipping.



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.

Avoid areas of high ecological value and create areas that are closed for (all) human activities.

- **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.

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 7* require a power density of 10 MW/km2. 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. 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 in the NISD. We therefore do not specify a location of OFPV activity in the NISD. 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. 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.

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 in the Full report) 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 in the Full report). 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.

Asset-level interventions nature-inclusive design

In addition to the spatial design, asset-level interventions (also framed as NID options) 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 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. 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. In order to get a better impression of the actual potential for (artificial) reef developments in this area, it might be worthwhile setting up research on already existing man-made structures in the area, such as oil & gas platforms and shipwrecks.

Reduce speed of turbine blades and add start/stop mechanism
To decrease bird 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 nature-enhancing measures, it is important to consider the decommissioning phase of the hub already at the design stage in order to avoid that well-functioning measures will be destroyed as infrastructure is decommissioned.

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, options at intermediate level scale, 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

Qualitative assessment of the ecological impact of the Hub North designs

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, brine and chemicals from the electrolysers, 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 sea birds. A solid cumulative assessment of all potential impacts, however, is not feasible due to uncertainties of how different types of impacts add up and the difficulties of predicting how currently existing impacts, e.g. from fishing or climate change, will be influenced by hub developments in the area.

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.

In the *tables 2* and *3*, we provide a summary of the qualitative comparative assessment of the standard design and the nature-inclusive design (NISD). The details and analysis underlying this assessment are available in Chapter 4 of the Full report.

Abiotic conditions

The effects of 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.

Biotic Conditions

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 spatial/large-scale and asset-level/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,

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 in the Full report) 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

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.

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.

The potential 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, we strongly advice 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.

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 in the Full report) 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

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