Preliminary study on the environmental effects of hydrogen production at sea

Final report

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Project Leader	K.A. Haans MSc
Project Director	A.H.J. van Kuijk MSc

Author(s)	Witteveen+Bos: M. Plantema MSc, C. van Erp MSc, L. Verweij MSc, J. van der Endt MSc
Checked by	J.L.P. Eggenkamp MSc
Approved by	K.A. Haans MSc B/a A.H.J. van Kuijk MSc

Paraph

Address	Witteveen+Bos Raadgevende ingenieurs B.V. | Deventer Daalsesingel 51c P.O. Box 24087 3502 MB Utrecht The Netherlands +31 30 765 19 00 www.witteveenbos.com CoC 38020751

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GLOSSARY

Glossary

ABM	General Assessment Methodology *(Algemene Beoordelingsmethodiek)*
AIS	Automated Identification System
BLPH	Baseload Power Hub
BREF	Best Available Techniques Reference
BAT	Best Available Techniques
CIW	Commission Integral Watermanagement
CTV	Crew Transfer Vessel
Demo	Demonstration project
DNV	Det Norske Veritas, certifying body
EIA	Environmental Impact Assessment
EMF	Electromagnetic Fields
FMEA	Failure Mode Effect Analysis
FERA	Frequency of Exceedance of Risk Acceptance criteria
HK	Hollandse Kust (offshore wind energy region)
HSE	Health, Safety and Environment
IA	Inter-array
ILT	Inspectie Leefomgeving en Tranpsort - Environmental and Transport Inspection
IMO	International Maritime Organization
KEC	Kader Ecologie en Cumulatie - Framework Ecologie and Cumulation
MER	Milieueffectrapportage
MOB	Man Overboard
MSD	Memorandum of Scope and level of Detail
MSFD	Marine Strategy Framework Directive
N2000	Natura 2000
NRD	Notitie Reikwijdte en Detailniveau
O&G	Oil and/or gas
O&M	Operations and Maintenance
OSS	Offshore Sub Station
PAWE	Pressurized Alkaline Water Electrolysis
PEM	Proton Exchange Membrane
QRA	Qualitative Risk Assessments
RO	Reversed Osmosis
RWS	Rijkswaterstaat
SODM	State Supervision of Mines *(Staatstoezicht op de Mijnen)*
SOV	Service Operations Vessel
TNW	Ten Noorden van de Wadden - North of the Wadden islands (offshore wind energy region)
W+B	Witteveen+Bos Raadgevende ingenieurs B.V.
WTG	Wind Turbine Generator

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SUMMARY

More knowledge needed about environmental impacts of increasing scale of offshore hydrogen production
To meet climate goals, the Dutch government plans to develop numerous offshore wind farms in the North Sea, aiming for 21 GW by 2031, 50 GW by 2040, and 70 GW by 2050. Due to onshore grid capacity limitations, offshore-produced hydrogen is considered an alternative for energy transport, with tens of GW of hydrogen production facilities expected by 2050. Demo 1 (30-100 MW) is planned for the Hollandse Kust (HK) region, and Demo 2 (500-700 MW) in the North of the Wadden Islands (TNW) region. Environmental impact assessments (EIAs) are required before construction. Currently, there is limited experience with offshore hydrogen production, with only two small pilot projects in operation: the PosHYdon project (1 MW)[1] by Neptune Energy and the Baseload Power Hub project (2.5 MW) by Cross Wind (Shell/Eneco)[2]. Due to limited experience with offshore hydrogen production, the Ministry of EZK commissioned a pre-study on environmental effects and research methods for central and decentral cases for Demo 1 and 2.

More insight in environmental effects and knowledge gaps of offshore hydrogen production
This *Preliminary Study on the Environmental Effects of Hydrogen Production at Sea* aims to provide an initial insight in to environmental effects, research methods and knowledge gaps for central and distributed cases for the Demo 1 and 2 offshore hydrogen production projects. This report serves as a precursor to an upcoming EIA process; Memorandum of Scope and level of Detail (MSD, *NRD in Dutch*) and project Environmental Impact Assessments (project MER's) for the two demonstration projects.

Key research question
The main research question: *What are the relevant environmental effects, related research methods and knowledge gaps, that can occur from hydrogen production at sea in four cases (small and large scale, centralized and decentralized) in TNW and HK region during all lifecycle phases?*

Collaborative effort with key contributors
This study was conducted by Witteveen+Bos and DNV, with input from a group of hydrogen experts. These experts have experience with hydrogen technologies and regulation of offshore applications. Key contributions came from several institutes, including the Ministries of EZK, I&W, and LNV, Rijkswaterstaat (RWS), Gasunie, TNO and RVO.

Study methodology
This study inventories the environmental effects, knowledge gaps, and research methods related to offshore hydrogen production. Impact assessments were not conducted, as these require an Environmental Impact Assessment (EIA). The research covers all lifecycle phases of four cases, limited to electrolyser platforms, inter-array cables and pipelines:
1 Demo 2: large-scale centralized production (495MW) in TNW region.
2 Same as case 1, but with decentralized production.
3 Demo 1: small-scale centralized production (45MW) in HK region.
4 Same as case 3, but with decentralized production.

[1] For the first time green hydrogen will be produced offshore on an operational platform. PoSHYdon: https://poshydon.com /en/home-en/

[2] Hydrogen. Crosswind: https://www.crosswindhkn.nl/ news/2021/12/hydrogen/

Technical descriptions of each case's conceptual design were drafted, followed by an overview of *lifecycle activities* (construction, operation, maintenance, decommissioning) Intervention-effect relationships were then determined, and knowledge gaps identified, based on comparable projects like offshore substations, wind turbines, and oil and gas platforms.

Results and recommendations per lifecycle phase

Construction Phase: environmental effects during construction are similar to those of an Offshore Substation (OSS) for centralized concepts or wind turbines for decentralized concepts. Key impacts include underwater noise during piling, and emissions of NO_x and CO_2. No additional knowledge gaps were identified..

Operation and Maintenance Phase: Significant environmental effects include emissions from hydrogen production units. Key knowledge gaps were identified in the following areas:

- *Cooling water intake and discharge:* The cooling loop requires vast amounts of water. Therefore, a risk of intake of species, like fish and larvae, with direct mortality as an effect will be present. Effects of pollution from discharge of cooling water with increased temperature, containing anti-fouling chemicals and brine will be present at the outlet.
    - *Recommendation: use a hydrological 3D model to quantify velocity profiles at the intake and outlet based on location-specific characteristics (water depth, currents, salinity), followed by an ecological assessment. Optimize design parameters iteratively for ecological and operational aspects.*
- *Noise during operation:* compressors may produce a substantial degree of (underwater) noise. It is unknown what the exact noise level from the different sources will be. Moreover, it is unknown what the impact from the disturbance effects to marine life and birds is.
    - *Recommendation: use of underwater noise models* for operational noise and ecological assessment.
- *Internal and external safety:* An offshore hydrogen platform will pose internal and external safety risks during all of its lifecycle phases, which cannot be compared one-to-one with current offshore practices.
    - *Recommendation:* further development of *technology, standards and advanced QRA's* are required to improve internal and external safety.
- *Emissions to air*: Fugitive emissions of hydrogen, oxygen, nitrogen, SF6, and KOH can occur during operation, along with intentional venting during commissioning or safety incidents. Knowledge gaps exist regarding the effects of these emissions.
    - *Recommendation: perform emission studies*, and studies on *hydrogen's effect on global warming*.
- *Cumulation:* knowledge gaps exist on the cumulative effects of offshore hydrogen production, including combined impacts with other activities like wind farms and effects on other North Sea users.
    - *Recommendation:* study cumulation with present and future environmental pressures. A mitigation strategy can be developed when the cumulative impact is mapped.

Decommissioning phase: decommissioning was assumed to mirror the construction phase in reverse, with comparable effects and no additional knowledge gaps. However, since decommissioning will occur decades later, methods may differ, indicating a potential knowledge gap.

Differences per case

Due to large uncertainties, it is unclear whether central (Cases 1 and 3) or decentralized (Cases 2 and 4) concepts have more environmental impact. Primary effects of Cases 1 and 2 are larger due to higher capacity, but impacts may vary by area. Further assessments are needed to determine specific environmental effects. Detailed information is in paragraphs 5.3 to 5.6.

- *Recommendation: it is advised to investigate location and project (case) specific effects and the difference between central and decentral concepts, to determine and assess their environmental impact.*

Quickscan Environment and Planning Permit

A quickscan identified Environment and Planning Permit conditions for the electrolyser and its cooling system, including requirements for water intake and discharge. Indicative standards apply to intake flow rate and ecological protection. For thermal cooling capacity over 50 MW, modeling exercises meeting Rijkswaterstaat requirements are needed for a permit.

2

INTRODUCTION

2.1 Reason and goal

The Dutch government (fourth Rutte cabinet) raised the climate ambitions by setting a target for a carbon free electricity supply by 2035 and a complete transition from a fossil fuels-based energy system to a climate neutral energy system in 2050 . This transition requires drastic investments in renewable energy sources but also in the electricity grid, as it is expected that it cannot cope with matching the growing supply of fluctuating green electricity with demand by 2030. A significant role for offshore wind energy is envisioned in the future energy system. The Dutch part of the North Sea will contain 21 GW of offshore wind by 2030, 50 GW by 2040 and up to 70 GW by 2050, according to the offshore wind roll-out map as explained in a letter to the parliament.

Currently, the onshore electricity grid is not yet prepared to receive, transport, and distribute the planned electricity from the North Sea. Simultaneously, the industrial and transportation sector need to become climate neutral but, while electrification will likely be the most efficient solution, not all industrial processes and modes of transportations can be easily electrified. These so called "hard to abate sectors" are considering hydrogen to take an important role as a facilitator in the energy transition. Moreover, hydrogen can be stored over a longer period and in larger quantities than electricity, and natural gas infrastructure can potentially be repurposed for hydrogen transportation. European and national ambitions are therefore including hydrogen production targets which for the Netherlands should lead to 4 GW in 2030 to 8 GW of electrolysis capacity in 2032 . Although no fixed targets have been set yet, more hydrogen capacity will be needed until 2050.

Offshore hydrogen production can potentially complement onshore production, as well as import of hydrogen. Next to that, space and capital can be saved on offshore electricity cables and grid integration at the landing point by producing hydrogen offshore. An additional advantage to onshore hydrogen production is the use of desalinated seawater over scarce fresh water.

However, the production of hydrogen offshore is new and uncertain. Currently, there are two small scale demonstration projects under development in the Netherlands. The first project is a 1 MW electrolyser on an oil platform in the North Sea, located around 13 kilometres off the coast from Scheveningen, named PosHYdon. The second offshore hydrogen project is the Baseload Power Hub (BLPH) from the Crosswind consortium. It involves a 2.5 MW electrolyser on a monopile to be commissioned by the end of 2025.

Limited knowledge is available on the effects from hydrogen production on the offshore environment, while the pressure on the ecological carrying capacity of the North Sea is increasing. So, it is necessary to build up knowledge and experience before the large-scale roll-out of hydrogen production facilities on the North Sea can be initiated.

Two demonstration projects are announced by the Ministry of Energy and Climate in order to develop knowledge and experience with offshore electrolysis. The first project is a medium scale plant, less than 100 MW, in the Hollandse Kust (HK) region, named Demonstration project 1 (Demo 1). The capacity of Demo 1 will be equivalent to the capacity of around three to seven offshore wind turbines. The aim is to develop it between 2027 and 2031 as an additional part of a wind farm in an already permitted lot in the HK area.

Gasunie is involved in Demo 1 to research the hydrogen transportation to shore. TenneT is involved to explore the opportunities for connecting the electrolyser to the substation.

The second project concerns a large-scale electrolysis plant of around 500 MW, named Demonstration project 2 (Demo 2). The Ten Noorden van de Wadden (TNW) region is the search area for Demo 2. This area is already assigned as a wind energy development area where hydrogen production can be included in the site decision. The location is also beneficial from the perspective of the envisioned offshore hydrogen network. For example, the existing gas grid infrastructure in the TNW region might be repurposed for the transportation of hydrogen. Next to that, a hybrid connection (a combination of electricity cable and a hydrogen pipeline), connected with wind farm Doordewind, is under consideration.

In figure 2.1, the wind energy regions Hollandse Kust and Ten Noorden van de Waddeneilanden are visualized. The Demo 1 and Demo 2 projects will be accommodated in windfarm areas in these regions. Next to the exact locations, many other design variables are still undecided upon. For example, the set-up (one central electrolyser unit or multiple decentral units at the base of the WTG) and the precise scale of both projects are not established yet. The demonstration projects will be used to:

1 Test the technology in an offshore environment.
2 Test the connection with offshore wind farms and transportation to shore.
3 Learn about the environmental effects of the aforementioned aspects in order to develop the necessary permits.

Prior to permit authorization of Demo 2, the environmental impact must be properly investigated. This is performed in a 'Memorandum of Scope and level of Detail' (MSD) (Dutch: Notitie Reikwijdte- en Detailniveau or NRD) followed by an Environmental Impact Assessment (EIA) (Dutch: Milieueffectrapportage or MER).

2.2 Scope and research questions

The environmental effects of electrolysers on platforms will be partly comparable to, and therefore known from, experiences from offshore wind farms and the oil and gas sector. For example, piling of a similar type of foundation, laying of electricity lines, and lifting of a comparable sized topside. However, there are also clear differences, such as the presence of hydrogen pipes, absorption of seawater and release of cooling water, of which environmental impacts are unknown.

Therefore, the Ministry of Climate and Energy (recently renamed to Ministry of Climate and Green Growth) assigned Witteveen+Bos and DNV the task of mapping the environmental effects and knowledge gaps of offshore hydrogen production for four different cases of offshore electrolysis. The cases consider different setups, locations, and production capacity. By mapping the environmental effects over the lifetime of an installation for the different cases and the existing knowledge gaps in this report it is aimed to prepare the government for the future EIA and permitting processes of offshore hydrogen projects.

This research includes all lifecycle phases, whilst being limited to the electrolyser platforms, inter-array cables and inter-array pipes. This is a preliminary study using existing knowledge and literature to identify effects and knowledge gaps. A (quantitative) impact assessment of the effects will follow in the EIA process.

This study aims to answer the following main research question and sub-questions:

- '*What are the most relevant environmental effects, related research methods and knowledge gaps that can occur from hydrogen production at sea in four cases (small and large scale, centralized and decentralized) in TNW and HK region during all lifecycle phases?*'
    - *'What components does the installation consist of and how are they described for the various cases?'*
    - *'What are the intervention-effect relationships in the different lifecycle phases (construction, operation, maintenance and disposal) of a hydrogen production platform in the case scenarios?'*
    - *'Which research methods are suitable for the intervention-effect relationships and which environmental effects need to be further investigated for these cases and lifecycle phases?'*

2.3 Process of the study

This study was conducted according to the following process. The first phase of the research commenced by a kick-off meeting with the client to share knowledge on the subject and exchange contact information of hydrogen experts who might be willing to cooperate in a questionnaire for this study. Then, in collaboration with the client the study cases were defined (see Chapter 3) and an inventory of reference projects was made. In the final step of this phase, for these cases technical descriptions of the different offshore hydrogen production setups were formulated. Subsequently, intervention-effect relationships were formulated by the project team, with the help of internal experts on the field of marine ecology. The relationships were specified for a base-case. The intervention-effect relationships, along with the technical descriptions, were submitted to external hydrogen experts and marine ecologists. The feedback of the experts was asked to provide on the intervention-effect relationships, the environmental impacts and the research methods was analysed and processed in this report. Next to that, a questionnaire was sent to acquire additional information on the environmental impacts from experts.

The third phase of the project started by analysing the feedback and the results of the questionnaire from the experts. Finally, the project was concluded by drafting the research report and delivering conclusions and recommendations to the client.

2.4 Reading guide

Chapter 3 describes the cases and methodology used in this study. Chapter 4 provides an overview of the case dependent conceptual designs, technical descriptions, and assumptions. The general and case-specific environmental effects of an offshore hydrogen platform are described in Chapter 5. Finally, in Chapter 5 the study is concluded and recommendations for starting points of future NRD's, EIA's and an Environmental and Planning Permits are listed.

Figure 2.1 Route map offshore wind energy with development areas for Demo 1 & 2, (source Rijksoverheid)

3

CASES AND METHODOLOGY

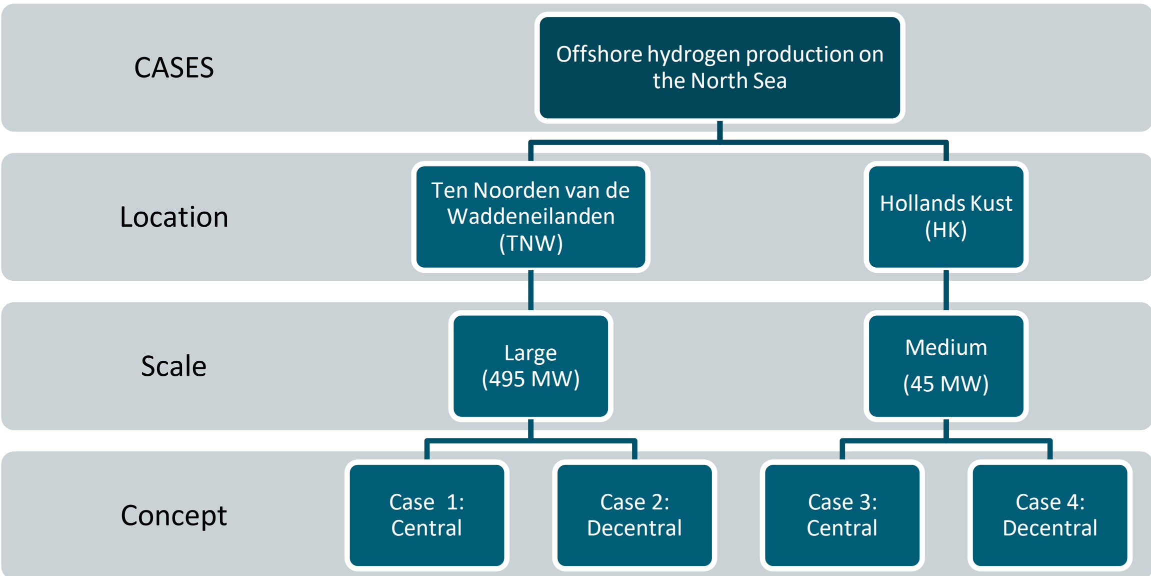
This chapter describes the cases and methodology used to determine the environmental effects for the cases.

3.1 Cases

To address the many unknown design choices of the offshore hydrogen production facility, four cases were defined as framework to determine known and unknown environmental effects. The cases have been defined according to the demonstration projects 1 and 2 and in conciliation with the client. Three design choices were taken as variables for creating the cases; location, size, and set-up (figure 3.1).

The locations of the cases, as mentioned in Chapter 2, are the HK-region (as co-use) and TNW. The size is either large scale (495 MW) or medium scale (45 MW). The large-scale capacity is based on the provisioned capacity of Demo 2. The medium scale is decided upon in correspondence with the client and refers to the combined capacity of three WTGs (Wind Turbine Generators) as foreseen for Demo 1. The hydrogen production concept is either centralized (on a platform) or decentralized (an individual installation at each WTG). It is already decided that in the HK-region a medium scale facility will be developed and in the TNW area a large-scale facility.

Figure 3.1: Decision tree of design choices leading to the four cases



3.2 Methodology

Technical descriptions of the hydrogen production facility in the four cases are developed in collaboration with DNV. Firstly, the facility is subdivided into the main components and activities. The PEM technology is chosen for each component, as, due to its smaller size, this is the most likely technology for offshore application. In the absence of a well-defined design for the new technologies and applications, a high-level approach was taken. For presently unknown design choices, like electrolyser technology, the option with the highest expected impact is chosen in order to get to a 'worst-case scenario'. The technical descriptions and design choices can be found in chapter 4. Secondly, one of the four cases was chosen as a starting point. Case 1 is taken as base-case for analysis, with likely the largest (compared to Case 3 and 4) and most concentrated effect (comparted to Case 2). The outcome of Case 1 was taken as the basis for the analysis of Case 2-4.

Then, the intervention-effect relationships of the main components and activities for Case 1 are determined by experts from DNV and Witteveen+Bos for each lifecycle phase, namely construction, operation, maintenance, and decommissioning. An exploratory *Failure Mode Effect Analysis* (FMEA) work session was performed by the project members of DNV and Witteveen+Bos, using the technical descriptions as input. This resulted in an exploratory overview of the effects, hazards and risks of the activities and substances used over the lifecycle of an offshore hydrogen plant.

FMEA

An FMEA is a widely used and proven method for safety analyses in various industries. In an FMEA, risks, their effects and solutions are identified by means of expert sessions/workshops in which relevant aspects/processes of a system are systematically addressed. In our approach, the relevant aspects/processes were based on the technical descriptions. For the FMEA workshops, the combined expertise of W+B and DNV was used, in which subject matter experts from different fields (environment, safety, electrical, gas treatment, etc.) contributed.

Ecological and non-ecological effects were identified for each lifecycle phase. Along with intervention-effect relationships, the impacts to the environment, the research methods and the potential knowledge gaps are listed for each (sub-)activity in a table, as can be seen in Chapter 5. After that, the differences in effects between Case 1 and the other three cases are analysed and described in Chapter 5.

Some of the expected effects (ecological, non-ecological or external safety) of the cases can be roughly estimated, as the structure resembles an offshore substation (OSS) and an offshore oil/gas platform. Nonetheless, most additional facilities (like electrolysers, compressors) that are required for offshore hydrogen production are novel technologies and require further research. It is indicated when similar effects of an activity or process can be expected, like underwater noise from pile driving during construction. Additionally, a reference to the effect determination and research method, like an EIA of an OSS, is provided. Effects which are not similar to current practices, for example the effect of heat discharge in open sea at the scale as is provisioned, received extra attention as they will be more precarious during the EIA process. The knowledge gap of these effects are indicated.

3.2.1 Methodology for the assessment of ecological and non-ecological knowledge gaps

To increase the readability, a complete overview of all existing ecological and non-ecological knowledge gaps is presented for Case 1. For the other cases, only additional knowledge gaps are provided.

For ecological effects and research methods knowledge gaps are inventoried according to five broad categories. These are:
1 Birds, as protected under the Environment and Planning Act (Omgevingswet).
2 Bats, as protected under the Environment and Planning Act (Omgevingswet).
3 Marine Mammals, as protected under the Environment and Planning Act (Omgevingswet).
4 Habitats, as protected under the Marine Strategy Framework Directive (MSFD) and the Environment and Planning Act (Omgevingswet), including onshore habitats.
5 Marine life, as protected under the Marine Strategy Framework Directive (MSFD) as MSFD descriptors.

For non-ecological effects and research methods knowledge gaps are related to existence EIA's for facilities with resembling components or activities, like an OSS or an oil & gas platform.

In table 3.1 the degree to which knowledge gaps are to be expected is determined for each intervention-effect relationship. The effects are labelled as:
- Known if they have been applied elsewhere.
- Partially known if the intervention has additional components or different effects sizes compared to known applications.
- Fully unknown if the entire intervention is novel.

Table 3.1 Colour coding used for knowledge gaps regarding ecological effects of offshore hydrogen production relative to other offshore activities

Knowledge gap
No significant new knowledge gaps for hydrogen production are expected - effects are known
Some knowledge gaps are expected - effects are partially known, research may be required to be able to do assessment
Substantial knowledge gaps expected - effects (of this scale) are unknown and cannot be assessed without additional research

For identified knowledge gaps, either the design aspect should be further developed in the design process, or the intervention-effect relationship should be studied in more detail. As such, a knowledge gaps identified in this report, provides a basis for future research, including an EIA.

3.2.2 Role of permitting authorities

The permitting authorities, such as Rijkswaterstaat, play a crucial role in overseeing environmental impact assessments (EIAs) to ensure that proposed developments adhere to regulatory standards and do not pose significant harm to the environment. Offshore hydrogen production facilities are likely to result in environmental impacts and are therefore eligible to conduct an EIA-procedure. Such an EIA must demonstrate that the anticipated impacts of their activities will not result in significant environmental effects[1].

Regulatory limitations and the discretion of the Competent Authority determine whether proposed activities are permissible within established permitting boundaries. This process ensures that the design of the installation aligns with permit restrictions. The focus of this study is to identify knowledge gaps regarding environmental impacts and, where possible, methods to investigate these effects. Addressing these knowledge gaps is essential for both developers and Competent Authorities to make informed decisions that mitigate the risk of undesirable environmental effects caused by the installation.

[1] Milieueffectrapportage. Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat: https://www.infomil.nl/ onderwerpen /integrale/mer/

3.2.3 Environmental and Planning permit requirements

A general overview has been set up that contains relevant aspects to consider regarding the Environmental and Planning Permit (formerly known as *Water Permit*), including chemicals, brine, and cooling water emissions, which is required to build the hydrogen production platform. See attached memo for legal requirements for an environmental and planning permit in Annex V. The conclusions of the quick scan on the permitability of water discharge activities on the North Sea are:

- Discharge of heated water to surface water cannot have significant negative effects to ecology;
- The CIW assessment framework (Commission Integral Water management)[1] is used to assess the heat emissions. The CIW falls under Rijkswaterstaat as the authorized institution. The CIW framework sets standards for rivers, canals, estuaries, and the North Sea area.
- Cooling water from industrial facilities exceeding 50MW require additional modelling exercises. For this reason, permitting for cooling water from hydrogen production facilities above 50MW should be obtained in accordance with Rijkswaterstaat.
- The maximum allowable temperature increase of the receiving water after it is fully mixed with cooling water is 3 °C.
- The maximum allowable temperature of the receiving water is dependent on the water type, for example, shellfish water may not exceed 25 °C
- The mixing zone that arises as a result of heated water discharge is not allowed to interact with the seabed.
- Ecological effects from brine discharge need to be further investigated.
- Ecological effects from antifouling chemicals need to be assessed with an emission/immission test and the dosage needs to be optimised.
- An electrolyser is an IPPC (Integrated Pollution Prevention and Control) installation, which means that it needs to conform with European Best Available Technologies documents.
- Measures need to be taken to prevent intake of organisms and local circumstances with regard to spawning areas, juvenile habitats and migratory routes need to be assessed.

3.3 Hydrogen experts input

Besides the technical descriptions and intervention-effect sheets, a questionnaire was made consisting of two parts. The first part aimed to identify the most significant environmental effects and the most important knowledge gaps about environmental impacts and their research methods, using a Top-5 list. The second part aimed to instigate the experts to make statements about the differences in environmental effects between the cases.

The technical descriptions, the overview of intervention-effect relationships and the questionnaire were sent to numerous (offshore) hydrogen experts. The experts were asked to give feedback and deliver input on the documents. Their feedback was analysed and incorporated in the study results. The complete sheets with environmental effects, including the implemented feedback and additions from the hydrogen experts, can be found in Annex II.

The analysis of the expert feedback has been performed by collating the comments on the technical descriptions and intervention-effect sheets. After that, the comments were processed. The technical descriptions are summarized in Chapter 4 and the complete descriptions, including the processed comments, can be found in Annex I. The questionnaire has been analysed by categorizing and synthesizing the items in Top-5 lists, to come to a list of environmental impacts in order of significance according to the experts. The statements were analysed by marking the messages and subsequently incorporating the messages in the conclusion of this study.

[1] Lozingsvoorschriften koelwater. Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat: https://www.infomil.nl/onderwerpen/integrale/activiteitenbesluit/activiteiten/afvalwater/koelwater/

4

TECHNICAL DESCRIPTIONS

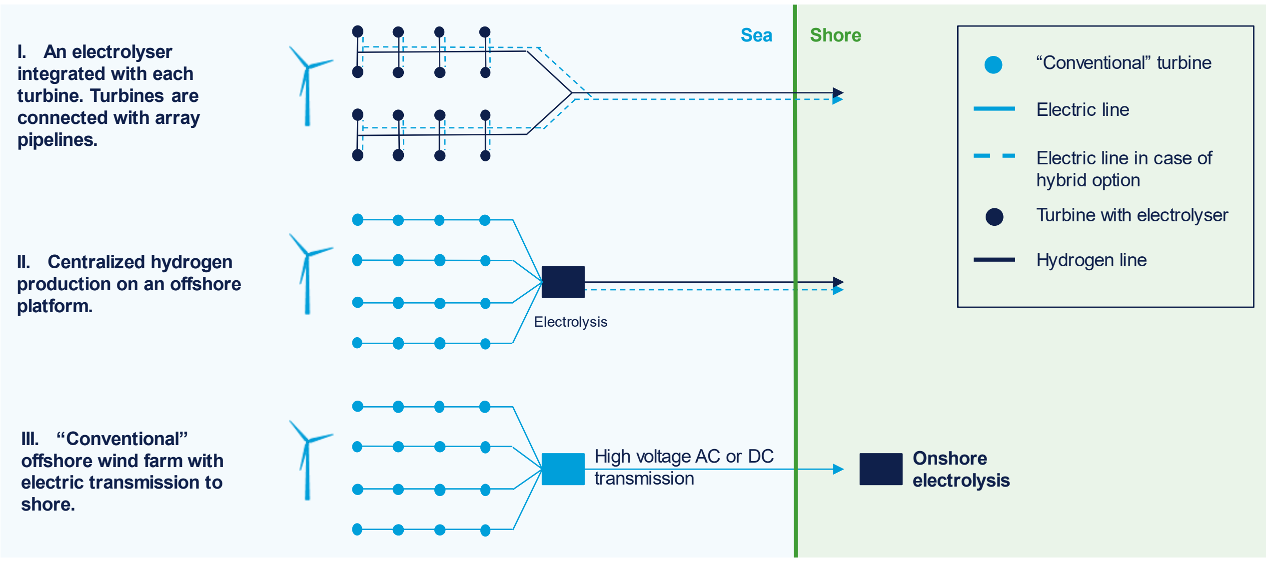
4.1 Introduction

Currently, no electrolysers of a comparable size to the demonstration projects are in operation on an offshore platform or wind turbines. Hence, this research is based on general conceptual designs and general assumptions. General concepts of offshore hydrogen production in an offshore wind farm or turbine are described in this paragraph. Next to that, the assumed technological design choices, like type of electrolyser, for the cases are explained. The detailed technical descriptions can be found in Annex I.

4.2 Offshore wind and hydrogen production concepts

Hydrogen production through electrolysis uses electricity to split water into hydrogen and oxygen. This electricity can be generated by renewable sources such as wind energy and with a direct connection to the source. figure 4.1 shows three possible configurations for connecting an electrolyser plant to an offshore wind farm.

Figure 4.1: Hydrogen production concepts



I. Decentralized offshore hydrogen production: The first configuration integrates the hydrogen production at the turbine. A smaller electrolyser unit is directly connected to the turbine to generate hydrogen and will omit the requirement for array cables. Instead, array pipelines are used for the transportation of hydrogen.

II. Centralized offshore hydrogen production: The second configuration resembles a conventional offshore wind farm but is not connect to the grid. Instead, the electricity is fed to an electrolyser system where hydrogen is produced. The electrolyser plant is located on a centralized platform (comparable to a sub-station), receiving electricity from the array cables. Alternatively, the electrolyser plant can be placed on a platform where multiple wind farms can feed into.
III. Onshore hydrogen production: The third configuration is more conventional. A wind farm is built and instead of connecting it to a grid, it is directly connected to the electrolyser plant located onshore.

In the three configurations provided above, all electricity is converted to hydrogen. Alternatively, a *hybrid system* can be chosen, where only a part of the electricity is converted into hydrogen. Hybrid systems have a connection to the electric grid (e.g. indicated with dashed light blue lines in configuration II) and a connection to the electrolyser. The connections, electric and hydrogen, can either both be designed to transport the full capacity or only a smaller part of the capacity of the connected wind farm. For example, from a 15 MW turbine, 10 MW can be connected to an electrolyser and the remaining 5 MW can be connected electrically. The connecting infrastructure, array pipes and cables and further export pipes and cables should be designed to the required capacity as well. Such a system allows the operator to choose an operation strategy based on the market prices of hydrogen and electricity.

This report focusses on concept I and II and are further elaborated below. Concept III and hybrid systems are out of scope.

4.2.1 Central concept

The central concept assumes hydrogen production on an offshore platform where multiple turbines are connected through array cables. The platform is equipped with a transformer system, an electrolyser, a water treatment system, and a cooling system. All equipment is placed on multiple decks, which can be lifted as a complete topside on the jackets. The concept uses sea water for cooling and, after water treatment, as feed water for the electrolyser.

Based on expert discussion with offshore operational experts it is unlikely that the first hydrogen production platform will be permanently unmanned, especially for Demo 2 due to its capacity, as the novel operation of offshore compressors and electrolysers require constant supervision and maintenance. The required maintenance actions and interval are still unknown but will likely be performed from a Service Operations Vessel (SOV). The platform will be decommissioned by lifting the topside and further dismantling it onshore.

4.2.2 Decentral concept

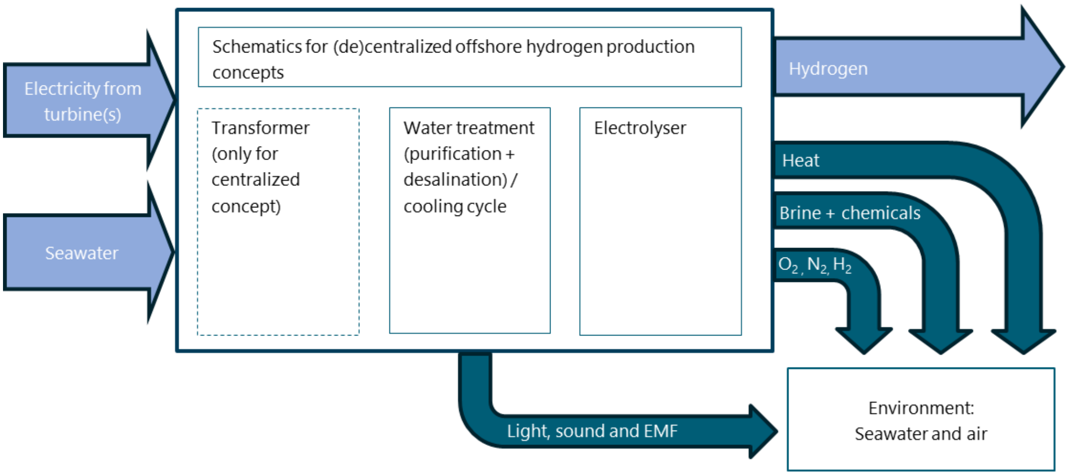
The decentral concept assumes that the hydrogen production is integrated in the wind turbine. A container with equipment, including a water treatment installation, an electrolyser, and a cooling system, is installed inside the turbine or on a working platform at the basis of the turbine tower. This concept also uses sea water for water treatment and as feed water for the electrolyser. The hydrogen will flow via inter-array pipelines to a central point and further to shore via a transfer export line. Additional compression of the hydrogen is required in the case of transportation over a long distance.

The construction of the turbine and substructure are assumed to be similar to a conventional turbine with a jacket foundation. Maintenance will be performed with a SOV in combination with a crew transfer vessel (CTV) to get the crew on the working platform. The required maintenance actions and intervals are still unknown. Finally, it is assumed that the container is decommissioned by lifting it from the working platform and further dismantling it onshore.

4.2.3 Basic schematics and general assumptions

A basic schematic overview of both concepts, with in- and out-flows, can be seen in Figure 4.2. The in-depth technical descriptions with detailed schematics, technical specifications and assumptions for each concept as formulated in the cases, including ingoing and discharged substances, and emissions, can be found in Annex I.

Figure 4.2: Schematic overview of (de)central concept (arrows not up to scale)



The general assumptions, applicable to both concepts, are listed below. The general assumptions are based on expert opinion from hydrogen experts at DNV. The assumed technological design choices are explained in the subsequent paragraphs.

General assumptions:
- A 5° Celsius increase in water temperature is assumed for the effluent water relative to the seawater;
- Oxygen and nitrogen are assumed to be vented to the air.
- Brine and (anti fouling) chemicals will be mixed with cooling water and subsequently emitted to the surrounding seawater.
- Waste water from (un)manned operation is collected, transported, and processed onshore.
- Compression will be applied, but it requires further optimisation if this will be decentralized or centralized, as well as an optimisation on the pressure regime.
- The cases are based on the demonstration projects, so it is assumed that no large-scale electrolysis will take place in HK region and no medium scale in the TNW region.

Temperature difference

The temperature increase of 5° Celsius is regarded as a starting point. 5°C is a relatively low temperature difference with surrounding water but will result in large volumes of cooling water (as temperature difference and volume of cooling water are communicating vessels) flowing in and out of the system. In future optimization studies, a larger temperature difference of e.g. +10°C or +15°C can be used to find the optimal point between operating efficiency, costs and environmental effects of increased water temperature and water flows.

4.2.4 Options and assumed technologies

Electrolyser technology
Currently, only Proton Exchange Membrane (PEM) and Pressurized Alkaline Water Electrolysis (PAWE), are being developed for offshore application and therefore both can be expected in the future. The key differences between the two technologies relevant for this study are described below:
- Maturity: PEM is assumed to be a less mature technology, but likely better suited for offshore application due to it's size;
- Footprint and weight: PAWE is assumed to have a higher footprint and weight.
- Operating flexibility: PAWE is assumed to have a lower operating flexibility, which means that it cannot handle large and sudden variations in capacity.
- Maintenance requirements and interval: PAWE requires more maintenance.
- Use of chemicals: PAWE requires lye (mix of water and KOH or naoh) in a closed system, PEM does not require lye.
- Degradation and efficiency: PEM is assumed to have a lower efficiency.

In this study PEM is being considered instead of alkaline electrolyser as PEM is expected to be the most likely technology to be applied, due to its smaller size, lighter weight, and less required chemicals.

When using substances during a discharge, an immission test, ABM test and BREF test (installation) must be carried out. These tests are essential for ensuring environmental quality and regulatory compliance. They help identify potential problems and implement measures to minimize environmental impact.

An *immission test* evaluates the concentrations of pollutants in the environment, particularly in air, water, or soil, after they have been released from a source such as an industrial installation. The goal is to determine whether these concentrations meet legal standards and whether they are harmful to humans and the environment. *ABM* stands for *General Assessment Methodology (Algemene Beoordelingsmethodiek)*. The ABM test is a standardized method for assessing the environmental impacts of certain substances or activities. It encompasses a wide range of environmental factors, such as air quality, water quality, soil quality, and ecology. The BREF test is an assessment of the techniques used in an installation to limit emissions. *BREF* stands for *Best Available Techniques Reference*. This includes evaluating technologies and methods considered as the best available techniques (BAT) to minimize environmental impact

Water treatment technology
Water is required for two purposes: feedwater to the hydrogen production process, and cooling water. Sea water can be used for both purposes but will require pre-treatment, especially for the feedwater as fresh water with a high purity is required. The feedwater is assumed to be extracted around the middle point between the seabed and the water line. A specific duty of care applies to the water extraction activity[1].

Feed water production can be done through reversed osmosis (RO) or through thermal desalination.
The main consideration between the two technologies are:
- Use of chemicals: RO uses more chemicals than thermal desalination. Anti-limescale is required to keep RO installations clean, this needs to be filtered and stored on-site so it can be transported to shore.
- Maintenance interval: RO requires more maintenance than thermal desalination, especially the exchange of filters and chemicals.
- Synergies with electrolysis process: waste heat from electrolysis process can be used during thermal desalination, the water treatment system and the cooling system can be integrated. However, operating temperatures of the PEM platform are expected to be lower than the temperature required for thermal desalination.

At this stage both technologies are considered for offshore hydrogen production.

[1] Besluit activiteiten leefomgeving - hoofdstuk 7. Overheid Wettenbank: https://wetten.overheid.nl/ BWBR0041330/2024-05-07

Cooling water

Once-through sea water cooling is assumed as the cooling method for this pre-study as this is currently the technical most viable cooling method. Sea water can be used as cooling water by adding chemicals such as chlorine (which form bromoform and chloroform). This additive is needed to keep the water ducts and the heat exchanger clean from marine growth. Alternative cleaning methods are in development (e.g. with bio-degradable sponges) which are less harmful to the environment. Moreover, alternative cooling methods, like closed-loop sub-sea cooling, may be possible. Future studies could focus on cooling systems so the MSD can short list one or a few cooling methods, which is/are assessed in the EIA.

Back-up power

In a conventional offshore wind farm an electrical connection with the grid is present, which can be used for back-up power to perform a 'black-start', run safety systems or to keep critical components running. A larger back-up power system is needed for offshore hydrogen production. This can be done through batteries, fuel cells (consuming hydrogen from the pipelines), small electrical grid connections, or a diesel generator (unlikely).

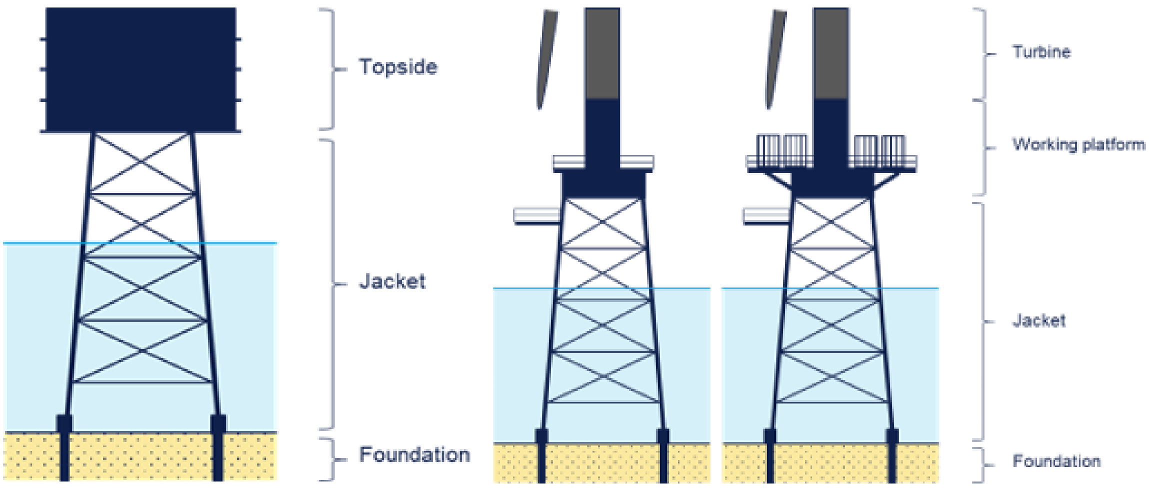
A battery electric storage system with Li-ion technology is assumed to be installed as back-up power for the design in this study.

Substructure

The wind turbines can be installed on a jacket or monopile foundation. As monopiles are already close to the end of the maximum design size, jacket foundations are assumed to be used of the set up in the decentralized configuration, as an electrolyser will add extra weight to the foundation.

The substructure of the platform in the centralized configuration is also assumed to be a jacket foundation. For the centralized platform the assumption is based on the fact that it is the most common type of foundation for an OSS, which resembles the hydrogen production platform.

Figure 4.3: Schematics for centralized concept (left) and decentralized concept (right)



5

ENVIRONMENTAL EFFECTS OF CASES

This chapter provides a global analysis of the environmental impacts associated with each of the four cases of offshore hydrogen production. It examines the effects of these activities across lifecycle phases and their implications for ecology, different users, and functions in the TNW and HK regions. Additionally, knowledge gaps are addressed which are essential for evaluating the environmental impact of both centralized and decentralized offshore hydrogen production.

As outlined in Chapter 3, this approach centres on clear differences in environmental effects among comparable installations and infrastructure. This allows to identify known, partially known, and unknown effects as well as research methodologies and research gaps that currently lack sufficient understanding. This examination draws from existing research, including EIAs and permits for similar installations like OSSs or oil and gas platforms, as well as industry standards[1].

To illustrate: currently implemented offshore activities, such as pile driving for offshore wind turbines, lead to negative effects on a variety of marine organisms. The extent of these effects is currently unknown and therefore contains knowledge gaps. However, since pile driving in the construction of offshore hydrogen facilities comprises the same activities and effects as pile driving in the construction of offshore wind turbines, this activity is not considered as a knowledge gap in this chapter. Moreover, there is a clear assessment framework to determine the ecological impact of pile driving. However, novel activities that produce more constant sound emissions (with different wavelengths and spectra) may have unforeseen ecological consequences and cannot be assessed according to the framework for pulse sound effects. Such additional knowledge gaps require further investigation in order to determine the nature and extent of potential ecological effects. As such, prevention and/or mitigation of ecological impacts resulting from these activities can be realized.

The environmental effects and the knowledge gaps of the four cases will be described in the following paragraphs, including a description of the TNW and HK areas. Firstly, general effects of offshore hydrogen production on the internal and external safety, co-use, and other activities, which are applicable for every case are described. Then, for each case, starting with Case 1, the general location-specific effects will be introduced first. After that, the effects specific to each lifecycle phase, divided into ecological and non-ecological effects, will be described.

[1] DNV rules and standards for offshore units - July 2023 edition. DNV: https://www.dnv.com/news/dnv-rules-and-standards-for-offshore-units-july-2023-edition-245184;
Safety of offshore oil and gas operations. European Union: https://energy.ec.europa.eu/topics/energy-security/safety-offshore-oil-and-gas-operations_en.

5.1 Impacts of offshore hydrogen production

The technical concept (central versus decentral), cable and pipeline configurations, capacities and dimensions differ between the four cases. However, in all cases the facilities have similar type of impacts. These impacts are described in 5.1.1 until 5.1.5 in general terms. In paragraphs 5.3, 5.4, 5.5 and 5.6 we describe the impacts per case in more detail.

5.1.1 Extraction of cooling water

The PEM method of hydrogen production involves significant heat generation, which is cooled using seawater. Therefore, water is extracted from the surroundings for cooling purposes and as feedwater for the electrolyser. The extraction of water can have effects on stratification and impact ecology as fish, fish larvae and floating organisms are absorbed in the system, leading to direct mortality. This is also explained in terms of the environment and planning permit requirements in paragraph 3.2.3.

5.1.2 Discharge of cooling water, chemicals, and brine

The discharged cooling water is assumed to be mixed with brine and cleaning chemicals. The cooling water discharged into the sea causes (one or more) thermal plumes. The dispersion of this thermal (contaminated) plume, which is dependent on local conditions, such as tidal currents and water depth, and cooling system design, with regard to out-flow temperature and velocity, are not yet well-understood. Moreover, the timing of brine and heat production are not necessarily simultaneous, which would have non-diluted brine emissions. The dispersion can be studied via a so-called *thermal plume modelling and assessment*.

Effects on ecology regarding various organisms in the TNW and HK area, are poorly understood. The heat, chemicals and brine discharge may affect the populations of various biota and negatively affect relevant habitats and or food availability. Furthermore, alteration of abiotic conditions as a result of heat, chemical and brine discharge may attract exotic species and lead to disruptions of existing ecosystems. Therefore, the exact increase of salinity and the effects of the brine water plume need to be modelled and further investigated. The exact affluent of cleaning chemicals need to be calculated and assessed whether it is within the regulatory limits.

5.1.3 Emissions

In all cases the installations may have controlled or uncontrolled gas emissions of hydrogen (H_2), oxygen (O_2), nitrogen (N_2) during commissioning and operation (purging) and carbon dioxide (CO_2) and (NO_x) emissions from construction and service vessels (controlled). These emissions may cause external safety risks, like a hydrogen fire in case of an undetected hydrogen leak or asphyxiation of personnel when nitrogen leaks in an enclosed space, and risks for the environment (e.g. global warming).

5.1.4 Noise

Noise is produced by a number of sources and in all lifecycle phases. Main sources for noise are pile driving (pulse noise) and construction vessel activity (ambient noise) during construction and commissioning. Furthermore, during the operational and maintenance phase, ambient noise is expected from service vessels and above water noise from compressors.

5.1.5 Increased maritime traffic - External safety risks

The large-scale installations require 24/7 supervision and remote (automatic) operation. The installations should probably be (regularly) manned for maintenance to be able to act upon failures or undesirable behaviour. This involves local presence of personnel and helicopter and/or ship movements to and from the facilities. There are risks of ship colliding with one central hydrogen production installation, or in case of decentralized production, with multiple units. The chance of a collision in a central concept is similar to chance of collision with an OSS and the chance of a collision in a decentral concept is similar to the chance of collision with a traditional offshore wind turbine.

However, the potential impact of a collision differs between a hydrogen production unit and a traditional OWF. A collision with an offshore hydrogen production facility may trigger *external safety risks*, such as an explosion. In case of an explosion, due to presence of higher volumes of hydrogen, the consequences of a collision with a central hydrogen installation can be more adverse than with decentralized installations. Related QRA's are necessary to properly manage the potential risks and the chance of occurrence of a central and a decentral offshore hydrogen production concept. Additionally, the increased maritime traffic in the vicinity of the platform lead to more disruptions for local habitats.

5.1.6 Risks due to failure of the installation - Internal safety risks

Failures within the installation or pipelines can lead to internal safety risks. A QRA to assess and mitigate the increased explosion risk associated with decentralized production. However, it should be mentioned that internal safety is not part of the EIA process.

5.2 Location-specific conditions

The activities of offshore hydrogen production may have location and Case specific effects on ecology (nature areas, species) and other users, function on the North Sea.

Figure 5.1 and Figure 5.2 show areas with a special ecological status in the Dutch waters and the German waters next to the TNW area. Figure 5.3 shows the current functional uses, maritime shipping zones and operating wind farms in the Dutch EEZ. Figure 5.4 shows the wind farm search areas, operating wind farms and some other functional uses of the Dutch EEZ as envisioned for the period 2022 to 2027. Additionally, the TNW region (case 1 and 2) and the HK region (case 3 and 4), where offshore hydrogen production is planned, have been indicated.

The Natura 2000-area 'Borkum Riffgrund', which is situated in the German EEZ and is protected under the Habitat Directive is located at the eastern side of the Dutch protected area 'Borkumse Stenen'. Additionally, Natura 2000-area 'Niedersächsisches Wattenmeer und angrenzendes Küstenmeer' lies eastward of Dutch Natura 2000-area 'Noordzee Kustzone' and is a designated Birds Directive area (see Figure 5.2).

The location specific effects are discussed per case in the next sections.

Figure 5.1 Areas in the Dutch North Sea with a special ecological status

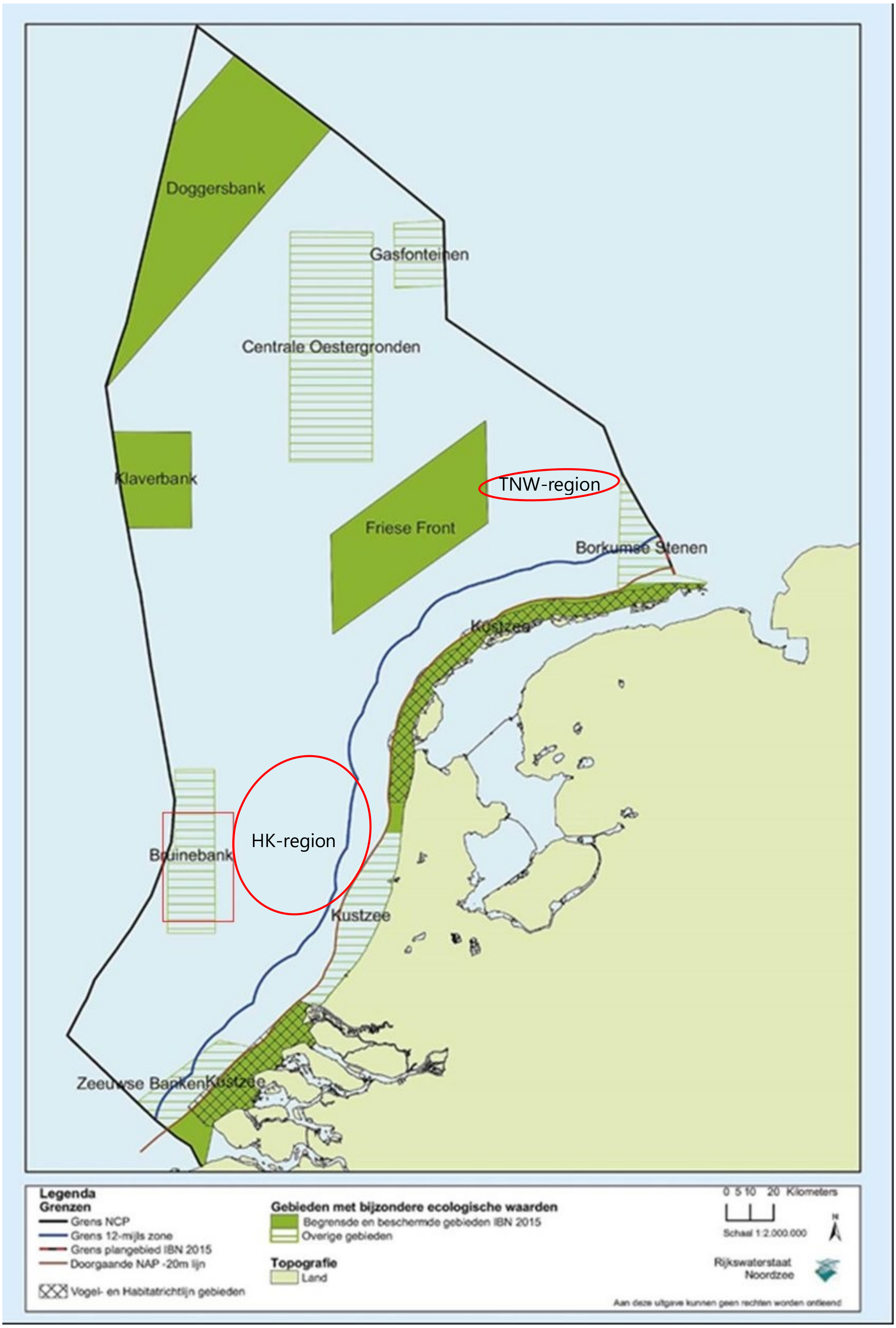


Figure 5.2 Areas in the German North Sea with a special ecological status

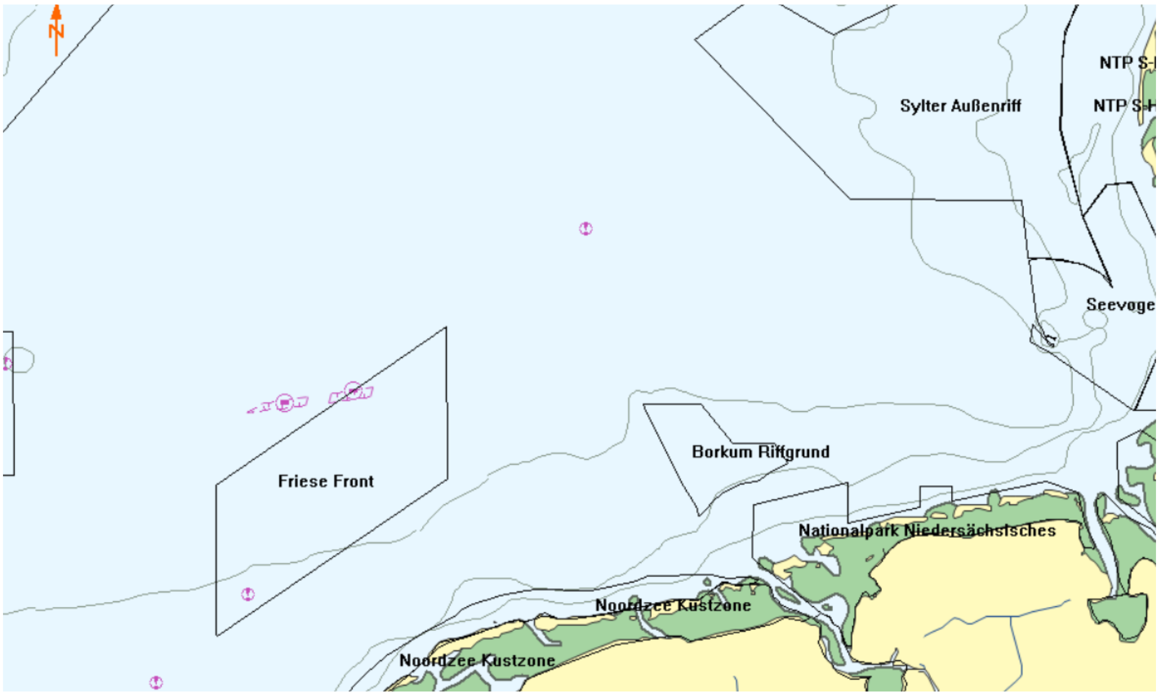
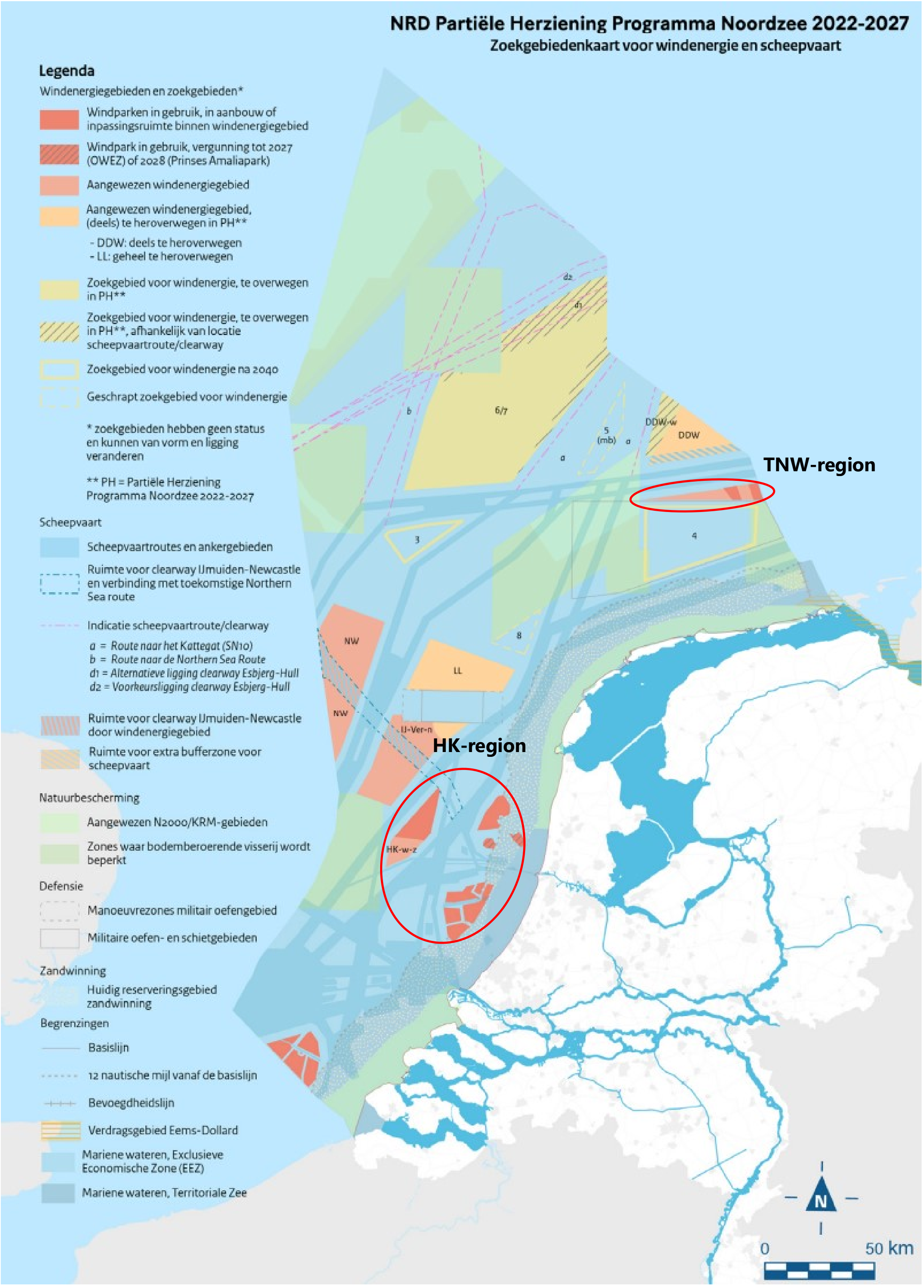


Figure 5.3: Functional uses on the North Sea (source: Programma Noordzee 2022-2027)

Figure 5.1 Search areas wind energy and maritime shipping lanes on the North Sea (source: draft scoping document Partial Revision Program North Sea 2022-2027)



Ecology

On the North Sea, various protected areas are present. These fall under the Bird or Habitat directive (Natura 2000) or the Marine Strategy Framework Directive (MSFD). To the west of the TNW region lies the nature protected areas known as the *Friese Front*, while to the southeast is the *Borkumse Stenen*. West of the HK region the *Bruine Bank* is situated, while the *Noordzeekustzone* and the *Voordelta* are located in the southeast. Furthermore, adjacent to these areas are the nature reserves of *Borkum Riffgrund* and *Niedersächsisches Wattenmeer und angrenzendes Küstenmeer* in the German North Sea.

Besides the protected areas, species and the natural habitat are protected under both Nature Restoration Law[1] as well as the MSFD. For example, offshore hydrogen production within the TNW and HK areas may potentially impact these natural habitats. The hydrographic effects and ecological effects of water extraction at the scale of Case 1 and 2 are unknown. Assessment is needed by 3D modelling of water velocities and spatial extent. Ecological and hydrographic effects of large-scale discharges of water with increased salinity, temperature and containing toxic chemicals are also unknown. In the following sections, the ecological effects will be determined per Case to assess the potential implications on these protected areas.

Biotic and abiotic conditions

Information on biotic and abiotic conditions of the HK and TNW wind area is available on the RVO website for the relevant wind areas. This includes previously executed metocean surveys and detailed information on seafloor conditions.[2]

Internal safety

As mentioned in paragraph 5.1.6, internal safety is not part of the EIA process, but some minor comments about internal safety are made as it is an important subject for the feasibility of offshore hydrogen. The installation will be designed in accordance with design guidelines and standards to be fail-safe. The design will undergo certification by a certifying body such as DNV or TÜV. Consequently, the design will adhere to applicable safety standards, comparable to electrical offshore substations. In the event of failures or emergencies, safety measures and procedures will be activated to minimize the effects. This process also ensures minimal environmental impact. For most of these incidents, the effects are known and can be controlled. However, as this installation involves new technology, there is no standard yet. Therefore, potential knowledge gaps exist, as appropriate safety measures and procedures are still being developed.

The development of adequate standards is crucial for safety and reliability and should cover the potential risks. However, many current standards for O&G and supporting simulation tools etc. are based on statistics collected over a long period. Such extensive statistics are lacking in the Case of hydrogen which is a significant knowledge gap. Additionally, this also has an impact on safety awareness of operating personnel. So, a precautionary approach needs to be taken as long as no relevant statistics are available.

External safety

Qualitative risk assessments (QRA) are crucial for determining minimal safety distances from the platform, particularly close to shipping lanes. These assessments involve evaluating the potential hazards posed by the platform's presence and activities, considering regulations regarding acceptable risks such as localized risks, and the chance that a potential hazard results in an incident. Table 5.3 gives an overview of external safety risks during the operational phase. By analysing these risks qualitatively, including the likelihood and consequences of incidents, appropriate safety measures and mitigation strategies can be established. This includes determining a safety zone around the platform where no access of third parties is allowed without permission of the operator. The safety zone mitigates risks to maritime traffic and ensuring compliance with safety regulations to safeguard both personnel and the environment. When it comes to personnel safety advice from SODM is to be requested. SODM is a Dutch regulatory authority responsible for overseeing the

The technical concept (central versus decentral), cable and pipeline configurations, capacities and dimensions differ between the four cases. However, in all cases the facilities have similar type of impacts. safe

[1] Nature Restoration Law. European Union: https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

[2] Netherlands Enterprise Agency. (2017). Hollandse Kust General Information. Netherlands Enterprise Agency: https://offshorewind.rvo.nl/file/download/15a8ab2c-65cb-4a72-9857-700fe08201ab/1523874367magazine%20-%20hollandse%20kust%20-%20where%20wind%20and%20water%20works%20-%20november%202017.pdf; and TNW General Information. Netherlands Enterprise Agency: https://offshorewind.rvo.nl/

and environmentally responsible exploration, extraction, and processing of mineral resources in the Netherlands. This includes activities related to oil, gas, geothermal energy, and other mining operations. SODM possesses specialized knowledge and expertise in the field of mining and resource extraction. They are well-versed in the risks associated with these activities and the best practices for mitigating them.

Co-use

There are offshore wind farms (such as Borssele OWF) which allow other activities within or nearby offshore wind farms, such as other renewable energy generation (i.e. floating solar panels), nature conservation/reconstruction, aquaculture (i.e. mussel and/or macro algae cultivation), or passive fishing.

When planning and operating hydrogen production on a central offshore platform or, decentralized, on wind turbines, consideration can be given to these activities to ensure compatibility and minimal interference. For instance, strategic placement of the platform and its infrastructure, such as pipelines and cables, can be done to minimize disruption to existing or potential activities within the wind farm. Additionally, measures can be taken to mitigate potential negative impacts, such as (reduction of) the emission of warm cooling water and cleaning chemicals, which may affect water quality or marine life. The relationship with co-use for food production fishing grounds adjacent to the wind farm are relevant and are to be mapped out.

All forms of co-use, including hydrogen, must adhere to the area passport just like all other forms of shared use. Any deviations from this can only occur after proper interdepartmental coordination and approval from Rijkswaterstaat as the Competent Authority.

Other activities

For other activities such as sand and gravel extraction, certain fishing methods, and military operations, it is essential to recognize that these cannot coexist within the offshore wind farm area, as the site is only reserved for wind energy generation and legally permitted co-use of the wind farm. However, when considering the placement of the hydrogen production platform, it is crucial to ensure a sufficient distance from these activities to prevent any adverse environmental impacts on them.

a. **Sand and gravel extraction** are significant activities in the North Sea, serving national interests such as coastal maintenance and land reclamation. A portion of the wind farms in the HK south and HK north offshore wind energy areas lies within the 12-mile zone, potentially impacting sand extraction operations. Specifically, it is the inter-array cables connecting the offshore wind farms to the grid that may affect sand extraction.
b. **Fisheries:** for the fishing industry, it is imperative to locate the hydrogen platform away from active fishing grounds to prevent interference with fishing operations and to minimize any potential risks to fishing vessels. Collaboration with fisheries stakeholders and utilizing data on fishing hotspots could inform the optimal placement of the platform.
c. **Defence:** in terms of defence activities, particularly military exercises and operations, the hydrogen platform(s) are always situated outside designated defence zones to avoid any conflicts or safety concerns. Case 1 and 2 are situated close to a designated defence zone. Coordination with relevant defence authorities is essential to ensure compatibility with defence operations and national security interests.
d. **Oil & gas:** careful consideration should be given to avoid interference or disruption to existing oil and gas infrastructure, including platforms and pipelines. Cooperation with oil and gas operators and thorough mapping of existing infrastructure can aid in identifying suitable locations for the hydrogen platform that minimize conflicts and risks.
e. **Telecommunications:** telecommunication cables, essential for data transmission and communication networks, must also be considered. The hydrogen platform should be sited away from existing telecom cable routes to prevent damage or disruption to these vital communication links. Collaboration with telecom companies is crucial, ensuring alignment with their requirements for crossing design, documentation in a crossing agreement, liability allocation, adherence to minimum distances, and protection of the cable crossing. By leveraging comprehensive data on cable routes, stakeholders can identify suitable placement options for the platform, and the installation of hydrogen pipelines and electricity cables, thereby minimizing risks to telecommunication infrastructure.

5.3 Case 1 - centralized, large-scale (TNW)

Figure 5.4 Section from Search areas wind energy and maritime shipping on the North Sea

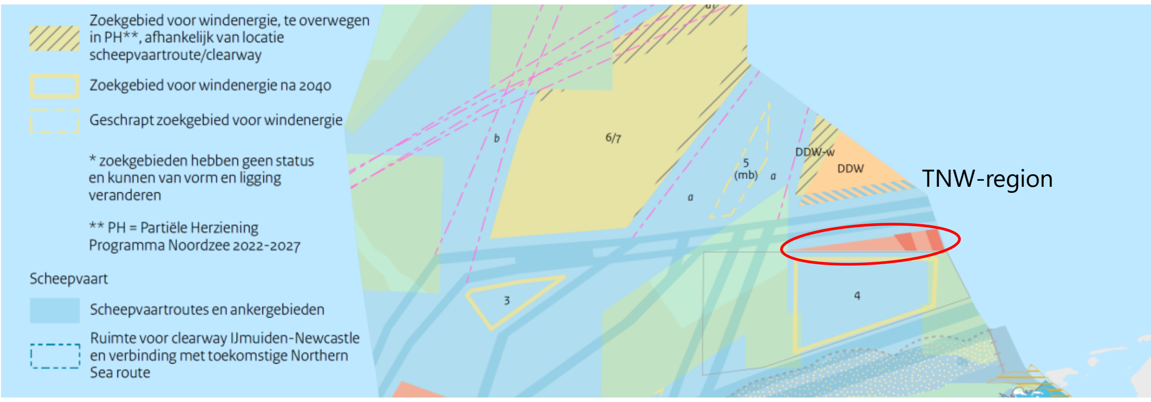


Figure 5.3 shows the TNW offshore wind farm area is bounded on the east side by the EEZ border. To the south, a defence training area forms a boundary. On the north side, there is a buffer zone between the wind farm and a moderately trafficked shipping route (to and from Germany). On the west side, there is a designated Natura 2000 area called the Friese Front. Furthermore, east to this area is the German Natura 2000 area Borkum Riffgrund.

Ecology effects in all lifecycle phases of Case 1 (TNW region)

Key environmental risks of the hydrogen platform are related to disturbances of species or habitats with a high protective status and negative effects on vulnerable species populations in the Wadden Sea.
For example, negative effects on birds and marine mammals are likely in multiple phases of the project due to the existence of migration routes of various animals, such as cetaceans, in the area. Additionally, the intake of fish larvae, such as sand eel, can result in a shortage of sand eel, which is an important food source for protected bird and marine mammal species. This is an example of how disturbances may affect protected species. For such effects, mitigation measures can be taking, such as working outside of seasons where animals are vulnerable. However, this cannot fully avoid effects on birds that are present throughout the year.

Furthermore, emissions from the cooling system of the electrolyser may lead to negative effects such as increased stratification due to heat addition and turbidity. This may affect the ecological functioning of the water column, as well as the benthic community. Namely, turbidity can also influence primary production further offshore by blocking light penetration into the water column. Furthermore, the effect of electrolyser discharges may possibly lead to destratification. This is especially relevant in the HK area, which is more stratified than the TNW area.

In this preliminary ecological assessment, activities that take place in the construction, operation, maintenance, and decommissioning phase of offshore hydrogen are considered. Commonly, calamities are not included in the assessment of ecological impact, unless the risk of these calamities is substantial. Currently, there is no reason to suspect a high risk of severe calamities. As such, calamities are not included in the ecological assessments and existing knowledge gaps.

5.3.1 Construction phase - Case 1

Table 5.1 shows all activities that are directly related to the construction phase. It includes the construction of the foundation of the platform, commissioning of cables and pipelines, installation of the electrolyser and shipping/helicopter movements that are related to these activities. Major effects include noise emissions by surveying, pile driving, shipping and disturbance of the seabed. Nonetheless, these activities are already known from other offshore applications as it will be comparable to the construction of an OSS (see e.g. [11]). Regardless of occurring impacts there are no addition knowledge gaps (besides known knowledge gaps from existing EIAs identified.

Ecology

Table 5.1 shows an overview of ecological effects, impacted species and knowledge gaps in the construction phase. In Annex IV you will find a table for the ecology, including environmental effects and research methods.

Table 5.1 Overview of ecological effects, impacted species and knowledge gaps in the construction phase of Case 1

Activity	Sub-activity	Intervention-effect relationship	Impacted species	Knowledge gap
pre-study	geophysical survey	underwater noise	marine mammals, marine life	no significant knowledge gaps
		light pollution	marine mammals, birds, marine life	no significant knowledge gaps
foundation	piling bottom side	underwater noise	marine mammals, marine life	no significant knowledge gaps
		above-water disturbance	birds, bats	no significant knowledge gaps
		nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps
		soil disturbance	marine life, habitats	no significant knowledge gaps
	application of erosion protection	nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps
		light pollution	marine mammals, birds, marine life	no significant knowledge gaps
		alteration of the substrate	marine life, habitats	no significant knowledge gaps
IA cables	burial	soil disturbance	marine life, habitats	no significant knowledge gaps
		alteration of the substrate	marine life, habitats	no significant knowledge gaps
		turbidity and resulting resedimentation	marine life	no significant knowledge gaps
		above-water disturbance	birds, bats	no significant knowledge gaps
		nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps
electrolyser	1x installation	noise emissions	marine mammals, marine life	no significant knowledge gaps
		above-water disturbance	birds	no significant knowledge gaps
		nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps
supply and removal of material, personnel, and equipment	limited vessel movements. a.o. for 1 large 495MW	nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps

Activity	Sub-activity	Intervention-effect relationship	Impacted species	Knowledge gap
	electrolyser on the platform			
		underwater noise	marine mammals, marine life	no significant knowledge gaps
		above water disturbance	birds	no significant knowledge gaps

Non-ecological environmental effects

Emissions and released substances in the construction phase

In the construction phase, there may be emissions such as H_2, N_2, and O_2, as well as released substances like brine and hypochlorite or potassium hydroxide. While emissions and discharges will be limited during construction due to the non-operational status of the installation, a peak exposure to the environment will occur for short periods during testing/commissioning. However, the effects of these emissions and substances are expected to be comparable to or much lower than those during the operational phase. Additionally, emissions from installation works, such as CO_2, are expected to be comparable to those from the construction of an offshore substation (OSS) or the installation of offshore wind turbines. Therefore, for the testing phase, a description of environmental effects is outlined for the operational phase.

Internal safety in the construction phase

As stated above, the installation will have a fail-safe-design. Potential internal safety risks during the construction phase were assumed to be equal or lower than during the operational phase. So, table 5.3 is referred to for the identified internal safety risks during construction. These risks will have to be further analysed to determine potential impact on the installation, the personnel, and the environment. Proactive measures have to be developed and implemented before construction can commence. These measures include stringent safety protocols, comprehensive staff training programs, and the use of protective equipment. Continuous monitoring may be included to ensure the effectiveness of risk management strategies to create a safe construction environment and a minimal likelihood of accidents and incidents. A calamity plan is always required during construction of the installation.

External safety in the construction phase

Similar to internal risks, the external risks were assumed to be equal or lower than during the operational phase. Table 5.3 applies to the construction phase as well. Increased presence of service vessels and heavy lifting vessels can be expected at the site. In the testing phase small amounts of hydrogen will be produced. These aspects lead to risks of accidents and collisions with offshore infrastructure with effects for the environment. However, similar situations exist when an O&G platform or an OSS are constructed. There are no addition knowledge gaps (besides known knowledge gaps from existing EIAs identified.

Maritime Safety

The maritime safety considerations for an offshore hydrogen production platform resemble those of an offshore O&G platform or an offshore substation (OSS) operated by TenneT. However, a maritime safety study and a QRA should take the heightened explosiveness and fire risk associated with hydrogen into account, especially for manned operation.

Helicopter safety

Helicopter safety is a critical aspect to consider in relation to offshore hydrogen production, given the potentially higher explosiveness and fire-prone properties of hydrogen as opposed to an OSS or O&G platform. This can be done via a QRA. This assessment should consider various factors, including the specific characteristics of hydrogen production and its potential risks to helicopter operations, like collisions due to pilot or machine malfunctions. Additionally, obtaining accurate data on zones and flight routes, as well as traffic intensities, is essential for ensuring safe helicopter operations. Such data can be acquired from the

Environmental and Transport Inspection (ILT), which plays a key role in regulating and monitoring air traffic in the region. Understanding these dynamics is crucial for effectively managing helicopter operations and mitigating safety risks, especially in areas with significant maritime activity.

In the vicinity of the TNW area exists an O&G platform, see Figure 5.3, adding another layer of complexity to the airspace and maritime traffic. Therefore, comprehensive coordination and risk assessment efforts are necessary to ensure the safe and efficient operation of helicopters in this environment. But, as the research methods for helicopter safety are known it is not considered as a novel knowledge gap.

Effects on co-users in the construction phase

The effects on co-users during the construction phase are negligible as there is only very little to no production of hydrogen during the construction phase.

Effects on and coordination with other users in the construction phase

In the construction phase, the environmental effects on other users are not significantly different from those experienced during the construction of a substation (OSS) or an O&G platform. Coordination and consultation with the aforementioned other users, including defence, fisheries, and owners of O&G pipelines and/or telecom cables, will be necessary to ensure minimal disruption and mitigate potential conflicts of interest. It's essential to consider the cumulative impacts of construction activities on marine ecosystems, fisheries, and existing infrastructure, taking proactive measures to minimize disturbances and adhere to regulatory requirements. Close collaboration and communication among stakeholders are vital to address any concerns and optimize the coexistence of various activities in the TNW area during the construction phase of the offshore hydrogen production platform.

Knowledge gaps

For the construction phase, no significant new knowledge gaps (besides known knowledge gaps from existing EIAs) are expected during the environmental assessment. Environmental and (marine) safety assessments are expected to be executed in a similar fashion as in, for example, offshore grid and pipeline projects. The knowledge gaps that result from the addition of an electrolyser are not insurmountable when making the assessment.

5.3.2 Operational phase - Case 1

During the operational phase, hydrogen will be produced on the platform. This requires significant amounts of water, of which the majority is discharged post-production. The production processes lead to different types of emissions, including heat, noise, light, hydrogen, oxygen and (antifouling) chemicals. The intake can be placed at a distance from the seabed (to reduce disturbance and intake of sand, fish, and other species). Moreover, logistic activities such as shipping to and from the platform may also affect the environment. Furthermore, electricity and hydrogen are transported to and from the platform, through cables and pipelines, respectively. Similar to a traditional offshore wind farm, environmental effects include the establishment of Electromagnetic fields (EMFs) around cables, which can have disrupting effects on the behaviour of a variety of marine organisms. Additionally, the presence of cable/pipeline crossings on the seafloor, the platform and its scour protection may disrupt existing habitats.

Ecology

An overview of the ecological effects and their knowledge gaps of the hydrogen platform during operation is provided in table 5.2.

Table 5.2 Overview of ecological effects, impacted species and knowledge gaps in the operational phase for Case 1

Activity	Sub-activity	Intervention-effect relationship	Impact	Knowledge gap
logistics	transport for maintenance and inspection	light pollution	birds, bats, marine mammals, marine life	intensity and frequency of transportation traffic unknown
		noise emissions	birds, bats, marine mammals, marine life	intensity and frequency of transportation traffic unknown
		nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps
electrolyser	water extraction for desalination and cooling (26.000 m^3/hour)	direct mortality of plankton, fish (including larvae and juveniles) and macrofauna due to intake	marine life, possibly marine mammals, and birds	loss of biomass unknown, risk of macrofauna intake unknown (1)
		effects on hydrographic properties (including stratification/de stratification)	marine life, habitats, possibly marine mammals, and birds	impact range and effect of hydrographic change unknown (1)
	emission of water 26.000 m^3/hour) with increased salinity (+0,13 ‰) and temperature (+5ºC)	effects on hydrographic properties (including stratification/de stratification)	marine life, habitats, possibly marine mammals, and birds	ecological effect unknown, hydrodynamic quality unknown (outflow rate, spatial extent of outflow rate) unknown (2)
	nitrogen emissions	effects if deposition reaches onshore habitats	habitats, birds	no significant knowledge gaps
	antifouling chemical emissions	toxic effects on organisms	marine mammals, marine life, habitats	quantity and flow rates new (2)
	leakage of brine, demiwater, KOH, O_2, N_2, H_2	in case of incidents this can have damaging effects on multiple organisms	marine mammals, marine life, habitats	no significant knowledge gaps
	compressor, pumps, fans	underwater noise	marine mammals, marine life, birds	intensities and spectra unknown (3)

Activity	Sub-activity	Intervention-effect relationship	Impact	Knowledge gap
	converter	electromagnetic radiation	marine mammals, marine life	insufficient knowledge about effects of EMF (4)
platform	lighting	light pollution	marine mammals, birds, marine life	no significant knowledge gaps
	sanitation/sewage	pollution by sewage discharge	marine life, marine mammals, birds	no significant knowledge gaps
	presence of platform	surface reduction, change in energy distribution in water column and disturbance above water	marine mammals, marine life, birds, habitats	no significant knowledge gaps
	vessel movement	underwater noise	marine mammals, marine life	no significant knowledge gaps
		disturbance above water	marine mammals, birds	no significant knowledge gaps
		nitrogen deposition	marine life, habitats	no significant knowledge gaps
cables/ pipelines	presence of cables	electromagnetic fields	marine mammals, marine life	insufficient knowledge about effects of EMF (4)
	scour protection pipe and cable crossing	surface loss	habitats, marine life	no significant knowledge gaps
	vessel movement	underwater noise	marine mammals, marine life	no significant knowledge gaps
		disturbance above water	marine mammals, birds	no significant knowledge gaps
		nitrogen emission and deposition	marine life, habitats	no significant knowledge gaps

1. Knowledge gaps on large scale water extraction

A major concern and knowledge gap with regard to the operation of the platform has to do with the large amounts of water being pumped in and out of the system. First and foremost, microfauna and macrofauna and small animals such as plankton are at risk to be pumped into the electrolyser and will die as a result. The intake can be placed at a distance from the seabed to prevent seabed disturbance, but the amount of plankton that is being pumped into the demiwater installation and the consequences this has for populations of marine mammals and birds, which are higher up the food chain, is still a significant knowledge gap. As of yet, it is impossible to make a distinction as to which types of organisms will be taken in by the system for different intake heights, as this is highly dependent on location-specific conditions, such as species abundances, hydrography, and seasonality.

Furthermore, the water velocity and inlet- and outlet dimensions are currently unknown, which makes it difficult to assess the degree to which microfauna, macrofauna and small animals may be pumped into the machine or protection grills. This is partly regulated, but the effect should be considered and accessed in detail in an EIA. Moreover, based on the CIW updated guidelines which are currently being drafted, for saltwater environments, a maximum intake velocity of 0,3m/s is maintained as a threshold for expected ecological effects when water flow is lower than 1800m^3/s. For flows larger than 1800m^3/s, effects are expected already at intake speeds of 0,15m/s. Finally, it is unknown what the ecosystem effects of pumping in large volumes of water are and how this may affect the hydrographic conditions, such as stratification and turbidity around the platform and, possibly, reaching further beyond the platform.

2. Knowledge gaps on large scale water emissions

The discharge of water with increased heat, increased salinity and antifouling chemicals is not new. However, the scale and context in which offshore hydrogen production is to be applied is unprecedented. Here, the marine strategy framework directive (MSFD) is of key concern, namely Descriptor 7*: Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems*, Descriptor 8: *Concentrations of contaminants are at levels not giving rise to pollution effects* and Descriptor 11: *Energy, including underwater noise.* Namely, the emission of water with an absolute increase in salinity of 0,13 ‰ in the North Sea (with regular salinity of 34-35 ‰) may be of concern. This is especially relevant considering that salinity is a key ecological parameter and determinant of biological functioning of many organisms. Most marine organisms are extremely sensitive to changes in salinities, especially in areas where relative stable salinities occur, like the North Sea. Furthermore, changes in temperature and salinity can influence the hydrography can influence stratification or mixing gradients in the water column, which may in turn influence primary production and thus lead to subsequent trophic effects (e.g. reduced food availability for consuming organisms). Investigating salinity and hydrography changes through modelling is therefore an important part of future studies into the effects. Impacts may reach far beyond the platform due to the sheer volumes of water that are being pumped in and out of the system.

The degree to which the discharge of water affects the hydrographic, and consequently, the ecological quality of the surrounding water is unknown. This makes it a knowledge gap with potentially large impact. To resolve this knowledge gap, hydrological modelling of the spatial extent (3D) of the outflow rate would be a good starting point. This should at least include a thermal and saline plume assessment, which addresses mixing and stratification effects, duration, and spatial extent of these changes, considering the local conditions like water depth and tidal currents. This should be combined with investigating the effects on protected species, populations, habitats, and MSFD-descriptors by determining threshold values for expected temperature, salinity, and chemical increases. This entails an assessment of protected areas in the vicinity of the TNW area, including conservation objectives. For the TNW area, this includes 'Noordzeekustzone' (N2000, Habitat Directive & Bird Directive), 'Friese Front' (N2000, Birds Directive and MSFD) and 'Borkumse Stenen' (MSFD). The extent of plume development is important to exclude direct and indirect effects on these areas. For some species, detailed information on threshold values for (temporary) changes in salinity and temperate may not be available. This poses an additional knowledge gap.

The effects of antifouling chemicals like hypochlorite and KOH for the cooling system and electrolyser are unknown, especially at the scale provisioned in Case 1. So, a plume assessment for the discharge of antifouling chemicals and the effect on ecology is required.

The hydrographic effects and ecological effects of large-scale water extraction are unknown - assessment is needed by 3D modelling of water velocities and spatial extent.

3. Knowledge gaps on (underwater) noise

Machinery, mainly the compressor, on the platform will produce noise. Increased noise levels around the platform could disrupt species, both above and below water. For above water, it can generally be presumed that birds will avoid the close proximity of platform. The knowledge gaps for this are not pressing. Underwater, noise vibration may reach further beyond the platform. This is greatly dependent on the water depth, sound level at the source, the conductance of vibration through the platform and soil into the water, and the frequency of the emitted sound. These aspects are largely unknown. Therefore, the noise levels from the machinery need to be quantified and the impact on species needs to be assessed in the EIA.

At the same time, there is no clear framework for the assessment of the effect of (semi-)continuous noise on vulnerable species. Especially the harbour porpoise, grey seal and common may be disturbed by underwater noise. For this species, a cumulative assessment framework is available (KEC 4.0), but this is only applicable for high impact noise (piling of monopiles and jackets). However, a methodology based on KEC 4.0 is available to assess the effects of continuous noise from vibro-piling.[1] Depending on the noise levels emitted, an assessment framework may need to be developed to be able to cumulate permanent noise disturbances with piling noise disturbances. On the other hand, if noise levels are limited, assessment through available literature may be sufficient.

4. Knowledge gaps on electromagnetic fields
The research on the effects of electromagnetic fields on ecology is still emerging. Electromagnetic fields are generated when electricity is transported via cables or by movements of water currents. The electric field can be confined by a grounded metal enclosure and decays rapidly in the marine environment; however, the magnetic field can radiate into the environment and induce a secondary electric field. Little is known about the consequences of this for fish and benthic animals. This knowledge gap is not unique to hydrogen production. In the next years, it is expected that research will resolve parts of the knowledge gaps around EMF (namely through the ElasmoPower research, research by WOZEP and TenneT)[2].

Non-ecological effects

Emissions and released substances in the operational phase
In the operational phase, there are emissions such as H_2, N_2, and O_2, as well as released substances like brine and hypochlorite or potassium hydroxide. H2 is vented sometimes for safety reasons. The system sometimes needs to be purged with Nitrogen, causing release of N2. O2 is a by-product of electrolysis. The effects of these emissions and substances are described in Table 5.3. Additionally, other emissions, such as CO_2, e.g. from diesel powered emergency generator, are to some extent (different running hours) expected to be comparable to those from the construction of an offshore substation (OSS) or the installation of offshore wind turbines. The effects of the emissions on the environment should be quantified in an EIA, the safety considerations of the emissions in a confined space are explained below.

Internal safety in the operational phase
The potential internal safety risks during the operational phase were identified and documented during a dedicated session and are listed in Table 5.3. The build-up of gasses in confined spaces can have serious consequences, like asphyxiation or explosions. The risks necessitate further analysis to assess their potential impact on the installation, personnel, and the surrounding environment.

Proactive measures, including the development and implementation of stringent safety protocols, comprehensive staff training programs, and the utilization of protective equipment, must be devised based on this analysis. Continuous monitoring may be integrated to verify the effectiveness of risk management strategies, ensuring a safe operational environment, and reducing the likelihood of accidents and incidents. Additionally, a Health, Safety and Environment (HSE) plan and a Quantitative Risk Assessment (QRA) are imperative to address (un)foreseen events during the platform's operational phase. Finally, an O&M philosophy, which definitively determines whether manned or unmanned operation is necessary and how the operation strategy develops over time, is currently lacking. So, the O&M philosophy is a relevant knowledge gap.

[1] Notitie voor berekening cumulatieve effecten van continue onderwatergeluid op bruinvissen. Noordzeeloket.

[2] Sharks, rays, and offshore power cables. Noordzeeloket: https://www.noordzeeloket.nl/functies-gebruik/windenergie/ecologie/wind-zee-ecologisch-programma-wozep/newsletter-wozep/wozep-newsletter-4/sharks-rays-offshore-power-cables/

External safety in the operational phase
External safety risks during the operation of the hydrogen platform were also identified and listed in Table 5.3 during the aforementioned session. Increased presence of service vessels can be expected at the site, which leads to an increased risk of accidents and collisions with offshore infrastructure with effects for the environment. However, similar situations exist when an O&G platform or an OSS are in operation. So, there are no significant knowledge gaps except for the additional electrolyser and hydrogen buffer. As such, an additional risk from a hydrogen fire or explosion will be needed to be accounted for in comparison with an OSS.

Maritime Safety in the operational phase
In the TNW area, there is a notable increase in maritime traffic movements, due to shipping routes, the wind farm, the operation and maintenance of the hydrogen production platform, and potential co-users of the wind farm. Comparatively, the maritime safety considerations for an offshore hydrogen production platform resembles those of an offshore O&G platform or an OSS operated by TenneT. For OSS installations, maintaining a safety distance of at least 500 meters from shipping routes is mandated. To comprehensively evaluate maritime safety and external risks specific to this situation, a maritime safety study (including modelling) conducted by specialized firms, along with a Quantitative Risk Assessment (QRA), are essential. Such assessments must account for the heightened explosiveness and fire risk associated with hydrogen.

Determining safe distances from shipping routes necessitates conducting an adequate maritime safety study. Additionally, the placement of personnel overseeing and maintaining the installation significantly impacts safety considerations, similar to a continuously manned natural gas extraction platform. However, given the higher explosiveness of hydrogen compared to natural gas, greater safety distances may be applicable. Essential data pertaining to shipping routes and traffic intensities can be sourced from various authorities, including the Mining Act, the North Sea Desk of RWS, the Dutch Coast Guard, and the International Maritime Organization (IMO).

Helicopter safety in the operational phase
In this Case helicopter safety is a critical aspect to consider, given the potentially more explosive and fire-prone properties of hydrogen. This can be done via a Quantitative Risk Assessment (QRA). This assessment should consider various factors, including the specific characteristics of hydrogen and its potential risks to helicopter operations. Additionally, obtaining accurate data on zones and flight routes, as well as traffic intensities, is essential for ensuring safe helicopter operations.

Aviation data can be acquired from the ILT, which plays a key role in regulating and monitoring air traffic in the region. Understanding these dynamics is crucial for effectively managing helicopter operations and mitigating safety risks, especially in areas with significant maritime activity. In the vicinity of the TNW area exists an O&G platform, adding another layer of complexity to the airspace and maritime traffic. Therefore, comprehensive coordination and risk assessment efforts are necessary to ensure the safe and efficient operation of helicopters in this environment.

Effects on co-users in the operational phase
These effects primarily arise from under- and above-water noise and vibration producing components, like a compressor, and the indirect effects of the emissions from the electrolysis process. Underwater noise generated during operation may disturb marine life in, for example an aquaculture facility, particularly sensitive species such as fish and marine mammals. Noise above water could deter birds. Measures to mitigate these effects may include implementing noise-reduction technologies, scheduling operational hours to minimize disturbance during critical periods for marine life, and establishing exclusion zones to protect sensitive habitats. The effects from noise and vibration during operation should be researched.

Furthermore, proper waste management practices should be implemented to prevent pollution of the marine environment from operation and maintenance related materials. Although, it is expected that operational waste and waste from the crew will be collected, a QRA can help in to assess the potential risk when the waste is accidentally released to the environment. Furthermore, collaborative planning and environmental monitoring efforts can help minimize the environmental footprint of the operational phase and ensure the sustainable coexistence of various activities within the offshore wind farm.

Effects on and coordination with other users in the operational phase
In the operational phase, the environmental effects on other users of the North Sea are not significantly different from those experienced during operation of a substation (OSS) or an O&G platform. The main difference is the indirect effect of the emissions of the platform on other users. The effects on other users should be investigated in the EIA phase.

It's essential to consider the cumulative impacts of operation activities on marine ecosystems and existing infrastructure, taking proactive measures to minimize disturbances and adhere to regulatory requirements. Close collaboration and communication among stakeholders are vital to address any concerns and optimize the coexistence of various activities in the TNW area during the operational phase of the offshore hydrogen production platform.

Table 5.3: Overview of non-ecological effects and knowledge gaps in the operational phase

Activity	Sub-activity	Intervention-effect relationship	Impact	Research method	Knowledge gap
internal safety incident in electrolyser	KOH leakage	personnel exposed to substance	skin damage	Quantitative Risk Assessment (QRA)	No significant knowledge gaps
	O2 leakage	system failure leading to fire/explosion	hazard for personnel, system, and environment	QRA, Fire and Explosion Risk Assessment (FERA)	Explosion effects unknown
	H2 leakage	system failure leading to fire/explosion	hazard for personnel, system, and environment	QRA, FERA	Explosion effects unknown
	H2 fugitive emissions	release of H2	GHG in atmosphere	emission studies, warming effects assessment	Residence time and CO2 equivalence unknown
	N2 leakage	N2 build up in enclosed area	asphyxiation	QRA	No significant knowledge gaps
	SF6 leakage	SF6 build up in enclosed area	asphyxiation	QRA	No significant knowledge gaps
	SF6 fugitive emissions	release of SF6	GHG (36.000 CO2 eq.) in atmosphere	emission studies, warming effects assessment	No significant knowledge gaps
	electrical equipment	system failure leading to fire/explosion	hazard for personnel, system, and environment	QRA, FERA, Fire Fighting Philosophy	No significant knowledge gaps
	battery	rapid discharge/ combustion	hazard for personnel, system, and environment	Risk analysis	No significant knowledge gaps
	transfer of staff to platform	man overboard (MOB)	hazard for personnel	Risk analysis	No significant knowledge gaps

Activity	Sub-activity	Intervention-effect relationship	Impact	Research method	Knowledge gap
external safety incident	extreme weather (storm, lightning, earthquake)	system failure leading to fire/explosion	hazard for personnel, system, and environment	QRA, FERA	Explosion effects unknown
		structural damage to platform	hazard for personnel, system, and environment	QRA	Impact of electrolyser fire/explosion on platform integrity or the other wind farm users
	ship collision	system failure leading to fire/explosion	hazard for personnel, system, and environment	QRA, FERA, ship collision study	Explosion effects unknown
		structural damage to platform	hazard for personnel, system, and environment	QRA, ship collision study	No significant knowledge gaps
		oil spill	hazard to marine mammals, marine life	QRA	No significant knowledge gaps
	helicopter collision	system failure leading to fire/explosion	hazard for personnel, system, and environment	QRA, FERA	Explosion effects unknown

Knowledge gaps

Four significant ecological knowledge gaps during the operational phase have been identified and described above. The ecological knowledge gaps related specifically to hydrogen production are related to the extraction and discharge of water and underwater noise. The listed knowledge gaps coincide with the feedback from the consultation with experts. The top 5 most important ecological effects with significant knowledge gaps according to the experts are heat discharge, brine discharge, discharge of chemicals, water extraction and noise.

The non-ecological environmental aspects of the hydrogen platform during operation are mainly resulting from the presence of hydrogen buffers. It is uncertain how the buffers or a ship collision will increase the risk on fire or an explosion during an internal or external safety incident and how that will affect the safety standard of the crew working on the platform.

5.3.3 Maintenance phase - Case 1

The maintenance phase consists of all activities that take place after commissioning that ensure operability and safety of the installation in the operational phase. This consists primarily of traffic for inspection of the platform, foundation, cables, and pipelines. The effects of these activities are well documented and mostly include light pollution, noise emissions, disturbance of animals above water and nitrogen emissions. Although maintenance of offshore hydrogen pipelines is a novel activity, the expected intervention-effect relationships in the maintenance phase are expected to be similar. Since the overall effects of maintenance are well-known from existing offshore applications no significant knowledge gaps are expected regarding ecological effects for any activity occurring during the maintenance phase (additional to known knowledge gaps from existing EIAs).

Table 5.4 Overview of knowledge gaps for maintenance activities, effects, and ecological impacts

Activity	Sub-activity	Intervention-effect relationship	Impact	Knowledge gap
Total installation	Inspection traffic	Light pollution	Marine mammals, birds, marine life	No significant knowledge gaps
		Underwater noise	Marine mammals, marine life	No significant knowledge gaps
		Disturbance above water	Birds	No significant knowledge gaps
		Nitrogen emission and deposition	Habitats, birds	No significant knowledge gaps
	Regular maintenance	Light pollution	Marine mammals, birds, marine life	No significant knowledge gaps
		Underwater noise	Marine mammals, marine life	No significant knowledge gaps
		Disturbance above water	Birds	No significant knowledge gaps
		Nitrogen emission and deposition	Habitats, birds	No significant knowledge gaps
Foundation	Regular maintenance	Light pollution	Marine mammals, birds, marine life	No significant knowledge gaps
		Underwater noise	Marine mammals, marine life	No significant knowledge gaps
		Disturbance above water	Birds	No significant knowledge gaps
		Nitrogen emission and deposition	Habitats, birds	No significant knowledge gaps
IA Cables	Regular maintenance	Light pollution	Marine mammals, birds, marine life	No significant knowledge gaps
		Underwater noise	Marine mammals, marine life	No significant knowledge gaps
		Disturbance above water	Birds	No significant knowledge gaps
		Nitrogen emission and deposition	Habitats and birds	No significant knowledge gaps
IA piping	Regular maintenance	Light pollution	Marine mammals, birds, marine life	No significant knowledge gaps
		Underwater noise	Marine mammals, marine life	No significant knowledge gaps
		Disturbance above water	Birds	No significant knowledge gaps
		Nitrogen emission and deposition	Habitats and birds	No significant knowledge gaps
Platform maintenance and access	Access by CTV/service vessel	Light pollution	Marine mammals, birds, marine life	No significant knowledge gaps
		Underwater noise	Marine mammals, marine life	No significant knowledge gaps
		Disturbance above water	Birds	No significant knowledge gaps

Activity	Sub-activity	Intervention-effect relationship	Impact	Knowledge gap
		Nitrogen emission and deposition	Habitats and birds	No significant knowledge gaps

Non-ecological effects

Internal and external safety

During maintenance of the hydrogen platform an increased presence of SOVs and CTVs is expected at the site. This leads to a higher risk of accidents and collisions with offshore infrastructure. A similar situation exists when an O&G platform or an OSS requires maintenance. However, in this case there is hydrogen storage and transportation infrastructure present. So, different or additional risks will need to be taken in to account. A calamity plan is required during maintenance of these installation to receive a permit, similar to the BLPH project (Crosswind). But the scale of the BLPH project is 200 times smaller. Therefore, there is a knowledge gap as the scales do not match.

Another point of attention is the internal safety of the people performing maintenance. A safe working environment needs to be created with sufficient facilities to react to a calamity. Moreover, living quarters need to be placed with sufficient distance to dangerous installations when the platform is permanently manned. This is a significant knowledge gap as existing offshore hydrogen projects are unmanned.

5.3.4 Decommissioning phase - Case 1

Decommissioning of the platform takes place far in the future at the end of the lifetime of the platform, which makes it an inherently uncertain phase. It includes the removal or treatment of all components of the platform, electrolyser and surrounding cables and pipelines. In recent EIAs, the decommissioning effects of offshore platforms are expected and assessed to be similar to the construction phase. Moreover, an electrolyser does not result in distinctive effects in the decommissioning phase. As such, the construction phase is normative in the assessment. The result is that most EIA risks in the decommissioning phase are lower or similar to the construction phase, therefore the knowledge gaps are assessed accordingly in this phase.

Table 6.4 Overview of knowledge gaps for decommissioning activities, effects, and ecological impacts

Activity	Sub-activity	Intervention-effect relationship	Impact	Knowledge gap
foundations removal	piling topside	nitrogen emission and deposition	habitats, birds	no significant knowledge gaps
		soil disturbance	marine life, habitats	no significant knowledge gaps
		underwater noise	marine mammals, marine life	no significant knowledge gaps
IA cables	removal or treatment	soil disturbance	marine life, habitats	no significant knowledge gaps
		alteration of the substrate	marine life, habitats	no significant knowledge gaps
		turbidity and resulting resedimentation	marine life	no significant knowledge gaps
		disturbance above water	birds	no significant knowledge gaps

Activity	Sub-activity	Intervention-effect relationship	Impact	Knowledge gap
IA piping	removal or treatment	soil disturbance	marine life, habitats	no significant knowledge gaps
		alteration of the substrate	marine life, habitats	no significant knowledge gaps
		turbidity and resulting resedimentation	marine life, birds	no significant knowledge gaps
		disturbance above water	birds	no significant knowledge gaps
electrolyser	demolition	disturbance above water	birds	no significant knowledge gaps
		underwater noise	marine mammals, marine life	no significant knowledge gaps
supply/removal of material, personnel, and equipment	shipping movements	nitrogen emission and deposition	habitats, birds	no significant knowledge gaps
		underwater noise	marine mammals, marine life	no significant knowledge gaps
		disturbance above water	birds	no significant knowledge gaps

Non-ecological effects

External safety
During the decommissioning phase of the hydrogen platform an increased presence of service vessels and heavy lifting vessels is expected at the site. This leads to a higher risk of accidents and collisions with offshore infrastructure. However, a similar situation exists when an O&G platform or an OSS is decommissioned. A calamity plan is required during decommissioning of these installation to receive an Environmental and Planning Permit. Therefore, there are no significant knowledge gaps with regard to safety.

5.4 Case 2 - decentralized, large-scale (TNW)

Case 2 decentralized approach comprises 33 distributed individual 15MW electrolysers across various wind turbines within the TNW offshore wind farm area. In this Case 33 electricity cables are replaced with 33 hydrogen pipelines. This shift from a single 495MW installation to multiple dispersed units introduces differences in both environmental and safety considerations. While both cases maintain similar intervention-effect relationships, the environmental effects in Case 2 differ due to the decentralized distribution of electrolysers. This decentralized arrangement spreads out the effects, including water throughput volumes, heat concentrations, antifouling chemicals, and salinity, across the wind farm area.

These effects are dependent on wind farm design parameters, such as distance between the wind turbines and operational full load hours per year. Effect also depends on design parameters of the hydrogen platform. A further consideration is the efficiency disparity between small, decentralized installations and a large-scale centralized platform. Typically, small electrolysers exhibit lower efficiency levels, potentially influencing total emissions and discharges. On the other hand, in Case 2, the electricity is directly converted into hydrogen within the wind turbine, thereby avoiding 66kV transformer losses as in Case 1. Further investigation is needed to determine environmental effects.

Ecology

In terms of ecology, Case 2's decentralized distribution spreads out the environmental effects, including factors such as water throughput volumes, heat concentrations, antifouling chemicals, and salinity. Comprehensive assessments, including plume evaluations of discharged water and analyses of noise and vibration levels, are essential for accurately evaluating the ecological impact of this decentralized approach. Additionally, the replacement of 33 electrical cables with hydrogen pipelines necessitates consideration of potential seabed effects, such as those observed with O&G pipelines. This may involve other effects to the seabed as diameter size and pipe laying technique may differ from electrical cables. Although the ecological effects may differ between Case 1 and Case 2, the knowledge gaps remain consistent, highlighting the need for continued research and risk assessment in both cases.

External safety
The decentralized setup of Case 2 has a different risk profile regarding external safety in comparison with Case 1. With 33 hydrogen production assets dispersed over the site, there is an increased risk of defects or incidents, such as ship collisions with production installations compared to Case 1, potentially involving higher risks, e.g. of an explosion. However, the impact of such collisions with individual turbines could be lower than with a centralized platform, as the effects of a loss of containment are smaller due to the limited inventories and smaller hydrogen pipelines. Additional safety concerns in Case 2 involve the risk of vessels sinking on inter-array (IA) pipelines or the potential for anchors damaging these pipes. This may lead to hydrogen leakage and associated safety hazards, such as fire and locally lower buoyancy of the seawater. Evaluation of the mentioned risks, as well as a quantitative risk assessment (QRA) to address the risks associated with the decentralized concept, are necessary.

Internal safety
The same holds for the risk on fire or explosions due to internals safety incidents. An evaluation of the increased collision risk and impact, mitigation measures, and a QRA (to assess and mitigate explosion risks associated with the decentralized concept) will be necessary.

Knowledge gaps
Although ecological effects will likely differ from Case 1, no differences are expected in terms of the actual knowledge gaps for Case 2. Furthermore, the environmental effects will depend on design parameters of the wind farm, including the spacing of the wind turbines and the distance to collection point for export pipeline. Also, environmental effects in the operational phase will be influenced by the number of operational (full load) hours per year.

5.4.1 Construction phase - Case 2

Table 5.5 shows the different ecological effects compared to Case 1. The effects of the pre-study, foundation, and IA cables (in a hybrid set-up) are similar to Case 1 (see table 5.1).

Table 5.5: Overview of different effects, impacted species and knowledge gaps in the construction phase of Case 2 compared to Case 1

Activity	Sub-activity	Intervention-effect relationship	Impacted species	Knowledge gap
IA piping	burial, construction of larger trench	soil disturbance	marine life, habitats	no significant knowledge gaps
		change in substrate	marine life, habitats	no significant knowledge gaps
		turbidity and resulting resedimentation	marine life	no significant knowledge gaps
		above-water disturbance	birds, bats	no significant knowledge gaps

Activity	Sub-activity	Intervention-effect relationship	Impacted species	Knowledge gap
		nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps
electrolyser	33x installation	noise emissions	marine mammals, marine life	no significant knowledge gaps
		above-water disturbance	birds	no significant knowledge gaps
		nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps
supply and removal of material, personnel, and equipment	increased vessel movements. a.o. for 33x 15MW electrolysers at the turbines	nitrogen emission and deposition	marine life, habitats, birds	no significant knowledge gaps
		underwater noise	marine mammals, marine life	no significant knowledge gaps
		above water disturbance	birds	no significant knowledge gaps

No differences in knowledge gaps are expected compared to the Case 1.

Non-ecological effects

As mentioned above, in a decentralized set-up environmental intervention-effect relationships are the same as in Case 1. In the construction phase, installation of electrolysers will only have little additional effects, as these units will be built in combination with the wind turbines. No additional foundation is needed, so there are no additional related effects. The laying of 33 pipelines instead of electrical cables may have higher impact on the seabed and thus potentially more effects for ecology, as mentioned above. For effects due to operational activities in the construction phase see paragraph 5.3.2.

5.4.2 Operational phase - Case 2

The ecological intervention-effect relationships and the knowledge gaps of the related effects of in the operational phase of Case 2 is similar as Case 1, see table 5.2. Different effects are expected due to the multiple hydrogen production locations.

Ecology

From an ecological standpoint, the decentralized distribution in Case 2 disperses environmental effects across various factors such as water throughput volumes, heat concentrations, antifouling chemicals, and salinity. Conducting comprehensive assessments, including plume evaluations of discharged water and analyses of noise and vibration levels, will be crucial for accurately assessing the ecological impact of this decentralized approach.

Non-ecological effects

The non-ecological effects from table 5.3 are comparable to the effects for Case 2, except for external safety incidents, as shown in table 5.6.

External safety

Having 33 hydrogen production assets scattered across the site elevates the likelihood of ship collisions with production installations compared to Case 1, potentially heightening the risk of fires and explosions. Nevertheless, the consequences of such collisions with individual turbines might be less severe than those with a centralized platform. Further safety considerations in Case 2 include the potential risk of vessels sinking on inter-array (IA) pipelines or causing damage to these pipes with anchors. Such incidents could result in hydrogen leakage and associated safety hazards, such as fire and localized reduction in seawater buoyancy. It is required to evaluate these risks and conduct a quantitative risk assessment (QRA) to address the safety concerns associated with the decentralized concept.

Table 5.6 Overview of different non-ecological effects in the operational phase of Case 2 compared to Case 1

Activity	Sub-activity	Intervention-effect relationship	Impact	Research method	Knowledge gap
external safety incident	collision or propulsion of ships	system failure leading to fire/explosion	hazard for personnel, system, and environment	QRA, FERA, ship collision study	Explosion effects unknown
	increased vessel movements	increased risk on maritime safety incidents	hazard for personnel, system, and environment	QRA, FERA, ship collision study	Explosion effects unknown
	IA pipe interference (due to sinking ship, a ship anchor, or hostile activities)	structural damage to IA pipes, leading to H2 leakage	hazard to environment	FERA	no significant knowledge gaps

No differences in knowledge gaps are expected compared to the Case 1.

5.4.3 Maintenance phase - Case 2

Typical risks in the maintenance phase are similar as in the Operational Phase of Case 2.

External safety
Maintenance of 33 individual electrolysers will require more transfers from vessel to turbine, compared to the transfer to a single platform, which can increase the likelihood of an accident, like MOB ("Man Overboard"). However, no significant differences in knowledge gaps are expected compared to the Case 1. Similar to Case 1 more shipping or helicopter movements will be required for the operational and maintenance phase. The assumption is that an Operation and Maintenance (O&M) team is present in the park, operating from a central location (offshore O&M centre) with a helicopter platform. From here maintenance personnel will travel to the wind turbines via Crew Transfer Vessels (CTVs), similar to or in combination with the maintenance of wind turbines. In a Quantitative Risk Assessment (QRA), it is expected that a higher number of vessel movements will need to be considered.

5.4.4 Decommissioning phase - Case 2

During the decommissioning phase of Case 2, the environmental effects will mirror to a large extent those observed during the construction phase of Case 2. Decommissioning involves dismantling and removing equipment and structures, which can lead to disturbances in the marine ecosystem.

Similar to the construction phase, decommissioning activities may include the removal of the substructure from the wind turbines. This process could result in disturbances to the seabed, sediment displacement, and potential release of contaminants into the surrounding water. Since decommissioning of the hydrogen installations will coincide with the decommissioning of wind turbines, these efforts will likely be combined, resulting in only slightly more disturbance of a similar kind. However, it's essential to consider factors such as the disposal of decommissioned equipment and materials, which may have additional environmental implications. The environmental effects from the removal of IA pipelines are assumed to be similar to IA cables.

No differences in knowledge gaps are expected compared to the base-case.

5.5 Case 3 - centralized, medium-scale (HK)

Figure 5.5 Section for HK region (Research areas wind energy and maritime shipping on the North Sea)

Case 3 involves the establishment of a medium-scale (45 MW) central hydrogen production platform in the HK-region, indicated in figure 5.5. This setup maintains similar intervention-effect relationships as observed in Case 1, but with a capacity approximately 10 times lower, resulting in impacts that are proportionally smaller as well. Consequently, the ecological effects in Case 3 will be lower due to reduced flow rates of cooling water, chemicals, brine, and lower emissions into the environment. It's important to note that they may not necessarily be 10 times smaller compared to Case 1.

Also, variations in effects are anticipated due to disparities in local conditions between the HK and TNW regions. For instance, the HK region is characterized by softer, sandier, and more dynamic sediment compared to the TNW region, which features more stratified sea water and muddy sediment. These differences necessitate thorough assessment once a definitive location is determined for the platform. Despite the expected differences in ecological effects between Case 3 and Case 1 due to variations in capacity and local conditions, no disparities are anticipated in terms of knowledge gaps.

5.5.1 Construction phase - Case 3

Similar intervention-effect relationships as Case 1. Environmental effects in the construction phase are expected to be lower as Case 1, due to the much smaller scale of the support structure of the platform with electrolyser. However, there may be different effects, due to site specific differences such as softer, sandier, and more dynamic sediment, and less stratification compared to the TNW region. Building the platform and cable laying may have other effects e.g. for ecology in this region.

No differences in knowledge gaps are expected compared to the Case 1.

5.5.2 Operational phase - Case 3

Similar intervention-effect relationships as Case 1. Environmental effects in the operational phase are expected to be lower as Case 1, due to the much smaller scale of the support structure of the platform with electrolyser.

No differences in knowledge gaps are expected compared to the Case 1.

5.5.3 Maintenance phase - Case 3

Similar intervention-effect relationships as Case 1. Environmental effects in the maintenance phase are expected to be lower as Case 1, due to the much smaller scale of the support structure of the platform with electrolyser.

No differences in knowledge gaps are expected compared to the Case 1.

5.5.4 Decommissioning phase - Case 3

Similar intervention-effect relationships as Case 1. Environmental effects in the decommissioning phase are expected to be lower as Case 1, due to the much smaller scale of the support structure of the platform with electrolyser.

No differences in knowledge gaps are expected compared to the Case 1.

5.5.5 Proposed research methods per (partially) knowledge gap

Knowledge gaps for Case 3 are the same compared to the Case 1 and require no new research methods. The research methods that have been proposed in Annex III apply here as well. Differences in capacity and local conditions are to be considered in the model set-up. For example, proximity of the Hollandse Kust (HK) region to protected areas or areas with an ecological status such as the 'Noordzeekustzone' and the 'Bruine Bank' (N2000, Birds Directive, see figure 5.1) may be affected by water plume development due to water emissions by the hydrogen facility and above and underwater noise from vessels and operation.

5.6 Case 4 - decentralized, medium-scale (HK)

Case 4 is expected to have similar effects compared to the Case 2. Again, the quality of the effects may be different due to lower capacity of this design compared to Case 2, as well as the difference in local conditions. These will have to be assessed in an appropriate assessment once definitive locations have been determined.

The safety issues are similar to Case 2 but on a smaller scale, so no additional significant knowledge gaps are identified.

5.6.1 Construction phase - Case 4

Similar intervention-effect relationships as Case 2. Environmental effects in the construction phase are expected to be lower than Case 2, due to the much lower number of installations. However, there may be different effects, due to site specific differences such as softer, sandier, and more dynamic sediment, and less stratification compared to the TNW region. Building the platform and cable laying may have other effects e.g. for ecology in this region.

No differences in knowledge gaps are expected compared to the Case 1.

5.6.2 Operational phase - Case 4

Similar intervention-effect relationships as Case 2. Environmental effects in the operational phase are expected to be lower as Case 1, due to the much lower number of installations.

No differences in knowledge gaps are expected compared to the Case 1.

5.6.3 Maintenance phase - Case 4

Similar intervention-effect relationships as Case 2. Environmental effects in the maintenance phase are expected to be lower than Case 2, due to the much lower number of installations.

No differences in knowledge gaps are expected compared to the Case 1.

5.6.4 Decommissioning phase - Case 4

Similar intervention-effect relationships as Case 2. Environmental effects in the decommissioning phase are expected to be lower than Case 2, due to the much lower number of installations.

No differences in knowledge gaps are expected compared to the Case 1.

5.6.5 Proposed research methods per (partially) knowledge gap

Knowledge gaps for Case 4 are the same compared to the Case 1 and 2 and require no additional research methods. The research methods that have been proposed in paragraph 5.3 apply here.

5.7 Broader environmental effects of offshore energy

In the North Sea broader environmental effects can occur as a result of multiple offshore wind farms and/or hydrogen production installations. The European Court of Auditors' report on offshore wind and hydrogen production in the North Sea presents several conclusions and highlights the need for careful planning and cooperation to minimize ecological impacts.

5.7.1 Broader environmental effects of offshore wind farms

A number of broader effects related to offshore wind farms have been mentioned in the European Court of Auditors' document. Effects to be considered in an EIA for offshore hydrogen production are:

1 Ecological stressors: offshore wind farms can cause various ecological stressors, such as underwater noise, changes in water quality, and alterations in migration patterns due to electromagnetic fields. These stressors can have widespread effects, although the most significant cumulative effects usually occur in the vicinity of the offshore installations.
2 Biodiversity: there is evidence that offshore wind farms can have both negative and positive effects on biodiversity. Negative effects include habitat loss, displacement of marine species, and potential collisions with installations. On the other hand, there can also be positive effects, such as habitat restoration due to the reduction or exclusion of human activities and higher densities of certain fish species and invertebrates within the wind farms.
3 Specific species: the harbour porpoise, a protected species, can experience negative effects from offshore wind farms, especially during construction phases. However, there is also evidence that harbour

porpoises can benefit from the availability of food and the absence of fishing vessels within the wind farms.

4 Cumulative effects: the cumulative environmental effects of offshore wind farms remain uncertain, partly due to knowledge gaps in the research on these effects. This makes it difficult to accurately predict the environmental impacts of future installations.

From our own experience we added two more broader effects of offshore wind farms:

5 Large-scale disturbance of birds: Birds can experience large-scale disturbances due to their high sensitivity, with potential impacts extending up to tens of kilometres from the wind farms.
6 Alteration of environmental patterns: the presence of wind farms and other substructures can alter airflows, wave patterns, sediment plumes, and water stratification, affecting primary production and the entire ecosystem.

5.7.2 Broader environmental effects of offshore hydrogen production

Hydrogen production can have broader effects on the North Sea. The European Court of Auditors' report mentions one aspect with broader effects:

1 Warm cooling water: the discharge of warm cooling water from electrolyser platforms in the North Sea can lead to thermal pollution. This can affect the local marine ecosystem, for example, by altering water quality and impacting temperature-sensitive marine organisms.

The pollution can be deteriorated even further by (cleaning) chemicals added to the cooling water.

5.7.3 Need for cooperation and spatial planning

Two key success factors put forward by the European Court of Auditors' report are:

1 Regional cooperation: the North Sea countries cooperate within the North Seas Energy Cooperation (NSEC) to facilitate the rollout of renewable offshore energy. Despite this cooperation, few joint projects have been realized so far.
2 Environmental legislation: the EU strategy for renewable offshore energy emphasizes the importance of coexistence between renewable energy and biodiversity. The deployment of offshore installations must comply with environmental legislation to minimize negative impacts on the marine environment.

6

CONCLUSIONS AND RECOMMENDATIONS: STARTING POINTS FOR NRD AND EIA

This chapter serves as a high-level guide for future scoping reports (NRDs), Environmental Impact Assessments (EIAs), and Environmental and Planning Permit in the offshore hydrogen production sector, building upon the results from this report.

Four distinct case studies have been examined:
- Case 1: Centralized, large-scale (495 MW) offshore hydrogen production platform in the TNW area.
- Case 2: Large-scale offshore hydrogen production with 15 MW decentralized installations at the base of 33 wind turbines in the TNW area.
- Case 3: Centralized, medium-scale (45 MW) offshore hydrogen production platform in the HK area.
- Case 4: Medium-scale offshore hydrogen production with 15 MW decentralized installations on 3 wind turbines in the HK area.

Firstly, the most relevant environmental effects during the lifetime of a hydrogen production platform and the respective knowledge gaps are given. Secondly, the cumulative, synergistic, and broader effects are described. Thirdly, a conclusion is given about the differences between the cases. A recommendation for further research is given for each conclusion.

6.1 Most relevant environmental effects

Technical designs for medium to large scale offshore hydrogen production platforms are in an early stage of development and include many uncertainties. Numerous trade-offs and design-decisions still need to be made, while technological development is also still ongoing. The identified environmental effects and the knowledge gaps are based on general technical descriptions from DNV. This means that future designs may result in different, additional, or fewer environmental effects than assumed in this research.

It is found that most intervention-effect relationships are not new as they can be related to current practices with O&G platforms, offshore substations, offshore cables/pipes, and nearshore hydrogen and power plants[1] (see also e.g. [4] and [6]). Part of the intervention-effect relationships are comparable to current practices in the construction and decommissioning phase. For the related effects it is referred to the EIAs of these (international) projects. However, there are some key differences between current practices and an offshore hydrogen platform which result in new and/or unknown environmental effects and causing related knowledge gaps. These effects are listed below and explained in more detail in the following paragraphs.

Firstly, the water flows at the inlets of the cooling system can lead to intake of marine life. At the outlet water outflows have hydrographic effects, like increased temperature, salinity, and contamination by antifouling chemical. Secondly, the operation and maintenance of the platform will result in environmental effects from disturbances, both from the platform itself, installations (like compressors, pumps, fans) as well as from vessels servicing the platform. Thirdly, a hydrogen production platform has unknown effects on the maritime safety. Fourthly, substances (gases) will be emitted to air during the operational phase of the platform and may possibly have effects on co-use activities in the windfarm.

[1] See NEN-ISO 22734:2019 en

Water flows at in- and outlet

The effects at the water in- and outlets of the offshore hydrogen production platform are significant and multifaceted. During operation, approximately 26,000 m^3/hour of water is extracted, with 99 % allocated for cooling purposes and 1 % for hydrogen production. The extraction process can lead to adverse effects on the hydrographic quality of the surrounding water, mainly close to the inlet and outlet of the platform.

At the water inlet, the flow of water may result in the direct mortality of small marine life, the in- and outlet could induce destratification of the water column and could attract exotic species. However, the quantitative impact of these effects on ecological systems and the effects on the food chain remain unknown. Therefore, it is recommended to develop a hydrological 3D model to assess the in and out flux rates' impact on species absorption rates and biomass loss, as well as stratification effects. A hydrological 3D model, based on the Delft3D model[1], simulates water movement in three dimensions to assess how influx and outflux rates affect species absorption rates, biomass loss, and stratification effects. This model gives insight into the spatial-temporal development of an effluent water plume. By complementing this with location specific data on the presence and distributions of marine life, it is possible to evaluate how substances (i.e. brine and chemicals) and heat entering the system influence species and biomass.

Additionally, the discharge of water, containing antifouling chemicals, brine, and heated cooling water, presents further hydrographic effects. The transferred heat to the surrounding seawater is contingent on the electrolyser's efficiency and cooling method, potentially resulting in the large discharge of thermal energy into the open sea. Moreover, the discharged water may contain elevated salinity levels and contaminants, posing unknown risks to surrounding species.

Recommendation

The degree of water intake and outflow may be optimized to reduce the effect. For example, if less cooling water is required (through alternative or more effective cooling methods), lower volumes may be discharged. This will reduce chemical discharge and lower effects on hydrodynamic conditions. However, the discharge water will have a higher salinity, as brine still has to be released. Additional, optimisation may consider discharging cooling water with a higher temperature (e.g. 10ºC instead of 5ºC). Again, this will lower discharged volumes, but different ecological effects may result from the high temperatures.

To address uncertainties mentioned, it is recommended to develop a *hydrological 3D model* to assess the effects of discharged water plumes, considering turbidity, water stratification, salinity, and temperature changes over time. Subsequently, an ecological assessment should be conducted to evaluate barrier effects and impacts on different biotopes. Additionally, determining the chemical composition and volume rate of antifouling agents is crucial for understanding their effects on species and ecosystem health. These comprehensive analyses are essential for informing mitigation measures and ensuring the sustainable operation of offshore hydrogen production platforms. Such analysis may be included in an EIA.

Noise

The main contributor to noise on the platform will originate from compressors, which are used to compress the hydrogen for transportation purposes. The other source of noise will come from ventilation systems, venting of oxygen, nitrogen and hydrogen and vessel movements to and from the platform for service and maintenance purposes. All sources of noise and vibration will disturb marine life and above water noise could disturb birds. However, it is unknown what the exact noise level from the different sources will be. Moreover, it is unknown what the impact from the disturbance effects to marine life and birds is.

Recommendation

Further investigation is needed, and *underwater noise models* should be made. Subsequently, a data consultation on species of fish, marine mammals and benthic life is recommended to assess the impact on marine life. Additionally, a literature study should be performed to assess the impact of disturbance from vessels to birds.

[1] Reference 2 Deltares. (n.d.). *Delft3D FM Suite 2D3D*. Deltares: https://www.deltares.nl/en/software-and-data/products/delft3d-flexible-mesh-suite

Internal and external safety
While the main focus of this study was on environmental impacts, safety was also considered at a high level. An offshore hydrogen platform will pose internal and external safety risks during all of its lifecycle phases, which cannot be compared one-to-one with current offshore practices. During operation there is a risk on hydrogen and oxygen leakages, and a risk of external safety incidents, for example a colliding service vessel, helicopter, or an extreme weather event. However, there are several knowledge gaps which can have a significant impact on internal and external safety.

These knowledge gaps are:
- Developers of offshore hydrogen projects aim for unmanned operation. While this can reduce safety risk and costs for maintenance, current operation and maintenance plans are not suitable for such operation and development is still required.
- Safety standards for offshore hydrogen production are currently still being. Such development is crucial for safe and reliable operation, but it will also require the adoption of such standards. Even if a standard is in place, the developers of offshore hydrogen production are not necessarily familiarized with the hazards and standards they will need to comply with.
- Analysis and simulation tools that support safety studies, like a (Comparative) QRA, a FERA and a ship collision study, rely on statistics (e.g. failure frequencies), which have been built for decades in the O&G industry, but these are still limited regarding hydrogen. This is a significant knowledge gap with regards to safety, which needs to be addressed. These studies should map the potential external safety risks associated with operation of an offshore hydrogen platform and rate the chance that a potential risk occurs.

Recommendation
Further development of *technology, standards and advanced QRA's* are required to improve internal and external safety.

Emissions to air
Intentional and unintentional emissions of gasses to air will occur during the lifetime of the hydrogen production platform. As mentioned in the previous paragraph, fugitive emissions of hydrogen and oxygen, but also nitrogen, SF6 and KOH, can occur during operation. Next to that, substances can be emitted intentionally (venting) during commissioning or as a precautionary measure in case of a safety incident during operation. Lastly, oxygen, a by-product from the electrolysis process, is emitted to the air during operation. While some substances have a negligible effect on the environment, the emission of hydrogen and SF6 can have significant effects.

It is known that SF6 is a GHG but the effects on global warming of hydrogen in the atmosphere is less known. Additionally, the quantities of emitted substances are currently unknown.

Recommendation: It is recommended to perform *emission studies*, and studies on *hydrogen's effect on global warming*.

General recommendation
For more detailed environmental impact analysis, it is advised also to ***take operational hours into consideration.*** This will give a more accurate assessment of the electrolyser's impacts on energy consumption, emissions, water use, equipment lifecycle, and thermal pollution. This also enables better planning and implementation of mitigation measures to minimize adverse environmental effects.

6.2 Cumulative, synergistic, and broader effects

The previous paragraphs have described the most significant knowledge gaps regarding the environmental effects of an offshore hydrogen platform. Other aspects, which were also mentioned by the experts, are the cumulative and synergistic effects, and broader effects which reach beyond the wind site (see paragraph 5.7). As much as there are knowledge gaps on the individual effects, there is a knowledge gap on their synergy.

On top of that, there can be cumulative effects from other activities, like the connected wind farm. Furthermore, it is unknown what the indirect effects on co-use and other users of the North Sea outside of the wind site will be, for example by considering food web interaction.

Recommendation: As hydrogen effects may reach (far) beyond the project site, cumulation with present and future environmental pressures should be studied explicitly. This to aid quantification of effects and enable a holistic environmental impact assessment. A mitigation strategy can be developed when the cumulative impact is mapped.

6.3 Case comparison

From this pre-study it is not yet possible to indicate if a centralized concept has a larger environmental impact than a decentralized concept with the same capacity. However, the generic differences and the subsequent knowledge gaps between the concepts have been identified.

The ecological impacts will cover a larger area in the decentralized concept. But it is unknown what the difference in effects, like barrier formation or intake of small marine life, between both concepts will be. It is also unknown to what degree the efficiency and emissions of a small, decentralized installation compares to one large scale centralized platform. So, in the decentralized concept, the plume assessment studies for heat, brine and chemicals, the noise and vibration studies, the destratification studies and direct mortality of marine life at the inlet should not only assess a single turbine but assess the cumulative effect of all hydrogen installations.

Another significant difference between the cases is the maritime safety aspects. Increased maritime traffic will be present in the Case of a decentralized concept, which increases the risk of a collision with a service vessel. Similarly, the risk of an explosion is higher as there are more production units, but the impact is lower compared to a central concept. Finally, the decentralized concept includes IA pipelines from the wind turbines to an export pipe instead of cables to a platform. This leads to a risk on hydrogen leakage due to a vessel related incident, like a drifting anchor over the seabed or a sinking vessel. The difference in magnitude of these risks between the concepts are still unknown.

Recommendation: an impact assessment is required to compare the ecological impact of relatively smaller effects over a larger area (decentral), or relatively large effects focused on a single location (central);
Recommendation: in order to address safety aspects, studies which consider Case specific, integral safety aspects, with a focus on the potential risks and the chance that a risk occurs, of hydrogen production facilities are recommended.

6.4 Broader environmental effects

Broader environmental effects in the North Sea can arise from the presence of multiple offshore wind farms and/or hydrogen production installations.
The following broader effects were identified from offshore wind farms:

1 Ecological stressors: offshore wind farms can cause various ecological stressors, such as underwater noise, changes in water quality, and alterations in migration patterns due to electromagnetic fields. These stressors can have widespread effects, although the most significant cumulative effects usually occur in the vicinity of the offshore installations.
2 Biodiversity: there is evidence that offshore wind farms can have both negative and positive effects on biodiversity. Negative effects include habitat loss, displacement of marine species, and potential collisions with installations. On the other hand, there can also be positive effects, such as habitat restoration due to the reduction or exclusion of human activities and higher densities of certain fish species and invertebrates within the wind farms.
3 Harbor porpoise: the harbour porpoise, a protected species, can experience negative effects from offshore wind farms, especially during construction phases. However, it is hypothesized that harbour

porpoises may benefit from the availability of food and the absence of fishing vessels within the wind farm.

4 Cumulative effects: the cumulative environmental effects of offshore wind farms remain uncertain, partly due to knowledge gaps in the research on these effects. This makes it difficult to accurately predict the environmental impacts of future installations.
5 Large-scale disturbance of birds: birds can experience large-scale disturbances due to their high sensitivity, with potential impacts extending up to tens of kilometres from the wind farms.
6 Alteration of environmental patterns: the presence of wind farms and other substructures can alter airflows, wave patterns, sediment plumes, and water stratification, affecting primary production and the entire ecosystem.

Broader environmental effects of offshore hydrogen production:

7 Warm cooling water: the discharge of warm cooling water from electrolyser platforms in the North Sea can lead to thermal pollution. This can affect the local marine ecosystem, for example, by altering water quality and impacting temperature-sensitive marine organisms. The pollution can be deteriorated even further by (cleaning) chemicals added to the cooling water.

Appendices

APPENDIX: TECHNICAL CASE DESCRIPTIONS

Technical descriptions cases

for Hydrogen Production at the North Sea

Ministry of Economic Affairs and Climate

24 July 2024

1.1 Introduction

In this paragraph we highlight some general concepts offshore hydrogen production in or near an offshore wind farm.

1.1.1 Offshore wind and hydrogen production concepts

Hydrogen production through electrolysis uses electricity to split water into hydrogen and oxygen. This electricity can be generated by renewable sources such as wind energy and with a direct connection to the source. The figure below (Figure 0-1) provides three possible configurations for connecting an electrolyser plant to an offshore wind farm.

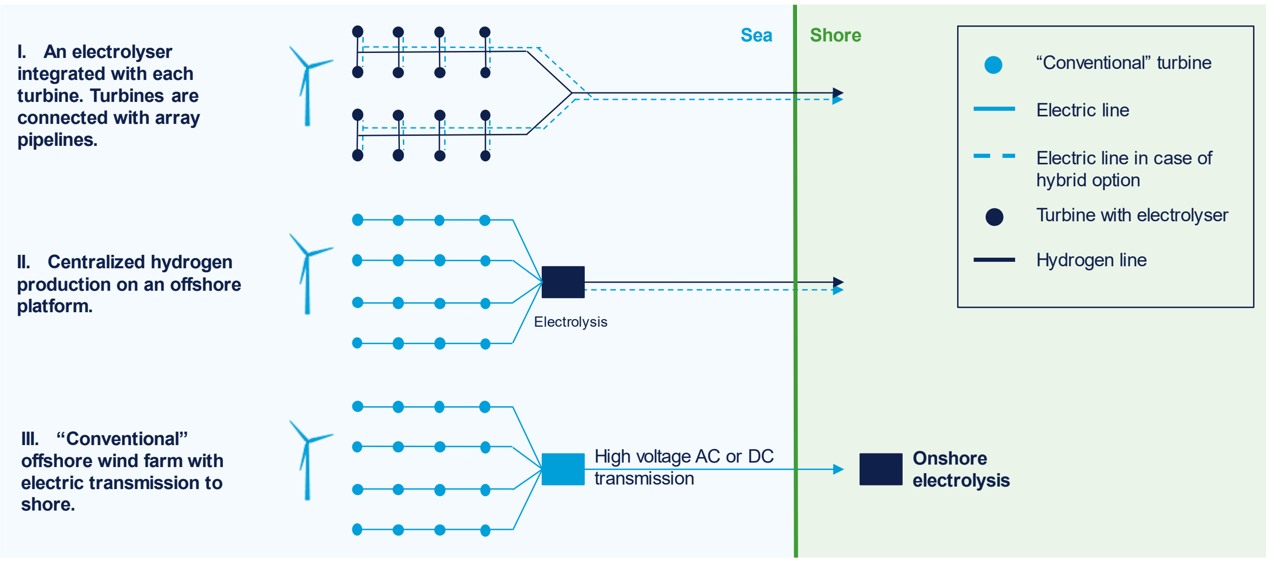


Figure 0-1 Offshore hydrogen production concepts.

I. The first configuration integrates the hydrogen production at the turbine. A smaller electrolyser unit is directly connected to the turbine to generate hydrogen and will omit the requirement for array cables. Instead array pipelines are used.
II. The second configuration still resembles a conventional offshore wind farm but will not connect to the grid. Instead, the electricity is fed to a electrolyser system and converted to hydrogen. The electrolyser plant is located on a centralized platform (comparable to a sub-station) and is receiving electricity from the array cables. Alternatively the electrolyser plant can be placed on a platform where multiple wind farms can feed into.
III. The third configuration is more conventional where a wind farm is built and instead of connecting to a grid, it is directly connected to the electrolyser plant which is located onshore.
IV. The three configurations provided above are dedicated. Here all electricity is converted to hydrogen, but alternatively a hybrid system can be chosen. A hybrid system has both a connection to the electric grid (indicated with dashed light blue lines) as well as a connection to the electrolyser. Both connections, electric and hydrogen, can be at full capacity or a smaller part of the capacity. E.g. for a 15 MW hybrid turbine, 10 MW can be converted to hydrogen with a 10 MW electrolyser and the remaining 5 MW can be connected electrically. The connecting infrastructure, array pipes and cables and further export pipes and cables should be designed to the required capacity as well. Such a system allows the operator to choose between different markets (hydrogen or electricity).

This report focusses on concept I and II and are further elaborated below, concept III and IV are out of scope. DNV provides their high-level view on a potential design, but it should be noted that further research and development is still needed. Both concepts are further described in subsequent sections.

1.1.2 Assumptions and bandwidths

Currently no (comparable) electrolysers are in operation on an offshore platform. Hence, this research will be based on numerous assumptions as there are no existing similar projects to compare to. The assumptions will be based on practices with an offshore substation (OSS) when possible. When a certain effect of an offshore electrolyser is not present in the case of an OSS, the assumption will be based on a different technology or practice, or categorized as an unknown. The assumptions are substantiated and the unknowns are listed in section X. Bandwidths in construction and operation are used when necessary to determine the worst-case scenario for a certain effect.

Other assumptions:

- An important assumption is the bandwidth for the increased temperature of cooling water that is discharged in the North Sea. For this temperature increase we assume a bandwidth of 5-15 degrees Celsius.
- Oxygen is assumed to be emitted to surroundings.
- Two cases are not examined in this study: large scale in *Hollandse Kust region* and small scale in the *North of the Wadden Islands region*.
- It is assumed that suppliers will be able to develop low maintenance equipment which allows for unmanned operation.
- Compression will be applied, but it requires further optimisation if this will be decentralized or centralized, as well as an optimisation on the pressure regime.

1.2 Technical concepts

First we explore technical options for the various installations and configurations. From this we make a selection for the various technical case descriptions.

1.2.1 Options and selected technologies

Electrolyser technology

Electrolysers have been operating for multiple decades already, but the energy transition has provided a boost for further development and upscaling. The main developments are related to upscaling of both systems and supply chain, improvement of performance, cost reduction and application/integration with renewable energy. These developments are mainly focussing for onshore application, but offshore application is increasingly being explored.

Offshore application poses new challenges such as a direct coupling to renewable energy (and therefore a rapid response time), should have a minimized footprint and weight, and should have minimized maintenance requirements. Currently only pressurized alkaline and PEM can meet these requirements and even with those technologies, further development is needed. Anion Exchange Membrane (AEM) could be another potential technology but is currently immature and its future is still uncertain.

At this stage both technologies, PEM and pressurized alkaline, are being developed for offshore application and therefore both can be expected in the future. The key differences between the two technologies relevant for this study are described below.

- Footprint and weight (and further development there-off)
    - Key developments currently include performance improvement through higher efficiencies and higher current density. Both developments can reduce the required weight and footprint. These developments also affect other components such as the cooling system.
- Operating flexibility and back-up power requirement
- Maintenance requirements and interval
- Pressurized alkaline requires lye (mix of water and KOH or NaOH)

- Slight difference in operating temperature
- Degradation and efficiency

For this study we select the alkaline electrolyser, because we judge this to be the “worst case” compared with PEM. It should however be noted that most developed offshore hydrogen production concepts consider PEM and this technology is therefore more likely to be applied.

Water treatment technology

Water is required for two purposes, feedwater to the hydrogen production process and cooling water. Sea water can be used for both purposes but will require treatment, especially for the feedwater.

The feedwater will need to be purified to very high purities as it has a direct influence on the electrolyser performance and degradation. This can be done through reverse osmosis (RO) or through thermal desalination. Additional deionization is likely required to make to final purification step. (Additional chemicals for purification are still to be determined).

The main consideration between the two technologies are:

- Use of chemicals. RO uses more chemicals compared to thermal desalination
- Maintenance interval, especially exchange of filters and chemicals with RO
- Synergies with “waste” heat.
    - With thermal desalination the heat from the electrolysis process can be used to desalinate feed water. Therefore the water treatment system and the cooling system can be integrated.

At this stage both technologies are considered for offshore hydrogen production.

Back-up power

There is a need for back-up power to:

- Run safety systems
- Keep critical components running
    - Ventilation
    - Anti frost
    - Etc.
- Start up after a shut down for both turbine and electrolyser

In conventional offshore wind an electrical connection with the grid is present. In some cases this is used to consume power from the grid to start up a wind farm. The offshore wind industry is currently working on so called “black-start” solutions. For offshore hydrogen production this challenge will be bigger and a larger back-up power system is needed. This can be done through batteries, fuel cells (consuming hydrogen from the pipelines), small electrical grid connections or diesel generator (unlikely).

Substructure

For the decentralized configuration a jacket or monopile can be applied. As monopiles are already close to the end of the maximum design size, we assume in this case the jacket foundation.
The construction of the inter array hydrogen pipes depends on the considered lay-out and pipe technology. In paragraph 1.2.3 we will further elaborate on this.

Compression

Compression will likely be done with reciprocating compressors as centrifugal compressors are less feasible for hydrogen. Reciprocating compressors can cause vibration which should be considered for an environmental assessment. The compressors can be placed directly at the electrolyser, at the platform for the central concept and at each turbine with the decentral concept, or a central compressor can be placed which has its own structure. The preferred selection will depend on an economical optimization and will require further investigation.

1.2.2 Central concept

The platform concept assumes hydrogen production on an offshore platform where multiple turbines are connected through array cables. The voltage received at the platform is 66-132 kV_{AC} where it is transformed to medium voltage (10-40 kV_{AC}) through a transformer system. Other equipment on the platform includes the electrolyser, the water treatment and the cooling. This concept also uses sea water for cooling and desalination and water treatment to provide clean water. All equipment is placed on multiple decks and the system boundaries are further clarified by the schematics below.

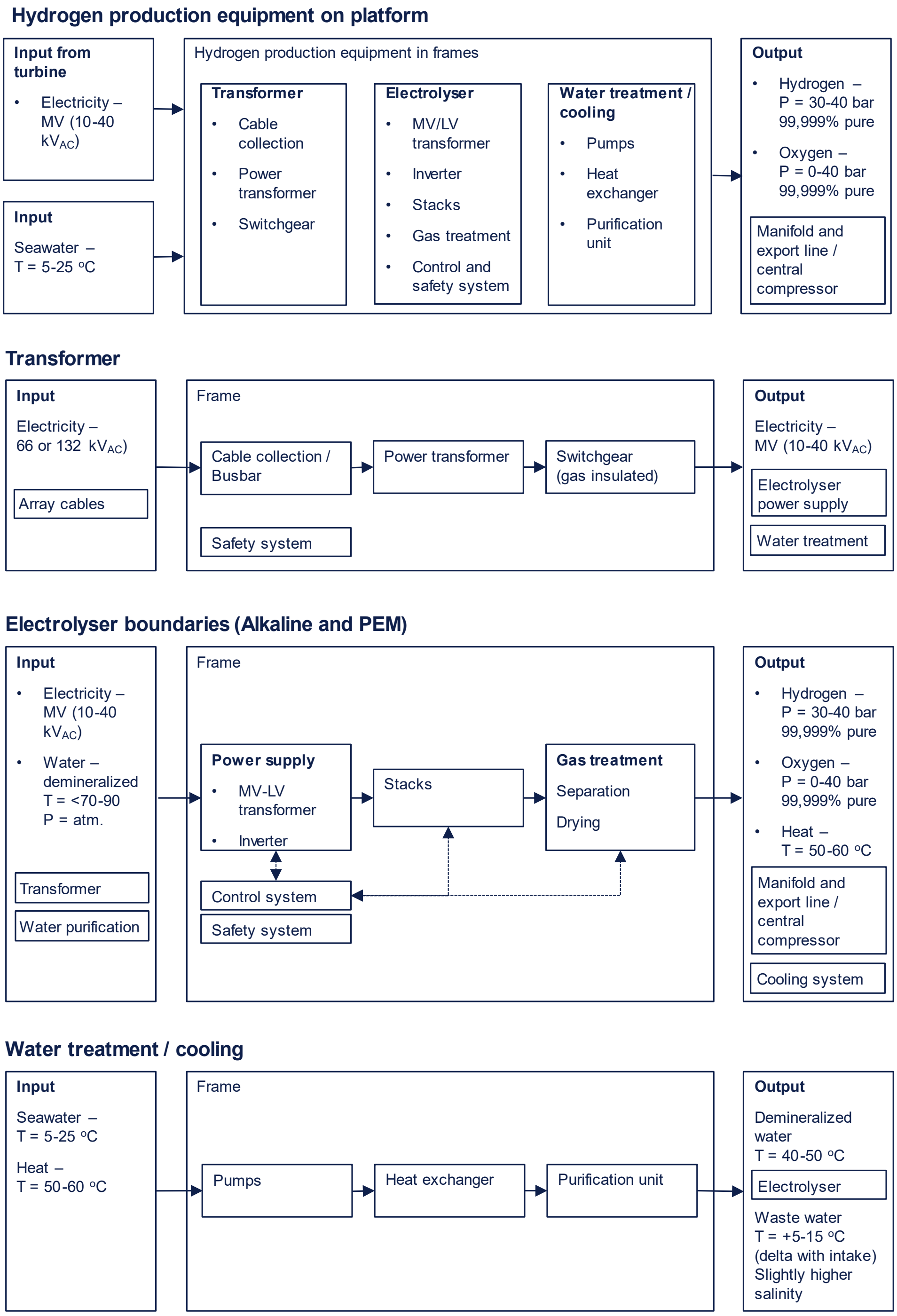
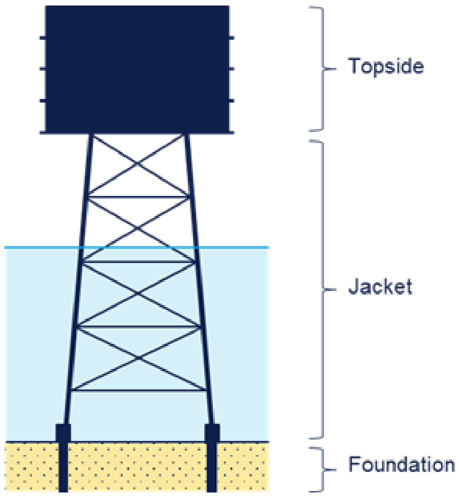


Figure 0-2 Schematics for platform concept, hydrogen production on an offshore platform.



Design and systems

The central and decentral designs of the electrolyser installation comprise both closed and open systems.

- Closed systems: all applied substances remain in the system. Under normal operation conditions these substances do not enter the environment. Any leakage from closed systems should be prevented/minimized and should be captured by leak tight floors or leak trays (common practice in offshore O&G).
- Open systems: substances (such as sea water and some chemicals) are entering and leaving the installation (such as cooling water, brine and some chemicals), in some cases they leave the installation as a different substance (hydrogen, oxygen). Some substances will end up in the environment, like cooling water, brine and some chemicals. The remaining substances will stay confined in pipelines (hydrogen, possibly oxygen).

Construction

Complete topside with single or dual lifting vessel (depending on available lifting vessels).

The construction process of offshore hydrogen platforms will likely be similar to offshore electrical substations. The period for the construction phase, and the part of the year in which this will take place, are still to be determined. During this period there will be noise, vibration and/or light pollution.

In this case installation of turbines and (electrical) inter array cables are assumed to be similar to conventional offshore wind farms.

Commissioning

Commissioning will include:

- acceptance testing including venting/flaring of hydrogen/oxygen and nitrogen
- filling of fluids and lubricants
- start of operations
- tightening of stacks and other equipment/connections
- dewatering and drying of flowlines

There is likely a knowledge gap with regard to commissioning sequence as no offshore hydrogen project has moved into a relevant development stage yet.

Operation and maintenance

During operation the following aspects will occur

- Venting/flaring of hydrogen, oxygen and nitrogen during start-stop sequences and in smaller quantities for balancing pressure (with some designs).

- Sea water will be extracted to provide feed water and cooling water. The water will be returned to the sea at elevated temperature and increased salinity (see table xx).
- Noise and vibrations will likely occur. The compressor is likely the main contributor to this emission.
- Other environmental effects such as electro-magnetic field (EMF). The main source for EMF will be caused by converters like IGBT (assumed) or Thyristor type. This effect may be comparable with OSS (to be checked).
- Light pollution is likely to occur, however in an unmanned situation this effect will be comparable with OSS (assumption).

Based on expert discussion with offshore operational experts it is unlikely that the hydrogen production platform will be permanently manned due to safety and cost considerations. Maintenance will therefore likely be done from a service and operation vessel (SOV). The required maintenance actions and interval are still unknown. Electrolyser OEM's are still developing their technology for offshore application. This includes improvement of remote operation and minimizing offshore maintenance. It can include:

- Preventive and corrective maintenance for all components including electrolyser, compressor, pumps, cooling system, water treatment, etc.)
- Exchange of lubricants, liquids and filters
- Tightening of stack and other equipment/connections
- Periodical visual checks
- Tests of safety system
- Exchange of large components every few years (such as electrolyser stacks). This requires small lifting vessels.
- Exchange of fluids (in case of alkaline but depends on OEM)
- Coating inspection and repair
- Replacement of components

Decommissioning

No information available. Due to presence of high value and scarce materials it is likely that the topside will be dismantled and lifted to shore for further decommissioning and recycling (we assume an obligation to dismantle at the end of life of the offshore wind farm and hydrogen production installations). Fluids can be drained and pumped to a ship for further disposing.

1.2.3 Decentral concept

The integrated concept assumes hydrogen production at the turbine where an electrolyser is located at the base of the turbine. Additional support structure is required to extend the working platform of the turbine for the hydrogen production equipment to be placed in containers. This equipment includes the electrolyser, water treatment and cooling and receives medium voltage (10-40 kV_{AC}) from the turbine. Seawater is used for both cooling and desalination and treated to supply clean water to the electrolyser. To further transport the produced hydrogen, a connection will be made to array pipelines which collect hydrogen from each turbine and further transport it to a manifold or central compressor. The system boundaries of the integrated turbine are provided in the schematics below (Figure 0-3).

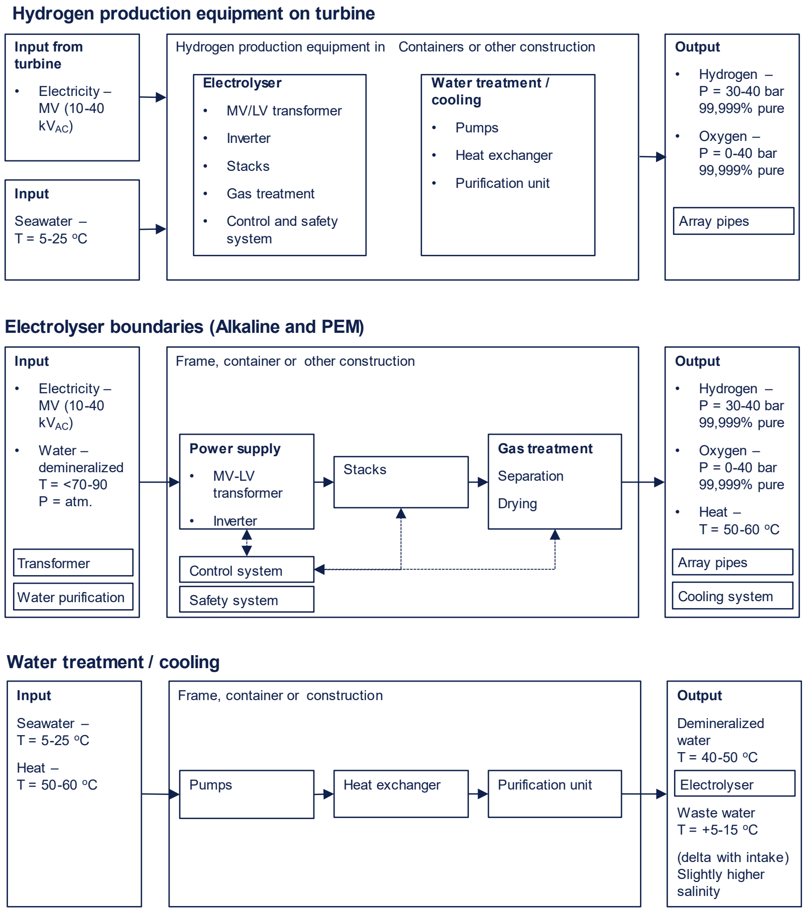
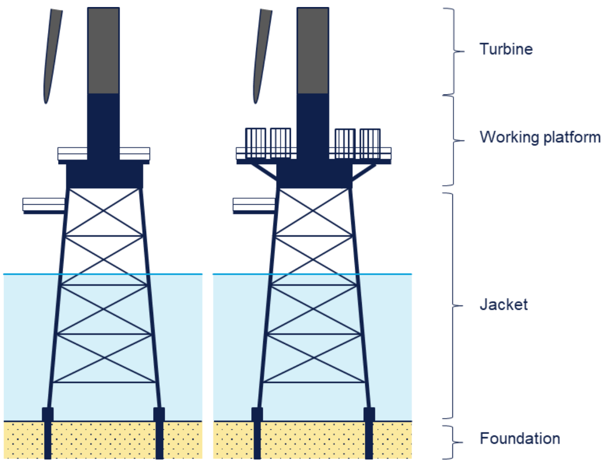


Figure 0-3 Schematics for integrated concept, hydrogen production directly at the offshore turbine.

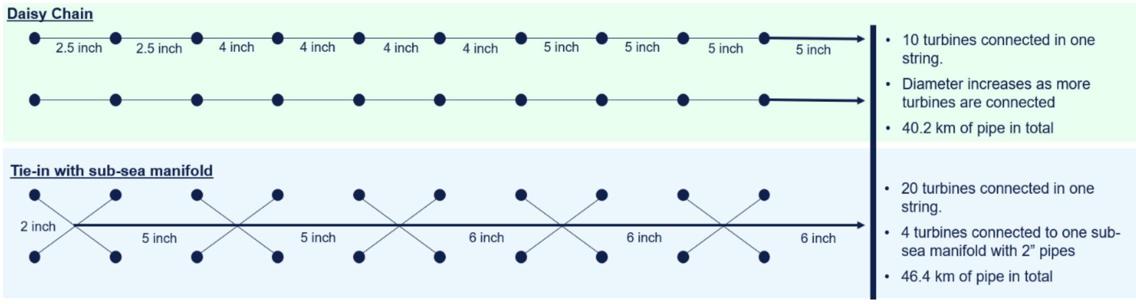


Construction

The construction of the turbine and its structure is assumed to be similar to “conventional” turbines. In case of a jacket foundation, the impact for the environment (e.g. under water noise) will be comparable or less than in case of a monopile foundation (assumption). In addition, if a containerized solution is considered, containers can be lifted on the turbine deck. Further connection of piping and cabling will be done by engineers on the turbine.

As indicated above, the construction of the array pipes depends on the considered lay-out and pipe technology. Different pipe technologies can be considered, welded steel pipes, coiled steel pipes or composite pipes (TCP). Each technology also has different methods for construction.

Examples of different lay-outs



Commissioning

Commissioning will include:

- acceptance testing including venting/flaring of hydrogen/oxygen and nitrogen
- filling of fluids and lubricants
- start of operations
- tightening of stacks and other equipment/connections

There is likely a knowledge gap with regard to commissioning sequence as no offshore hydrogen project has moved into a relevant development stage yet. Both wind turbine and elektrolyser system need to be tested separately. For this reason simultaneous commissioning is not possible or very difficult. Another challenge is the discharge of produced electricity in during hot commissioning of the wind turbines, because the electrolyser in not in operation yet.

Operation and maintenance

During operation the following aspects will occur

- Venting/flaring of hydrogen, oxygen and nitrogen during start-stop sequences and in smaller quantities for balancing pressure (with some designs).
- Sea water will be extracted to provide feed water and cooling water. The water will be returned to the sea at elevated temperature and increased salinity (see table xx).
- Noise and vibrations will likely occur. The compressor is likely the main contributor to this emission but it is unknown if this will be done for each individual turbine.
- Other emissions such as electro-magnetic radiation and light are likely to occur.

Maintenance will therefore be done from a service and operation vessel (SOV) in combination with a crew transfer vessel (CTV). The required maintenance actions and interval are still unknown. Electrolyser OEM's are still developing their technology for offshore application. This includes improvement of remote operation and minimizing offshore maintenance. It can include:

- Exchange of lubricants and filters
- Tightening of stack and other equipment/connections
- Periodical visual checks
- Tests of safety system
- Exchange of large components every few years (such as electrolyser stacks). This requires small lifting vessels.
- Exchange of fluids (in case of alkaline but depends on OEM)
- In case of (unplanned) shut-downs a manual re-start might be required.
- Exchange of (small/large) modular components (e.g. the complete electrolyser container)

Decommissioning

No information available. Due to presence of high value and scarce materials it is likely that equipment will be dismantled and lifted to shore for further decommissioning and recycling. If a containerized solution is selected this is a relatively easy procedure. Fluids can be drained and pumped to a ship for further disposal.

1.3 Overview technical specifications

The table below provides an overview of the technical specifications for multiple concepts. Note that these are indicative values with a high degree of uncertainty due to novelty and further development of technology, difference between suppliers, performance difference due to fluctuating energy input and degradation etc. However, the certainty level and level of detail is assumed to be sufficient for the exploratory purpose of this study.

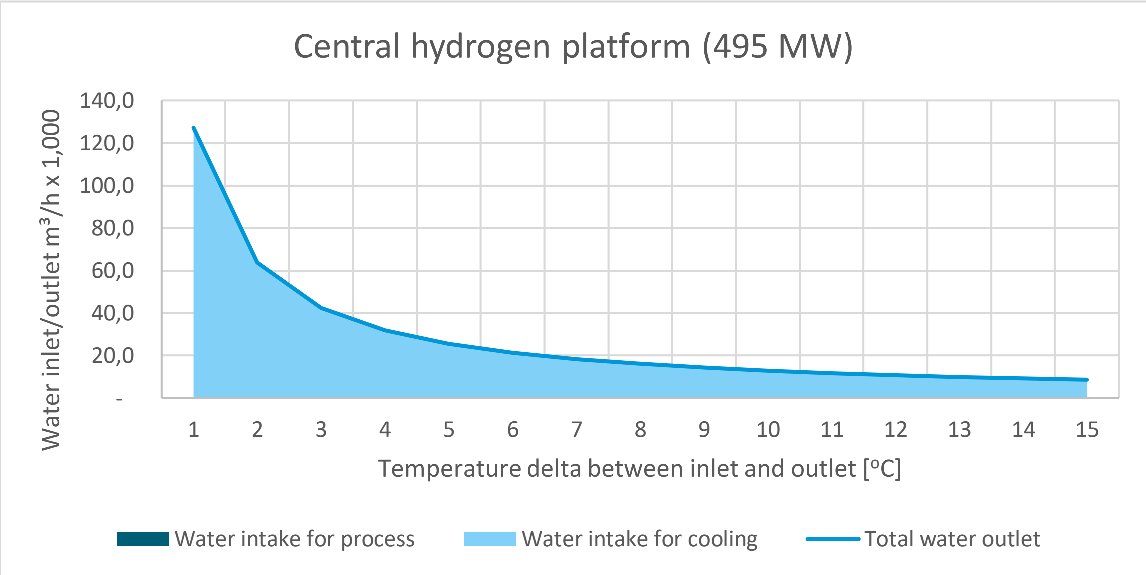
	Unit	Large centralized platform	Small scale centralised	Decentralized per WTG	Comments
Capacity electrolyser (el)	MW	495	95	15	
Full load hours	h/y	4500	4500	4500	
Flows in					
Electricity (66-130 kV)	MW	495	95	15	
Sea water	m^3/h	25,704	4,932	779	
	m^3/y	115,668,000	22,194,000	3,500,000	
salinity	*‰*	34,5	34,5	34,5	Average salinity of North Sea water
Feed water	*m^3/h*	324	62	*10*	Water used for H2 production process
	m^3/y	1,458,000	279,000	*44,000*	
Cooling water	*m^3/h*	25,380	4,870	*770*	Water used for cooling
	m^3/y	114,210,000	21,920,000	*3,460,000*	
Flows out					
Hydrogen	kg/h	8,715	1,675	265	
	kt/y	39.20	7.50	1.20	
Oxygen	kg/h	69,300	13,300	2,100	
	kt/y	34.30	1.26	0.03	
Water	m^3/h	25,604	4,914	776	Combined (feed water reject and cooling water)
	m^3/y	115,218,000	22,113,000	3,492,000	
temperature increase	℃	5	5	5	Increase between cooling water inlet and outlet
salinity	‰	34.6	34.6	34.6	0.13‰ increase (absolute)
Feed water					
Feed water reject	*m^3/h*	226	43	*7*	Reject stream from water treatment
salinity	*‰*	*49.3*	*49.3*	*49.3*	Salinity of reject water only, 14.7‰ increase (absolute)
Cooling water					
Cooling water	*m^3/h*	25,380	4,870	*770*	
Temperature increase	*ΔC*	5	5	*5*	Increase between cooling water inlet and outlet
Rejected heat	*MWh/h*	152	29	*5*	Heat is produced due to efficiency losses mainly

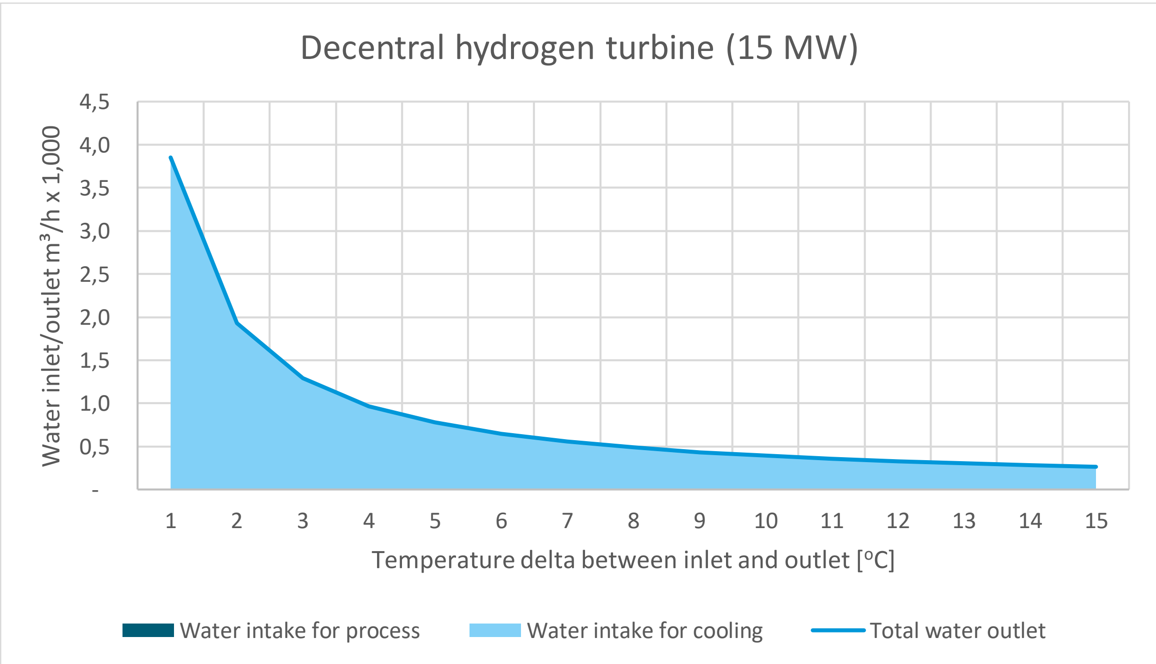
					from the electrolysis process.
salinity	‰	34.5	34.5	34.5	No increase in salinity of cooling water
Emissions (operational)					
H_2					H_2, O_2 and N_2 will be vented/flared during stop/start sequences and could possibly occur during operation in small amounts to balance pressure. The quantities are unknown due to lack of operational data.
O_2					
N_2					
Heat		Already covered with cooling water			
Noise					Noise and vibration can occur. Main source of noise and vibration will be the compressor
Vibration					
Electro magnetic					Electro magnetic radiation from electrical equipment
Light					Emergency and navigational lighting
Anti fouling agents					Depending on design and local conditions, anti fouling agents can be applied.
Design					
Foundation		Jacket	Monopile/Jacket	Jacket	
Structure		Platform	Platform	extended turbine platform	
Cables		??	??	-	Not additional to conventional wind farm
Pipeline diameter					
Export	inch	12-30"	12-30"	12-30"	Depending on pressure and distance
Array	inch	-	-	<10"	Diameter can increase if weighted coating is applied.
Burried?		yes	yes	yes	Assumption
Cooling		Sea water	Sea water	Sea water	
Back-up power		Li-ion	Li-ion	Li-ion	To be solved by industry
Water storage tanks		Small	Small	Small	Buffering
hydrogen buffer tanks		Small	Small	Small	To avoid suction at compressor inlet
Compression		Reciprocating	Reciprocating	Reciprocating*	*If needed
Water treatment		RO	RO	RO	
Substances		SF_6			in case of gas insulated switchgear
These substances are in a closed system. Exposure to the environment will only occur through incidents but not through normal operation (unless stated on the section on emissions)		Demineralized water			
		Brine			
		KOH			in case of alkaline electrolyser
		H_2			
		O_2			
		Nitrogen			For purging

		Heat transfer fluid (i.e. glycol)		Can occur depending on design of cooling system
		DI resins		For deionisation
Manned		Unlikely	No	

One of the potentially largest environmental effects is related to the water intake and outlet. There is a strong relation between the volume of water intake and outlet and the selected temperature delta. In our analysis we assumed a temperature delta of 5°C as an acceptable limit. This is a relatively low delta which is often accepted by regulatory bodies and environmental parties. The downside of this low delta is that the water intake and outlet flow is high to assure sufficient heat can be exchanged with the sea water. Higher temperature deltas will allow for lower volumes of water intake and outlet. The relationship is provided in the figure below for both the centralized platform and a single decentralized hydrogen turbine.

The water intake for the electrolysis process which will be converted to hydrogen is constant and is not affected by the selected temperature delta. This is also plotted on the figures, but is too small to see.





CASE DESCRIPTIONS

See below an overview of the four (4) cases to be examined for environmental effects of hydrogen production offshore.

	Hollandse Kust region	North of the Wadden islands region
Centralized	1	3
Decentralized	2	4
Small scale (50-100MW)	√	N.a.
Large scale (500-700MW)	N.a.	√

Hereunder we display the four (4) case descriptions.

1.4 Case 1: Centralized - small scale - HKW

Case 1 is one (1) centralised small scale (50-100 MW) installation on an offshore platform in the Hollandse Kust region. The small scale centralized configuration is described in paragraph 1.3. For small scale we assume 95 MW (worst case for small scale).

1.5 Case 2: Decentralized - small scale - HKW

Case 2 is a decentralised small scale (50-100 MW) configuration with four (4) offshore wind turbines with 15 MW electrolyser each in the Hollandse Kust region. From these (4) wind turbines hydrogen inter array pipelines run to the central hydrogen export pipeline. The decentralised installation per wind turbine is described in paragraph 1.2.3. For small scale we assume 7 x 15 MW = 95 MW (worst case for small scale). All values per wind turbine to be multiplied by 7.

1.6 Case 3: Centralized - large scale - TNW

Case 3 is one (1) centralised large scale (500-700 MW) installation in the North of the Wadden islands region. This large scale centralized configuration is described in paragraph 1.2.2. For large scale we assume 495 MW.

1.7 Case 4: Decentralized - large scale - TNW

Case 4 is a decentralised large scale (500-700 MW) configuration with 33 offshore wind turbines with 15 MW electrolyser each in the North of the Wadden islands region. From these wind turbines hydrogen inter array pipelines run to the central hydrogen export pipeline. The decentralised installation per wind turbine is described in paragraph 1.2.3. For large scale we assume 33 x 15 = 495 MW. All values per wind turbine to be multiplied by 33.

2

ANNEX I INTRODUCTION TO DIFFERENT ELECTROLYSER TECHNOLOGIES

At a basic level, electrolysis splits water (H2O) into hydrogen (H2) and oxygen (O2) by applying an electric current. As simple as it sounds, researchers and developers have optimized this process and currently there are four main technologies; Alkaline, Proton Exchange Membrane (PEM), Solid Oxide Electrolysis (SOE) and Anion Exchange Membrane (AEM).

Alkaline Electrolysis
Alkaline is most developed, but the increasing interest in green hydrogen boosts further development. The focus of manufacturers is on performance efficiency and safety improvements, cost reduction and upscaling of the electrolyser sizes and production lines. Where the established alkaline technology was mainly atmospheric, pressurized systems have also entered the market. Pressurized stack systems require less downstream external compression which is generally needed for most applications. Pressurized systems are also better equipped to respond to changes in power input (e.g. from renewable energy). This gives pressurized alkaline the advantage to still compete with other technologies such as PEM. The main challenges are to develop inherently safe design for larger and larger concepts, for instance regarding cross-over of oxygen internally, safe blow-down with venting/flaring, and reducing leaks with improving the "weak links" such as valves, seals etc..

Proton Exchange Membrane (PEM)
PEM has seen much development over the last decade and has established a position on the electrolyser market. PEM is known for its ability to ramp up and down very quickly, making it a suitable technology to follow changes in power input from renewable energy. The focus areas for development are very similar to alkaline but are expected to follow a steeper learning curve to catch up with alkaline. Additional development with PEM goes to the reduction and recycling of Iridium, a rare material which could limit very large scale expansion of PEM.

Solid Oxide Electrolysis (SOE)
SOE has reached commercialization and recent investments have led to competitiveness in the market and upscaling of production capacity. The technology is mainly recognized for high operating temperatures (500-900oC), high efficiencies, and the use of steam instead of liquid water. The technology is commercially available, but is still far behind AE and PEM in terms of scale and maturity. The current focus for development is commercialization, upscaling, lifetime improvement and cost reduction. The latter two still need much development to compete with Alkaline and PEM. A unique advantage of SOE is its capability to directly form syngas using co-electrolysis of steam and CO2, and to produce a mixture of hydrogen and nitrogen with co-electrolysis of steam and air. The latter is advantageous combined with ammonia production, saving costs on air separation units to produce nitrogen and the possibility to use waste heat for steam production. SOE is also capable of operating in reverse, acting as a fuel cell.

Anion Exchange Membrane (AEM)
AEM is the latest developed technology and has not yet commercialized at relevant scale. It shares many similarities with PEM in terms of design but uses cheaper materials. The main focus of development is lifetime improvement before it will enter commercialization, cost reduction and further improvements.

	Current | 2030[A]	Alkaline	Pressurized Alkaline	PEM	SOE	AEM
Efficiency	kWh/Nm³	4.7 | 4.3	4.7 | 4.3	4.8 | 4.5	3.6 | 3.3 [B]	4.8 (stack only)
Stack lifetime	hours	80,000 | 100,000	80,000 | 100,000	50,000 | >80,000	20,000 | >20,000	5,000
Flexibility	Time to reach nominal capacity	Minutes	<10s	<1s	<1s [C]	<1s
Pressure	bar	Atm.	<40 | <70	<40 | <70	atm. | <20	<35
Commercial status		Available	Available	Available	Available	Under development

A: Predictions based on manufacturer indications, literature or FCH JU targets.
B: Efficiency of SOE assumes external heat is provided.
C: Hot system in laboratory, unknown for commercial systems

II

APPENDIX: ENQUÊTE WATERSTOFEXPERTS

ENQUÊTE WATERSTOF EXPERTS

Subject	Voorstudie Waterstofproductie op Zee
Project code	139730
Date	05 December 2023
Reference	-
Author(s)	C. van Erp MSc, M.R. Plantema MSc, J. Douma MSc, P. Oliver MSc
Appendices	Technical descriptions; Overview Environmental Impacts
To	Waterstofexperts

Beste Waterstofexpert,

Hartelijk bedankt voor uw interesse in dit project en uw bereidheid tot medewerking aan deze enquête. Witteveen+Bos en DNV voeren in opdracht van het ministerie van Economische Zaken en Klimaat (EZK) een vooronderzoek (quick scan) uit naar milieueffecten van waterstofproductie op zee. Deze enquête maakt onderdeel uit dit onderzoek.

Doel

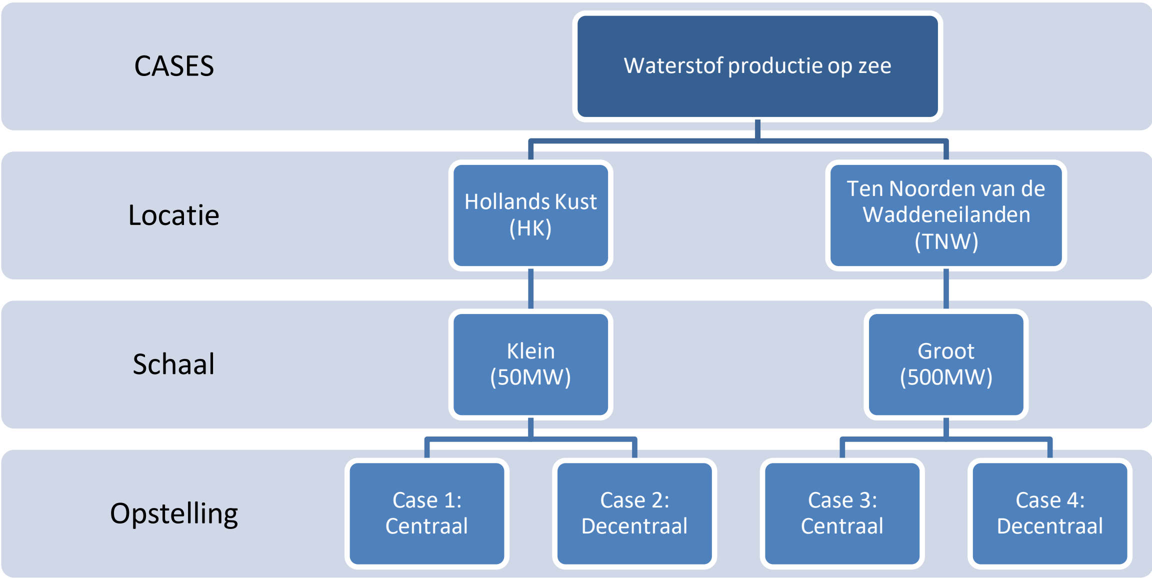
Het doel van deze enquête is voor verschillende casussen zo correct en compleet mogelijk inzicht te krijgen in de minder of nog onbekende milieueffecten van waterstofproductie op zee. Uw inbreng zal verwerkt worden in onze eindrapportage van het vooronderzoek.

Het onderzoek

Het vooronderzoek loopt vooruit op nog op te stellen NRD's (Notitie Reikwijdte en Detailniveau), MER's (milieueffectrapportage) en vergunningen voor twee demonstratieprojecten, zie Kamerbrief voorkeurslocaties demonstratieprojecten waterstof op zee. In ons onderzoek richten we ons met name op de minder of onbekende milieueffecten van waterstofproductie op zee. De bepaling en beoordeling van milieueffecten zullen in de NRD- en MER-fase verder besproken en onderzocht worden. Daarom laten wij deze voor nu buiten beschouwing.

In het onderzoek beschouwen wij vier casussen. We inventariseren de milieueffecten voor elke levensfase (constructie, ingebruikname, operatie en ontmanteling). Hierbij geven wij aan of milieueffecten 'reeds bekend' (groen), 'deels bekend' (geel) of 'onbekend' (rood) zijn. De vier cases zijn opgesteld vanuit drie verschillende kenmerken: locatie op de Noordzee, schaal en productie-opstelling. De twee potentiële locaties zijn 'Hollandse Kust' (HK) en 'Ten Noorden van de Waddeneilanden' (TNW), in de bijlage zijn beide locaties aangegeven op de windenergiegebieden kaart van de Rijksoverheid. De opties voor schaalgrote zijn <100MW (kleinschalig) of 500MW (grootschalig) aan waterstof productie vermogen. De derde afweging betreft de productie-opstelling, waar in een centrale opstelling de waterstof productie op één platform plaatsvindt en bij een decentrale opstelling op meerdere windturbines waterstof wordt geproduceerd. De vier cases zijn te zien in de onderstaande afbeelding.

Afbeelding 1 Kenmerken voor de casussen



Werkwijze enquête

Voor deze enquête verzoeken wij u de volgende informatie door te nemen en hierop te reageren:

- A Technical case descriptions;
- B Vragen en stellingen;
- C Overview environmental impacts and research methods.

Onderdeel A. Technical case descriptions

Het 'Technical case descriptions' document betreft technische achtergrondinformatie over de verschillende casussen. Het document is nog in wording en bevat op sommige plekken nog hiaten. U hoeft op dit document geen commentaar te geven. Uw commentaar ten aanzien van foutieve of ontbrekende informatie is desondanks zeer welkom.

Onderdeel B. Vragen en stellingen

Na deze introductie volgt 'Onderdeel B' met een reeks vragen en stellingen. In dit onderdeel vindt u tevens een nadere toelichting. Graag ontvangen wij voor dit onderdeel uw reactie.

Onderdeel C. Overview environmental impacts and research methods

Voor 'Onderdeel C' verzoeken wij u het Excel-bestand 'Environmental impacts and research methods' te openen. Hierin treft u vier sheets, waarin onder andere ingreep-effect-relaties en milieueffecten per levensfase zijn beschreven. Graag vragen wij u om per sheet de ingevulde informatie te beoordelen op correctheid en volledigheid. In kolom H kunt u per regel uw opmerkingen, suggesties en aanvullingen plaatsen.

De eindrapportage zal in het Engels zijn. Om verlies aan betekenis en/of vergissingen door vertaling te voorkomen, heeft het onze voorkeur als u uw reactie in het Engels geeft.

Veel succes en bij voorbaat hartelijk dank voor uw medewerking!

Onderdeel A. Technical case descriptions

Bijgevoegd is het document 'Technical case descriptions'. Dit document dient met name als **achtergrondinformatie** ten aanzien van de technische configuraties en de hiervoor gedane aannames. Op dit moment is het document nog in ontwikkeling en op een aantal onderdelen nog onvolledig. Desgewenst kunt u commentaar geven ten aanzien van naar uw mening foutieve en/of ontbrekende informatie (graag met verwijzing naar pagina en regelnummer):

- naar mijn mening is de volgende informatie foutief: ...(facultatief)......
- naar mijn mening ontbreekt de volgende relevante informatie: ...(facultatief).....

Onderdeel B. Vragen en stellingen

Hieronder volgen enkele **vragen en stellingen**. Graag nodigen wij u uit om hierop uw antwoorden en/of reactie te geven.

Naam:

1. Wat zijn naar uw mening de **belangrijkste milieueffecten** die bij waterstofproductie op zee kunnen optreden? Geef uw top 5 en motiveer kort waarom.

Top	Belangrijkste milieueffecten	Motivatie
1		
2		
3		
4		
5		

2. Over welke relevante milieueffecten ontbreekt naar uw mening nog belangrijke kennis over de **mogelijke impact?** Geef uw top 5 en motiveer kort waarom.

Top	Ontbrekende kennis over mogelijke impact van milieueffecten	Motivatie
1		
2		
3		
4		
5		

3. Over welke relevante milieueffecten ontbreekt naar uw mening nog belangrijke kennis over de **onderzoeksmethode**? Geef uw top 5 en motiveer kort waarom.

Top	Ontbrekende kennis over onderzoeksmethoden	Motivatie
1		
2		
3		
4		
5		

Om onze 'worst-case benadering' te toetsen, horen wij graag uw mening over onderstaande stellingen:

Stelling 1

Alle ingreep-effectrelaties (bijv. opwarming zeewater door lozing van koelwater) zullen bij een kleinschalig centrale opstelling zullen in hetzelfde gebied hetzelfde zijn als bij de grootschalig centrale opstelling. De effecten (bijv. minder primaire productie) zullen bij de kleinschalige opstelling naar rato kleiner zijn.

☐ Eens met de stelling, want:
☐ Oneens met de stelling, want:

Stelling 2

In het HK-gebied zullen dezelfde ingreep-effectrelaties optreden als in het TNW-gebied en zullen de effecten naar rato van het opwekvermogen van de elektrolysers vergelijkbaar zijn. Voor zover effecten locatie-specifiek zijn, zullen de effecten mogelijk naar rato anders zijn dan in het TNW-gebied en zullen in het MER nader onderzocht moeten worden.

☐ Eens met de stelling: Ik verwacht geen relatief grotere of andere effecten voor een centrale opstelling in het HK-gebied dan in het TNW-gebied, want:
☐ Oneens met de stelling: Ik verwacht wel relatief grotere of andere effecten voor een centrale opstelling in het HK-gebied dan in het TNW-gebied, want:

Stelling 3

Alle ingreep-effectrelaties zullen in het TNW-gebied voor de decentrale opstelling hetzelfde zijn als voor de centrale (grootschalige) opstelling. De effecten per turbine zullen naar rato van het opwekvermogen vergelijkbaar zijn met de centrale (grootschalige) opstelling. Het is vooraf echter niet te zeggen of sommatie van alle losse effecten meer of minder zullen zijn dan bij de centrale opstelling (bij gelijke vermogens). Dit kan bovendien per effect verschillen en zal in het MER nader onderzocht moeten worden.

☐ Eens met de stelling: Ik verwacht dat de som van de effecten van een decentrale opstelling wel vergelijkbaar is met die van een centrale opstelling, want:
☐ Oneens met de stelling: Ik verwacht dat de som van de effecten van een decentrale opstelling niet vergelijkbaar is met die van een centrale opstelling, want:

Stelling 4

In het HK-gebied zullen de ingreep-effectrelaties voor de (kleinschalige) decentrale opstelling naar rato hetzelfde zijn als bij de centrale opstelling in het TNW-gebied. Als eerder genoemd kunnen enkele effecten locatie-specifiek zijn. Die effecten zullen mogelijk anders uitpakken dan in het TNW-gebied en zullen in het MER nader onderzocht moeten worden.

☐ Eens met de stelling: Ik verwacht geen relatief grotere effecten/andere effecten voor een decentrale opstelling in het HK-gebied, want:
☐ Oneens met de stelling: Ik verwacht relatief grotere effecten/andere effecten voor een decentrale opstelling in het HK-gebied, want:

Onderdeel C. Overview environmental impacts and research methods

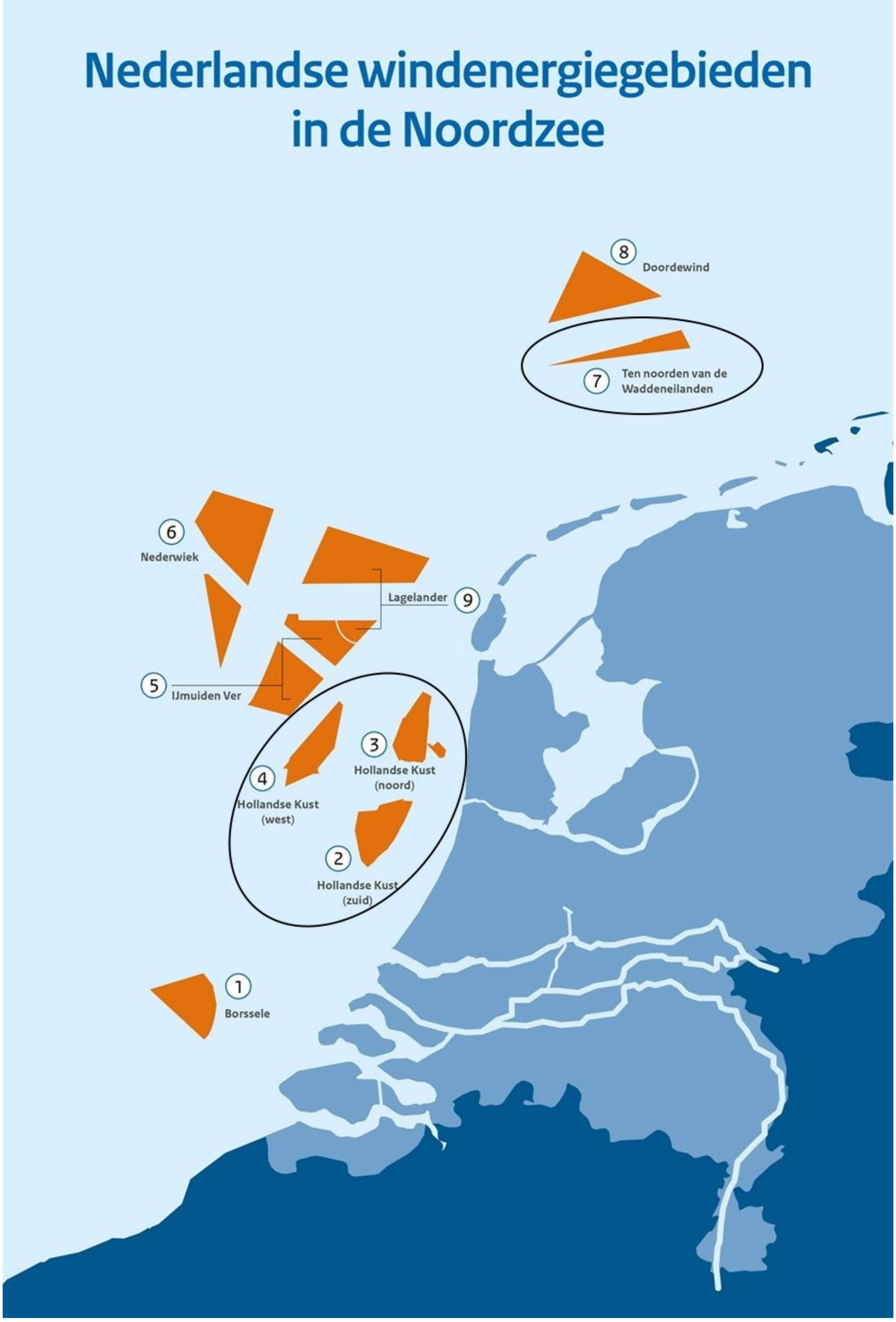
Voor onderdeel C verwijzen wij u naar het meegezonden Excel bestand. Wij verzoeken u per sheet de ingevulde informatie te beoordelen op correctheid en volledigheid. In kolom H kunt u per regel uw opmerkingen, suggesties en aanvullingen plaatsen.

Bijlage

Windenergiegebiedenkaart van de Rijksoverheid

In de zwarte cirkels zijn de windenergiegebieden binnen de scope van deze voorstudie weergegeven.

Afbeelding 2 Windenergiegebiedenkaart van de Rijksoverheid



III

APPENDIX: TABLES OF ECOLOGICAL EFFECTS IN ALL LIFECYCLE PHASES OF CASE 1

An overview of all relevant intervention-effect relationships is given in the following sub-sections for each phase of the project. These tables are meant to provide an overview of ecological effects and associated research methods that are needed to specify these. We determine ecological effects based on normal functioning of the installation. As such, safety hazards are not considered, unless there is a justifiable reason to assume that such hazards will lead to significant effects during normal functioning.

Construction phase

The most notable effects related to the construction phase are noise effects due to pile-driving and installation activities as well as shipping movements and start-up of the electrolyser. Additionally, installation activities will lead to disturbance of the seabed. Due to the novelty of noise effects from the electrolyser this type of noise requires a new research method.

Table III.1 Construction phase

Activity	Sub-activity	Intervention-effect relationship	Ecological effect	Research method
pre-study	geophysical survey	underwater noise	disturbance of noise-sensitive organisms (mammals, fish)	underwater noise modelling, assessment in cumulation (KEC).
foundation	piling bottomside	light pollution	effect of light on behaviour of species (species specific effects to be determined)	literature study and data consultation on the ecological effects of light and different light intensities on relevant biota.
		underwater noise	disturbance of noise-sensitive organisms (mammals, fish)	underwater noise modelling, assessment in cumulation (KEC).
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.
		soil disturbance	deterioration of benthic life	modelling of released sludge and resedimentation/sealing of benthic life.
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
	application scour protection	light pollution	effect of light on behaviour of species	literature study and data consultation on the ecological effects of light and different

			(species specific effects to be determined)	light intensities on relevant biota.
		alteration of the substrate	influence on fish, primary production, benthic life	consult literature, data and/or ecological survey for the species present.
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
IA cables	cable burial	soil disturbance	deterioration of benthic life	consult literature, data and/or ecological survey for the species present.
		alteration of the substrate	influence on fish, primary production, benthic life	modelling of released sludge and resedimentation/sealing of benthic life.
		turbidity and resulting resedimentation	influence on fish, primary production, benthic life	modelling of released sludge and resedimentation/sealing of benthic life.
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
IA pipes	pipeline burial	soil disturbance	deterioration of benthic life	consult literature, data and/or ecological survey for the species present.
		alteration of the substrate	influence on fish, primary production, benthic life - larger scale than cables due to size difference	modelling of released sludge and resedimentation/sealing of benthic life.
		turbidity and resulting resedimentation	influence on fish, primary production, benthic life	modelling of released sludge and resedimentation/sealing of soil life.
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
electrolyser	installation topside	nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.

		underwater noise (ambient noise)	disturbance of noise-sensitive organisms (mammals, fish)	unknown noise effects. data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. consult species-specific ambient noise impact indicators for OSPAR (under development).
supply and removal of material, personnel, and equipment	shipping movements	nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
		underwater noise (ambient noise)	disturbance of noise-sensitive organisms (mammals, fish)	data consultation on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. consult species-specific ambient noise impact indicators for OSPAR (under development) [1].
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.

Operational phase

Novel effects including research methods for effects occurring due to the operation of the electrolyser have been indicated in Chapter 5. Known intervention-effect relationships include the effects of light, noise, nitrogen emissions, introduction, and presence of new material in the water column and on the seabed and the presence of electromagnetic fields (EMF). Although EMFs are a known effect in the sense that they are also present in existing offshore cabling, the ecological effects are still a significant knowledge gap and currently undergoing research.

[1] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

Table V.2-1 Operational phase

Activity	Sub-activity	Intervention-effect relationship	Ecological effect	Research method
logistics	transport for maintenance and inspection	light pollution	effect of light on behaviour of species (species specific effects to be determined)	literature study and data consultation on the ecological effects of light and different light intensities on relevant biota.
		underwater noise (ambient)	disturbance of noise-sensitive organisms (mammals, fish)	literature study, data consultation and/or ecological survey on species of fish, marine mammals, and benthic life. Consult species-specific ambient noise impact indicators for OSPAR (under development) [1].
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
	water extraction	extraction of seawater for desalination (352m3/uur)	influx rate of seawater on marine life (i.e. loss of plankton biomass, mortality of fish (including juveniles and larvae) and macrofauna due to intake) and effects on hydrographic properties (including stratification)	hydrological 3D modelling of: - The effect of the influx rate on the intake of different body sizes - The volume of plankton biomass lost (per m3) over time for specific influx rates - The effect of the influx rates on the stratification of the water column, including the spatial extent (i.e. distance from source). based on results of the 3D model, expert judgment of available data and information regarding species presence and distributions in the area, in order to assess the ecological effects of the effluent plume

[1] Reference Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

electrolyser		extraction of seawater for cooling (26000m3/hour)		
	water discharge	emission of water with increased salinity (1.3‰) (26000m3/uur)	direct (i.e. disturbance) and indirect effects (i.e. water turbulence, salinity, turbidity, stratification effects) of outflow rate velocity on marine life	hydrological modelling of the spatial extent (3D) of the outflow rate and the effects on turbidity, water stratification: - Salinity change of surrounding water over time - Temporal and spatial extent of salinity change (i.e. distance from source) and stratification effects. Literature review on the effects of these parameters on different biotopes.
		heat discharge	influence of local temperature increase on marine life	hydrological modelling of: - Temperature increase of surrounding water over time - Temporal and spatial extent of temperature (i.e. distance from source) and stratification effects. Literature review of the effects of water temperature increase on different biotopes.
	cleaning	antifouling	toxic effects on organisms and possibly bioaccumulation	investigate chemical composition, volumes/rates and perform literature review and expert judgement of effects of chemicals on species.
	noise from compressor	incidental and ambient noise	disturbance of marine life (mammals, fish)	unknown noise effects. Data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. Consult species-specific ambient noise impact indicators for OSPAR (under development)[1].
	converter	electromagnetic radiation	effects on electrosensitive and magneto sensitive animals	EMF study to identify any areas of high EMF, consult literature

[1] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

				and data for the species present.
platform	light	light pollution	effect of light on behaviour of species (species specific effects to be determined)	literature study and data consultation on the ecological effects of light and different light intensities on relevant biota.
	platform presence	surface reduction	degradation of soil life and soil integrity	data and literature consultation and/or ecological survey on the presence of benthic species.
		change in energy distribution	marine life (primary production, fish, marine mammals)	assessment of stratification effects and ecological consequences (location and case dependent). Literature consultation on ecosystem effects due to presence of vertical structures.
		disturbance	disturbance of birds and macrofauna	data and literature consultation on species presence.
	toilets	chemical pollution	determine relevant substances and the respective ecological effects	determine relevant substances and the respective ecological effects.
	ship movements	underwater noise (ambient)	disturbance of noise-sensitive organisms (mammals, fish)	data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. Consult species-specific ambient noise impact indicators for OSPAR (under development) [1].
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
cables and pipelines	presence of cables	electromagnetic fields	disturbance of fish and mammals	data and literature consultation on species presence. Assess current state of EMF research on ecological effects.
	stone deposit pipe and cable crossing	surface loss (including rock deposit)	degradation of soil life and soil integrity	data and literature consultation and/or ecological survey on the presence of benthic species.

[1] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

	ship movements	underwater noise (ambient)	disturbance of noise-sensitive organisms (mammals, fish)	data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. Consult species-specific ambient noise impact indicators for OSPAR (under development)[1].
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.

Table V.2-2 Operational phase

Activity	Sub-activity	Intervention-effect relationship	Ecological effect	Research method
logistics	transport for maintenance and inspection	light pollution	effect of light on behaviour of species (species specific effects to be determined)	literature study and data consultation on the ecological effects of light and different light intensities on relevant biota.
		underwater noise (ambient)	disturbance of noise-sensitive organisms (mammals, fish)	literature study and data consultation and/or ecological survey on species of fish, marine mammals, and benthic life. Consult species-specific ambient noise impact indicators for OSPAR (under development) [2].
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
	water extraction	extraction of seawater for desalination (352m3/uur)	influx rate of seawater on marine life (i.e. loss of plankton biomass and mortality of macrofauna due to intake) and effects on hydrographic properties (including stratification)	hydrological 3D modelling of: - The effect of the influx rate on the intake of different body sizes - The volume of plankton biomass lost (per m3) over time for specific influx rates - The effect of the influx rates on the stratification of the water column, including the spatial extent (i.e. distance from source).

[1] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise
[2] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

electrolyser		extraction of seawater for cooling (26000m3/hour)		
	water discharge	emission of water with increased salinity (1.3‰) (26000m3/uur)	direct (i.e. disturbance) and indirect effects (i.e. water turbulence, salinity, turbidity, stratification effects) of outflow rate velocity on marine life	hydrological modelling of the spatial extent (3D) of the outflow rate and the effects on turbidity, water stratification: - Salinity change of surrounding water over time - Temporal and spatial extent of salinity change (i.e. distance from source) and stratification effects. Literature review on the effects of these parameters on different biotopes.
		heat discharge	influence of local temperature increase on marine life	hydrological modelling of: - Temperature increase of surrounding water over time - Temporal and spatial extent of temperature (i.e. distance from source) and stratification effects. Literature review of the effects of water temperature increase on different biotopes.
	cleaning	antifouling	toxic effects on organisms and possibly bioaccumulation	investigate chemical composition, volumes/rates and perform literature review and expert judgement of effects of chemicals on species.
	noise from compressor	incidental and ambient noise	disturbance of marine life (mammals, fish)	unknown noise effects. Data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. Consult species-specific ambient noise impact indicators for OSPAR (under development) [1].
	converter	electromagnetic radiation	effects on electrosensitive and magneto sensitive animals	EMF study to identify any areas of high EMF, consult literature and data for the species present.

[1] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

platform	light	light pollution	effect of light on behaviour of species (species specific effects to be determined)	literature study and data consultation on the ecological effects of light and different light intensities on relevant biota.
	platform presence	surface reduction	degradation of soil life and soil integrity	data and literature consultation and/or ecological survey on the presence of benthic species.
		change in energy distribution	marine life (primary production, fish, marine mammals)	assessment of stratification effects and ecological consequences (location and case dependent). Literature consultation on ecosystem effects due to presence of vertical structures.
		disturbance	disturbance of birds and macrofauna	data and literature consultation on species presence.
	toilets	chemical pollution	determine relevant substances and the respective ecological effects	determine relevant substances and the respective ecological effects.
	ship movements	underwater noise (ambient)	disturbance of noise-sensitive organisms (mammals, fish)	data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. Consult species-specific ambient noise impact indicators for OSPAR (under development) [1].
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.
cables and pipelines	presence of cables	electromagnetic fields	disturbance of fish and mammals	data and literature consultation on species presence. Assess current state of EMF research on ecological effects.
	stone deposit pipe and cable crossing	surface loss (including rock deposit)	degradation of soil life and soil integrity	data and literature consultation and/or ecological survey on the presence of benthic species.

[1] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

	shipmovements	underwater noise (ambient)	disturbance of noise-sensitive organisms (mammals, fish)	data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. Consult species-specific ambient noise impact indicators for OSPAR (under development) [1].
		disturbance by movement above water	disturbance of birds	consult literature and data for the species present.
		nitrogen emission and deposition	desiccation and overgrowth	assessment according to legal framework, possibly including AERIUS calculation.

Maintenance phase

The maintenance phase consists of maintenance activities to various components of the installation. Although these activities are different, they can be regarded as similar as they consists mostly of inspection by ship. For this reason, the list of activities in this phase have been simplified to the general ecological effects associated with ship activity.

Table V.3 Maintenance phase

Activity	Sub-activity	Intervention-effect relationship	Ecological effect	Research method
Maintenance activities	Shipping	Light pollution	Effect of light on behaviour of species (species specific effects to be determined)	Literature study and data consultation on the ecological effects of light and different light intensities on relevant biota.
	Underwater noise (ambient)		Disturbance of noise-sensitive organisms (mammals, fish)	Data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. Consult species-specific ambient noise impact indicators for OSPAR (under development) [2].

[1] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

[2] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

Activity	Sub-activity	Intervention-effect relationship	Ecological effect	Research method
	Nitrogen emission and deposition		Desiccation and overgrowth	Assessment according to legal framework, possibly including AERIUS calculation.
	Disturbance by movement above water		Disturbance of birds	Consult literature and data for the species present.

Decommissioning phase

The ecological effects of decommissioning are still unknown, as the issue of how decommissioning of renewable energy infrastructure should be handled is still standing. For this reason, the expected effects of decommissioning activities can only be judged in a generalistic fashion. For assessing the ecological effects occurring in the decommissioning phase we assume a full removal of the installation.

Table V.4 Decommissioning phase

Activity	Sub-activity	Intervention-effect relationship	Ecological effect	Research method
Foundations removal	Piling bottomside - removal or treatment	Underwater noise	Disturbance of noise-sensitive organisms (mammals, fish)	Underwater noise modelling.
	Disturbance by movement above water		Disturbance of birds	Consult literature and data for the species present.
	Soil disturbance		Deterioration of benthic life	Modelling of released sludge and resedimentation/sealing of benthic life.
IA Cables	Removal or treatment -	Soil disturbance	Deterioration of benthic life	Modelling of released sludge and resedimentation/sealing of benthic life.
	Alteration of the substrate		Influence on fish, primary production, benthic life	Consult literature and data for the species present.
	Turbidity and resulting resedimentation		Influence on fish, primary production, benthic life	Modelling of released sludge and resedimentation/sealing of benthic life.
	Disturbance by movement above water		Disturbance of birds	Consult literature and data for the species present.
IA Piping	Removal or treatment (likely to be cleaned, opened to environment, and left in place)	Soil disturbance	Deterioration of benthic life	Modelling of released sludge and resedimentation/sealing of benthic life.

Activity	Sub-activity	Intervention-effect relationship	Ecological effect	Research method
	Alteration of the substrate		Influence on fish, primary production, benthic life	Consult literature and data for the species present.
	Turbidity and resulting resedimentation		Influence on behaviour of marine life (i.e. fish) and foraging seabirds	Modelling of released sludge and resedimentation/sealing of benthic life.
	Disturbance by movement above water		Disturbance of birds	Consult literature and data for the species present.
Electrolyser	Demolition by means of stabilized crane vessels (jack-up)	Disturbance by movement above water	Disturbance of birds	Consult literature and data for the species present.
	Underwater noise		Disturbance of noise-sensitive organisms (mammals, fish)	Underwater noise modelling.
Supply/removal of material, personnel, and equipment)	Shipping movements	Nitrogen emission and deposition	Desiccation and overgrowth	Assessment according to legal framework, possibly including AERIUS calculation.
	Underwater noise (ambient)		Disturbance of noise-sensitive organisms (mammals, fish)	Data consultation and/or ecological survey on species of fish, marine mammals, and benthic life, possibly including modelling of underwater noise. Consult species-specific ambient noise impact indicators for OSPAR (under development) [1].
	Disturbance by movement above water		Disturbance of birds	Consult literature and data for the species present.

[1] Underwater noise. OSPAR: https://www.ospar.org/work-areas/eiha/noise

IV

APPENDIX: ELECTROLYSER AT SEA - QUICKSCAN ENVIRONMENTAL AND PLANNING PERMIT

IV.1 INTRODUCTION

A preliminary study is being conducted for the Ministry of Economic Affairs and Climate Policy (EZK) on the environmental impacts of hydrogen production at sea. This preliminary study is a precursor to the NRD and EIA procedures. Two cases are being investigated:

- Case 1 (base case): a medium-scale demo project with an electrolyser of <100 MW at the offshore wind farms Hollandse Kust (North, South, and West).
- Case 2: a large-scale electrolyser (approximately 500 MW) at the offshore wind farm North of the Wadden Islands.

Part of this preliminary study includes a quick scan of water permits. This note provides details on that aspect.

IV.2 Relevant aspects

The required water is taken from the sea. A portion of the water is used for the production of demineralized water through a reverse osmosis (RO) installation. The majority is used as cooling water.

Cooling water

A portion of the energy is converted into heat during the electrolysis process. For a 500 MW electrolyser, approximately 150 MW of heat needs to be dissipated. Seawater is taken in for cooling, and the warmed water is also returned to the sea. Currently, the assumption is that there will be a maximum temperature difference of 5 ºC between the intake and the discharged water. Calculations indicate that in this case, approximately 25,000 m^3/hour of cooling water is needed (and thus taken in and discharged). Sodium hypochlorite is dosed into the cooling water to control microbiological growth in the cooling water system.

Demiwater production

During the production of demineralized water, a concentrated stream is generated that contains the salts removed from the demineralized water. This stream is added to the cooling water, so that the streams are discharged together into the sea. It is expected that the salt content in the discharged water will increase by approximately 1% compared to the seawater. The exact composition of the salty concentrate stream and the discharged water are not yet known at this time.

Household wastewater and cleaning water

Household wastewater and cleaning water are brought to land by ship and are therefore not discharged at sea. This is not considered here.

IV.3 Analysis

For the direct discharge into a surface water body managed by the state (a 'discharge activity' under the Environment and Planning Act), as well as for the extraction and construction of an installation in a restricted area, an environmental permit is required. Since January 1, 2024, the Environment and Planning Act has been in effect.[1] Previously, discharge permits were issued for discharges, but under the Environment and Planning Act, an environmental permit for discharge activities is required. The Environment and Planning Act and the Decree on Activities in the Living Environment also apply to the North Sea. These regulations are applicable to the entire Exclusive Economic Zone (EEZ).[2]

In addition to national legislation, international treaties also apply to discharges into the North Sea. Relevant are the Convention and the London Protocol. Obligations arising from these are incorporated into Dutch legislation and are therefore not further discussed here.

Discharge of heat

The discharge of heat into a surface water body can have adverse effects on the ecology of the surface water. Therefore, the heat discharge must be assessed and must not have significant adverse effects on the surface water in order to be permissible. The methodology for assessing heat discharges is described in the CIW document 'Assessment System for Heat Discharges' *(Beoordelingssystematiek warmtelozingen)*.[3] This is designated in Annex XVIII of the Decree on the Quality of the Living Environment as a document containing assessment rules that must be applied when evaluating a permit application. In this document, the maximum warming of the receiving water is specified as a maximum of 3°C, with a maximum that varies depending on the type of water. For shellfish waters, the maximum temperature is 25°C. Furthermore, it is stipulated that the mixing zone (the area that warms above 25°C) must not touch the bottom. The mixing zone is defined as the part of the water system (in the vicinity of a discharge point) that has been brought to a temperature greater than or equal to 25°C due to a heat discharge and is bounded by the spatial 25°C isotherm.

For inland surface waters, a rapid assessment method, the mixing zone assessment, has been developed, which allows a simple calculation to determine whether the heat discharge can be permitted. However, this method is not applicable to discharges into the sea. The warming of the receiving surface water and the extent of the mixing zone can be determined using 3D models. These models provide insight into the functioning of the water system and the effects of heat discharges on it. This allows for an assessment of whether adverse ecological effects can be expected. It is necessary to coordinate with the competent authority on how these effects should be investigated and assessed in this specific case. In addition, heat discharges can have effects on MSFD descriptors, particularly Descriptor 11 - *Energy inputs, including underwater noise*. For this reason, an assessment must also be conducted to determine the effects on these parameters.

Discharge of substances

The discharged water has an increased salt concentration compared to the intake water. These are substances that were already present in the water but have increased in concentration. Locally, at the point of discharge, the elevated concentrations may have potential adverse effects on aquatic organisms. The ecological effects of this need to be further investigated in coordination with the competent authority.

Furthermore, sodium hypochlorite (with active chlorine as the working component) is added to the water. When active chlorine is dosed into cooling water, various chemical reactions occur with substances present in the water. As a result, the discharged water contains residual active chlorine and harmful transformation

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1 Reference 18 Omgevingswet. Rijksoverheid: https://www.rijksoverheid.nl/onderwerpen/omgevingswet

2 The Exclusive Economic Zone (EEZ) is the area extending up to 200 nautical miles from the coast of the Netherlands. This area includes the Dutch territorial sea (up to 12 nautical miles) and a portion of international waters. Within the EEZ, a state has certain rights, such as the right to exploit natural resources, conduct fishing activities, or conduct scientific research.

3 Lozingsvoorschriften koelwater. Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat: https://www.infomil.nl/onderwerpen/integrale/activiteitenbesluit/activiteiten/afvalwater/koelwater/

products (mainly chloroform and bromoform). The effects of this discharge on the surface water must be assessed using the emission/immission assessment.

Additionally, attention must be paid to the dosing of active chlorine. The dosing should be optimized to avoid overdosing. Overdosing leads to the formation of more harmful byproducts. For cooling water, the requirement is a maximum of 0.5 mg/l free available chlorine during continuous dosing of sodium hypochlorite.

Intake of cooling water

The large-scale extraction of surface water for cooling purposes can harm the aquatic environment. Organisms, particularly juvenile fish that cannot resist the flow, can be drawn in with the intake of cooling water. The intake of fish and subsequent mortality can have a significant impact on the natural population in the extraction area. Therefore, measures must be taken to prevent or minimize the intake of fish as much as possible.

An electrolyser is an IPPC (Integrated Pollution Prevention and Control) installation and must therefore comply with European BAT (Best Available Techniques) documents. The BREF (Best Available Techniques Reference Document) for Cooling Systems (2001) describes measures to limit the intake of fish and other aquatic organisms. It is noted that determining BAT for a specific situation requires a location-specific assessment. Additionally, potential measures are extensively described in the report 'Desk Study on Technical and Operational Measures at Cooling Water Intakes to Reduce the Effects of Fish Intake' by KEMA.
In summary, the following measures must be taken:

- Optimize the position, depth, and design of the water intake. The intake should be equipped with intake protection. The most suitable depth depends on the type of fish present in the area and at which depth they predominantly occur.
- Limit the intake water flow rate (<0.3 m/s) (e.g., by increasing the cross-section of the intake). For intakes with a flow rate greater than 1800 m3, an intake speed of no more than 0.15 m/s should be maintained. However, these rules only apply to permit issuance for extraction from surface waters, with the exception of the North Sea.
- Optimize the mesh size of the cooling water screens (larger is better);
- Implement a fish return system. This can involve using a gentle water jet to return fish and placing collection/transport containers to improve fish survival.

Cooling water extraction can only lead to adverse effects on the population level of organisms in the water system from which the water is extracted if organisms that are sensitive to intake, such as fish larvae and juvenile fish, are actually present in the water system. The necessary measures depend on the local conditions and which fish populations, spawning areas, and migration routes are present. Preferably, the extraction should not take place in spawning areas, juvenile fish nursery areas, or migration routes. Local conditions must be investigated and assessed in this context. The competent authority must verify whether BAT (Best Available Techniques)[1] has been applied.

[1] The most recent BAT (Best Available Techniques) measures are from the 'Revision of the Ecological Assessment Methodology for Cooling Water Extraction' by ATKB (April 17, 2019).

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