North Sea Energy
offshore system integration

5.1

North Sea Energy 2020-2022

The Potential of Shared Offshore Logistics

North Sea Energy 2020-2022

Unlock the low-carbon energy potential North Sea with optimal value for society and nature

The North Sea Energy program and its consortium partners aim to identify and assess opportunities for synergies between energy sectors offshore. The program aims to integrate all dominant low-carbon energy developments at the North Sea, including: offshore wind deployment, offshore hydrogen infrastructure, carbon capture, transport and storage, energy hubs, energy interconnections, energy storage and more.

Strategic sector coupling and integration of these low-carbon energy developments provides options to reduce CO2 emissions, enable & accelerate the energy transition and reduce costs. The consortium is a public private partnership consisting of a large number of (international) partners and offers new perspectives regarding the technical, environmental, ecological, safety, societal, legal, regulatory and economic feasibility for these options.

In this fourth phase of the program a particular focus has been placed on the identification of North Sea Energy Hubs where system integration projects could be materialized and advanced. This includes system integration technologies strategically connecting infrastructures and services of electricity, hydrogen, natural gas and CO2. A fit-for-purpose strategy plan per hub and short-term development plan has been developed to fast-track system integration projects, such as: offshore hydrogen production, platform electrification, CO2 transport and storage and energy storage.

The multi-disciplinary work lines and themes are further geared towards analyses on the barriers and drivers from the perspective of society, regulatory framework, standards, safety, integrity and reliability and ecology & environment. Synergies for the operation and maintenance for offshore assets in wind and oil and gas sector are identified. And a new online Atlas has been released to showcase the spatial challenges and opportunities on the North Sea. Finally, a system perspective is presented with an assessment of energy system and market dynamics of introducing offshore system integration and offshore hubs in the North Sea region. Insights from all work lines have been integrated in a Roadmap and Action Agenda for offshore system integration at the North Sea.

The last two years of research has yielded a series of 12 reports on system integration on the North Sea. These reports give new insights and perspectives from different knowledge disciplines. It highlights the dynamics, opportunities and barriers we are going to face in the future. We aim that these perspectives and insights help the offshore sectors and governments in speeding-up the transition.

We wish to thank the consortium partners, executive partners and the sounding board. Without the active involvement from all partners that provided technical or financial support, knowledge, critical feedback and positive energy this result would not have been possible.

North Sea offshore system integration Energy

5.1

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The Potential of Shared Offshore Logistics

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Table of Contents

1 Introduction

1.1 Background

Offshore logistics play a key role in ensuring the safe and efficient installation, operation and decommissioning of offshore energy systems. This sector is currently facing substantial changes due to the planned decline in offshore gas production and the rapid growth of offshore wind, as seen in Figure 1. Currently, significant attention is given to the costs, efficiency and environmental footprint of offshore logistics services which leads to a strong drive towards cost and emission reductions by optimizing installation, operation and maintenance (O&M) and reuse and decommissioning in the offshore wind and gas sectors.

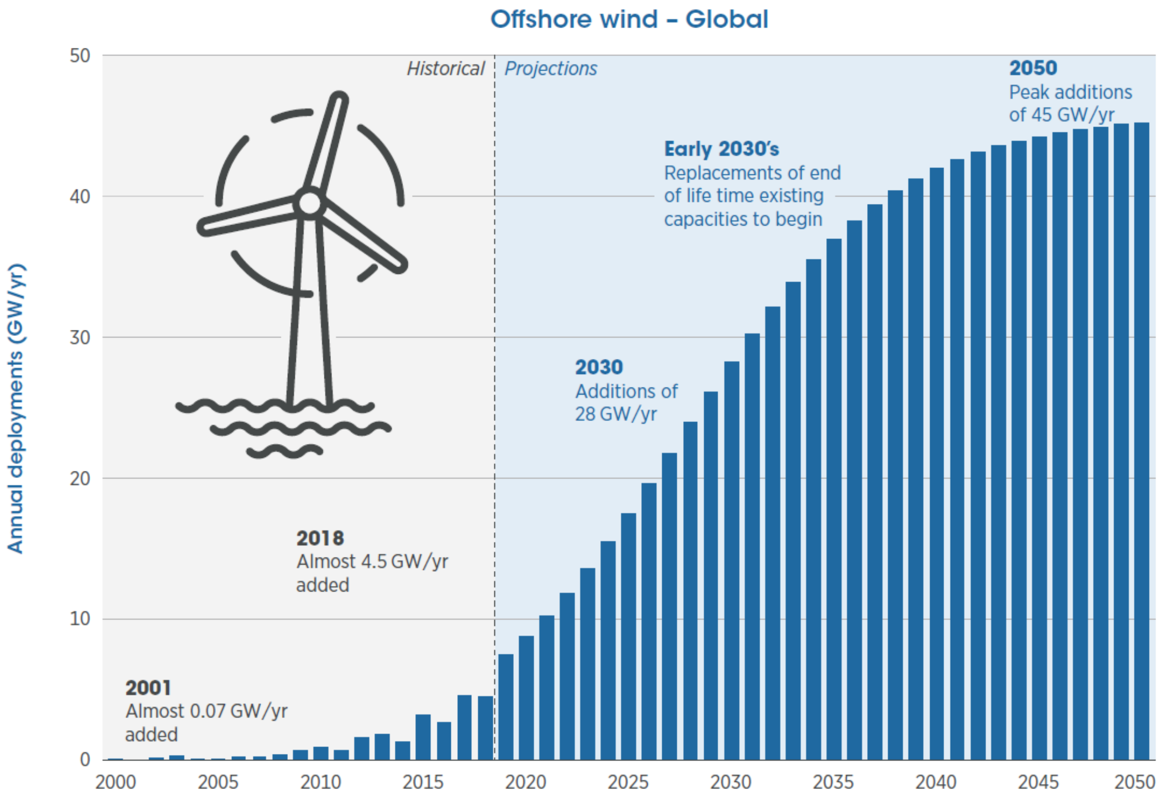

Figure 1 Historical and projected global offshore wind farm installations (Future of wind: deployment, investment, technology, grid integration and socio economic aspects, 2019)

One of the main aspects of system integration is reduction of energy production costs and integral emissions associated with it. It is important to note that in order to realize and operate the integrated energy systems, there are logistic and services requirements. As of now, the vessels and logistic services required for offshore wind and oil and gas activities are handled completely separately.

To provide more insights, offshore wind O&M costs per annum can be estimated around 75 M£ for a 1 GW wind farm (BVG Associates, 2019) which are currently focused on introducing technologies and processes to improve performance, targeting higher energy outputs at a lower cost, shifting away from reactive maintenance and purely local decision-making. Further, the largest wind farm owners are taking operation of their wind farms in-house increasingly early. This means that – unlike the wind turbine manufacturers, who currently provide the bulk of such services under contract – maximising (safe) profit is the objective, rather than simply satisfying a contract. Gas O&M costs are strongly driven by challenges in mature offshore gas assets, leading to more frequent interventions and visits. As the landscape in the upcoming years and decades will change, there is a large opportunity for cost, as well as emission, reductions through sharing logistics among different operators, and between gas and wind sector.

The planning and operation of energy production systems (oil and gas, H2, wind) in the North Sea is performed by different operators, similar to their logistic services. In order to maximize the efficiency of these systems and ensure the security of supply, it is required to orchestrate different energy commodities and their services. Advances in (safe) digital technologies could be key in unlocking the full benefits of such integrated energy systems and logistics in the (Dutch) offshore sector. Technologies such as blockchain, secure data sharing, drone, cloud, etc. could provide an IT backbone leading to an integrated North Sea energy system and logistic services.

1.1.1 State-of-the-art

For the offshore structures, the life cycle can be divided into the following stages (after their planning); installation & commissioning, operation & maintenance, reuse/re-purposing and decommissioning or replacement. Each of these stages is likely to require variations in logistic services, vessels and timeline. Thus, it is important to identify the logistical needs of the wind farms and oil and gas assets at different stages as mentioned above.

The main tasks during the installation and commissioning phase will be the transport of complete assemblies from vendors and manufacturing facilities, port facilities installation, offshore substation installation and sea-based support (Roberts, 2014). A schematic overview of the standard logistic process is shown in Figure 2 (although feeder vessels are likely to be used for further-offshore farms).

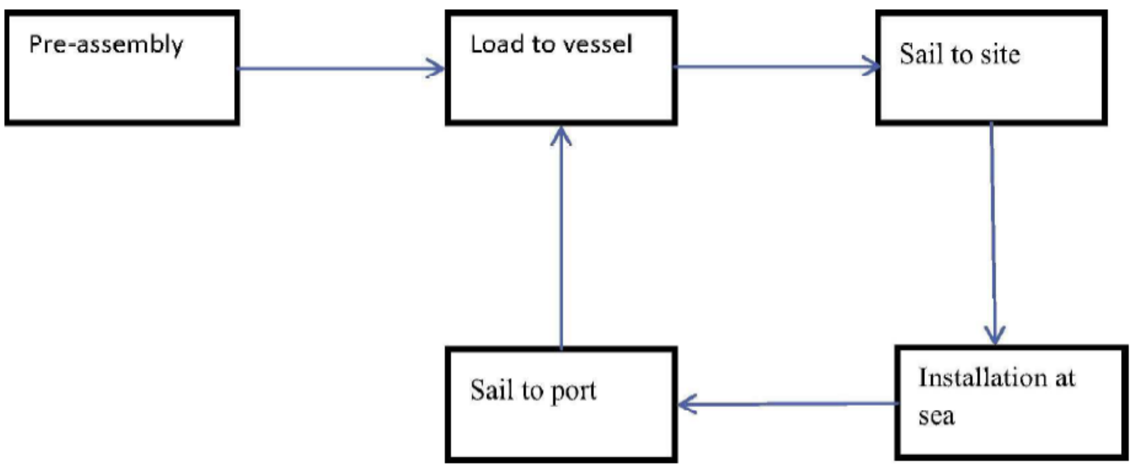

Figure 2 A schematic overview of the logistic processes of the installation phase of an offshore wind turbine (Vis, 2016)

The operation and maintenance phase consists of servicing the locations, performing repairs and replacing failed or degraded components throughout the entire operational period. The task lists generated daily consist of both scheduled (time-based and condition-based) maintenance and unforeseen failures, each requiring varying vessel sizes, technician team sizes and skills. While in the recent past, reactive maintenance dominated, unscheduled maintenance can now be less than 25% of work undertaken on modern wind farms with the latest 5MW+ turbines.

Traditionally, wind farms are operated using small Crew Transfer Vessels (CTVs), scheduled from shore each day. However, wind farms further offshore instead require Service Operation Vessels (SOVs), which may stay offshore for several weeks. SOVs bring several advantages in maintenance planning of offshore farms, e.g. staying longer at sea, reducing transfer times between the wind farm and onshore facility, and working at heavier weather conditions. However, SOVs are expensive compared with CTVs, and so their effective and efficient use is extremely important.

The averaged operational lifetime of the wind farms and oil and gas structure is estimated at around 20-25 years (Topham, Sustainable decommissioning of an offshore wind farm, 2017) and 20-30 years (El Reedy, 2012), respectively. A large number of wells and platforms are approaching their end of life, which will make them available for reusing and repurposing or decommissioning. Several options such as offshore electrification, carbon capture and storage, and hydrogen production and storage can be considered for extending the useful lifetime of offshore installations. There will be around 50 installations decommissioned in the upcoming decade, for which maintenance activities will be required before re-use and repurposing (see Figure 3). For the reuse, infrastructure maintenance will be required until the time that the asset is ready to be reused. Depending on the required facility for the reuse options, some of the services of the decommissioning and installation phases will be required. The decommissioning phase and its required supply chain are less understood for wind farms as they are still in development phase. The expected number of wind turbines to be decommissioned is shown in Figure 4. For a shorter wind turbine design life, repowering the site could be an option to extend their lifetime. In this case, the site can be partially (installing new components) or fully (replacing the entire turbine) repowered (Topham, Challenges of decommissioning offshore wind farms, 2019)

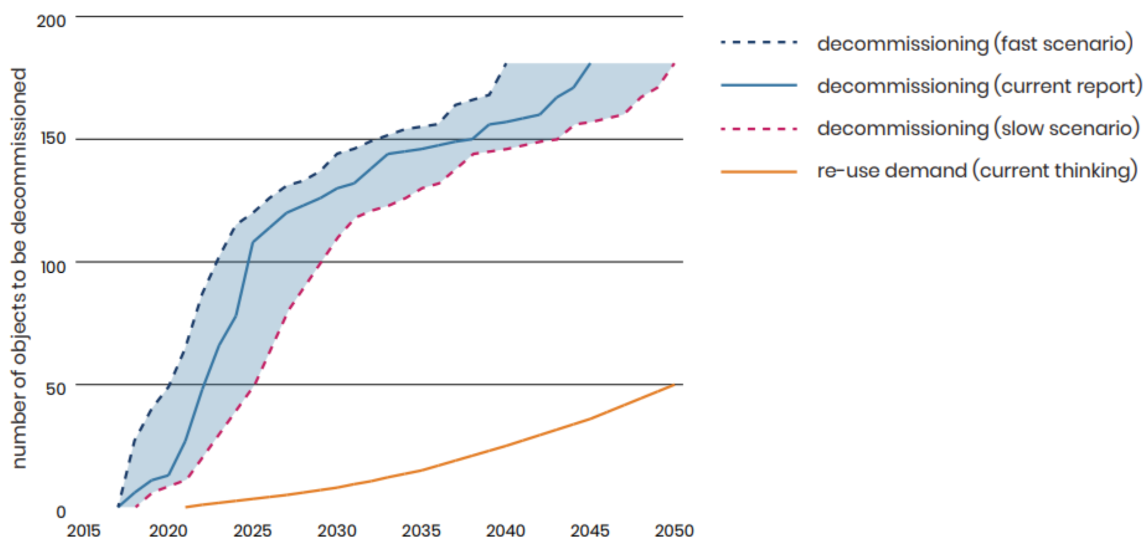

Figure 3 Offshore installations available for decommissioning and reuse (including both platforms and subsea) (Nextstep, 2018)

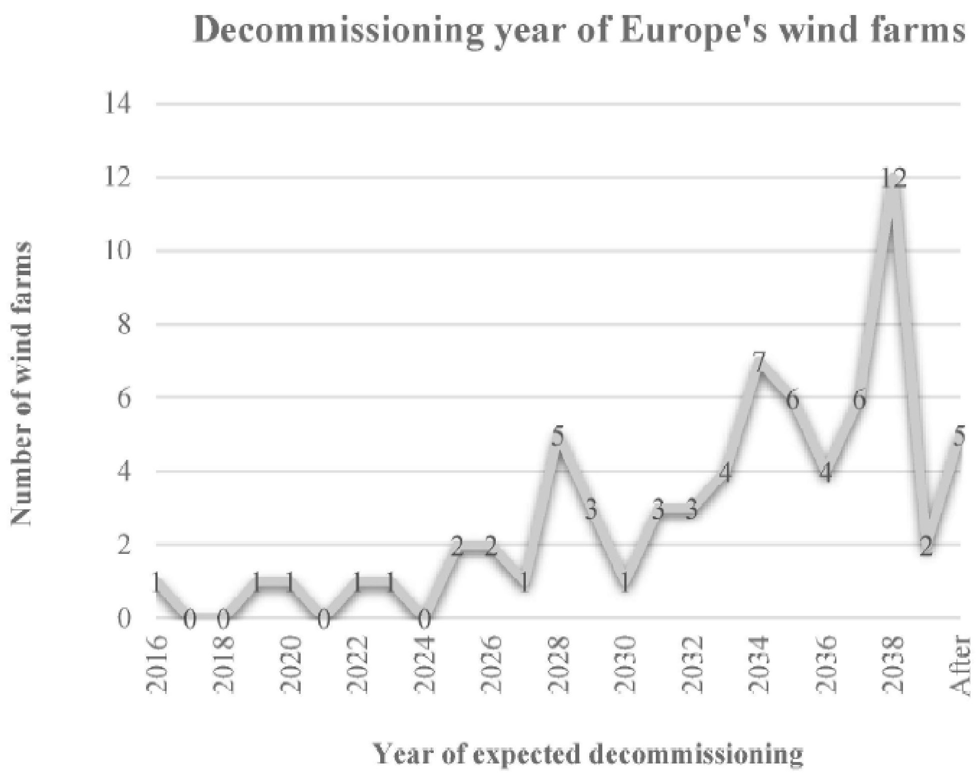

Figure 4 The expected number of wind farm to be decommissioned (Topham, Sustainable decommissioning of an offshore wind farm, 2017)

1.1.2 Current practice of logistic services

Offshore platforms, which are part of the Dutch oil and gas producers in the Dutch, Danish, UK and German continental shelf, have organised themselves into a collaboration concept (snspool) in which cost allocation and vessel capacity and resources (base, equipment and personnel) are shared amongst the operators based on the participation levels. The logistic collaboration is based on the geographical clustering of platforms on the respective continental shelves and the clustering of possible satellite platforms connected to a mother platform. As most of the production platforms operate only during the day, the offshore handling is planned so that sailing times between locations is optimized for night hours, to keep waiting times at the locations to a minimum. The North Sea offshore supply chain is divided into 5 main sectors (see Figure 5):

- Southern sector P/Q sector
- UK sector J sector combined with K sector
- Dutch part K and L sector
- Northern part of Dutch sector and German A sector with F sector
- G and M sector with near coast AWG platform

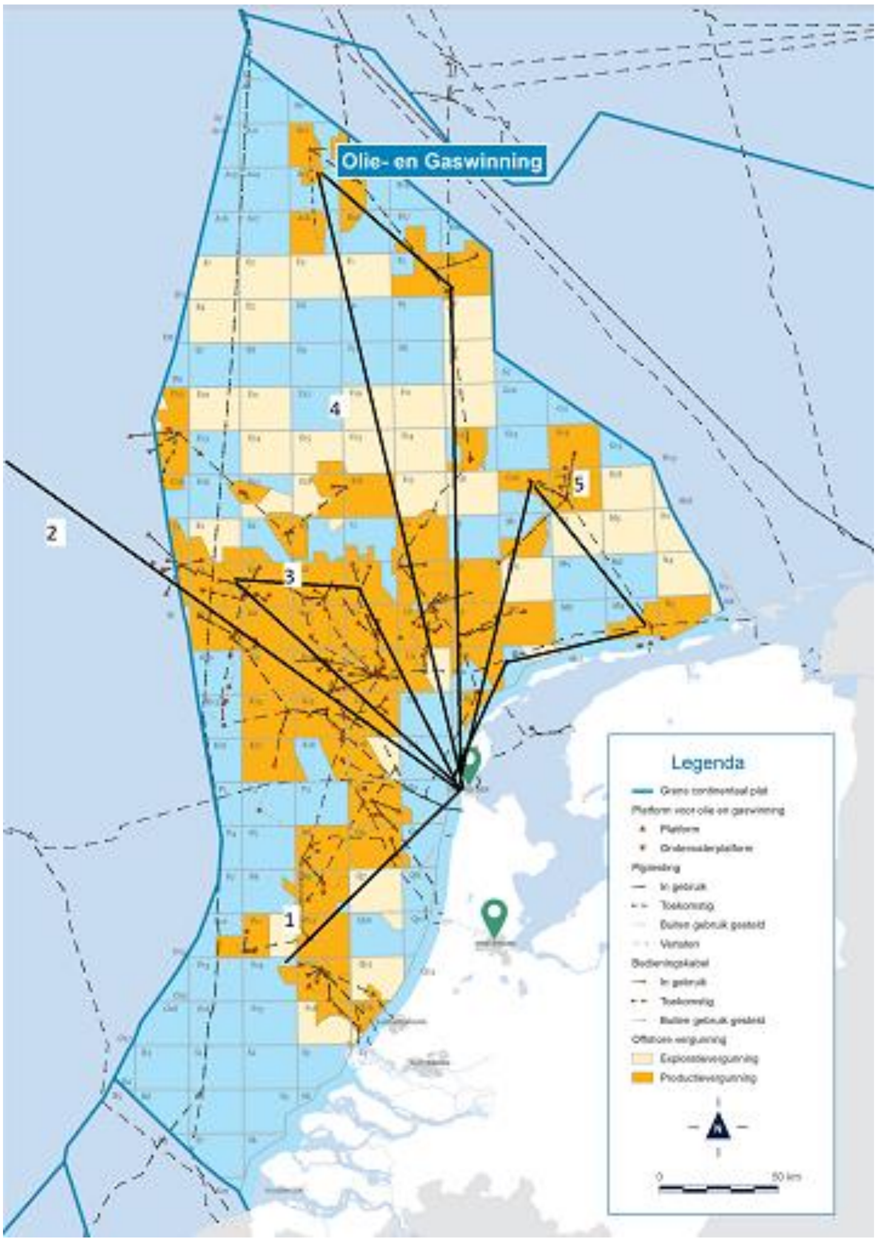

Figure 5 Offshore logistics clusters

1.1.2.1 Vessel Scheduling

The vessel scheduling based on the operator production schedules depends on the combination of helicopter scheduling, manning strategy of the platforms and satellites and the planned activities on the platforms, which are primarily inspection and maintenance schedules. The main driving factors for the scheduling frequency of platforms, besides maintenance, are the deliveries of food (for manned platforms), water, fuel and chemicals. The determining factor for manned platforms is food deliveries, with visit intervals between 2 and 3 weeks. For unmanned platforms, the spread is wider. The available facilities differ and electrification determines the need for fuel deliveries. The spread in visit intervals goes from once every 3 weeks to every 7 weeks. The electrification of platforms in the future will significantly impact the visit frequency, especially for unmanned platforms. The approximate amount of offshore oil and gas platforms, combined with satellites, totals about 150 platforms. These platforms are supplied with a pool of 4 offshore supply vessels (OSV) with a total number of 48 different voyages in a 12 week schedule. The 4 OSV vessels are all under a long term charter (> 1 year). In case of adverse weather in which platforms cannot be supplied, the backlog creates the need for additional capacity. This capacity is chartered on the spot market, mostly on short term (< 2 weeks) or for a cargo run.

1.1.2.2 Fleet Size

In 2021 the supply chain changed from company clustering (create voyage based on sharing needs within the operator), to sharing needs between operators, combining more platforms. This had 3 major consequences:

1. Operators faced more complex logistics within their organisation as warehousing becomes fragmented (multiple cargo runs serving multiple platforms)
2. Voyages becoming longer, hence food supplies had to be organized using specialized containers
3. Helicopter schedules had to adapt new vessel handling schedules at satellites and offshore platforms.

The benefits of clustering geographically vs operator clustering meant a cost saving of 20% due to a decrease in vessel capacity. This cost-saving outweighed the consequences for the operators. As the voyages became longer, the deck utility increased per vessel, and sharing levels between operators increased.
Due to the increase of deck usage, the vessel selection had to adapt to increased capacity. While in previous clustering the OSV fleet mixture primarily consisted of UT755 type and a deck space of around 700 m^2, there was a need for a slightly larger deck capacity. This resulted in chartering vessels with up to 850 m^2 of deck space. The change to mid-size OSV also meant that more sustainable and emission efficient vessels could be chartered.

1.1.3 Optimized shared logistics

Offshore wind farm O&M planning follows the same decision process every day, depending on the work orders which should be done (and can be done with the available technicians and spare parts) and the weather forecast. A transfer plan must be created which allocates certain tasks to certain teams of technicians, placing them on certain vessels.

Currently, rules of thumb on wind speed and wave height are used to decide whether to do only essential maintenance (a ‘production day’) or cancel all maintenance due to poor weather (‘a weather day’). Further, it is still common practice that the order in which teams are dropped-off and the order in which each team conducts its work is not pre-planned, but decided on the day at sea.

Over the past 3 years, TNO has developed and validated a simulation optimisation solution for such wind farms, called *Despatch*, which generates transfer plans which maximise the business objectives of the planning organisation. Through testing, development and adoption by wind farms in Europe and Asia, it has proven to change the approach of planners and increase the profitability of wind farms. For instance, a 2018 study on Princess Amalia wind farm showed that optimization could lead to an increase of yield of more than 1%, equalling an increased income of around 60 k€ per month (Stock-Williams & Krishna Swamy, 2018). A further case study using Despatch demonstrated a 70% reduction in CTV costs for unscheduled maintenance on a wind farm with over 99% energy availability.

However, as wind farms grow larger and are placed further offshore, daily access with CTVs becomes uneconomic, due to the travel time. Wind farms such as Gemini are therefore maintained using Service Operation Vessels (SOVs), which stay offshore for approximately 2 weeks. These 60m+ vessels bring several advantages in maintenance planning of offshore farms, e.g. staying longer at sea, reducing transfer times between the offshore and the onshore facility, and working in heavier weather conditions. However, SOVs are expensive compared with CTVs, and so their effective and efficient use is very important. They also often require small daughter craft to enable fast drop-off and pick-up of technicians, particularly to meet safety requirements. Further, they can be occasionally re-supplied during their voyage by helicopters and CTVs. Such a boundary between shore-based and SOV-based maintenance is illustrated in Figure 6.

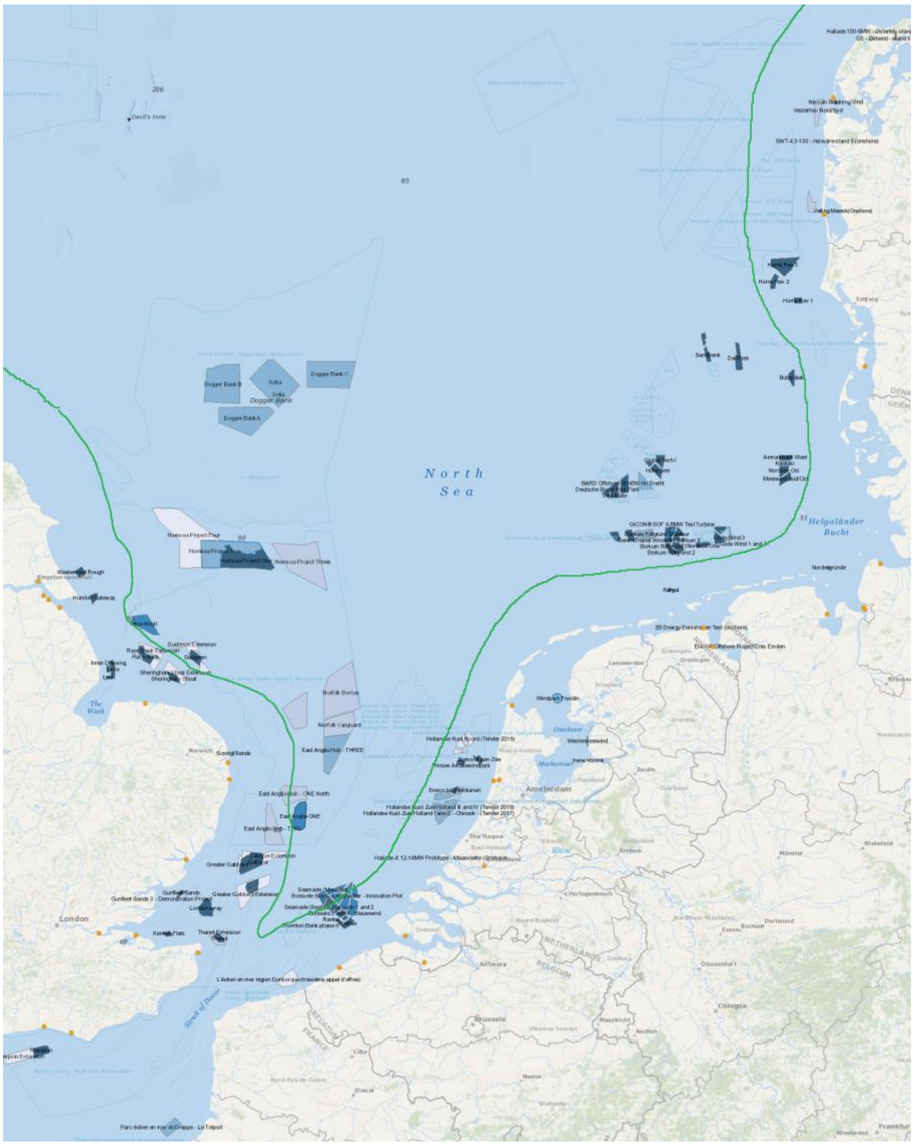

Figure 6 An approximate boundary indicating the area for the shore-based and SOV-based maintenance

With greater uncertainty, more complex interactions, and vessels with higher daily costs, comes greater opportunities for improvement. Rules of thumb are likely to perform poorly, particularly when considering market-exposed wind farms, where the cost-income trade-off is much finer. Many possible scenarios exist when considering the choice between transferring people to the turbine via the daughter craft(s) or via the gangway of the SOV, the impacts of which cannot be analysed without such a simulation tool. Significantly higher savings in absolute terms are therefore expected for these wind farms than those in the earlier studies mentioned above. Further, the complexity of the operations means that several orders of magnitude more options are available. In such cases, the power of computers to sort through such options quickly and effectively can be far superior to that of humans.

SOVs have long-term charter day rates on the order of 5-10 times those of crew transfer vessels (based on the latest information from a shipbroker). Each SOV can be assumed to consume up to 750 cbm of bunker fuel per voyage (on the high side), which costed approximately 400 €/cbm (pre-2022 cost figures, 2022 estimates can be more than twice higher). Over a typical year of 12 offshore trips, approximately 3,600,000 € is therefore spent on fuel alone. A reduction of only 5% in this fuel cost—through more efficient route, path and transfer planning—leads to a saving of 180,000 €/yr.

The capabilities required of SOVs are rather similar to those from the Platform Supply Vessels (PSVs) used in Oil & Gas, therefore there is potential for sharing of resources on a short-term and long-term basis. Commercial concerns are likely to arise, however, seeing as contractual cooperation between different players is already required to deliver offshore wind farm logistics on a daily basis. The other potential limitation is response time for when a wind farm needs a vessel to pick up and deliver technicians regularly within the wind farm, whereas PSVs generally travel over a greater sea area. However, a coordinated network of vessels serving many customers is likely to be considered more feasible if its financial benefits are demonstrated convincingly in this project.

As already indicated, there have been some steps made in order to demonstrate the added value of shared logistics concepts at either offshore wind or oil and gas sectors. Additionally, at each sector, the operators and service providers are actively developing predictive tools to optimize the logistic plans in advance. One of the missing points in the North Sea is whether a shared concept for offshore wind and oil and gas can be demonstrated to not only aim at cost savings, but also minimizing the emissions of the supply chain. Such a synergy between the two sectors could be further enhanced with optimizing the maintenance and services schedules by employing the power of predictive models and state-of-the-art optimization workflows (see Figure 7).

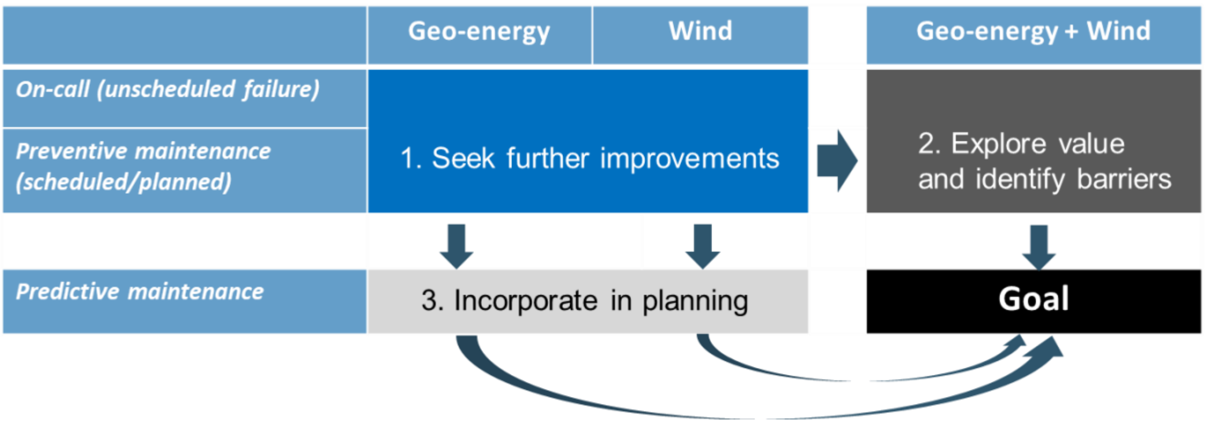

Figure 7 Sketch of the status of offshore O&M logistics for wind and oil and gas sectors and the ultimate goal of the NSE project on a shared and smart logistic concept

1.1.4 Digitalization in logistics and energy systems

In logistics and energy systems, the role of digitalization is becoming more prominent, like in most other industries. Through digitalization, many processes can be automated, standardized, and made more efficient, ultimately saving time and reducing costs and emissions. This acceleration can be seen as being two-fold. Firstly, digitalization can help standardize and automate tasks that previously would be done manually. Through digital infrastructures including RFID, AIS, and IoT systems, measurement data and vessel locations can continuously be streamed to centralized servers and distributed for additional analysis and interpretation. Using this data, key performance indicators and asset statuses can continuously be kept up-to-date and presented in clear and insightful ways to improve an organization's decision-making process. In addition, paperwork can be centralized and streamlined, using smart software packages making use of the data obtained at different levels of the logistics chain to aid in filling out and filing the proper forms, reducing redundancy and leaving more time for people to do the job they were trained to do.

Secondly, artificial intelligence and machine learning models can be used to accelerate and improve the underlying models employed by the digitalized systems. Deep learning models allow for highly accurate and very fast modelling of complex systems, making it possible to set up digital twins, optimize designs, and forecast different scenarios at much higher rates than ever before. Advanced optimization algorithms can automatically determine optimal maintenance schedules, taking into account aspects like distance between off-shore structures, weather forecasts, and task priorities to come to the most efficient maintenance vessel routes, saving time and reducing emissions. Reinforcement learning and other advanced control methods can help manage highly dynamic renewable energy systems, ensuring efficient and cost-effective security of the energy supply by smartly choosing whether to directly deliver the power or (partly) store it for later use, based on current and forecasted energy prices and weather patterns.
Other digital technologies could also be utilized to support the integration of hybrid energy systems in the North Sea, such as blockchain or secure multi-party computation systems which could enable these digital infrastructures and models to be shared by all relevant stakeholders without the need for sharing sensitive or proprietary data, improving the efficiency not only of each individual organization, but of the sector or supply chain as a whole.
The integration of the North Sea with IT infrastructure and digital technologies could provide opportunities to the full supply chain and operators by orchestrating planning, operation, reuse and decommissioning activities. Within this project the role of digital technologies in the future of North Sea logistics and more broadly energy systems will be analysed.

1.2 Research questions

Two research questions were formulated to address the challenges and opportunities mentioned above;

- What are the challenges and potential benefits of shared, optimized logistics between offshore oil and gas and wind sectors?
- What are the key digital technologies applicable to optimize the integrated North Sea energy sector?

This report focusses on the first research question which is about the identification of potential benefits and challenges of a shared and synchronized logistics. The second research question will be addressed in a separate report, NSE 4 WP5(b) digitalization in NSE, since the topic is not only focussing on the digitalization of the logistics but also on the digitalization of the North Sea energy system.

2 Methodology

2.1 Research activities

The activities to address the research questions in the section 1.2 are divided into three main parts:

- Synergy identification: Identify the key challenges and technologies for realizing shared and smart logistics
- Survey of current practises within O&M and logistics in the offshore sector (available information and data, interviews with relevant stakeholders).
- Identification of potential sharing concepts, e.g. sharing crew, vessels, supply and installation vessels, maintenance vessels, warehousing, helicopter services etc. which will be linked to the energy hubs selected in WP1.
- Identify the digital technologies and capabilities that can expediate the transition towards optimized and shared logistics with an outlook on North Sea energy systems.
- Organise a workshop with relevant stakeholders to 1) bring together gas, wind and logistics operators and 2) identify their shared challenges and differences in the status-quo as well as in a shared logistics future.
- Identify potential use-cases and scenarios where shared logistics can add value on cost and emission reduction
- Proof-of-concept for shared (and / or smart) logistics: quantifying the potential cost and emission savings in the scenarios identified from the synergy identification tasks
- Select use-case and collect relevant data.
- Develop logistic transport and emission models for the selected cases. The information for the emission models will be derived in cooperation with WP4.
- Simulate the potential benefits of sharing logistics.
- Dissemination: to disseminate the outcome of the case studies in a demo tool and a workshop
- Produce an interactive demo-tool for the selected use-case and scenarios which will be implemented in the North Sea Atlas.
- Organise a workshop to disseminate findings.
- The outcome of the digitalization survey will contribute to the North Sea energy roadmap to be developed in WP 7.

2.2 Scope

In this section we discuss the technical, spatial and temporal scope of the study. The technical scope focuses on the integration of logistics needs and services in the wind and geo-energy sectors on the following aspects:

- Considering the lifecycle of geo-energy and wind installations
- Technical and regulatory aspects define the boundary conditions of the case study
- Role of novel digital technologies in the shared logistics

State-of-the-art forecasting and optimization algorithms will be employed to investigate potential savings achievable by shared and smart logistic concepts. In addition, knowledge and models from WP 4 on the emissions will be integrated in the study.

The spatial scope of the case study in WP 5 will be the (Dutch) North Sea. The temporal scope is envisioned up to 2050 for potential cost and emission savings by shared and smart logistics between geo-energy and wind developments. The selected case study in WP 5 will be aligned with the energy hubs as described in WP 1.

2.2.1 Boundary conditions

As described, the case study in WP 5 will be based on one of the hubs selected from WP 1. The timeline of O&G activities, wind developments and reuse and decommissioning options will be dependent on the inputs from hubs. Regulatory constraints for combining O&G and wind logistics will be considered in defining the case study and selecting the feasible shared and smart logistic concept. Logistic sharing scenarios will consider potential sharing of resources for the operation and maintenance of offshore wind and O&G assets.

2.3 Data collection

Relevant data on the O&M activities and requirements of both offshore oil and gas and wind is needed for the project. The data such as type of services, frequency of visits and the current methods to organize and plan the services is necessary. For the oil and gas services, it is planned to organize interviews with several operators in the North Sea to collect this data. Additionally, Peterson Energy Logistics will provide data from their historical visits and services to different blocks of the North Sea. For the data on offshore wind O&M, an extensive literature study will be performed to collect data. If required, the missing information will be received from wind operators or service companies during the workshop in part 1. The outcome of interviews with industry experts suggests that focus should be on quantifying logistic sharing benefits for O&M activities rather than construction or decommissioning activities.

2.4 Interaction with other WPs

North Sea energy hubs studied in WP 1 are one of the central themes in the NSE 4 project. Different integration concepts and solutions will be analysed in WP 1 and relevant data on the existing and future activities will be collected. This information will be used to steer the case study for the logistic optimization in WP 5. It is not intended to perform a full logistic chain optimization in a specific area of one of these hubs. The envisioned timeline and activities in these hubs will be used to shape the case study for the logistics work package to make the outcome of the WP generalizable for other hubs or integration solutions.

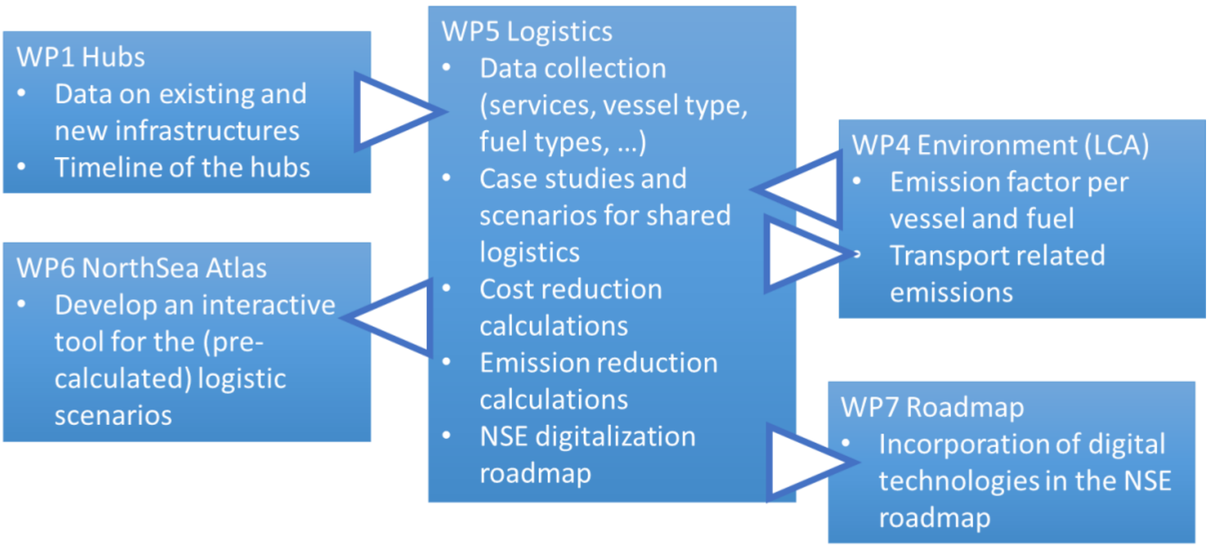

Figure 8 Interaction of different NSE program WPs with logistic WP

3 Trends in the North Sea

This section lists general development trends in the Dutch North Sea which has a direct impact on the logistics and service needs. Plans for offshore wind development up to 2050 are identified, and the proximity of upcoming wind farms from the energy hubs (mentioned in WP 1) is estimated. The status of existing O&G platforms and vessels used for O&M are listed.

3.1 Offshore wind development

Up to 2030, the Dutch government has a concrete roadmap for wind farm development in the Dutch North Sea, with the aim of installing 11.5 GW of offshore wind farms (Figure 9). As of 2021, developers have been chosen to build Hollandse Kust Zuid (HKZ) and Hollandse Kust Noord (HKN). In the coming years, tenders for the remaining wind farms will be scheduled for developers to compete on. In late 2021, the Dutch government released and ambitious new plan which called for nearly doubling the offshore wind installed capacity by 2030 to 22 GW. The revised plan identifies five zones (two in the south, two in the north and one in the east) as seen in Figure 9 (right).

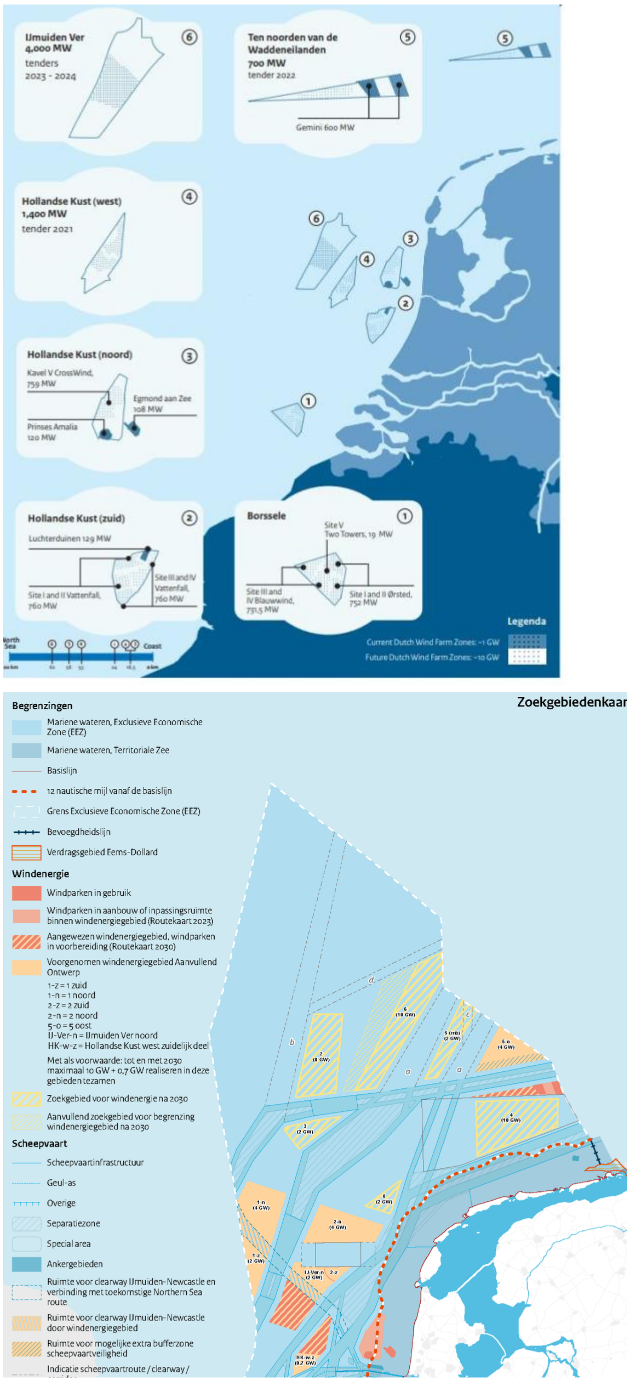

Figure 9 Offshore wind development until 2030 (left) and revised offshore wind development plan until 2030 targeting 22 GW installed capacity (right)

Beyond 2030, there are some uncertainties on upcoming offshore wind farms in terms of sites and capacities. A 2021 report from the Nationaal Water Programma (NWP) (Ministerie van Infrastrucuur en Waterstaat, 2021) estimates development of an additional 27 GW of offshore wind in 8 search areas by 2040 (see Figure 10). The search areas are depicted in yellow with each having a maximum capacity of possible offshore wind farms. Search areas 4, 6 and 7 have the largest maximum capacity with 10 GW, 10 GW and 8 GW respectively. To arrive to a sum of 27 GW by 2040, the OWF development per search area is estimated as per Table 1.

Table 1 Search areas in the North Sea according to Nationaal Water Programma (NWP)

Search Area	Max. capacity	Closest hub	Adjusted capacity (until 2040)
Search Area 1	6 GW	Hub West	3 GW
Search Area 2	5 GW	Hub West	3 GW
Search Area 3	2 GW	Hub West	1 GW
Search Area 4	10 GW	Hub East	6 GW
Search Area 5	6 GW	Hub East	3 GW
Search Area 6	10 GW	Hub North	6 GW
Search Area 7	8 GW	Hub North	4 GW
Search Area 8	2 GW	Hub West	1 GW
			Total: 27 GW

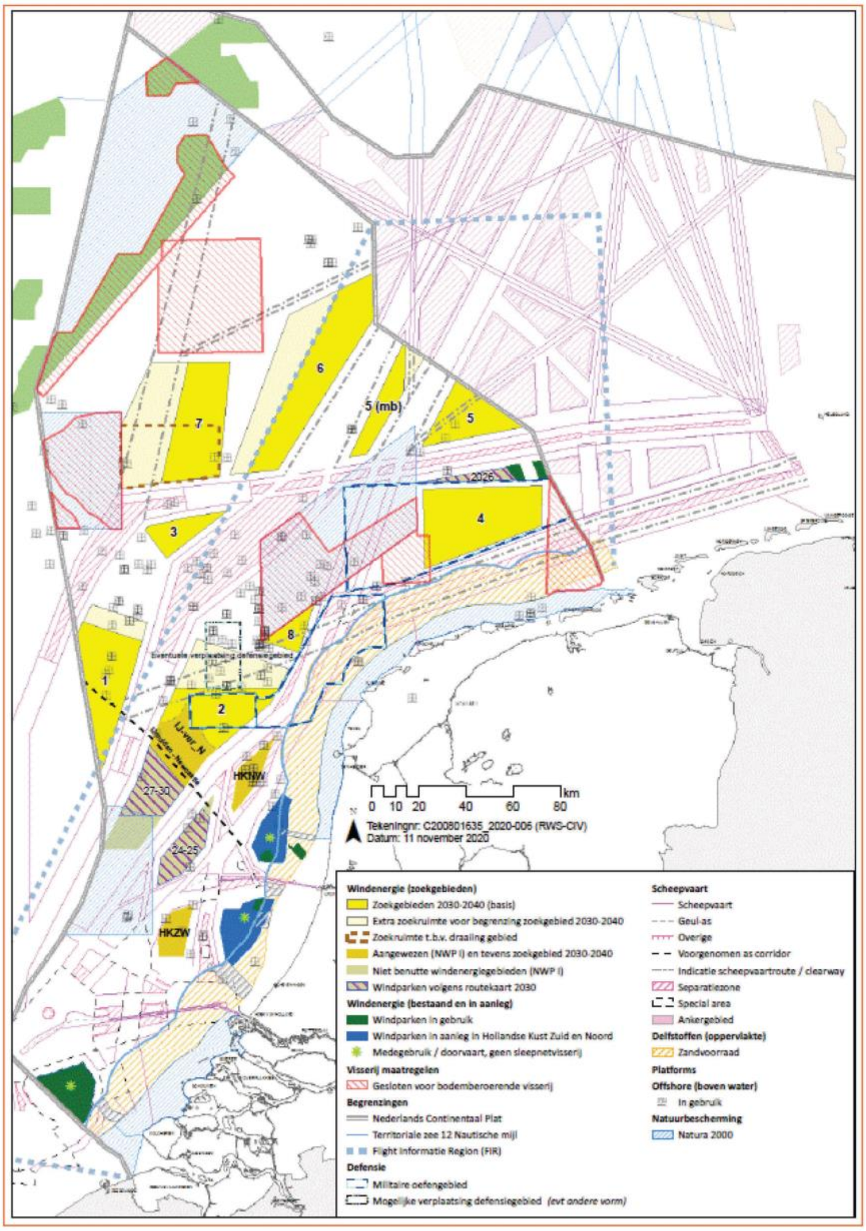

Figure 10 Offshore wind development until 2040 according to Nationaal Water Programma (NWP)

As far as projections beyond 2040 are concerned, the uncertainty in terms of both locations and capacity naturally increases. From 2040 to 2050, a report from the North Sea Energy outlook published in 2020 (North Sea Energy Outlook report, 2030) estimates a development of between 38 GW and 72 GW by 2050 for the Netherlands. The Netherlands' Environmental Agency (PBL) published a report in 2018, with an estimate of between 22 GW and 60 GW by 2050 (PBL Netherlands Environmental Assessment agency, 2018).

3.2 Oil and gas platforms

Many oil and gas platforms in the Dutch North Sea are approaching the end of their economic life. In the coming decades, it is expected that many of the offshore wells, platforms and pipelines will have been decommissioned or re-used. Decommissioning of offshore installations can take many years. First, wells are plugged and the pipelines for the process installations are depressurised. In most cases, top sides will then be cleaned. The subsea installations and the top sides can then be removed, followed by the removal of jackets and piles using removal vessels.

Instead of decommissioning the platforms, re-using them is an option. One possible way is CO_2 storage in depleted gas fields offshore. Another possibility is the generation of hydrogen offshore using wind energy, and its subsequent transport to shore using pipelines or vessels. This could provide an opportunity for re-used platforms to act as refuelling stations for hydrogen powered vessels. Re-use of platforms is also possible as a storage location for large offshore wind turbine components.

The development of carbon capture and storage (CCS) would necessitate a large capital expenditure to construct CO_2 transport pipelines and CO_2 storage sites with infrastructure such as compressor stations and injection equipment. The production of green hydrogen on repurposed oil and gas assets using offshore wind power will introduce logistics and maintenance requirements for offshore electrolysis systems including electrolysers, their containers and array cables connections from offshore wind farms.

3.3 Energy hubs

In WP1 of the NSE 4 project, three energy hubs have been identified viz. Hub West, Hub East and Hub North (See Figure 11)

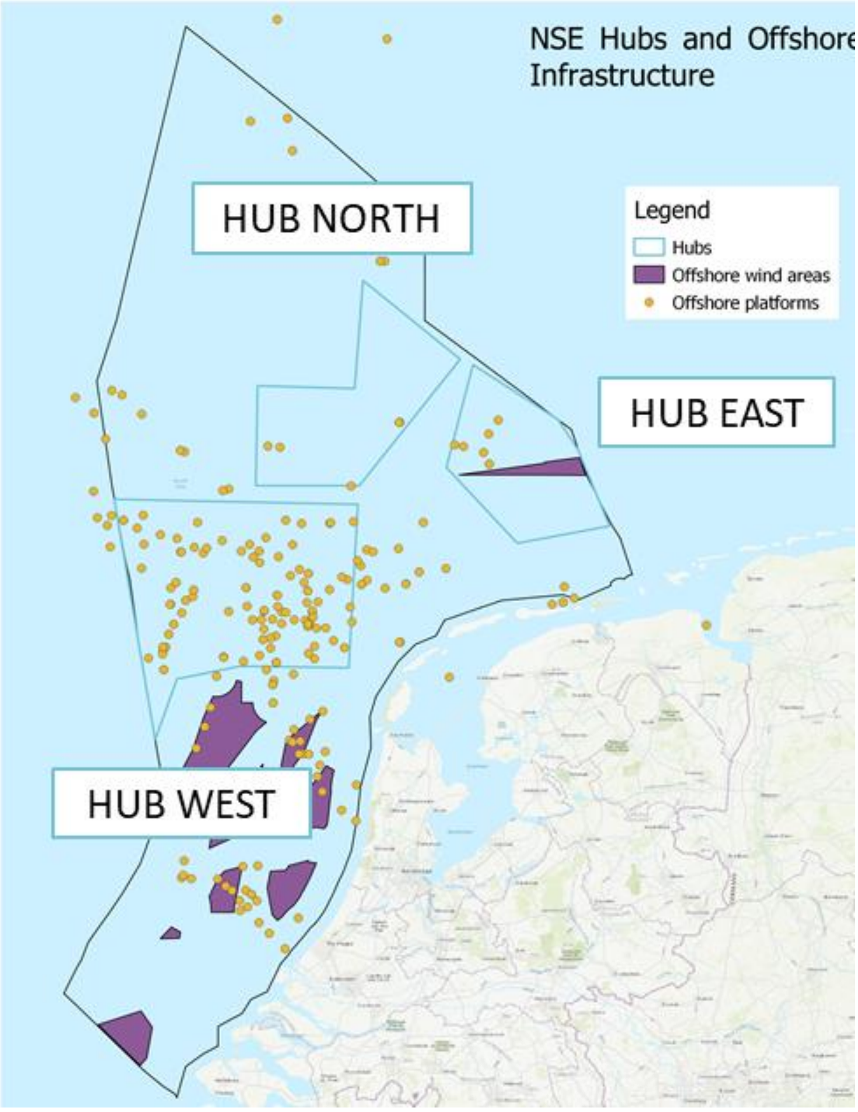

Figure 11 Energy hubs in the North Sea as defined in WP 1 of NSE 4

3.3.1 Hub West

Figure 10 shows search areas 4 and 5, which are among two of the larger search areas, being accessible from Hub West. To construct the logistic sharing scenarios, an estimate of the offshore wind farms capacity that can be operated in this region is needed. From Table 1, a total of 8 GW additional is expected between 2030 and 2040. This is above an expected existing capacity of 6 GW until 2030, resulting from HKN, Hollandse Kust West (HKW) and IJmuiden Ver (IJV) wind farms. Hollandse Kust Zuid (HKZ) and farms to its south such as Borssele are considered too far away from Hub West. Table 2 shows an example of annual development of offshore wind in the Hub West from 2030 to 2040, with the assumption that search areas closest to the shore are constructed first. Due to the high density of both wind farms and oil and gas platforms in this region, high levels of logistics activity is expected in this region, leading to higher possibilities of finding synergies between wind and O&G activities.

Table 2 Yearly capacity of offshore wind farms accessible for maintenance from Hub West

Year	OWF capacity for O&M (GW) (cumulative)	Location of new OWF
Up to 2030	6 GW	HKN, HKW, IJV
2031	7 GW	Search area 2
2032	8 GW	Search area 2
2033	8 GW	
2034	9 GW	Search area 2
2035	10 GW	Search area 8
2036	11 GW	Search area 1
2037	12 GW	Search area 1
2038	13 GW	Search area 1
2039	13 GW	
2040	14 GW	Search area 3
2050		

There is a considerable density of oil and gas (O&G) platforms accessible from Hub West (Figure 12) with blocks P and Q blocks being closest to shore, followed by blocks K and L, which are further north and farther away from the coast.

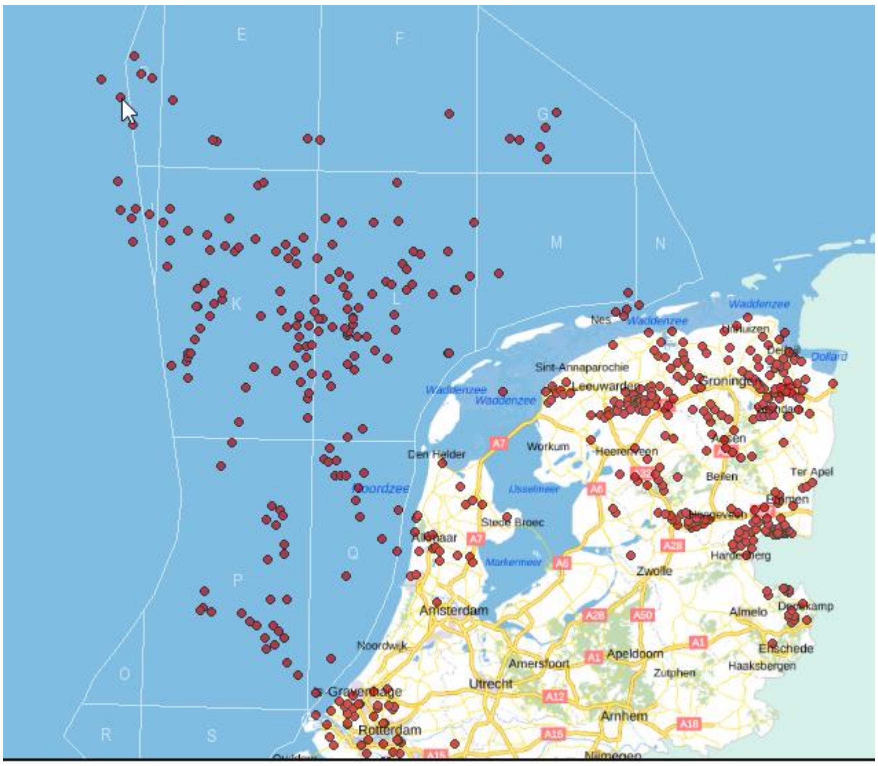

Figure 12 Oil and gas platforms accessible from Hub West (P&Q blocks, K&L blocks)

3.3.2 Hub East

Figure 10 shows search areas 4 and 5, which are two of the larger search areas, being accessible from Hub East. From Table 1, a total of 8 GW additional is expected between 2030 and 2040. This is above an expected existing capacity of slightly more than 1 GW until 2030, resulting from Gemini and Ten

Noorden van de Waddeneilanden (TNW) wind farms. Table 3 shows an example of annual development in Hub East from 2030 to 2040, with the assumption that search areas closest to the shore are constructed first. Until 2030, the offshore wind farm capacity in this region is relatively low compared to Hub West. Same is the case for oil and gas assets, with a lower density of platforms compared to Hub West. However, with the scale of offshore wind activity set to increase beyond 2030, and with an increase in re-use of O&G platforms to store CO_2 or produce hydrogen, synergies between offshore activities would increase after 2030.

Table 3 Yearly capacity of offshore wind farms accessible for maintenance from Hub East

Year	OWF capacity for O&M (GW) (cumulative)	Location of new OWF
Up to 2030	1 GW	Gemini, TNW
2031	2 GW	Search area 4
2032	3 GW	Search area 4
2033	4 GW	Search area 4
2034	5 GW	Search area 4
2035	6 GW	Search area 4
2036	7 GW	Search area 4
2037	8 GW	Search area 5
2038	9 GW	Search area 5
2039	9 GW	
2040	10 GW	Search area 5

Current oil and gas platforms belonging to the N and G blocks are in the area near Hub East. Also included upon completion will be the N05 platform, to be electrified by the Riffgat offshore wind farm in German waters (Figure 13)

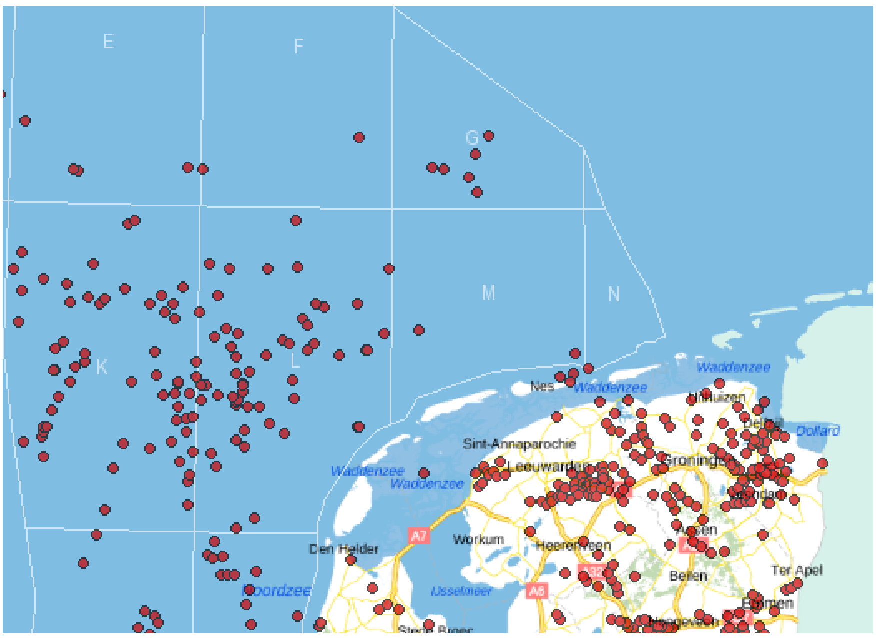

Figure 13 Oil and gas platforms in N and G blocks accessible from Hub East

3.3.3 Hub North

Figure 10 shows search areas 6 and 7, which are again two of the larger search areas, being accessible from Hub North. From Table 1, a total of 10 GW additional is expected between 2030 and 2040. No existing wind farms are present in this region. Since there is a larger temporal uncertainty in offshore wind farm developments near Hub North as compared to Hub West and Hub East, the scenarios developed in later chapters only focus qualitatively on region near Hub North. Table 4 shows an example of annual development near Hub North from 2030 to 2040, with the assumption that search areas closest to the shore are constructed first.

Table 4 Yearly capacity of offshore wind farms accessible for maintenance from Hub North

Year	OWF capacity for O&M (GW) (cumulative)	Location of new OWF
Up to 2030	0 GW	
2031	1 GW	Search area 6
2032	2 GW	Search area 6
2033	3 GW	Search area 6
2034	4 GW	Search area 6
2035	5 GW	Search area 6
2036	6 GW	Search area 6
2037	7 GW	Search area 7
2038	8 GW	Search area 7
2039	9 GW	Search area 7
2040	10 GW	Search area 7

3.4 Vessels used for O&M

3.4.1 Crew transfer vessels (CTVs)

CTV’s are a common vessel that provide access to offshore wind turbines located in close proximity to shore. Typically, small spare parts required for daily maintenance which are carried to wind turbines by the CTV. Each day, the vessel usually visits multiple wind turbines that need inspection or small repairs, and drops technicians off. The technician carrying capacity onboard a CTV is 10-15. A transfer plan is created at the start of each day which allocates certain maintenance tasks to certain teams of technicians. There are more than 400 operational CTVs, and they are further classified based on their hull shapes into monohull, catamaran, trimaran, small waterplane area twin hull (SWATH) and surface effect ship (SES) (Hu & Yung, 2020).

3.4.2 Service operational vessels (SOV)

Offshore wind farms installed far from shore cannot be accessed by daily CTVs. Currently, many SOVs (or walk-to-work (W2W) vessels) used to maintain far offshore wind farms which are permanently or temporarily installed with motion compensated gangways. SOVs remain offshore for extended periods without needing to go back and forth to the shore. An SOV can host around 50 technicians, small to medium spare parts and repair facilities for a longer time offshore, allowing O&M tasks to be more efficiently conducted and avoiding longer transit times.

SOV transit speeds in the wind farm are generally low (around 12 knots), especially when sailing on Dynamic Positioning (DP) mode. In large wind farms, SOVs may therefore have long transit times between turbines that are far from each other. To solve this problem and access multiple turbines simultaneously, many SOVs are equipped with daughter crafts, which are fast cruising boats.

3.4.3 Vessels for large component replacement

Replacement of large components like blades, gearboxes and generators are typically done using jack-up vessels (JUV). Due to its ability to lift itself out of the water a stable platform is created, from which a large crane can be operated.

Specialized cable laying vessels (CLVs) are used to disconnect parts of inter array cable strings, both when towing floating wind turbines to port and when rectifying failures in array cables. The vessel has the necessary equipment to dig up and remove the failed cable, lay the new cable and bury it.

Figure 14 Vessel used in offshore wind O&M (from left to right CTV, SOV and jack-up vessel)

3.4.4 Platform supply vessels (PSV)

To supply oil and gas platforms with goods, tools, supplies and personnel, platform supply vessels are used. The vessels are up to 100m in length and are usually equipped with class 1 or 2 dynamic positioning. PSVs help to transport not just heavy structural equipment, but also smaller structural material like cement, concrete and chemical compounds for sub-water boring operations. PSVs can be chartered to visit several platforms per voyage with varying deck space utilization, depending on the type of work for which support is needed.

3.4.5 Anchor handling vessels

In case of floating wind farms, due to the lack of a stable support structure, the replacement of large components sometimes take place at the port. For this, anchor handling vessels (AHV) (with tug boats) disconnect floating wind turbines from their mooring systems, and tow failed turbines to the port for repair.

In the O&G industry, AHVs are mainly built to handle anchors for oil rigs, tow them to location, and use them to secure the rigs in place.

3.4.6 Helicopters

For offshore wind farms, helicopters can provide access through the hoisting platform on top of the wind turbine nacelle or through the helideck of the substation. Helicopters can significantly decrease the travelling time compared to CTVs but they are expensive and can only carry a small number of technicians (usually 3 - 6). For O&G platforms, they can provide services such as transport of personnel and small supplies to various offshore platforms.



Figure 15 Vessel used in offshore O&M (from left to right PSV, AHT and helicopter)

3.5 Energy islands

Energy island in the future could be a central hub from where offshore activities for O&G platforms and future wind farms can be coordinated. The island could act as a hub for energy collection from surrounding wind farms. Production of sustainable fuels such as green hydrogen using electrolysers can be supported on the island, as can activities such as warehousing for wind turbine spare parts, accommodation services for personnel, marshalling port for large component replacement or installation vessels. Islands could also provide options for refuelling and sheltering of offshore vessels. An estimation of the island footprint and costs needed to support hydrogen production, transportation and power system requirements is seen in (NSE 3.8 Offshore Energy Islands, 2020), a deliverable of North Sea Energy (NSE) 3. Sample locations of energy islands near Hub West and Hub East, as an output from WP1 of NSE4 are in Figure 16.

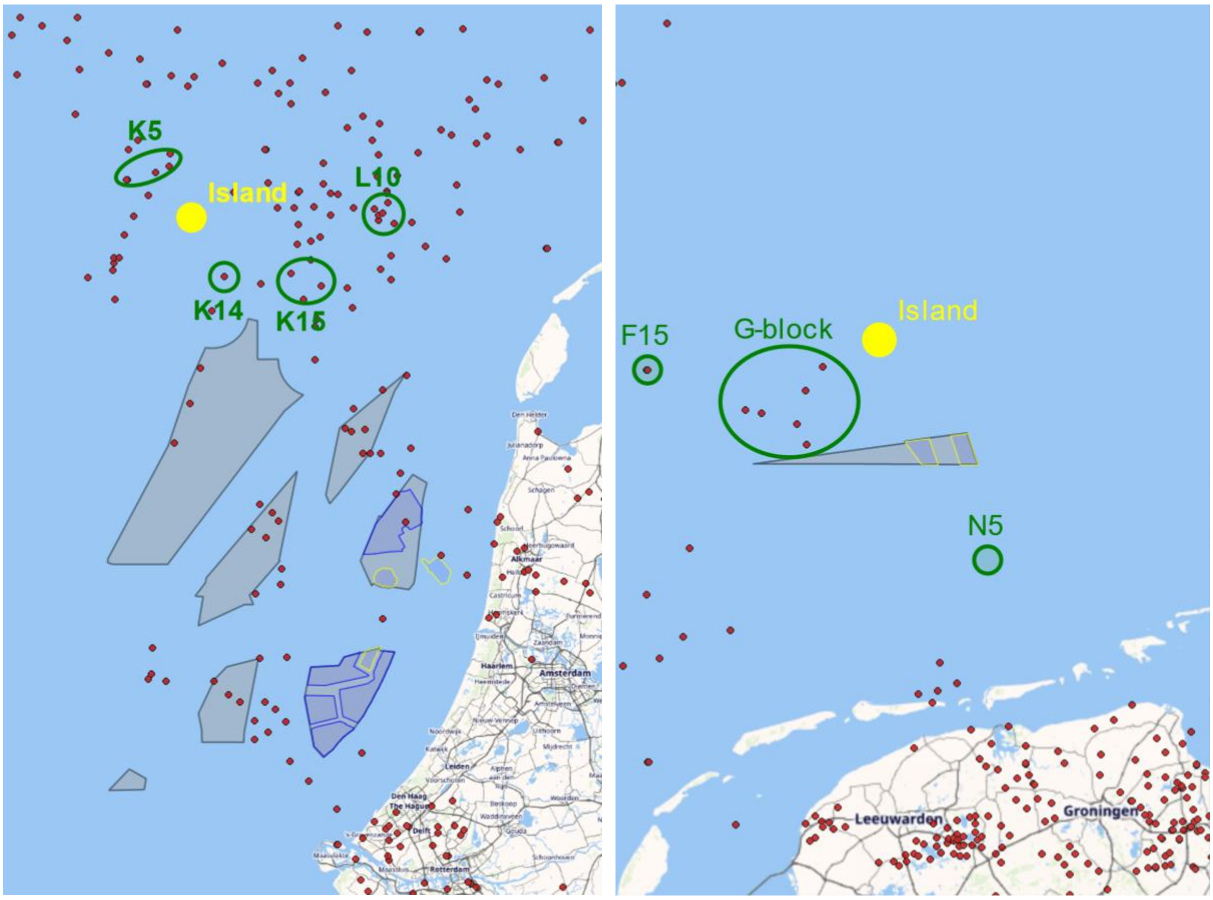

Figure 16 Potential locations for energy islands near Hub West (left) and Hub East

4 Scenarios

In order to evaluate the possibilities and potential benefits of logistic sharing concepts, scenarios need to be created that reflect the possible future state of the North Sea area and the logistics needs within it. In the previous chapter, these developments have been identified and described. In this chapter the developments will be converted to a set of constraints with different realizations options. For instance, one constraint is the location of the primary technician base, which has possible realization options of on shore, on the maintenance vessel, on a converted platform, or on an artificial energy island. By combining options from each of the constraints, a scenario can be built. For the spatial scope, the hubs from WP1 were used as a starting point. Since there are more uncertainties in the development of Hub North, only Hub West and East were used in the logistics scenarios. In total, seven scenarios were created, four for the area around Hub West, and three for the area around Hub East. The simulations were not run for all scenarios, however. Scenarios with a set of realizations that were very similar to other scenarios were not run, as the savings were deemed likely to be to similar to warrant proper simulation.

To ensure that all relevant constraints and options would be considered during the creation of the scenarios, a workshop was held together with partners from the North Sea Energy consortium. Within this workshop, the participants were asked to add to the list of constraints and options, and to create their own scenario. Using this information, the scenarios previously created have been updated and finalized.

4.1 Scenario constraints

The logistics constraints incorporated in the scenarios describe the biggest factors that are likely to affect the logistic system of the future North Sea energy sector. They have been based on the developments covered in Chapter 0, and are divided into four high-level groups:

- Spatial and temporal constraints
  - Maximum distance between the offshore structures and shore
  - Starting timeframe of operation and maintenance period
  - The location of the primary technician
- Logistic system constraints
  - The main logistic vessel used
  - Available secondary transport options
  - The primary vessel fuel used
- Energy island constraints
  - Availability and state of the island
  - Island uses
- Offshore platform constraints
  - Density of operating platforms
  - Additional (re-)use of platforms
  - Platform electrification

In the coming subsections, each of the different constraints and their realization options will be briefly discussed.

4.1.1 Spatial and temporal constraints

4.1.1.1 Distance to shore

The distance to shore constraint describes the maximum distance between the offshore structures to service (wind turbines, platforms, artificial islands), and primarily affects the type of vessels around which the maintenance strategy can be shaped, and the need for offshore structures to serve as additional bases, refueling stations, or providers of other services otherwise covered by the port.

In general, the maximum distances between offshore structures and the shore in Hub West are larger than those of Hub East.

4.1.1.2 Start O&M period

When the operation & maintenance period starts depends on the completion of the construction of wind farms or conversion of re-used platforms. Starting periods of five years were considered between the start of the temporal scope (2030) and five years before its end (2050). The starting time of the O&M period will affect the duration of the logistic needs, and affects the technology available at the time (for instance, energy islands are only considered to be available at later periods).

4.1.1.3 Technician base

The technician base is considered the primary locations at which technicians stay during maintenance campaigns, and depends on the distance to offshore structures availability of (converted) offshore structures. Considered options are on shore (at a port), on the primary maintenance vessel (for instance an SOV), on a converted offshore platform, or on an artificial energy island.

The location of the technician base will have a large effect on the logistics system, as it affects the distances required to be travelled, availability of storage and supplies at the technician base, and the operation and maintenance needs of the base itself.

4.1.2 Logistic system constraints

4.1.2.1 Main logistics vessel

The main logistic vessel is the primary vessel around which the logistic strategy is built, and depends on the distance to offshore structures and location of the technician base and type of the service. Options include crew transfer vessels (CTVs), service operation vessels (SOVs), surface effect ships (SESs), supply vessels, and walk-to-work vessels.

The primary type of logistic vessel is one of the most important constraints for a scenario, as it affects in large part the maintenance strategies possible, the speed of service, amount of supplies transferable by the vessel, fuel use, and emissions. In addition, the main vessel used also determines the additional transport options needed.

4.1.2.2 Additional transport option(s)

Besides the primary logistic vessel, there will be other transport options required to fulfil other tasks such as (additional) supply, emergency transport, smaller scale transport of people, etc. Options that might be required for these tasks are: helicopters, daughter craft, large scale supply ferries. The use of additional transport options can largely affect the emissions of a maintenance strategy.

4.1.2.3 Primary vessel fuel used

The primary fuel used to power the vessels within the logistics system depends on the current level of technological development at the start of the O&M period. Earlier on, fossil fuels will likely still be the main option, but over time, a shift is expected to occur to renewable options such as biofuels, hydrogen, and electricity.

The main fuel will largely impact the amount of emissions, and could possible effect the actions radius of the transport options, and determine the refueling locations.

4.1.3 Energy island constraints

4.1.3.1 Island availability

The availability of an artificial energy island in the North Sea is a constraint with one of the largest potential impacts on the future logistic system, and sharing concepts, but at the same time is also one of the most uncertain ones. There are many questions surrounding such islands that are currently unknown yet. How big will the island be, who owns or operates the island, which amenities will it have, does it have a permanent port and how big will it be? Within this analysis, we consider three options, no island at all, a small-scale island without large-capacity port (and this limited availability for long-term stays), and a full-capacity island with port.

The availability of an artificial island will have a large effect on the future logistics system, from technician base, to vessel use, to warehousing of supplies and refueling options.

4.1.3.2 Additional island use(s)

When an island is available, the way it is used can also impact the logistics scenario. Here we consider additional uses such as hydrogen production, technician base, warehousing, data centers (which would require additional maintenance and or security that could influence logistics), and tourism. Which uses the island serves determines the logistics strategy that can be employed (e.g. using the island as a technician base), vessel use (based on the port size), and synergies with other sectors (transporting technicians/supplies together with tourists).

4.1.4 Offshore platform constraints

4.1.4.1 Operating platform density

How many offshore platforms are within the area covered by the logistics scenario, how close they are located to each other and other offshore structures, and how many will still be operational during the O&M period can have a large effect on the maintenance strategy, routing options, sharing potential, and emissions. As it is very uncertain how many platforms will still be producing gas in the future, and how many platforms near depleted wells will be converted for other purposes, we have loosely defined three density options, low (only a few platforms close by, or more platforms spread out), medium (a decent number of platforms close by or many spread out), and high (many platforms close by).

4.1.4.2 Additional platform use

Whether or not offshore platform have additional functionalities will affect the logistics system due to changes in the type of maintenance required (and its frequency), and the ratio of manned versus unmanned platforms (which affect what supplies are needed and also their frequency). The options considered are the use of the platform as a technician base, conversion to CO_2 storage or hydrogen production, and warehousing.

4.1.4.3 Platform electrification

Perhaps a simple constraint, but whether or not a platform is fully electrified (changing from fuel powered equipment to electricity-based options, where the electricity comes from nearby wind farms), can have a considerable impact on emissions, but also on maintenance needs, and the potential for sharing technicians with offshore wind farms.

4.2 Creating scenarios

Scenarios are created by combining different options within each constraint described in the previous sections. This is done by drawing lines through an “options table”, a table in which all constraints and their realization options are summarized. Once the options have been selected, some of the high-level details of the scenario are worked out.

4.2.1 Option tables

Table 5 and Table 6 give the scenario options tables for Hub West and Hub East, respectively. As can be seen, they are largely the same, with a few options that are available in Hub West not being possible for Hub East. Firstly, the distances to shore will naturally differ due to the difference in location. In addition, due to the location of the Wadden islands in Hub East, the minimum distance to the nearest port is large for CTVs to be possible as the main vessel option. Furthermore, the number of platforms in Hub East is much lower, so the platform density will never be high. Finally, the subsurface in the Hub East area is considered unsuitable for depleted gas fields to be used for CO_2 storage, and as such, this option for additional platform use is unavailable here.

Table 5 Scenario options table for Hub West

Distance to shore	Start O&M Period	Technician base	Main logistics vessel	Additional transport option	Main vessel fuel	Island availability	Additional island use	Operational platform density	Alternative platform use	Platform electrification
<30 km	2030-2035	Shore	CTV	None	Fossil	Yes, with port	None	Low	None	Yes
30-80 km	2035-2040	Vessel	SOV	Helicopter	Hydrogen	Yes, without port	Technician base	Medium	Technician base	No
80+ km	2040-2045	Island	SES	Daughter craft	Bio	No	Hydrogen production	High	Hydrogen production	
		Platform	Supply vessel	Supply ferry	Electricity		Warehousing		CO2 storage	
							Data centres		Warehousing	
							Tourism			

Table 6 Scenario options table for Hub East

Distance to shore	Start O&M Period	Technician base	Main logistics vessel	Additional transport option	Main vessel fuel	Island availability	Additional island use	Operational platform density	Alternative platform use	Platform electrification
40-60 km	2030-2035	Vessel	CTV	None	Fossil	Yes, with port	None	Low	None	Yes
60+ km	2035-2040	Island	SOV	Helicopter	Hydrogen	Yes, without port	Technician base	Medium	Technician base	No
	2040-2045	Platform	SES	Daughter craft	Bio	No	Hydrogen production		Hydrogen production	
			Supply vessel	Supply ferry	Electricity		Warehousing		Warehousing	
							Data centres			
							Tourism			

To create a scenario with the option table, a line is drawn from the first constraint on the left, to the last one on the right, connecting all options to be included in the scenario with each other. An example of this is given in Table 7. For further details on the given example, see Section 4.4.

Table 7 Example of a scenario created by connecting different options in a options table

Distance to shore	Start O&M Period	Technician base	Main logistics vessel	Additional transport option	Main vessel fuel	Island availability	Additional island use	Operational platform density	Alternative platform use	Platform electrification
<30 km	2030-2035	Shore	CTV	None	Fossil	Yes, with port	None	Low	None	Yes
30-80 km	2035-2040	Vessel	SOV	Helicopter	Hydrogen	Yes, without port	Technician base	Medium	Technician base	No
80+ km	2040-2045	Island	SES	Daughter craft	Bio	No	Hydrogen production	High	Hydrogen production	
		Platform	Supply vessel	Supply ferry	Electricity		Warehousing		CO2 storage	
							Data centres		Warehousing	
							Tourism			

4.2.2 High-level details

While the complete detailed scenario (including simulation) will be worked out at a later stage, some high-level details of each scenario will be presented in this chapter, these include as general storyline for the scenario describing the chosen options and their substantiation, a description of the main logistical needs, the main platforms and wind farms included in the scenario, and potential sharing concepts within the scenario. These high-level details are given for the selected scenarios in Sections 4.4 and 4.5.

4.3 Workshop input

As a part of the work package, a workshop was held with partners from the North Sea Energy project. The goal of this workshop was to discuss logistic needs and options, gather inputs on the options table, and present scenarios already created and receive feedback on these scenarios. Using these inputs, the scenarios were updated and finalized. In this section we briefly summarize the most important discussion points that came up during the workshop. Appendix A.1 gives a visual overview of the some of the topics discussed during the workshop.

4.3.1 Updated scenario options tables

During the workshop, the participants were given the possibility to add additional constraints and/or options to the scenario tables as shown in Table 5 and Table 6. Here we briefly list all the additional options that were also included later on during the discussions on the scenarios, for the full list of all suggested additional options, refer to Appendix A.2. The final scenario tables for Hub West and Hub East can be found in Table 8 and Table 9 respectively.

Technician base

An interesting suggestion was made for the technician base aspect, which relied on (partially) autonomous O&M where the expert advised from a remote location (likely on shore). This option would likely be available much later in the future as it require considerable technological advances, but is a creative and interesting option nonetheless.

Additional transport option

Many suggestions were made for additional transport options that had not been included yet, such as:

- Feeder vessels. Mid-size freight ships for transporting containers
- Walk-to-work vessels. Vessels that use a movable gangway to directly connect to an offshore structure
- Vessel trains. Similar to daughter craft, but using the vessels to move between main vessel and port, instead of the main vessel itself having to move to port itself
- Drones. Using (autonomous) drones to deliver small spare parts or supplies to offshore structures.
- CO2 transport ships. Using ships transporting liquid CO2 to offshore storage facilities to also deliver supplies or technicians. This option is only relevant for locations were CO2 is possible, so will not be considered in Hub East.

Main vessel fuels

Additional fuel options such as synthetic methanol (produced from hydrogen), ammonia, and gas-to-liquid (GTL) were suggested.

Additional island use

A significant number of extra additional island uses were suggested, such as:

- Vessel sheltering. Using the island's port to shelter vessels during bad weather.
- Fuel station. Use the island for the storage of fuels and refueling of vessels.

Table 8 Updated scenario options table for Hub West. Additional inputs from workshop given in red

Distance to shore	Start O&M Period	Technician base	Main logistics vessel	Additional transport option	Main vessel fuel	Island availability	Additional island use	Operational platform density	Alternative platform use	Platform electrifi-cation
<30 km	2030-2035	Shore	CTV	None	Fossil	Yes, with port	None	Low	None	Yes
30-80 km	2035-2040	Vessel	SOV	Helicopter	Hydrogen	Yes, without port	Technician base	Medium	Technician base	No
80+ km	2040-2045	Island	SES	Daughter craft	Bio	No	Hydrogen production	High	Hydrogen production	
		Platform	Supply vessel	Supply ferry	Electricity		Ware-housing		CO_2/H_2 storage	
		Autonomous		Feeder vessel	Synthetic methanol		Data centres		Ware-housing	
				Walk-to-work	Ammonia		Tourism			
				Vessel train	GTL		Vessel sheltering			
				Drones			Fuel station			
				CO_2 shipping						

Table 9 Updated scenario options table for Hub East. Additional inputs from workshop given in red

Distance to shore	Start O&M Period	Technician base	Main logistics vessel	Additional transport option	Main vessel fuel	Island availability	Additional island use	Operational platform density	Alternative platform use	Platform electrifi-cation
40-60 km	2030-2035	Vessel	CTV	None	Fossil	Yes, with port	None	Low	None	Yes
60+ km	2035-2040	Island	SOV	Helicopter	Hydrogen	Yes, without port	Technician base	Medium	Technician base	No
	2040-2045	Platform	SES	Daughter craft	Bio	No	Hydrogen production		Hydrogen production	
		Autonomous	Supply vessel	Supply ferry	Electricity		Ware-housing		Ware-housing	
				Feeder vessel	Synthetic methanol		Data centres			
				Walk-to-work	Ammonia		Tourism			
				Vessel train	GTL		Vessel sheltering			
				Drones			Fuel station			

4.3.2 Suggested sharing concepts

During the workshop, the participants were also asked to come up with their own scenarios, and logistic needs and potential sharing concepts within it. In this subsection, the main results are discussed, and where possible, they will be incorporated in the final scenarios.

Operational system integration

While perhaps not a synergy on its own, operational system integration will be a crucial step required in making logistics sharing concepts possible. Having common cargo prioritization, HSE (health, safety, environment) policies, and a common booking platform for vessels will be key in optimizing the benefits of logistics sharing.

Sharing fleet mixture

There are large differences in the types of vessels used for servicing offshore structures between different sectors. Whereas the O&G industry mainly uses larger, slower supply vessels for crew transfer and resupplying platforms, the wind sector relies more on faster CTVs for short distances and SOVs for long distances. Sharing these vessel types between industries could enable both sectors to leverage the benefits of each vessel type in the situation that best suits them. For instance, currently in the O&G industry, when a crucial part is forgotten to be supplied, a second supply vessel is sent out with only that missing part which is slow (something undesirable when time is of the essence) and leads to low deck utilization and inefficient transport. If in this case, a CTV from the wind sector could be used, it would save time, and reduce costs and emissions.

Crew transfer

The transfer of crew (technicians, engineers, supporting staff) to offshore structures is one of the largest logistic needs in offshore operation and maintenance. Sharing concepts regarding crew can be roughly divided into two areas:

- Sharing the crew; In the case of platform electrifications or hydrogen production, there will likely be overlap between technicians needed for O&M of wind turbines and electrical equipment on converted platforms or the energy island. In addition, when long-term stay takes place offshore, supporting staff might share considerable overlap between sectors.
- Sharing crew transport; If no overlap in crew is present, synergies could still be found in sharing the transport options used to transfer crew to or between offshore structures.

Supply transport

Synergies could be found in the sharing of supply vessels for offshore structures. Currently, such a system is in place within the O&G industry which is the SNSPOOL (see Section 1.1.3), but this could be extrapolated to include the wind sector and potential future hydrogen production or CO_2 storage industries (for instance, by using vessels to supply parts to wind construction operations).

Facility sharing

Having a shared base of operation, warehousing, and port access can not only reduce overhead costs, but will make sharing of vessels, supplies, and staff much easier. In addition, it will likely reduce hurdles in communication and cooperation between different companies/sectors.

Incidental transport

Incidental transport refers to any spontaneous transport that can be performed by a vessel/transport option that otherwise has a different purpose. For instance, if a CTV is going towards a wind farm to deliver technicians, it could be used to also deliver supplies to the O&G platform before the normally scheduled supply vessel.

4.4 Hub West scenarios

In this section, high-level descriptions will be given for the four scenarios defined for Hub West, these include a scenario in which the logistics strategy revolves around the shore, an SOV (with drones as a variation) and artificial energy island. The quantification of logistic parameters and detailed KPIs will be defined in the detailed simulation activities of the work package.

4.4.1 Shore based

Description

The first scenario for Hub West considers the earliest time period within the temporal scope. The selected options taken into account in this scenario can be found in Table 10. As discussed in Section 3.1, some of the wind farms to be built before 2030 are relatively close to shore and will require CTVs for daily maintenance, with the sparse use of helicopters in transferring personnel.

As this scenario revolves around early developments and vessels that operate close to shore, it is expected that fossil fuels still make up a significant part of the fuel mix. In addition, no artificial island will be available yet, and the use of platforms as a possible storage of CO_2 is considered.

At this point in time, the main wind farms included in the scenario will be the upcoming Hollandse Kust Noord (HKN) and Hollandse Kust West (HKW), a total of 2 GW. Main platforms included in the scenario are existing platforms in the P-block platforms in the Q-block (See Figure 12).

Table 10 Options included in the shore based scenario for Hub West

Shore distance	O&M start time	Technician base	Main vessel	Additional transport option	Main vessel fuel	Island availability	Island use	Platform density	Alternative platform use	Platform electrification
<30 km	2030-2035	Shore	CTV, supply vessel	Helicopter, walk-to-work vessel	Fossil/GTL	No	None	Medium	None, CO2 storage	Yes

Logistic needs

Logistic needs in this scenario will not differ significantly from the current situation. For the wind farms this will mostly consist of scheduled and unscheduled maintenance of the turbines. For offshore platforms this will be maintenance of the equipment, as well as transport of more specific supplies (food, cleaning chemicals, waste removal) to manned platforms.

Potential sharing synergies

Synergies will most likely focus on the sharing of vessels and in some cases technicians between the wind and O&G sectors. For instance using daily CTVs to supply offshore platforms, using PSVs to transport technicians to wind farms on the way to transporting spare parts to platforms, or using the same technicians to service the wind farms as well as electrified platforms. An investigation into the optimal utilization of PSV deck space will be made when demands are placed from offshore platforms as well as offshore wind turbine spares and technicians.

4.4.2 SOV based

Description

In this scenario, the envisaged timeline is in accordance with offshore wind developments further offshore at a later temporal scope. Since the offshore wind farms are further away from shore, daily access to them via CTVs will no longer be possible; this scenario sees the use of SOVs as the vessel for daily maintenance. Smaller daughter crafts will be used to service the offshore structures from the SOV. The SOV acts as a base for technician accommodation, with a specific periods for the personnel shifts (e.g. bi-weekly basis).
Fossil fuels are still the dominant fuel source for offshore vessels, but there is some penetration of alternative fuels such as hydrogen in the market, especially during the latter part of the temporal scope. In addition, no artificial island will be available yet, and the use of platforms as a possible storage of CO_2 is considered.

By 2030, 4 GW of wind farms at Ijmuiden Ver will be realized and included in this scenario. Also included will be wind farms in the upcoming search areas 2 and 8. The total wind farm capacity in this scenario is 8 GW. Main platforms included in the scenario are platforms in the L-block and K-block (Figure 12).

Table 11 Options included in the SOV based scenario for Hub West

Shore distance	O&M start time	Technician base	Main vessel	Additional transport option	Main vessel fuel	Island availability	Island use	Platform density	Alternative platform use	Platform electrification
30-80 km	2030-2035	Vessel	SOV	Daughter craft, Supply ferry	Fossil, hydrogen	No	None	High	CO2 storage	Yes

Logistic needs

For the wind farms the logistics will mainly consist of scheduled and unscheduled maintenance of the turbines. For offshore platforms this will be maintenance of the equipment, as well as transport of more specific supplies (food, cleaning chemicals, waste removal) to manned platforms. For the SOV itself, supply ferry vessels are expected to perform crew and supply transfer on a regular basis. The SOV would also require to re-fuel at the port on a regular basis.

Potential sharing synergies

Synergies will most likely focus on the sharing of vessels and in some cases technicians between the wind and O&G sectors. For instance using the SOV and its daughter crafts to supply offshore platforms or using PSVs to transport technicians to wind farms on the way to transporting spare parts to platforms. The common use of ferries to supply both the offshore platforms and SOVs can be considered.

4.4.3 SOV based considering drone utilization

Description

This scenario is seen as a sensitivity to the SOV based scenario described in the earlier section. In addition to the prior scenario, this scenario assumes a higher rate of adoption of drones to inspect offshore structures. Components such as blades that would otherwise require long periods of scheduled maintenance for visual inspections will be inspected by drones. This could improve the reliability of inspections, lead to fewer workplace accidents, provide access to otherwise inaccessible areas and ultimately reduce downtime and result in cost savings. The use of drones could also be subsea, which in addition to ROVs can provide a useful alternative to inspect subsea components of offshore platforms.

With the adoption of drones, digital twins and robots in turbine nacelles, expert human judgement may only be needed from control rooms onshore. Besides the use of drones for inspection, the supply of small payloads (up to 50 kg) can be considered. While qualitatively considered, this scenario ultimately was not run due to the savings being considered too similar with that of the SOV based scenario.

Logistic needs

The general needs in this scenario are similar to those in the SOV based scenario. There is a decrease in personnel offshore in this scenario, which is due to the adoption of drones and a reduction in need for scheduled visual inspections. Costs for logistics using drones is assumed in this scenario.

Potential sharing synergies

In addition to the synergies identified in the SOV based scenario, the shared use of drones (including subsea drones) for both offshore wind turbines and O&G platforms is considered.

4.4.4 Island based

Description

This scenario is based on long term developments in the Hub West region. Wind farm expansion takes place towards regions north of Ijmuiden Ver. However, within the scenario, an energy island is available and around which O&M strategies are based. The island is used as a base for personnel accommodation and a warehouse for large components, and with a port it can be accessed by SOVs which maintain wind farms around the island. In addition to SOVs, smaller daughter crafts will be used to service the offshore structures from the SOV. SOVs in this scenario mainly use alternative fuels such as hydrogen and electricity.

Wind farms in search areas 1 & 3 are included in this scenario. The total wind farm capacity in this scenario is 4 GW. Main platforms included in the scenario are platforms in the eastern part of K-block, southern parts of E and F blocks and D-block (See Figure 12).

Table 12 Options included in the Island based scenario for Hub West

Shore distance	O&M start time	Technician base	Main vessel	Additional transport option	Main vessel fuel	Island availability	Island use	Platform density	Alternative platform use	Platform electrification
80+ km	2035-2040	Island	SOV, supply vessel	Daughter craft, Supply ferry, CO_2 transport vessel, walk-to-work vessel	Hydrogen, ammonia, electricity	Yes, with port	Technician base, warehouse, vessel sheltering	Medium	CO2 storage	Yes

Logistic needs

For the wind farms the logistics will mainly consist of scheduled and unscheduled maintenance of the turbines. For offshore platforms this will be maintenance of the equipment, as well as transport of more specific supplies (food, cleaning chemicals, waste removal) to manned platforms. For the island, supply ferry vessels are expected to perform crew and supply transfer on a regular basis. Additionally, the SOVs would refuel, carry supplies and personnel from the island, thereby reducing the downtime arising from SOVs needing to frequently visit the shore in order to refuel.

Potential sharing synergies

Synergies can mainly be found in the sharing of the island infrastructure as a common hub for offshore wind and O&G platform personnel and spare components. In addition, supply ferries can be used to provide for the common supplies and maintenance needs of offshore wind farms and O&G platforms. Finally, the use of SOVs to supply offshore platforms in addition to wind farms is investigated.

4.5 Hub East scenarios

In this sections, high-level descriptions will be given for the three scenarios defined for Hub East. These include a scenario in which the logistics strategy revolves around an SOV, converted platform, and artificial energy island, respectively.

4.5.1 SOV based

Description

The first scenario for Hub East considers the earliest time period within the temporal scope, and can be viewed as a partial extrapolation of the current situation. The selected options taken into account in this scenario can be found in Table 13.

The minimum distance to shore in Hub East is already above what makes using CTV directly from shore difficult. As such, the strategy is built around the use of SOVs and supply vessels, with the SOV serving as the main technician base during extensive maintenance campaigns. Smaller daughter crafts will be used to service the offshore structures from the SOV, and will resupply the SOV from shore in a vessel train.

As this scenario revolves around early developments, it is expected that fossil fuels still make up a significant fraction of the fuel mix, with the rest being made up of hydrogen. In addition, no artificial island will be available yet, and the re-use of platforms is not considered.

At this point in time, the main wind farms included in the scenario will be the existing Gemini farm, the tendered “Ten noorden van de Waddeneilanden” (TNW) wind farm, and the future wind farms planned in search area 4 south of Gemini (see Figure 10). In total, the expected combined size of the wind farm will be around 10-11 GW. Main platforms included in the scenario are existing platforms in the G-block, and the planned N-05 platform.

Table 13 Options included in the SOV based scenario for Hub East

Shore distance	O&M start time	Technician base	Main vessel	Additional transport option	Main vessel fuel	Island availability	Island use	Platform density	Alternative platform use	Platform electrification
40-60 km	2030-2035	Vessel	SOV, supply vessel	Daughter craft, vessel train	Fossil/GTL, hydrogen	No	None	Low	None	Yes

Logistic needs

Logistic needs in this scenario will not differ significantly from the current situation. For the wind farms this will mostly consist of routine and emergency maintenance of the turbines. For offshore platforms this will be maintenance of the equipment, as well as transport of more specific supplies (food, cleaning chemicals, waste removal) to manned platforms.

Potential sharing synergies

Due to the early nature of this scenario, sharing synergies will most likely be limited to the sharing of vessels and in some cases technicians between the wind and O&G sectors. For instance using SOVs to supply offshore platforms, using supply vessels to transport technicians to wind farms on the way to transporting goods to platforms, or using the same electricians to service the wind farms as well as electrified platforms. In addition, sharing facilities at the port or even on the SOV base could be an interesting synergy in this scenario.

4.5.2 Platform based

Description

The platform based scenario for Hub East is a variation of the vessel-focused SOV based scenario, where the logistics scenario is created around a converted platform (or cluster of platforms). Apart from the technician base, transport options, and platform use, the scenario is identical to the SOV scenario; the full list of included options is given in Table 14.

In the scenario, the platform base will be used for longer-term stay of technicians and other staff and the warehousing of supplies and equipment. From the platform, CTVs and supply vessels will go out to service the surrounding structures. The platform scenario can be considered an option somewhere in between the SOV strategy, and a full-scale offshore island, having more space and potential for long-term stay than an SOV, but more limited potential for additional uses and docking of larger vessels than an island.

Table 14 Options included in the platform based scenario for Hub East

Shore distance	O&M start time	Technician base	Main vessel	Additional transport option	Main vessel fuel	Island availability	Island use	Platform density	Alternative platform use	Platform electrification
40-60 km	2030-2035	Platform	CTV, supply vessel	Helicopter, walk-to-work vessel	Fossil/GTL, hydrogen	No	None	Low	Technician base, warehousing	Yes

Logistic needs

Most logistical needs will be similar as in the SOV based scenario, with maintenance of the offshore wind turbines and O&G equipment being the primary drivers of transport of technicians and supplies. However, with the use of a platform as technician base, it will likely require more maintenance and supply of critical goods such as food, water, and (cleaning) chemicals, and the removal of waste. In addition, more supporting staff will likely be required on the platform base, requiring increased transport of personnel. This scenario was not simulated due to its similarities with the previous scenario, but just considered qualitatively.

Potential sharing synergies

Compared to the SOV strategy, there might not be many unique synergies to the platform based scenario, but the use of a converted platform as offshore technician base could encourage closer collaboration and integration between the wind and O&G sector, sharing technicians, supporting staff, warehousing, as well as vessels and additional transport options. In addition, since both sectors share a central offshore hub, sharing of incidental transport (having a technician or supplies transported by a vessel with a different intended purpose) could see higher potential.

4.5.3 Island based

Description

The last scenario for Hub East revolves around the late-term developments in Hub East, its option are given in Table 15. Wind farm expansion is taking place further North. However, within the scenario, an energy island is available as offshore technician base. As the area around Hub East is smaller, CTVs and supply vessels can be used to transport technicians from the island base to wind farms and platforms. Feeder vessels deliver the necessary supplies to the island.

Within the scenario it is assumed that hydrogen production will take place both on the island, as well as on converted platforms. Due to this high availability of hydrogen, most vessels have been converted to run on hydrogen power. In addition to hydrogen production, in this scenario we will also look into the possibility of transporting and monetizing oxygen production (a by-product in the conversion of water to hydrogen that is normally discarded due to its heavily corrosive properties). While requiring additional storage and transport, oxygen could be a lucrative by-product, and its transport could enable additional incidental transport synergies.

The main wind farms included in this scenario are the Gemini, TNW wind farm, and any wind farms planned in search areas 4 and 5, respectively to the south and north(-west) of the Gemini park (See Figure 10). Main
platforms included are the G- and N-block platforms also included in the SOV scenario, with the possibility of extending as far as the (north-)east of the F-block.

Table 15 Options included in the island based scenario for Hub East

Shore distance	O&M start time	Technician base	Main vessel	Additional transport option	Main vessel fuel	Island availability	Island use	Platform density	Alternative platform use	Platform electrification
60+ km	2035-2040	Island	CTV, supply vessel	Feeder vessel, walk-to-work vessel	Hydrogen, methanol	Yes, with port	Technician base, warehousing, hydrogen production, vessel sheltering	Low	Hydrogen production	Yes

Logistic needs

With an artificial island as main technician base, logistics needs will likely increase around it. The island itself will require considerable maintenance to all its amenities, including the port, warehouses, living facilities, and technical installations. In addition, with the increase of hydrogen production and decrease of O&G activities, maintenance needs will shift considerably. However, it is currently difficult to estimate exactly the frequency of, and the equipment/technicians necessary for (offshore) hydrogen production. In addition, if the island is used as a (semi-)permanent base, the need for supporting staff (cleaning, cooking, security) will also increase, requiring additional crew transfer.

On the other side, having a large central offshore hub should reduce the distance between technician base and offshore structures, and the frequency of smaller scale travel between shore and offshore structures.

The production of oxygen in tandem with hydrogen also brings further logistic needs with it, including its storage and transport. Due to the danger surrounding pure oxygen (especially at high pressures), there will have to be strict measures in place, potentially additional inspection to make sure it can be produced safely offshore.

Potential sharing synergies

Like the offshore platform scenario, synergies can mainly be found in the sharing of the island infrastructure, and the logistic vessels. Introducing oxygen production can introduce additional synergies with sharing technicians/staff, and the possibility of incidental transport of people or supplies on the oxygen tankers.

4.6 Key Performance Indicators

In this section, the key performance indicators (KPIs) that will be used to evaluate the scenario simulations will be briefly described. The KPIs include: cost (benefits), uptime availability of the assets, travel distance of vessels and transport options, and emissions of transport and technician base operation.

4.6.1 Costs benefits

One of criterion is the total costs that could be saved through sharing principles. With the cost benefits KPI the difference in costs between the conventional, no sharing strategy and the sharing strategy for each scenario is measured. Costs can come from many factors, including vessel costs and maintenance, fuel costs, crew salaries, equipment and supply costs, cost of spare parts, operations costs for technician bases, costs incurred due to asset downtime, etc.

4.6.2 Uptime availability

Uptime availability measures the total time the offshore assets are in production. Any time an asset has to stop operation due to failures, the uptime availability decreases until maintenance is performed. Thus, uptime maintenance is a measure of how fast and efficient the O&M strategy is.

4.6.3 Travel distance

Travel distance will mainly impact the total emissions generated within a scenario, but also gives a measure of the spatial efficiency of the logistics system and gives a good indication of the potential time and effort that might be saved by employing certain sharing concepts.

4.6.4 Emissions

A major part of the benefits of shared logistics is that of reducing CO_2 (equivalent) and NO_x emissions by reducing travel time and distance. When simulating the scenarios, total emissions will thus be one of the most important KPIs by which they will be evaluated.

While emissions are closely related to travel distance, as burning fuel to power the vessels and additional transport options will be a major contributor to emissions, it also includes the emissions generated to power the technician base.

5 Simulation methods

The scenarios as defined in the previous chapter will be simulated in order to evaluate the potential benefits of shared logistics when it comes to costs, emissions, and other metrics. This evaluation will be done using two different pre-existing tools owned and developed by TNO: O&M planner (Flexible decision support software for offshore operations, 2021), which will be used to evaluate the costs and travel distances associated with multi-year O&M campaigns of each scenario, and Despatch, which will be used to work out the short-term planning of O&M activities and vessel routes in 1-2 selected scenarios. In the first two sections of this chapter, these two simulation tools are briefly explained.

As both tools mentioned have originally been developed for the wind energy industry, they had to be extrapolated such that it would also be possible to model O&M activities related to the offshore oil and gas (and hydrogen and CCS in the future) industry. For this, data received from one of the NSE partners involved in this work package was analysed, and used in the simulation tools. In the last section of this chapter, details of this data analysis are provided.

5.1 O&M Planner – long-term cost analysis

O&M Planner is a simulation tool owned and developed by TNO's Wind energy department and used to model and evaluate the costs of long-term (multi-year) operation and maintenance (O&M) campaigns of offshore wind farms. The main user interface of O&M Planner is shown in Figure 17. Within the tool, possible maintenance activities (inspections, repairs, replacements, etc.) that might occur during the operation of an offshore wind farm can be defined, along with their frequency of occurrence, activity duration, and associated replacement part costs. The tool then uses a probabilistic approach to estimate the number and type of O&M activities that occur during a given simulation timeframe. Using additional vessel, technician, and geospatial data, the tool can calculate, among others, the total costs, vessel distance covered, and uptime percentage.

While originally developed for the wind sector, additions were made to O&M Planner such that it could also be used to incorporate the supplying of offshore platforms. For this, platform visit frequencies and average platform visit times were derived from data received from ONE Peterson, for further details see Section 5.3. O&M Planner is used in this work package in order to investigate the potential costs/emission benefits of sharing logistics between the O&G and wind industries when compared to keeping them separated.

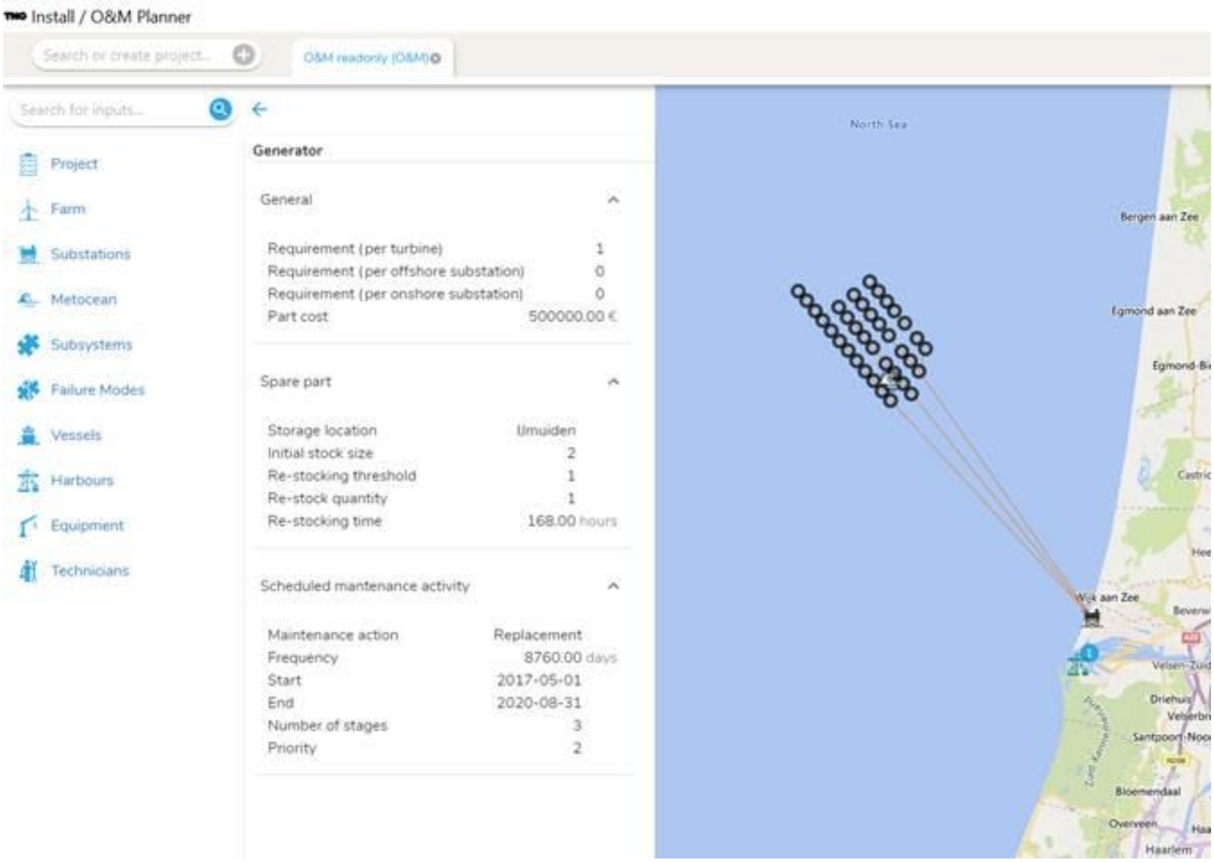

Figure 17 View of the main user interface of the O&M Planner software tool

5.2 Despatch – short-term activity planning

Like O&M Planner, Despatch is a simulation tool owned and developed by TNO's wind department. While O&M Planner focuses on the long-term cost evaluation of O&M campaigns, Despatch is used to model the detailed planning of when to schedule the needed O&M activities, how many vessels and technicians to use, and how to plan the route between the offshore structures (short-term planning). Figure 18 gives an example of the main view of the Despatch user interface.

While Despatch can be used to evaluate the main KPI's of a pre-existing schedule, its main power lies in the optimization functionalities built into the tool. Using these capabilities, Despatch can, given a list of work orders and available vessels and technicians, calculate the optimal scheduling of all O&M activities. This can be done in order to optimize many different KPI's. As Despatch is much more detailed, short-term oriented, and computationally intensive than O&M Planner, it has only been used for 2 scenarios in order to give an indication of how a shared logistics system could be scheduled.

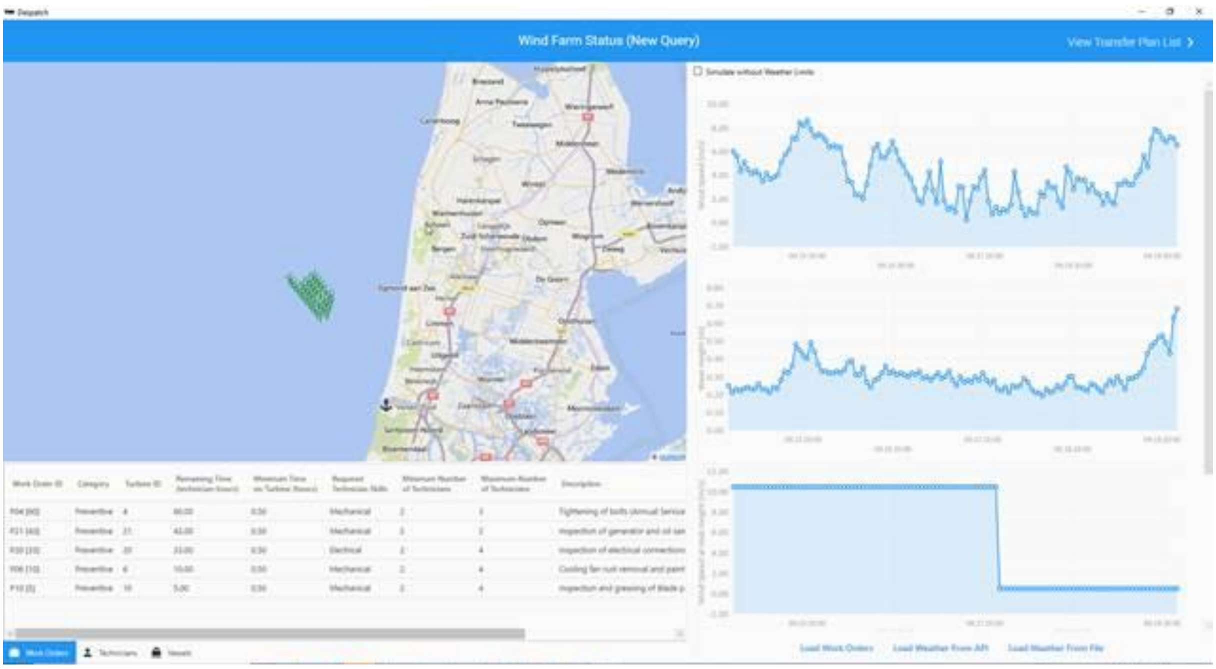

Figure 18 View of the main user interface of the Despatch software tool

5.3 O&G data analysis

The existing simulation framework used within this project was originally designed specifically to model O&M activities and costs for the offshore wind industry. The framework makes use of known failure probabilities and repair times in order to estimate to expected costs of multi-year maintenance campaigns. In order to extend the capabilities of this framework to also include O&M activities for the oil and gas industry, the average frequency and duration of platform visits must be known. This information was derived from vessel activity data received from NSE partner ONE Peterson. This dataset contained information on the starting and end times of the different activities undergone by the vessels in their fleet and the location these activities took place at (offshore platforms or ports). Data was received for a five year period between 2015 and 2019.

5.3.1 O&G activities data

Figure 19 gives an overview of the 38 different types of activities recorded in the dataset. As can be seen, the data is dominated by the ‘HO’, ‘PASS’, and ‘WOHP’ activities, standing for ‘Handling Offshore’, ‘Passage’, and ‘Waiting on departure (in port)’, respectively. Together making up almost half of all the activity instances.

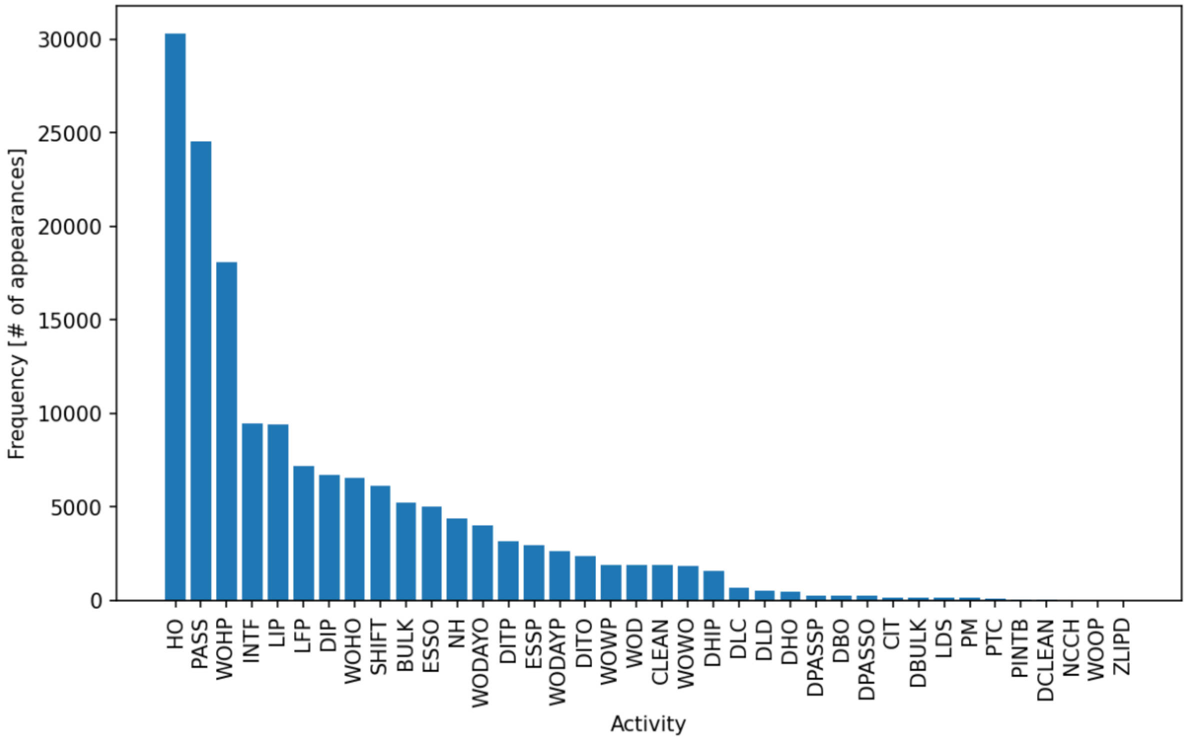

Figure 19 Number of times every activity in the vessel activity dataset appears

In this project, only the handling offshore activities are possible to consider, as these encapsulate all the durations a vessel is busy offshore at a platform, and can be combined with offshore wind O&M tasks. As the starting and end times of each handling offshore instance are known, it is possible to calculate both the average duration of handling offshore activities and the frequency at which they occur, which can then both be included in the simulation framework to model how often such activities take place during a maintenance campaign and how long it takes to execute them.

As not only the activities themselves are known, but also where they take place, it is possible to not only model the overall average frequency and duration of the handling offshore activity, but also those for specific offshore platforms, making the modelling results more realistic. Figure 20 shows a box plot comparison of the average durations of handling offshore activities for five selected platforms, while Figure 21 shows a similar plot for the average frequencies between handling offshore instances for the same platforms. As can be seen, average duration varies around 2 hours, while the frequency between platform visits varies around 150 hours, although the variation (and outlier values) between platforms differs more significantly.

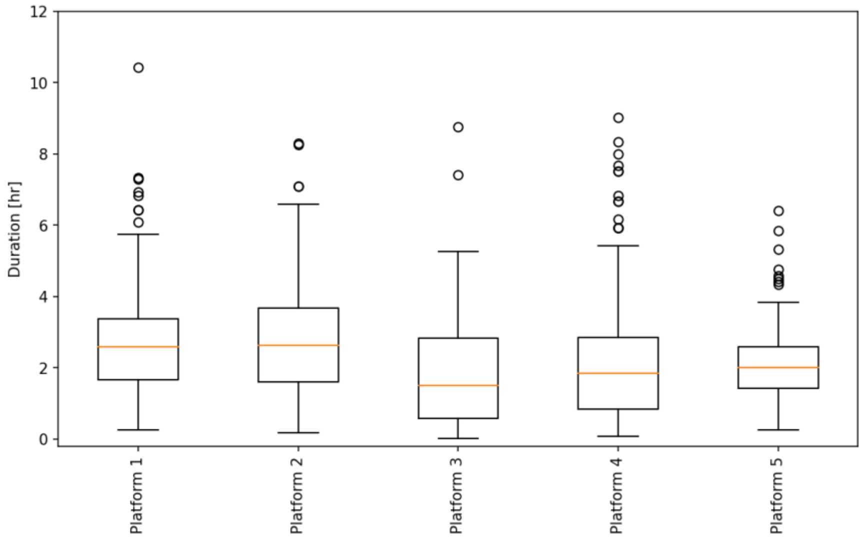

Figure 20 Box plots showing the distribution of the duration of the handling offshore activity for selected platforms

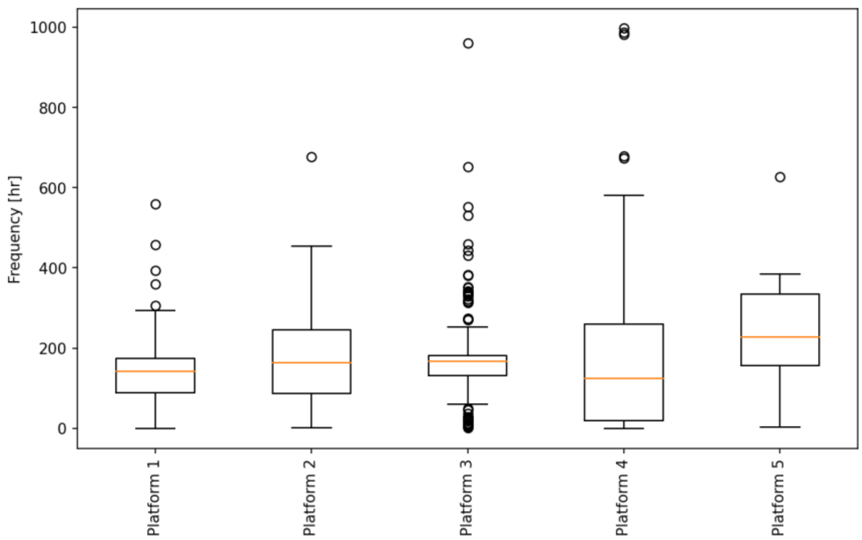

Figure 21 Box plots showing the distribution of the duration between the occurrence (or frequency of occurrence) of the handling offshore activity for selected platforms

For all platforms in the vessel activity dataset, the average duration and frequency of the handling offshore activity have been determined. When the scenarios are modelled, the platforms included in the scenario are selected, and their respective durations and frequencies are added to the modelling parameters.

5.3.2 Fuel data

In order to estimate the emissions and costs associated with the O&M activities for the oil and gas industry, the average speed and fuel consumption of the a number of platform supply vessels in ONE Peterson's fleet was analysed. Again, data was received from ONE Peterson, which contained information on the journeys of three vessels, including data on their average speeds and fuel consumption on different trips. As the simulation software only provides us with the distances travelled by the vessels, this information is needed in order to estimate the travel times and fuel consumption of the vessels. In turn, these values can later be used to calculate the associated costs (a combination of vessel day rate, labour costs and fuel costs) and emissions.

Figure 22 shows a box plot for the absolute speed over ground for the three vessels in the dataset combined. As can be seen, the range is quite wide (between 2 and 14 mph), which is likely due to the large variability in weather conditions during the different passages. Unfortunately, no data is available for these conditions. On average, the vessels' speed over ground is around 8.6 mph.

Figure 23 shows the fuel consumption in litres per hour for the vessels in the dataset. In this case, the data has been divided between the two main type of activities associated with fuel consumption: handling offshore (fuel consumed while activities take place around the platform), and passage (fuel consumed while travelling between platform(s) and port). While both activities have a comparable average consumption (about 320 L/hr for handling offshore, and 350 L/hr during passage), their variations differ significantly. As the plot shows, the fuel consumption distribution is much wider for the passage activity, which again is most likely contributable to the variations in weather conditions (and in turn speed) that affect the vessels travel at sea.

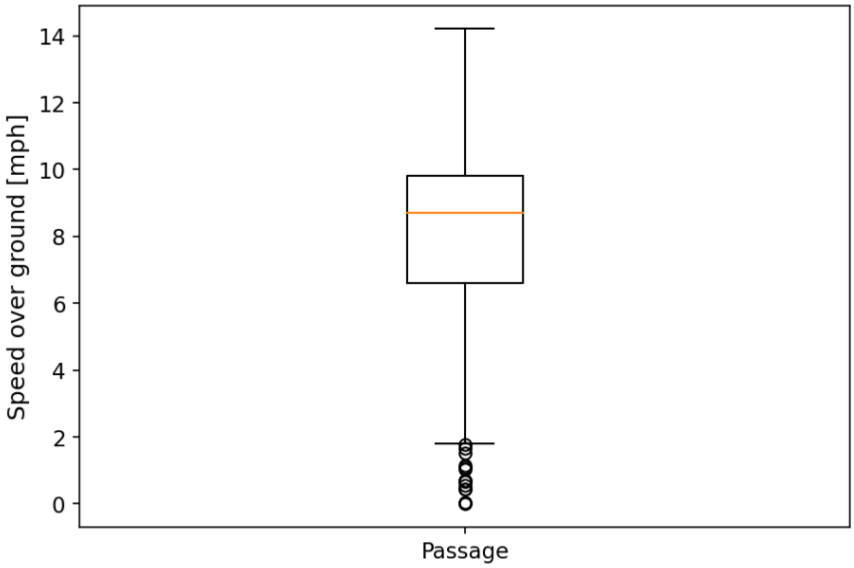

Figure 22 Box plot of the speed distribution of the platform supply vessels. Speed is measured as the absolute speed over ground

When simulating the long-term O&M campaigns using O&M planner, the speed and fuel consumption data will be used to calculate the costs and emissions associated with the O&M activities for the offshore platforms included in the modelled scenarios.

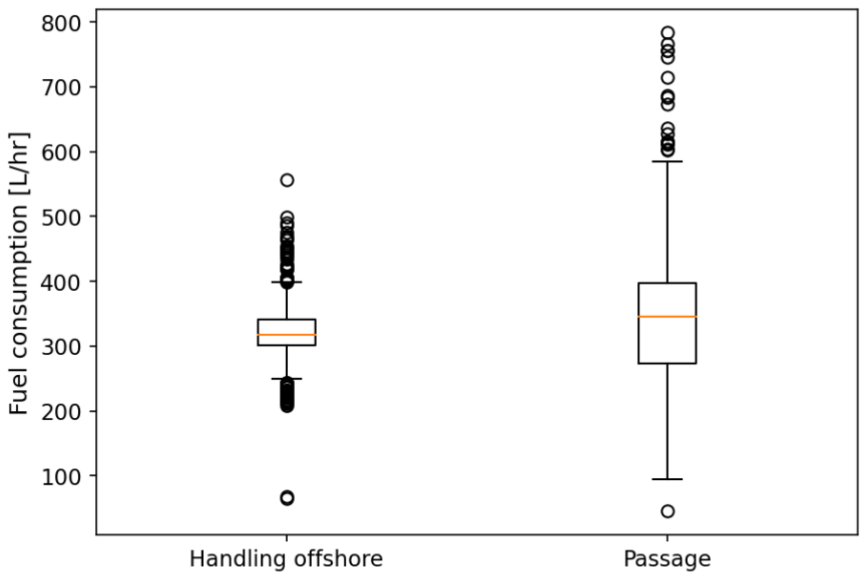

Figure 23 Box plots of the fuel consumption of the platform supply vessels for both the handling offshore and passage activities

6 Simulation results

This chapter discusses results of the simulations performed for each of the scenarios. For each scenario, the result of a baseline case, in which no logistics sharing takes place and O&M costs for wind farms and O&G platforms are calculated separately, is compared to a combined case, in which logistics sharing does take place for wind farm and O&G platforms. Platform supply vessel rates and fuel costs for the O&G scenarios were received from ONE Peterson, and are 8250 €/day and 534 €/L. For all scenarios, the offshore platforms within the region for which the most data was available were included in the simulations. Although specific port locations are modelled for the purposes of the simulations, the change in departure point from the shore for vessels will not have a large impact on the trends observed in the results, although the absolute numbers will change to a small degree. In practice, the departure points could be based factors such as the availability of vessels, infrastructure at port etc.

6.1 Hub West

The scenarios evaluated for Hub West included: a shore based scenario, in which all O&M activities were serviced from a port on the Dutch mainland, an SOV based scenario, where a large SOV ship was used in combination with smaller daughter crafts to service the wind farms and offshore platforms, and finally an island based scenario, in which a combination of SOV and daughter crafts were deployed from an artificial island further from the shore. For more details on the scenarios, the reader is referred to Section 4.4.

6.1.1 Shore based scenario

6.1.1.1 Simulation details

The shore based scenario of Hub West focusses on offshore structures located relatively close to the Dutch shore; specifically the region close to current offshore wind farm development activities in the Hollandse Kust region. The simulation includes the wind farm “Hollandse Kust Noord” (HKN), and a selection of six O&G platforms in the P and Q blocks of the Dutch North Sea. Figure 24 shows a map with the locations of all the structures considered.

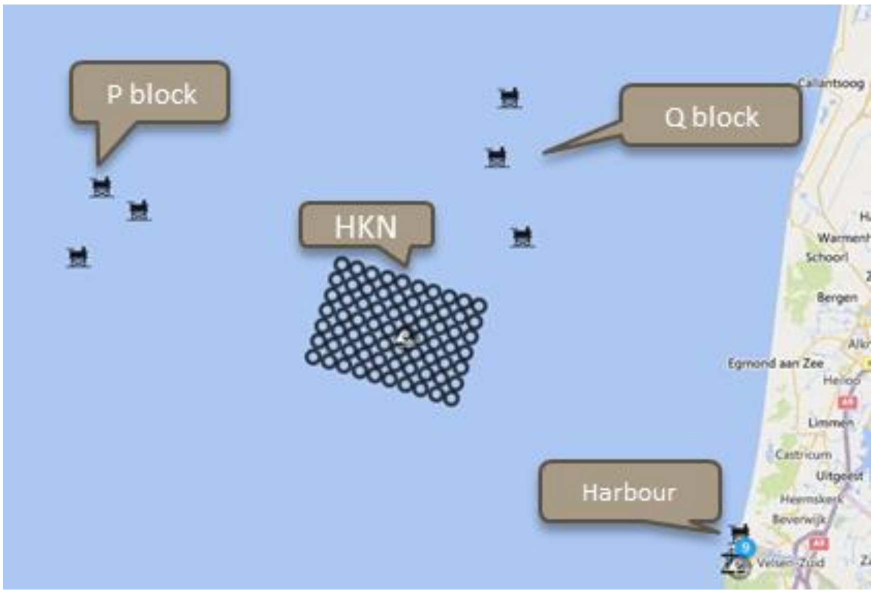

Figure 24 Locations of wind farm and offshore platforms modelled in the shore based scenario of Hub West

The six offshore platforms in the baseline case have a distance between 13 to 30 km from the centre of wind farm “Hollandse Kust Noord” (HKN) and each have a different number of events (from 60 to 190 events) per 5 years with an average visit duration of the vessels varying between 2.5 to 3.5 hours per visit. The frequency of the visits is dependent on several factors including the size of platform, complexity of the production and processes, ageing of the facilities, etc. The details of the assumptions can be found in Annex A.3, with the average number of events per platform per year as 21, and an average scheduling frequency for O&G platform tasks of 17 days. In total, three CTV’s were simulated to maintain the offshore wind farm for both the baseline and combined cases. The difference between baseline and combined cases is mentioned in Table. Three CTV’s were chosen based on the O&M requirements of the offshore wind farms and the idea behind this assumption was to check whether the available CTV’s for offshore wind farms will be sufficient to address the handling offshore activities of oil and gas platforms without a big impact on the availability.

6.1.1.2 Simulation outcomes

Table 16 shows a comparison of the main KPI’s between the baseline and combined cases of the shore based Hub West scenario. As mentioned, in the baseline case, costs of the wind farm O&M activities and those of the O&G platforms are calculated separately, while in the combined case they are calculated together.

The total OPEX cost in the baseline case (22.89 M€/yr.) is 1.9 M€/yr. higher than the total costs in the combined logistics case (20.99 M€). At the same time, the availability of the wind farm (the percentage of time for which the wind farm is fully operational) decreases by only a tenth of a percentage. Thus, in this case, by combining the activities of the wind and O&G platforms, 1.9 M€, around 8% of the total OPEX cost, can be saved per year without a large impact on the wind farm’s energy production.

On the other hand, looking at the total distance covered by the CTVs, a large increase (+33%) is seen for the combined case. This is due to the fact that in the combined case, a larger area has to be covered by the same number of vessels which were initially planned only for the offshore wind farms. For the same reason, the number of working days of vessels also increases, albeit to a lesser degree with 6.5%. However, this has decreased the number of wait days, which indicates that in the baseline case, the vessels are used less efficiently than in the combined case. However, the combined distance travelled by all vessels increases by only 5%, which would reflect in emission calculations.

A final impact seen in the combined case is the increase in average service time of the O&G activities, which has gone up from 1 day to 8 days, meaning that on average it takes up to 8 days before an offshore platform is serviced. Since the O&G activities considered are all related to the supply of non-critical material, the impact of the increased service time is considered minimal. Overall, the increased service time in the combined case should be compared against the additional PSV costs in the baseline case.

Table 16 Main O&M Planner simulation cost results for the shore based scenario of Hub West

Parameter	Baseline	Combined case (% change w.r.t baseline)
Description	3 CTVs perform wind farm activities; 1 PSV performs O&G activities	3 CTVs perform both wind farm and O&G activities; no PSV used
WF availability (%t, %y)	86.9; 86.6	86.8; 86.5
OPEX cost of CTVs (M€/yr.)	20.57	20.99
OPEX cost of PSV (M€/yr.)	2.32	N/A
Total OPEX costs (M€/yr.)	22.89	20.99 (-8%)
CTV (*3) distance (km/yr.)	33019	43928 (+33%)
PSV distance (km/yr.)	8820	0
Total distance (all vessels) (km/yr.)	41839	43928 (+5%)
CTV (*3) work days (per yr.)	570	607 (+6%)
CTV (*3) wait days (per yr.)	50	38
Average service time HO (days)	1	8

The distances travelled by the main access vessels and the component (plus personnel) weight onboard during trips are used to calculate the ton-km in the two cases. From the ton-km value, the emission of CO_2 and other gases is calculated from (Otten, 't Hoen, & den Boer, 2017) both tank-to-wheel (TTW) and well-to-wheel (WTW) emissions. Tank-to-wheel emissions consider only the emissions created by the vessel itself, while well-to-wheel emissions consider also the emissions created in the entire process of producing and transporting the fuel.

All results for default diesel fuel are listed in Table 17. In terms of TTW emissions, CO_2 emissions in the combined case (5.62 tonnes/yr.) are 1.78 tonnes lower than the baseline case (7.4 tonnes/yr.), while WTW emissions are reduced by around 2.22 tonnes. As the emission reductions between the baseline and combined case are solely due to a decrease in the distance travelled, the TTW and WTW cases both have a total CO_2 emission reduction of 24%. For the same reason, we see an equal 24% reduction of all other emissions (SO_2, $PM_{2.5}$ and PM_{10} particulates, and NO_x) when going from the baseline case to the combined case.

Table 17 Main emission results for the shore based scenario of Hub West

Parameter	Baseline		Combined case	
CTV (*3) distance (km/yr.)	33019		43928	
PSV distance (km/yr.)	8820		0	
	TTW	**WTW**	**TTW**	**WTW**
CO_2 equivalent emissions (tonnes/yr.)	7.40	9.25	5.62 (-24%)	7.03 (-24%)
SO_2 emissions (tonnes/yr.)	0.0046	0.0139	0.0035 (-24%)	0.0105 (-24%)
$PM_{2.5}$ and PM_{10} emissions (tonnes/yr.)	0.0033	0.0037	0.0025 (-24%)	0.0028 (-24%)
NO_x emissions (tonnes/yr.)	0.1535	0.157	0.1167 (-24%)	0.119 (-24%)

In addition, Table 18 gives the calculated emissions for four alternative fuels, including heavy fuel oil whose emissions have been (partially) offset using a scrubber (HFO + scrubber), liquified natural gas (LNG), electricity, and hydrogen. The table shows that TTW emissions for both electricity and hydrogen are zero and are therefore considered the best option for all types of emissions. However, the picture changes slightly when looking at the full WTW emissions. While hydrogen and electricity are both still the best option for CO_2 emissions, reducing them by a further 12% over the default fuel of diesel, only electricity scores the best when it comes to NO_x emissions (86% reduction). Perhaps surprisingly, when it comes to SO_2 and particulate emissions, LNG scores the best (although no data was available for SO_2 emissions of electricity and hydrogen). This is because WTW emissions for electricity are calculated based on the average Dutch energy mix, which includes both renewable and non-renewable sources, and therefore has relatively high particulate matter emissions associated with the still high fraction of fossil fuel energy production (Otten, 't Hoen, & den Boer, 2017). This is also the reason that the CO_2 emissions for electricity are still relatively high. If in the future, the energy mix changes to predominantly or 100% renewable, emissions for electricity (and hydrogen created from electricity) are expected to reduce even further, reaching values close to their TTW emissions. In short, by adopting a shared logistics approach and moving over to renewable fuels, total well-to-wheel CO_2 emissions could be reduced by up to a third (33%), the equivalent of around 3 tonnes per year. Because HFO is no longer permitted for DP operating vessels in the North Sea, future work can also consider alternative fuels such as Ultra-low-sulfur diesel (ULSD), hydrotreated vegetable oil (HVO), or ethanol.

Table 18 Emissions of alternative fuels for the combined case of the shore based scenario of Hub West

Parameter	Diesel		HFO + scrubber		LNG		Electricity*		Hydrogen*	
	TTW	WTW	TTW	WTW	TTW	WTW	TTW	WTW	TTW	WTW
CO_2 (tonnes/yr.)	5.62	7.03	5.84	6.74	5.45	6.82	0	6.19	0	6.19
SO_2 (tonnes/yr.)	0.0035	0.0105	0.002	0.0063	3.5E-5	0.0063	0	N/A**	0	N/A**
$PM_{2.5}$ and PM_{10} (tonnes/yr.)	0.0025	0.0028	0.0030	0.0033	0.00028	0.00037	0	0.00056	0	0.0022
NO_x (tonnes/yr.)	0.1167	0.119	0.140	0.142	0.0152	0.0179	0	0.0165	0	0.0221

* No emission data was available for electricity and hydrogen for sea shipping. These numbers have been adapted from the data for truck transport

** No data was available for SO2 emissions of electricity and hydrogen

6.1.1.3 Extrapolation over a larger area

The outcomes discussed above were estimated for a smaller section of the shore based scenario of Hub West, as highlighted by the yellow region in Figure 25. Additional wind farms and O&G platforms in the Hub West shore based scenario are indicated in the red region. The two additional wind farm zones in the red region are of a similar installed capacity and are proximal to a similar number of O&G platforms as in the simulated case. Their distances to shore are slightly higher than the simulated scenario, although they can still be serviced by CTVs from the shore. Given the linear increase in installed wind farm capacity and number of O&G platforms in the extrapolated red region compared to the simulated yellow region, a linear extrapolation could be made for the potential combined logistics and cost savings in the larger Hub West shore based scenario region.

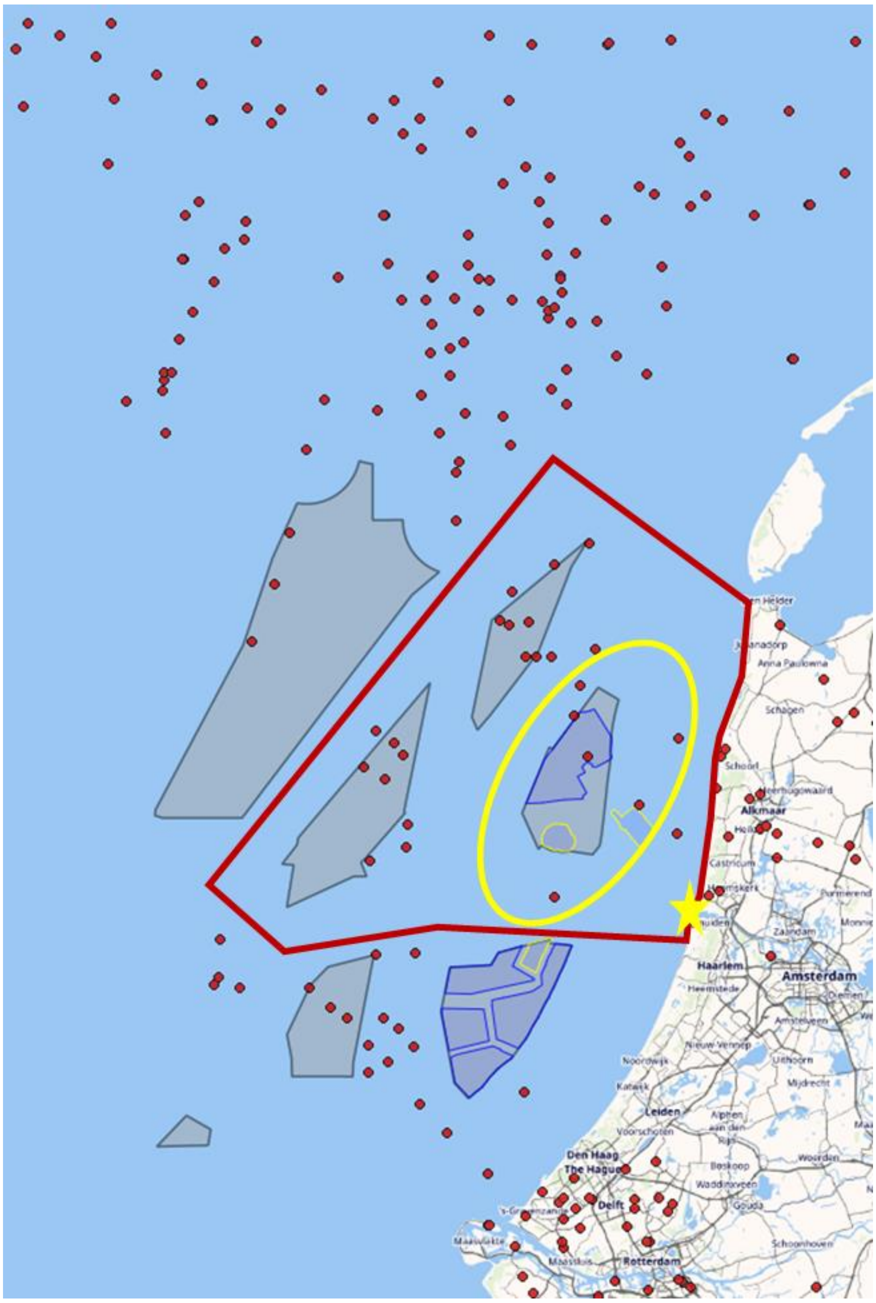

Figure 25 Locations of wind farm and offshore platforms modelled in the shore based scenario of Hub West

The additional wind farms and offshore platforms (Table 19), are roughly three times that of the modelled scenario, and are expected to required 9 CTVs for combined maintenance. The cost savings for the entire shore based region of Hub West are estimated to be roughly 5.7 M€/yr. and the potential (well-to-wheel) CO_2 emission savings to be around 6.7 tonnes/yr., which could increase to up to around 9.2 tonnes/yr. when switching to renewable fuels. The average service time in the extrapolated scenario is not expected to change from the modelled scenario of 8 days, since the number of vessels will scale according to the amount of additional work expected in the extrapolated scenario. However, since the potential OPEX savings are now three times that of the modelled scenario, adding an extra CTV to improve average service times for the extrapolated scenario can be a justified investment

Table 19 Extrapolated cost and CO_2 emission savings for the entire shore area of Hub West

Parameter	Modelled scenario	Extrapolated scenario
WFs included	Hollandse Kust Noord	Hollandse Kust Noord and West
OWF capacity	0.76 GW	2.25 GW
Number of O&G platforms	6	18
Number and type of vessels needed for combined OWF and O&G maintenance	3 CTVs	9 CTVs
Potential OPEX savings	1.9 M€/yr.	5.7 M€/yr.
Potential CO_2 emission savings (WTW)	2.22 tonnes/yr.	6.66 tonnes/yr.
Potential CO_2 savings renewable fuels (WTW)	3.06 tonnes/yr.	9.18 tonnes/yr.

6.1.1.4 Example of a daily plan

In the previous section, the cost and emission savings for shared logistics on a long-term was demonstrated. Further savings might be possible in the optimizing daily O&M plans. This section describes a particular day in the combined service of O&G platforms and O&M of wind farms (a winter day in February was selected) to show how much additional savings could be possible by optimizing the shared O&M daily schedules in the North Sea. Three activities are in the task order list at the start of the day.

- Perform maintenance on a failed turbine T59
- Perform activity handling offshore (HO) on a platform in Q block (Q4X)
- Perform activity handling offshore (HO) on a platform in P block (P4X)

Two CTVs leave from a designated port at the start of the day to perform the day's activities. One CTV caters to both handling offshore activities, whereas the second CTV provides access to technicians to the failed turbine T59. Table 20 describes the vessel's activities on this particular day.

Table 20 Details of simulation carried out on a single day with two CTVs

Vessel	Task	Start point	Destination	Start time	End time
CTV 1	Transit	Port	Q4X	2030-02-07T08:00:00	2030-02-07T09:42:05
	Activity HO	Q4X		2030-02-07T09:42:05	2030-02-07T11:17:11
	Transit	Q4X	P4X	2030-02-07T11:17:11	2030-02-07T12:16:18
	Activity HO	P4X		2030-02-07T12:16:18	2030-02-07T14:50:47
	Transit	P4X	Port	2030-02-07T14:50:47	2030-02-07T16:23:46
CTV2	Transfer techs	Port	CTV2	2030-02-07T08:00:00	2030-02-07T08:42:00
	Transit	Port	T59	2030-02-07T08:42:00	2030-02-07T09:42:35
	Transfer techs	CTV	T59	2030-02-07T09:42:35	2030-02-07T10:09:35
	Techs work	T59		2030-02-07T10:09:35	2030-02-07T14:54:27
	Transfer techs	T59	CTV	2030-02-07T14:54:27	2030-02-07T15:18:27
	Transit	T59	Port	2030-02-07T15:18:27	2030-02-07T16:19:12
	Transfer techs	Port		2030-02-07T16:19:12	2030-02-07T16:58:00

CTV 1 first transits from port to platform Q4X. After performing the activity 'handling offshore' for the required time, the vessel transits to platform P4X. After performing the activity 'handling offshore' for the required time, CTV1 sails back to port. CTV2 also starts its day with transferring technicians onboard and sailing to T59 for repair activity. The vessel transfers technicians onto the turbine and waits for work to be performed. Due to the shift end time of technicians, they get onboard the vessel in time for the transit back to port before their end of shift. The route followed from port to the platforms Q4X and P4X are in solid green lines and the route back to port is in solid yellow line, whereas the route to and from the T59 is in the dashed green and yellow lines in Figure 27. For this specific case, the model did not find an optimum schedule for the combined O&M between OWF and O&G platforms.

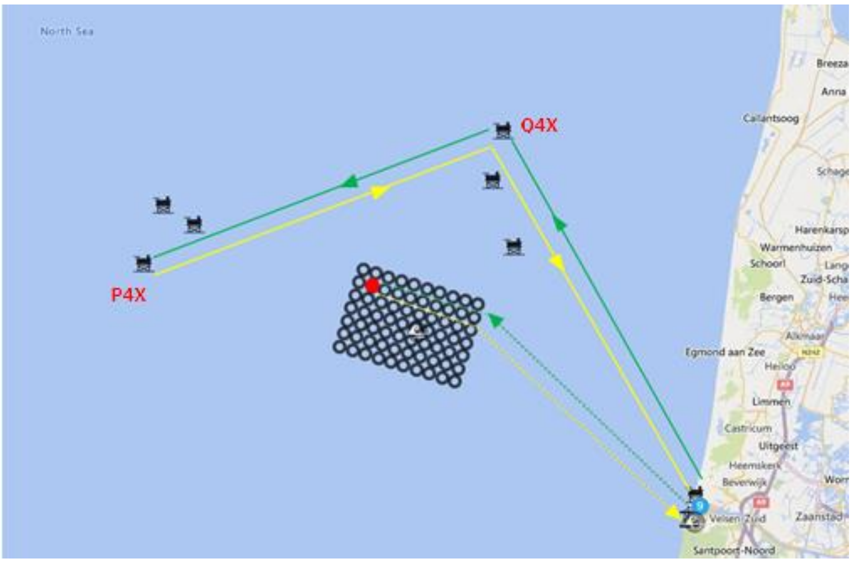

Figure 26 Route to and from port to platforms and wind turbine on a particular day in simulation

6.1.2 SOV based scenario

6.1.2.1 Simulation details

In the SOV based scenario of Hub West, offshore structures are considered to be located relatively far away from shore, focusing on the "Ijmuiden Ver" wind farm, and five O&G platforms in the P- and K-blocks of the North Sea. Again, platforms were selected based on the data availability. Figure 27 gives the locations of the offshore structures considered in the SOV based scenario of Hub West.

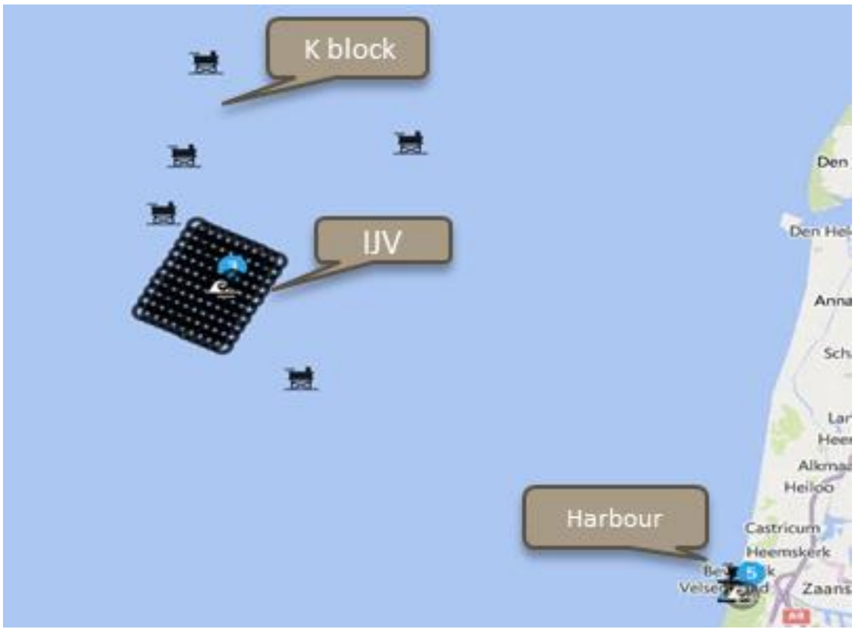

Figure 27 Locations of wind farm and offshore platforms modelled in the SOV based scenario of Hub West

The offshore platforms in this scenario are between 13 to 35 km from the centre of the offshore wind farm (IJV). The frequency of the maintenance action varies between 27 to 190 events per 5 years with an average duration of visits between 1.5 to 3.6 hours (much longer in K-block platforms). The details of the assumptions can be found in Annex A.3, with the average number of events per platform per year as 18, and an average scheduling frequency for O&G platform tasks of 20 days. For both the baseline and combined cases, a single SOV vessel with two smaller daughter craft were modelled in the simulations to perform the O&M activities.

6.1.2.2 Simulation outcomes

Table 21 give a comparison of main KPI's between the baseline and combined logistics cases for the SOV based scenario of Hub West.

The baseline logistics case has a higher total OPEX cost (40.23 M€/yr.) than the combined case (37.56 M€/yr.), leading to a profit of 2.67 M€/yr. At the same time, the overall wind turbine availability has also gone down. The profit margin is higher than in the shore based scenario because the distance to the platforms in the K-block is higher than for those in the P- and Q-block, especially for the PSV which travels from shore. In other words, the SOV and daughter crafts operating from the wind farm, are able in a more cost-effective way than a PSV, to perform visits to nearby O&G platforms, while there is a slight decrease in wind farm availability.

In addition, the difference in distance covered for SOV and two daughter crafts is considerably higher for the combined case. However, in the baseline case, the PSV travels long distances from shore to O&G platforms, which leads to a large annual distance, and when combined with the distances covered by SOV and daughter crafts, they exceed the distance travelled in the combined case by 33%. Moreover, both the workdays and wait days have both gone up in the combined scenario. The average service time for O&G visits also increased significantly to around 5 days but is lower than for the shore based scenario.

Table 21 Main O&M Planner simulation results for the SOV based scenario of Hub West, DC stands for Daughter craft

Parameter	Baseline	Combined (% change w.r.t baseline)
Description	1 SOV (and 2 dc's) perform wind farm activities; 1 PSV performs O&G activities	1 SOV (and 2 dc's) perform both wind farm and O&G activities; no PSV used
WT availability (%t, %y)	93.6; 93.3	92.8; 92.5
OPEX cost of SOV (plus 2DC) (M€/yr.)	37.55	37.56
OPEX cost of PSV (M€/yr.)	2.68	N/A
Total OPEX costs (M€/yr.)	40.23	37.56 (-7%)
SOV (plus 2DC) dist. (km/yr.)	9811	16520 (+68%)
PSV distance (km/yr.)	14720	0
Total distance (all vessels) (km/yr.)	24531	16520 (-33%)
SOV (plus 2DC) work days (per yr.)	707	762 (+8%)
SOV (plus 2DC) wait days (per yr.)	53	76
Average service time HO (days)	1	5

Table 22 lists the TTW and WTW emissions for the SOV based scenario of Hub West. Again, the reduction in emissions for both the TTW and WTW emissions going from the baseline to combined case are equal, at around 26% in this case. This corresponds to a CO_2 reduction of 3.13 tonnes/yr. for TTW, and 3.91 tonnes/yr. for WTW, which are higher than the emission savings in the shore based scenario.

As the emissions factors used for alternative fuels are the same for each scenario, the relative reductions are also the same. For this reason, the detailed number of emissions for alternative fuels have been left out here, and the reader is referred to Table 18.

Table 22 Main emission results for the SOV based scenario of Hub West

Parameter	Baseline		Combined case	
SOV distance (km/yr.)	9812		16520	
PSV distance (km/yr.)	14720		0	
	TTW	**WTW**	**TTW**	**WTW**
CO_2 equivalent emissions (tonnes/yr.)	11.97	14.96	8.84 (-26%)	11.052 (-26%)
SO_2 emissions (tonnes/yr.)	0.0074	0.0224	0.0055 (-26%)	0.0165 (-26%)
$PM_{2.5}$ and PM_{10} emissions (tonnes/yr.)	0.0053	0.0059	0.0040 (-26%)	0.0044 (-26%)
NO_x emissions (tonnes/yr.)	0.248	0.2543	0.183 (-26%)	0.1878 (-26%)

6.1.2.3 Extrapolation over a larger area

The outcomes discussed above were estimated for a smaller section of the Ijmuiden Ver wind farm, highlighted by the yellow region in Figure 28. From Figure 9 and Figure 10, the red region consists of additional wind farms IJV-n (2 GW) and 2-n (4 GW), amounting to 6 GW, which is three times that of the simulated scenario. However, there are approximately 40 O&G platforms in this extrapolated region, which is an eight-fold increase compared to the five O&G platforms in the simulated scenarios. Except the platforms which are on the edges of the entire Hub West SOV region, the remaining platforms have good proximity to the additional wind farms zones.

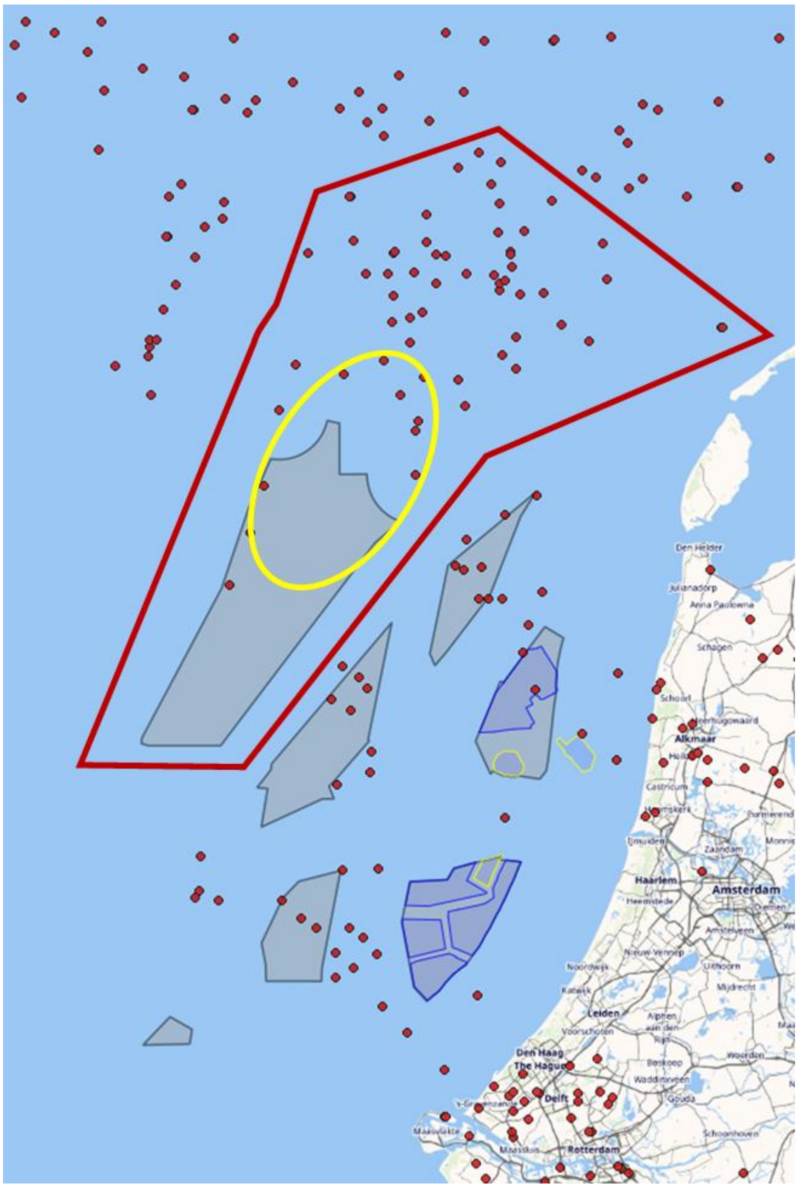

Figure 28 Locations of wind farm and offshore platforms modelled in the SOV based scenario of Hub West

Including the additional wind farms (Table 23) increases the installed capacity by four times in the extrapolated scenario as compared to the modelled scenario. The use of four times the number of vessels compared to the modelled scenario (4 SOVs and 8 daughter drafts), with each of the vessel sets maintaining around 5 O&G platforms will result in potential OPEX gains of 10.68 M€/yr. Having said that, in the extrapolated scenario, there is the possibility of increasing the number of O&G platforms per vessel set to beyond 5.

Assuming a similar number of handling offshore (HO) events across platforms, increasing the O&G platforms per vessel can reduced combined logistics costs even further, but this would also result in a further reduction wind farm availability and O&G platform service time. On the other hand, increasing the number of vessels in the extrapolated scenario will result in additional OPEX costs, but would help reduce platform service time and wind farm downtime. In practice, the latter option of increasing the number of vessels in the extrapolated scenario could be more beneficial as there could be other O&G platform activities besides handling offshore which can be combined with offshore wind O&M activities.

Also, looking at the emission numbers, a significant impact can be seen, with an absolute reduction of CO_2 emissions of up to 15.54 tonnes/yr. using the same fuel as currently in use, with the potential to save 17.52 tonnes/yr. when switching to renewable fuels.

Table 23 Extrapolated cost and CO_2 emission savings for the entire far-shore area of Hub West

Parameter	Modelled scenario	Extrapolated scenario
WFs included	IJV (partial)	IJV (full); IJV-n. 2n
OWF capacity	2 GW	8 GW
Number of O&G platforms	5	35 to 40
Number and type of vessels needed for combined OWF and O&G maintenance	1 SOV + 2 daughter crafts	4 SOV + 8 daughter crafts
Potential OPEX gains	2.67 M€/yr.	10.68 M€/yr.
Potential CO_2 emission savings (WTW)	3.91 tonnes/yr.	15.54 tonnes/yr.
Potential CO_2 savings renewable fuels (WTW)	4.37 tonnes/yr.	17.52 tonnes/yr.

6.1.2.4 Example of a daily plan

This section describes a particular day in the combined service of O&G platforms and O&M of wind farms. The day described is a simulation output for 17th of June in the year 2030. Three activities are in the task order list at the start of the day

- Perform maintenance on a failed turbine T4
- Perform maintenance on a failed turbine T3
- Perform activity handling offshore (HO) on platform P6X

A daughter craft leaves from the offshore base at the centre of the wind farm at the start of the day to drop technicians off on the two turbines, perform the activity needed at the platform and return to port before the shift end time of the offshore technicians.
Table 24 describes the vessel's activities on this particular day.

Table 24 Details of simulation carried out on a single day with a daughter draft

Task	Start point	Destination	Start time	End time
Pickup tech team1, tech team2	Base	daughter craft (dc)	2030-06-17T08:00:00	2030-06-17T08:51:00
Transit dc	Base	T4	2030-06-17T08:51:00	2030-06-17T09:17:50
Drop tech team 1	dc	T4	2030-06-17T09:17:50	2030-06-17T09:41:50
Transit dc	T4	T3	2030-06-17T09:41:50	2030-06-17T09:45:53
Drop tech team 2	dc	T3	2030-06-17T09:45:53	2030-06-17T10:09:53
Transit dc	T3	P6X	2030-06-17T10:09:53	2030-06-17T10:54:00
Perform HO activity	P6X		2030-06-17T10:54:00	2030-06-17T14:20:59
Transit dc	P6X	T3	2030-06-17T14:20:59	2030-06-17T15:05:06
Pickup tech team 2	T3	dc	2030-06-17T15:05:06	2030-06-17T15:29:06
Transit dc	T3	T4	2030-06-17T15:29:06	2030-06-17T15:33:09
Pickup tech team 1	T4	dc	2030-06-17T15:33:09	2030-06-17T15:57:09
Transit dc	T4	Base	2030-06-17T15:57:09	2030-06-17T16:24:00
Drop tech teams 1,2	Base		2030-06-17T16:24:00	2030-06-17T17:15:00

The daughter craft first transits from the offshore base to turbine T4. After dropping off technician team 1 at the turbine T4, the vessel transits to turbine T3. After dropping off technician team 2 at turbine T3, the vessel transits to the platform P6X to perform activity 'handling offshore'. Finally, the vessel travels to and picks up the technician teams in reverse, i.e., team 2 is picked up from turbine T3 following which the vessel transits to T4 and picks up team 1. The route followed from base to platform P6X is in green and the route back to base is in yellow in Figure 29. Compared to the example in section 6.1.1.4, in this case, the model finds an optimum schedule for the combined O&M between OWF and O&G platforms.

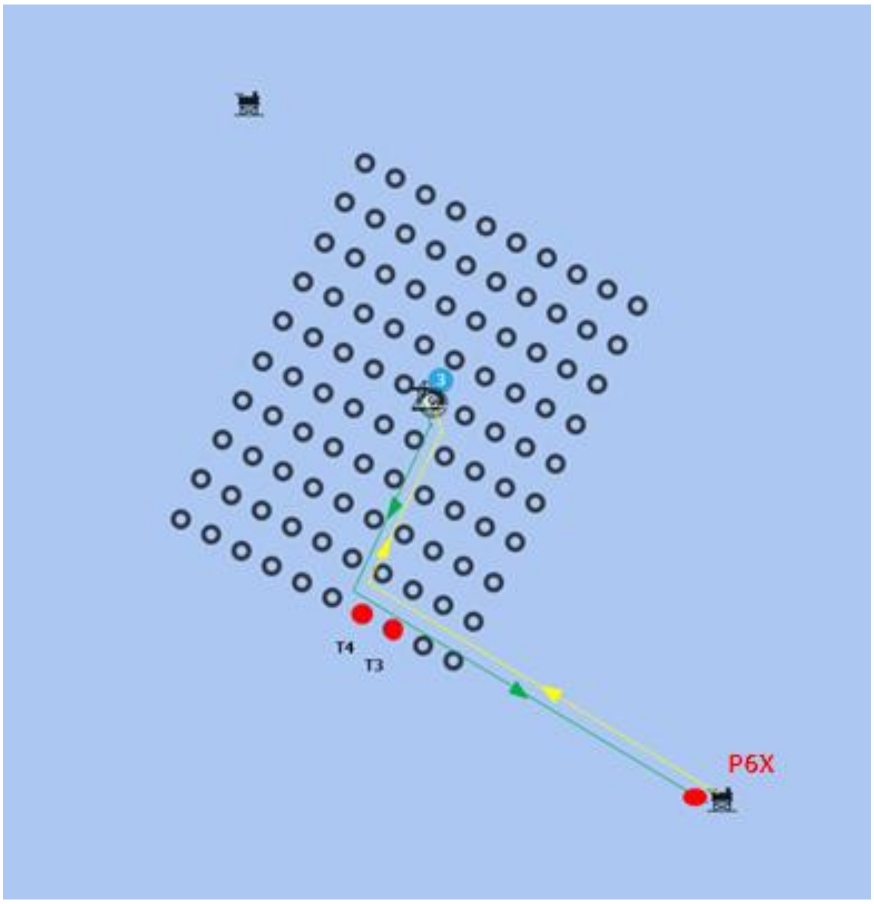

Figure 29 Route to and from the offshore base (middle of wind farm) to platform P6X on a particular day during the simulation

6.1.3 Island based scenario

6.1.3.1 Simulation details

In the island based scenario of Hub West, offshore structures located very far away from shore in the wind farm zone (search area 3 with 2 GW installed capacity) are considered (see Figure 9 and Figure 10), and five O&G platforms in the eastern part of K-block of the North Sea. Again, platforms were selected based on data availability, and their proximity to the example wind farm and island. Figure 30 gives the locations of the offshore structures considered in the island based scenario of Hub West. The information on the frequency and duration of visits to platforms can be found in Annex A.3, with the average number of events per platform per year as 25, and an average scheduling frequency for O&G platform tasks of 14 days. The offshore island is modelled at a distance of 20 km south west from the wind farm centre near the K-block of platforms.

For both the baseline and combined cases, a single SOV vessel with two smaller daughter craft, is stationed in the wind farm, were modelled in the simulations to perform the O&M activities. For the baseline case, a PSV is modelled either from the onshore port or from the island to perform O&G activities.

Figure 30 Locations of wind farm and offshore platforms modelled in the island based scenario of Hub West (right shows a zoomed in image)

6.1.3.2 Simulation outcomes

Table 25 shows a comparison of the main simulation KPI's between the baseline and combined logistics cases for the island based scenario of Hub West.

The combined case with an OPEX cost of 30.2 M€/yr. saves a significant 4.2 M€/yr. which is around 12% compared to the baseline (34.4 M€/yr.). This is around 50% more than for the SOV based scenario and is done with a similar reduction in wind turbine availability. This shows how an offshore island with port could save considerable costs when compared to the SOV based scenario that did not include a base of operations on an artificial island. The main reason for higher savings is the long distances from port required by the PSV to travel to the far away O&G platforms. When the PSV is stationed at the offshore island rather than at the onshore port, the total OPEX cost in the baseline case reduces to 32.0 M€/yr., thus resulting in an annual saving of 1.8 M€/yr. or around 6%, which is comparable to savings in the SOV based scenario.

Compared to the previous scenarios, the total distance covered by the SOV and daughter crafts has practically doubled in the combined case. This is an increase compared to the SOV based scenario, and the likely reason for this increase is because the number of visits to the platforms in the K4, K2 and K5 blocks in this scenario are higher than for those K14, K17 and K18 blocks in the previous scenario. However, in the baseline case, the PSV travels very long distances from port on the shore to O&G platforms, which leads to a large annual distance, and when combined with the distances covered by SOV and daughter crafts, they far exceed the distance travelled in the combined case. Similarly, as in the shore based scenario, the total working days have increased, indicating that the vessels are used more efficiently. Finally, the average O&G service time also increases from 1 to 6 days.

Table 25 Main O&M Planner simulation results for the island based scenario of Hub West

Parameter	Baseline	Combined
Description	1 SOV (+ 2 dc's) perform wind farm activities; 1 PSV (either from island or onshore port) performs O&G activities	1 SOV (+ 2 dc's) perform wind farm activities; no PSV is used
WT availability (%t, %y)	93.4,93.1	92.6,92.3
OPEX cost of SOV (plus DCs) (M€/yr.)	29.8	30.2
OPEX cost of PSV (stationed at onshore port) (M€/yr.)	4.6	N/A
Total OPEX costs (PSV at onshore port) (M€/yr.)	34.4	30.2 (-12%)
OPEX cost of PSV (stationed at island) costs (M€/yr.)	2.20	N/A
Total OPEX costs (PSV at island) (M€/yr.)	32.0	30.2 (-6%)
SOV (plus 2DC) dist. (km/yr.)	10189	18458 (+81%)
PSV distance (PSV at onshore port) (km/yr.)	55000	0
PSV distance (PSV at island) (km/yr.)	5000	0
SOV (plus 2DC) workdays (per yr.)	702	780 (+11%)
SOV (plus 2DC) wait days (per yr.)	60	78
Average service time HO (days)	1	6

Table 26 lists the TTW and WTW emissions for the island based scenario of Hub West, when the PSV is stationed at the onshore port. Table 27 assumes that the PSV is stationed at the island. When the PSV is stationed at the onshore port, CO_2 emissions in the combined case are significantly lower than for the baseline case, roughly 14.2 tonnes/yr. for the TTW numbers, and 17.7 tonnes/yr. for the WTW emissions. This amounts to a total emission reduction of 53% when going from the baseline to the combined logistics case, which is significantly higher than for the previous scenarios, and is due to the long distances covered by the PSV in the baseline case from onshore ports to the O&G platforms, which are much further away from the shore than in the previous scenarios

Table 26 Main emission results for the island based scenario of Hub West (PSV stationed at onshore port)

Parameter	Baseline		Combined case	
SOV distance (km/yr.)	10189		18458	
PSV distance (PSV at onshore port) (km/yr.)	55000		0	
	TTW	**WTW**	**TTW**	**WTW**
CO_2 equivalent emissions (tonnes/yr.)	26.72	33.41	12.55 (-53%)	15.68 (-53%)
SO_2 emissions (tonnes/yr.)	0.0167	0.0501	0.0078 (-53%)	0.0235 (-53%)
$PM_{2.5}$ and PM_{10} emissions (tonnes/yr.)	0.0120	0.0133	0.0056 (-53%)	0.0062 (-53%)
NO_x emissions (tonnes/yr.)	0.55	0.568	0.26 (-53%)	0.266 (-53%)

Alternatively, when the PSV is stationed at the island, the TTW and WTW emissions increase in the combined case. This is expected, as the combined SOV (with daughter craft) and PSV distance in the baseline is lower than the SOV (with daughter craft) distance in the combined case. An increase of 44%

is seen in both TTW and WTW emissions in the combined case. Again, detailed emissions numbers for alternative fuels have been left out, and the reader is referred to Table 18.

Table 27 Main emission results for the island based scenario of Hub West (PSV stationed at island)

Parameter	Baseline		Combined case	
SOV distance (km/yr.)	10189		18458	
PSV distance (PSV at onshore port) (km/yr.)	5000		0	
	TTW	**WTW**	**TTW**	**WTW**
CO_2 equivalent emissions (tonnes/yr.)	8.72	10.91	12.55 (+44%)	15.68 (+44%)
SO_2 emissions (tonnes/yr.)	0.0054	0.0163	0.0078 (+44%)	0.0235 (+44%)
$PM_{2.5}$ and PM_{10} emissions (tonnes/yr.)	0.0039	0.0043	0.0056 (+44%)	0.0062 (+44%)
NO_x emissions (tonnes/yr.)	0.1811	0.1854	0.26 (+44%)	0.266 (+44%)

6.1.3.3 Extrapolation over a larger area

The outcomes discussed above were estimated for a smaller section of the Hub West region, highlighted by the yellow region in Figure 31. From Figure 9 and Figure 10, the yellow region consists of the wind farm zone 3, which with a capacity of 2 GW and five O&G platforms. The yellow star in Figure 31 represents the island location, and there are five O&G platforms in the modelled scenario. In the extrapolated region, shown by the red area, an additional 4GW wind farm (wind farm 1-n) is expected to the south of wind farm zone 3, with around fifteen O&G platforms, which is a linear increase compared to the increase in wind farm capacity. The area under the green region depicts many O&G platforms, which are all far away from the wind farm sites, and are therefore excluded from the extrapolated scenario.

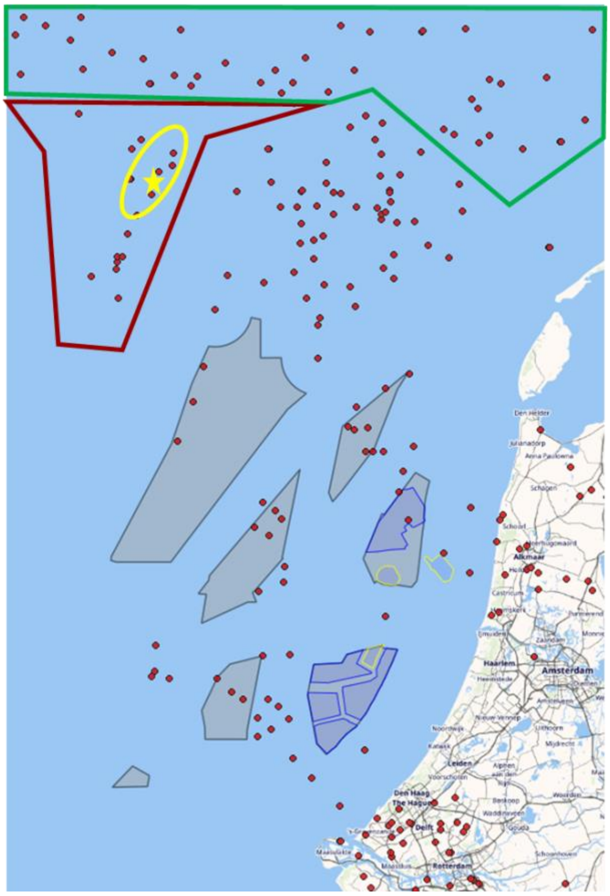

Figure 31 Locations of wind farm and offshore platforms modelled in the island based scenario of Hub West (the island is indicated by the yellow star)

Wind farm 1-n is planned in the Hub West island region in addition to wind farm zone 3. The installed capacity of wind farm 1-n is 4 GW, and there is a total of 6 GW of offshore wind farms in this region to be maintained. If the OPEX differences are extrapolated to the larger Hub West area, the total profits will increase to around between 5.4 M€/yr. and 12.6 M€/yr. depending on whether the PSV is stationed at the onshore port or island.

Table 28 Extrapolated cost savings for the entire island area of Hub West

Parameter	Modelled scenario	Extrapolated scenario
WFs included	Wind farm zone 3	Wind farm zone 3 (2GW) , wind farm 1-n (4 GW)
OWF capacity	2 GW	6 GW
Number of O&G platforms	5	12-15
Number and types of vessels needed for combined OWF and O&G maintenance	1 SOV + 2 daughter crafts	3 SOV + 6 daughter crafts
Potential OPEX gains (PSV at onshore port)	4.2 M€/yr.	12.6 M€/yr.
Potential OPEX gains (PSV at island)	1.8 M€/yr.	5.4 M€/yr.
Potential CO_2 emission savings (WTW) (PSV at island, PSV at onshore port)	(-) 4.8 tonnes/yr., 17.7 tonnes/yr.	9-) 14.4 tonnes/yr., 53.10 tonnes/yr.
Potential CO_2 savings renewable fuels (WTW) (PSV at island, PSV at onshore port)	(-) 4.2 tonnes/yr., 19.57 tonnes/yr.	(-) 12.6 tonnes/yr., 58.72 tonnes/yr.

6.2 Hub East

The scenarios evaluated in Hub East were similar in nature to those of Hub West. However, since the offshore structures in Hub East are further from shore than in Hub West, no shore based scenario was considered. In addition, the island based scenario of Hub East focused more on the use of CTVs instead of SOVs to service the offshore structures. For more details on the scenarios of Hub East, the reader is referred to Section 4.5.

6.2.1 SOV based scenario

6.2.1.1 Simulation details

In the SOV based scenario of Hub East, the offshore structures are chosen farther away from shore. The simulated wind farm is zone 5-Oost (2 GW), and the platforms chosen are close by, in the G-block of the North Sea. Platforms were chosen when information was available for them, and are shown in Figure 32.

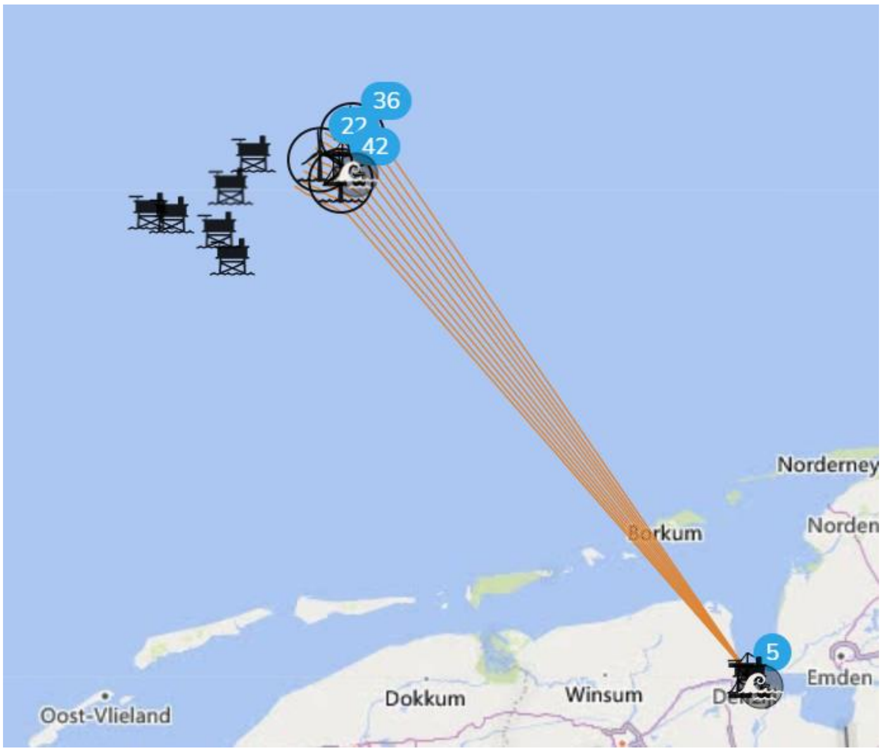

Figure 32: Locations of wind farm and offshore platforms modelled in the SOV based scenario of Hub East

The offshore platforms in this scenario are between 17 and 37 km from the centre of wind farm zone 5-oost, with a maintenance frequency of between 150 and 470 actions per year, which is significantly higher than the corresponding SOV based simulation for Hub West. The average duration of the visits is between 1.3 – 2 hours. Full details can be found in Annex A.3, with the average number of events per platform per year as 54, and an average scheduling frequency for O&G platform tasks of 17 days. For both simulations, an SOV with 3 smaller daughter crafts was chosen, so account for the increased number of O&G platform maintenance actions required.

6.2.1.2 Simulation outcomes

Table 29 gives the main simulation outcomes of the SOV based scenario of Hub East. Unlike in the SOV based scenario of Hub West, the combined logistics approach of Hub East scenario does lead to quite high cost savings, around 6.85 M€/yr. Moreover, the wind turbine availability decreases only slightly, implying that the use of vessels to service O&G platforms were properly planned, in the combined case, such that wind farm maintenance tasks are not significantly delayed.

The combined travel distance of all vessels in the combined case is about 35% lower than in the baseline case, which stem from the high PSV distances. This is a larger effect than was found for Hub West, largely due to the higher number of visits to O&G platforms required by the PSV in this scenario. The increase of total working days by roughly 20%, combined with the decrease in total waiting days, shows once more that the vessels in the combined scenario are used more efficiently than when they are used just for wind farm maintenance, as the number of vessels remains constant.

Finally, the average service time for the O&G activities increased slightly by around 2 days. Thus, while OPEX has decreased, this comes at the cost of longer service time (days until a platform is supplied).

Table 29 Main O&M Planner simulation results for the SOV based scenario of Hub East

Parameter	Baseline	Combined
Description	1 SOV (and 3 dc's) perform wind farm activities; 1 PSV performs O&G activities	1 SOV (and 3 dc's) perform both wind farm and O&G activities; no PSV used
WT availability (%t, %y)	93.7; 93.5	93.06; 92.67
OPEX cost of SOV (+DCs) (M€/yr.)	38.0	39.75
OPEX cost of PSV (M€/yr.)	8.6	N/A
Total OPEX costs (M€/yr.)	46.6	39.75 (-15%)
SOV (plus 3DC) dist. (km/yr.)	10095	25601
PSV distance (km/yr.)	63430	0
SOV (plus 3DC) work days (per yr.)	724	892
SOV (plus 3DC) wait days (per yr.)	112	110
Average service time HO (days)	1	2

Table 30 shows the emission savings due to the difference in ton-km for the two cases, for both TTW and WTW situations. The reduction in emissions for both cases is 41%, which is a reduction of 12.29 and 15.36 tonnes/yr. of CO_2, respectively. This is much higher than in the corresponding SOV simulation for Hub West, in large part due to the difference in number of maintenance actions required for the platforms. Once again, the detailed number of emissions for alternative fuels have been left out here, and the reader is referred to Table 18.

Table 30 Main emission results for the SOV based scenario of Hub East

Parameter	Baseline		Combined case	
SOV (plus 3DC) dist. (km/yr.)	10095		25601	
PSV distance (km/yr.)	63430		0	
	TTW	**WTW**	**TTW**	**WTW**
CO_2 equivalent emissions (tonnes/yr.)	29.70	37.12	17.41	21.76
SO_2 emissions (tonnes/yr.)	0.0186	0.0557	0.0109	0.0326
$PM_{2.5}$ and PM_{10} emissions (tonnes/yr.)	0.0134	0.0148	0.0078	0.0087
NO_x emissions (tonnes/yr.)	0.6163	0.6311	0.3612	0.3699

In contrast to scenarios simulated in Hub West, an extrapolation to the entirety of Hub East was considered unnecessary due to the quantity and location of remaining platforms. Apart from the platforms from the G-block studied in this simulation, there is also one platform in the NW corner of Hub West, as well as several platforms surrounding the eastern part of Ameland, as in Figure 33. The former of these is unlikely to create a large marginal difference in cost savings, and the latter platforms are close enough to shore for a PSV stationed at port to effectively service it. It was deemed unlikely that the benefit of logistic sharing with an SOV stationed at the offshore wind farm location would outweigh the distance that daughter crafts would need to travel to reach those platforms, especially considering the small distances a port based PSV would need to travel. Therefore, a linear extrapolation of the higher total wind farm capacity of Hub East to OPEX cost savings was not deemed necessary.

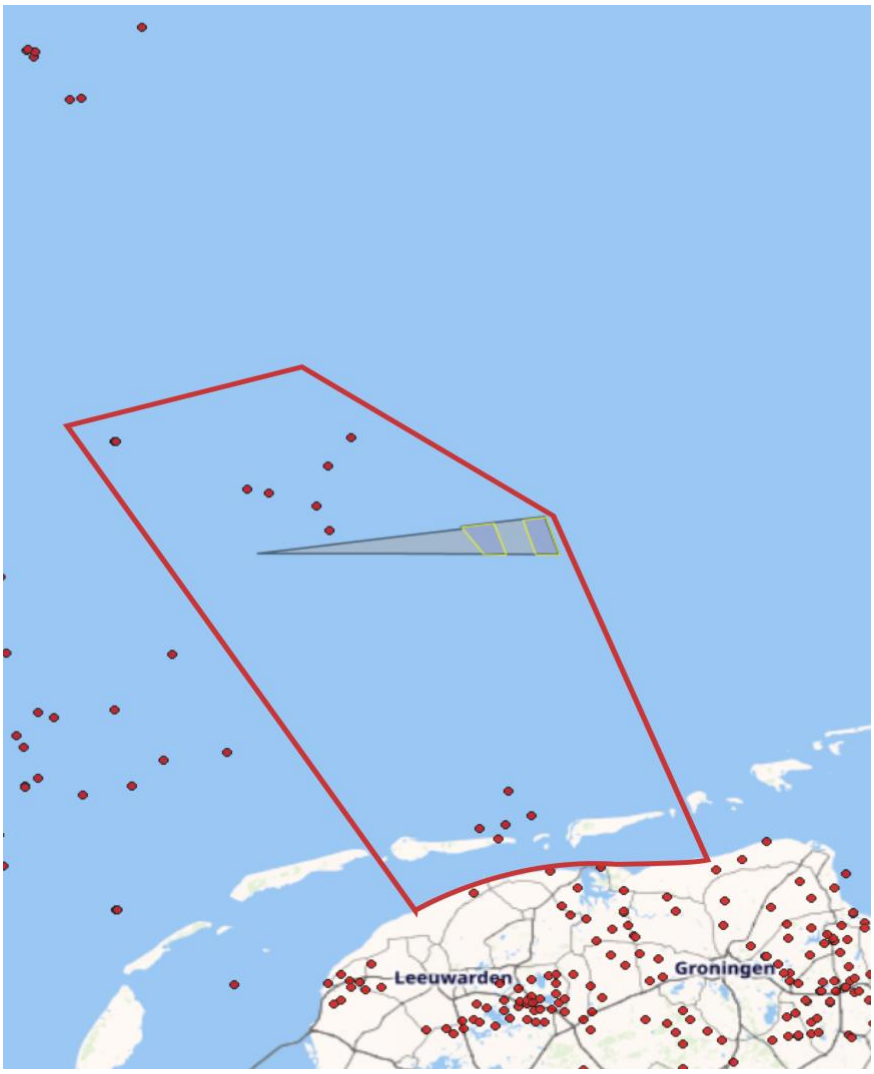

Figure 33: Platform locations in Hub West

6.2.2 Island based scenario

6.2.2.1 Simulation details

Due to the total number of platforms, especially those with maintenance information, being much smaller than in Hub West, the details are the same as in the SOV based simulation, i.e. the wind farm capacity is 2 GW and the same platforms are chosen. Thus, the information in Table 41 is the same as in Table 40, with the difference of the vessels used in the simulation, so the average number of events per platform per year is 54, and an average scheduling frequency for O&G platform tasks is 17 days In contrast to the SOV based scenario, 5 CTVs were used for both the baseline and combined cases. These were stationed at an island located 14 km from the centre of the wind farm. For the baseline case, results were calculated with the PSV stationed at both the port, and at the island itself, giving a range of results and subsequent cost/emission savings depending on the situation.

Figure 34: Locations of wind farm and offshore platforms modelled in the island based scenario of Hub East

6.2.2.2 Simulation outcomes

Table 31 gives the main simulation outcomes of the island based scenario of Hub East. The savings of 6.3- 9.4 M€/yr. (depending on if the PSV is stationed at port or at the island, respectively) are even higher than with Hub West, also due to the platforms requiring more visits, thus requiring more use of the PSV. Similar to the SOV based scenario, wind farm availability decreases only slightly when combining O&G efforts, implying again a more efficient use of non-working vessel time.

The combined travel distance of all vessels in the combined case is between 7 and 50% lower than in the baseline case, the latter of which stems from high PSV distances when stationed at the port. This is a larger effect than was found for Hub West, mainly due to the higher number of visits to O&G platforms required by the PSV in this scenario.

The increase of total working days by roughly 8%, combined with the decrease in total waiting days, shows once more that the vessels in the combined scenario are used more efficiently than when they are used just for wind farm maintenance, as the number of vessels remains constant.

Finally, the average service time for the O&G activities increased slightly until 5 days. Thus, while OPEX has decreased, this again comes at the cost of longer service time (days until a platform is supplied).

Table 31 Main O&M Planner simulation results for the island based scenario of Hub East

Parameter	Baseline	Combined
Description	5 CTVs perform wind farm activities; 1 PSV (either from island or onshore port) performs O&G activities	5 CTVs perform wind farm activities; no PSV is used
WT availability (%t, %y)	87.7; 86.8	87.6; 86.6
OPEX cost of CTV (*5) (M€/yr.)	51.7	50.9
OPEX cost of PSV (M€/yr.)	5.5-8.6	N/A
Total OPEX costs (M€/yr.)	57.2-60.3	50.9 (-11 to -16%)
CTV (*5) dist. (km/yr.)	19466	26720
PSV distance (km/yr.)	17734-63430	0
CTV (*5) work days (per yr.)	674	730
CTV (*5) wait days (per yr.)	212	214
Average service time HO (days)	1	5

Table 32 shows the emission savings due to the difference in ton-km for the two cases, for both TTW and WTW situations. Depending on where the PSV travels from in the baseline case, the emission reductions could be anywhere between 7% and 50%. This is comparable to the island based Hub West scenario because of the similarity of large PSV travel distances, but also to the SOV based scenario because of the high number of platform maintenance actions. Once again, the detailed number of emissions for alternative fuels have been left out here, and the reader is referred to Table 18.

Table 32 Main emission results for the island based scenario of Hub East

Parameter	Baseline		Combined case	
CTV (*5) dist. (km/yr.)	19466		26720	
PSV distance (km/yr.)	17734-63430		0	
	TTW	**WTW**	**TTW**	**WTW**
CO_2 equivalent emissions (tonnes/yr.)	19.62-36.07	24.53-45.09	18.17	22.71
SO_2 emissions (tonnes/yr.)	0.0123-0.0225	0.0368-0.0676	0.0114	0.0341
$PM_{2.5}$ and PM_{10} emissions (tonnes/yr.)	0.0088-0.0162	0.0098-0.0180	0.0082	0.0091
NO_x emissions (tonnes/yr.)	0.4071-0.7485	0.4170-0.7665	0.3770	0.3861

Similar to the SOV based scenario, the quantity and location of remaining platforms is too low to expect a linear extrapolation to be meaningful. The remaining platforms close to the eastern part of Ameland are close enough for a PSV stationed at the port to service, and any CTVs stationed at the island would need to travel a much larger distance south to perform the same service, potentially negating any positive effect of logistic sharing. Thus, any linear extrapolation for the entire capacity of Hub East was deemed unlikely to be accurate.

6.3 Summary of Hub West and Hub East results

Overall, five scenarios were modelled and analysed in sections 6.1 and 6.2 above. Hub West included a shore based scenario (with CTVs), SOV based scenario and island based scenario. Hub East included an SOV based scenario and an island based scenario. Table 33 highlights the comparison of results between the five scenarios, and shows that the potential OPEX savings and emission reductions are higher for Hub East in the simulated scenarios. This is primarily driven by the number of activities per O&G platform per year, since the wind farm installed capacity is kept the same. Within Hub West, the cost and emission savings are higher when the offshore structures are far from shore and need an SOV for combined maintenance. This is due to the fact that the savings result from the absence of a PSV specifically for O&G platform activities.

Table 33 Comparison of main KPIs from simulated scenarios

Hub	Hub West		Hub East		
Description	Shore based scenario	SOV based scenario	Island based scenario	SOV based scenario	Island based scenario
WFs included	Hollandse Kust Noord	IJV (partial)	WF zone 3	5-oost	Search area 5
OWF capacity	0.76 GW	2 GW	2 GW	2 GW	2 GW
O&G platforms (number of)	6	5	5	6	6
Avg. number of O&G platform activities	21 events per platform per year	18 events per platform per year	25 events per platform per year	55 events per platform per year	55 events per platform per year
Number & type of vessels for combined OWF and O&G maintenance	3 CTVs	1 SOV (+ 2DCs)	1 SOV (+ 2DCs)	1 SOV (+ 3DCs)	5 CTVs
Avg. service time of O&G platforms	8 days	5 days	6 days	2 days	5 days
Potential OPEX savings (simulated)	1.9 M€/yr. (8%)	2.67 M€/yr. (7%)	1.8-4.2 M€/yr. (6-12%)	6.85 M€/yr. (15%)	6.3-9.4 M€/yr. (11-16%)
Potential CO2 emission savings	2.22 tonnes/yr.	4.37 tonnes/yr.	19.57 tonnes/yr.	15.36 tonnes/yr.	22.38 tonnes/yr.

Table 35 shows the overall cost and emission savings for hub west and hub east from the extrapolated scenarios mentioned in sections 6.1 and 6.2. The extrapolated scenarios cover most of the proposed offshore wind farm development regions and oil and gas platforms over the North Sea region. The cost savings potential for the entire Hub West region is estimated to be 21.7 to 28.9 M€/yr. and the equivalent number for the region Hub East region is estimated to be 13.2 to 16.3 M€/yr. The emission savings have a much more uncertain range, and this is due to the PSV stationing location (onshore port or island) in the island-based scenarios.

Table 34 Cost savings for Hub West and Hub East over the entire (extrapolated) regions

Hub	Number of scenarios	Cost savings	Emission savings
Hub West	3 (shore based, SOV based, island based)	21.7-28.9 M€/yr.	7.8-75.3 tonnes/yr.
Hub East	2 (SOV based, island based)	13.2-16.3 M€/yr.	17.2-37.6 tonnes/yr.

7 The future of shared offshore logistics

7.1 Hub North

In contrast to the analysis of cost savings in Hub West and Hub East, which were conducted through the use of simulating scenarios with and without logistics sharing, scenarios in Hub North will be qualitatively described and discussed. There is currently no wind farm capacity in Hub North, with 10GW planned between 2030 and 2040. This timeline suggests greater uncertainty compared with Hubs West and East, given that logistical strategies will change significantly by then. Any simulation results for Hub North will likely be outdated by the time these strategies come into play. However, it is important to note that based on the outcome of the scenarios for hub west and east, since the cost and emission savings were larger where the distance of the platforms from the shore was increased, by only considering the distance to shore it is expected that shared logistics concepts for hub North is a must and will lead to a significant cost and emission reduction.

A lot of these strategy changes are due to already existing trends in offshore maintenance. For example individual wind turbine capacities are becoming increasingly large to exploit the savings in reduced vessel trip numbers. However, with increasing wind turbine capacities, the resource loss due to turbine downtime becomes increasingly high and it becomes more important to have a vessel close by to perform necessary corrective maintenance. Current logistic strategies for Service Operation Vessels (SOVs) include periodic return trips to shore to restock parts, transfer technician crews, and refuel. For SOVs based in Hub North, where wind farms are farther from shore (> 100 km), these trips will take longer, compounding the potential resource loss of turbine downtime.

A strategy wherein the SOV is permanently stationed at the offshore wind farm location can be envisioned as a solution to the above problem. Ensuring the constant supply of the SOVs is thus paramount, which introduces the concept of a 'feeder vessel', whose job it is to travel between the port and the SOV and perform the equipment/technician/fuel restocking process. The challenge would then be to deploy the feeder vessel at the appropriate schedule to keep the SOV fully stocked. However, this concept could be extended to cover either the regional (entire Hub area), the entire North Sea Wind Farm, or some combination thereof. This could be performed by individual vessels deploying to the SOV sites under coordination of the relevant ports, or through a group of vessels, a 'vessel train', which would travel as a group visiting all necessary SOV sites in the area. In this vessel train concept, unmanned follower vessels follow a manned lead vessel through a command and control system, reducing the amount of required crew members. However, the savings in lower crew requirements would need to outweigh both the extra cost of the follower vessels following a non-optimal route, and the higher CAPEX costs of this type of vessel. It is important to note that this strategy would also need to satisfy IMO requirements concerning ship manning levels.

In the case of Hub North, coordination between O&G and offshore wind farm maintenance can thus be taken as a result of these feeder vessels servicing both platforms and wind farms simultaneously. Instead of PSVs operating independently to service platforms in Hub North, feeder vessels that service SOVs can be properly equipped to also service O&G platforms. Especially in the case of Hub North, where the travel distance of PSVs is significantly larger than for Hubs West and East, this is likely to result in significant cost savings both in terms of fuel and vessel day rates. Given suitable scheduling, this is also unlikely to result in significant losses in wind farm availabilities – as this depends more on the SOV/daughter craft being in the vicinity of the wind farm. Indeed, if the SOV is properly stocked and replenished in terms of parts, fuel, technicians, and other necessities, there should not be a drop in wind farm availability at all.

As the Netherlands aims to become climate neutral by 2050, it is likely that the energy system will undergo a significant change, being reliant on a stable and large supply of hydrogen. The shift will bring 3 to 4 GW of electrolysis capacity by 2030, and will be supported by a national hydrogen network, which reuses existing gas pipelines for the purpose of transporting hydrogen. An example of this is the connection from Search Area 6 to the existing NOGAT pipeline, which lands at Den Helder (Netherlands Enterprise Agency RVO, 2021).

Surplus electricity from offshore wind farms would be used by dedicated electrolysers, either on energy islands, centralized platforms or integrated in wind turbines to produce green hydrogen, thereby contributing to the prevention of grid congestion. Several utilities companies have announced demonstration projects looking at hydrogen production offshore.

It is therefore likely that wind farms to be built in Hub North by 2040 will include offshore hydrogen generation infrastructure. Maintenance considerations for such non-traditional wind farms haven't currently been explored, but the presence of offshore electrolysers, compression stations, desalination units, array and export pipelines will require new skill sets for maintenance. More research is needed on aspects such as maintenance strategies, resources, tools, health safety & environment (HSE) among others for future generations of offshore wind farms. The current activities in deploying offshore Hydrogen production and storage will provide more realistic O&M requirements to the future plans in the hub North.

7.2 The role of ports in a future integrated offshore energy system

Ports will have a crucial role in facilitating the O&M activities of an integrated energy system. Examples of the ports role are, but not limited to, dealing with different type of vessels required to perform a construction, installation or O&M activity, fuel stations which are affected by the trends in the new fuels for vessels (electrical, hydrogen, green fuels etc.), optimum scheduling of the port traffic etc. To better sketch the critical role of ports in a shared logistics concept, a meeting was held to facilitate a discussion between representatives of the three ports within the NSE consortium (Port of Amsterdam, Port of Den Helder, Port of Rotterdam) focusing on the role of the ports in the logistics system of the future North Sea Energy area.

The idea that ports are specialized in one single phase of an offshore structures' lifecycle (construction/ installation, O&M, decommissioning) is slowly disappearing. Ports are already focusing a lot more on facilitating all these phases, and will likely continue to do so more and more in the future. However, while having the capability to cover all aspects, it is expected that certain ports will specialize in one or more of these aspects. This specialization mainly comes from the constraints such as port size, port traffic, water depth and geographical locations. For instance, a port with high traffic and suited for larger vessels might be less suited to daily "milk run" type of O&M activities in which a single specific wind farm is serviced with smaller vessels. However, it is highly unlikely that a port could specialize only in one phase in particular because of specific characteristics of ports, e.g. location, space or specific services that are located in the port.

Furthermore, the activities that can be performed in a port also heavily depends on the investment climate, as well as the availability of technical expertise and craftsmen. Construction activities see labour competition from other countries. Especially for decommissioning, there is currently no business case to make it economically viable to have a (greenfield) location or terminal for this purpose only. Combined with the varied nature of decommissioning activities itself (i.e., decommissioning of wind turbines or offshore platforms can differ a lot) and volume of decommissioning object in the context of the Southern North Sea makes investments in decommissioning infrastructure risky.

One suggested option to facilitate the delegation of activities related to which lifecycle phase to ports is a joint body in which ports collaborate to allocate these activities to Dutch port areas, perhaps during the tendering phase, to provide a pipeline of projects that can increase certainty for ports and help reduce investment risks. In this way, it would be clearer for customers to know which entities to contact, and lead to an improved efficiency for ports in terms of future activities. This improved security for ports would likely also result in increased investments in the port itself, as when the port knows what activities it will perform in the future, there is less risk in investing in the proper infrastructure and tools to enable such activities.

A single clear activity that would benefit most from integration of ports has not been identified, as it is expected that most activities would necessitate some form of collaboration or sharing of assets/space/etc. In fact, a lot of activities already make use of multiple ports for different functions. For instance, wind turbine foundations come from Rotterdam, the turbine from Esbjerg by way of Groningen, which also performs the installation of the turbine, while installation of cables is done from Amsterdam. Finally, O&M and installation support is serviced from Ijmuiden.

When it comes to what is required to be shared, one of the main things identified was space. As previously mentioned, a lot of the physical space is required to facilitate logistics activities, which is limited and is constrained by other port industries (processing plants, import/export, warehousing, etc.) and other purposes (e.g. housing, recreation). Optimally using all available port space will likely require ports to share their logistics space for certain activities. Especially when ports are geographically close, sharing of space becomes much easier and more feasible, and ports can better divide supply and demand of activities between them. This additional outsourcing of supply/demand should be weighed against the cost of transporting these goods from the supply port to the demand port. In addition to space, it will also be important to share information. In terms of what activities are going on, what is needed to complete these activities, and what resources are available per port to do so. Without having a good and secure sharing of the data between ports, it will be challenging to find potential synergies and activities that could be shared in the first place. In addition, when activities have to be spread out across ports, a good overview is needed of available space, expertise, tools, and labour available at each port in order to allocate them properly.

It is important to keep in mind that most ports are more than just a place to facilitate offshore logistics. There are many other industries that make use of port space. At the same time, when allocating port space it should be considered whether such activities really require the same water bound locations like for offshore wind is needed (e.g., electrolysers might be handy close to the sea/ water, but could be placed elsewhere in the port on non-water bound locations or offshore).

8 Conclusions and future work

This work aims to answer the research question on what the challenges and potential benefits are of shared, optimised logistics between offshore energy systems. In particular O&M activities of offshore wind farms are combined with the handling offshore activities on O&G platforms as these encapsulate all the durations a vessel is busy offshore at a platform and can be combined with offshore wind O&M tasks. Data such as frequency of visits and the current methods to organize and plan services for the oil and gas services, were obtained from partners in the NSE consortium from their historical visits and services to different blocks of the North Sea. For the data on offshore wind O&M, an extensive literature study was performed to collect data. In WP1 of the NSE 4 project, three energy hubs were identified viz. Hub West, Hub East and Hub North. In order to evaluate the possibilities and potential benefits of logistic sharing concepts, scenarios were created for each hub which reflected the possible future state of the North Sea area and the logistics needs within it.

Three scenarios were modelled for Hub West, the first scenario considered the earliest time period within the temporal scope (before 2030), with wind farms relatively close to shore requiring CTVs for daily maintenance. The second scenario modelled the use of SOVs as the vessel for daily maintenance, for wind farm further offshore and in the third scenario, an island was used as a base for personnel accommodation and a warehouse for large components. For Hub East, two scenarios were modelled, the first where wind farms and nearby O&G platform activities are performed with an SOV, and the second where an island was modelled from which CTVs operate to maintain the wind farms and O&G platforms. In addition to the five modelled scenarios (three for Hub West and two for Hub East), the Hub West scenarios were extrapolated over a larger region, since the potential for wind farm development activity and the O&G platform density is highest for this hub. Results showed that the potential cost savings potential for the entire Hub West region is estimated to be **21.7 to 28.9 M€/yr.** and the equivalent number for the region Hub East region is estimated to be **13.2 to 16.3 M€/yr**. The corresponding emission savings potential for the Hub West region is estimated to be **7.8-75.3 tonnes/yr.** and for the Hub East region is estimated to be **17.2-37.6 tonnes/yr**. The large variation ranges on the emission savings results from the island based scenarios, where the PSV is modelled to either operate from the island (resulting in lower emission savings) or from the onshore port (resulting in higher emission savings)

In contrast to the analysis of cost savings in Hub West and Hub East, which were conducted through the use of simulating scenarios with and without logistics sharing, scenarios in Hub North were qualitatively discussed. There is currently no wind farm capacity in Hub North, with 10GW planned between 2030 and 2040. This timeline suggests greater uncertainty compared with Hubs West and East, given that logistical strategies will change significantly by then. A strategy wherein SOVs are permanently stationed at offshore wind farm locations can be plausible, thus ensuring the constant supply of these SOVs is paramount, which introduces the concept of a ‘feeder vessel’, whose job it is to travel between the port and the SOVs and perform the equipment/technician/fuel restocking process.

Also, ports will have a crucial role in facilitating the O&M activities of an integrated energy system. The idea that ports are specialized in one single phase of an offshore structures’ lifecycle (construction/installation, O&M, decommissioning) is disappearing, and there is a focus on facilitating all these phases. Overall, the current way in which logistics are handled will not be viable to handle the future growth of activities. Thus, research will be needed into looking at new types of logistics systems. Although this study modelled economic and logistics impact with the use of vessels from an island in hubs West and East, an extension could be to perform life cycle analysis to estimate the CO2 saving in realizing a port on the island to perform logistics versus performing logistics with vessels from a base on the shore.

One of the aspect which will be worth exploring in the future work is the impact of new shared logistics on the life-cycle cost and emission of the new concepts (considering the costs of building new vessels with different fuels, charging stations, etc.) to objectively compare the different scenarios from the life-cycle point of view. In addition, the current scope of work was limited to the operation and maintenance services and additional cost and emission savings might be possible by considering the other phases of the project, such as installation and decommissioning.

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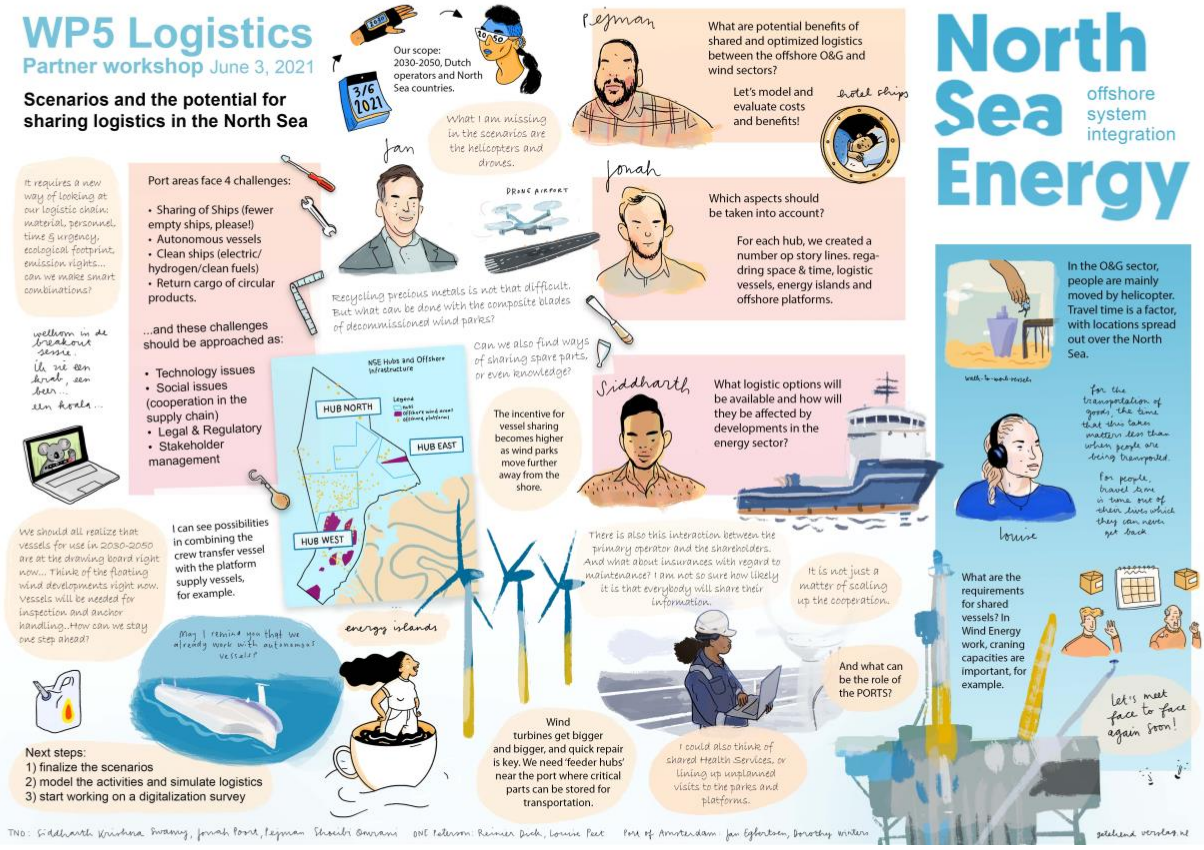
A.1 Logistics workshop summary



A.2 Scenario tables including all additional options

During the workshop, the participants were given the possibility to add additional aspects and/or options to the scenario tables as shown in Table 5 and Table 6. In the main text of this report, only those additional options which were later also included in the discussion on the scenarios were listed; here the full list of options is given, and can be found in Table 8 and Table 9 respectively.

Start O&M period

A final starting period of operation and maintenance activities beyond 2045 was suggested as an option to include late-term developments that have additional logistic needs. Since the temporal scope of the work package goes up to 2050, this starting time was considered too late to take into account in the detailed analyses.

Technician base

An interesting suggestion was made for the technician base aspect, which relied on (partially) autonomous O&M where the expert advised from a remote location (likely on shore). This option would likely be available much later in the future as it require considerable technological advances, but is a creative and interesting option nonetheless.

Additional transport option

Many suggestions were made for additional transport options that hadn't been included yet, they include:

- Feeder vessels. Mid-size freight ships for transporting containers
- Walk-to-work vessels. Vessels that use a movable gangway to directly connect to an offshore structure
- Vessel trains. Similar to daughter craft, but using the vessels to move between main vessel and port, instead of the main vessel itself having to move to port itself
- Drones. Using (autonomous) drones to deliver small spare parts or supplies to offshore structures.
- CO2 transport ships. Using ships transporting liquid CO2 to offshore storage facilities to also deliver supplies or technicians. This option is only relevant for locations were CO2 is possible, so will not be considered in Hub East.

Main vessel fuels

Additional fuel options such as synthetic methanol (produced from hydrogen), ammonia, and gas-to-liquid (GTL) were suggested.

Additional island use

A significant number of extra additional island uses were suggested, such as:

- Vessel sheltering. Using the island's port to shelter vessels during bad weather.
- Transport hub. Using the island not just as a single destination structure, but have it also function as a larger hub for sea or even air travel or transport. This options was later not mentioned during the discussion of the scenarios, so has been left out of further consideration.
- Substation. Install an electrical converter substation on the island to serve as an electrical hub for wind farms. This options was later not mentioned during the discussion of the scenarios, so has been left out of further consideration.
- Fuel station. Use the island for the storage of fuels and refueling of vessels.
- Control room. Use the island as a control room for logistics activities. This option was considered largely equivalent as the technician base option, so not explicitly considered in the scenarios.

Alternative platform use

Similar as was suggested for an additional island use, a converted platform could be used as an electrical converter substation. This options was later not mentioned during the discussion of the scenarios, so has been left out of further consideration

Table 35 Full updated scenario options table for Hub West. Additional inputs from workshop that were included in the scenarios are given in red, while those not included in the discussions are given in grey

Distance to shore	Start O&M Period	Technician base	Main logistics vessel	Additional transport option	Main vessel fuel	Island availability	Additional island use	Operational platform density	Alternative platform use	Platform electrifi-cation
<30 km	2030-2035	Shore	CTV	None	Fossil	Yes, with port	None	Low	None	Yes
30-80 km	2035-2040	Vessel	SOV	Helicopter	Hydrogen	Yes, without port	Technician base	Medium	Technician base	No
80+ km	2040-2045	Island	SES	Daughter craft	Bio	No	Hydrogen production	High	Hydrogen production	
	2045+	Platform	Supply vessel	Supply ferry	Electricity		Ware-housing		CO_2/H_2 storage	
		Autono-mous		Feeder vessel	Synthetic methanol		Data centres		Ware-housing	
				Walk-to-work	Ammonia		Tourism		Substation	
				Vessel train	GTL		Vessel sheltering			
				Drones			Transport hub			
				CO_2 shipping			Substation			
							Fuel station			
							Control room			

Table 36 Full updated scenario options table for Hub East. Additional inputs from workshop that were included in the scenarios are given in red, while those not included in the discussions are given in grey

Distance to shore	Start O&M Period	Technician base	Main logistics vessel	Additional transport option	Main vessel fuel	Island availability	Additional island use	Operational platform density	Alternative platform use	Platform electrifi-cation
40-60 km	2030-2035	Vessel	CTV	None	Fossil	Yes, with port	None	Low	None	Yes
60+ km	2035-2040	Island	SOV	Helicopter	Hydrogen	Yes, without port	Technician base	Medium	Technician base	No
	2040-2045	Platform	SES	Daughter craft	Bio	No	Hydrogen production		Hydrogen production	
	2045+	Autono-mous	Supply vessel	Supply ferry	Electricity		Ware-housing		Ware-housing	
				Feeder vessel	Synthetic methanol		Data centres		Substation	
				Walk-to-work	Ammonia		Tourism			
				Vessel train	GTL		Vessel sheltering			
				Drones			Transport hub			
							Substation			
							Fuel station			
							Control room			

A.3 Scenarios data and assumptions

Hub west; Shore based scenario

Table 37 gives the specific location and O&M activity frequency and durations for the six O&G platforms included in the shore based scenario of Hub West. These numbers were used in O&M planner to simulate the total number of platform visits, visit durations, and travel distances to and from the platforms.

Table 37 Platform locations and visit frequency and durations for the six platforms included in the shore based scenario of Hub West

Platform name	Distance from HKN centre	Freq. of maintenance actions	Avg. duration of visits
Q1	17 km	76 events in 5 years	2.54 h
Q2	13 km	61 events in 5 years	2.46 h
Q3	23 km	95 events in 5 years	3.12 h
P1	28 km	77 events in 5 years	2.40 h
P2	25 km	122 events in 5 years	2.80 h
P3	29 km	190 events in 5 years	3.63 h

Hub west; SOV based scenario

The relative locations to the centre of the Ijmuiden Ver wind farm and platform visit frequencies and durations are given in Table 38. As can be seen, the number of visits and visit durations of the platforms in the K-block are lower than for those in the P-block.

Table 38 Platform locations and visit frequency and durations for the five platforms included in the SOV based scenario of Hub West

Platform name	Distance from IJV centre	Freq. of maintenance actions	Avg. duration of visits
K1	33.5 km	27 events in 5 years	1.51 h
K2	19.5 km	27 events in 5 years	1.51 h
K3	33.5 km	27 events in 5 years	1.51 h
P1	13 km	190 events in 5 years	3.63 h
P2	17 km	190 events in 5 years	3.63 h

Hub west; Island based scenario

The relative locations to the centre of the wind farm zone 3 and platform visit frequencies and durations are given in
Table 39. As can be seen, the number of visits to K5-A is higher than most other platforms.

Table 39 Platform locations and visit frequency and durations for the five platforms included in the island based scenario of Hub West

Platform name	Distance from Wind farm zone 3 centre	Freq. of maintenance actions	Avg. duration of visits
K2-X	5 km	174 events in 5 years	2.14 h
K4-X	30 km	70 events in 5 years	1.47 h
K5-X	35 km	252 events in 5 years	1.85 h
K4-Y	35 km	66 events in 5 years	1.38 h
K5-Y	20 km	66 events in 5 years	1.25 h

Hub East; SOV based scenario

The relative locations to the centre of the wind farm 5-oost and platform visit frequencies and durations are given in Table 40. As can be seen, the number of visits to G17-X and G17-Y is higher than most other platforms.

Table 40 Platform locations and visit frequency and durations for the six platforms included in the SOV based scenario of Hub East

Platform name	Distance from Wind farm 5-Oost centre	Freq. of maintenance actions	Avg. duration of visits
G17-X	27 km	470 events in 5 years	1.3 h
G17-Y	27km	470 events in 5 years	1.3 h
G16-X	37 km	150 events in 5 years	1.8 h
G16-Y	34 km	150 events in 5 years	1.8 h
G14-X	17 km	196 events in 5 years	2.0 h
G14-Y	21 km	196 events in 5 years	2.0 h

Hub East; Island based scenario

The relative locations to the centre of the wind farm 5-oost and platform visit frequencies and durations are given in Table 41. As can be seen, the number of visits to G17-X and G17-Y is higher than most other platforms.

Table 41 Platform locations and visit frequency and durations for the six platforms included in the Island based scenario of Hub East

Platform name	Distance from Wind farm 5-Oost centre	Freq. of maintenance actions	Avg. duration of visits
G17-X	27 km	470 events in 5 years	1.3 h
G17-Y	27km	470 events in 5 years	1.3 h
G16-X	37 km	150 events in 5 years	1.8 h
G16-Y	34 km	150 events in 5 years	1.8 h
G14-X	17 km	196 events in 5 years	2.0 h
G14-Y	21 km	196 events in 5 years	2.0 h

In collaboration and appreciation to

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