ENERGINET

MARINE ENVIRONMENTAL STUDIES – NORTH SEA I

NAVIGATIONAL RISK ASSESSMENT

27 NOVEMBER 2024

CONFIDENTIAL

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ENERGINET

PROJECTNAME: MARINE ENVIRONMENTAL STUDIES – NORTH SEA I
PROJECT NO.: 22003230
DATE: 27-11-2024
VERSION: 1.0
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DESCRIPTION: NAVIGATIONAL RISK ASSESSMENT

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Abbreviation	Explanation
AIS	Automatic Identification System
AoI	Area of Interest
AtoN	Aids to Navigation
BSH	Bundesamt für Seeschifffahrt und Hydrographie (German Maritime Authority)
COLREGS	Convention on the International Regulations for Preventing Collisions at Sea, 1972
CTV	Crew Transfer Vessel
CWAS	Construction Works at Sea
DDM	Denmark's Depth Model
DEA	Danish Energy Agency
DMA	Danish Maritime Authority
DMI	Danish Meteorological Institute
EIA	Environmental Impact Assessment
ECC	Export cable corridor
EEZ	Exclusive Economic Zone
ETV	Emergency Towing Vessels
FSA	Formal Safety Assessment
HAZID	Hazard Identification
HR (I-III)	Horns Rev OWFs
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IMO	International Maritime Organization
Metocean	Refers to the syllabic abbreviation of meteorology and (physical) oceanography
MSL	Mean sea level
MSP	Maritime Spatial Plan
NM	Nautical mile
NtM	Notices to Mariners
NSI.1	North Sea I OWF, Subarea 1
NSI.1-A1	North Sea I OWF, Subarea 1, Area 1
NSI.1-A2	North Sea I OWF, Subarea 1, Area 2
NSI.1-A3	North Sea I OWF, Subarea 1, Area 3
NSI.2	North Sea I OWF, Subarea 2
NSII	North Sea II OWF (Energy Island North Sea)
O&M	Operation and maintenance
OWF	Offshore Wind Farm
Racon	Radar beacon.
SOV	Service Operational Vessel
SAR	Search and Rescue
TSS	Traffic separation system
VHN	Vesterhav North OWF
VHS	Vesterhav South OWF
WTG	Wind Turbine Generator

1 SUMMARY

BACKGROUND

In order to enable the realization of the political agreements on significantly more energy production from offshore wind before the end of 2030, the Danish Energy Agency (DEA) has drawn up a plan for the establishment of offshore wind farms (OWFs) in three areas in the North Sea, the Kattegat and the Baltic Sea, respectively.

WSP A/S has been contracted by Energinet to perform marine environmental studies for the planned North Sea I OWF (NSI.1 area) for six work packages focusing on: benthic ecology, fish and fisheries, underwater noise and vibrations, radar (civil) and radio interference as well as maritime traffic and safety of navigation. The content of this report is only related to work concerning maritime traffic and navigational safety in the NSI.1 area.

The NSI area is divided into two sub-areas; subarea 1 (NSI.1) and subarea 2 (NSI.2). The present assessment of maritime traffic and safety of navigation addresses NSI.1, including the potential cumulative effects from existing and future OWFs in the Danish North Sea sector. NSI.1 has a total area of approx. 1,344 km^2 and is located 20-60 km west of Ringkøbing Fjord and Hvide Sande in the Danish part of the North Sea. NSI.1 is further divided into three areas (NSI.1-A1, NSI.1-A2 and NSI.1-A3) – each with an associated ECC connecting the OWFs to the onshore grid.

OBJECTIVE

The objective of this study is to undertake a pre-liminary navigational risk assessment for both the construction and operation of the planned three OWFs in the NSI.1 area, addressing how, where, and to what potential extent the planned OWF build-out impacts maritime traffic and the safety of navigation.

The risk assessment addresses the potential changes in frequency index (collisions, allisions and groundings) as well as consequence index caused by the build-out of OWFs in the North Sea, with a focus on establishment of NSI.1. This results in a qualitative risk index and recommendation of mitigation measures.

This pre-liminary navigational risk assessment relies on a series of conservative, (worst-case) assumptions regarding the planned build-out of offshore wind farms in the NSI.1 area. Future concessionaries will need to conduct project-specific navigational risk assessments. This includes performing quantitative analysis of the implementation of the suggested project-specific mitigation measures.

Relevant approved and planned OWFs are included in the risk assessment, i.e. Vesterhav South OWF, Thor OWF, NSI.2 OWF and North Sea II OWF (Energy Island North Sea). The risk assessment will be based on a defined investigation area (hereafter called Area of Interest) comprising an area of approx. 170x200 km west off Hvide Sande in the North Sea. Further, the assessment will be based on modelling collision frequencies, as well as traffic modelling and rerouting for different generic layout scenarios according to the future build-out of OWFs in the Danish North Sea sector. This Area of Interest (AoI) is considered adequate for assessing the impact on the maritime traffic conditions, traffic movements and rerouting as well as calculations of accident frequencies both cumulatively and in relation to the NSI.1 area itself. Generally, the risk assessment will address the entire NSI.1 area, but it will also assess each of the three areas in NSI.1 individually (i.e. NSI.1-A1-A3), especially regarding differences in risk levels between the areas.

METHODOLOGY

The assessment of navigational safety has been carried out using the standard method and risk assessment approach, following the guidelines of the International Maritime Organization (IMO) for Formal Safety Assessment (FSA). Following this methodology, the risk assessment started with a hazard identification session, carried out on 28th of November 2023 in Hvide Sande. Hazard Identification (HAZID) is a systematic and qualitatively process for identifying unintended hazards and incidents. The participants represented different stakeholders using the waters around NSI.1 as well as different professions and case officers from both the Danish Energy Agency (DEA) and the Danish Maritime Authority (DMA). The initial hazard identification is followed by a risk assessment using the IALA “IWRAP tool” to quantify navigational risks based on Automatic Identification

Systems (AIS) data. Basically, the risk assessment is based on detailed mapping of waterway characteristics including analysis of overall traffic routes and distributions, ship types as well as metocean characteristics. The IWRAP MKII software calculates the probability of allisions, collisions or groundings for a vessel operating on a specified route. In IWRAP, the maritime traffic is defined by a series of legs orientated in different directions.

Maritime traffic in and around the NSI.1 area has been analyzed based on AIS-data from 2022, which show all ship movements for one year. For each future build-out scenario of OWFs in the eastern part of the North Sea, it has been analyzed how the maritime traffic will be rerouted and adapted to new traffic conditions.

The following risk evaluation and modelling is conducted as a comparative analysis, where the navigational safety risk is assessed for different scenarios, including existing, approved and planned OWFs. The navigational risk analysis undertaken for the planned offshore wind build-out in the NSI.1 area are split into four different scenarios. For each modelled scenario a detailed description of the proposed traffic rerouting and final model setup is provided, which forms the basis for the quantitative analyses and calculations of accident frequencies.

The first two scenarios – 1) baseline scenario (Vesterhav South, Thor OWF) and 2) NSI.1 OWF – are relevant to understand how the OWF build-out in the NSI.1 area will impact the maritime traffic and the navigational safety in and around the area, and if mitigations are needed to avoid or reduce impacts. The other two scenarios – 3) NSI.2 OWF and 4) NSII OWF are relevant to understand how the OWF build-out in the NSI.1 area will potentially impact the future OWF build-out in the NSI.2 and NSII OWF area. The purpose of scenario 3) and 4) is to provide insight to the potential consequences for the Maritime Spatial Plan (MSP) for Danish waters and its allocation of areas for offshore wind (NSI.2 and NSII). Since scenario 3) and 4) are not directly linked to the navigational safety implications of the OWFs in the NSI.1 area, the results of this part of the risk analysis are presented in an appendix to the report.

Generic WTG layouts for NSI.1, NSI.2 and NSII have been generated as input parameters for the IWRAP-model to calculate accident frequencies. The calculated return periods for groundings, allisions and collisions are summarized and compared for the different scenarios, and percentage changes between scenarios are addressed. In addition, some of the most contributing legs according to incidents frequencies are discussed.

A qualitative risk assessment is performed based on the DMA scheme for "Construction Works at Sea" (CWAS). Consequences are classified on a scale from 0 to 4, indicating the severity from limited to catastrophic damage. The frequency of incidents is classified using a probability scale from 0 to 7. An indicative risk index (resulting in risk classes) is provided for each of the accident types related to scenario 1 and scenario 2 by combining the estimated consequence index with the calculated collision frequencies.

Based on the results of the HAZID study (qualitative risk assessment) and this quantitative risk assessment, several initial risk reducing measures for NSI.1 are proposed.

RESULTS AND CONCLUSIONS

The maritime traffic and navigational safety have been assessed in connection with the construction and operation of offshore WTGs and other technical structures within the NSI.1 area. Cumulative effects have been considered in line with the development of several OWFs in the Danish part of the North Sea. Therefore, approved and planned OWFs (i.e. Vesterhav South, Thor OWF, North Sea I and North Sea II) have been included in the present navigational risk assessment.

The AIS data shows that the traffic density is highest in the northwestern part of NSI.1 (in NSI.1-A3) and lowest in the southern part (NSI.1-A1). The most dominant ship type within NSI.1 is cargo ships, followed by fishing vessels and tankers, respectively. Based on the current traffic condition, seven main traffic routes representative for the overall waterway characteristics have been identified. For each scenario a final model setup with a proposed traffic rerouting have been discussed. Based on generic WTG layouts and future rerouting traffic conditions, the return periods for three types of accidents (groundings, allisions and collisions) have been calculated and compared individually across different scenarios.

Based on present navigational risk assessment, the percentage changes in return period (accident frequency) between baseline scenario (scenario 1) and scenario 2 have been calculated:
The modelling shows that the grounding frequency will decrease by 7% (return period decreases from 35 to 38 years). Correspondingly, the modelling shows that the total allision frequency will increase by 92% (return period increases from 2,245 to 185 years) and the total collision frequency will increase by 37% (return period increases from 42 to 26 years). This significant increase in allision frequency is simply explained by the construction of NSI.1 OWFs (grid of WTGs) in open waters characterized by medium to high density of maritime traffic. The construction of NSI.1. leads to traffic movements and rerouting, which results in higher traffic density in the routes around the planned OWF. Higher density means greater risk of collisions between ships. Another reason for the increasing collision frequency is due to narrowing of the traffic routes.

This risk assessment indicates that the establishment of NSI.1 OWF is expected to cause a limited increase in the overall risk for maritime traffic. The average risk index is assessed to increase by one risk class for both powered and drifting allisions due to the establishment of NSI.1. The average risk index remains unchanged for both powered and drifting groundings, as well as for collision.

The highest risk level, both before and after the establishment of NSI.1, is assessed to be associated with ship-ship collisions. An increase in the risk of collisions is anticipated due to the densification of traffic in the main routes west and east of NSI.1.

All estimated risk classes for each incident type, except for collisions and drifting allisions, are assessed to have an acceptable risk level (risk class 5 or less). The model indicates that the risk of ship-ship collisions and drifting allisions can reach an unacceptable risk level and therefore mitigation measures need to be implemented. Recommended mitigation measures are described in the report and it is assessed that the implementation of mitigation measures, based on the current knowledge and assumptions about the offshore wind build-out in the NS1.I area, will be sufficient to reduce the risks to an acceptable level.

There are no governing quantitative risk acceptance requirements for the establishment of OWFs. In Denmark, the approval of the navigational risk levels is done as a case-by-case approach by DMA. Therefore, based on the calculated return periods and overall risk evaluation, it is not possible to make a definite conclusion whether the risk is acceptable or not. Instead, calculated accident frequencies combined with the assessed indicative risk index are presented and discussed with the authorities. Based on that, DMA will decide whether the OWF build-out scenarios in NSI.1 are compatible with the overall safety of navigation in the area and decide if any mitigations should be implemented.

2 INTRODUCTION

2.1 BACKGROUND

In order to accelerate the build-out of Danish offshore wind production, it was decided with the agreement on the Finance Act for 2022 to offer an additional 2 GW of offshore wind for establishment before the end of 2030. In addition, the parties behind the Climate Agreement on Green Power and Heat 2022 of 25 June 2022 (hereinafter Climate Agreement 2022) decided, that areas that can accommodate an additional 4 GW of offshore wind must be offered for establishment before the end of 2030. Most recently, a political agreement was concluded on 30 May 2023, which establishes the framework for the Climate Agreement 2022 with the development of 9 GW of offshore wind, which potentially can be increased to 14 GW or more if the concessionaires – i.e. the tenderers who will set up the offshore wind turbines – use the freedom included in the agreement to establish capacity in addition to the tendered minimum capacity of 1 GW per tendered area.

In order to enable the realization of the political agreements on significantly more energy production from offshore wind before the end of 2030, the Danish Energy Agency (DEA) has drawn up a plan for the establishment of offshore wind farms in three areas in the North Sea, the Kattegat and the Baltic Sea, respectively.

WSP A/S has been contracted by Energinet to perform marine environmental studies for the planned North Sea I OWF (named NSI) for six work packages focusing on: benthic ecology, fish and fisheries, underwater noise and vibrations, radar (civil) and radio interference as well as maritime traffic and safety of navigation in the study area. The content of this report is only related to work concerning maritime traffic and navigational safety in the NSI.1 area.

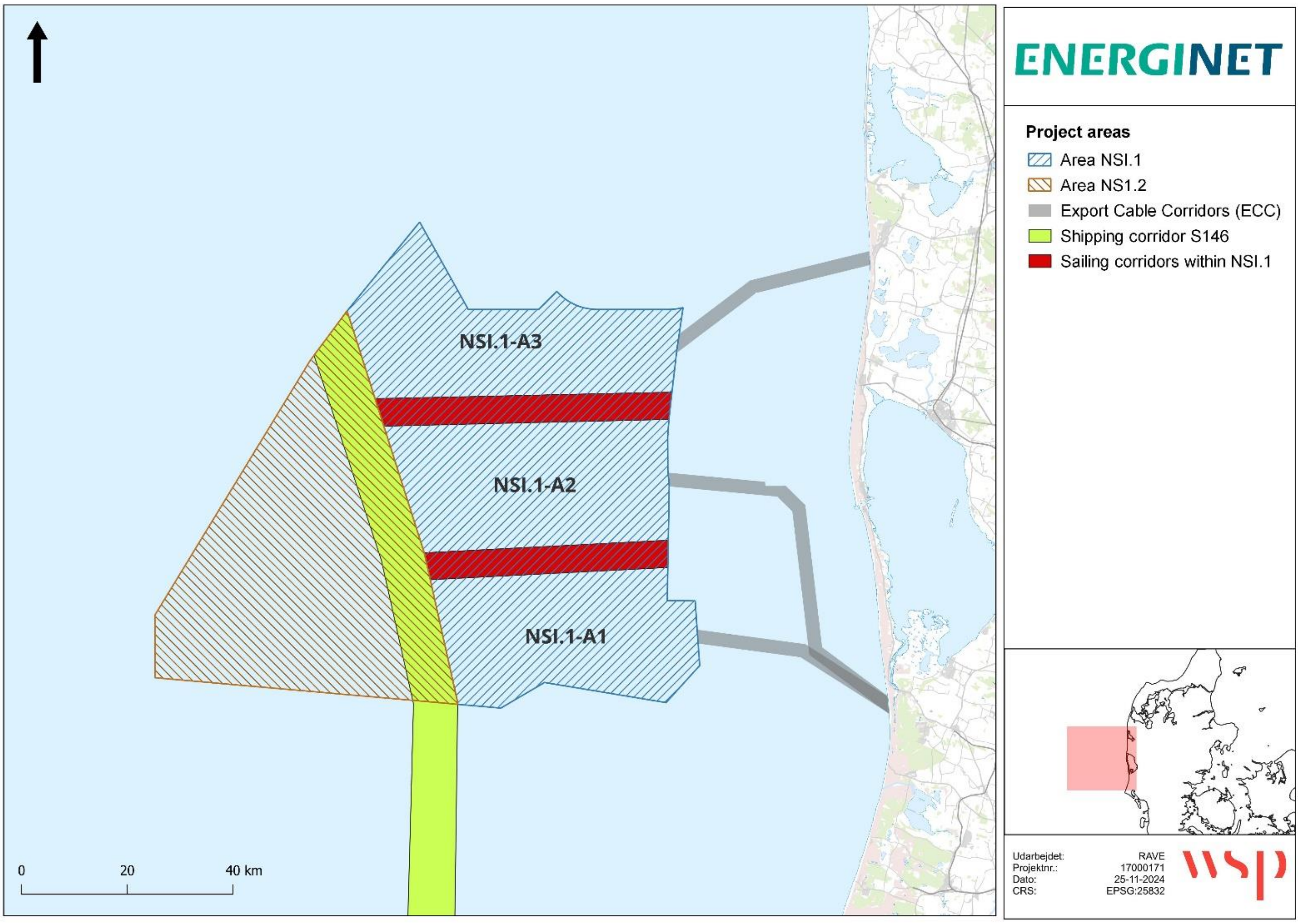


Figure 2-1. The map shows the division of NSI into subarea 1 (blue) (NSI.1) and subarea 2 (red) (NSI.2). The present hazard identification and navigational risk assessment only covers NSI.1 including the three areas (NSI.1-A1, NSI.1-A2 and NSI.1-A3). The map also shows the planned

shipping corridor S146 according to the Maritime Spatial Plan (Denmark's maritime spatial plan, 2024) as well as the planned internal sailing corridors within the NSI.1 area.

The NSI area is divided into two subareas (Figure 2-1); Subarea 1 (NSI.1) and subarea 2 (NSI.2). The present risk assessment of maritime traffic and safety of navigation addresses NSI.1, including the potential cumulative effects from future OWFs in the Danish North Sea sector. The area of NSI.1 is further divided into three areas (Figure 2-1), which are described in Chapter 3 under "Project description and Area of Interest" (see Chapter 3).

The overall purpose of the marine environmental studies - which marine traffic and safety of navigation is part of - is twofold:

1) Describe the baseline conditions for the specific parameter collectively for the NSI.1 area and for each of the three areas that NSI.1 is divided into. This will form part of the basis for the subsequent Environmental Impact Assessment (EIA) that the concessionaire(s) must carry out.

2) Provide an assessment of the risks related to establishing an offshore wind farm in the area in relation to potential impacts on the specific parameter. This will form part of the basis for further risk assessments.

2.2 OBJECTIVE AND PURPOSE

As part of marine feasibility studies, WSP has performed a navigational risk assessment for NSI.1, which is summarized in this technical report. The assessment reviews both the construction and operation phases of the planned OWFs. The objective of this navigational risk assessment is to assess how, where, and how much the planned OWF build-out impacts the maritime traffic, and to assess the potential changes in risk of collisions, allisions and groundings caused by the build-out.

The purpose of this study is to provide a description and mapping of the existing maritime traffic in and around the OWF areas, cf. section 4.5 "Analysis basis", which contains a detailed review of the current traffic routes (scenario 0). Further, the purpose is to provide an assessment of the maritime traffic and navigational safety based on an analysis of the area around the NSI.1 OWF areas. In connection with the marine feasibility studies for the future build-out of NSI.1 OWF, a series of analyses will be carried out of the expected changes in sailing conditions, traffic patterns and safety of navigation, which the construction and operation of OWFs in the area may cause. The assessment will be based on modelling of accident frequencies and rerouting for different generic layout scenarios (scenario 1-4, see definition below) according to the future build-out of offshore wind farms in the Danish North Sea sector.

Cumulative effects are considered in accordance with the development and build-out of future OWFs in the Danish part of the North Sea. Therefore, approved and planned OWFs are included in the risk assessment. In consultation with Energinet and DMA, it has been decided that it concerns the OWFs Vesterhav South (VHS), Thor OWF, NSI.2 and North Sea II (North Sea Energy Island). Consequently, the objective of the risk assessment will be based on a defined investigation area (hereafter called Area of Interest - AoI), which covers an area of approx. 170x200 km west off Hvide Sande in the North Sea. This AoI is considered adequate for assessing the impact on the maritime traffic conditions, traffic rerouting and calculations of accident frequencies both cumulatively and in relation to the NSI.1 area itself. Therefore, the basis traffic analyses, as well as the rerouting analysis and the accident frequencies for the different modelling scenarios will be investigated for the entire AoI. Generally, the risk assessment will be considered for the entire NSI.1 area, however, if there are differences in the assessments, these are addressed individually for each area i.e. NSI.1-A1, NSI.1-A2 and NSI.1-A3.

The navigational risk analysis undertaken for the planned offshore wind buildout in the NSI.1 area are split into four different scenarios. The first two scenarios – 1) baseline scenario (see Chapter 7) and 2) NSI.1 OWF (see Chapter 8) – are relevant to understand how the OWF build-out in the NSI.1 area will impact the maritime traffic and the navigational safety in and around the area, and if mitigations are needed to avoid or reduce impacts.

The other two scenarios – 3) NSI.1 + NSI.2 OWF (see Appendix - Chapter 14) and 4) NSI.1 + NSI.2 + NSII OWF (see Appendix 2 – see Chapter 15) are relevant to understand how the OWF build-out in the NSI.1 area will potentially impact the future OWF build-out in the NSI.2 and NSII area. The purpose of scenario 3) and 4) is to provide insight to the potential consequences for the

Maritime Spatial Plan (MSP) for Danish waters and its allocation of areas for offshore wind (NSI.2 and NSII). Since scenario 3) and 4) are not directly linked to the navigational safety implications of the OWFs in the NSI.1 area, the results of this part of the risk analysis are presented in an appendix to the report.

The risk assessment addresses the potential changes in frequency index (collisions, allisions and groundings) as well as consequence index caused by the build-out of OWFs in the North Sea, with a focus on establishment of NSI.1. This results in a qualitative risk index and recommendation of mitigation measures.

This pre-liminary navigational risk assessment relies on a series of conservative, (worst-case) assumptions regarding the planned build-out of offshore wind farms in the NSI.1 area. Future concessionaries will need to conduct project-specific navigational risk assessments. This includes performing quantitative analysis of the implementation of the suggested project-specific mitigation measures.

3 PROJECT DESCRIPTION AND AREA OF INTEREST

This chapter describes the area where NSI.1 OWFs and export cable corridors (ECCs) are planned to be established (see section 3.1). AoI covers a defined gross area around existing and future OWFs in the North Sea, constructed to perform this present risk analysis (see section 3.2). For NSI.1 and AoI, a description of bathymetry and weather conditions (see section 3.3), overall waterway characteristics comprising information of current maritime traffic conditions (see section 3.4), technical specifications for the offshore WTGs in relation to the different OWFs, as well as generic layouts used for the risk assessment and calculations of accident frequencies (see section 3.5) is provided. Furthermore, there will be a description of relevant shipping corridors (maritime traffic routes) and development zones for offshore wind build-out according to the Marine Spatial Plan in Denmark (see section 3.6).

3.1 NSI.1 OWF LOCATION

The NSI area is divided into two subareas; subarea 1 (NSI.1) and subarea 2 (NSI.2) (Figure 2-1). This report deals with the identification and assessment of maritime traffic and safety of navigation in relation to NSI.1. NSI.1 has a total area of approx. 1,344 km^2 and is located 20-60 km west of Ringkøbing Fjord and Hvide Sande in the Danish part of the North Sea. NSI.1 is further divided into three areas (NSI.1-A1, NSI.1-A2 and NSI.1-A3) – each with an associated ECC connecting the OWFs to the onshore grid. Between the three areas, two sailing corridors are planned in an east-west direction, each with a width of approx. 3,0 km (Figure 2-1). The purpose of these corridors is to ensure a smooth flow of maritime traffic to and from Hvide Sande Harbor - especially for smaller vessels such as pleasure and fishing vessels.

Table 3-1 shows the size for each area within NSI.1 and the shortest distance to the west coast of Jutland. The size of each area within NSI.1 is approximately 400 km^2, apart from NSI.1-A1, which is a bit smaller. The total area of NSI.1 includes the two sailing corridors (Figure 2-1).

Table 3-1. Size and distance to coast for the three areas within NSI.1.

North Sea I, NSI.1	Area [km^2]	Shortest distance to shoreline [km]
NSI.1-A1	366	20
NSI.1-A2	401	20
NSI.1-A3	400	20
NSI.1 total	1,344	20

3.2 AREA OF INTEREST

The regional part of the Danish North Sea sector around NSI.1 is characterized by the presences of several OWFs (Figure 3-1), which are at different development stages. This means, that some of the OWFs are either in operation, under construction, approved (with Construction Permit) or planned (early development stage, planned in Maritime Spatial Plan).

The shortest distances to the existing OWFs in operation and the planned areas for future OWF build-out are presented in Table 3-2. The locations of these OWFs, are presented in Figure 3-1.

Table 3-2. Minimum distance from NSI.1 to existing and future OWFs. The individual OWFs are presented by development stage. *The reserved area to offshore wind development is presented in section 3.6. MSP: Maritime Spatial Plan.

OWF area	Shortest distance OWF and NSI.1 [km]	Development stage
Vesterhav North (VHN)	39.6	In operation since primo 2024
Vesterhav South (VHS)	10.0	In operation since primo 2024
Horns Rev I (HRI)	33.3	In operation since 2002

Horns Rev II (HRII)	17.4	In operation since 2009
Horns Rev III (HRIII)	7.4	In operation since 2019
Thor	3.0	Approved. Expected full operation in 2027
North Sea I, Subarea 2 (NSI.2)	0	Planned in the MSP*
North Sea II (Energy Island) (NSII)	16.7	Planned in the MSP*

Two existing OWFs, Vesterhav North (VHN) and Vesterhav South (VHS), are located outside Thyborøn and Hvide Sande. They are situated north and east off NSI.1, respectively (Figure 3-1) and have been in operation since primo 2024. South of NSI.1 is the Horns Rev area, where three OWFs (HRI, HRII and HRIII) (Figure 3-1) are in operation. HRIII is located closest to NSI.1 and has been in operation since 2019. Thor OWF is located just north of NSI.1 and is under construction in 2024 – 2026.

The planned OWF areas NSI.2 and North Sea II are both located west of NSI.1 (Figure 3-1). NSII is located west of the shipping corridor S10, whereas NSI.2 is located west of shipping corridor S146 (Figure 3-6). See section 3.6 for more information about the shipping corridors listed in the Marine Spatial Plan.

In order to perform a complete navigational risk analysis for NSI.1, it has been decided that the risk assessment should consider all these existing and future OWFs. Therefore, a gross area has been defined around all these OWFs based on a cumulative distance of 37 km from the NSI.1 area. The distance of 37 km is an experience value that recently has been used in connection with similar OWF projects in Denmark. The gross area is called AoI and covers a total area of approx. 170x200 km. This AoI is considered adequate for assessing the impact on the maritime traffic conditions, traffic rerouting and calculations of accident frequencies both cumulatively and in relation to the NSI.1 area itself. With a distance greater than 39 km, Vesterhav North OWF is located too far away to be considered impacting NSI.1 in regard to maritime traffic and navigational safety. Thus, VHN will not be included in the following modelling scenarios and in the overall traffic analysis (see section 4.4).

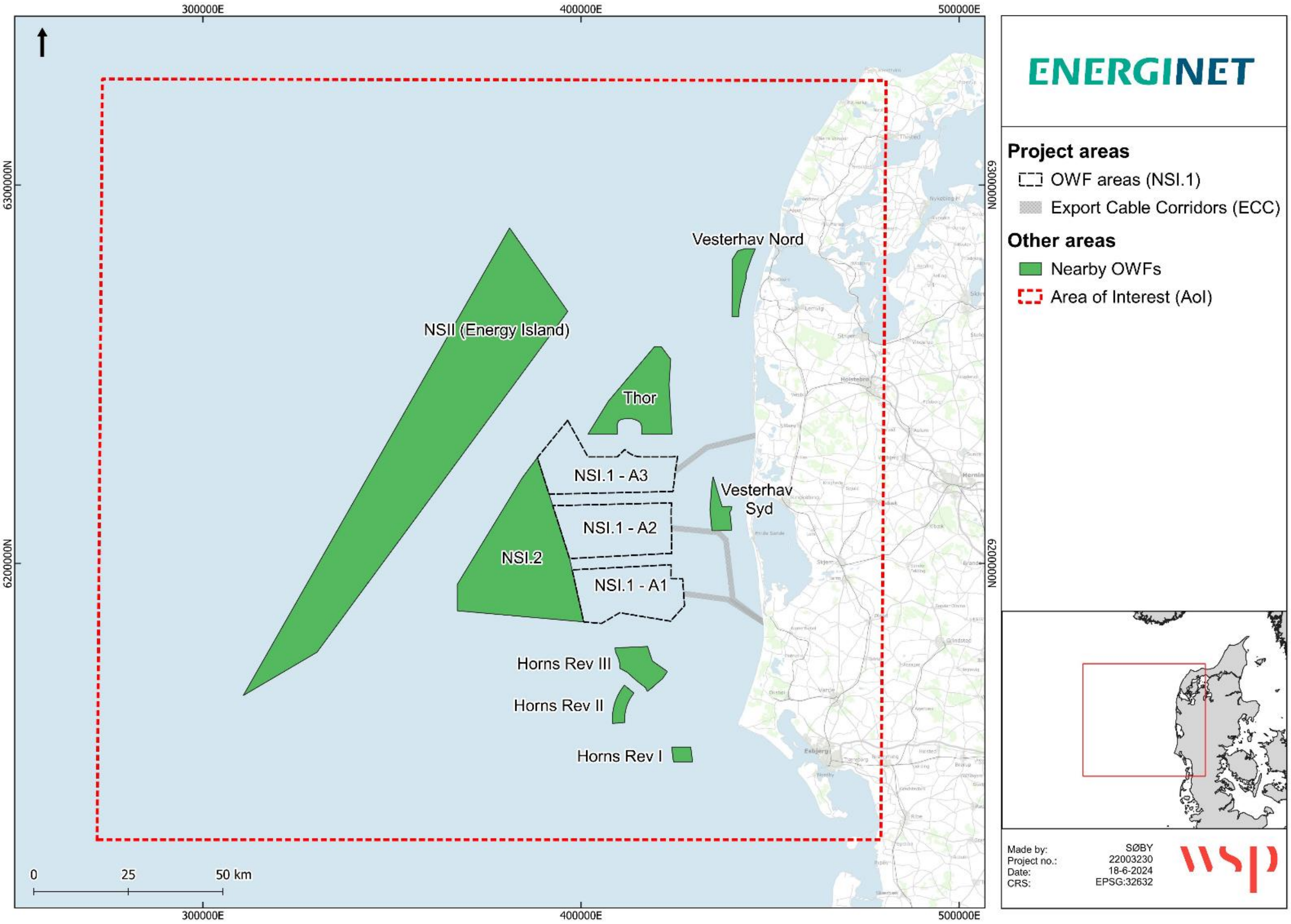


Figure 3-1. Overview of the defined AoI and location of existing and future OWFs in the regional part of the Danish North Sea sector.

3.3 METOCEAN CONDITIONS

The water depth within NSI.1 is ranging from 20-35 m. In general, the water depth is greater to the north (in NSI.1-A3) (>30 m) and lower to the south (in NSI.1-A1) (<25 m) (Figure 3-2). The shallow water towards south is related to the ground of Horns Rev, which is a shallow sandy reef in the eastern North Sea off the most western point of Denmark, Blåvands Huk, where the three Horns Rev OWFs (HRI, HRII and HRIII) are located. Locally, the water depth on top of Horns Rev is around 5-10 m.

Generally, the water depth within AoI increases towards northwest (seawards) and decreases towards east (landwards). Overall, the depth curves are parallel to the shoreline, except in the northwestern corner of the AoI, where the pattern is more irregular. In the northwestern part of AoI, the water depth locally reaches a maximum of more than 60 m. Around NSII, the water depth is about 35-45 m and within NSI.2 there is a local area with a shallower water depth of 15 m (Figure 3-2).

A detailed map of the bathymetry around NSI.1 OWF and in the AoI in general is shown in Figure 3-2.

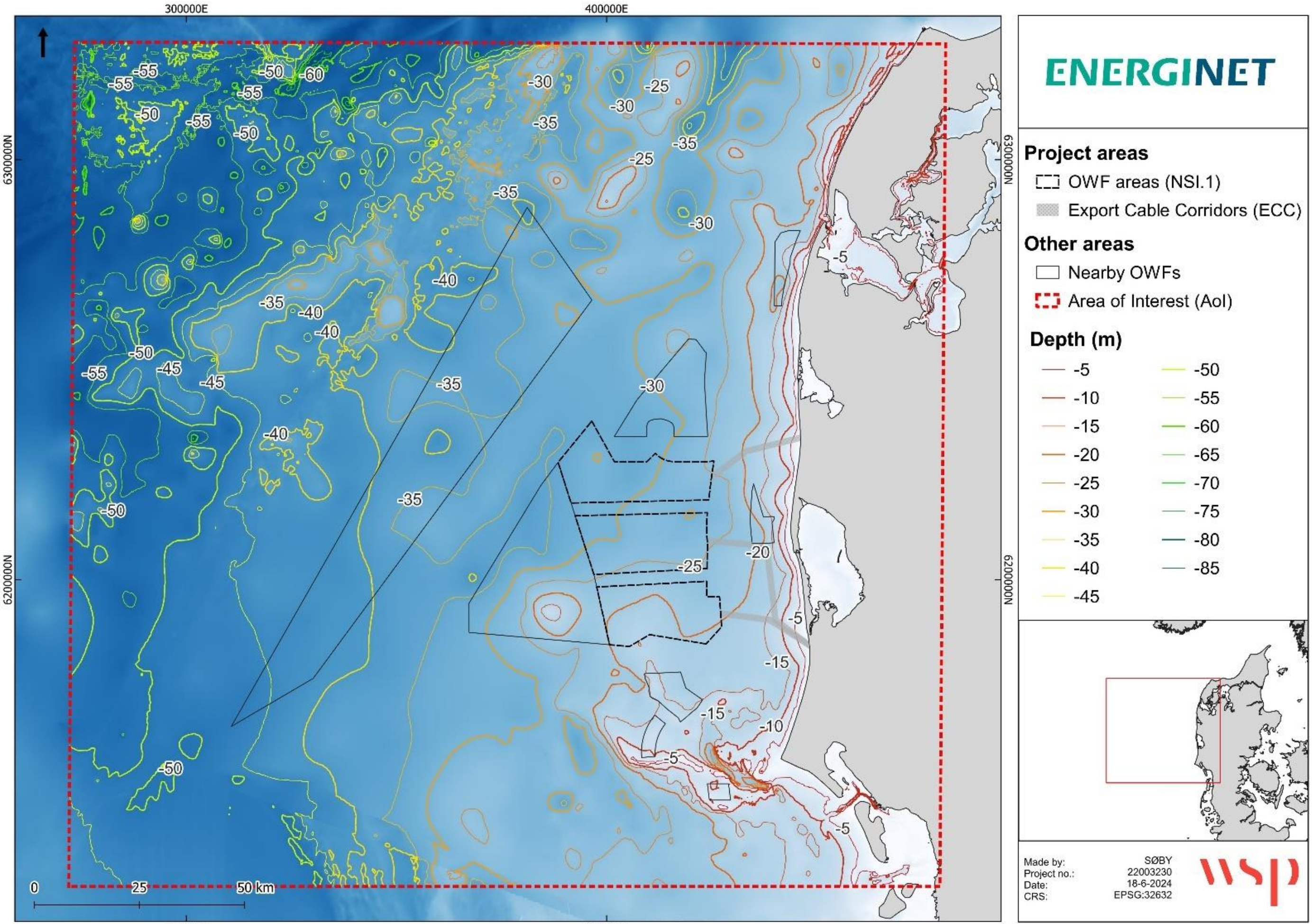
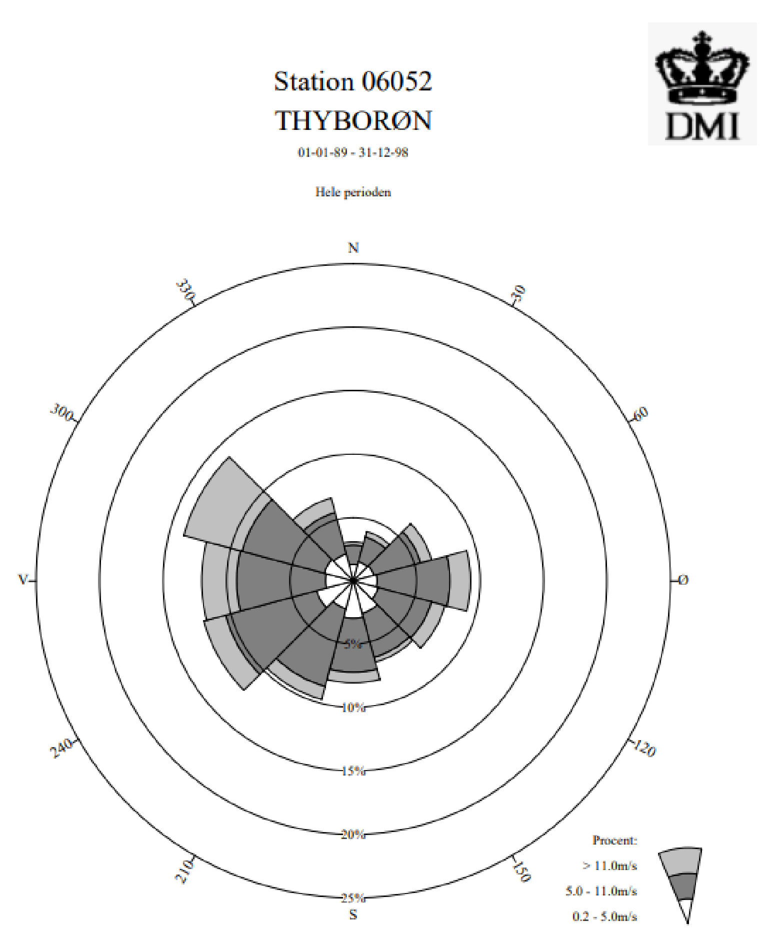


Figure 3-2. Bathymetry around NSI.1 OWF and in the AoI in general. Depths are from EMODnet (EMODnet, 2024).

Wind and current control how vessels are drifting in cause of loss of maneuverability. Typically, these two factors are combined to a so-called drift rose, that indicates the possibility of a ship drifting in a given direction at a certain speed. In contrast to the inner Danish Waters, the drifting pattern in the Danish North Sea Sector is almost exclusively controlled by the wind conditions, while the contribution from sea currents is negligible. For more information about this, see section 4.3.4 and Appendix 3 (see Chapter 16).

Figure 3-3 shows a wind rose that illustrates the wind conditions at Thyborøn over a 30-year period from 1961-1990 (DMI, 1999). The wind rose indicates the direction and frequency of the wind based on the wind measurements at the given location. Additionally, Figure 3-3 shows the percentage distributions of the wind measurements for the different wind strengths.



	N	30	60	Ø	120	150	S	210	240	V	300	330	Ialt
%	3.1	4.0	6.4	9.3	7.5	6.6	8.1	9.7	12.2	12.0	13.8	6.8	99.4
% 0.2-5.0m/s	1.3	1.6	1.7	1.9	2.1	2.7	3.0	2.3	3.0	2.2	2.4	2.2	26.3
% 5.0-11.0m/s	1.5	2.0	3.8	5.7	4.3	3.6	4.2	6.3	7.4	7.0	6.7	3.4	56.0
% > 11.0m/s	0.3	0.4	0.9	1.6	1.1	0.4	0.8	1.1	1.8	2.8	4.8	1.2	17.1
Middel hastighed	6.0	6.3	7.2	7.6	7.2	5.8	6.3	7.1	7.3	8.3	9.2	7.0	7.4
Største hastighed	18.5	22.1	19.0	20.6	20.6	16.5	21.6	20.6	23.7	32.9	30.9	21.6	32.9

Totalt antal observationer = 29201
Vindstille defineret som hastighed <= 0.2m/s
Antal observationer med vindstille/varierende vind: 178 = 0.6%

Kilde: DMI

Figure 3-3. Wind rose for the period 1961-1996 measured at Thyborøn, station 06052 (DMI, 1999).

Overall, the wind measurements show that there is primarily wind from southwest, west and northwest. Strong winds also occur most frequently from these directions with the strongest wind from northwest. Winds from the north and northeast are rare, while easterly winds are more frequent and occasionally relatively strong. NSI.1 is located in open water, which means that the wind landwards is relatively stable in direction and strength. Wind conditions are estimated to be very uniform within NSI.1 compared to the rest of AoI. Strong winds from western directions will contribute to waves building up over a long distance in open waters towards NSI.1.

The sea current along the west coast of Jutland is typically north-south and determined by wind and tide. The reason for the direction of the current is that when the water flow landwards, the current is deflected either south or north as it approaches the coast.

How the above metocean characteristics for NSI.1 and the AoI in general are incorporated into the risk assessment and modelling of collision frequencies, are addressed in section 4.3 (see Table 4-1).

3.4 WATERWAY CHARACTERISTICS

NSI.1 is located in open water in the eastern part of the North Sea in an area characterized by medium to high maritime traffic density. A sea chart with location of the planned NSI.1 OWFs area is shown in Figure 3-4.

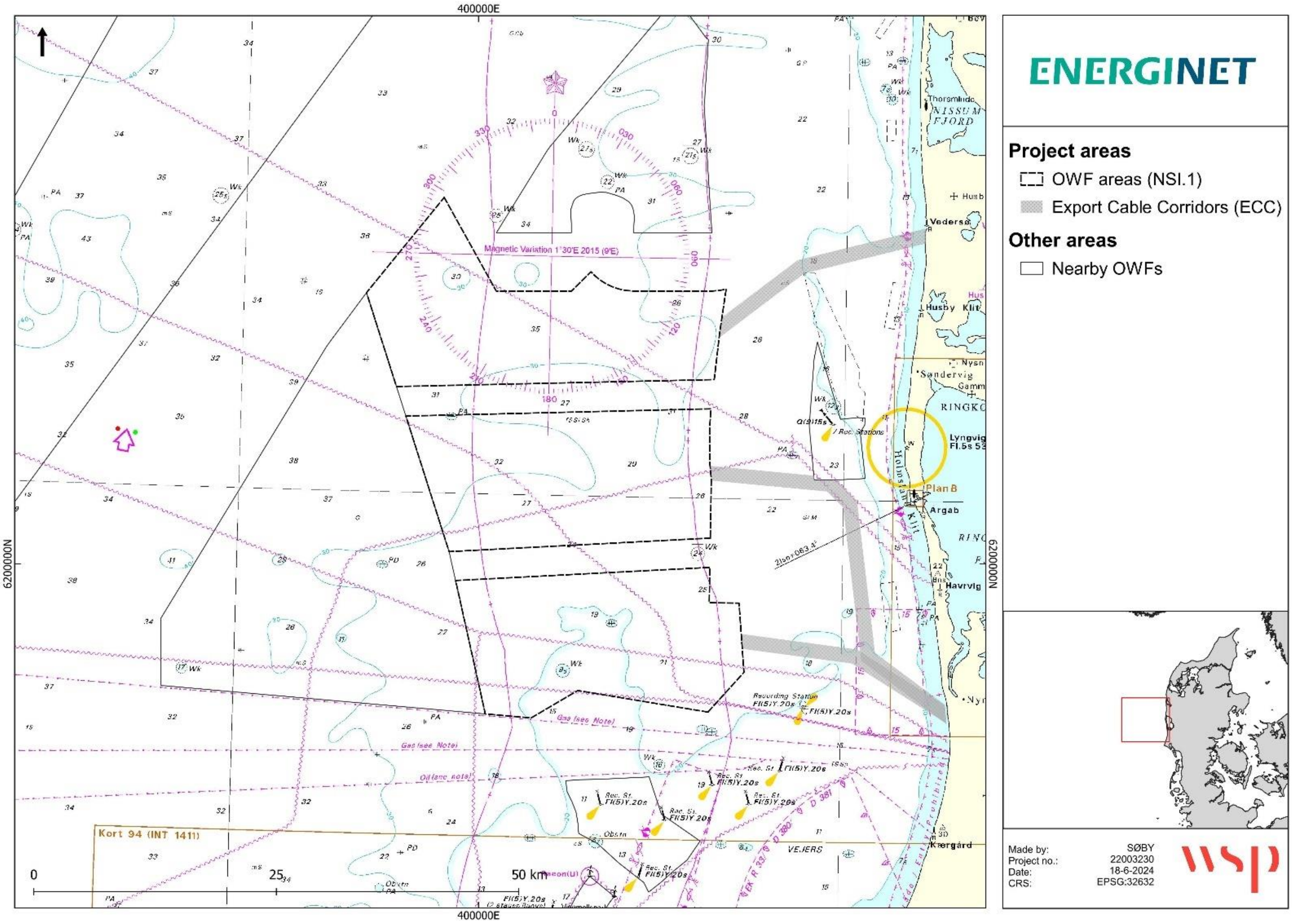


Figure 3-4. Nautical chart for the waters around NSI.1.

The nautical chart confirms that there are no traffic separation systems (TSS) or recommended IMO-routes in the waters around NSI.1. Thus, the present traffic routes do not follow any specific recommendations and designated traffic routes or corridors based on the nautical chart and TSS will not be a part of the IWRAP modelling.

In the North Sea, including Denmark and Germany, there is a 24/7 emergency response which is stationed in several nearby ports on the west coast of Denmark and Germany, where several tugboats and emergency towing vessels (ETV) are ready in case of emergency.

Due to the bathymetric conditions, the maritime traffic is scattered all throughout the open waters around NSI.1 (see section 5.1). Only the shallower waters in the southern part of the AoI (around the ground of Horns Rev) are characterized by less dense flow of maritime traffic. Although the maritime traffic is scattered, it does follow certain traffic routes with high traffic density (see section 5.2). Some of these traffic routes are compatible with the designated shipping corridors in the Danish MSP (see section 3.6). The most important and largest shipping corridor along the Danish west coast (cf. S10 in Denmark's Maritime Plan) runs west of NSI.1, where a very high density of maritime traffic is prevailing. S10 is a major shipping corridor connecting the international traffic between between the English Channel (Southern North Sea) and Skagerrak. The northwestern part of NSI.1 extends approx. 9 km into the main maritime traffic route, and directly borders the shipping corridor (S10) towards NW. Less dominant maritime traffic routes cross the central part of NSI.1 in a S-N direction, intersecting all three areas within NSI.1. The traffic routes that cross the area are both related to maritime traffic west and east of the Horns Rev OWFs. NSI.1 directly borders shipping corridor S146 located between NSI.1 and NSI.2. For more information about nearby shipping corridors implemented in the MSP, see section 3.6. In addition to the above-mentioned shipping corridors and overall maritime traffic pattern, the maritime traffic is related to the nearby harbours (see Figure 5-1), see description below.

The primary harbors in the region are from north to south; Thyborøn, Thorsminde, Hvide Sande, and Esbjerg. The harbors of Hvide Sande and Thorsminde are the closest harbors. The shortest distances to the nearby harbors from NSI.1 OWF are presented in Table 3-3.

Table 3-3. Minimum distance from NSI.1 to nearby harbors along the west coast of Denmark.

Harbor	Shortest distance from NSI.1 [km]
Thyborøn	63
Thorsminde	28
Hvide Sande	20
Esbjerg	56

Thyborøn Port is located at the entrance from the North Sea to Limfjorden. With a strategic location close to both fishing grounds, neighboring countries around the North Sea, gravel extraction areas and the future OWF build-out in the North Sea, the port supports four equally important business areas - fishing, cargo, maritime service, and offshore wind. Thyborøn Harbor is located about 63 km northeast of the NSI.1 area.

Thorsminde is a smaller harbor than Thyborøn and with fewer traffic activities. Since the harbor has the shortest distance to Thor OWF, RWE has chosen Thorsminde Harbor as facility platform (for the operation and maintenance activities (O&M port). Thorsminde Harbor is located about 28 km northeast of the NSI.1 area.

The Port of Hvide Sande supports the maritime transport of goods, fishing, passengers, and other activities that require a port location. Furthermore, it is close to both current and upcoming OWFs in the North Sea. This makes the port attractive as a base for installation and Operations & Maintenance, including crew transport. Hvide Sande Harbor is located about 20 km east of the NSI.1 area.

Port Esbjerg is the largest port along the Danish west coast with several thousand arrivals each year. Port Esbjerg is the world's largest port for offshore wind activities and is an active hub for the offshore industry in the Danish North Sea. Port Esbjerg is located about 56 km southeast of NSI.1 area (straight line).

For a detailed description of the maritime traffic conditions around NSI.1 and in AoI, see Chapter 4.5 “Analysis basis”.

3.5 TECHNICAL SPECIFICATION AND WTG LAYOUTS

In accordance with the project concept, build-out with offshore WTGs is planned in NSI.1, so that a minimum of 3,000 MW and up to 10,467 MW offshore wind can be established with the possibility of division into several park areas. In connection with the strategic environmental assessment, layout scenarios have been prepared with 15 MW and 27 MW turbines, respectively (DEA, 2024). The present navigational risk assessment will be based on the layout scenarios, which include the maximum build-out in the NSI.1 area, the so-called overplanting scenarios (see section 4.4.2 “modelling scenarios”).

The actual number of WTGs has not been determined at this stage and the final WTG layout for NSI.1 will be determined by the future concessionaire(s). Therefore, the actual distance between each WTG is not known - nor is the diameter/size of the WTGs. In order to meet the future project-specific sailing analysis, the present navigational risk assessment is based on an overplanting scenario. Such a scenario is generally based on a WTG layout with many small turbines with less mutual distance between the turbines. The WTG location complies with the requirement that the rotor must be within the outer boundary of the area, which ensures safe sailing conditions in the nearby shipping corridors listed in the Danish MSP i.e. shipping corridor S10 and S146 going west and south of the NSI.1 area, as well as other maritime traffic routes. For the NSI.1 area, the distance to outer boundaries is: 120 meters (assuming a WTG with a rotor diameter of up to 240 meters).

On that basis, the present navigational risk assessment is based on a generic WTG layout scenario with 15 MW turbines and overplanting with 699 WTGs evenly distributed in the NSI.1 area. For this scenario, the distance between the WTGs is at least 1,000 meters. The generated generic WTG layout for NSI.1 area is illustrated in section 4.4.2 "modelling scenarios.

An illustration of a proposed offshore WTG in NSI.1 and related terminology is shown in Figure 3-5. For NSI.1 the rotor diameter is expected to be approximately 240 m with a tip clearance of 25 – 30 m above mean sea level (MSL).

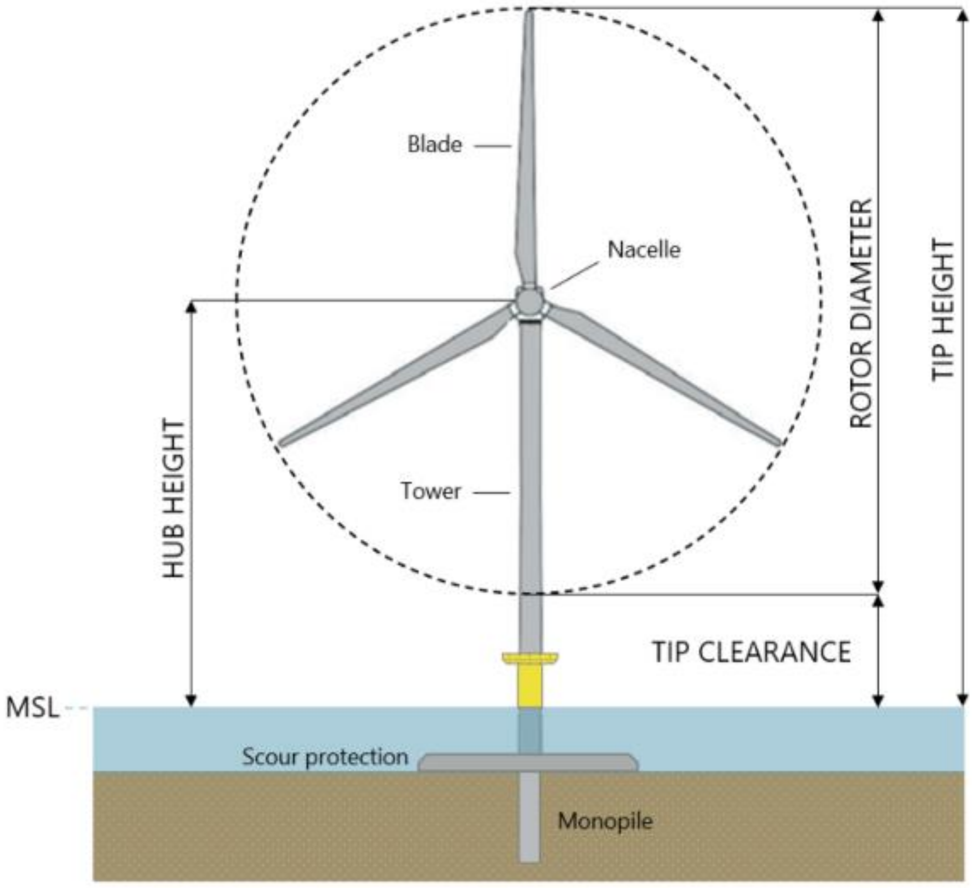


Figure 3-5. Graphic illustration of an offshore WTG with technical designations.

3.6 MARITIME SPATIAL PLANNING

The maritime spatial plan (MSP) implements a holistic spatial planning for the entire Danish marine area i.e. the territorial sea and the Exclusive Economic Zone (EEZ) (Denmark's maritime spatial plan, 2024). The purpose of the MSP is to promote economic growth, the development of marine areas and the utilization of marine resources on a sustainable basis. The maritime spatial plan covers the entire Danish marine area (Denmark's maritime spatial plan, 2024).

The NSI.1 area is located within a larger area reserved in the MSP for renewable energy (Ev) in the North Sea (Figure 3-6). According to the MSP, two primary shipping corridors are defined in the area close to NSI.1 (Figure 3-6). A new SE-NW running shipping corridor is planned between NSI.1 and NSI.2 (cf. shipping corridor S146) which leads maritime traffic from the south into S10, the international shipping corridor. Overall, shipping corridors are the formal designation for designated zones for maritime traffic (Denmark's maritime spatial plan, 2024). The real maritime traffic routes do not necessarily follow these designated zones. Overall, international shipping corridors reflect international maritime traffic in transit between different countries and waters.

Shipping corridor S10, which runs west of NSI.1, is the most important and largest traffic route along the Danish west coast and is characterized by very high traffic density. The NSI.1 area directly borders shipping corridor S146 located between NSI.1 and NSI.2. The northwestern part of NSI.1 directly borders the international shipping corridor (S10) towards NW.

In Figure 3-6, the position of the NSI.1 area and the shipping corridors implemented in the MSP are shown. To the west, large areas of “development zones for renewables energy and energy islands (Ei) are found. The eastern part is related to the planned NSII OWF located west of S10.Thor OWF and NSI.2 is located within the areas of “development zones for renewables energy (Ev) (Figure 3-6).

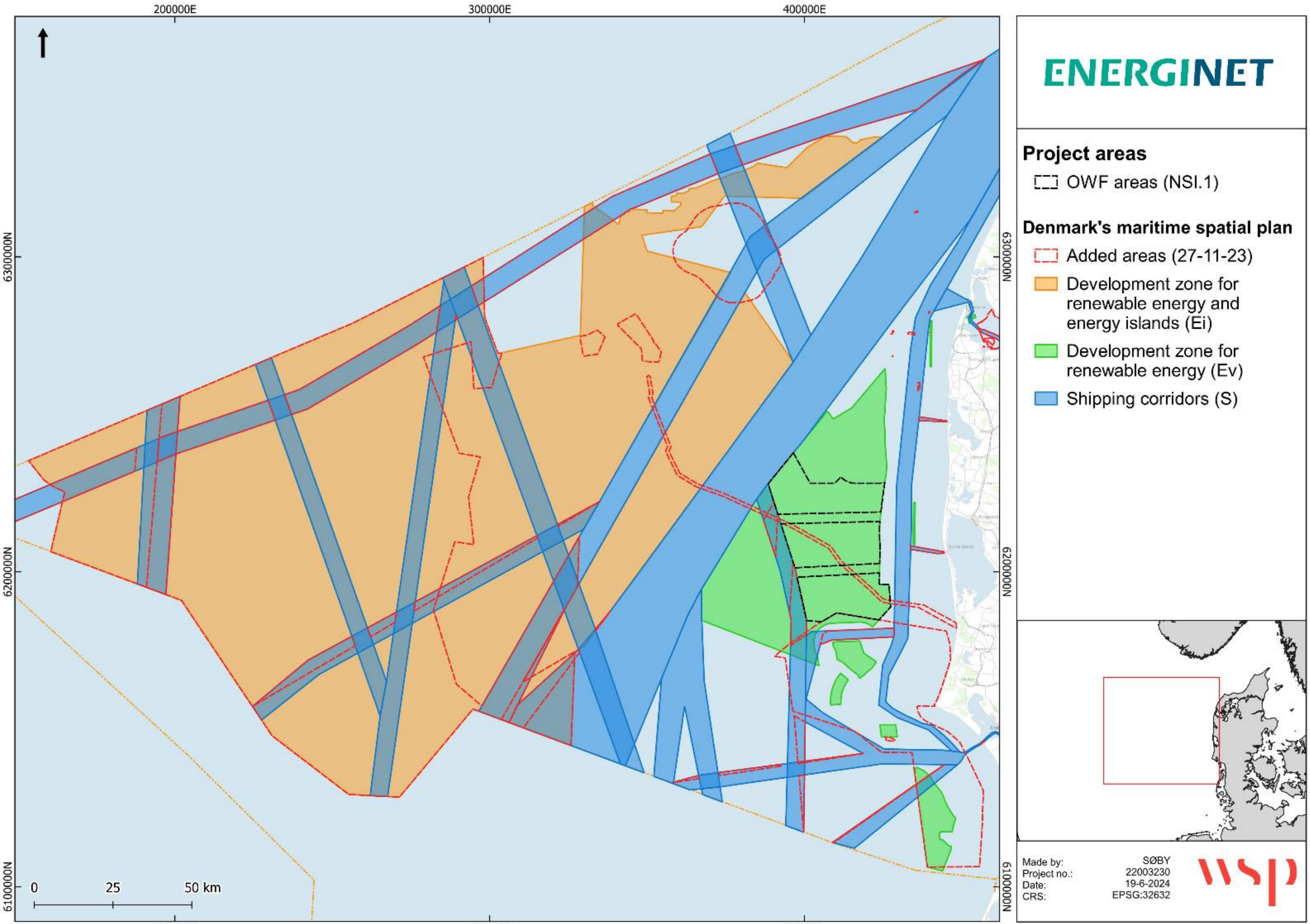


Figure 3-6. Location of the planned NSI.1 OWF areas relatively to Danish Maritime Spatial Planning including shipping corridors (S), development zones for Renewable energy (Ev) and Renewable energy and energy islands (Ei) (Denmark's maritime spatial plan, 2024).

4 METHODOLOGY

4.1 GENEREL METHOD

The assessment of navigational safety has been carried out based on the standard method from the International Maritime Organization (IMO). The IMO has created a guideline for formal safety assessment (FSA), which is used as a framework for risk assessment (IMO, 2018). A schematic illustration of the FSA process and standard risk assessment approach is shown in Figure 4-1. The FSA principles are followed for the early phase of the project; the hazard identification and initial risk assessment, including the effect of recommended risk reducing measures, developed as part of the background information in relation to navigational safety assessment and for a future environmental impact assessment for a specific project.

Figure 4-1. Overall risk assessment process regarding maritime traffic and navigational safety (IMO, 2018).

Generally, the FSA consists of five steps (phases):

1) Identification of hazards (a list of all relevant accident scenarios with potential causes and outcomes)
2) Assessment of risks (evaluation of risk factors)
3) Risk control options (devising regulatory measures to control and reduce the identified risks)
4) cost benefit assessment (determining cost effectiveness of each risk control option
5) recommendations for decision-making (information about the hazards, their associated risks and the cost effectiveness of alternative risk control options is provided).

The above general methodology will be implemented according to the risk evaluation for the NSI.1 area, but also in connection to the three areas (NSI.1-A1, NSI.1-A2 and NSI.1-A3), individually.

The FSA methodology is a process intended for rule making purposes. For this study rule making is not the objective, therefore the steps ‘risk control options’ and ‘cost benefit assessment’, cf. 4) and 5) are excluded from the scope of work.

There are no governing quantitative risk acceptance requirements for the establishment of OWFs. In Denmark, the approval of the navigational risk levels is done as a project-by-project approach by DMA. Therefore, based on the calculated return periods and overall risk evaluation, it is not possible to make a definite conclusion whether the risk is acceptable or not. Instead, calculated accident frequencies combined with the assessed indicative risk index are presented and discussed with the authorities. Based on that, DMA will decide whether the OWF build-out scenarios in NSI.1 are compatible with the overall safety of navigation in the area and decide if any mitigations should be implemented.

4.2 HAZARD IDENTIFICATION

In order to accommodate the above risk assessment methodology regarding hazard identification, a HAZID workshop was carried out. The overall purpose of the workshop was to consult the maritime users of the waters within and around NSI.1 in identifying possible hazards (HAZID), in order to address the effect on navigational safety in relation to the establishment of NSI.1 OWF. The hazard identification presents phase 1 in the overall IMO risk assessment process (see Figure 4-1).

The objective of the hazard identification was to identify and evaluate all relevant hazards associated in relation to the construction and operation and phase, and to assess the sources of the hazards or sets of circumstances, which may cause the hazards, and their potential consequences. Further, the objective was to generate a comprehensive list of hazards based on those events and circumstances that might lead to possible unwanted consequences within the scope of the risk assessment process.

The HAZID meeting was conducted as a workshop event in “Fiskeriets Hus” in Hvide Sande on the 28th of November 2023. This meeting was primarily for Danish maritime stakeholders. The participants represented different stakeholders using the waters around NSI.1, as well as different professions and case officers from both the DEA and the Danish Maritime Authority (DMA), resulting in a broad group of expertise and knowledge to ensure that all relevant risks were identified. In addition, a digital meeting was held on the 15th of December 2023 between WSP, Energinet and the Danish and German maritime authorities (BSH) (international HAZID workshop).

Various aspects of the project were systematically reviewed, for example offshore construction work, cable laying, , operation and maintenance activities, cumulative effects, location of the individual areas, maritime traffic routes, ship types, etc. Each of the three areas were considered individually (i.e. NSI.1-A1, NSI.1-A2 and NSI.1-A3). As NSI.1-A3 is the area that is closest to the main shipping corridor (S10 in MSP), and where the intensity of commercial traffic is greatest, the focus at the workshop was on that area.

At the workshop, it was also discussed how nearby existing, approved and planned OWFs (HRI, HRII, HRIII, Thor, VHN, VHS, NSI.2 and NSII) will individually and cumulatively affect maritime traffic and the overall safety of navigation in the area around NSI.1 and in the AoI in general. These "cumulative effects" will be implemented in the modelling setup and presented risk assessment.

The agenda of the HAZID workshop was divided into two general sessions. In the first session, hazards and accidents – based on a brainstorm and a further development of the HAZID-protocol – were identified (accident and identification). In the second session, the identified hazards and accidents from the first session were risk assessed. For more details on the methodology for the HAZID analysis, see the HAZID report in Appendix 4 (Chapter 17). During the sessions, all participants had the opportunity to ask questions, make comments or provide concrete input to the HAZID-protocol.

A full method description, including the frequency and consequence classes for risk ranking (IMO classes), is provided in the HAZID report for NSI.1 OWF, see Appendix 4 (Chapter 17).

To achieve a comprehensive risk assessment, a detailed explanation and linkage of the potential consequences with frequency calculations (IWRAP) are conducted. Using the Construction Works at Sea scheme from DMA, a qualitative assessment of the consequences and the indicative risk index has been determined (see section 4.5). This will be addressed by including and elaborating on the associated impact assessments in the HAZID protocol.

The results from the HAZID workshop and the integrated HAZID protocol (phase 1) are included and further processed within the current risk assessment (phase 2).

4.3 RISK ASSESSMENT AND INPUT DATA

The maritime traffic and navigational safety are investigated using AIS data (Automatic Identification System), making it possible to quantify the vessel activity in the AoI. AIS data provides a detailed geographic and temporal description of the maritime traffic in a region (see section 4.3.2). AIS data, together with the collected input from the hazard identification (see section 4.2) and bathymetry and wind data (see section 4.3.3 and 4.3.4), form the data basis for the risk assessment. The risk evaluation is based on the 'Guidelines for Formal Safety Assessment (FSA)' published by International Maritime Organization IMO (IMO, 2018).

This navigational risk assessment considers only the risks that the ships, their crews and the marine environment are exposed to. Specific damage to technical structures within the OWF (such as WTGs, cables, transformers etc.) is not the subject of this analysis, unless they are thought to cause consequential damage to seafarers and/or the environment.

A description of the current maritime traffic constitutes the central input for a navigational risk assessment. In this context, AIS data has been used as the primary data basis for addressing the current maritime traffic conditions (scenario 0) (see Chapter 4.5). Scenario '0' refers to the current maritime traffic conditions based on the AIS data from 2022. Because the predominant part of the maritime traffic is following certain traffic routes (waterways) (should not be confused with actual TSS, see section 3.4) or designated zones for shipping corridors listed in the Danish MSP (see section 3.6)), the modelling of the maritime traffic and the associated models of the risk of collisions, allisions and groundings, usually adopts a route-based description of the maritime traffic. The current traffic routes and patterns based on the AIS data is presented in section 5.2.

The following risk evaluation and modelling is done as a comparative analysis, where the risk between different scenarios according to the existing and approved OWFs (HRI, HRII, HRIII, Thor, VHS and VHN) together with the planned future build-out of OWFs in the Danish North Sea sector (i.e. NSI.2 and NSII) in operation is addressed and compared. These different modelling scenarios are described in section 4.4.2.

Based on the calculated frequencies in IWRAP for each modelled scenario, a frequency index will be determined using the CWAS scheme from DMA for each incident type. Consequently, an indicative risk index will be provided for each of the scenarios, addressing different accident types and ship types (see section 4.5).

As earlier mentioned, VHN is not considered impacting NSI.1 regarding maritime traffic and navigational safety, due to geographical distances (see section 3.2).

No hazard identification and risk assessment has been carried out in relation to the decommissioning phase. It is assumed that the implementation of such will be part of a decommissioning plan for each of the OWFs in the area.

4.3.1 IWRAP TOOL

Modelling of the maritime traffic, rerouting and accident frequencies are done using the IALA-recommended software IWRAP MKII version 7.0.0 (hereinafter referred to as IWRAP). IALA stands for International Association of Marine Aids to Navigation and Lighthouse Authorities. Accident frequencies calculated by IWRAP include ship-ship collisions, ship-wind turbine collisions, called allisions, and groundings (coast or shallow waters). This tool has commonly been used in relation to different maritime traffic and navigational risk assessments in Denmark and Northern Europe (e.g. Energy Island Bornholm, Thor, Jammerland, Aflandshage and Nordre Flint OWF etc.).

The IWRAP MKII software calculates the probability of allision, collision or grounding for a vessel operating on a specified traffic route. In relation to groundings and allisions the calculation will be based on both powered and drifting accidents (see section 4.4). Since the majority of maritime traffic is following certain traffic routes (waterways) – which can be more or less well-defined – the modelling of the ship traffic and the associated risk models for allisions, collisions and groundings usually adopts a route-based description of the traffic. The description of the maritime traffic based on AIS is thus used as basis for definition of the routes in the IWRAP-model (see Chapter 6).

A full method description of IWRAP can be found on the IWRAP Mk2 Wiki site. Project settings and parameters for the model are found in Appendix 3 (see Chapter 16). To accommodate modelling in IWRAP, a number of relevant input parameters and data are necessary, which is explained in the following sections (see section 4.3.2 to 4.3.6).

4.3.2 AIS DATA

AIS data is used as basis data to quantify ship movements within the AoI and is the most important data source for the risk calculations and the risk evaluation. The present risk analysis applies AIS-data from all of 2022 (full calendar year) downloaded from DMA, which provides the most relevant and up-to-date traffic patterns in the area. The data set used covers an area of approx. 170x200 km west off Hvide Sande in the North Sea, and is considered adequate for the present risk evaluation and calculations of accident frequencies for the AoI, including the different modelling scenarios regarding the OWF build-out in the Danish North Sea sector (see section 4.4.2).

AIS is a maritime radio system for automatic identification of ships and other units related to shipping. The system works by ships equipped with an AIS transmitter, which frequently sends a digital radio message in the reserved VHF band. The message contains information about the ship's name, geographical location, course, speed and draft. Information about the ship's MMSI number, IMO number, ship type, size, etc. is also available.

Regulation requires AIS to be fitted on board all ships of 300 gross tonnage and upwards engaged in international voyages, cargo ships of 500 gross tonnage and upwards not engaged in international voyages, and all passenger ships irrespective of size. These ships carry the mandatory type A AIS-transceiver.

For military vessels there are no requirements regarding AIS, thus their activity might not be observed. The same applies for smaller vessels such as pleasure boats (recreational traffic), where only a smaller part of pleasure boats is expected to carry an AIS onboard. Not all vessels are correctly registered on their AIS transmitter. Consequently, these vessels have an unknow vessel type and are designated as other vessels in this study.

Ships sailing without an AIS transceiver are not included in the data analysis. Most smaller fishing vessels and leisure crafts do not carry an AIS transceiver, and therefore these ship types will not be represented in the data, and consequently are omitted from the risk quantification. However, smaller fishing vessels and leisure crafts are primarily expected to operate in nearshore waters east of the NSI.1 area. An increasing share of the larger pleasure crafts carry the low-cost alternative of AIS transceiver type B, producing enough data to make representable traffic patterns and routes evaluations for recreational activities. This amount of pleasure crafts is therefore included in the data analysis.

In connection with similar FSA' in inner Danish waters, an upward adjustment of the number of pleasure crafts has been made to compensate for those sailing without AIS. Since the AoI is located more than 20 km from the shore and in the North Sea, these ship types are not expected to have significant activity in this area. Therefore, this adjustment is not considered relevant for the present risk evaluation.

4.3.3 BATHYMETRY

Bathymetry data (depth model) is a necessary input parameter to run the model and is crucial for the calculations of grounding accidents (both powered and drifting). Since there are no grounds or shallow waters below 10 m in the vicinity of the NSI.1 area or the nearby shipping corridors and overall waterways, it is assessed that there is no risks of grounding in the vicinity of NSI.1 or in existing and future OWFs in the Danish North Sea sector. Since IWRAP modelling is based on a larger AoI, the contribution to the grounding frequencies only reflects coastal areas close to the west coast of Jutland and the shallow waters around the ground of Horns Rev.

The bathymetry in the AoI is based on data from Denmark's Depth Model (DDM) (see Table 4-1). The bathymetry dataset is simplified to ensure that the IWRAP tool runs smoothly. Depth curves for 0 m, 10 m, 35 m and 50 m are included in the model. The 10 m curve is especially relevant for groundings, and the 35 m depth curve allows for IWRAP to model the probability for emergency anchoring in case of blackout, engine failure and uncontrolled drifting (Rambøll, Thor Offshore Wind Farm. Navigational Risk Assessment. , 2022). Locally, the water depth is less than 10 m at the ground of Horns Rev (see section 3.3).

The construction of WTGs in open waters will theoretically lead to less drifting groundings, since the drifting ships potentially will collide with a WTG (drifting allision) before running aground (Rambøll, Thor Offshore Wind Farm. Navigational Risk Assessment. , 2022). In general, groundings are difficult to model due to coastal dredging activities that occur close to shore where the water is shallow. Consequently, the total grounding frequency for the different scenarios is probably overestimated.

4.3.4 WIND AND DRIFTING

In cases where a vessel loses propulsion, e.g. blackout and engine failure, it will begin to drift. The drifting direction is partly determined by a drifting rose, which is governed by the prevailing wind direction and speed. The wind rose is from DMI given by wind data measured at Thyborøn (DMI, 1999). There is more recent wind data from Thyborøn, but the data from 1999 is the latest published reference, that shows analyzed and quality-assured wind data for Thyborøn. In connection with a future detailed project-specific navigational risk assessment analysis conducted by the concessionaires, it will be appropriate to implement more recent wind data. The wind rose is adapted into a drifting rose, as the probability of a ship drifting in each direction is given as a percentage by the wind direction from Thyborøn (see Table 4-1). The speed of a drifting ship is set to 1 knot in IWRAP. The distribution used for the drifting rose is also outlined in (Rambøll, Thor Offshore Wind Farm. Navigational Risk Assessment. , 2022). In about 3% of the time, there was no wind measured at Thyborøn. However, this is not included in the model, since the IWRAP software does not support a function of "no wind", cf. Appendix 3 (see Chapter 16). This results in a more conservative model, resulting in slightly higher frequencies for drifting collisions and allisions.

Table 4-1. Metocean characteristics for waters around NSI.1 and data input for modelling in IWRAP.

Data	Characteristics	Modelling in IWRAP
Water depth	The water depth within NSI.1 is around 20-35 m (see section 3.3).	The bathymetry in the AoI is based on data from Denmark's Depth Model (DDM) and is applied in IWRAP, which will affect both powered and drifting groundings.
Prevailing wind direction	Prevalent wind direction is from west (southwest, west and northwest) (see section 3.3)	The prevalent wind direction has been applied in IWRAP, and will affect the drift direction (drift grounding and drift allisions).
Ice	There is no risk of ice in the open waters of the North Sea and will not affect the maritime traffic	Ice is not modelled in IWRAP
Visibility (fog, precipitation)	No available data and not relevant	Visibility is not modelled in IWRAP
Sea current	The speed of the sea current should not pose any additional risks (see section 3.3).	Sea currents are not modelled in IWRAP
Waves	Waves in AoI are assessed to not cause any disturbance to the commercial traffic. Smaller vessels may be affected by waves, as in any other location.	Waves are not modelled in IWRAP

4.3.5 SHIP TYPE CLASSIFICATION

AIS data from DMA contains several unique ship types, which IWRAP organizes into 14 overall ship type categories (IWRAP MK II, 2008). However, when using these AIS data, IWRAP organizes all tankers and cargo ships into two overall groups (see Table 4-2). Ship types 1-8 are often classed together as "cargo ships and tankers", as they follow similar traffic patterns and are all larger ships with significant lengths and draughts. For a more comprehensive list of which ship types IWRAP group into these ship types, see: https://www.iala-aism.org/wiki/iwrap/index.php/Ship_Type_Mapping (IWRAP MK II, 2008).

In the IWRAP analyses, all ships sailing faster than 60 knots have been excluded, as helicopters are included in AIS data and can be filtered out in this way.

Table 4-2. The IWRAP-tool uses the following 14 overall ship type categories (IWRAP MK II, 2008).

IWRAP ship type	Ship code	Description
Crude oil tanker	1	Large and homogeneous group of crude oil tankers
Oil products tanker	2	Oil products carried by this ship type has different properties than crude oil.
Chemical tanker	3	Chemical tankers generally have more separate tanks than other tankers. They carry chemicals which in many cases are dissolved in the ocean when spilled. This is why marginal types such as wine and juice tanks are included here.
Gas tanker	4	Gas tankers present a different risk of explosion than oil and chemical tankers
Container ship	5	Often fast ships categorized as just 'cargo'
General cargo ship	6	Often older and slower ships, also often categorized as 'cargo'
Bulk carrier	7	Large and homogeneous group
Ro-Ro cargo ship	8	Has special stability problems, but also often categorized as 'cargo'
Passenger ship	9	All ships carrying more than 12 passengers, sailing less than 30 knots

Fast ferry	10	All passenger ships sailing faster than 30 knots
Support ship	11	A large group consisting mainly of small and slow work-related crafts. Also includes supply ships, tugs, and pilots.
Fishing ship	12	Most fishing ships do not carry an AIS transponder, but from a collision analysis point of view their presence could be important. The question of whether the ship is fishing or sailing can be filtered out using the sailing speed.
Other ship	13	All other, and undefined ships. Includes naval ships.
Pleasure boat	14	AIS is not obligatory for pleasure vessels smaller than 15 m. The fraction of pleasure boats equipped with (and using) AIS is unknown.

This ship type classification is incorporated in the following navigational risk evaluation and in the basic traffic analysis (see Chapter 4.5).

4.3.6 WTG LOCATIONS AND SHAPE

The specific location of the WTGs in the NSI.1 area (including NSI.1-A1, NSI.1-A2 and NSI.1-A3) are essential data parameters and are included in the model setup. The number of WTGs has an influence on the impact on maritime traffic and will potentially affect both collisions and allisions. If several WTGs are built, each of these potentially could cause disturbances. More WTGs in an area decrease the distance between them, possibly blocking visibility and leading to an increased risk of ship collisions and allisions.

As earlier mentioned, the actual number of WTGs has not been determined at this stage and the final WTG layout for NSI.1 and the other planned OWFs will be determined by the future concessionaire(s). Therefore, generic WTG layouts for NSI.1, NSI.2 and NSII have been generated as input parameters to the IWRAP-model. Calculations of accident frequencies are based on a generic placement of WTGs (various layout scenarios).

The present navigational risk assessment is based on a generic WTG layout scenario with 15 MW turbines and overplanting with 699 WTGs evenly distributed in the NSI.1 area. In this scenario, the distance between the WTGs is at least 1,000 meters. For more information about the various modelling scenarios see section 4.4.2.

The WTG locations are included as individual structures as shapefiles in the IWRAP model. To ensure that IWRAP runs smoothly, each WTG is formed as a square and not a circle. It is assessed that WTGs shaped as squares cause a more conservative model setup resulting in higher frequencies compared to a modelling where WTGs were presented as circles

4.4 MODELLING OF RISK

The modelling of maritime traffic is done in IWRAP-tool. Input from the hazard identification has been considered in the modelling process. IWRAP as a modelling tool is used to calculate the frequency of collisions between ships, or between ships and offshore WTGs (allisions) as well as groundings. Modelling principles and collision models for maritime traffic are described in Appendix 3 (see Chapter 16).

The model is based on three different types of accidents:
- Groundings (when a ship runs aground)
- Allisions, which are collisions between ships and fixed obstacles (WTGs and platforms)
- Collisions between ships

Groundings and allisions
Two types of groundings are modelled; powered and drifting. Powered groundings typically occur due to human error, where the vessel sails aground, while drifting groundings occur in the event of a breakdown or blackout, where the vessel drifts aground.

The modelling of allisions is also divided into powered and drifting allisions. Drifting allisions occur in the event of a breakdown or blackout, where the vessel drifts into a WTG. Drifting vessels are moving slowly at about 1 knot (depending on vessel size and weather conditions), so the impact will be slow and probably the ship will be drifting with the side facing in the forward direction. For smaller vessels, the WTG will probably deflect the vessel or stop it. For very large vessels the consequences can be worse with the WTG being seriously damaged and potentially in need of a replacement.

A vessel coming out of course can potentially collide with a WTG, so-called powered allisions. Relative to the above case of a drifting allision, the velocity impact energies are much higher. Hence, more material damage can be expected from the powered allision relative to the drifting allision.

In the event of engine failure, the ship might anchor and restart the machine before grounding or allision occurs. This is considered in IWRAP. Frequency of groundings and allisions will be affected by the number of structures along the modelled traffic routes, as a ship might collide with a WTG before it runs aground.

Collisions

The modelling of ship-ship collisions, as implemented in IWRAP, are shown in Figure 4-2. Ship-ship collisions are divided into five different types; head-on, overtaking, bend, crossing and merging collisions. Head-on and overtaking collisions occur within one single traffic route. Head-on collisions happens when two ships sailing in opposite directions collide, which can be typical for narrower waterway corridors. Overtaking collisions happens when the passing of two ships sailing in the same direction leads to a collision, and this type occurs more frequently on larger traffic routes, as many different types of ships sail at varying speeds.

Collisions are also modelled in waypoints, where two or more routes meet. Collisions related to crossing routes are called crossing collisions while collisions related to merging/splitting routes are called merging collisions. If a collision occurs in a waypoint where a route changes direction, it is called a bending collision.

All the above-mentioned collision types occurs while the ships are sailing and are thus to be compared with powered allisions and groundings. One or two ships with engine failure or blackout will start drifting and can potentially lead to a ship-ship collision. However, this case is unlikely and therefore ship-ship collisions due to one or two drifting ships are not a part of the IWRAP model.

Establishment of OWFs can affect all types of ship-ship collisions, as the rerouting of maritime traffic can lead to increased traffic in some routes and/or narrowing of traffic routes. Narrower maritime traffic routes will lead to reduced ability for the ships to make evasive maneuvers.

For more details about consequences and risk indices for the different types of accidents is referred to section 10.3.

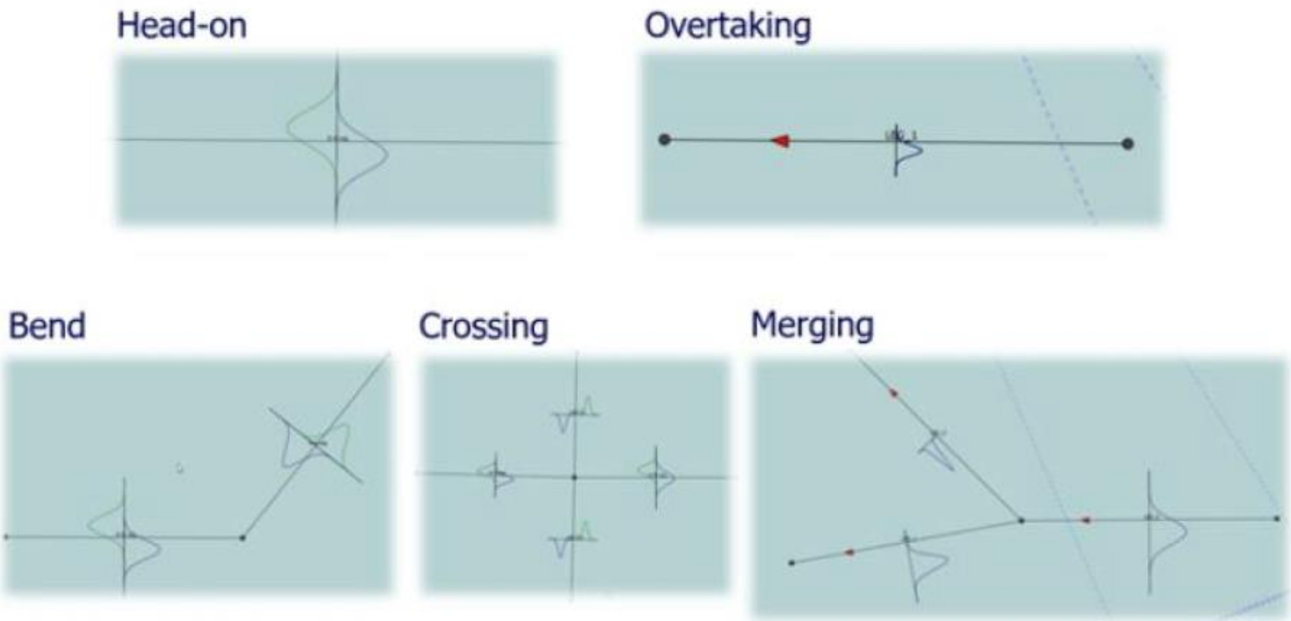


Figure 4-2. The different event types of ship-ship collisions modelled in IWRAP.

Return periods

During the operational phase, allisions from drifting ships and powered ships may occur. In addition, collisions between ships can occur because of increased traffic and changes in traffic patterns (rerouting). Furthermore, groundings may also occur because of traffic rerouting.

A ship that drifts is mostly affected by the direction of the wind. By looking at the direction from which the wind mainly blows in the North Sea, there may be maritime traffic routes which pose a higher risk than other traffic routes. The risk of an accident is stated as a "return period", i.e. the calculated duration between accident events. A higher accident frequency equals a lower return period.

Establishment of WTGs in the NSI.1 area, will influence the way ships in the area navigate and thereby their sailing patterns. The maritime traffic will adapt to the new surroundings (the presence of WTGs), which might lead to more ships (higher traffic density) following the same traffic routes, potentially resulting in a change in the frequency of groundings, allisions and collisions.

4.4.1 FISHING VESSELS AND PLEASURE BOATS

Fishing vessels and pleasure boats do not necessarily follow certain maritime traffic routes or shipping corridors stated in the MSP. Both vessel types can sail within the OWF areas in operation, but fishing vessels are not allowed to undertake trawling activities close to submarine cables (200 m restriction). Other fishing activities may take place within an OWF, if there is sufficient space between each WTG, but it is uncertain to what extend these activities will occur (see section 10.2.2).

During the operational phase, pleasure boats and fishing vessels are allowed to pass through an OWF, and due to relatively large distances (>1,000 m) between the expected WTG locations, it is considered likely to happen. A certain amount of the recreational traffic will probably follow the two sailing corridors between the three OWF areas within NSI.1 mainly related to the traffic pattern in and out of Hvide Sande Harbor (Figure 2-1).

Despite that activities from fishing vessels and pleasure boats are expected to take place within the OWF, this will not be included in the IWRAP modelling. Fishing vessels and pleasure boats will most likely not follow any certain traffic routes. Furthermore, it is uncertain to what extent ship movements related to fishing and pleasure sailing within the OWF area will occur. Thus, fishing vessels and pleasure boats are fully rerouted in the same way as all other ship types as part of the proposed traffic model for each scenario, which consequently gives the most conservative model result.

4.4.2 MODELLING SCENARIOS

A navigational risk analysis is performed based on an overplanting scenario, where offshore WTGs are established in the NSI.1 area (i.e. in the three areas NSI.1-A1, NSI.1-A2 and NSI.1-A3), and where a quantitative calculation of return periods is made for accidents (allision, collision and grounding), using the IALA risk software tool IWRAP.

The following risk evaluation and modelling are done as a comparative analysis, where the risk between different scenarios according to the existing and approved OWFs (the so-called baseline scenario; Scenario 1) together with the planned future build-out of OWFs in the Danish North Sea sector (i.e. NSI.1, NSI.2 and NSII) (scenario 2-4) in operation is addressed and compared. The baseline scenario will be based on existing and approved OWFs (HRI, HRII, HRIII, VHS and Thor) but without the establishment of NSI.1 area. The results from this comparative analysis are presented in Chapter 9 (comparison between scenario 1 and 2) as well as section 14.3 and 15.3 (comparison of scenario 3 and 4 relatively to former scenarios).

The navigational risk analysis for NSI.1 is carried out so that the overall risk evaluation and return period calculations are obtained for the following scenarios:
Scenario 0: This scenario is not modelled in IWRAP. Scenario 0 represents the data basic (cf. AIS data set from year 2022, see Chapter 4.5) related to the identification of waypoints and routes in IWRAP (see Chapter 6) which must be rerouted according to the following modelled scenarios (scenario 1-4). The AIS data is based on 2022 data, which it several years before the establishment of Thor OWF. VHS OWF was partly under construction and operation in 2022, and hence this year do not fully reflect the post construction traffic conditions of VHS. Therefore, scenario 0 (data set) only includes HRI, HRII, HRIII - since they all were in operation in 2022.
Scenario 1: Modelled baseline scenario where WTGs in NSI.1 and other future planned OWF areas are not established, but where the relevant existing / approved OWFs are included (i.e. VHS and Thor) as well as the existing Horns Rev OWFs, cf. scenario 0.
Scenario 2: Modelled scenario with overplanting in the three areas in NSI.1 (NSI.1-A1, NSI.1-A2 and NSI.1-A3), as well as the relevant existing/approved OWFs, cf. scenario 1).
Scenario 3: Modelled scenario with scenario 2) and overplanting build-out of NSI.2
Scenario 4: Modelled scenario with scenario 3) and overplanting build-out of the NSII.

As earlier mentioned, VHN OWF is not included in the modelling scenarios, since it is placed to far from NSI.1 to impact the maritime traffic conditions.

Generic WTG layouts for NSI.1, NSI.2 and NSII have been generated as input parameter to the IWRAP-model. Calculations of accident frequencies are based on generic placement of WTGs (various layout scenarios). Further, the calculations of accident frequencies (allision, collision and grounding) are based on AIS-data from 2022 (see section 4.3.1). For Thor and VHS, the WTG layouts are based on actual planned WTG locations received from RWE and Vattenfall.

The generated generic layouts are based on different input parameters and assumptions, which include:
NSI.1: Generic layout with a minimum distance of 1,000 m between each WTG (overplanting scenario). For the NSI.1 areas, the minimum distance to the outer area boundary is 120 meters (assuming a WTG with a rotor diameter of up to 240 meters).
NSI.2 and NSII: Generic layout with a minimum distance of 1,200 m between each WTG in NSI.2 and NSII (overplanting scenario). For the NSI.2 and NSII areas, the minimum distance to the outer area boundaries is 160 meters (assuming WTG with rotor diameter up to 320 meters).

In IWRAP, the diameter of the monopiles was used in the collision frequency modelling. The following diameter were used for the different WTGs in the different OWFs: **NSI.1:** 12 m diameter; **NSI.2**: 18 m diameter; **NSII:** 18 m diameter

The generated generic WTG layout for the different OWFs is presented in Figure 4-3.

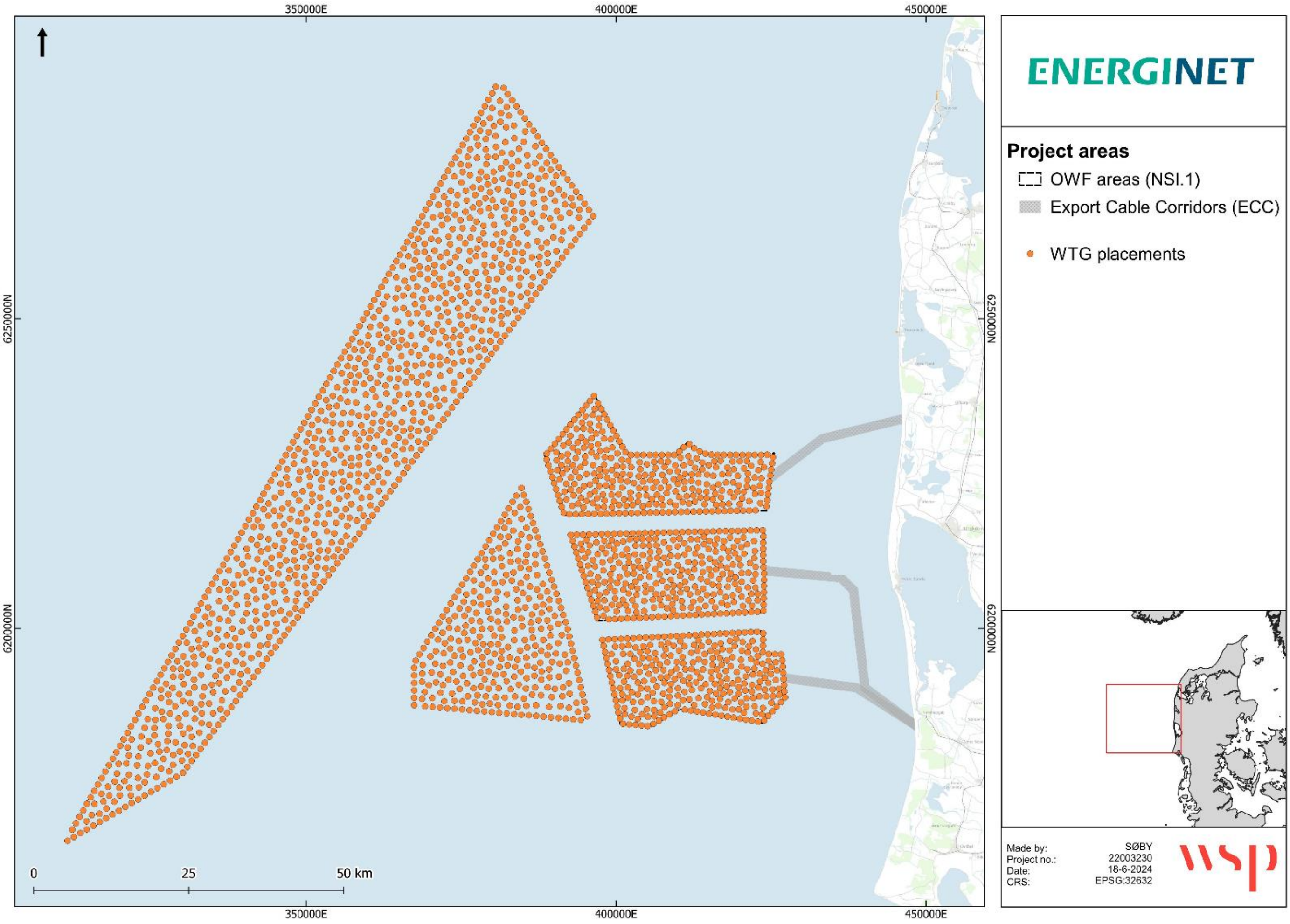


Figure 4-3. Generic WTG layout for NSI.1, NSI.2 and NSII (WTGs are strongly oversized for visualization).

4.4.3 TRAFFIC REROUTING

In IWRAP, the maritime traffic routes are described by a series of waypoints connected by legs. On each leg, the number of vessels as a function of size and type and their overall spreading, are defined. The present risk analysis applies AIS-data from the year 2022, where traffic routes are identified and described by legs and waypoints and referred to as scenario 0 (see Chapter 6). The construction of future OWFs will affect the marine traffic conditions around NSI.1 and in AoI in general, as it is in scenario 0, and thus there must be performed a traffic rerouting for each scenario (i.e. scenario 1-4) (see Chapter 7-8 as well as section 14 and 15).

The traffic rerouting is done by modifying legs that cross a given OWF. In some cases, it is assessed that the traffic in a leg will move to avoid crossing the OWF. In these cases, the leg is slightly moved. Further, the traffic in legs can be rerouted, whereby all or a part of the traffic in each leg is rerouted to an existing leg or a newly defined leg. After this rerouting the original leg are deleted. Additionally, waypoints can be deleted or added, where new intersections occur.

For each scenario there will be a detailed statement of the individual steps that describes the traffic adjustments based on the development from one modelled scenario in IWRAP to another (called traffic modelling and rerouting). This adjustment includes rerouting and movement of legs and waypoints according to the stepwise build-out of planned OWFs in the Danish North Sea sector. In these sections there will be tables presenting the proposed rerouting which leads to the final proposed model setup for each scenario. The specific traffic movements according to movements of legs and/or waypoints are just described within the text.

4.4.4 TRAFFIC DISTRIBUTIONS

The maritime traffic in each leg distributes in a specific pattern that varies in the leg cross section in both directions and is defined by one or more lateral distributions. Information about these distributions is extracted from the AIS data in 2022. Some of the original lateral distributions has an excessive wide tail, which has arisen during the extraction from the AIS data. The excessive wide tails can cause improbable groundings, allisions and collisions during the modelling. Therefore, distributions with excessive wide tails have been narrowed to reflect the realistic lateral distribution of traffic in these legs. This adjustment has only been carried out in scenario 1, since the following scenarios is based upon the scenario before.

In each scenario, the distributions in all legs have been assessed to examine if the distributions should be adjusted or not. Existing legs that are not affected by the construction of the planned OWFs in the corresponding scenario, will maintain their lateral distributions from the former scenario. As the maritime traffic is rerouted, either by being moved slightly or moved into completely new legs, the default distributions of traffic may change.

Legs that have only been altered slightly will maintain their former lateral distribution.

The traffic distributions of heavily affected legs will be assessed based on the specific leg and the distance to an OWF. In general, it is expected that the traffic in these legs will distribute as in the former scenario. However, in some cases the normal or uniform distributions have been narrowed, if the leg is near a planned OWF.

New legs have no baseline data and are therefore added distributions. Following the description of lateral distribution of traffic (ABL A. , 2021) these added distributions are implemented as a new normal distribution in each direction in new legs. If the traffic pattern shows a natural separation of the two traffic directions (see separation detected, Figure 4-4 right), this is maintained in the new traffic distributions. In open sea, the distribution will be wider (have a larger std. dev.) compared to more confined routes (ABL A. , 2021). This is illustrated below in Figure 4-4.

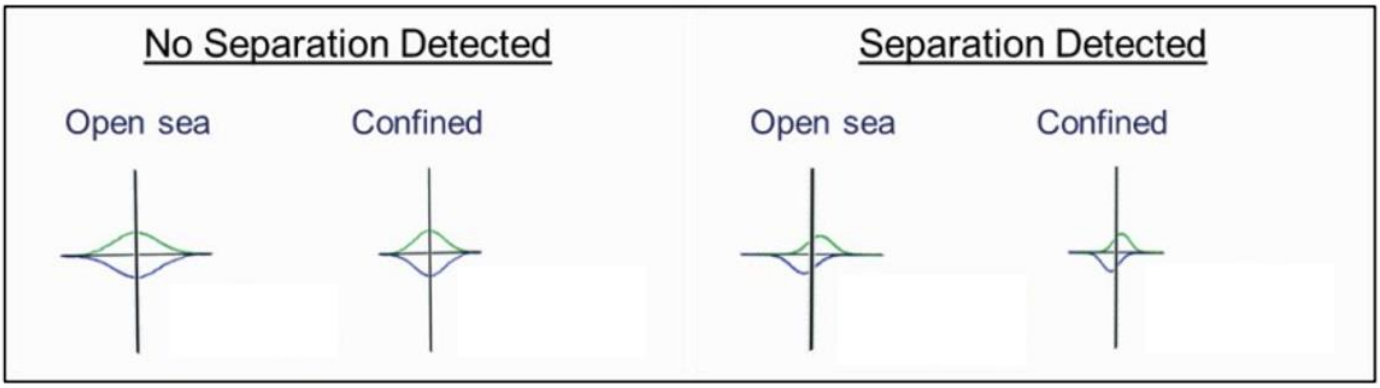


Figure 4-4. Lateral maritime traffic distribution of new or heavily affected routes. From (ABL A. , 2021).

In some legs a uniform distribution is added on top of the normal distribution to include traffic not following the normal distribution but sailing along the boundary of the route.

In new legs which are confined by an OWF on both sides, two uniform distributions, one on each side, is added in each direction. The two uniform distributions allow for a small amount of traffic to travel close to the OWFs, and the normal distribution allows most maritime traffic to pass with the greatest distance possible from the OWFs (the distributions are weighted 94%, 3% and 3% respectively). About 10% of the tail of the normal distribution was chosen to enter the OWFs, to account for ships that might still travel into the OWFs, which specially applies for fishing vessels and pleasure boats.

4.4.5 CONSTRUCTION PHASE

In order to calculate an actual risk of accident during the construction phase, it is necessary to know the overall construction plan for NSI.1. For instance, it is necessary to know how many vessels are working in the area during the construction phase, how often they sail to port and to which port they sail. In connection with the cable laying work near the coast and along the export cable corridors during the construction phase, there is a risk of collision between cable installation vessels and other maritime traffic. Installation vessels can be both stationary during cable laying and in transit, where they cross the traffic routes.

In connection with the shipping of building material and other elements to work areas, the transport of heavy traffic from the work port to the construction areas during the construction phase are increased. These work vessels can collide with the existing maritime traffic. In connection with crew transport (Crew Transfer Vessel, CTV) and service operation vessels (SOVs) out to the work areas, there is regular traffic of fast-moving crew vessels during the construction phase, which can also collide with existing maritime traffic.

The above-mentioned navigational risks according to the construction phase are qualitatively assessed in the HAZID report (see Appendix 4, Chapter 17) and is also described in section 10.1.

The navigational risks according to the construction phases of each of the OWFs in the NSI.1 area are not part of the present navigational risk assessment. Specific navigational risk assessments will be performed by the developers (concessionaires) of the OWFs, as part of the approval procedure for the specific projects.

4.4.6 OPERATION PHASE

In connection with service maintenance of the WTGs and other technical structures of the OWF, during the operation phase, there will be regular traffic of fast-moving crew vessels (Crew Transfer Vessel, CTVs) and service operation vessels (SOVs) between the OWF and service harbors. Further, the ongoing maintenance of the WTGs and submarine cables will generate some additional ship traffic in the area. As for the construction phase, the CTVs and SOVs can collide with existing ships, but as the extent of service and maintenance surveys are expected to be limited, they are assessed to have only a negligible impact to the overall risk in the area.

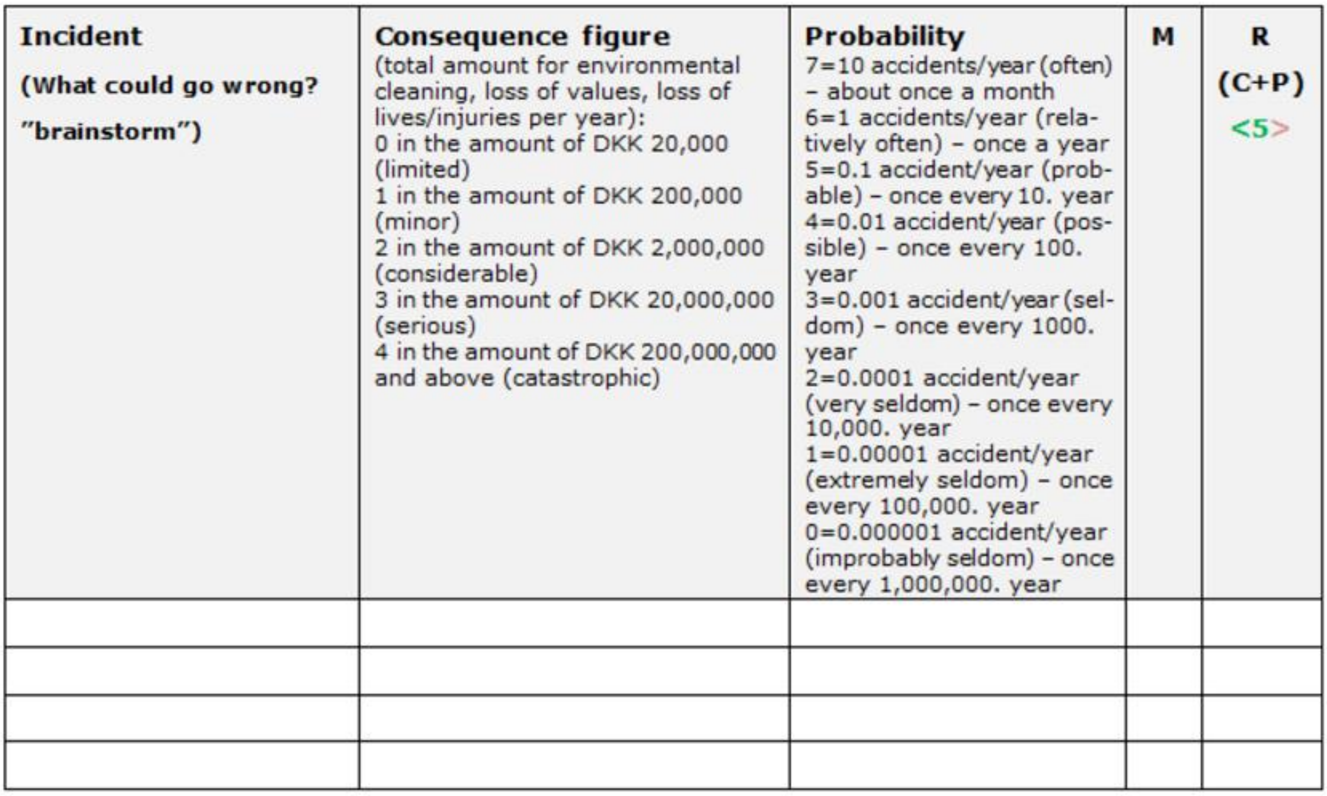
The above-mentioned navigational risks according to the operation phase is qualitatively assessed in the HAZID report (see Appendix 4, Chapter 17).

The navigational risks according to the operational phases of each of the OWFs in the NSI.1 area are not part of the present navigational risk assessment. Specific navigational risk assessments will be performed by the developers (concessionaires) of the OWFs, as part of the approval procedure for the specific projects.

4.5 CONSEQUENCES AND INDICATIVE RISK INDEX

A qualitative assessment of incident consequences is performed using the DMA CWAS scheme, referencing bullet 19, which results in an indicative risk index. This scheme is known as the “Assessment of safety of navigation in connection with marine construction works (Figure 4-5). Consequences are classified on a scale from 0 to 4, indicating the severity from limited to catastrophic damage. The frequency of incidents is classified using a probability scale from 0 to 7, where a frequency of 3 represents a rare occurrence, and a frequency of 5 indicate a probable occurrence.

In general, this risk assessment method follows IMO and has also been used during the hazard identification (see table 1 and 2 in the HAZID report, see Chapter 17). In the HAZID protocol, consequence is categorized into three distinct areas: person, property and environment. The consequence figure stated in the indicative risk index presents an average consequence and this is combined with the estimated frequencies to produce the indicative risk index (Figure 4-5).



Incident **(What could go wrong?** **"brainstorm")**	**Consequence figure** (total amount for environmental cleaning, loss of values, loss of lives/injuries per year): 0 in the amount of DKK 20,000 (limited) 1 in the amount of DKK 200,000 (minor) 2 in the amount of DKK 2,000,000 (considerable) 3 in the amount of DKK 20,000,000 (serious) 4 in the amount of DKK 200,000,000 and above (catastrophic)	**Probability** 7=10 accidents/year (often) – about once a month 6=1 accidents/year (relatively often) – once a year 5=0.1 accident/year (probable) – once every 10. year 4=0.01 accident/year (possible) – once every 100. year 3=0.001 accident/year (seldom) – once every 1000. year 2=0.0001 accident/year (very seldom) – once every 10,000. year 1=0.00001 accident/year (extremely seldom) – once every 100,000. year 0=0.000001 accident/year (improbably seldom) – once every 1,000,000. year	**M**	**R** **(C+P)** <5>

Figure 4-5. Danish Maritime Authority's risk assessment scheme concerning Construction works at Sea (CWAS). M represents recommended mitigation measures whereas R represents risk index. The risk index equals consequence index (C) + frequency index (probability) (P). The incident represents the different types of accidents (collision, grounding and allision).

The indicative risk index generated in this study does not consider the implementation of specific mitigation measures. However, the evaluation of the various identified risks does take into account the effects of implementing these mitigation measures. The purpose of determining this risk index is to demonstrate that it is feasible to build-out offshore wind farms in the NSI.1 while maintaining navigational safety at an acceptable level. Furthermore, the risk index can be used as a data basis for future project-specific risk assessments conducted by the concessionaires.

Indicative risk indices for the various incidents (e.g. collision, allisions and groundings) for scenario 1 and 2, are presented in section 10.3. Generally, a risk level of 5 or less is considered acceptable (see CWAS scheme) and risk levels above 5 typically requires implementation of mitigation measures.

5 ANALYSIS BASIS (SCENARIO 0)

The hazard identification and navigational risk assessment are based on AIS data from the calendar year 2022 and the data set within AoI covers an area of 170x200 km in the Danish part of the North Sea around the NSI.1 area. In this chapter, density maps of maritime traffic for different vessel types illustrating the current maritime traffic conditions are shown. Basically, a traffic density map indicates the intensity of maritime traffic through a certain area and highlights the main maritime traffic routes (traffic pattern) used by the maritime traffic. The maritime traffic routes are defined in agreement with the discussed routes and patterns in the hazard identification (see Appendix 4, Chapter 17).

5.1 CURRENT MARITIME TRAFFIC

The density plot for all ship types is shown in Figure 5-1. This plot shows areas with low and dense density of maritime traffic and thereby indicates the most important maritime traffic routes around NSI.1 and in the AoI in general. Also shown are OWF areas and development zones for renewables and energy islands (either existing, approved, under development or in early planning), that are covered by this navigational risk assessment. The density plot is based on AIS records from 2022 obtained from DMA.

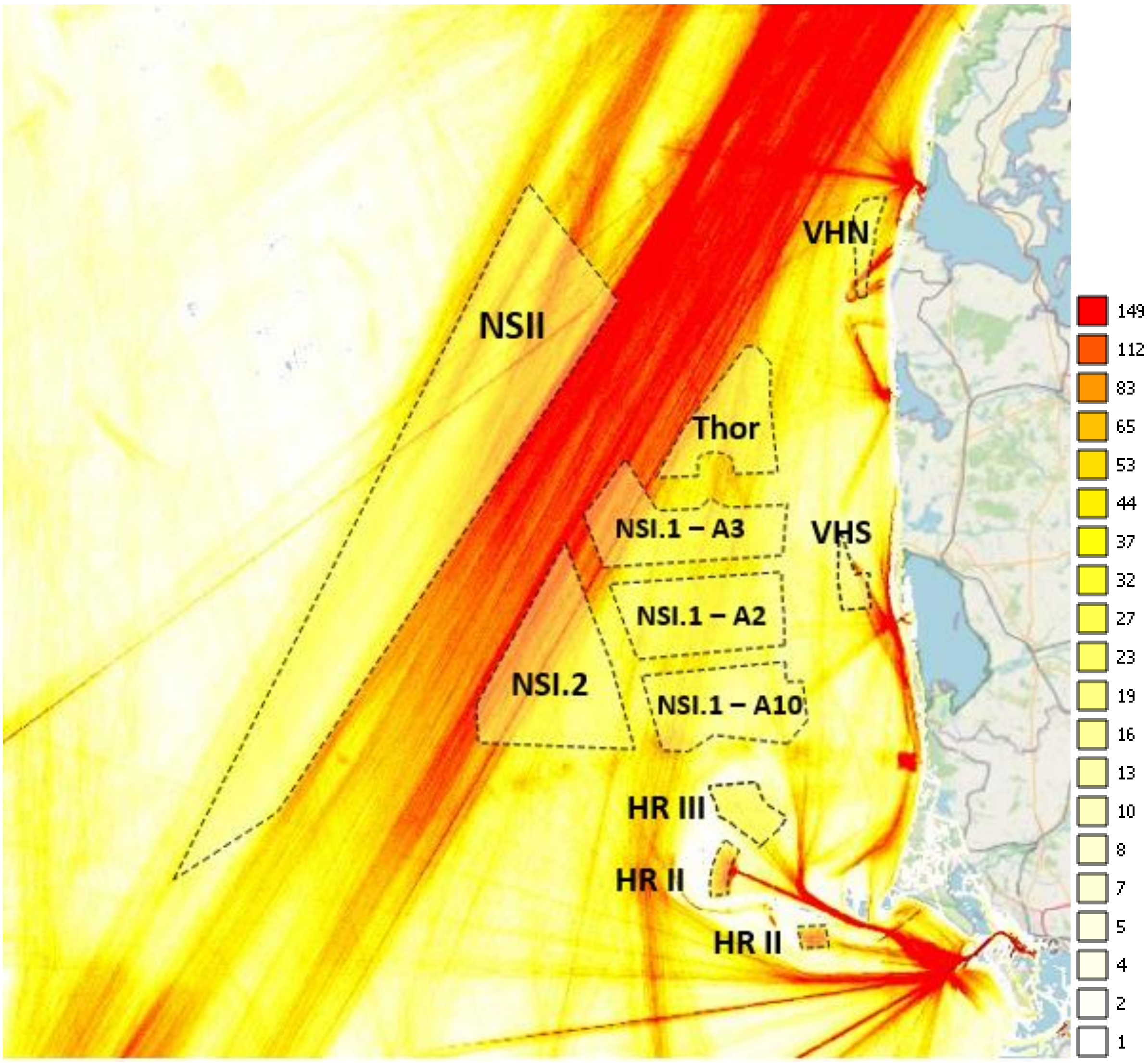


Figure 5-1. Traffic density map of all ship types in the AoI around NSI.1. The colours represent the number of ships passing through each cell (50 x 50 m) in the year 2022 (see legend). OWF areas and development zones for renewables and energy islands are included.

Densities based on most frequent ship types are also showcased in Figure 5-2. Based on the distribution of the different ship types it is possible to map the current maritime traffic pattern and waterway characteristics.

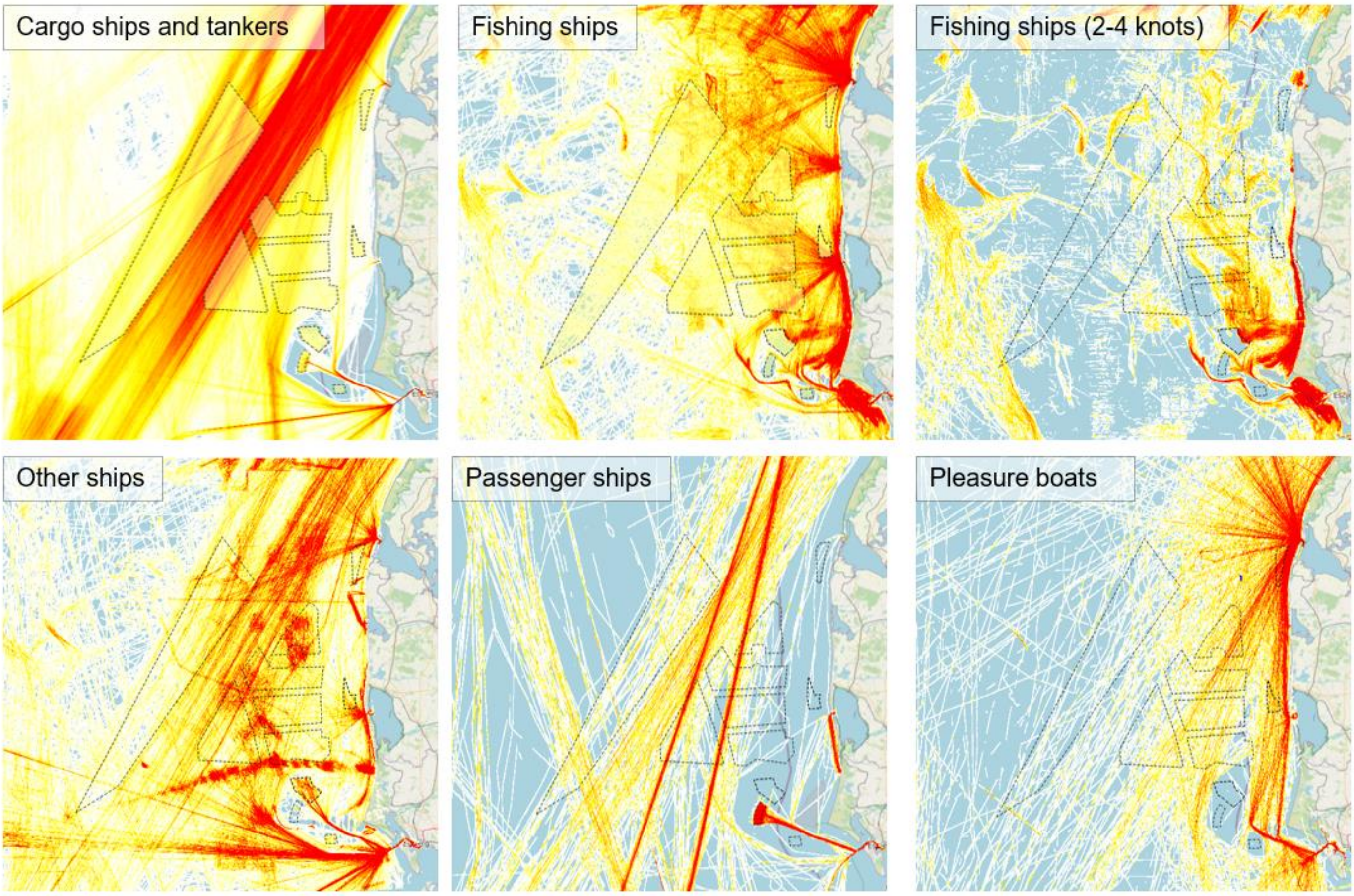


Figure 5-2. Traffic density maps related to the most relevant and frequent ship type categories. Cargo ships and tankers: 0-125 ships per cell in 2022. Fishing ships 0-19 ships per cell in 2022. Passenger ships 0-8 ships per cell in 2022. Pleasure boats 0-7 ships per cell in 2022.

Initially, it can be concluded, that NSI.1 is located in an area characterized by medium to high density of maritime traffic (reddish colors). Overall, the density of maritime traffic is highest in the northwestern part of NSI.1 and lowest in the southern part. The lower density towards south is due to the shallower waters related to the ground of Horns Rev (Figure 5-1).

The most important and largest maritime traffic route along the Danish west coast (cf. shipping corridor S10 in MSP) runs west of NSI.1 orientated SW-NE, and a very high density of maritime traffic is recorded in the northwesternmost part of the area, primarily in the northwestern part of NSI.1-A3. Less dominant maritime traffic routes cross the central part of NSI.1 in a S-N direction, intersecting all three areas within NSI.1. For more information regarding the specific maritime traffic routes, see section 5.2.

5.1.1 CARGO SHIPS AND TANKERS

The most dominant ship type within NSI.1 is cargo ships, followed by fishing vessels and tankers, respectively (see Figure 5-2). Overall, the largest cargo and tanker ships follow the major maritime traffic route west of the NSI.1 area (shipping corridor S10). The maritime traffic on this route is primarily related to international traffic between the English Channel (Southern North Sea) and Skagerrak, cf. Route 1, 2 and 4 in section 5.2. The maritime traffic that follows this route is widely scattered and sails closely along an approx. 26 km wide traffic route (reddish colors in Figure 5-1). The actual width of shipping corridor S10 west of NSI.1, as designated in the MSP, is approx. 17 km (see Figure 3-6)

Smaller commercial tankers and cargo ships also sail through NSI.1 (see Figure 5-1, cargo ships and tankers), cf. route 3 in section 5.2. This maritime traffic is related to routes to and from Northern Germany (e.g. Hamburg, Bremerhaven, Cuxhaven).

The maritime traffic that sails through the NSI.1 area is also related to traffic to and from the Port of Esbjerg. Route 3 is related to traffic which sail west of the existing Horns Rev OWFs. A smaller proportion of tankers and cargo ships to and from Esbjerg Harbor sail east of the Horns Rev OWFs and east of NSI.1, cf. Route 7 in section 5.2. As there are generally few tankers that call Hvide Sande Harbor, there are only a few tankers that cross the area (crosses Route 7) in an east-west direction (cf. Route 5 – In/Out Hvide Sande).

5.1.2 FERRIES AND DREDGING VESSELS

The AIS data used from 2022 shows that there was a ferry route through the western part of NSI.1 related to the Eemshaven-Kristiansand ferry route (see in Figure 5-2, passenger ships). The ferry company Holland Norway Lines, which started the ferry connection between the Netherlands and Norway in April 2022, has subsequently gone bankrupt. There is no indication that another shipping company should have resumed this ferry route, meaning that ferries are not currently expected to sail through NSI.1. Several passenger ships sail just west of the area following the maritime traffic pattern within the shipping corridor of S10 (cf. Route 1, in section 5.2.1).

The analysis of AIS data shows that dredging vessels are sailing within the AoI. In IWRAP, dredging vessels are included in the ship type category called “support ship” as “supply ships” (see Table 4-2). Thus, it is not possible to extract sailing patterns individually for dredging vessels. However, based on a total plot for all support ships it is possible to address some overall waterway characteristic related to dredging activities.

The waterway characteristics for support ships based on AIS data from 2022 are presented in Figure 5-3. Overall, dredging vessels sail between Port of Esbjerg and several raw material extraction sites on Jyske Rev north of NSI.1 and Thor OWF. This maritime traffic goes directly through the NSI.1 area, mainly in the eastern part and is partly related to Route 7 (see section 5.2.7). Dredging vessels also sail from Thyborøn and Hanstholm to Jyske Rev (see Figure 5-3), however this is not relevant for present navigational risk assessment.

Other dredging activities are seen along the west coast of Denmark (see Figure 5-3). Here the dredging vessels sail in and out of harbors of Hvide Sande (cf. Route 5 in section 5.2.5), Thorsminde (cf. Route 6 in section 5.2.6) and Thyborøn. The density map illustrates that the dredging vessels are dumping their sediment load along the shoreline. The maritime traffic related to dredging activities in and out of Thorsminde and Hvide Sande are not necessarily affected by traffic rerouting around the NSI.1. area, but the dredging might be affected during cable-laying activities during construction phase, since the dredging vessels crosses the planned export cable corridors (Figure 2-1).

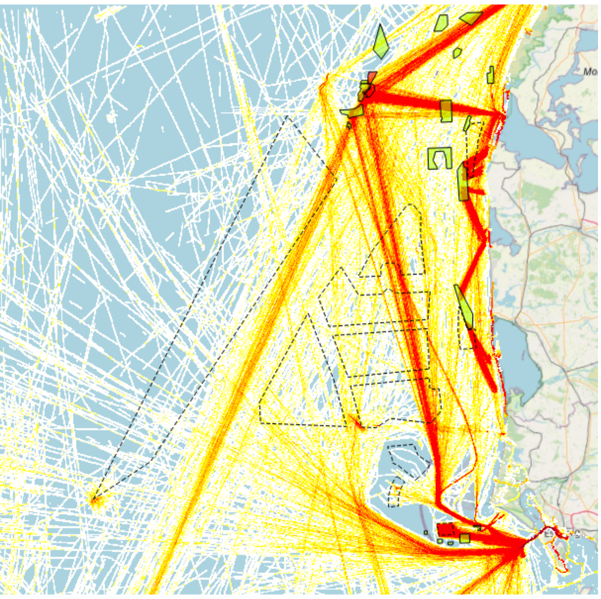


Figure 5-3. Density map for support ships within the AoI. Marked with green are nearby marine extraction area for sand and gravel.

5.1.3 FISHING VESSELS AND PLEASURE CRAFTS

Within the AoI, cargo ships and tankers generally follow certain and larger shipping corridors in open waters, while fishing ships and pleasure crafts cannot be allocated to specific lanes (see Figure 5-2, fishing ships and pleasure boats). Basically, fishing vessels and pleasure boats are considered non-transit vessels.

Fishing ships sailing at 2-4 knots indicate where the vessels fish, and not just where they are in transit to and from harbors (see Figure 5-2, fishing ships 2-4 knots). Most of the NSI.1 area is dominated by fishing vessels in transit, however the fishing activities (low speed indicator) tend to be prevailing in the southern and eastern part of NSI.1. Therefore, fishing activities tend to be more common in NSI.1-A1 relative to NSI.1-A3.

Basically, the density of pleasure crafts and fishing vessels are larger closer to the coast relative to the deeper parts of the AoI. The opposite applies for commercial traffic (cargo ships, tankers and passenger ships) (see Figure 5-2). The number of pleasure boats is greatest outside the NSI.1 area along the shoreline, however, there tend to be some transit of pleasure boats along the SW-NE going routes within the NSI.1 area. This may be due to errors in reporting the ship type.

5.1.4 OTHER SHIPS

Other ships can include search and rescue vessels (SAR), coastal surveillance, survey ships, military ships, offshore related ships, etc. Other ships may also be related crew transport (CTVs), as well as other service and maintenance vessels (SOVs) related to operation of existing OWFs in the North Sea (see Figure 5-2, other ships).

5.2 CURRENT MARITIME TRAFFIC ROUTES

The most dominant maritime traffic routes have been identified based on the AIS density plot in Figure 5-1 and Figure 5-2, and are shown in Figure 5-4. In total, seven main traffic routes have been identified within the AoI around the NSI.1 area. These traffic routes are used to map the existing maritime traffic conditions described in this chapter according to scenario 0.

Route 1 and 2 indicate a broad lane of commercial traffic orientated SW-NE, covering a lot of dense maritime traffic between the Netherlands (Southern North Sea) and Skagerrak (see Figure 5-4). According to Figure 5-2 cargo ships and tankers are prevailing along these routes (see further details in section 5.2.1 and 5.2.2, respectively for Route 1 and 2)

Route 3 covers the N-S traffic going through Thor OWF and NSI.1 OWF (see Figure 5-4). According to Figure 5-2, this maritime traffic route is dominated by cargo ships and tankers as well as passenger ships. In addition, there appears to sail pleasure crafts and dredging vessels along this route (see further details in section 5.2.3).

Route 4 covers the commercial traffic going SW-NE through NSII to and from England (English Channel) (see Figure 5-4). The maritime traffic along this route covers two parallel traffic lanes which crosses Route 2. According to Figure 5-2, cargo ships and tankers are prevailing along this route (see further details in section 5.2.4).

Route 5 and 6 covers some of the coastal traffic to and from the harbors and fjords, which often forms a fan-like pattern on the density map (radial pattern from the harbors and seawards) (see Figure 5-4). According to Figure 5-2, this maritime traffic is mostly related to pleasure crafts and fishing vessels in transit). East-west oriented traffic along the west coast of Jutland can be related to dredging operations and dumping of sediment onto the coast in relation to coastal protection (cf. other ships in Figure 5-2). (see further details in section 5.2.5 and 5.2.6).

Route 7 indicates the maritime traffic travelling N-S along the coast of Western Jutland going east off Horns Rev OWFs (see Figure 5-4). Basically, Route 7 touches the easternmost part of NSI.1. According to Figure 5-2, this maritime traffic is mostly related to pleasure crafts and smaller cargo ships and tankers. In addition, a minor portion of dredging vessels occur along this route (see further details in section 5.2.7).

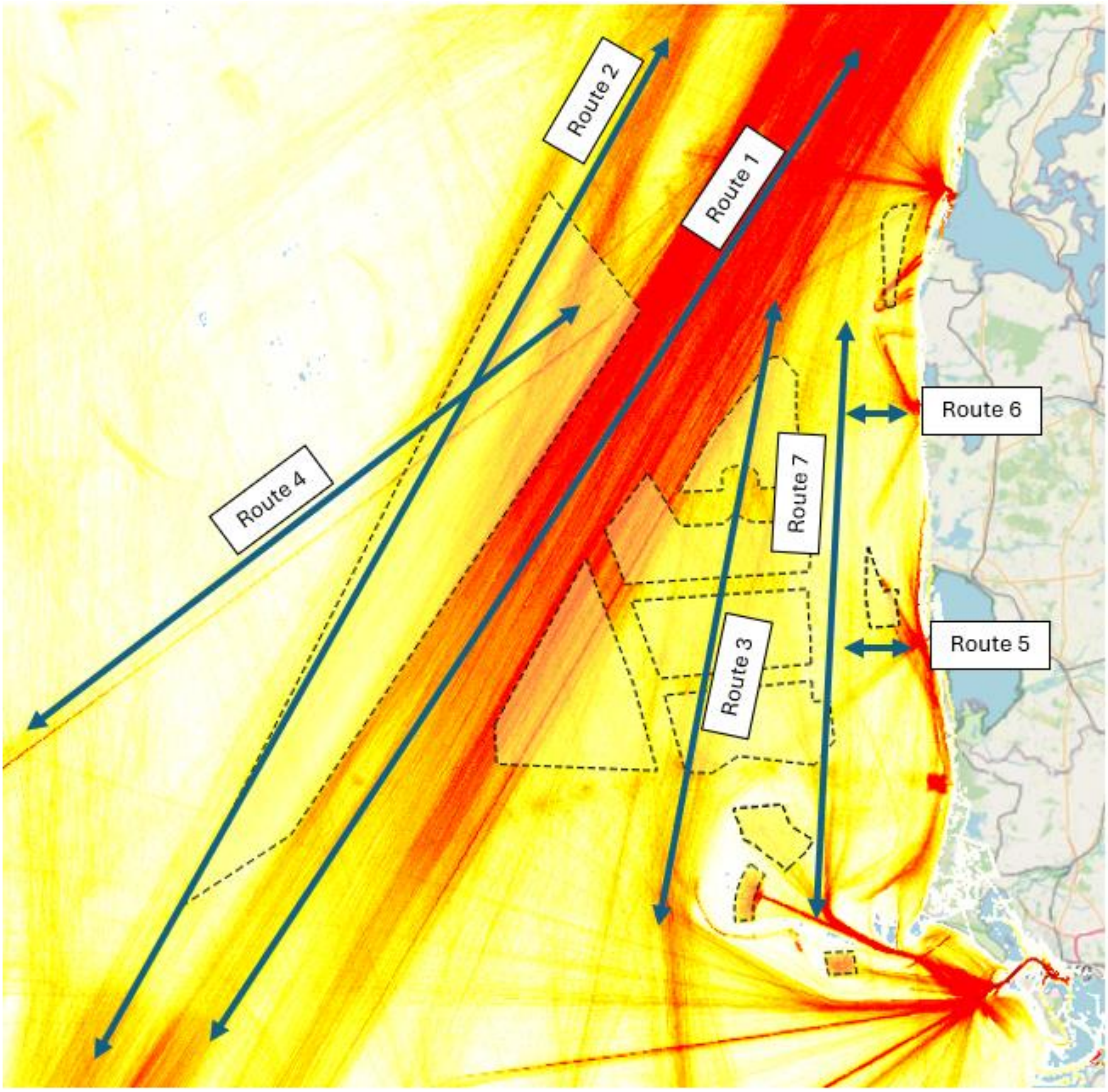


Figure 5-4. Traffic density map of all ship types in the AoI. All existing and future OWFs are included. Major maritime traffic routes have been highlighted (cf. Route 1-7).

The overall characteristic of each route is presented in more details below. The data is showcased as ship counts, which is the number of ships crossing a line on the route, which is placed where the route is most trafficked. Data is not sorted based on unique ships, so the same ship might be counted several times, if it has used the route several times during 2022.

5.2.1 ROUTE 1 – INTERNATIONAL SHIPPING CORRIDOR (MSP: S10)

Figure 5-5 presents the ship characteristics of maritime traffic in Route 1, which is the broad band of dense traffic observed northwest of NSI.1. The traffic is generated by larger commercial vessels sailing to and from the Netherlands and Southern North Sea, from or to destinations in Skagerrak or further into Kattegat or the Baltic Sea. A total of 19,727 vessels used this traffic route in 2022. This route corresponds to the shipping corridor S10 stated in the MSP.

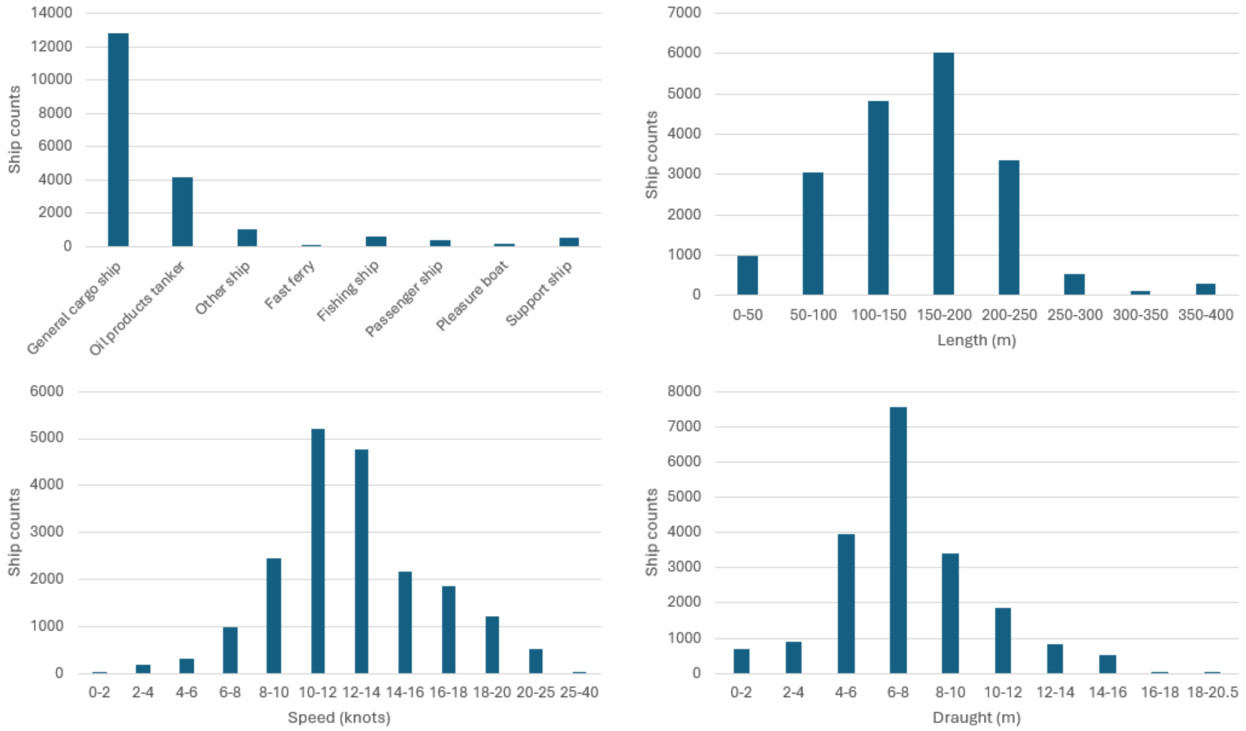


Figure 5-5. Route 1 maritime traffic statistics. Top left is the ship counts per ship type; top right is the ship counts distributed per length in 50 m intervals. Bottom left is speed in knots distributed in intervals of 2 knots, bottom right is draught in meters, distributed in 2 m intervals.

The distribution of ship types in Route 1 shown in Figure 5-5 clearly shows, that the maritime traffic is dominated by cargo ships, which include bulk and goods carriers and container ships, and accounts for about 65% of the overall traffic in Route 1. Tankers are the second most frequent ship type and account for about 21% of the total traffic. The last 14% of the traffic is distributed on fishing ships, passenger ships, pleasure boats, support ships and other ship types.

The distribution of vessel length, shown in the top right in Figure 5-5, shows that the maritime traffic is dominated by vessels between 50-250 m with a peak around 150-200 m. A few vessels are very long with a length at 350-400 m. The distribution of speed over ground, shown in the bottom left in Figure 5-5, shows that the vessel speed follows an almost normal distribution, with a mean speed of approximately 12.7 knots. The bottom right of Figure 5-5 displays the distribution of the draught for the vessels in Route 1. Most vessels have a draught between 4-10 m with a peak around 6-8 m, though vessels might vary their draught according to the actual load e.g. cargo vessels.

5.2.2 ROUTE 2 – THROUGH NSII

Route 2 describes the maritime traffic that is more or less parallel with Route 1, but is situated slightly NW of Route 1, and is going through the planned NSII OWF. The traffic composition and end goal of the traffic are similar to Route 1. Figure 5-6 presents the ship characteristics of maritime traffic in Route 2. A total of 6,109 vessels used the route in 2022.

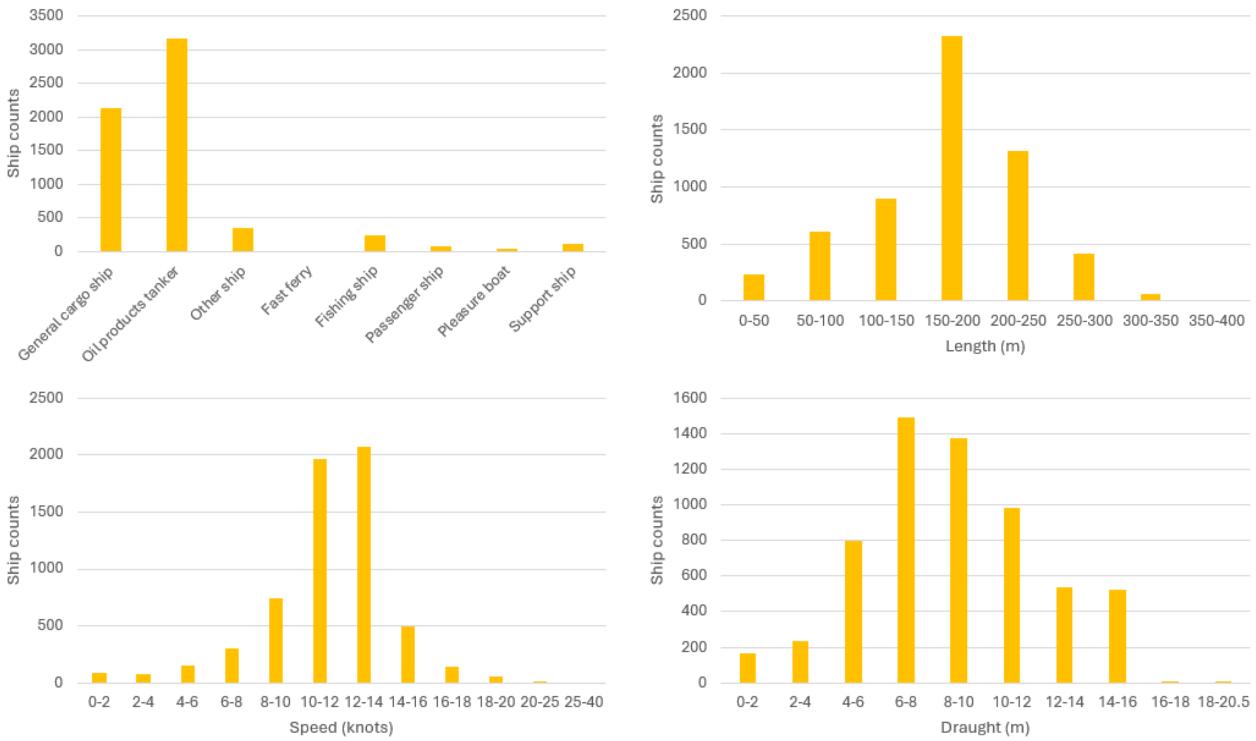


Figure 5-6. Route 2 maritime traffic statistics. Top left is the ship counts per ship type; top right is the ship counts distributed per length in 50 m intervals. Bottom left is speed in knots distributed in intervals of 2 knots, bottom right is draught in meters, distributed in 2 m intervals.

The maritime traffic in Route 2 is less intense compared to Route 1 and is dominated by tankers (52%) and cargo vessels (35 %). The main difference between Route 1 and 2, is the proportion of tankers which are much larger for Route 2 compared to Route 1. The length distribution in Route 2 is dominated by 150-200 m but also 200-250 m is frequent, which are both primarily cargo ships and tankers.

The distribution of speed over ground, shown in the bottom left in Figure 5-6, shows that the vessel speed follows an almost normal distribution, with a mean speed of approximately 11.5 knots. The bottom right of Figure 5-6 displays the distribution of the draught for the vessels in Route 2. Most vessels have a draught between 4-12 m with a peak around 6-10 m, though vessels might vary their draught according to the actual load e.g. cargo vessels.

5.2.3 ROUTE 3 – THROUGH THOR AND NSI.1

This route describes the N-S traffic going through Thor OWF and NSI.1 OWF. Figure 5-7 presents the ship characteristics of maritime traffic in Route 3. A total of 3,355 vessels used the route in 2022.

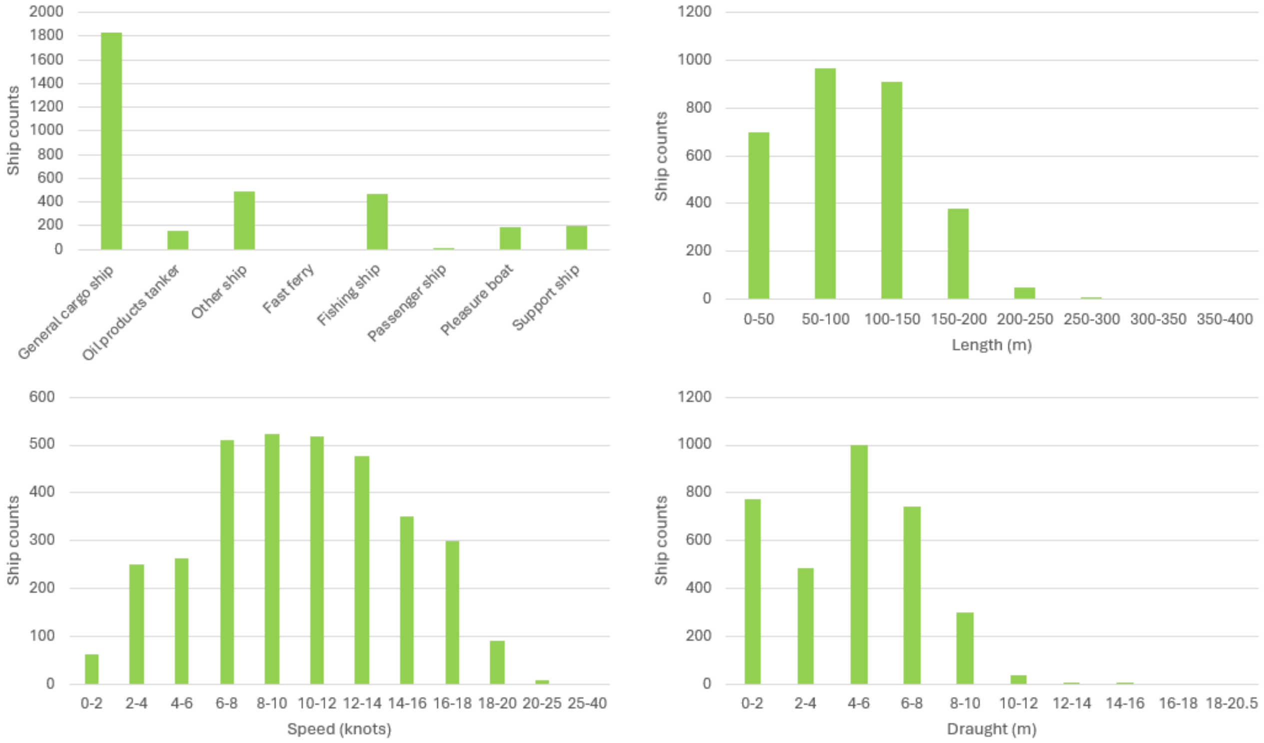


Figure 5-7. Route 3 maritime traffic statistics. Top left is the ship counts per ship type; top right is the ship counts distributed per length in 50 m intervals. Bottom left is speed in knots distributed in intervals of 2 knots, bottom right is draught in meters, distributed in 2 m intervals.

In Route 3, the maritime traffic is dominated by cargo ships (55%), however other vessels (15%) and fishing ships (14%) are also frequent. The distribution of ship lengths shows relatively fewer larger ships and more small vessels, compared to Route 1 and Route 2. The traffic is more coastal with a larger amount of smaller cargo ships and fishing vessels, compared with the larger tankers and cargo ships in the shipping corridor (S10) and further towards west. The same trend is evident regarding a relatively lower sailing speed, and a draught which is most often below 6-8 m.

These values are also consistent with the occurrence of pleasure crafts along Route 3. It is estimated that a given proportion of dredging vessels will contribute to the above values, which are included in the ship type category “support ships”.

5.2.4 ROUTE 4 – SW-NE CROSSING TRAFFIC

Route 4 describes two separate traffic routes going SW/NE through NSII to and from England (English Channel). Figure 5-8 presents the ship characteristics of maritime traffic in Route 4. A total of 247 vessels used the route in 2022.

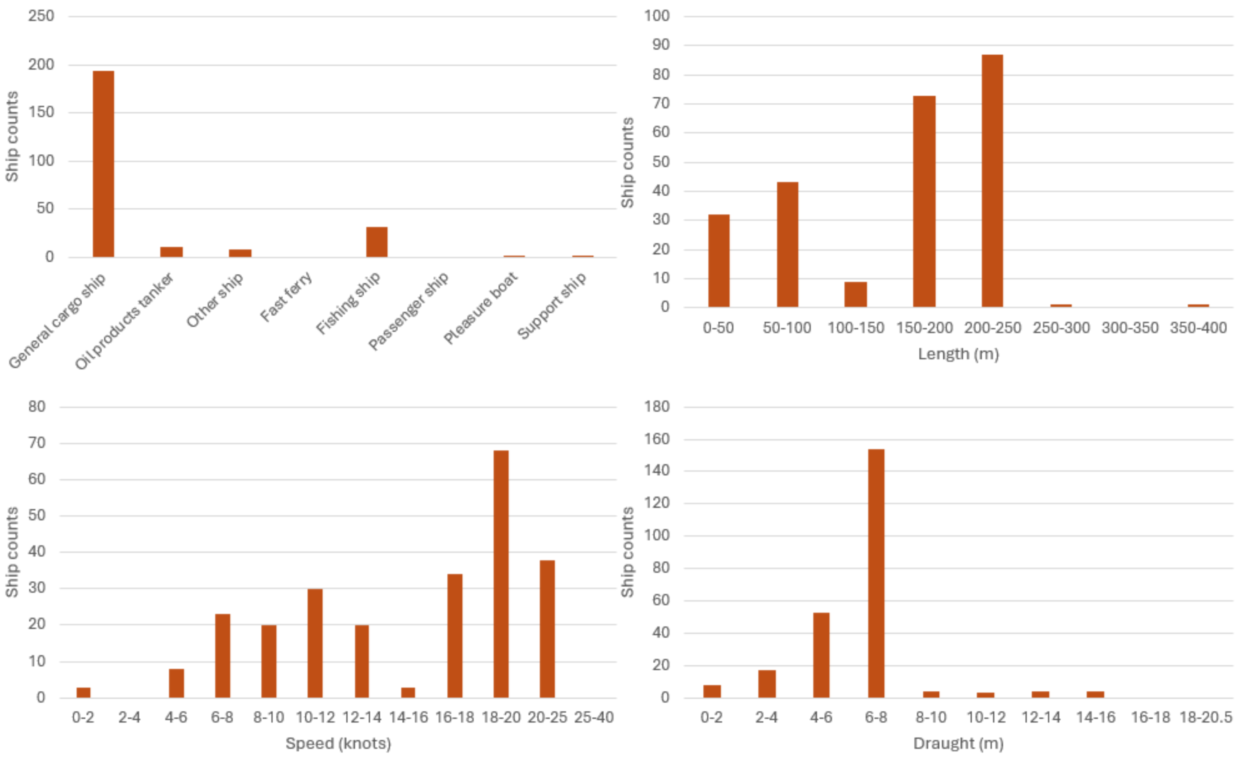


Figure 5-8. Route 4 maritime traffic statistics. Top left is the ship counts per ship type; top right is the ship counts distributed per length in 50 m intervals. Bottom left is speed in knots distributed in intervals of 2 knots, bottom right is draught in meters, distributed in 2 m intervals.

The traffic density in Route 4 is low and dominated by cargo ships (79%) travelling to and from England (English Channel) and Skagerrak. The ship length and speed distributions show a broad division with few ships with a length of 100-150 m and a speed of 14-16 knots, but relatively many ships on either side of this gap. Most ships in route 4 have a draught of 6-8 m.

5.2.5 ROUTE 5 – IN/OUT HVIDE SANDE

This route describes the coastal traffic in and out of Hvide Sande with a general direction going radially out of the harbor. The maritime traffic is headed both for VHS OWF and the extraction area towards north as well as the planned NSI.1 OWF towards west. Figure 5-9 presents the ship characteristics of maritime traffic in Route 5. A total of 3,014 vessels used the route in 2022.

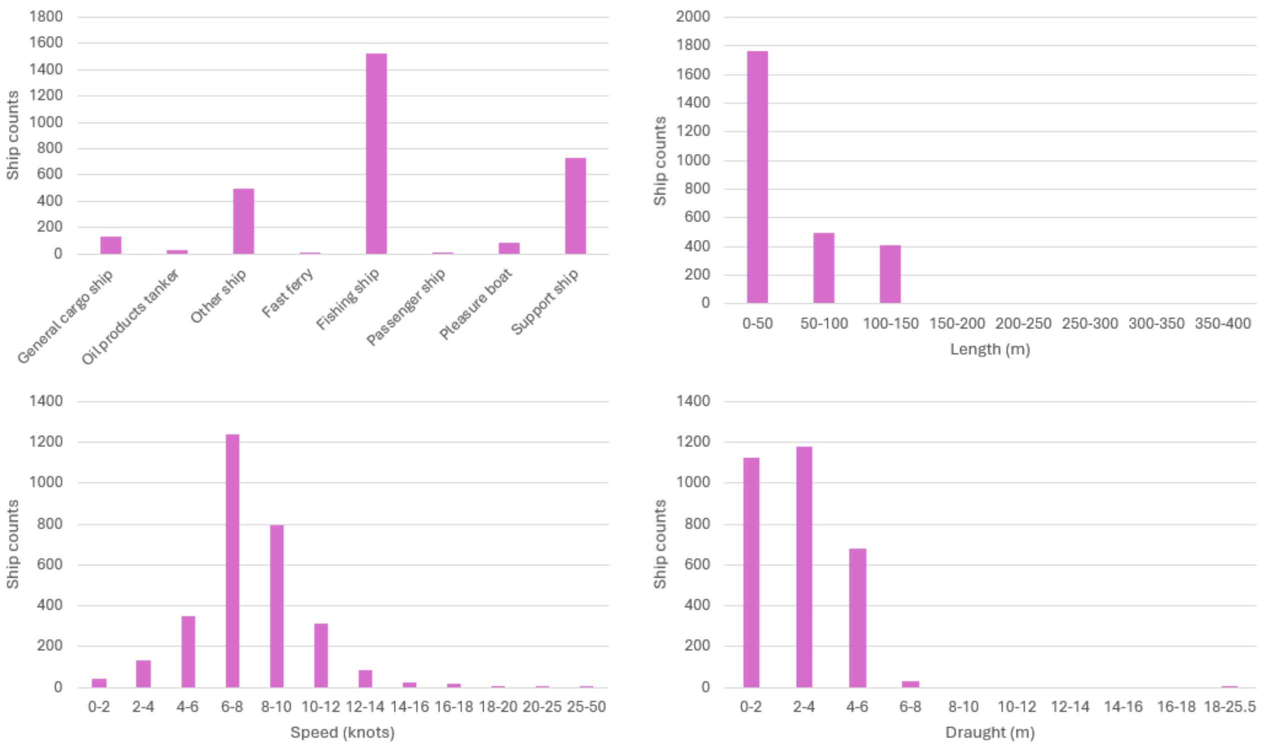


Figure 5-9. Route 5 maritime traffic statistics. Top left is the ship counts per ship type; top right is the ship counts distributed per length in 50 m intervals. Bottom left is speed in knots distributed in intervals of 2 knots, bottom right is draught in meters, distributed in 2 m intervals.

Route 5 is dominated by fishing vessels (51%), with a significant amount of support ships (24%) and other ships (16%) present as well. The length distribution shows ship lengths between 0 m and 150 m with most vessels being between 0-50 m. The draught is “0” for 903 vessels, indicating that about a third of vessels in this route have not registered their draught. The speed over ground has an almost normal distribution with a mean value of around 8 knots. Overall, these values indicate that Route 5 is dominated by maritime traffic of smaller vessels. A large amount of the support ships is related to dredging activities.

5.2.6 ROUTE 6 – IN/OUT THORSMINDE

This route describes the coastal traffic in and out of Thorsminde with a general direction going radially out of the harbor. The maritime traffic is headed both northwest towards VHN OWF and west towards Thor OWF. Figure 5-10 presents the ship characteristics of maritime traffic in Route 6. A total of 2,394 vessels used the route in 2022.

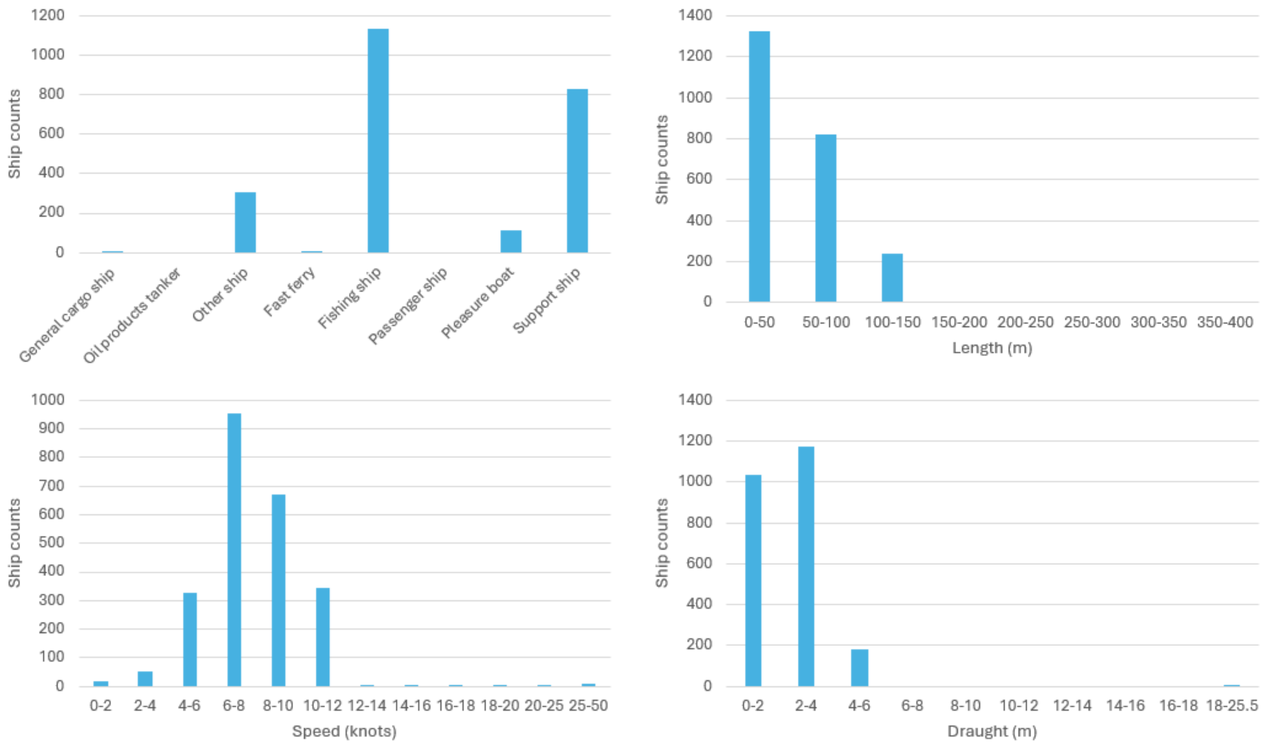


Figure 5-10. Route 6 maritime traffic statistics. Top left is the ship counts per ship type; top right is the ship counts distributed per length in 50 m intervals. Bottom left is speed in knots distributed in intervals of 2 knots, bottom right is draught in meters, distributed in 2 m intervals.

Route 6 is dominated by fishing vessels (47%) and support ships (35%), with a significant number of other ships (13%) and pleasure boats (5%) present as well. The length distribution shows ship lengths between 0 m and 150 m with most vessels being between 0 m to 50 m. The draught is “0” for 732 vessels, indicating that about a third of vessels in this route have not registered their draught. The speed over ground has a mean value at around 8 knots. Overall, these values indicate that Route 6 is dominated by maritime traffic of smaller vessels. A large amount of the support ships is related to dredging activities.

Basically, the traffic characteristics for Route 5 and Route 6 are very similar.

5.2.7 ROUTE 7 – COASTAL N-S TRAFFIC

This route describes the coastal traffic heading north-south along the coast of Western Jutland in the open waters west of VHN and VHS OWFs. Figure 5-11 presents the ship characteristics of maritime traffic in Route 7. A total of 523 vessels used the route in 2022.

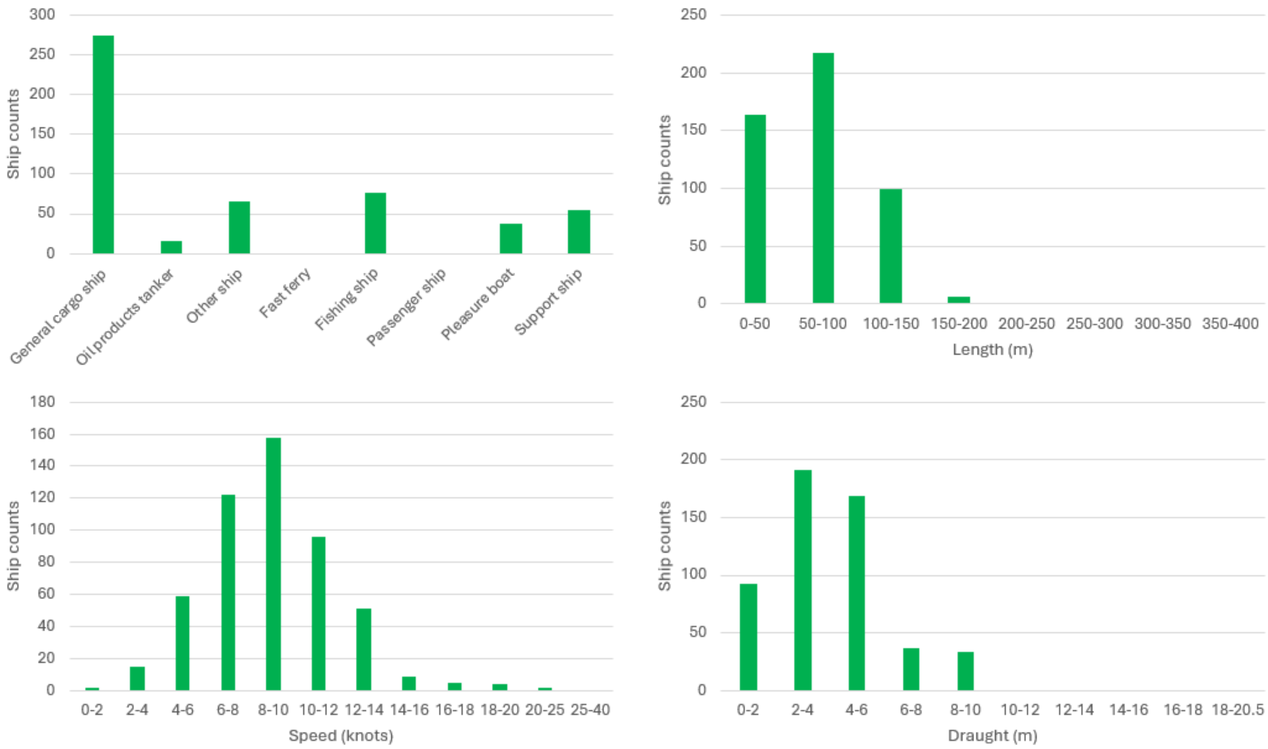


Figure 5-11. Route 7 maritime traffic statistics. Top left is the ship counts per ship type; top right is the ship counts distributed per length in 50 m intervals. Bottom left is speed in knots distributed in intervals of 2 knots, bottom right is draught in meters, distributed in 2 m intervals.

Route 7 is dominated by cargo ships (52%), with a significant number of other ships (12%), fishing ships (15%), pleasure boats (7%) and support ships (10%) present as well. The length distribution shows ship lengths between 0 m and 150 m with most vessels being between 50 m to 100 m. The speed over ground has an almost normal distribution with a mean value of around 9 knots. The draught varies between 0-10 m with a peak around 2-6 m, though vessels might vary their draught according to the actual load e.g. cargo vessels.

These values are also consistent with the occurrence of pleasure craft along Route 7. It is also estimated that a given proportion of dredging vessels will contribute to the above values, which is included in the ship type category “support ships”.

5.2.8 OVERALL ROUTE CHARACTERISTICS

Based on the above detailed examination of the characteristics for each traffic route, it is possible to draw some overall conclusions. The results from the above route characteristics have been compiled in Table 5-1.

Route 1 is by far the most trafficked route in the AoI where the total ship counts is more than three times as high as for Route 2, which is the second most trafficked route. Generally, the most trafficked routes (i.e. Route 1, 2 and 3) are located furthest from the shore and are all dominated by cargo ships and partly tankers. This is also reflected by the length of ships, with the greatest lengths in Route 1, 2 and 3. In addition, the ship length is also large for Route 4, which is consistent with its offshore location. Also, the draught is highest in Route 1, 2, 3 and 4, which again is consistent with the dominance of larger commercial vessels.

The total ship counts are also relatively high in Route 5 and 6. The characteristics of these two routes are very similar even though it refers to two different harbours. The vessels here are smaller with lower draught and the maritime traffic is dominated by fishing boats. The high number of vessels in Route 5 and 6 is caused by daily transit of fishing boats, pleasure crafts and partly dredging vessels in and out of the harbors. The greatest values for maximum speed are seen in Route 5 and 6 which is related to fast-going vessels sailing close to shore.

Table 5-1. List showing the overall waterway and route characteristics for the seven routes in the AoI.

Route	Route 1	Route 2	Route 3	Route 4	Route 5	Route 6	Route 7
Total ship counts (number)	19,727	6,109	3,355	247	3,014	2,394	523
Length (m) Max/avg	400/156.4	399/171	399/87.9	382/166.1	221/40.0	111/47.7	231/67.5
Speed (knots) Max/avg	37.8/12.7	24.8/11.5	23.1/10.3	22.1/15.0	46.4/8.0	45.6/8.0	23.8/9.0
Draught (m) Max/avg	20.5/7.4	20.0/8.7	14.8/4.6	14.7/6.6	25.5/2.5	25.5/2.5	9.6/3.8

5.3 CURRENT ACCIDENTS

Shipping accidents in the Baltic Sea are reported annually by the Baltic Marine Environment (Helcom, 2021) and are used in the FSA for Energy Islands Bornholm (Rambøll, Energy Islands Bornholm, Technical report - Maritime traffic and navigational safety, 2022). However, OSPAR do not has implemented smiliar reports for the North Sea Region. As a result, it has not been possible to provide an account of current accident statistics for the North Sea, which has also been the case for similar FSAs (for instances see (Rambøll, Thor Offshore Wind Farm. Navigational Risk Assessment. , 2022).

This was also stated by DMA at the HAZID workshop. Thus, there is no specific knowledge on how often an incident occurs (e.g. allisions as well as collisions and grounding as a direct consequence of the presence of a given OWF) and what consequences an incident actually have.

Since there is no available information regarding accident statistics for the North Sea Region, it has not been possible to compare the calculated frequencies in IWRAP with the historical accident statistics in the AoI.

6 TRAFFIC MODEL ANNO 2022 (SCENARIO 0)

The AIS data from 2022 are the basis for the traffic model in IWRAP (main data input), showcased in Figure 6-1. In IWRAP, the traffic is defined by a series of legs in different directions north-south or east-west. Ship data as identified in the AIS data, is extracted to the various legs presenting the overall traffic conditions. The maritime traffic in these legs is represented by blue and green histograms illustrating how the traffic distributes in the leg in each direction. The dots in each plot indicate the waypoints where the legs join, merge or split.

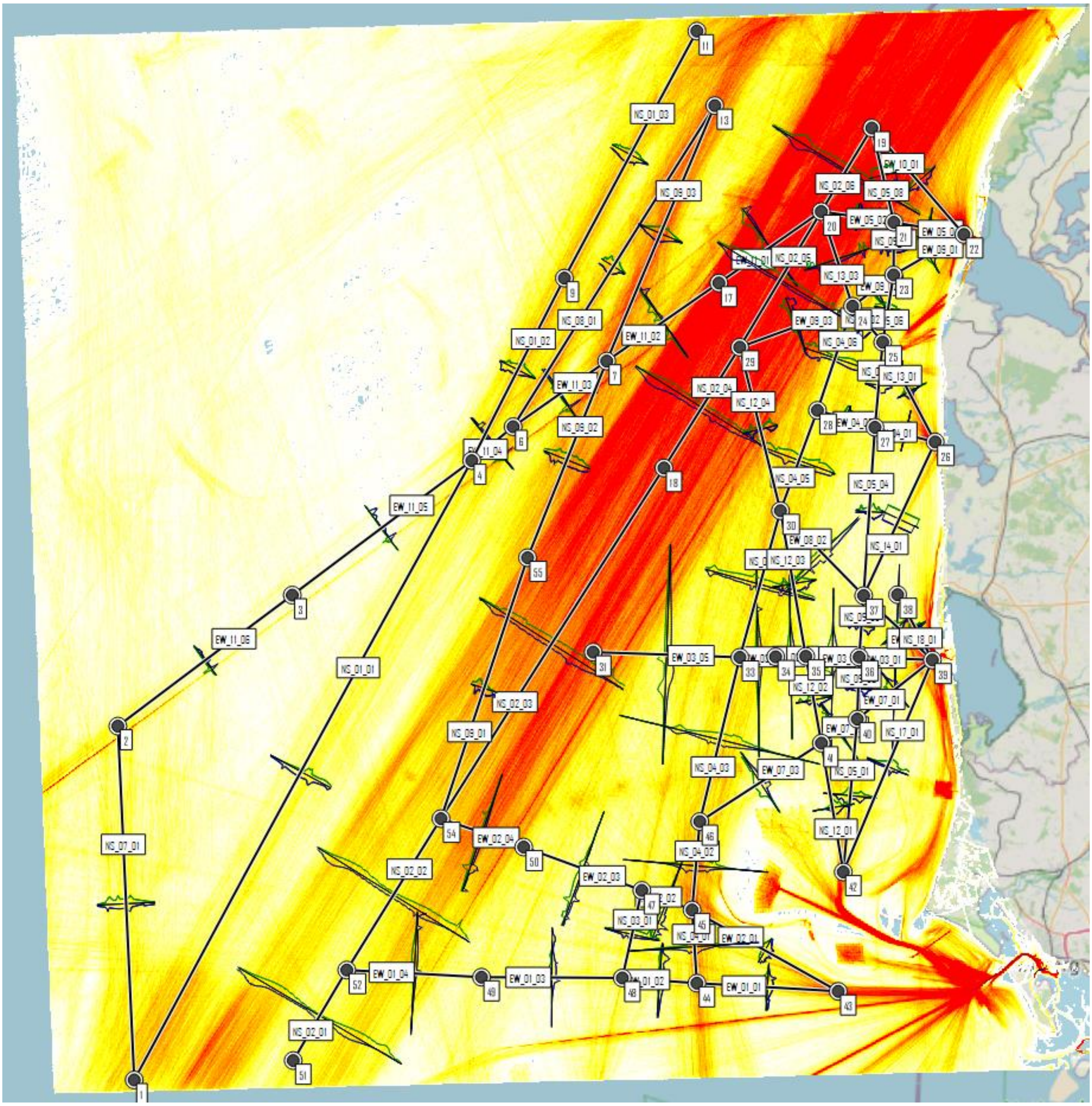


Figure 6-1. Traffic model in IWRAP based on AIS data from anno 2022 (scenario 0).

6.1 AREA WITH LOW AIS SIGNAL

There is observed an overall decrease in the traffic density especially in the southwestern part of the model area. This is most visible in the southern legs of the shipping corridor S10 (Route 1) (i.e. NS_02_01 to NS_02_03) (see Figure 6-1), where the density of maritime traffic decreases towards southwest with increasing distance to land. The decrease in traffic density is described in other studies and is due to weak AIS coverage in the area (ABL A. , 2021) which affects the amount of incoming AIS positions and ultimately the traffic density. The AIS signal range depends on the antenna height. For ship-to-ship connections, the range is approximately 20 nautical miles (37 km). Depending on the antenna height, coastal stations receive signals within a radius of 50-100 km.

Before setting up the models, the maritime traffic in the affected legs must be adjusted. It is chosen only to adjust the legs NS_01_01 and NS_02_01 to NS_02_03, since these legs represent dense maritime traffic routes (large vessel density) near other OWFs and are in the center of the area lacking AIS coverage.

Figure 6-2 indicates that the maritime traffic is not affected in the leg NS_02_04, which is found to represent the 100% level of the traffic in the legs with missing traffic (i.e. NS_02_01 to NS_02_03). Furthest to the south in leg NS_02_01, the maritime traffic has decreased to 34 and 31% in northern and southern direction, respectively. This is adjusted by replacing all the observed traffic in NS_02_01 to NS_02_03 with the observed traffic in NS_02_04.

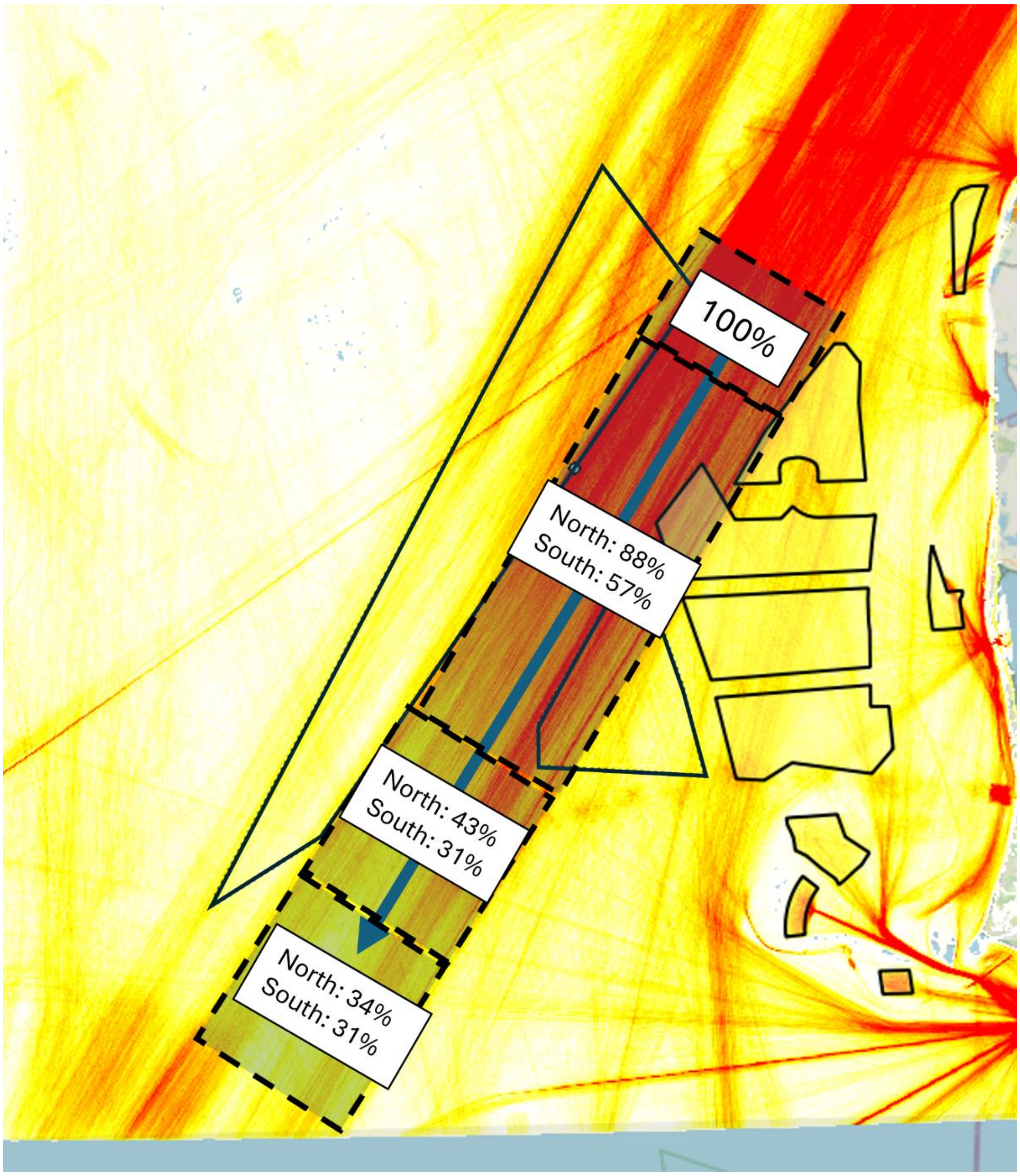


Figure 6-2. Percent decrease in total maritime traffic in northern and southern directions in NS_02_01 to NS_02_03.

The leg NS_01_01 is also adjusted. Since the center of this leg is near NS_02_02, these two legs may have a lack of maritime traffic on the same level and therefore also an adjustment factor on the same level. The adjustment factor is found to be 2.3 and 3.2 in NS_02_02 for northern and southern directions, respectively. Since NS_01_01 is located further offshore, it is assumed that there is a higher lack of AIS coverage in NS_01_01. Therefore, the maritime traffic in NS_01_01 is corrected by a higher adjustment factor of 3 and 4 for northern and southern directions, respectively.

It is not known whether the weak AIS coverage mainly affects type B receivers, which is mainly found on pleasure boats and smaller ships. However, it is found that tankers and cargo ships account for 94% of the missing traffic when comparing the maritime traffic in NS_02_04 to NS_02_01, and therefore it is assessed that other ship types are an insignificant part of the maritime traffic in the abovementioned adjustment.

7 MODELLING OF SCENARIO 1 (BASELINE)

Modelling of scenario 1 is based on traffic movements and rerouting from scenario 0 (see Chapter 6) to scenario 1 (baseline). This chapter explains the stepwise process of the traffic movement and rerouting according to scenario 1 due to the construction of VHS and Thor OWFs.

7.1 TRAFFIC MODELLING AND REROUTING

VHS OWF

The construction of VHS OWF will affect the maritime traffic to and from Hvide Sande in a northwestern direction, which is described in leg EW_08_01. Since AIS data is based on 2022 data, the full effect of VHS (build in primo 2024) is not seen in the AIS data and in the overall traffic conditions. As a consequence, the maritime traffic, which primarily consists of pleasure crafts, fishing ships and other smaller ships (cf. Route 5 in section 5.2), will most likely be rerouted south and west of VHS to leg EW_03_01 and leg NS_05_03 via waypoint 36. Traffic in leg NS_18_01 do not cross the VHS OWF area but ends east of it. This traffic is related to dredging activities in and out of Hvide Sande Harbor (see section 5.1.2). Consequently, this traffic will not be rerouted and will remain unchanged. The rest of the traffic in scenario 0 will not be affected by the construction of VHS OWF.

Due to the establishment of VHS OWF, the maritime traffic is rerouted as described in Table 7-1 and illustrated in Figure 7-1.

Table 7-1. Proposed traffic rerouting related to the construction of VHS OWF in scenario 1.

Amount of traffic	Affected leg in scenario 0		Affected leg in scenario 1	
	Leg	Direction	Leg	Direction
100%	EW_08_01	Northwest	EW_03_01	West
100%	EW_08_01	Southeast	EW_03_01	East
100%	EW_08_01	Northwest	NS_05_03	North
100%	EW_08_01	Southeast	NS_05_03	South

After rerouting, all maritime traffic in EW_08_01 in both directions are deleted.

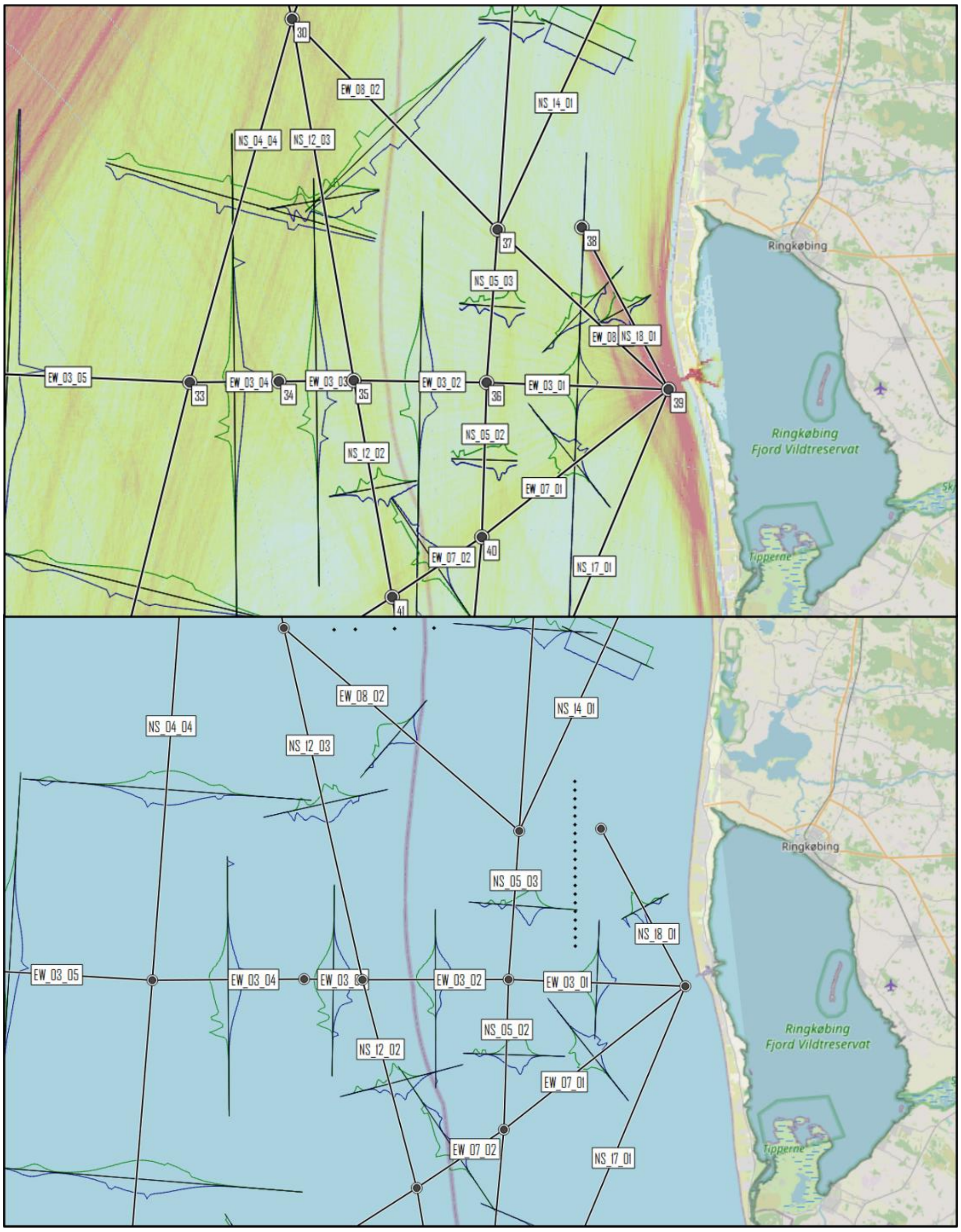


Figure 7-1. Illustration of the traffic rerouting related to the construction of VHS OWF. The top figure illustrates the AIS data and the current traffic conditions including the identified legs and waypoint in IWRAP (scenario 0). The bottom figure illustrates the rerouted traffic conditions in scenario 1 (baseline).

Thor OWF

The construction of Thor OWF will affect the maritime traffic in leg NS_12, where the legs NS_12_03 and NS_12_04 cross this OWF. Consequently, the maritime traffic in these two legs must be rerouted in order to avoid ships passing through Thor OWF. The legs are moved to the west by dragging waypoints 29, 30 and 35 around 2 km to the west to ensure a sufficient distance to the western side of THOR OWF and without any traffic overlapping the OWF. By dragging waypoint 30 towards west, the distance between leg EW_08_02 and Thor OWF will be greater (Figure 7-2).

Furthermore, the construction of Thor OWF will affect the traffic in leg NS_04, where the legs NS_04_05 and NS_04_06 cross the OWF and thus must be moved and rerouted. Most of the maritime traffic in these two legs is assumed to be ships sailing between major harbors in northwestern Germany and Skagerrak (cf. Route 3 in section 5.2). The increased sailing distance for these ships seems overall to be equal if they navigate east or west of Thor OWF. It is assumed that the ships will navigate to the shipping corridor S10 which is located west of Thor OWF. This will also give the most conservative analyze, since there is more dense maritime traffic in this area.

Seen from south to north, the maritime traffic must navigate more directly to the north to avoid Thor OWF. This is done by doing the following and is illustrated in Figure 7-2.

- Waypoint 33 is moved around 5 km to the west.
- NS_04_04 is moved to the west and goes between waypoint 33 and the new waypoint no. 56.
- NS_04_05 is moved to the west and goes between new waypoint no. 56 and waypoint 29 in shipping corridor S10.
- Traffic in NS_04_06 is rerouted to leg EW_09_03, as described in Table 7-2.
- All traffic in NS_04_06 is deleted after the rerouting.

Table 7-2. Proposed traffic rerouting related to the construction of Thor OWF in scenario 1.

Amount of traffic	**Affected leg in scenario 0**		**Affected leg in scenario 1**	
	Leg	**Direction**	**Leg**	**Direction**
100%	NS_04_06	Northeast	EW_09_03	Northeast
100%	NS_04_06	Southwest	EW_09_03	Southwest

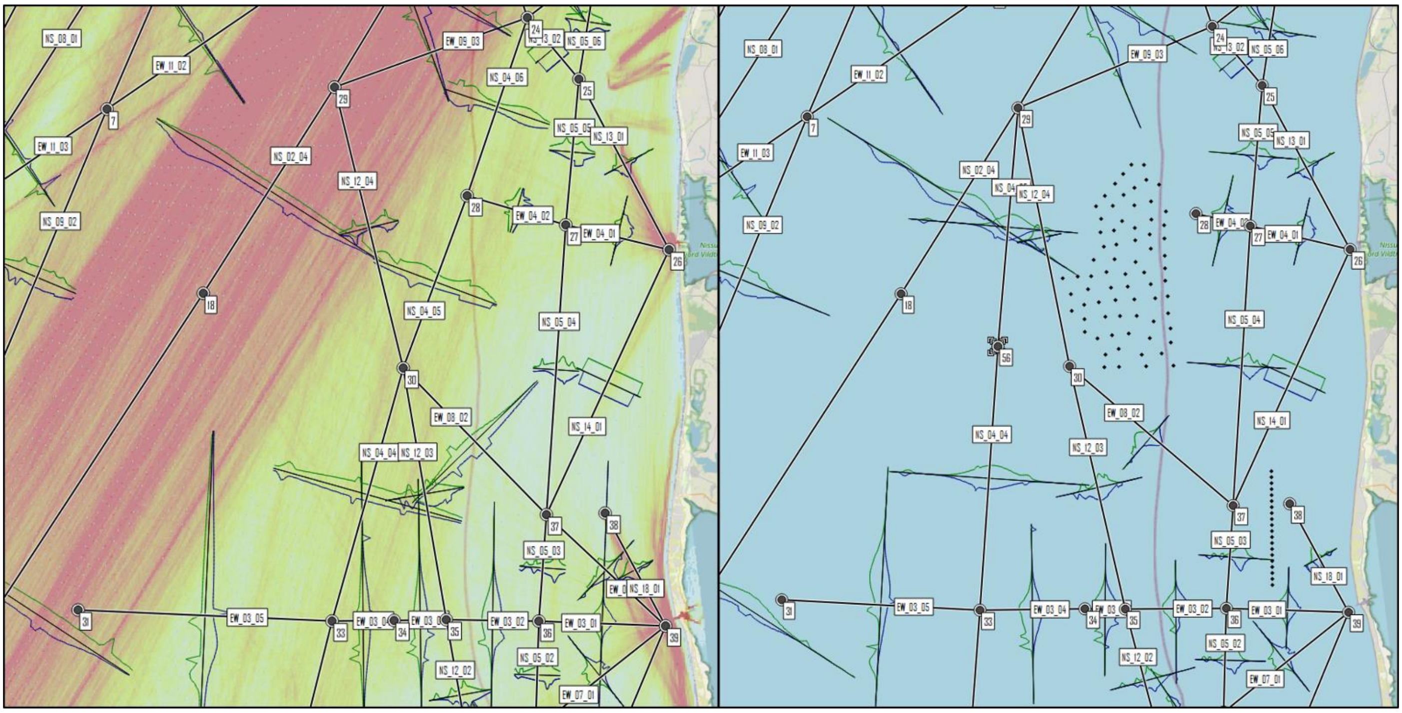


Figure 7-2. Illustration of the traffic movements and rerouting related to the construction of Thor and VHS OWFs. The figure to the left illustrates the AIS data and the current maritime traffic conditions including the identified legs and waypoint in IWRAP (scenario 0). The figure to the right illustrates the traffic movements and rerouting in scenario 1 (baseline).

7.1.1 FINAL MODEL SETUP

Following the proposed traffic movements and rerouting from scenario 0 to scenario 1, outlined in the previous section, based on the construction of the OWFs of VHS and Thor, the final model setup for scenario 1 (baseline) can be seen below in Figure 7-3.

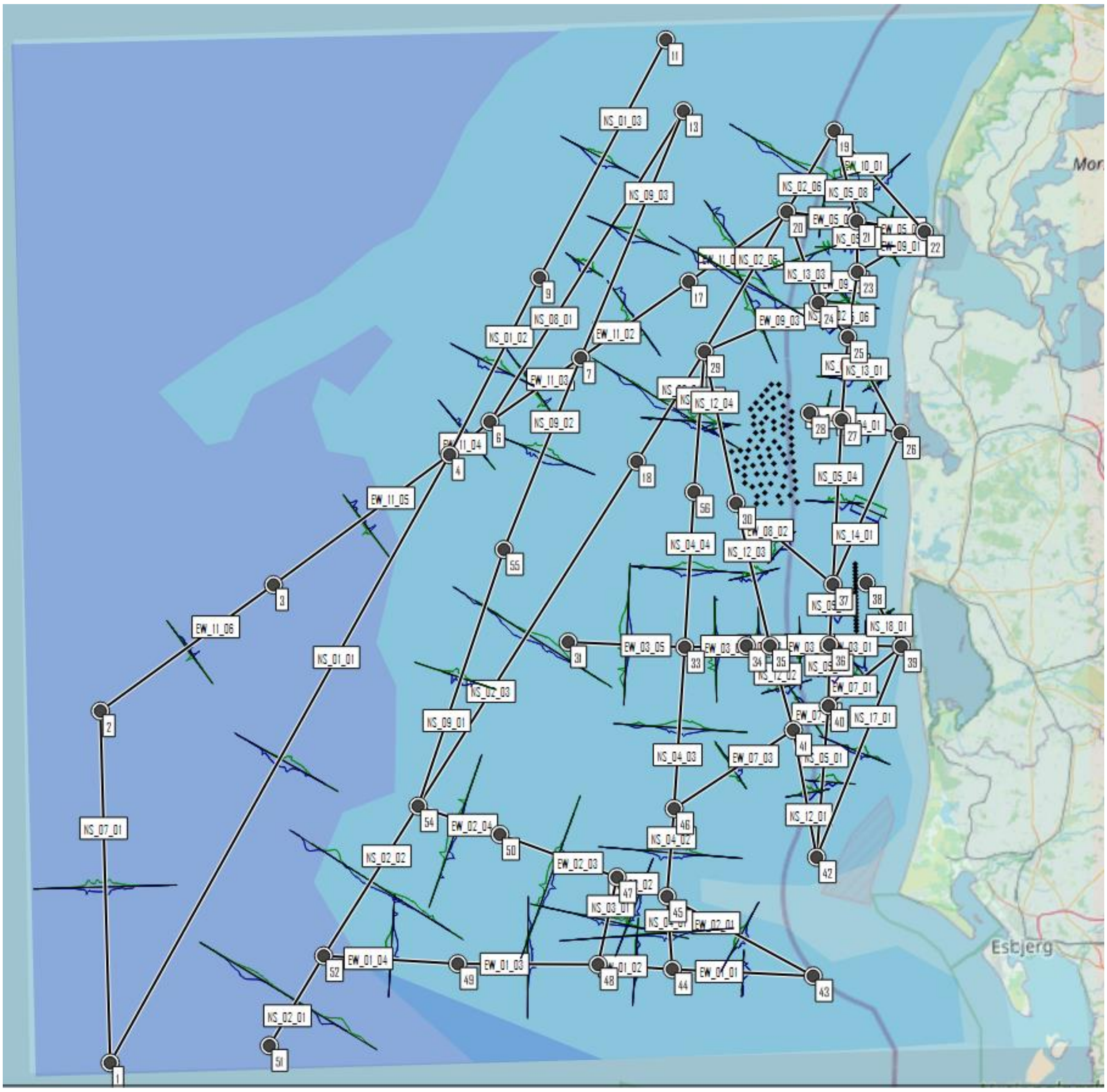


Figure 7-3. Proposed traffic model for scenario 1 based on the modelling of VHS and Thor OWFs.

7.2 FREQUENCY MODELLING

The overall results of the frequency modelling (calculation of return periods) based on scenario 1 in relation to the operation phase are shown in Table 7-3 with years between incidents and the corresponding yearly frequency. The frequency model is based on the entire AoI area.

Table 7-3. Overall frequency modelling results of scenario 1 (presented with at least three digits).

Scenario 1	Return period (years between incident)	Frequency (yr^{-1})
Powered grounding	6,094	1.64E-04
Drifting groundings	35.6	2.81E-02
Total groundings	**35.4**	**2.83E-02**
Powered allisions	17,750	5.63E-05
Drifting allisions	2,571	3.89E-04
Total allisions	**2,245**	**4.45E-04**

Overtaking	118	8.49E-03
HeadOn	98.9	1.01E-02
Crossing	1,098	9.11E-04
Merging	325	3.07E-03
Bend	948	1.06E-03
Total collisions	**42.3**	**2.37E-02**

For total grounding, the calculated return period for scenario 1 is around 35 years between incidents. For total allision, i.e., collision between ship and obstacles, the return period for scenario 1 is about 2,245 years, while total ship-ship collision are about once every 42 years (Table 7-3). For scenario 1, the most frequent accident type is grounding. Overall, the total frequency of groundings and collisions is in the approximately same order of magnitude. In fact, the actual grounding frequency is much lower in the areas around the OWFs, as there is no risk of groundings in the open waters with the proposed traffic rerouting (see section 4.3.3). As earlier mentioned, the main contributions to the grounding frequency are from the most coastal areas and from the ground of Horns Rev.

The calculations indicate that the return periods are much higher (lower frequencies) for powered accidents relatively to drifting accidents. For instances, powered allisions are 4-5 times less frequent compared to drifting allisions (4-5 times longer return period).

For ship-ship collisions the most frequent type of accident is “HeadOn” collision followed by “Overtaking”. The frequency related to “Crossing” and “Bend” collisions is very low (around 1,000 years), whereas “Merging” is intermedial. “HeadOn” collision is about 11 times more frequent compared to “Crossing” (Table 7-3).

Based on the frequencies listed in Table 7-3, a frequency index relative to the DMA CWAS scheme “Construction Works at Sea” is provided for each incident type. The score (IMO risk class) for scenario 1 is presented in Table 10-1.

7.2.1 GROUNDINGS

Most groundings in the model for scenario 1 are due to cargo ships (47%), tankers (15%) and fishing ships (15%). The powered groundings in scenario 1 occur in a few legs, see Table 7-4 (left), where 99% of the powered groundings is related to two legs. Most powered groundings are found in leg NS_14_01 (covering 66% of all powered groundings) located near the coast north of VHS OWF. The second largest contributor is leg NS_04_02, which is located just north of the ground of Horns Rev.

As shown in Table 7-4 (right), drifting groundings is not controlled by individual legs, however many different routes contribute to the drifting grounding statistics. In fact, the four most contributing legs, only covers 47% of all drifting groundings in the model.

87% of the groundings in the model for scenario 1 are caused by ships colliding with land (0 m water depth curve), which will not be affected by the rerouting of maritime traffic in relation to the planned OWFs. The remaining part (13%) of the groundings are related to the 10 m curve, mainly close to the shore and near the ground of Horns Rev.

Table 7-4. The four most contributing legs to powered groundings (left) and drifting groundings (right) in scenario 1.

Leg	Powered groundings (%)
NS_14_01	65.7
NS_04_02	33.6
NS_04_01	0.6
EW_09_03	0.1

Leg	Drifting groundings (%)
NS_02_05	19.4
NS_02_06	13.9
NS_02_03	8.9
EW_05_01	4.4

Total	**100**

Total	**46.7**

7.2.2 ALLISIONS

According to scenario 1, most of the powered allisions occurs in a few legs, see Table 7-5 (left), where around 96% of the powered allisions is related to three legs. Most powered allisions are found in leg NS_02_04 (covering 55% of all powered allisions) located just west of Thor OWF. The second largest contributor is leg NS_14_01, which is located northwest of VHS OWF. These allisions occurs during strong winds from west and northwest.

As shown in Table 7-5 (right), drifting allisions are not controlled by individual legs, however many different legs contribute to the drifting allisions statistics. In fact, the three most contributing legs, only covers 46% of all drifting allisions in the model. Most drifting allisions are recorded in leg NS_14_01, which is located northwest of VHS OWF.

Table 7-5. The seven most contributing legs to powered allisions (left) and drifting allisions (right) in scenario 1.

Leg	Powered allisions (%)
NS_02_04	55.0
NS_14_01	27.9
EW_03_01	12.9
NS_12_04	2.2
EW_04_02	1.3
NS_12_03	0.3
NS_04_05	0.2
Total	**99.7**

Leg	Drifting allisions (%)
NS_14_01	16.3
EW_03_01	15.3
NS_12_04	14.7
EW_04_02	7.5
NS_12_03	5.7
NS_04_05	5.6
NS_05_04	4.4
Total	**69.4**

The WTGs that are most exposed to allisions are in the northern and southern part of VHS and in the northern and western part of Thor. The WTGs less exposed to allisions are located centrally in VHS and Thor.

7.2.3 COLLISIONS

According to scenario 1, HeadOn and Overtaking ship-ship collisions is modelled to be the leading cause of collisions. Most of the Head-on and Overtaking collisions are related to leg NS_02_03; about 36% and 33%, respectively, followed by NS_02_05 (Table 7-6). In addition, most of these two collision types involve cargo ships and tankers in leg NS_02_03. Basically, the six most contributing legs are related to NS_02 for both HeadOn and Overtaking collision, which all are legs within the heavily trafficked shipping corridor S10 that have been slightly narrowed in their traffic distribution. Thus, it can be concluded that 86-95% of all collisions in relation to scenario 1 occurs in shipping corridor S10, whereas collisions are relatively rare in the surrounding areas.

Crossing, merging and bend collisions are not included in Table 7-6, as these collisions happen at the intersection of different legs and cannot be divided onto individual legs.

Table 7-6. The seven most contributing legs to HeadOn collisions (left) and overtaking collisions (right) in scenario 1. These two incident types are the most frequent collisions for scenario 1 (see Table 7-3).

Leg	HeadOn collisions (%)
NS_02_03	35.6
NS_02_05	16.5
NS_02_06	10.8
NS_02_04	9.5
NS_02_01	8.0
NS_02_02	5.2
NS_01_01	4.3
Total	**89.8**

Leg	Overtaking collisions (%)
NS_02_03	33.3
NS_02_05	18.9
NS_02_04	15.1
NS_02_06	12.4
NS_02_02	9.2
NS_02_01	6.3
NS_04_04	0.8
Total	**96.1**

8 MODELLING OF SCENARIO 2

Modelling of scenario 2 is based on traffic movements and rerouting from scenario 1 (see section 7.1) to scenario 2. This chapter explains the stepwise process of the traffic movement and rerouting according to scenario 2 due to the construction of NSI.1 OWFs.

8.1 TRAFFIC MODELLING AND REROUTING

NSI.1 - Rerouting to sailing corridors between NSI.1-A1 to NSI.1-A3

The construction of NSI.1 will affect the traffic to and from Hvide Sande. Namely fishing ships and other smaller ships dominate in the three OWF areas in NSI.1, cf. Route 5 in section 5.2. It is assumed that smaller vessels that pass through the NSI.1 areas will reroute and either sail south or north of NSI.1 or between the areas along the two sailing corridors. All maritime traffic in leg EW_03_01-05 except in EW_03_01 (which is east of the OWF) will most likely adapt and sail into these two internal sailing corridors. Thus, maritime traffic in EW_03_02 is rerouted to new legs in the sailing corridors between NSI.1-A1 and A2 as well as NSI.1-A2 and A3 with 50% each (NEW_EW_01_02 and NEW_EW_02_01). Maritime traffic to and from the sailing corridor in NEW_EW_01_02 (between NSI.1-A1 and A2) is connected to Hvide Sande by the new leg NEW_EW_01_01. The maritime traffic in NEW_EW_01_01 and NEW_EW_01_02 is assumed to be the same. The traffic rerouting is described in Table 8-1.

Ships sailing in legs EW_03_03 to EW_03_05 have most likely been sailing in leg EW_03_02 (maritime traffic in leg EW_03_02 is representative for the traffic in the entire leg EW_03) (see Table 8-1).

Table 8-1. Proposed traffic rerouting in leg EW_03_02 related to the construction of NSI.1 OWF.

Amount of traffic	Affected leg in scenario 1		Affected leg in scenario 2	
	Leg	Direction	Leg	Direction
50%	EW_03_02 (EW_03)	East	NEW_EW_01_01	East
50%	EW_03_02 (EW_03)	East	NEW_EW_01_02	East
50%	EW_03_02 (EW_03)	West	NEW_EW_01_01	West
50%	EW_03_02 (EW_03)	West	NEW_EW_01_02	West
50%	EW_03_02 (EW_03)	East	NEW_EW_02_01	East
50%	EW_03_02 (EW_03)	West	NEW_EW_02_01	West

After rerouting, all maritime traffic in leg EW_03_02 to EW_03_05 in both directions are deleted.

The traffic described in EW_07_02 must be rerouted due to the construction of NSI.1-A1 OWF. It is assumed that 20% of the traffic will be rerouted to the sailing corridor in leg NEW_EW_01_02 and thus also to the connecting leg NEW_EW_01_01 (Table 8-2). The remaining 80% is assumed to be rerouted south of NSI.1-A1 in the new leg NEW_EW_03_01-04, which is further described in section “Between NSI.1-A1 and Horns Rev OWFs”.

Table 8-2. Proposed traffic rerouting in leg EW_07_02 related to the construction of NSI.1 OWF.

Amount of traffic	Affected leg in scenario 1		Affected leg in scenario 2	
	Leg	Direction	Leg	Direction
20%	EW_07_02	Northeast	NEW_EW_01_01	East
20%	EW_07_02	Northeast	NEW_EW_01_02	East
20%	EW_07_02	Southwest	NEW_EW_01_01	West
20%	EW_07_02	Southwest	NEW_EW_01_02	West

The rerouting of EW_03_01 (altered due to construction of VHS in scenario 1) will adapt further, since some of the traffic will head directly toward the southern sailing corridor between NSI.1-A1 and A2 in the new leg NEW_EW_01_01. This is assumed to be equal to 50% of the traffic in EW_03_02, as mentioned above. These 50% are deleted from the already adapted EW_03_01 (Table 8-3).

Table 8-3. Proposed traffic rerouting in leg EW_03_01 related to the construction of NSI.1 OWF.

Amount of traffic	Affected leg in scenario 1		Transformation
	Leg	Direction	
50%	EW_03_01	East	Deleted
50%	EW_03_01	West	Deleted

In the northern part of NSI.1, the leg EW_08_02 must also be rerouted and it is assumed that 20% of the maritime traffic in this leg will be rerouted to the sailing corridor between NSI.1-A2 and A3 (new leg NEW_EW_02_01) (Table 8-4). The remaining 80% will be rerouted north of NSI.1-A3 in the new leg NEW_NS_01_01-03, which is further described in section "Between NSI.1-A3 and Thor OWF").

Table 8-4. Proposed traffic rerouting in leg EW_08_02 related to the construction of NSI.1 OWF.

Amount of traffic	Affected leg in scenario 1		Affected leg in scenario 2	
	Leg	Direction	Leg	Direction
20%	EW_08_02	East	NEW_EW_02_01	East
20%	EW_08_02	West	NEW_EW_02_01	West

EW_07_02 and EW 08_02 are used to further rerouting, which is described later.

All traffic rerouting related to the two sailing corridors between the three NSI.1 OWF areas as well as the rerouting towards south near Horns Rev OWFs and towards north near Thor OWF, is illustrated in Figure 8-1 (south), Figure 8-2 (central) and Figure 8-3 (north).

Between NSI.1-A1 and Horns Rev OWFs

The construction of NSI.1-A1 will affect the maritime traffic to and from Hvide Sande in the legs EW_07_01-03. It is assumed that 80% of the traffic in legs EW_07_01-03 will reroute to the new legs NEW_EW_03_01-04 which is a new traffic route between NSI.1 and Horns Rev OWFs. The maritime traffic is rerouted as described in Table 8-5.

Table 8-5. Proposed traffic rerouting in leg EW_07_01 to _03 related to the construction of NSI.1 and Horns Rev OWFs (new traffic route between NSI.1 and Horns Rev OWFs).

Amount of traffic	Affected leg in scenario 1		Affected leg in scenario 2	
	Leg	Direction	Leg	Direction
80%	EW_07_01	Southwest	NEW_EW_03_01	Southwest
80%	EW_07_01	Northeast	NEW_EW_03_01	Northeast
80%	EW_07_01	Southwest	NEW_EW_03_02	Southwest
80%	EW_07_01	Northeast	NEW_EW_03_02	Northeast
80%	EW_07_02	Southwest	NEW_EW_03_03	West
80%	EW_07_02	Northeast	NEW_EW_03_03	East
80%	EW_07_03	Southwest	NEW_EW_03_04	Southwest
80%	EW_07_03	Northeast	NEW_EW_03_04	Northeast

The establishment of leg NEW_EW_03 includes three new waypoints (no. 57, 58 and 59). After this rerouting, all maritime traffic in leg EW_07_01-03 in both directions are deleted.

All traffic rerouting related to the new traffic route between NSI.1 A1 and Horns Rev OWFs is illustrated in Figure 8-1.

Between NSI.1-A3 and Thor OWF

As mentioned earlier, some of the maritime traffic will most likely be rerouted to the new traffic route between NSI.1 and Thor OWF. It is assumed that 80% of the maritime traffic in the leg EW_08_02 will be rerouted to this route. The maritime traffic is rerouted to the new legs NEW_NS_01_01 and NEW_NS_01_02 as described in Table 8-6.

Table 8-6. Proposed traffic rerouting in leg EW_08_02 related to the construction of NSI.1 and Thor OWF (new traffic route between NSI.1 and Thor OWF).

Amount of traffic	Affected leg in scenario 1		Affected leg in scenario 2	
	Leg	Direction	Leg	Direction
80%	EW_08_02	Northwest	NEW_NS_01_01	North
80%	EW_08_02	Southeast	NEW_NS_01_01	South
80%	EW_08_02	Northwest	NEW_NS_01_02	West
80%	EW_08_02	Southeast	NEW_NS_01_02	East

Additionally, the maritime traffic in leg NS_12_03-04 will most likely be rerouted either east of Thor OWF or to the new traffic route between NSI.1-A3 and Thor OWF (leg NEW_NS_01_01-03). It is assumed that 20% will reroute to this new traffic route. The remaining 80% will be described further in section "East of NSI.1 and Thor OWF"). The new leg NEW_NS_01_03 is connected to the shipping corridor S10 by waypoint 29. The maritime traffic is rerouted as described in Table 8-7.

A major part of the traffic in NS_12 is related to dredging vessels that sails between Esbjerg and Jyske Rev northwest of Thor OWF and west of Thyborøn, where the dredgers are operating in raw material extraction sites (see section 5.1.2). 5.1.2These sites are covering a relatively large area. Therefore, the rerouted traffic from NS_12 east and west of Thor OWF are assumed not to sail to the exact same locations and consequently not all the traffic meets at the same waypoint after the rerouting.

Table 8-7. Proposed traffic rerouting in leg NS_12_03 and NS_12_04 related to the construction of NSI.1 and Thor (new traffic route between NSI.1 and Thor OWF).

Amount of traffic	Affected leg in scenario 1		Affected leg in scenario 2	
	Leg	Direction	Leg	Direction
20%	NS_12_03	Northwest	NEW_NS_01_01	Northwest
20%	NS_12_03	Northwest	NEW_NS_01_02	Northwest
20%	NS_12_03	Southeast	NEW_NS_01_01	Southeast
20%	NS_12_03	Southeast	NEW_NS_01_02	Southeast
20%	NS_12_04	Northwest	NEW_NS_01_03	Northwest
20%	NS_12_04	Southeast	NEW_NS_01_03	Southeast

The establishment of leg NEW_NS_01 includes two new waypoints (no. 60 and 61). After rerouting, all maritime traffic in leg EW_08_02 in both directions are deleted. Leg NS_12 is adjusted further which is described below.

All traffic rerouting related to the new traffic route between NSI.1-A3 and Thor OWF is illustrated in Figure 8-2 and Figure 8-3.

East of NSI.1 and Thor OWF

As described earlier, the maritime traffic in leg NS_12 must be rerouted due to the construction of NSI.1 OWF. It is assumed that all maritime traffic in the legs NS_12 will be rerouted east of NSI.1 OWF. In the southern part all traffic will be rerouted to the legs NS_05_01-03, which is described in Table 8-8.

Table 8-8. Proposed traffic rerouting in leg NS_12_01-03 related to the construction of NSI.1 OWF.

Amount of traffic	Affected leg in scenario 1		Affected leg in scenario 2	
	Leg	Direction	Leg	Direction
100%	NS_12_01	Northwest	NS_05_01	Northeast
100%	NS_12_01	Southeast	NS_05_01	Southwest
100%	NS_12_02	Northwest	NS_05_02	North
100%	NS_12_02	Southeast	NS_05_02	South
100%	NS_12_03	Northwest	NS_05_03	North
100%	NS_12_03	Southeast	NS_05_03	South

Additionally, there will be some minor adjustments to the legs NS_05_01 to NS_05_02. Due to the new legs connecting Hvide Sande to the two sailing corridors between the three NSI.1 OWF areas, the legs NS_05_01 and NS_05_02 has been subdivided into two legs each:

NS_05_01 -> NS_05_01a + NS_05_01b
NS_05_02 -> NS_05_02a + NS_05_02b

Two new waypoints (57 and 62) are added where the legs cross and they are dragged around 9 km to the east, to ensure a safer distance when navigating around NSI.1 OWF.

Further north, from waypoint 37, the maritime traffic will split and 80% of the traffic in NS_12_03 and NS_12_04 will continue in the new legs NEW_NS_02_01 and NEW_NS_02_02, respectively (Table 8-9), which is ultimately connected to the shipping corridor S10 by the new waypoint 63.

The remaining 20% of the traffic in NS_12_03 and NS_12_04 has been rerouted through the new traffic route between NSI.1-A3 and Thor OWF, which is described in section “Between NSI.1-A3 and Thor OWF“.

Table 8-9. Proposed traffic rerouting in leg NS_12_03 and NS_12_04 related to the construction of NSI.1 and Thor OWF.

Amount of traffic	**Affected leg in scenario 1**		**Affected leg in scenario 2**	
	Leg	**Direction**	**Leg**	**Direction**
80%	NS_12_03	Northwest	NEW_NS_02_01	Northwest
80%	NS_12_03	Southeast	NEW_NS_02_01	Southeast
80%	NS_12_04	Northwest	NEW_NS_02_02	Northwest
80%	NS_12_04	Southeast	NEW_NS_02_02	Southeast

After traffic movement and rerouting, all maritime traffic in leg NS_12_01-04 in both directions are deleted.

The rerouting east of Thor OWF causes some existing legs to split up. The new waypoint 63 splits the leg NS_02_05 into NS_02_05a and NS_02_05b. The leg EW_09_03 is also split into two parts named EW_09_03a and EW_09_03b at the new waypoint 64. Furthermore, there will be a minor adjustment to leg EW_04, where the traffic will go in a more northern direction to avoid passing through Thor OWF. This is simply done by moving waypoint 27 about 5 km to the north and adding a new waypoint (no. 65) which is connected to the new leg NEW_NS_02_01, which subsequently is subdivided as follows:

NEW_NS_02_01 -> NEW_NS_02_01a and NEW_NS_02_01b

All traffic movements and rerouting related to east of NSI.1 and Thor OWFs, is illustrated in Figure 8-1, Figure 8-2 and Figure 8-3.

West of NSI.1 OWF

The maritime traffic in leg NS_04 will be affected by the construction of NSI.1 OWF, and thus the maritime traffic must be rerouted. It is expected that the traffic will be rerouted west of NSI.1 OWF. The legs NS_04_01-04 will only change orientation from northeast/southwest to northwest/southeast and thus rerouted west of NSI.1 OWF. The traffic in NS_04_04 is connected to NS_02 in the new waypoint no. 66 located in the shipping corridor S10, which splits NS_02_03 into to parts:

NS_02_03 -> NS_02_03a and NS_02_03b

From the new waypoint 66 to waypoint 29 the maritime traffic will be rerouted into the existing leg NS_02_03b and NS_02_04 which is described in Table 8-10.

Table 8-10. Proposed traffic rerouting in leg NS_04_04 and NS_04_05 related to the construction of NSI.1 OWF.

Amount of traffic	**Affected leg in scenario 1**		**Affected leg in scenario 2**	
	Leg	**Direction**	**Leg**	**Direction**
100%	NS_04_04	Northeast	NS_02_03b	Northeast

100%	NS_04_04	Southwest	NS_02_03b	Southwest
100%	NS_04_05	Northeast	NS_02_04	Northeast
100%	NS_04_05	Southwest	NS_02_04	Southwest

After the movement of all traffic in leg NS_04_05 in both directions are deleted.

Furthermore, the legs NEW_EW_01 and NEW_EW_02, which passes through the two internal sailing corridors between NSI.1 A1-A3, are connected to leg NS_04 west of NSI.1 in the new waypoints no. 67 and 68. The new waypoint 68 subdivides leg NS_04_03 into NS_04_03a and NS_04_03b. The traffic in NEW_EW_01 and NEW_EW_02 mainly consists of fishing ships, which most likely will move their fishing activities to the area west of NSI.1 OWF (in scenario 2). Therefore, none of the traffic in NEW_EW_01 and NEW_EW_02 are rerouted into NS_04.

All traffic movements and rerouting related to the area west of NSI.1 and Thor OWF, is illustrated in Figure 8-1, Figure 8-2 and Figure 8-3.

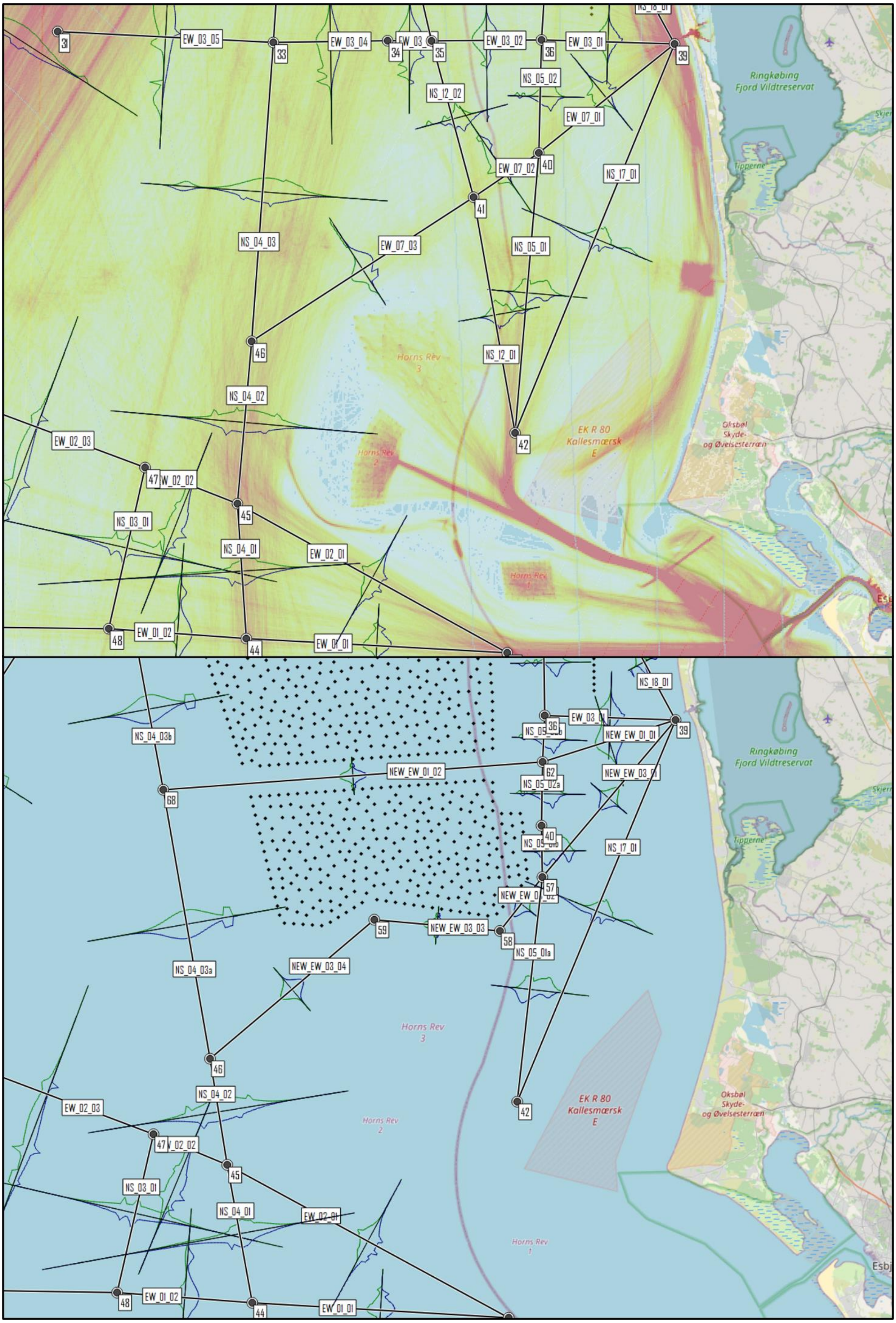


Figure 8-1. Illustration of the traffic movements and rerouting related to the construction of NSI.1 OWF in the North Sea (southern part). The top figure illustrates the conditions in scenario 1 (baseline), while the bottom figure illustrates the rerouted traffic conditions in scenario 2.

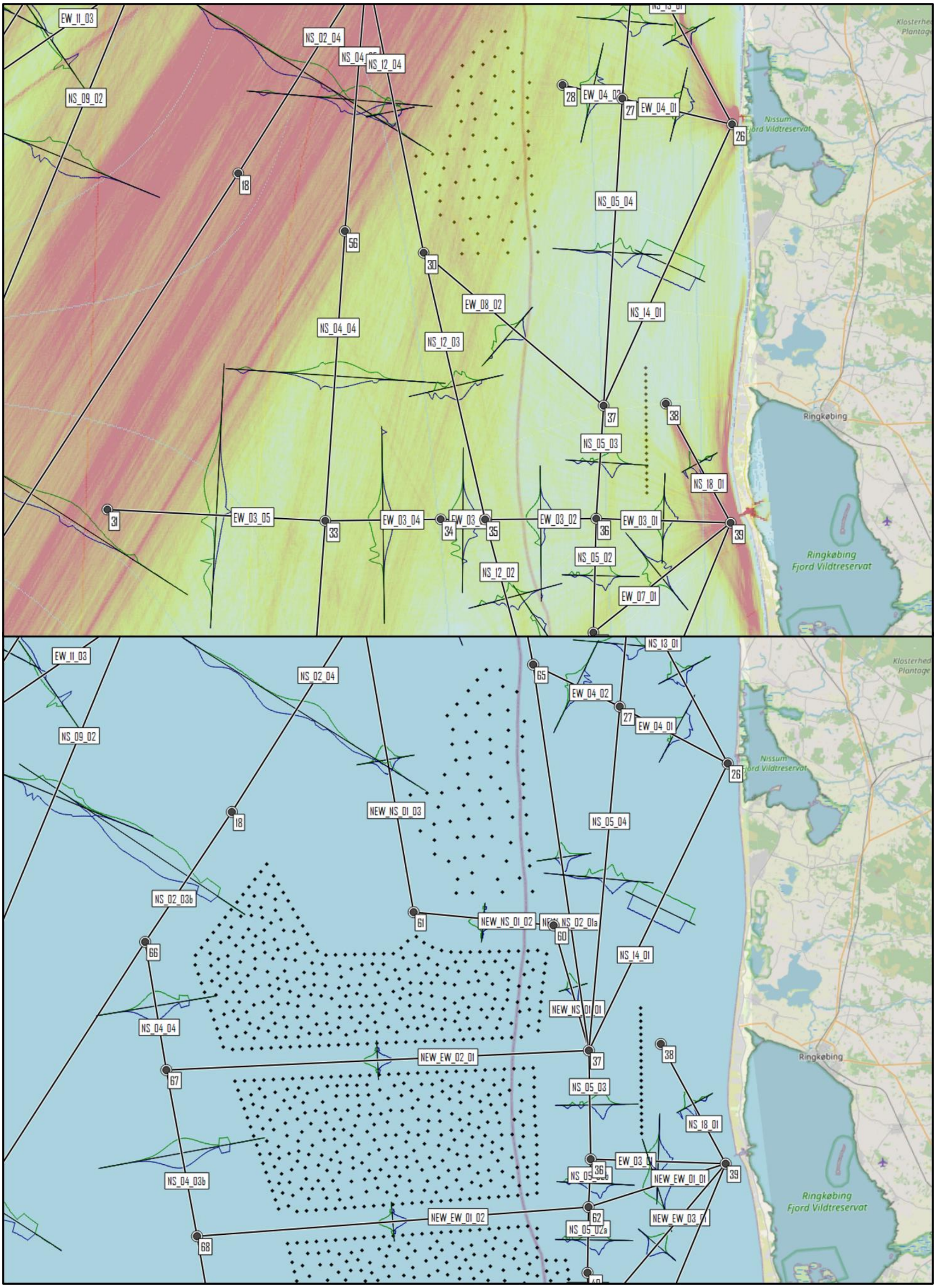


Figure 8-2. Illustration of the traffic movements and rerouting related to the construction of NSI.1 OWF in the North Sea (central part). The top figure illustrates the conditions in scenario 1 (baseline), while the bottom figure illustrates the rerouted traffic conditions in scenario 2.

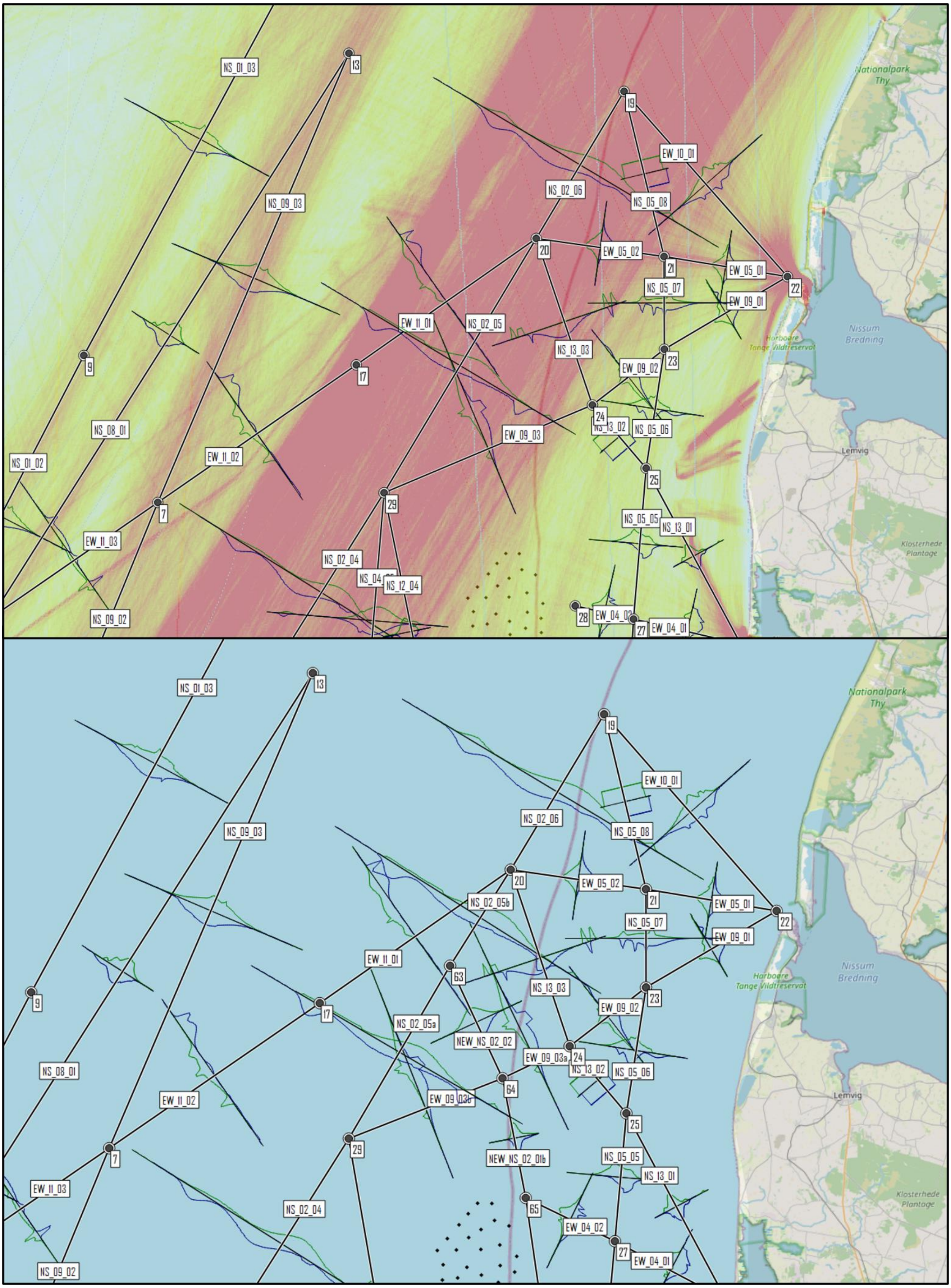


Figure 8-3. Illustration of the traffic movements and rerouting related to the construction of NSI.1 OWF in the North Sea (northern part). The top figure illustrates the conditions in scenario 1 (baseline), while the bottom figure illustrates the rerouted traffic conditions in scenario 2.

8.1.1 FINAL MODEL SETUP

Following the proposed traffic movements and rerouting from scenario 1 (baseline) to scenario 2, outlined in the previous section, based on the construction of the NSI.1 OWF, the final model setup for scenario 2 can be seen below in Figure 8-4.

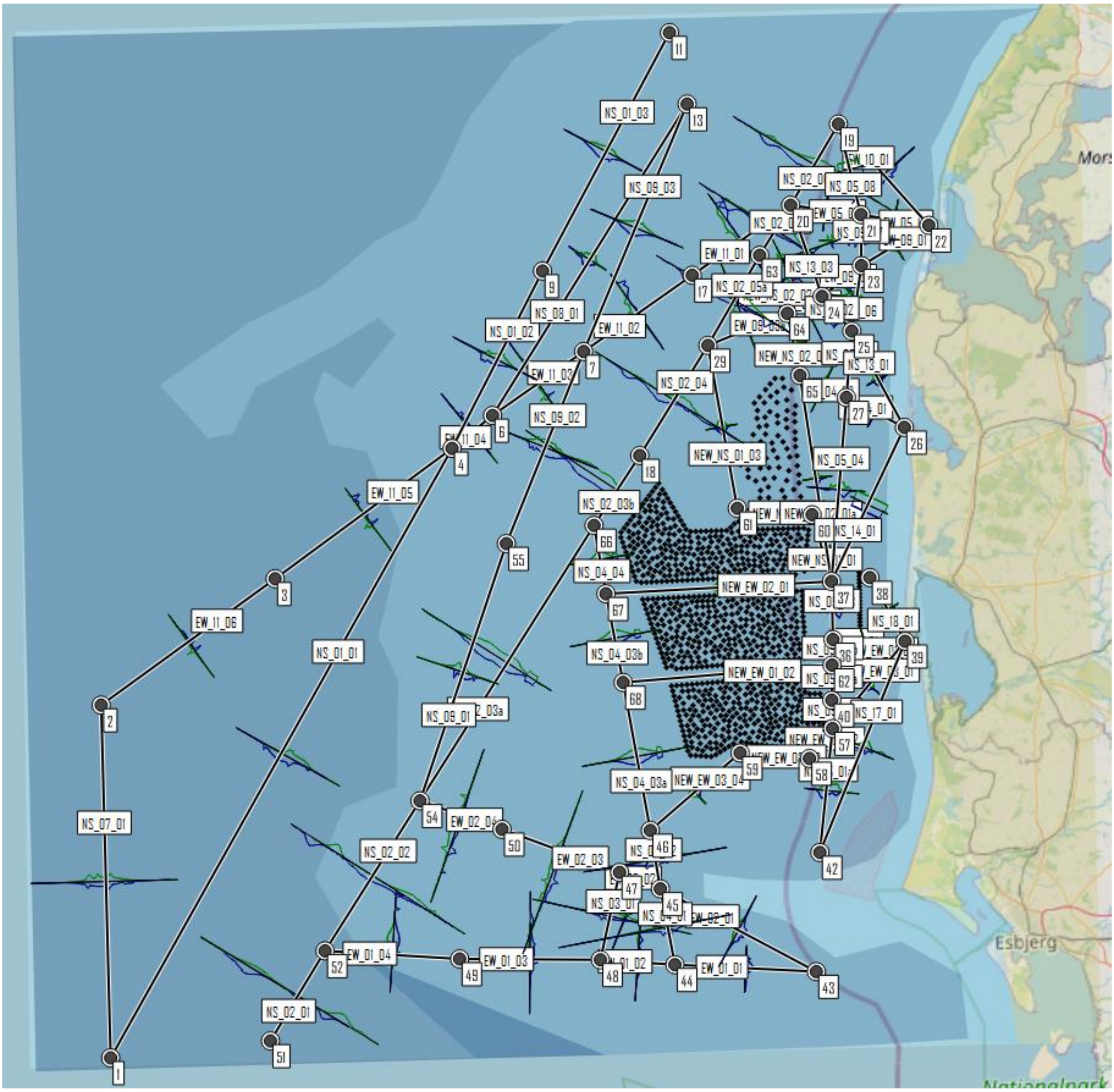


Figure 8-4. Proposed traffic model for scenario 2 based on the modelling of NSI.1 OWF as well the previous modelled scenario related to VHS and Thor OWFs.

8.2 FREQUENCY MODELLING

The overall results of the frequency modelling (calculation of return periods) based on scenario 2 in relation to the operation phase are shown in Table 8-11 with years between incidents and the corresponding yearly frequency. The frequency model is based on the entire AoI area.

Table 8-11. Overall frequency modelling results of scenario 2 (presented with at least three digits).

Scenario 2	Return period (years between incident)	Frequency (yr^{-1})
Powered groundings	7,856	1.27E-04
Drifting groundings	37.8	2.64E-02
Total groundings	**37.7**	**2.66E-02**
Powered allisions	2,272	4.40E-04
Drifting allisions	202	4.96E-03
Total allisions	**185**	**5.40E-03**
Overtaking	113	8.84E-03
HeadOn	75.0	1.33E-02
Crossing	82.0	1.22E-02
Merging	527	1.90E-03
Bend	665	1.51E-03
Total collisions	**26.5**	**3.78E-02**

For total groundings, the calculated return period for scenario 2 is around 38 years between incidents. For total allisions, i.e., collisions between ship and obstacles, the return period for scenario 2 is about 185 years, while total ship-ship collisions are about once every 27 years (Table 8-11). For scenario 2, the most frequent accident type is collisions. Overall, the total frequency of groundings and collisions is in the approximately same order of magnitude. In fact, the real grounding frequency is much lower in the areas around the OWFs since there are no risk of groundings in the open waters with the proposed traffic rerouting (see section 4.3.3). As earlier mentioned, the main contributors to the grounding frequency are from the most coastal areas and from the ground of Horns Rev.

The calculations indicate that the return periods are much higher (lower frequencies) for powered accidents relatively to drifting accidents. For instances, powered allisions are 11 times less frequent compared to drifting allisions (11 times longer return period).

For ship-ship collisions the most frequent type of accident is “HeadOn” collision followed by “Crossing”. The frequency related to “Merging” and “Bend” collisions is low (around 500-600 years), whereas “Overtaking” is intermedial. “HeadOn” collision is about 9 times more frequent compared to “Bend” (Table 8-11).

Based on the frequencies listed in Table 8-11, a frequency index relative to the DMA scheme “Construction Works at Sea” is provided for each incident type. The determined score (IMO risk class) for scenario 2 is presented in Table 10-2.

8.2.1 GROUNDINGS

Most groundings in the model are due to cargo ships (46%), tankers (15%) and fishing ships (15%). Most of the powered groundings for scenario 2 occur in a few legs, see Table 8-12 (left), where 95% of the powered groundings is related to two legs. Most powered groundings are found in leg NS_14_01 (covering 65% of all powered groundings) located in the coastal area north of VHS OWF. The second largest contributor is leg NS_05_01a, which is located in the coastal areas southeast of NSI.1 area and just north of the ground of Horns Rev.

As shown in Table 8-12 (right), drifting groundings are not controlled by individual legs, however many different legs contribute to the drifting grounding statistics. In fact, the five most contributing legs only covers 44% of all drifting grounding in the model.

85% of the groundings in the model are caused by ships colliding with land (0 m water depth curve), which will not be affected by the rerouting of traffic in relation to the planned NSI.1 OWF. The remaining part (15%) of the groundings are related to the 10 m curve.

Table 8-12. The five most contributing legs to powered groundings (left) and drifting groundings (right) in scenario 2.

Leg	Powered groundings (%)
NS_14_01	65.3
NS_05_01a	29.3
NS_04_02	3.5
NEW_EW_01_01	1.0
NS_04_01	0.9
Total	**100**

Leg	Drifting groundings (%)
NS_02_06	14.8
NS_02_05b	10.9
NS_02_05a	8.8
EW_05_01	4.7
NS_02_03a	4.6
Total	**43.8**

8.2.2 ALLISIONS

According to scenario 2, most of the powered allisions occur in a few legs, see Table 8-13 (left), where around 80% of the powered allisions is related to four legs. Most powered allisions are found in route NS_05 (within leg NS_05_02a and NS_05_01a (covering 59% of all powered allisions) located in the coastal areas southeast of NSI.1 area where the WTGs are located close to traffic routes.

As shown in Table 8-13 (right), drifting allisions in scenario 2 tend to be more controlled by individual legs compared to scenario 1, however still many different legs contribute to the drifting allisions statistics. In fact, the seven most contributing legs, only covers 74% of all drifting allisions in the model. Most drifting allisions are recorded in leg NS_02_03a, which is located west of NSI.1 OWF within the shipping corridor S10 and allisions will mainly occur during strong winds from west.

Table 8-13. The seven most contributing legs to powered allisions (left) and drifting allisions (right) in scenario 2.

Leg	Powered allisions (%)
NS_05_02a	31.8
NS_05_01a	27.1
NEW_EW_03_04	11.9
NEW_EW_03_03	9.2
NS_02_04	8.1
NEW_NS_01_03	2.8
NS_02_03b	2.2
Total	**93.1**

Leg	Drifting allisions (%)
NS_02_03a	39.4
NS_04_03a	7.5
NEW_EW_01_02	6.5
NEW_EW_02_01	6.3
NS_04_03b	6.3
NS_04_04	4.6
NS_05_01a	3.5
Total	**74.1**

Overall, the WTGs that are most exposed to allisions are in the western and southern part of NSI.1, however there a few very exposed WTGs along the eastern part of NSI.1 A1. The WTGs less exposed to allisions are located centrally in all NSI.1 areas and in the northern part of NSI.1 A3.

8.2.3 COLLISIONS

According to scenario 2, HeadOn collisions is modelled to be the leading cause of collisions. Most of the Head-on and Overtaking ship-ship collisions is related to leg NS_02_03a, NS_02_03b and NS_02_04; which in total covers about 58% and 55%, respectively (Table 8-14). In addition, most of these two collision types involve cargo ships and tankers in leg NS_02. Basically, all seven most contributing legs are related to NS_02 for both HeadOn and Overtaking collision, which all are legs within the shipping corridor S10 that have been narrowed significantly in their traffic distribution. Thus, it can be concluded that 85-91% of all collisions in relation to scenario 2 occurs in shipping corridor S10, whereas collisions are relatively rare in the surrounding areas.

Crossing, merging and bend collisions are not included in Table 8-14, as these collisions happen at the intersection of different legs and cannot be divided into individual legs.

Table 8-14. The seven most contributing legs to HeadOn collisions (left) and overtaking collisions (right) in scenario 2.

Leg	HeadOn collisions (%)
NS_02_03a	35.7
NS_02_03b	13.6
NS_02_04	9.1
NS_02_06	8.2
NS_02_05a	8.0
NS_02_01	6.0
NS_02_05b	4.5
Total	**85.2**

Leg	Overtaking collisions (%)
NS_02_04	22.5
NS_02_03a	19.0
NS_02_03b	13.8
NS_02_06	11.9
NS_02_02	8.8
NS_02_05a	7.9
NS_02_05b	6.6
Total	**90.5**

9 COMPARISON BETWEEN SCENARIO 1 AND 2

The present risk evaluation and modelling are conducted as a comparative analysis, comparing the calculated risks (incident frequencies) across different scenarios based on the existing, approved and future build-out of OWFs in the Danish North Sea sector. The existing OWFs include HRI, HRII and HRIII (scenario 0), whereas the approved OWFs include VHS and Thor (scenario 1 - baseline). The modelled scenario 2 includes the build-out of NSI.1 OWF. In this chapter the calculated return periods (frequencies of incidents) for scenarios 1 and 2 are compared and risk evaluated. Correspondingly, the calculated return periods for scenarios 2 and 3 are compared and risk evaluated in section 14.3 and for scenario 3 and 4 in section 15.3.

The calculated return periods in terms of groundings (powered and drifting) and ship-WTG collisions (powered and drifting allisions) as well as ship-ship collisions (during overtaking, heads-on, crossing, merging and bending) related to the two different scenarios are presented in Table 9-1. The risk evaluations focus on the numerical outputs from the model, i.e. the accident frequencies.

Table 9-1. Risk evaluation (comparison) of the calculated return periods modelled for scenario 1 and 2 (presented with at least three digits).

	Return period (years between incidents)	
Incident type	**Scenario 1**	**Scenario 2**
Powered groundings	6,094	7,856
Drifting groundings	35.6	37.8
Total groundings	**35.4**	**37.7**
Powered allisions	17,750	2,272
Drifting allisions	2,571	202
Total allision	**2,245**	**185**
Overtaking	118	113
HeadOn	98.9	75.0
Crossing	1,098	82.0
Merging	325	527
Bend	948	665
Total collisions	**42.3**	**26.5**

According to Table 9-1, the lowest frequency (longest return period) for both scenarios is related to powered allisions followed by powered groundings. In general, the frequency of drifting accidents (drifting groundings and drifting allisions) is much higher relative to powered accidents. In other words, drifting accidents occur more often than powered accidents. In scenario 1, the most frequent accident type is grounding, while in scenario 2, it is collision. For both scenarios, the most frequent collision type is “HeadOn”. Overall, the total frequency of groundings and collisions is approximately the same, while the total allision frequency in both scenarios is significantly higher than the total frequency of groundings and collisions.

The overall change in incident frequencies between scenario 1 (baseline) and scenario 2 is shown in Table 9-2. A positive percentage means the frequency will increase (shorter return period), resulting in fewer years between incidents. Conversely, a negative percentage means the frequency will decrease (longer return period), resulting in more years between incidents.

Table 9-2. Percentage changes in the incident frequency for scenario 2 relative to scenario 1.

	Changes in percentage (%)
Powered grounding	-29

Drifting grounding	-6
Total groundings	**-7**
Powered allisions	87
Drifting allisions	92
Total allision	**92**
Overtaking	4
HeadOn	24
Crossing	93
Merging	-62
Bend	30
Total collisions	**37**

In the following sections, the percentage differences for each incident type (groundings, allisions, and collisions) are further discussed.

9.1 GROUNDINGS

The modelling shows that the total grounding frequency will decrease by 7% (Table 9-2) from scenario 1 to scenario 2 with the build-out of WTGs in the NSI.1 area. The greatest reduction will be related to powered groundings. The overall reduction in grounding frequency will mainly be caused by the rerouting of maritime traffic west of NSI.1 where the distance to the coast is larger.

The data show a very small decrease in number of groundings after establishment of NSI.1 relative to the baseline scenario (from scenario 1 to scenario 2). This cannot be considered a significant change, and it is assumed that the related traffic movements and rerouting due to the presence of NSI.1. OWF do not affect the risk of groundings.

It is not expected that the return periods for groundings will vary significantly between the modeled scenarios, as most traffic movements and rerouting will occur at a sufficient distance from the coast.

9.2 ALLISIONS

The greatest change in frequency (according to overall accident types) between scenario 1 and 2, are related to allisions. The modelling shows that the total allision frequency will increase by 92% from scenario 1 to scenario 2 (Table 9-2) with the build-out of WTGs in the NSI.1 area. The allision risk related to VHS and Thor OWF is included in the modelling of scenario 1 (see section 7.2.2). This significant increase in allision frequency is explained by the construction of NSI.1 OWFs in open waters dominated by medium to high density of maritime traffic, which is rerouted as proposed in this study. Obviously, it is expected that presence of more WTGs, result in greater allision risk. The percentage change will be similar for powered and drifting allisions (Table 9-1).

9.3 COLLISIONS

The modelling shows that the total collision frequency will increase by 37% from scenario 1 to scenario 2 with the build-out of WTGs in the NSI.1 area. There is great variation in the contribution from the different types of collisions. Crossings will increase by 93%, while merging will decrease by 62%. The remaining collision types (overtaking, head-on and bending) are all calculated to increase between 4 to 30% (Table 9-2).

The traffic will be rerouted west of NSI.1 (cf. shipping corridor S10 stated in the MSP), but also east of NSI.1 and in the internal sailing corridors within the NSI.1 area, as well as into new traffic routes north and south of NSI.1 OWF. These traffic movements and rerouting results in higher traffic density, which ultimately will lead to a greater risk of collisions between ships. The largest difference in Head-On collisions between scenario 1 and 2 is observed in leg NS_02_03a (in S10) where the return period will increase with 853 years between incidences. Another reason for the increasing collision frequency is due to narrowing of the shipping corridor S10, where much of the traffic will be rerouted into and where the traffic density will be greatest.

The significant increase in crossing collisions is also related to the increased traffic density in S10, where more ships need to cross into the major shipping corridor.

10 QUALITATIVE RISK ASSESSMENT

The above calculations of return periods and maritime traffic analysis is primarily based on quantitative studies implemented in the present navigational risk assessment. However, several other relevant aspects of the maritime traffic and navigational safety are qualitatively addressed below. These include submarine cables (inter-array cables and export cable corridors) (see section 10.1.1), inspection and maintenance (see section 10.2.1), fishing and pleasure sailing (see section 10.2.2), Search and rescue (see section 10.2.3) and cumulative effects (see section 10.2.5).

The presence of work-related vessels during the construction and operation phases is generally expected to pose an additional risk to current traffic conditions. However, due to the low number of work vessels and the implementation of specific risk-reducing measures (as stated below), this risk is assessed to be low. These measures might include nautical information and notification, recommended risk-reducing measures and a plan for the use of vessels during construction and operation, all of which are standard requirements related to establishment of OWFs in Denmark (Construction Permits). These measures are stated in the sections below, as well as in Chapter 11, and largely follow similar conditions stated in the Construction Permit for VHS (DEA, 2016) and Aflandshage OWF (DEA, 2022).

Initially, these risks were qualitatively assessed during the hazard identification process. In this section, these risks and their corresponding consequences will be further discussed and addressed. Finally, this qualitative risk assessment will cover the overall indicative risk index, based on the determining of frequency and consequence indices (see section 10.3).

10.1 CONSTRUCTION PHASE

The construction phase has not been addressed in the quantified risk assessment. Therefore, the qualitative findings and recommendation are derived from the HAZID study (see Appendix 4, Chapter 17).

During the construction phase, work and installation vessels will operate in and around NSI.1. These vessels are mainly expected to be support vessels, CTVs as well as larger vessels for the installation of foundations, turbines and cables (such as SOVs and jack-ups). These vessels can be both stationary during work (e.g. cable laying) and in transit (mainly fast-moving vessels), crossing traffic routes. Essentially, there is a risk of collision between work-related vessels and other maritime traffic.

All types of maritime traffic related to construction activities to and from the construction site, as well as work-related traffic (such as crew transport, cable-laying activities etc.) must always follow general maritime rules.

The presence of guard vessels in the area during the construction phase will significantly reduce the frequency of accidents. Preparedness in the form of tugs and emergency towing vessels (ETV) can reduce return periods by up to 60% (ABL, 2023). ETVs are assumed to mitigate risks by primarily preventing drifting allisions. There is already a 24/7 preparedness in the North Sea, both in Denmark and Germany (existing mitigation measures). In line with the increasing development of OWFs in the North Sea, consideration should be given to expanding the emergency capacity. Agreements can be made with tugboats stationed close to NSI.1 (see Chapter 11).

Collision frequencies and consequences are not quantified for the construction phase. Depending on the selected work port for NSI.1 OWF, it is recommended that work vessels and personnel transport adhere to the existing traffic routes and shipping corridors outlined in the MSP. Furthermore, it is expected that construction vessels will act according to COLREGS (normal IMO rules for interaction between ships).

In the construction phase sailing will be prohibited in the construction site. The construction area will be closed off by a restriction zone to avoid unauthorized trespassing of the area (e.g. fishers, pleasure crafts and other smaller vessels), which is standard procedure to reduce the risk during construction (DEA, 2016) (DEA, 2022). In addition, all fishing activities from the construction area will be suspended. Based on previous experience, a safety zone of 500 meters has been used in connection with similar OWF projects. At the HAZID workshop, the DMA also mentioned this specific safety distance. The dimensions of this restriction zone likely cover parts of the entire OWF area and depend on the overall build-out sequence (see section 11.3). In general, the distribution of this restriction zone will vary in size over time. This will be an integrated part of a future Construction Permit. This is also described in the chapter about mitigation measures (see Chapter 11). Based on experience, the distance between the construction work and shore (also nearby harbours) (more than 20 km) is assumed not to pose an elevated risk to the navigational safety in the area associated with fishing and pleasure sailing. Markings and communication of the construction must be coordinated between relevant authorities, contractors, relevant harbours, sailing unions and other local associations (see Chapter 11).

The navigational risks in the construction phase of each of the OWFs in the NSI.1 area, as well as future OWFs, are not part of the present navigational risk assessment. Specific navigational risk assessments will be performed by the developers (concessionaires) of the OWFs, as part of the approval procedure for the specific projects. This will follow conditions as stated in a forthcoming Construction Permit (see (DEA, 2016) as an example).

To reduce the risk during construction, it is anticipated that the construction site will be marked with Aids to Navigation (AtoN). These aids, which can be physical or digital, will mark work areas and help ships navigate safely through the area. All measures, communications, and other activities must comply with DMA regulations to ensure that all vessels in the area are informed.

10.1.1 SUBMARINE CABLES

During the construction phase, there will be cable-lying activities related to both inter-array cables between the WTGs within the NSI.1 area and the three export cable corridors. Without the right measures, this work could potentially affect maritime traffic, mainly in areas where the work vessels cross existing maritime routes. The construction vessels used in connection with cable-lying activities will overall have limited manoeuvrability and will thereby be more exposed to collisions from crossing maritime traffic. Additionally, the danger associated with cable work is greatest near the coast due to shallow waters and limited manoeuvrability. These cable-laying vessels can be both stationary when laying cables and in transit before and after work activities resulting in crossing of current traffic routes. It is a standard requirement to announce maritime activities in Notices to Mariners (NtM) (see section 11.3). Each cable installation vessel is equipped by its own safety marking (existing mitigation measure, cf. section 11.1).

The above-mentioned navigational risks according to submarine cables in the construction phase are qualitatively assessed in the HAZID report (see Appendix 4, Chapter 17). The anticipated work-related traffic to and from the OWF and the export cable corridors is expected to be limited and temporary and is not expected to significantly impact the overall risk index of the area.

The future concessionaires will be required to conduct navigational risk assessments specific to each project. These assessments will be part of the approval process and will be based on a detailed project plan and form the basis of the specific consent conditions regarding navigational safety (cf. Construction Permit, see (DEA, 2016) as an example). The anticipated work-related traffic to and from the OWF and the export cable corridors is expected to be limited and temporary. It is not expected to significantly impact the overall risk index of the area.

10.2 OPERATION PHASE

10.2.1 INSPECTION AND MAINTENANCE TRAFFIC

The operational phase of the OWFs planned within NSI.1 area will entail ongoing operation and maintenance (O&M-activities) which will generate additional ship traffic to and from the OWF and nearby ports. When operating outside the OWF, the maintenance vessels are expected to follow regular traffic patterns and comply with the COLREGS (normal IMO rules for interaction between ships).

It is expected that O&M-activities will be conducted by a crew transfer vessel (CTV) and that during the annual service period, a service operation vessel (SOV) will visit each turbine for service and maintenance. The anticipated traffic to and from the OWF is expected to be limited and temporary. It is not expected to significantly impact the overall risk index of the area.

10.2.2 FISHING AND PLEASURE SAILING

The fishing activities are likely to be affected by the operation of OWFs within the NSI.1 area. The impact on commercial fishery is separately assessed in a technical report (WSP, 2024). General recommendation regarding commercial fishery is stated in section 11.2.

The presence of the large WTGs on the sea may be an attractive sight for pleasure crafts, including motor vessels, which can cause an increased allision risk for these ship types. However, this interest will probably decrease with further OWF build-out in the North Sea. The proportion of smaller pleasure crafts in the waters around NSI.1 is also limited, since the distance to the coast is large (>20 km).

It is expected that pleasure crafts and fishing vessels will likely continue navigating through the OWF area during the operational phase. These vessels are anticipated to maintain their current varied sailing patterns, as described in section 4.4.1, rather than adhering to specific traffic routes. Since the IWRAP modeling tool relies on specific traffic routes it is challenging to estimate the rerouting of pleasure crafts and fishing vessels without a defined route pattern.

As some pleasure crafts and fishing vessels are proposed to reroute to the two internal sailing corridors (and not sail within the NSI.1 OWF), these ship types have been fully rerouted in the same way as all other ship types in the proposed traffic model for each scenario. This rerouting provides the most conservative model result regarding ship-ship collisions, while the model result is less conservative concerning allisions. Consequently, the most realistic scenario stated in this qualitative risk assessment for fishing and pleasure sailing differs from the modelling scenarios in the quantitative risk assessment.

Crossing traffic between the shipping corridor S10 and NSI.1 entails an increased risk of collision and the need for evasive maneuvers. This is particularly applicable to smaller vessels, including fishing vessels and pleasure crafts, which will typically sail within the NSI.1 area. In addition, maritime traffic inside the OWF creates uncertainty on radar signals, since it is difficult to distinguish between radar signals from WTGs and actual maritime traffic within the OWF area (see section 10.2.4). Consequently, there will be an increasing collision risk between non-transiting vessels such as pleasure craft and fishing vessels and transiting vessels (primarily cargo and tankers). This risk is assessed to be particularly high near the waypoints of 18 and 66 along the shipping corridor S10 close to the outer most WTGs in the NSI.1 area. This specific risk is assessed to significantly contribute to the collision frequency (ship-ship) and can be minimized by implementing mitigation measures (see Chapter 11).

In relation to pleasure yachting, various local information campaigns are recommended and via several relevant communication channels. For fishing vessels, supplementary information campaigns are also proposed locally and via Danish Fishers PO. These are standard procedures associated with offshore construction works.

Based on the above review, the overall impact on the navigational risk for fishing and pleasure sailing activities in the operational phase of OWFs in the NSI.1 area is qualitatively assessed to be low.

The above-mentioned navigational risks according to fishing and pleasure sailing in both the construction and operation phase are qualitatively assessed in the HAZID report (see Appendix 4, Chapter 17).

10.2.3 SAR OPERATIONS

At the HAZID workshop, there was broad agreement that the presence of WTGs at sea is not an obstacle to search and rescue operations (SAR operations). In general, there is more than 1,000 meters between each WTG. Thus, there will be sufficient space to perform search and rescue operations within the NSI.1 area, if relevant. Rescue from helicopter might be limited near the WTG, however due to the free space between the WTGs, it is possible to navigate close to specific locations within the OWF.

10.2.4 RADAR DISTURBANCES

More WTGs cause more interference/radar shadow and other radar disturbances. A separate risk analysis is carried out for radar where radar disturbance will be assessed (WSP 2024, in prep.). It is assumed that this risk analysis also includes the cumulative effects resulting from the OWF build-out in the North Sea, as described in this navigational risk assessment.

Interference with radar might affect navigational safety and this issue was specifically mentioned at the HAZID workshop as a potential risk.

The results of separate risk analyses regarding radar disturbances related to the establishment of the NSI.1. OWFs will be included in the detailed FSA reports, which must be conducted by the individual concession winners at a later stage.

10.2.5 CUMULATIVE EFFECTS

In the MSP for Danish waters, large areas in the North Sea are reserved for the future build-out of OWFs (renewable energy). Overall, the future build-out of OWFs in the Danish North Sea sector will lead to movements and rerouting of maritime traffic in open waters. Since several OWFs are planned to be constructed in the same regional part of the Danish North Sea sector, it will result in significant changes in the waterway characteristics such as fewer traffic routes, narrowing of traffic routes and densifying traffic in the current traffic routes. Thus, there will cumulatively be an additional impact relatively to the current traffic conditions and navigational safety. The risk of collisions with WTGs (allisions) will naturally increase in line with on-going build-out of OWFs. The changes in the waterway characteristics might also lead to more collisions (ship-ship) within the individual traffic routes. The establishment of NSI.1 will – together with other OWFs in the area, contribute to an overall increased risk index which is addressed in this navigational risk assessment.

In connection with the present navigational risk assessment for the NSI.1 area, cumulative effects have been considered in line with the development of several OWFs in the Danish part of the North Sea. The assessment of the cumulative effects is based on the modelling of the different scenarios (cf. scenario 1-4) according to the future build-out of OWFs in the area (see section 4.4.2). The modelling both includes already constructed, approved and planned OWFs in order to address the full potential build-out of wind power and the corresponding accumulated impact on the maritime traffic and navigational safety. The assessment of the cumulative effects is based on a worst-case scenario, where all of the planned OWFs are realized and established (see Appendix 1, Chapter 14 and Appendix 2, Chapter 15.

The above-mentioned cumulative effects are only related to the actual operation of the different OWFs (after establishment). According to the hazard identification, a qualitative and cumulatively risk assessment for the construction phase has been discussed (see Appendix 4, Chapter 17). During the construction phase, there will potentially be cumulative impacts associated with work-related traffic between the work port and the construction area, as well as along the export cable corridors. In the operational phase there will also be potential cumulative impacts associated with service vessels and personnel transport.

Potentially, several OWFs can be built simultaneously, whereby the work-related traffic in the construction phase from the work port can be related to one or more OWFs in the North Sea. Since the work-related traffic does not have to cross major traffic routes, the risk of ship-to-ship collision is considered low. Several work vessels associated with several OWFs do not change that fact. It is assumed that even the largest harbor, Esbjerg, does not have the facilities to handle several OWF constructions at the same time, making it unlikely that several parks will be built simultaneously.

In both project phases, personnel transport may occur from one or more ports to several different OWFs at the same time causing an increased risk of ship-ship collision in both phases. As CTVs must not cross major traffic routes, the risk of ship-ship collision is considered to be low. Several CTVs in connection with several OWFs at the same time does not change that fact.

According to the MSP, a new SE-NW orientated shipping corridor S146 is designated between NSI.1 and NSI.2 leading the traffic from the south into the shipping corridor S10 towards north and vice versa (see section 3.6). As a result of the build-out of several OWFs in the North Sea, this new designated shipping corridor in the MSP is of crucial importance in relation to navigational safety and will have the capacity to handle the derived cumulative traffic that may come in connection with the diversion of traffic from several planned OWFs including NSI.1 and NSI.2. The new designated shipping corridor S146 is an integrated element of the present navigational risk assessment, and the accumulated cumulative impact according to the planned build-out of OWFs in the regional area, is calculated and assessed (see Appendix 1, Chapter 14 and Appendix 2, Chapter 15.

Traffic along the main route (shipping corridor S10) takes place within a very wide corridor (>50 km). After narrowing of this shipping corridor - because of the build-out of NSI.1 OWF - the corridor is assessed to still have the required width to handle the capacity in the area and there is no assessment of congestion on this route. This is further reflected by the risk indices concerning collision outlined in Table 10-2. According to the MSP, this shipping corridor (S10) constitutes an extra wide corridor which supports a future traffic separation system (TSS) or recommended IMO-route, if needed. The narrowing of shipping corridor S10, as a result of the cumulative build-out of OWFs in the regional area, is an integrated element of the present navigational risk assessment and traffic rerouting (see Appendix 1, Chapter 14 and Appendix 2, Chapter 15). Ultimately, however, it is the DMA that makes the final assessment of whether the assessed risk level is acceptable or not.

10.3 CONSEQUENCES

As a result of the intense ship traffic and build-out of OWFs in the North Sea, there is a significant probability of collisions and allisions. This is reflected, among other things, by the estimation of accident frequencies in Chapter 9. The consequence index associated with ship-ship collision or grounding event are generally the same order before and after establishment of OWFs in the area. As a result of the large volume of traffic with commercial traffic on the main routes in and around the planned OWF, many collisions may involve larger, commercial ships. The consequence of allisions is dependent on collision angle, the vessel type, size of vessel and the vessel speed. In principle, the consequence index associated with further expansion of the North Sea are the same for the individual accident types (more WTGs do not necessary enhance the consequences). In general, frequent drifting collisions and allisions will probably give rise to smaller consequences.

The consequences of collisions or allisions can be severe due to the types of vessels operating in the area. Both incidents can lead to material damage, personal injury, and environmental impact, especially in the case of an oil spill. However, severity of collision scenarios can vary greatly. The consequences of a collision can range from severe head-on collisions at high speeds to more superficial impacts at lower speed. Most collisions will not involve the largest ships or result in the most critical damage scenarios.

There are several potential consequences related to allisions. The least severe consequence is that a drifting vessel hits a WTG at low speed. In this event, there may be minor damage to both vessel and WTG. It is likely that all personnel and passengers, as well as the structures, would not experience any injury or damage. Personnel and crew should in this event have sufficient time to prepare for impact and thereby ensure all persons are in safe locations.

The severity of an allision generally increases with the speed of impact and size of the vessel. However, smaller vessels like pleasure crafts or fishing vessels may also experience severe damage if striking a wind turbine at high speed. A powered allision (at high speed) would likely result in the most severe consequences for both the vessel and WTG. Worst-case scenario of a powered allision and collision could result in the following:

- Personnel/passenger injury or fatality
- Major damages to the vessel. Damages could potentially be so severe that vessel foundering is possible. Damages could also result in a release of cargo.
- Major damages to the wind turbine and/or foundation

Collisions and allisions involving large tankers can have significant environmental consequences due to the risk of oil spills. The consequence is clearly greatest in the North Sea, where the largest tankers are sailing. It is considered less likely that cargo ships, tankers and other larger vessels with double hulls will cause environmental damage. Therefore, the likelihood of a serious oil spill occurring after an incident is reduced. Thus, the IMO risk class for Environment for tankers is reduced from 4 to 3, which has been implemented in the HAZID protocol.

10.3.1 CONSEQUENCES ANALYSIS AND RISK INDEX

Based on the “Construction Works at Sea” scheme from the DMA (see section 4.5), a qualitative assessment of the consequence and the indicative risk index has been determined. This assessment has been conducted for scenario 1 (Table 10-1) and scenario 2 (Table 10-2).

Below is a qualitative assessment of the individual accident types, which serves as input to the indicative risk index for scenario 1 and scenario 2. Generally, the consequence associated with a certain accident is identical for all three areas within the NSI.1 area. For instance, this means that the consequence index associated with cargo ships and drifting allisions is the same for all three OWF areas.

POWERED GROUNDING

The conditions for powered grounding are very similar for both scenario 1 and 2, which is why they are assessed together in the following section.

Most groundings in the model for scenarios 1 and 2 are due to cargo ships (46-47%), tankers (15%) and fishing ships (15%). Most of the powered groundings for scenario 1 and 2 occur in a few legs, where 95-99% of the powered groundings is related to two legs. Most powered groundings are found in leg NS_14_01 (covering 65-66% of all powered groundings) located near the coast north of VHS OWF.

85-87% of the groundings in the model for scenario 1 and 2 are caused by ships colliding with land (0 m water depth curve), which will not be affected by the rerouting of maritime traffic in relation to the planned OWFs. The remaining part (13-15%) of the groundings are related to the 10 m curve, mainly close to the shore and near the ground of Horns Rev.

The larger vessels are expected to be safely away from the shore and the ground of Horns Rev, thus not affecting the actual powered groundings. Based on the above assessment the consequence score is assessed to be 0-1, see Table 10-1 for scenario 1 and Table 10-2 for scenario 2.

DRIFTING GROUNDING

The risk analysis indicates that drifting groundings are not controlled by individual legs; instead, various routes contribute to the drifting grounding statistics for both scenarios. In fact, the four to five most contributing legs accounts for only 47% and 44% of all drifting groundings in the model for scenario 1 and 2, respectively.

Most drifting groundings are modelled to come from the main shipping corridor (S10: Route 1), north of Thor OWF and NSI.1. In this area, the main traffic sails closer to shore, making it the shortest distance to shore in the event of a drifting ship. The maritime traffic along this route is dominated by cargo ships, which include bulk and goods carriers and container ships, and accounts for about 65% of the overall traffic in Route 1. Tankers are the second most frequent ship type and account for about 21% of the total traffic. The last 14% of the traffic is distributed on fishing ships, passenger ships, pleasure boats, support ships and other ship types. The maritime traffic is dominated by vessels between 50-250 m with a peak around 150-200 m in length. The shore and sea bottom sediments in this area consist mainly of soft and loose sediment, which reduces the degree of damage in the event of grounding. Consequently, the assessed consequence index is 0-1, see Table 10-1 for scenario 1 and Table 10-2 for scenario 2.

POWERED ALLISION

A vessel deviating from its course can potentially collide with a wind turbine, resulting in what is known as a powered allision. Compared to a drifting allision, the velocities and impact energies involved are significantly higher. Consequently, powered allisions are likely to cause more substantial material damage than drifting allisions (higher IMO consequence class).

According to scenario 1, most of the powered allisions occur in a few legs, where around 96% of the powered allisions is related to three legs. Most powered allisions are found in leg NS_02_04 (covering 55% of all powered allisions) located just west of Thor OWF close to the placements of WTGs. This traffic mainly represents the flow of traffic along Route 1 – International shipping corridor (see section 5.2.1).

According to scenario 2, most of the powered allisions occur in a few legs, where around 80% of the powered allisions is related to four legs. Most powered allisions are found in route NS_05 (covering 59% of all powered allisions) located in the coastal areas southeast of NSI.1 area where the WTGs are located close to traffic routes. This traffic mainly represents the flow of traffic along Route 7 – Coastal N-S traffic (see section 5.2.7).

Due to the heavy traffic of larger commercial vessels primarily along Route 1, and to some extent along Route 7, as well as its proximity to the WTGs placements, the consequence index for powered allisions is assessed to be 2-3. As previously mentioned, the IMO consequence class for tankers has been reduced from 4 to 3 due to the presence of double hulls.

DRIFTING ALLISION

When a ship is drifting, it can collide with a wind turbine, an event known as a drifting allision. Drifting ships move slowly, at about 1 knot, so the impact is likely to be gentle, with the ship's side facing forward. For smaller vessels, the turbine will likely deflect or stop the vessel. However, for very large vessels, the consequences can be more severe, potentially causing serious damage to the turbine and necessitating its replacement.

Generally, drifting allisions are not controlled by individual legs, however many different legs contribute to the drifting allisions statistics for both scenarios. According to scenario 1, most drifting allisions are recorded in leg NS_14_01, which is located northwest of VHS OWF (represented by Route 7). According to scenario 2, most drifting allisions are recorded in leg NS_02_03a, which is located west of NSI.1 OWF within the shipping corridor S10 (represented by Route 1) and allisions will mainly occur during strong winds from west.

Due to the heavy traffic of larger commercial vessels primarily along Route 1, and to some extent along Route 7, as well as its proximity to the WTGs placements, the consequence index for drifting allisions is assessed to be 1-3, see Table 10-1 for scenario 1 and Table 10-2 for scenario 2. As previously mentioned, the IMO consequence class for tankers has been reduced from 4 to 3 due to the presence of double hulls.

COLLISION

The maritime traffic in the area is unregulated, resulting in several observed routes being described as distributions with wide lateral dispersions. For instance, Route 1, the main shipping corridor (S10), is observed to have a very wide corridor (>50 km) which explains why head-on collisions dominate ship-ship collisions. The model indicates that the most contributing legs for both scenarios are related to NS_02 for both HeadOn and Overtaking collision (the second most common collision type). These legs are located within the shipping corridor S10, which has been narrowed significantly in its traffic distribution. Consequently, it can be concluded that 85-95% of all collisions for both scenarios occur in Route 1, whereas collisions are relatively rare in the surrounding areas.

Additionally, most of these two collision types involve cargo ships and tankers in leg NS_02. Due to the heavy traffic of larger commercial vessels along Route 1, and the concentration of traffic along this route as a result of the proposed rerouting model, the consequence index for drifting allisions is assessed to be 1-3, see Table 10-1 for scenario 1 and Table 10-2 for scenario 2. Generally, due to the diversity of the traffic and the large available space, the consequence index is not easily determined. Again, the IMO consequence class for tankers has been reduced from 4 to 3 due to the presence of double hulls.

INDICATIVE RISK INDEX

An indicative risk index is provided for each of the accident types related to scenario 1 (Table 10-1) and scenario 2 (Table 10-2). It is assessed that the maximum possible consequence will not occur for all collisions. Most collisions will not involve the largest possible ships or the most critical damage scenarios. Therefore, an average consequence index is assumed, combined with the calculated collision frequencies, leading to indicative risk indices for the two scenarios.

Table 10-1. Assessment of risk index based on scenario 1 (IMO risk classes). Parentheses indicate that the index is within the range but far from the value inside the parentheses.

Incident	Frequency Index	Consequence Index	Risk Index
Powered grounding	2-3	0-1	2-4 (3)
Drifting grounding	4-5	0-1	4-6 (5)
Powered allision	(1)-2	2-3	3-5 (4)
Drifting allision	(2)-3	2-3	4-6 (5)
Collision	4-5	1-3	5-8 (6-7)

Table 10-2. Assessment of risk index based on scenario 2 (IMO risk classes). Parentheses indicate that the index is within the range but far from the value inside the parentheses.

Incident	Frequency Index	Consequence Index	Risk Index
Powered grounding	2-3	0-1	2-4 (3)
Drifting grounding	4-5	0-1	4-6 (5)
Powered allision	(2)-3	2-3	4-6 (5)
Drifting allision	3-4	1-3	4-7 (5-6)
Collision	4-5	1-3	5-8 (6-7)

The estimated IMO risk classes for each incident type have been compared for both scenarios and the different OWF areas within NSI.1. Essentially, the establishment of NSI.1 OWF is expected to cause a limited increase in the overall risk for maritime traffic. The average risk index is assessed to increase by a maximum of one IMO risk for both powered and drifting allisions due to the establishment of NSI.1. The average risk index remains unchanged for both powered and drifting grounding, as well as for collision.

The highest risk level, both before and after the establishment of NSI.1, is assessed to be associated with ship-ship collisions. An increase in the risk of collisions is anticipated due to the densification of traffic mainly in Route 1 and Route 7 west and east of NSI.1, respectively. However, the area west of NSI.1 is expected to experience an increased concentration of ship traffic in an already heavily trafficked area, which could lead to an increased local risk.

The wind turbines are situated outside the major traffic routes, and most allisions are estimated to occur with drifting ships (higher frequency index for drifting allisions relatively to powered), which typically move at lower speeds (lower consequence index for drifting allisions relatively to powered).

There are neglectable changes in frequency index for both powered and drifting groundings from scenario 1 to 2. Overall, the consequence remains the same. Therefore, the risk index for groundings remains unchanged.

Overall, the presence of more WTGs in the North Sea increases the frequency of allisions, both for drifting and powered. The consequence of an allision is independent of the number of WTGs. Thus, the consequence index remains unchanged, ranging between 1 and 3. It is not expected that more than one WTG would be hit per incident.

There will presumably be an increased risk level associated with ship-ship collisions, however it is not considered sufficient to increase the overall risk index. The change in ship-ship collisions due to rerouting traffic slightly increases the frequency, but the consequence of an incident remains the same, with a consequence index of 1-3.

Due to its proximity to shipping corridor S10, NSI.1-A3 has a higher calculated frequency index for collisions compared to the other two locations. When combined with the estimated consequence indices, the indicative risk index for collisions is slightly higher for NSI.1-A3. However, this does not necessarily impact the overall risk level. Locally, the risk index for NSI.1-A3 can be assessed to be level 7, whereas it remains at level 6 for NSI.1-A1 and NSI.1-A2.

All estimated IMO risk classes for each incident type, except for collisions and drifting allisions, are assessed to have an acceptable risk level (IMO class 5 or less). However, the model indicates that the risk of ship-ship collisions and drifting allisions is too high (unacceptable risk level). It is important to note that this risk level associated to collisions is already high (before the build-out of OWFs) and is largely linked to the intense commercial traffic that invariably passes through the area. The risk level associated with collisions will increase with further build-out of OWFs in the North Sea.

As the assessment of ship-ship collision and drifting allisions indicates an unacceptable risk level it should be expected that mitigation measures are needed to minimize these risks. Chapter 11 provides recommendation for mitigation measures that can reduce the risk level to an acceptable level. Ultimately, however, the DMA makes the final assessment of whether the assessed risk level for the specific project is acceptable.

11 MITIGATION MEASURES

In this chapter, a list of proposed risk-reducing measures (mitigation measures) that can potentially be applied during the construction (see section 11.3) and operational phase (see section 11.4) is presented. Furthermore, there is a presentation of existing mitigation measures (see section 11.1) and some general recommendations regarding mitigation measures (see section 11.2). These stated mitigation measures are primarily the result of the qualitative risk assessment conducted in cooperation with all relevant maritime stakeholders and authorities at the HAZID workshop (see Appendix 4, Chapter 17). Since this risk assessment is conducted in relation to the overall build-out of OWFs in the NSI.1 area and is not associated with a specific project, the presented mitigation measures may not all be relevant for subsequent specific projects. In general, they represent objective solutions to address the increasing navigational risk level resulting from the OWF build-out in the North Sea. Future specific navigational risk assessments will be performed by the developers (concessionaires) for the individual areas within the NSI.1 area, as part of the approval procedure for the specific projects.

Many of the recommended mitigations measures listed below will be an integrated part of a OWF project in Danish waters and will be included in the permit from the DEA (see Construction Permit for VHS (DEA, 2016) and Aflandshage OWF (DEA, 2022) as examples).

All the presented mitigation measures will, to varying extent, contribute to a reduction in the frequency of incident (allisions, collisions and groundings) calculated in the present navigational risk assessment. These measures will also impact the indicative risk index, which will be addressed in navigational risk assessment of the specific OWF projects in the NSI.1 area. Consequently, these recommended mitigation measures are not implemented in the evaluation of the indicative risk level.

11.1 EXISTING MITIGATION MEASURES

At the HAZID workshop, the existing safety measures were discussed, which also appears in the HAZID protocol (see Appendix 4, Chapter 17. The most important existing safety measures and risk-reducing measures associated with the present navigational risk assessment are listed below.

- In the North Sea, including Denmark and Germany, there is a 24/7 emergency system which is stationed in several nearby ports in the North Sea, where several tugboats and emergency towing vessels (Emergency Towing Vessels ETV) are ready.
- Installation vessels have their own markings.
- A separate risk analysis is carried out for radar and radar disturbance (WSP 2024, in prep.). The results of separate risk analyses regarding radar disturbances related to the establishment of the NSI.1. OWFs will be included in the detailed FSA reports, which must be conducted by the individual concession winners at a later stage.
- Joint maritime coordination of traffic in the North Sea (Announcements in Notices to Mariners)
- The tip clearance of 20 m (distance from sea level to the outermost wing tip) is a mitigation measure itself. The tip clearance generally increases with increasing height of the WTGs.
- The new shipping corridor S146 as stated in the MSP, ensures sufficient space for transit and maneuvering. This shipping corridor is an integrated part of the present navigational risk assessment and can be perceived as an existing mitigation measure.
- Markings and lightening are following the existing practice, cf. IALA's recommendation for marking WTGs (IALA guideline G1162 - The Marking of Offshore Man-made Structures)

11.2 GENERAL RECOMMENDATIONS

The following general recommendations regarding mitigation measures is divided into two groups. The first group refers to recommendations that need to be implemented and further investigated by the maritime authorities, while the second group refers to recommendations that need to be implemented and further investigated by future developers.

Recommendations to be implemented and/or further investigated by the maritime authorities:

- There is an ongoing dialogue between maritime authorities about more AIS-base stations in the North Sea, with the purpose of improving the preventive monitoring of navigational safety. Necessity and effect of establishing additional AIS base stations should be examined. This is also relevant for NSI.1. OWF. Implementing this mitigation could potentially reduce the accident frequency in the North Sea, particularly the collision frequency associated with the shipping corridor S10 west of NSI.1, where the risk level is currently assessed to be unacceptable.
- A possible risk-reducing measure would be the establishment of an international ship route system (traffic separation system TSS), as seen in Germany and the Netherlands, as well as in the most trafficked waters in Denmark (e.g. Øresund). Alternatively, recommended IMO routes that divide traffic into northbound and southbound traffic can be implemented, without introduction the more restrictive TSS (recommended route is a route of undefined width, for the convenience of ships in transit, which is often marked by centreline buoys). However, the introduction of such systems requires international approval through IMO based on documented need, which is why Denmark cannot independently set up these systems. The introduction of IMO measures is a lengthy process that may also require coordination with neighboring countries, which is why the establishment of route systems cannot stand alone as a risk-reducing measure.
- In many cases, joint coordination of maritime traffic is essential for maintaining safety of navigation. Common maritime coordination (e.g. announcements in Notices to Mariners) already exists. However, due to the planned OWF build-out in the North Sea, which extends across international borders, this coordination will likely need to be expanded in the future. In this context, joint maritime coordination of all work-related traffic (Work Vessel Coordination) and other maritime traffic during the construction phase can be ensured. This is particularly relevant if multiple OWFs are built simultaneously in the North Sea Region.
- Guard vessels in the area during the construction phase will reduce the frequency of accidents. Guard vessels are an integrated part of the dialogue with the maritime authorities and a part of a future Construction Permit. Preparedness in the form of tugboats and emergency towing vessels (ETV) can reduce return periods by up to 60% (ABL, 2023). ETVs are assumed to mitigate risks by primarily preventing drifting allisions. There already exists a 24/7 emergency in the North Sea, both in Denmark and Germany (existing mitigation measures). In step with increasing build-out of OWF in the North Sea, it should be considered to expand the emergency capacity. It is possible to made fixed agreements with tugboats stationed close to the NSI.1 OWF.
- It should be investigated whether there is a need for additional marking, e.g. at RACON. Radar beacon (short: racon) is defined as "A transmitter-receiver associated with a fixed navigational mark which, when triggered by a radar, automatically returns a distinctive signal which can appear on the display of the triggering radar, providing range, bearing and identification information." Permanent safety marking on the sea must be approved by the DMA (DEA, 2016) (DEA, 2022).

Recommendations to be implemented and/or further investigated by future developers:

- Foundations can be collision-friendly and without sharp edges. This is a standard requirement for Construction Permit (DEA, 2016) (DEA, 2022).
- In relation to pleasure yachting, various information campaigns are proposed locally and via several relevant communication channels.
- In relation to fishing vessels, supplementary information campaigns are also proposed locally and via the Danish Fishing Association. Newsletter via FOGA. Plotter files can be provided to local fishermen.
- Planning for a subsequent project-specific site, along with the vessel plan and specific risk reducing measures, can be conducted in dialogue with DMA. This will be an integrated part of a future Construction Permit (DEA, 2016) (DEA, 2022).

- Developer can contact local fishermen in order to organize the construction activities and reduce the impact on the fishery (DEA, 2016) (DEA, 2022).
- Developer can enter into an operation and maintenance agreement (O&M agreement) with a company, which is registered by the DEA and which is certified to carry out service and maintenance of WTGs. Documentation for an O&M agreement can be forwarded to the DEA (DEA, 2022).
- It is a standard procedure to announce long-term activities in NtM (DEA, 2016) (DEA, 2022). Conditions and nautical information about construction area, restriction zone and special work vessel corridors that result in temporary corrections of sea charts, can be reported in NtM. This notice is published continuously on the agency's website. Weekly summaries appear as digital news papers.
- It is recommended that all WTGs will be marked on nautical charts with an appropriate legend, such as ‘turbine’ and/or danger circle. This may include ID number. Additionally, submarine cables must be marked (e.g. prohibited to carry out fishing activity with bottom-contacting gear).

11.3 CONSTRUCTION PHASE

- Relevant marking of construction area (AtoN), restriction zones and traffic routes should be considered (floating and temporary marking) - especially towards the two shipping corridors (S146 + S10) stated in the MSP. Temporary sea marking must be approved by the DMA (DEA, 2016) (DEA, 2022).
- Depending on the specific circumstances, it may be appropriate to establish a temporary work corridor between the work port and the NSI.1 area (construction site) as a preventive measure (DEA, 2016) (DEA, 2022). To ensure safe crossing of construction-related ship movements (such as transport of personnel and components), it is essential to concentrate such movements to few corridors.
- Depending on the selected work port for NSI.1, it is recommended that work-related vessels and personnel transport follow the existing traffic routes (traffic patterns).
- To avoid narrowing of the traffic routes around NSI.1, the temporary safety zone (restriction zone) during the construction phase can be reduced from 500 m to 200 m – particularly relevant to the west and north-west towards the shipping corridors S10 and S146. The exact dimension of this restriction zone is determined on a case-by-case basis by the DMA. This specific mitigation is assessed to potentially reduce collision frequency, at least during the construction phase, associated with the shipping corridor S10 west of NSI.1, where the risk level is currently assessed to be unacceptable.
- Guard vessels can reject vessels that do not comply with the restrictions around the work area. There may be a particular need to reject pleasure crafts during the summer period, when the intensity is typically higher. Due to the distance from coast it will probably have a low impact.
- Another recommendation is to place temporary light buoys on unfinished structures (foundations) during construction phase. This specific mitigation is assessed to potentially reduce allision frequency, at least during the construction phase.
- All construction and vessel activities can be carefully planned and follow the conditions stated in a future Construction Permit (see Construction Permit for VHS as an example, (DEA, 2016)). Furthermore, the final planning can be assessed in accordance with the Danish Maritime Authority's guidance for construction works at sea.

11.4 OPERATION PHASE

- Sufficient communication between the Marine Assistance Service (MAS) and the WTG operator can be ensured to stop a WTG in the event of an allision. It is expected that DMA will require WTGs to be stoppable in emergencies, making it important to clarify how quickly the WTGs can be stopped (cf. notice no. 1229 03/10/2023 paragraph 13). This procedure must be approved by DMA.
- Depending on the selected maintenance port for O&M activities, it is recommended that the service vessels and personnel transport follow the existing traffic patterns to and from the ports. If several parks are serviced with

personnel transport from the same port and at the same time, joint coordination of maritime traffic for all involved OWFs should be ensured.

- The design of the WTG layouts can ensure the greatest possible distance from the outermost WTGs to the trafficked routes, minimizing the narrowing of the traffic routes. In additional, the positions of the WTGs (boundary of the OWF area) can be placed parallel with the flow of the maritime traffic. These design features help minimise the risk of allisions and ship-ship collisions. The actual design and placement of the WTGs closest to the most trafficked routes, as well as the distance to the shipping corridors S146 and S10, are assessed to be of great importance in reducing the frequency of collisions and allisions.

12 CONCLUSIONS

The maritime traffic and navigational safety have been assessed in connection with the construction and operation of offshore WTGs and other technical structures within the NSI.1 area. This navigational risk assessment has assessed how, where, and to what potential extent the planned OWF build-out impacts maritime traffic and the safety of navigation. Furthermore, it has assessed the potential changes in frequency index (collisions, allisions and groundings) as well as consequence index caused by the build-out of OWFs in the North Sea, with a focus on establishment of NSI.1.

Cumulative effects have been considered in accordance with the development of several OWFs in the Danish part of the North Sea. Therefore, both approved and planned OWFs (i.e. Vesterhav South, Thor OWF, North Sea I and North Sea II) have been included in the analysis of the maritime traffic and safety of navigation.

Maritime traffic in and around the NSI.1 area has been analyzed based on AIS-data from 2022, which show all ship movements for one year. For each future build-out scenario of OWFs in the relevant part of the North Sea, it has been analyzed how the maritime traffic will be rerouted and adapted to new traffic conditions. The AIS data shows that the traffic density is highest in the northwestern part of NSI.1 (in NSI.1-A3) and lowest in the southern part (NSI.1-A1). The most dominant ship type within NSI.1 is cargo ships, followed by fishing vessels and tankers, respectively. Based on the current traffic condition, seven main traffic routes representative for the overall waterway characteristics have been identified. In IWRAP, the maritime traffic is defined by a series of legs orientated in different directions. For each scenario a final model setup with traffic distribution and rerouting have been discussed. Based on generic WTG layouts and the future rerouting traffic conditions, the return periods for three types of accidents (grounding, allision and collision) related to the different scenarios have been calculated and compared, individually.

Based on the present navigational risk assessment, the percentage changes in return period (accident frequency) between baseline scenario (scenario 1) and scenario 2 have been calculated:
Due to the construction of NSI.1 (compared to the baseline scenario), the modelling shows that total grounding frequency will decrease by 7% from scenario 1 to scenario 2 (return period decreases from 35 to 38 years). Correspondingly, the modelling shows that total allision frequency will increase by 92% (return period increases from 2,245 to 185 years) and total collision frequency will increase by 37% from scenario 1 to scenario 2 (return period increases from 42 to 26 years). This significant increase in allision frequency is simply explained by the construction of NSI.1 OWFs (dense grid of WTGs) in open waters characterized by medium to high density of maritime traffic. The construction of NSI.1. leads to traffic movements and rerouting resulting in higher traffic density in already trafficked routes around the planned OWF. Higher density means greater risk of collisions between ships. Another reason for the increasing collision frequency is due to narrowing of the traffic routes which already are heavily trafficked. As stated above, the establishment of NSI.1. does not lead to a significant change in the frequency of groundings in the area.

This risk assessment indicates that the establishment of NSI.1 OWF is expected to cause a limited increase in the overall risk for maritime traffic. The average risk index is assessed to increase by one IMO risk for both powered and drifting allisions due to the establishment of NSI.1. The average risk index remains unchanged for both powered and drifting groundings, as well as for collision.

The highest risk level, both before and after the establishment of NSI.1, is assessed to be associated with ship-ship collisions. An increase in the risk of collisions is anticipated due to the densification of traffic mainly in Route 1 and Route 7 west and east of NSI.1, respectively. However, the area west of NSI.1 is expected to experience an increased concentration of ship traffic in an already heavily trafficked area, which could lead to an increased local risk.

The wind turbines are situated outside the major traffic routes, and most allisions are estimated to occur with drifting ships (higher frequency index for drifting allisions relatively to powered), which typically move at lower speeds (lower consequence index for drifting allisions relatively to powered).

All estimated risk classes for each incident type, except for collisions and drifting allisions, are assessed to have an acceptable risk level (risk class 5 or less). The model indicates that the risk of ship-ship collisions and drifting allisions can reach an unacceptable risk level and therefore mitigation measures need to be implemented. Recommended mitigation measures are described in the report and it is assessed that the implementation of mitigation measures, based on the current knowledge and assumptions about the offshore wind build-out in the NS1.I area, will be sufficient to reduce the risks to an acceptable level.

There are no governing quantitative risk acceptance requirements for the establishment of OWFs. In Denmark, the approval of the navigational risk levels is done as a case-by-case approach by DMA. Therefore, based on the calculated return periods and overall risk evaluation, it is not possible to make a definite conclusion whether the risk is acceptable or not. Instead, the calculated accident frequencies combined with the indicative risk index are presented and discussed with the authorities, subsequently. Based on these results, the DMA will decide whether the OWF build-out in NSI.1 is compatible with the overall safety of navigation in the area and decide if any mitigation measures should be implemented or further investigated.

Based on the present navigational risk assessment, the most significant potential impacts on navigational safety for both the construction and operation of OWFs in the NSI.1. area, are listed below.

Potential impacts during construction of the NSI.1. OWF area:

- Construction-related traffic to and from the construction site will interact with other maritime traffic in the area. The specific routes for construction-related traffic will depend on the selected work port, and the work-related vessels' need to cross current traffic routes.
- Within the planned OWF areas, the presence of construction vessels (vessels with limited maneuverability) will constitute a local risk.
- In connection with cable-laying activities, work-related vessels will have to operate within the planned OWF areas, between the three areas of NSI.1, as well as between the NSI.1. area and the shoreline (export cable corridors). In this context, several trafficked routes will need to be crossed by construction-related traffic, of which some vessels will have limited maneuverability.

Potential impacts after establishment of the NSI.1. OWF area:

- The WTG will contribute visible obstacles in the open waters, just as they will be visible on radars.
- Sailing between the WTGs are permitted, however most commercial ships and other larger vessels will follow rerouted waterways around the planned OWF. Fishing vessels and pleasure crafts will, to varying degrees, continue to sail within the OWF areas.
- Establishment of NSI.1. will require rerouting of several maritime traffic routes, so that ships can navigate around the planned OWFs. Consequently, there is a significant increase in the total collision frequency in the area due to the presence of NSI.1. OWF. However, this will not affect the overall frequency risk index.
- The risk for ship-ship collisions and groundings is still assessed to be larger than the risk for allisions with WTGs even after establishment of NSI.1. OWF. In line with further OWF build-out in the North Sea (i.e. NSI.2 and NSII), the calculated return periods for allisions will be of the same or lower magnitude relative to groundings and collisions (see Chapter 14 and 15).
- The risk of allisions is most significant at the WTGs placed closest to the trafficked routes. This means that the shipping corridors of S146 and S10 are affecting the allision frequency in the western part of the NSI.1 area. Additionally, the traffic east of the OWFs areas is contributing to the allision frequency in the eastern part of the NSI.1.
- Several traffic routes around the planned OWF areas are heavily trafficked (both existing and newly established routes), and it is inevitable that ships will experience blackouts or machine failures at intervals. Depending on the wind conditions, this will give rise to the risk of drifting allisions.
- The increasing collision frequency is due to both the rise in traffic density and narrowing of the shipping corridor S10, where most traffic will be rerouted. This shipping corridor is already heavily trafficked, and the increased density will exacerbate the risk.

- Vessels using the traffic routes near the planned OWFs will need to navigate around the WTGs. The presence of these WTGs will reduce the space available for evasive maneuvers in the event of potential ship-ship collisions, thereby narrowing the traffic routes.
- In Danish waters, there is a prohibition on anchoring within a zone of 200 m from submarine cables. The cables, both the inter-array cables and export cables will therefore give rise to a ban on anchoring and fishing with bottom trawling gear.

13 REFERENCES

ABL. (2023). *Route SN10: Formal Safety Assessment.* ABL.

ABL, A. (2021). *Shipping analysis of the North Sea.* Deutsches Bundesministerium des Innern, Für Bau und Heimat.

DEA. (2016). *Tilladelse til etablering af havvindmølleparken, Vester Syd, med tilhørende elforsyningsnet på søterritoriet i Nordsøen (etableringstiladelse).*

DEA. (2022). *Tilladelse til etablering af elproduktionsanlægget Aflandshage Vindmøllepark (hefter "etableringstilladelse").*

DEA. (2024). *Udkast til afgrænsning af miljøvurdering af Plan for Nordsøen I*. Hentet fra https://ens.dk/sites/ens.dk/files/Vindmoller_hav/udkast_til_afgraensning_af_miljoevurdering_af_plan_for_nordsoeen_i.pdf

Denmark's maritime spatial plan. (2024). Hentet fra https://havplan.dk/en/page/info

DMI. (1999). *Observed Wind Speed and Direction in Denmark- with Climatological Standard Normals 1961-90.*

EMODnet. (2024). Hentet fra European Marine Observation and Data Network: https://emodnet.ec.europa.eu/en

Fujii, Y., Yamanouchi, H., & Matui, T. (1984). *Survey on Vessel Traffic Management Systems and Brief Introduction to Marine Traffic Studies.* Electronic Navigation Research Institute Papers No. 45.

Helcom. (2021). *Baltic Marine Environment Protection Commision, Shipping Accidents in the Baltic Sea*. Hentet fra https://helcom.fi/media/publications/Helcom-report-on-Shipping-accidents-in-the-Baltic-Sea-2020-1.pdf .

IMO. (2018). *REVISED GUIDELINES FOR FORMAL SAFETY ASSESSMENT (FSA) FOR USE IN THE IMO RULE-MAKING PROCESS.*

IWRAP MK II. (2008). *Basic Modelling Principles for Prediction of Collision and Grounding Frequencies, Rev. 4.* Techincal University of Denmark: Peter Friis-Hansen.

Rambøll. (2022). *Energy Islands Bornholm, Technical report - Maritime traffic and navigational safety.* Rambøll.

Rambøll. (2022). *Thor Offshore Wind Farm. Navigational Risk Assessment. .* NIRAS / Thor Wind Farm I/S.

WSP. (2024). *Marine Environmental studies - North Sea I. Technical report - Commercial fisheries.*

APPENDICES

APPENDIX 1 – MODELLING OF SCENARIO 3 (CHAPTER 14)

APPENDIX 2 – MODELLING OF SCENARIO 4 (CHAPTER 15)

APPENDIX 3 – IWRAP FREQUENCY MODEL SETUP (CHAPTER 16)

APPENDIX 4 – HAZID REPORT (CHAPTER 17)

14 APPENDIX 1 - MODELLING OF SCENARIO 3

Modelling of scenario 3 is based on traffic movements and rerouting from scenario 2 (see section 8.1) to scenario 3. This chapter explains the stepwise process of the traffic movement and rerouting according to scenario 3 due to the construction of NSI.2 OWF.

14.1 TRAFFIC MODELLING AND REROUTING

Between NSI.1 and NSI.2 (S146)

The construction of NSI.2 OWF affects leg NS_04, connecting maritime traffic to and from harbors in northwestern Germany to Skagerrak. Due to the planned build-out of OWFs in the Danish North Sea it has been decided to establish a new shipping corridor between NSI.1 and NSI.2 (cf. S146 in the MSP) where the maritime traffic can be rerouted through. The maritime traffic in S146 is described by the new leg NEW_NS_03_01-04 in this model. The two southernmost legs NS_04 (NS_04_01 and NS_04_02) are slightly moved and will get a more directly north-south direction, but no traffic will be rerouted to these two legs. The traffic in NS_04_03a, NS_04_03b and NS_04_04 will be rerouted to the new leg NEW_NS_03 as described in Table 14-1.

The legs NEW_EW_01 and NEW_EW_02 are connected to NEW_NS_03 in the new waypoints 70 and 71. Additionally, there is added a new waypoint (no. 69) where the leg changes direction which connects NEW_NS_03_01 and NEW_NS_03_02.

Table 14-1. Proposed traffic rerouting in leg NS_04 related to the construction of NSI.2.

Amount of traffic	Affected leg in scenario 2		Affected leg in scenario 3	
	Leg	Direction	Leg	Direction
100%	NS_04_03a	Northwest	NEW_NS_03_01	North
100%	NS_04_03a	Southeast	NEW_NS_03_01	South
100%	NS_04_03a	Northwest	NEW_NS_03_02	Northwest
100%	NS_04_03a	Southeast	NEW_NS_03_02	Southeast
100%	NS_04_03b	Northwest	NEW_NS_03_03	Northwest
100%	NS_04_03b	Southeast	NEW_NS_03_03	Southeast
100%	NS_04_04	Northwest	NEW_NS_03_04	Northwest
100%	NS_04_04	Southeast	NEW_NS_03_04	Southeast

After rerouting, all traffic in leg NS_04 in both directions is deleted.

Fishing activities, which may take place in the NSI.2 area in scenario 2 (before construction of OWF), is not assumed to continue during and after the construction of NSI.2. These activities are assumed either to cease or move to other places. To do the most conservative analyze, it is assumed that the fishing activities will continue further offshore and must therefore reroute. The traffic in the two sailing corridors between NSI.1-A1 to A3, including fishing ships, is assumed to most likely continue north or south in S146 around the NSI.2 area. It is assumed that the traffic in NEW_EW_01_02 will reroute towards south into S146 in the legs NEW_NS_03_01 and NEW_NS_03_02, while traffic in NEW_EW_02_01, will reroute towards north into S146 in the leg NEW_NS_03_04. None of the traffic from the sailing corridors between NSI.1-A1 to A3 is expected to reroute in the combining leg NEW_NS_03_03. The traffic is rerouted as described in Table 14-2.

Table 14-2. Proposed traffic rerouting in leg NEW_EW_01_02 and NEW_EW_02_01 related to the construction of NSI.2 OWF.

Amount of traffic	Affected leg in scenario 2		Affected leg in scenario 3	
	Leg	Direction	Leg	Direction
100%	NEW_EW_01_02	East	NEW_NS_03_01	North
100%	NEW_EW_01_02	East	NEW_NS_03_02	Northwest
100%	NEW_EW_01_02	West	NEW_NS_03_01	South

100%	NEW_EW_01_02	West	NEW_NS_03_02	Southeast
100%	NEW_EW_02_01	East	NEW_NS_03_04	Southeast
100%	NEW_EW_02_01	West	NEW_NS_03_04	Northwest

The number of WTGs directly bordering shipping corridor S10 (leg NS_02) is much more comprehensive in this scenario, which includes NSI.2, compared to previous scenarios. Therefore, it is assumed that the general traffic in S10 will move to the northwest with about 11 km, which corresponds to the distance NSI.1 and NSI.2 extends into the existing traffic route in NS_02. Thus, the passing ships ensure a safe distance to the NSI.1 and NSI.2 OWF. This is simply done by dragging the following waypoints in NS_02 (no. 51, 52, 54, 66, 18 and 29) about 5-11 km to the northwest.

Traffic re-routing related to the shipping corridor S146 is illustrated in Figure 14-1.

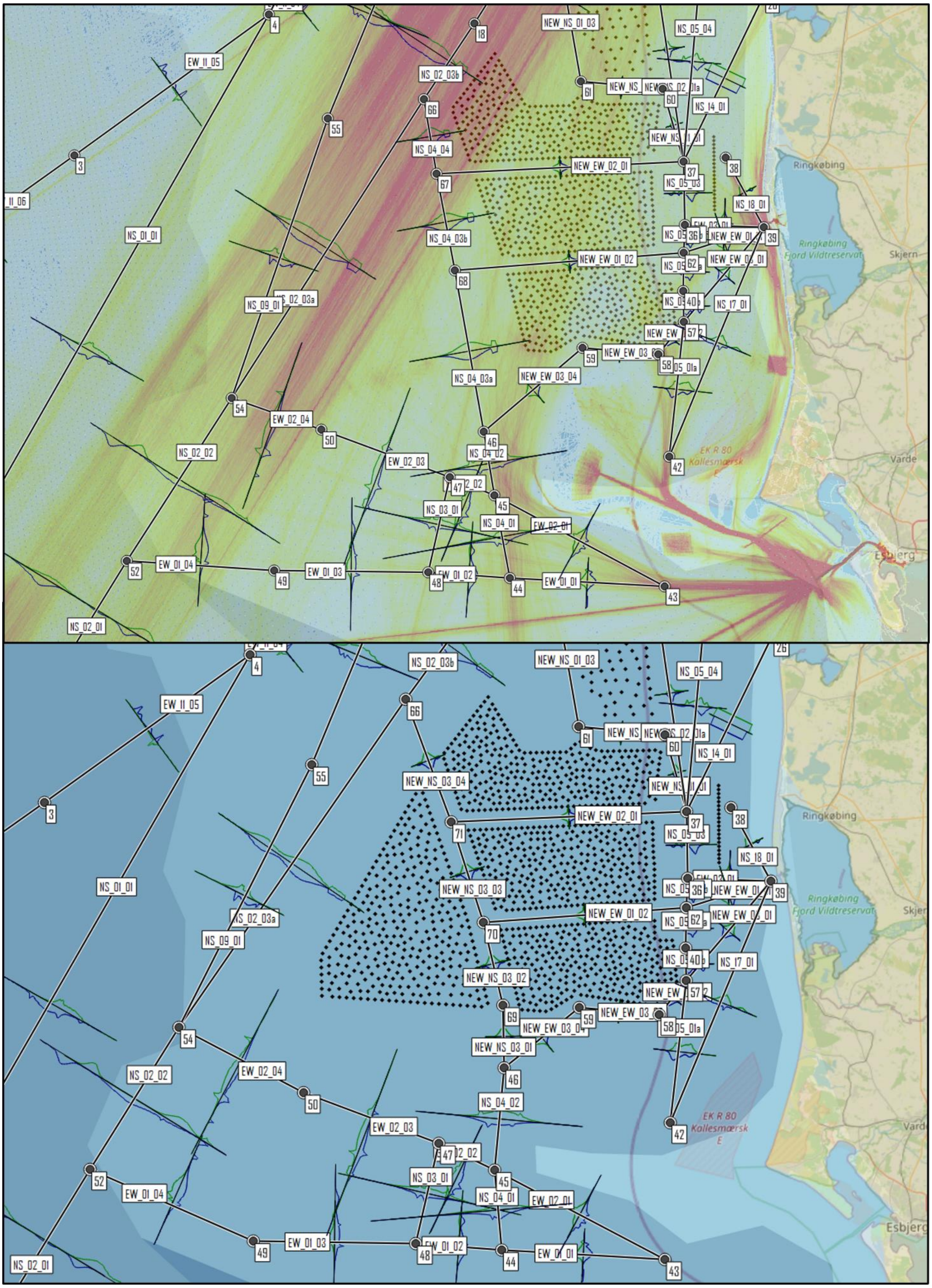


Figure 14-1. Illustration of the traffic movements and rerouting related to the construction of NSI.2 OWF. The top figure illustrates the conditions in scenario 2, while the bottom figure illustrates the rerouted maritime traffic conditions in scenario 3.

14.1.1 FINAL MODEL SETUP

Following the proposed traffic movements and rerouting from scenario 2 to scenario 3, outlined in the previous section, and based on the construction of the NSI.2 OWF, the final model setup for scenario 3 can be seen below in Figure 14-2.

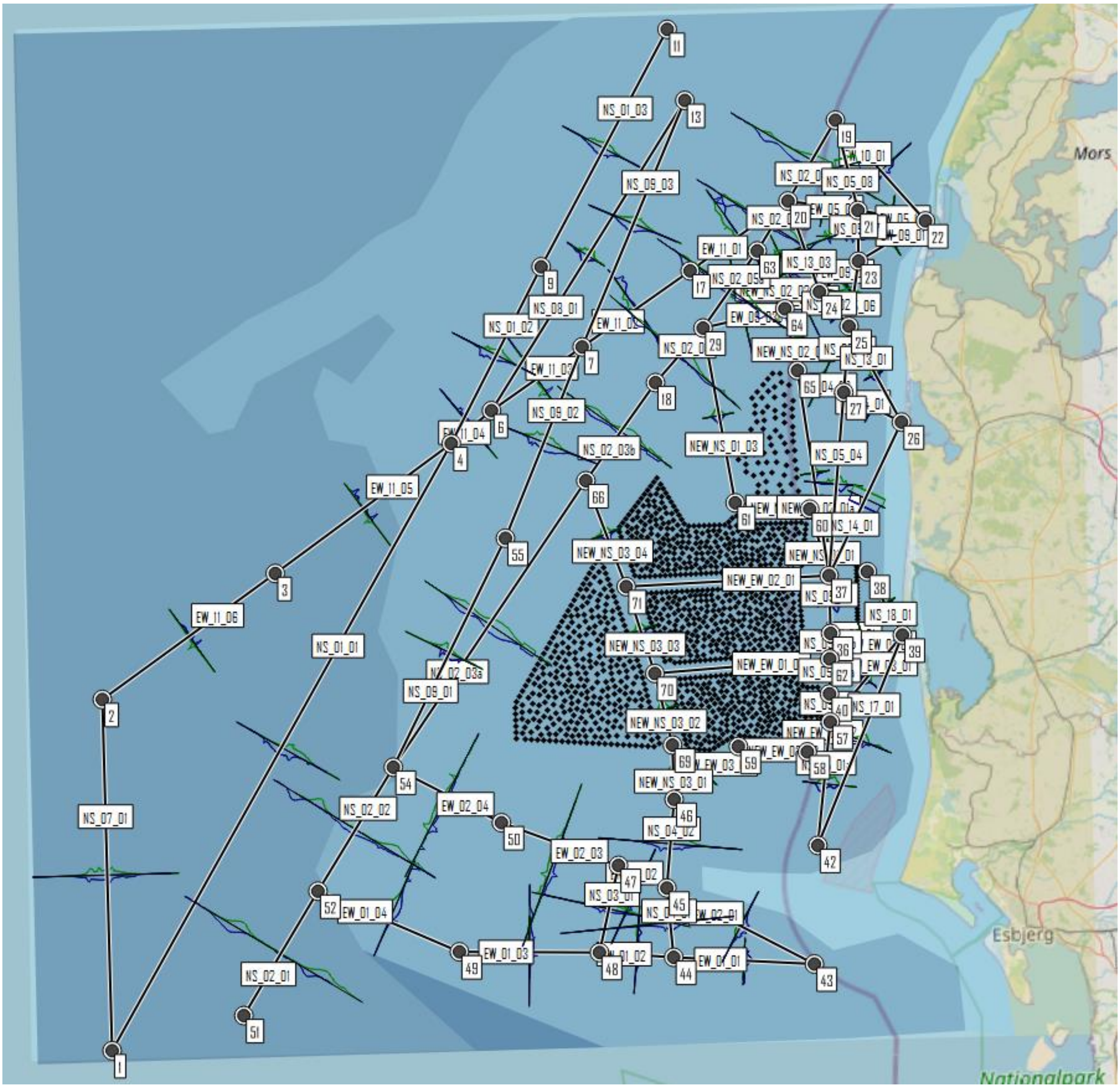


Figure 14-2. Proposed traffic model for scenario 3 based on the modelling of NSI.2 OWF as well the previous modelled scenarios related to VHS, Thor, NSI.1 OWFs.

14.2 FREQUENCY MODELLING

The overall results of the frequency modelling (calculation of return periods) based on scenario 3 in relation to the operation phase are shown in Table 14-3 with years between incidents and the corresponding yearly frequency. The frequency model is based on the entire AoI area.

Table 14-3. Overall frequency modelling results of scenario 3.

Scenario 3	Return period (years between incident)	Frequency (yr^{-1})
Powered groundings	5,989	1.67E-04
Drifting groundings	37.1	2.70E-02
Total groundings	**36.8**	**2.72E-02**
Powered allisions	183	5.45E-03
Drifting allisions	88.6	1.13E-02
Total allisions	**59.7**	**1.68E-02**
Overtaking	108	9.31E-03
HeadOn	68.9	1.45E-02
Crossing	81.9	1.22E-02
Merging	501	2.00E-03
Bend	449	2.23E-03
Total collisions	**24.8**	**4.03E-02**

For total groundings, the calculated return period for scenario 3 is around 37 years between incidents. For total allisions, i.e., collisions between ship and obstacles, the return period for scenario 3 is about 60 years, while total ship-ship collisions are about once every 25 years (Table 14-3). For scenario 3, the most frequent accident type is collisions. Overall, the total frequency of groundings and collisions is in the approximately same order of magnitude

The calculations indicate that the return periods are higher (lower frequencies) for powered accident relatively to drifting accidents. For instances, powered allisions are 2 times less frequent compared to drifting allisions (2 times longer return period).

For ship-ship collisions the most frequent type of accident is “HeadOn” collision followed by “Crossing”. The frequency related to “Merging” and “Bend” collisions is low, whereas “Overtaking” is intermedial. “HeadOn” collision is about 7 times more frequent compared to “Merging” (Table 14-3).

14.2.1 GROUNDINGS

Most groundings in the model are due to cargo ships (46%), tankers (15%) and fishing ships (15%). Most of the powered groundings for scenario 3 are strongly influenced by a few legs, see Table 14-4 (left), where 99% of the powered groundings is related to three legs. Most powered groundings are found in leg NS_14_01 (covering 50% of all powered groundings) located in the nearshore area north of VHS OWF. The second largest contributor is leg NS_04_02, which is located in the shallow waters northwest of the ground of Horns Rev.

As shown in Table 14-4 (right), drifting groundings are not controlled by individual legs, however many different legs contribute to the drifting grounding statistics. In fact, the five most contributing legs, only covers 43% of all drifting grounding in the model.

85% of the groundings in the model are caused by ships colliding with land (0 m water depth curve), which will not be affected by the rerouting of traffic in relation to the planned NSI.2 OWF. The remaining part (15%) of the groundings are related to the 10 m curve.

Table 14-4. The five most contributing legs to powered groundings (left) and drifting groundings (right) in scenario 3.

Leg	Powered groundings (%)
NS_14_01	49.8
NS_04_02	26.6
NS_05_01a	22.3
NEW_EW_01_01	0.7
NS_04_01	0.5
Total	**100**

Leg	Drifting groundings (%)
NS_02_06	14.5
NS_02_05b	10.7
NS_02_05a	8.3
EW_05_01	4.6
NS_02_03a	4.4
Total	**42.4**

14.2.2 ALLISIONS

According to scenario 3, most of the powered allisions occur in a few legs , see Table 15-7 (left). Most powered allisions are found in route NS_02_03a (covering 92% of all powered allisions) located west of NSI.1 and NSI.2 OWFs within the shipping corridor S10 where the WTGs are located close to the traffic routes.

As shown in Table 15-7 (right), drifting allisions in scenario 3 tend to be more controlled by individual legs compared to scenario 1, however still many different legs contribute to the drifting allisions statistics. In fact, the seven most contributing legs, covers 84% of all drifting allisions in the model. Most drifting allisions are recorded in leg NS_02_03a, which is located west of NSI.1 and NSI.2 OWFs within the shipping corridor S10 and allisions will mainly occurs during strong winds from west. The other legs with most drifting allisions are found in the shipping corridor (S146) and in the sailing corridors between NSI.1 A1 to A3.

Table 14-5. The seven most contributing legs to powered allisions (left) and drifting allisions (right) in scenario 3.

Leg	Powered allisions (%)
NS_02_03a	91.8
NS_05_02a	2.6
NS_05_01a	2.2
NEW_EW_03_04	0.9
NEW_EW_03_03	0.7
NEW_NS_03_03	0.4
NEW_NS_03_01	0.3
Total	**98.9**

Leg	Drifting allisions (%)
NS_02_03a	46.2
NEW_NS_03_03	11.9
NEW_NS_03_02	9.2
NEW_NS_03_04	9.0
NEW_EW_02_01	2.8
NEW_EW_01_02	2.6
NEW_NS_03_01	2.6
Total	**84.4**

14.2.3 COLLISIONS

According to scenario 3, HeadOn collisions is modelled to be the leading cause of collisions. Most of the Head-on and overtaking ship-ship collisions is related to leg NS_02_03a and NS_02_03b; which in total covers about 51 and 56%, respectively (Table 14-6). In addition, most of these two collision types involve cargo ships and tankers in leg NS_02. Basically, all seven most contributing legs are related to NS_02 for both HeadOn and Overtaking collisions, which all are legs within the shipping corridor S10 that have been narrowed significantly in their traffic distribution. Thus, it can be concluded that 83-92% of all collisions (HeadOn and Overtaking) in relation to scenario 3 occur in the shipping corridor S10, whereas collisions are relatively rare in the surrounding areas.

Crossing, merging and bend collisions are not included in Table 14-6, as these collisions happen at the intersection of different legs and cannot be divided onto individual legs.

Table 14-6. The seven most contributing legs to HeadOn collisions (left) and overtaking collisions (right) in scenario 3.

Leg	HeadOn collisions (%)
NS_02_03a	33.4
NS_02_03b	17.9
NS_02_01	8.8

Leg	Overtaking collisions (%)
NS_02_03a	31.4
NS_02_03b	24.5
NS_02_06	11.3

NS_02_06	7.5
NS_02_05a	6.7
NS_02_04	4.7
NS_02_05b	4.2
Total	**83.2**

NS_02_01	8.1
NS_02_02	7.3
NS_02_05b	6.3
NS_02_04	3.4
Total	**92.3**

14.3 COMPARISON BETWEEN SCENARIO 2 AND 3

In this section the calculated return periods (frequencies of incidents) for scenarios 2 and 3 are compared and risk evaluated. The calculated return periods in terms of groundings (powered and drifting) and ship-WTG collisions (powered and drifting allisions) as well as ship-ship collisions (during Overtaking, HeadsOn, Crossing, Merging and Bending) related to the two different scenarios are presented in Table 14-7. The risk evaluations focus on the numerical outputs from the model, i.e. the accident frequencies.

Table 14-7. Risk evaluation (comparison) of the calculated return periods modelled for scenario 1 and 2 (presented with at least three digits).

	Return period (years between incidents)	
Incident type	**Scenario 2**	**Scenario 3**
Powered grounding	7,856	5,989
Drifting grounding	37.8	37.1
Total groundings	**37.7**	**36.8**
Powered allisions	2,272	183
Drifting allisions	202	88.6
Total allision	**185**	**59.7**
Overtaking	113	108
HeadOn	75.0	68.9
Crossing	82.0	81.9
Merging	527	501
Bend	665	449
Total collisions	**26.5**	**24.8**

According to Table 14-7, the lowest frequency (longest return period) for both scenarios will be related to powered groundings followed by powered allisions for scenario 2 and merging collisions for scenario 3. In general, the frequency of drifting accidents (drifting groundings and drifting allisions) will be much higher relative to powered accidents. In other words, drifting accidents will occur more often than powered accidents. For both scenarios, the most frequent accident type will be total collisions. For both scenarios, the most frequent collision type will be “HeadOn” followed by “Crossings”. Overall, the total grounding frequency will almost be identical for both scenarios. For comparison, the total allision frequency for scenario 2 will be many times greater than the total groundings and collision frequency. Correspondingly, this factor will be much less dominant for scenario 3.

The overall change in incident frequencies between scenario 2 and 3 is shown in Table 14-8. A positive percentage means the frequency will increase (shorter return period), resulting in fewer years between incidents. Conversely, a negative percentage means the frequency will decrease (longer return period), resulting in more years between incidents.

Table 14-8. Percentage changes in the incident frequency for scenario 3 relative to scenario 2.

	Changes in percentage (%)
Powered grounding	24
Drifting grounding	2
Total groundings	**2**
Powered allisions	92
Drifting allisions	56
Total allision	**68**
Overtaking	5
HeadOn	8
Crossing	0
Merging	5
Bend	32
Total collisions	**6**

In the following sections, the percentage differences for each incident type (groundings, allisions, and collisions) are further discussed.

14.3.1 GROUNDINGS

The modelling shows that the total grounding frequency will increase by 2% from scenario 2 to scenario 3 with the build-out of WTGs in the NSI.2 area. The greatest increase will be related to powered groundings, where the traffic that are rerouted through the shipping corridor S146 consequently will sail closer to Horns Rev in the leg NS_04_02. However, the total grounding frequency indicate that the risk of groundings will not significantly change due to the establishment of NSI.2 (Table 14-8).

14.3.2 ALLISIONS

The greatest change in frequency (according to overall accident types) between scenario 2 and 3 will be related to allisions. The modelling shows that the total allision frequency will increase by 68% (92% for powered allisions and 56% for drifting allisions) from scenario 2 to scenario 3 with the build-out of WTGs in the NSI.2 area. This significant increase in allision frequency will be explained by the construction of NSI.2 OWF in open waters dominated by medium to high density of maritime traffic in the shipping corridors S10, S146 and other nearby traffic routes. Obviously, it is expected that presences of more WTGs results in greater allision risk (Table 14-8).

14.3.3 COLLISIONS

The modelling shows that the total collision frequency will increase by 6% from scenario 2 to scenario 3 with the build-out of WTGs in the NSI.2 area. There will be great variation in the contribution from the different types of collisions. Crossings will not change at all, while “Bend” will increase by 32%. The remaining collision types (Overtaking, HeadOn and Bending) are all calculated to increase less than 8% (Table 14-8).

Due to the presence of NSI.2 the maritime traffic will be rerouted, and some current traffic routes will be deleted. The primary reason why the frequency increases, is because the maritime traffic will be rerouted through the shipping corridor S146, which results in higher traffic density and consequently a greater risk of collision between ships.

15 APPENDIX 2 - MODELLING OF SCENARIO 4

Modelling of scenario 4 is based on traffic movements and rerouting from scenario 3 (see section 14) to scenario 4. This chapter explains the stepwise process of the traffic movement and rerouting according to scenario 4 due to the construction of NSII OWF.

15.1 TRAFFIC MODELLING AND REROUTING

Between NSI and NSII (S10)

The construction of NSII will affect the traffic in leg NS_09, which will be rerouted eastwards into the shipping corridor S10. North of NSII, the maritime traffic in NS_09 will be connected to NS_02 (S10) in waypoint 18 via the two new legs NEW_NS_04_01 and NEW_NS_04_02. Furthermore, the traffic in NS_09_02 and NS_09_01 is rerouted into the shipping corridor S10 in the existing legs NS_02_03b and NS_02_03a, respectively. The traffic is rerouted as described in Table 15-1.

Table 15-1. Proposed traffic rerouting in leg NS_09 into the shipping corridor S10.

Amount of traffic	Affected leg in scenario 3		Affected leg in scenario 4	
	Leg	Direction	Leg	Direction
100%	NS_09_03	Northeast	NEW_NS_04_01	Northeast
100%	NS_09_03	Southwest	NEW_NS_04_01	Southwest
100%	NS_09_03	Northeast	NEW_NS_04_02	Northeast
100%	NS_09_03	Southwest	NEW_NS_04_02	Southwest
100%	NS_09_02	Northeast	NS_02_03b	Northeast
100%	NS_09_02	Southwest	NS_02_03b	Southwest
100%	NS_09_01	Northeast	NS_02_03a	Northeast
100%	NS_09_01	Southwest	NS_02_03a	Southwest

After rerouting, all traffic in leg NS_09 in both directions is deleted.

NSII will stretch into the shipping corridor S10 and cause the maritime traffic to sail in a narrower corridor, and thus it is expected that most of the traffic will sail central in the corridor between NSI (NSI.1 and NSI.2) and NSII. Therefore, the following waypoints in NS_02; waypoints 52, 54, 66, 18 and 29 are moved around 2 km to the southeast (compared to their position in scenario 3), to get a position more centrally located in between NSI and NSII.

The number of WTGs bordering the shipping corridor S10 (leg NS_02) are much more comprehensive in this scenario, which includes NSII, compared to previous scenarios. Therefore, it is assumed that the general maritime traffic in S10 will move to the southeast with about 3-10 km. Thus, the passing ships ensure a safe distance to the WTGs on both sides of the NSII, NSI.1 and NSI.2 OWF. This is simply done by dragging the following waypoints in NS_02 (no. 51, 52, 54, 66, 18 and 29) 3-10 km to the southeast.

West of NSII OWF

The construction of NSII will affect the traffic in leg NS_01, where the southeastern side of the legs reaches into the OWF. Consequently, the central part of the route in leg NS_01 is moved to northwest by dragging waypoints 4 and 9 approximately 11 and 7 km, respectively, to ensure a sufficient distance to the OWFs western side and without any traffic overlapping the OWF. Furthermore, the maritime traffic in leg NS_08_01 must reroute to avoid entering the area of NSII, and thus the orientation of the leg is adjusted, so that the leg runs between waypoint 9 and 13. Additionally, the traffic in leg NS_08_01 is rerouted to NS_01_02, which is described in Table 15-2.

Table 15-2. Proposed traffic rerouting in leg NS_08_01 related to the construction NSII.

Amount of traffic	Affected leg in scenario 3		Affected leg in scenario 4	
	Leg	**Direction**	**Leg**	**Direction**
100%	NS_08_01	Northeast	NS_01_02	Northeast
100%	NS_08_01	Southwest	NS_01_02	Southwest

The traffic in leg EW_11 must be rerouted to avoid entering the area of NSII. EW_11_01 is moved further north and crosses NEW_NS_04_01 in the new waypoint no. 72. EW_11_02 is also moved north and runs between the new waypoint no. 72 and the new waypoint no. 73 north of NSII OWF, where it connects with NS_08_01 towards west. NS_08_01 splits up into two identical legs:
NS_08_01 -> NS_08_01a and NS_08_01b

The traffic in EW_11_02 is rerouted to NS_08_01a as described in Table 15-3.

Table 15-3. Proposed traffic rerouting in leg EW_11_02 related to the construction NSII.

Amount of traffic	Affected leg in scenario 3		Affected leg in scenario 4	
	Leg	**Direction**	**Leg**	**Direction**
100%	EW_11_02	Northeast	NS_08_01a	Northeast
100%	EW_11_02	Southwest	NS_08_01a	Southwest

The traffic in EW_11_03 is moved to NS_01_02 (Table 15-4), which is edited once as mentioned above. Traffic in EW_11_04 is deleted, as all traffic in this is leg will be redirected with the EW_11_03 to NS_01_02 movement.

Table 15-4. Proposed traffic rerouting in leg EW_11_03 related to the construction of NSII.

Amount of traffic	Affected leg in scenario 3		Affected leg in scenario 4	
	Leg	**Direction**	**Leg**	**Direction**
100%	EW_11_03	Northeast	NS_01_02	Northeast
100%	EW_11_03	Southwest	NS_01_02	Southwest

After the movement and rerouting, all traffic in leg EW_11_03 and EW_11_04 in both directions are deleted.

The traffic in EW_11_05 and EW_11_06 are not, except for a minor adjustment to the position of waypoint 3 to get a more direct route after the rerouting.

Traffic rerouting related to the construction of NSII OWF is illustrated in Figure 15-1 (northern part) and Figure 15-2 (southern part).

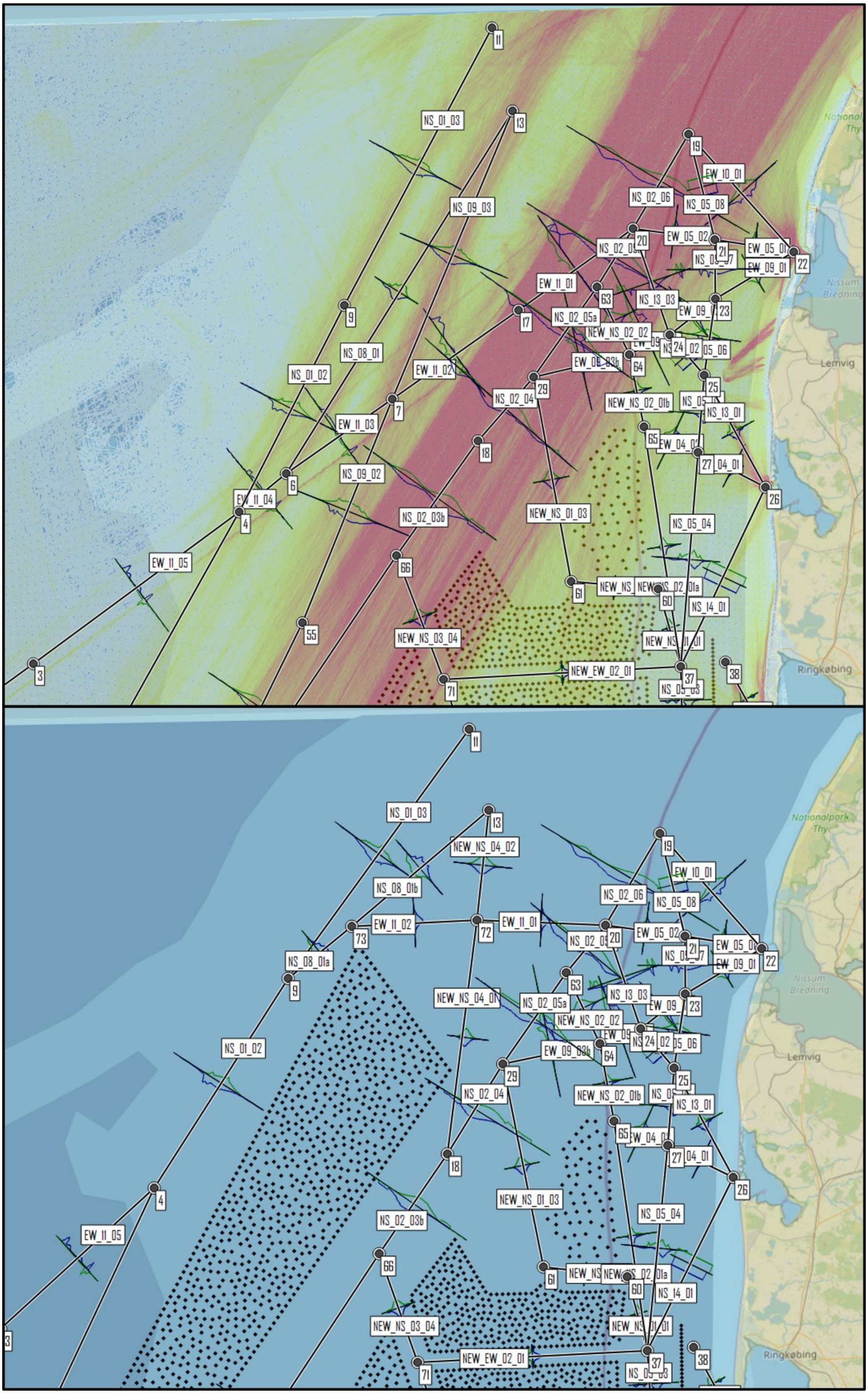


Figure 15-1. Illustration of the traffic movements and rerouting related to the construction of NSII (northern part). The top figure illustrates the conditions in scenario 3, while the bottom figure illustrates the rerouted traffic conditions in scenario 4.

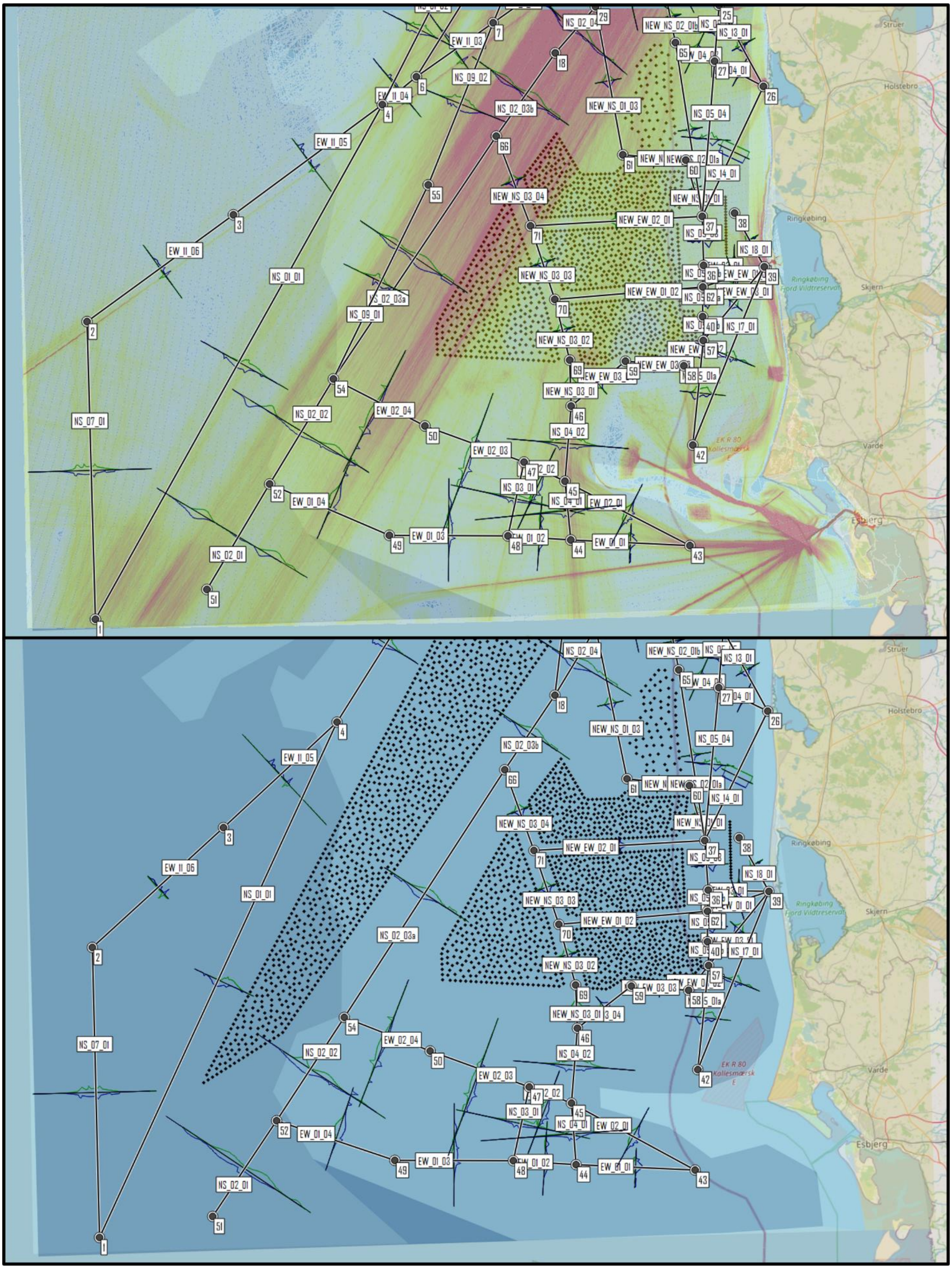


Figure 15-2. Illustration of the traffic movements and rerouting related to the construction of NSII (southern part). The top figure illustrates the conditions in scenario 3, while the bottom figure illustrates the rerouted traffic conditions in scenario 4.

15.1.1 FINAL MODEL SETUP

Following the proposed traffic movements and rerouting from scenario 3 to scenario 4, outlined in the previous section, and based on the construction of the NSII OWF, the final model setup can be seen below in Figure 15-3.

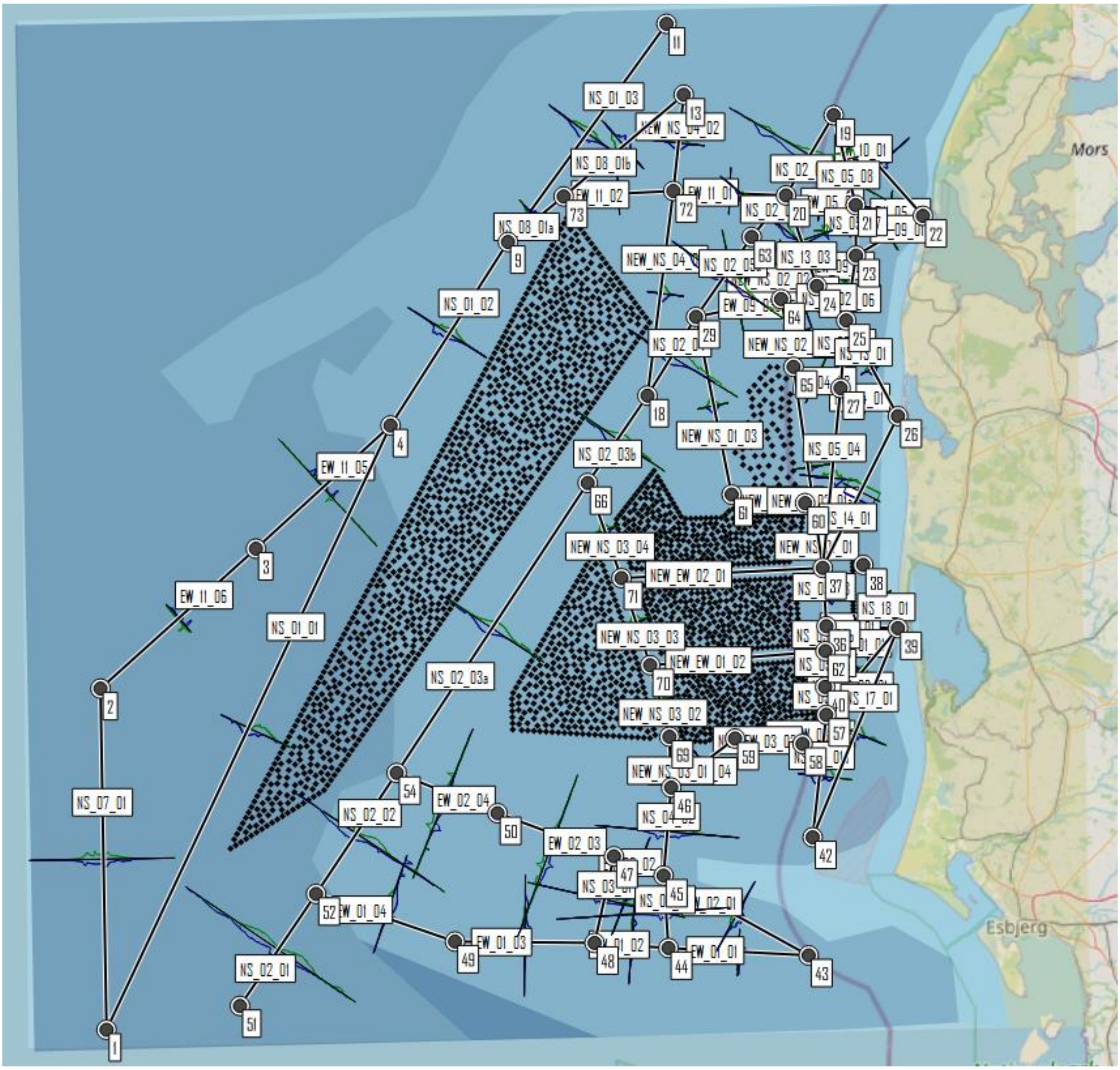


Figure 15-3. Proposed traffic model for scenario 4 based on the modelling of NSII OWF as well the previous modelled scenarios related to VHS, Thor, NSI.1 and NSI.2 OWFs.

15.2 FREQUENCY MODELLING

The overall results of the frequency modelling (calculation of return periods) based on scenario 4 in relation to the operation phase are shown in Table 15-5 with years between incidents and the corresponding yearly frequency. The frequency model is based on the entire AoI area.

Table 15-5. Overall frequency modelling results of scenario 4.

Scenario 4	Return period (Years between incident)	Frequency (yr^{-1})
Powered groundings	6,029	1.66E-04
Drifting groundings	36.0	2.78E-02
Total groundings	**35.7**	2.80E-02
Powered allisions	223	4.50E-03
Drifting allisions	35.4	2.83E-02
Total allisions	**30.5**	**3.28E-02**
Overtaking	160	6.23E-03
HeadOn	47.0	2.13E-02
Crossing	56.4	1.77E-02
Merging	234	4.28E-03
Bend	268	3.74E-03
Total collisions	**18.8**	**5.33E-02**

For total groundings, the calculated return period for scenario 4 is around 36 years between incidents. For total allisions, i.e., collisions between ship and obstacles, the return period for scenario 4 is about 31 years, while total ship-ship collisions are about once every 19 years (Table 15-5). Thus, it can be concluded, that collisions are the most frequent incident type followed by groundings.

The calculations indicates that the return periods are much higher (lower frequencies) for powered accidents relatively to drifting accidents. For instances, powered allisions are 6 times less frequent compared to drifting allisions (6 times longer return period). (Table 15-5).

For ship-ship collisions the most frequent type of accident is “HeadOn” collision followed by “Crossing”. The frequency related to merging and bend collisions is very low, whereas “Overtaking” is intermedial. “HeadOn” collision is 5-6 times more frequent compared to “Bend” (Table 15-5).

15.2.1 GROUNDINGS

Most groundings in the model are due to cargo ships (47%), tankers (15%) and fishing ships (15%). The powered groundings can be explained by four legs, see Table 15-6 (left), where 100% of the powered groundings will be related to four routes. Most powered groundings are found in route NS_14_01 (cover 43% of all groundings) located just northwest of Hvide Sande and near the coast. The second largest contributor is leg NS_04_02, which is located just west of the ground of Horns Rev.

As shown in Table 15-6 (right), drifting groundings will not be controlled by individual legs, however many different routes contribute to the drifting grounding statistics.

84% of the groundings in the model are caused by ships colliding with land (0 m water depth curve), which will not be affected by the rerouting of traffic in relation to the planned NSII OWF. The remaining part (16%) of the groundings are related to the 10 m curve.

Table 15-6. The five most contributing legs to powered groundings (left) and drifting groundings (right) in scenario 4.

Leg	Powered groundings (%)
NS_14_01	43.7
NS_04_02	33.2
NS_05_01a	22.5
NS_04_01	0.6
Total	**100**

Leg	Drifting groundings (%)
NS_02_06	14.0
NS_02_05b	9.7
NS_02_05a	7.2
NS_02_03b	5.7
Total	**39.3**

15.2.2 ALLISIONS

Most allisions (76% of powered and 48% of drifting) are recorded by the model in leg NS_02_03a, which is situated between NSI.2 and NSII where the shipping corridor S10 is most narrow. The second most contributing leg (powered allisions) is NS_02_02, which also is located between NSII and NSI.1. In total, these two legs contribute with 86% of the powered allisions, (Table 14-5 left). Overall, the WTGs most exposed to allisions are located in the southeastern part of NSII and along the western part of NSI.2 and the northwestern part of NSI.1 A3.

Table 15-7. The seven most contributing legs to powered allisions (left) and drifting allisions (right) in scenario 4.

Leg	Powered allisions (%)
NS_02_03a	75.5
NS_02_02	10.0
NS_05_2a	3.2
NS_01_01	1.9
NS_02_04	1.7
NS_05_01a	1.7
NEW_EW_03_04	1.1
Total	**95.0**

Leg	Drifting allisions (%)
NS_02_03a	47.8
NS_02_03b	13.8
NS_01_01	7.7
NEW_NS_03_03	4.9
NEW_NS_03_04	4.1
NEW_NS_03_02	3.9
NS_02_04	3.2
Total	**85.5**

15.2.3 COLLISIONS

For ship-ship collisions, HeadOn collisions is modelled to be the leading cause of collisions. Most of the Head-on and overtaking ship-ship collisions is related to leg NS_02_03a; about 34% and 27%, respectively, followed by NS_02_03b. In addition, most of these two collision types involve cargo ships and tankers in leg NS_02 (Table 15-8). Basically, all the seven most contributing legs are related to NS_02 for both HeadOn and Overtaking collisions, which all are legs within the shipping corridor S10 that have been narrowed significantly in their traffic distribution. Thus, it can be concluded that 86-88% of all collisions (HeadOn and Overtaking) in relation to scenario 4 occur along shipping corridor S10, whereas collisions are relatively rare in the surrounding areas.

Crossing, Merging and Bend collisions are not included in Table 15-8, as these collisions happen at the intersection of different legs and cannot be divided onto individual legs.

Table 15-8. The seven most contributing legs to HeadOn collisions (left) and overtaking collisions (right) in scenario 4.

Leg	HeadOn collisions (%)
NS_02_03a	34.1
NS_02_03b	17.5
NS_02_04	8.7
NS_02_02	8.6
NS_02_05a	6.0
NS_02_01	5.8
NS_02_06	5.1
Total	**85.8**

Leg	Overtaking collisions (%)
NS_02_03a	26.8
NS_02_03b	15.0
NS_02_02	13.3
NS_02_01	12.3
NS_02_04	8.3
NS_02_05b	6.2
NS_02_05a	5.9
Total	**87.7**

15.3 COMPARISON BETWEEN SCENARIO 3 AND 4

In this section the calculated return periods (frequencies of incidents) for scenarios 3 and 4 are compared and risk evaluated. The calculated return periods in terms of groundings (powered and drifting) and ship-WTG collisions (powered and drifting allisions) as well as ship-ship collisions (during Overtaking, HeadOn, Crossing, Merging and Bending) related to the two different scenarios are presented in Table 15-9. The risk evaluations focus on the numerical outputs from the model, i.e. the accident frequencies.

Table 15-9. Risk evaluation (comparison) of the calculated return periods modelled for scenario 3 and 4 (presented with at least three digits).

	Return period (years between incidents)	
Incident type	**Scenario 3**	**Scenario 4**
Powered grounding	5,989	6,029
Drifting grounding	37.1	36.0
Total groundings	**36.8**	**35.7**
Powered allisions	183	223
Drifting allisions	88.6	35.4
Total allision	**59.7**	**30.5**
Overtaking	108	160
HeadOn	68.9	47.0
Crossing	81.9	56.4
Merging	501	234
Bend	449	268
Total collisions	**24.8**	**18.8**

According to Table 15-9, the lowest frequency (longest return period) for both scenarios will be related to powered groundings followed by powered “merging” collisions for scenario 3 and “bend” collision for scenario 4. In general, the frequency of drifting accidents (drifting groundings and drifting allisions) will be much higher relative to powered accidents. In other words, drifting accidents occur more often than powered accidents. For both scenarios, the most frequent accident type will be total collisions. For both scenarios, the most frequent collision type will be “HeadOn” followed by “Crossings”. Overall, the total grounding frequency will almost be identical for both scenarios. Total allisions will be the least frequent accident type for scenario 3, whereas total grounding will be the least frequent accident type for scenario 4.

The overall change in incident frequencies between scenario 3 and 4 is shown in Table 14-8. A positive percentage means the frequency will increase (shorter return period), resulting in fewer years between incidents. Conversely, a negative percentage means the frequency will decrease (longer return period), resulting in more years between incidents.

Table 15-10. Percentage changes in the incident frequency for scenario 4 relatively to scenario 3.

	Changes in percentage (%)
Powered grounding	-1
Drifting grounding	3
Total groundings	**2**
Powered allisions	-21
Drifting allisions	60
Total allision	**49**
Overtaking	-49
HeadOn	32
Crossing	31

Merging	53
Bend	40
Total collisions	**24**

In the following sections, the percentage differences for each incident type (groundings, allisions, and collisions) are further discussed.

15.3.1 GROUNDINGS

The modelling shows that the total grounding frequency will increase by 2% from scenario 3 to scenario 4 with the build-out of WTGs in the NSII area. Overall, the calculations indicate that the risk of groundings will be unchanged due to the establishment of NSII (Table 15-10).

15.3.2 ALLISIONS

The greatest change in frequency (according to overall accident types) between scenario 3 and 4 will be related to allisions. The modelling shows that the total allision frequency will increase by 49% (shorter return period) from scenario 3 to scenario 4 with the build-out of WTGs in the NSII area. This increase is due to a higher frequency of drifting allisions, where ships with engine failure or blackout are more likely to collide with WTGs. In this scenario, WTGs are present on both sides of the shipping corridor S10, and with a bordering length about 130 km between NSII and S10, the total allision frequency is expected to rise. Conversely, the frequency of powered allisions will decrease with the construction of NSII OWF (Table 15-10).

15.3.3 COLLISIONS

The modelling shows that the total collision frequency will increase by 24% from scenario 3 to scenario 4 with the build-out of WTGs in the NSII area. There is great variation in the contribution from the different types of collisions. “Overtaking” will decrease by 49%, while “Bend” will increase by 53% (Table 15-10).

Due to the presence of NSII, the maritime traffic will be rerouted, and some current traffic routes will be deleted. Most traffic will be rerouted east of the NSII OWF (cf. shipping corridor S10 stated in the MSP. This traffic movements and rerouting results in higher traffic density in certain routes. Higher density means greater risk of collision between ships. Another reason for the increasing collision frequency will be due to narrowing of the shipping corridor S10, where most traffic will be rerouted into and where the traffic density will be greatest.

16 APPENDIX 3 – IWRAP FREQUENCY MODEL SETUP

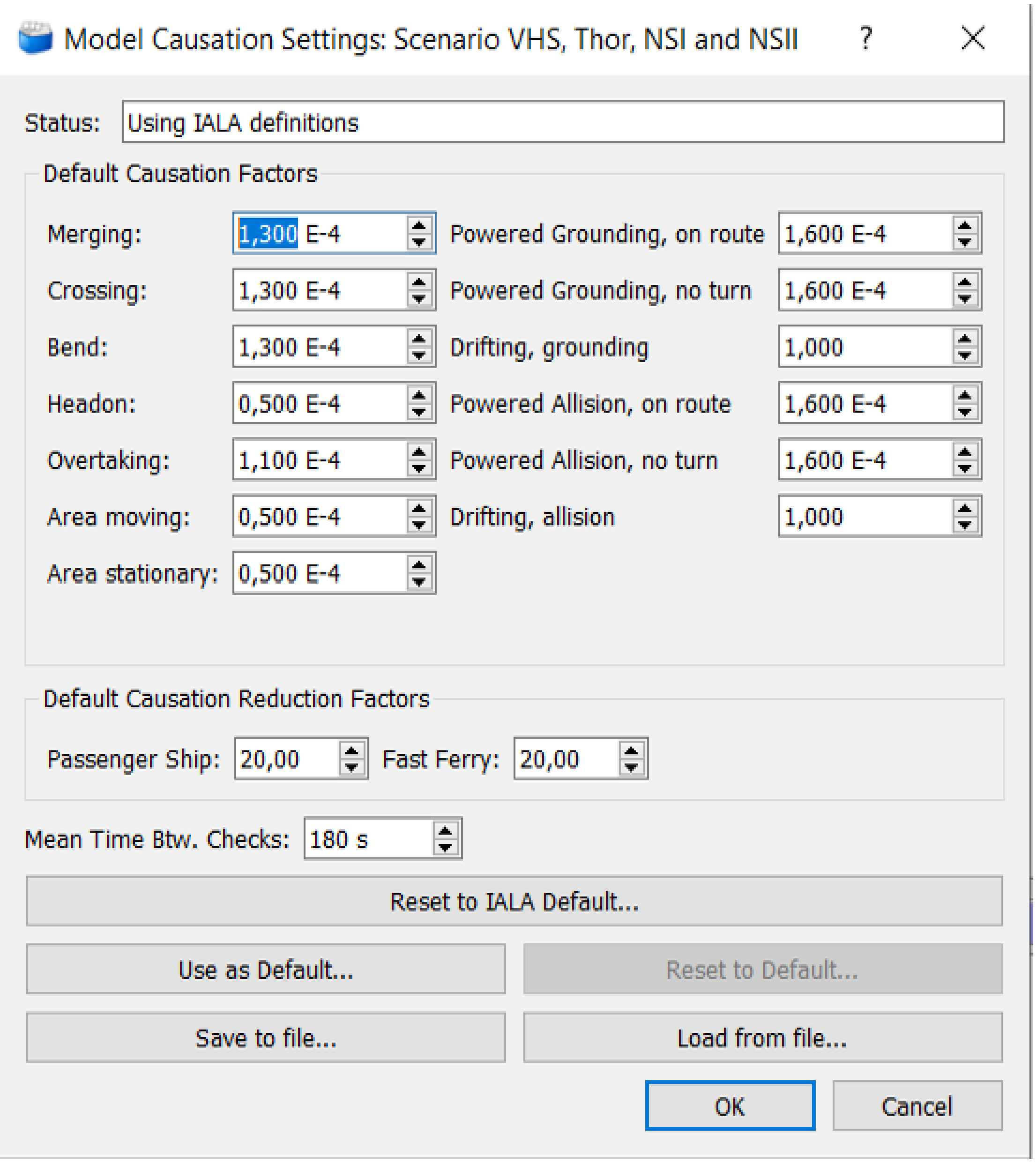
Modelling principles / collision models.
The IWRAP tool is used for accident modelling for ship-ship and ship-wind turbine collisions (allisions). The method is purely based on statistics. IWRAP has been part of the IALA risk toolbox since 2008 (IALA risk management tools).

IWRAP models maritime traffic along defined routes (legs) with statistical lateral distributions. For details on how the IWRAP model works, please refer to the IWRAP User Manual and to the IALA wiki page on IWRAP (IWRAP MK II, 2008). In the following, the settings used in the models are described.

In the model, a geometric calculation is made based on sailing speed and sailing direction and compared with a causation factor model that scales the frequency of a human error in relation to how long a ship will be heading towards an obstacle and the distance to the obstacle. For the ship-ship collision a Bayesian Network model is formulated in the IWRAP software.
Technical errors are errors that lead to situations where the navigator cannot control the ship and thus avoid a potential collision. Basically, engine failure and steering failure are the two main types of technical failure. An engine failure will cause the ship to stop working, and a steering failure will cause the ship to go in circles. Generic frequencies of engine failure and steering failure are based on general statistical data for commercial vessels. The IWRAP tool includes engine failure/drifting ship modelling but does not implement the steering failure.

Causation factors
The causation factor models the probability of the officer on the watch not reacting in time given that he is on collision course with another vessel or on grounding course. These values for human failure have been described in detail in (Fujii, Yamanouchi, & Matui, 1984) and (IWRAP MK II, 2008), and default values in IWRAP are now industry standard. The values used can be seen in Figure 16-1.

Ferry routes and passenger ships typically have a lower causation factor, due to navigators' increased awareness and knowledge of the area. The default setting in IWRAP of reducing the causation factor by 20 is used (Figure 16-1).



Model Causation Settings: Scenario VHS, Thor, NSI and NSII

Status: Using IALA definitions

Default Causation Factors

Merging: 1,300 E-4
Crossing: 1,300 E-4
Bend: 1,300 E-4
Headon: 0,500 E-4
Overtaking: 1,100 E-4
Area moving: 0,500 E-4
Area stationary: 0,500 E-4
Powered Grounding, on route 1,600 E-4
Powered Grounding, no turn 1,600 E-4
Drifting, grounding 1,000
Powered Allision, on route 1,600 E-4
Powered Allision, no turn 1,600 E-4
Drifting, allision 1,000

Default Causation Reduction Factors

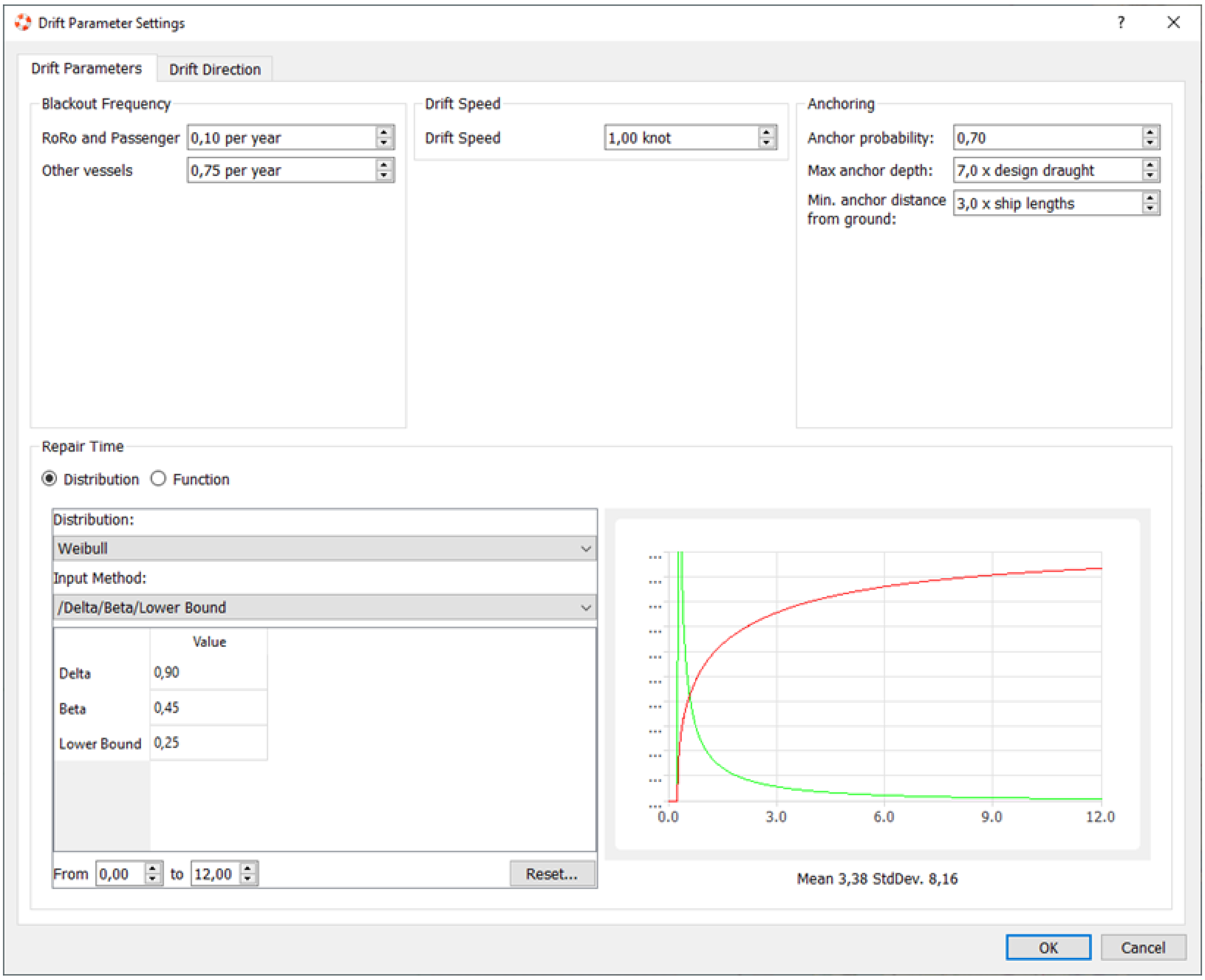
Passenger Ship: 20,00
Fast Ferry: 20,00

Mean Time Btw. Checks: 180 s

Figure 16-1. Causation factors used in IWRAP.

Drifting ships

In the case of engine failure or other accidents that might lead a ship to start drifting, there is a chance that the error is rectified, and the ship becomes maneuverable before the ship collides with an obstacle or grounds. The repair time is modeled in IWRAP as a cumulative Weibull distribution (Figure 16-2). The probability that a drifting ship will be able to anchor and prevent a collision or grounding is set to the default parameter for IWRAP at 70% - in reality the possibility of anchoring will vary greatly within the AoI due to the great differences in depth. Passenger ships have a lower blackout frequency than other ships. The relative scaling of the blackout frequency between passenger ships and other vessels is based on the standard scaling in IWRAP. The probability of drift in each direction is assumed to be given by the distribution of wind directions measured at Thyborøn (DMI, 1999), see Figure 3-3 and Figure 16-3. In 3.1% of the time, there is no wind and thus no direction in which drift is modelled. This is not supported by IWRAP. Here a ship will always drift. This is considered conservative in the model results.



Drift Parameter Settings

Drift Parameters | Drift Direction

Blackout Frequency

RoRo and Passenger: 0,10 per year

Other vessels: 0,75 per year

Drift Speed

Drift Speed: 1,00 knot

Anchoring

Anchor probability: 0,70

Max anchor depth: 7,0 x design draught

Min. anchor distance from ground: 3,0 x ship lengths

Repair Time

● Distribution ○ Function

Distribution: Weibull

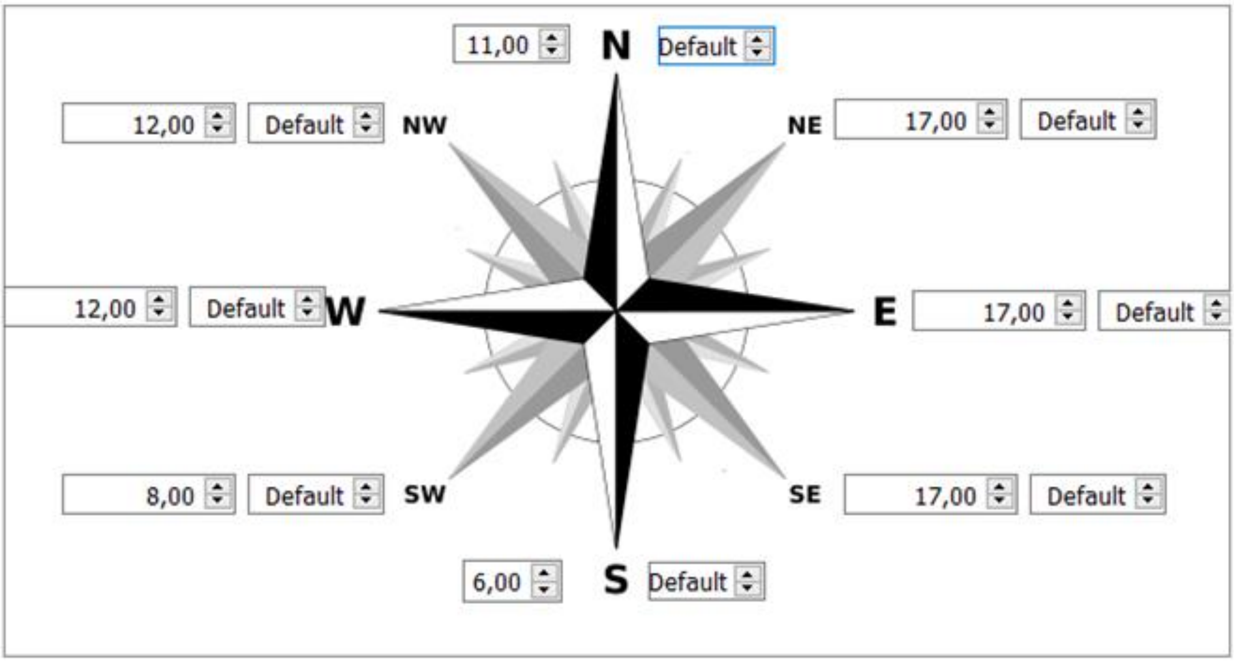
Input Method: /Delta/Beta/Lower Bound

	Value
Delta	0,90
Beta	0,45
Lower Bound	0,25

From 0,00 to 12,00

Mean 3,38 StdDev. 8,16

Figure 16-2. Operating parameters and settings for drifting ships.



N: 11,00 Default

NE: 17,00 Default

E: 17,00 Default

SE: 17,00 Default

S: 6,00 Default

SW: 8,00 Default

W: 12,00 Default

NW: 12,00 Default

Figure 16-3. Probability of a ship drifting in a given direction, given as a percentage by the wind direction distribution from Thyborøn (DMI, 1999).

17 APPENDIX 4 – HAZID REPORT