NAVIGATIONAL RISK ASSESSMENT OF HESSELØ OFFSHORE WIND FARM

Risk Assessment Report

NIRAS A/S

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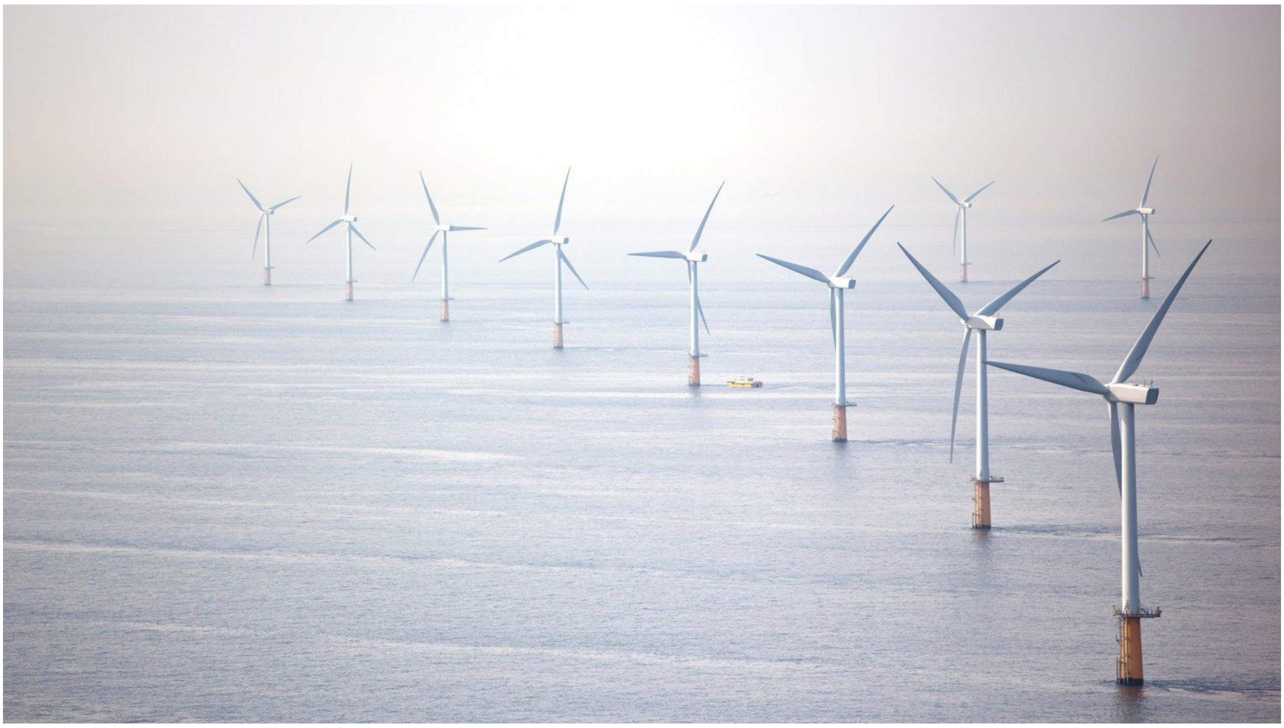

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C	2022-01-31	Update of ship-ship collision frequencies.	KRUGER	HAJOH	

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EXECUTIVE SUMMARY

The objective of this navigational risk assessment is to assess how, where, and how much the Hesselø Offshore Wind Farm (OWF) project impacts the maritime traffic, and to assess the potential changes in risk of collisions and groundings caused by the project. The methodology applied when estimating the navigational risk is a standard risk assessment approach, based on the guidelines of the International Maritime Organisation (IMO) for Formal Safety Assessment (FSA).

The following sections summarized the main findings from the risk assessment. Recommendations and follow-up actions identified in the HAZID study and in the Risk Assessment are listed in chapter 5.

Hazard identification

A total of 65 hazards were identified and discussed in the HAZID workshop. The complete HAZID log sheet with all 65 hazards, their causes, consequences, and existing safety measures, as well as any identified recommendations, is documented in DNV Report no. 2021-0483 [1].

The hazards ranked in the high-risk area (red area) are mainly related to the Stena Line route between Halmstad and Grenaa (which will be "blocked" by the OWF) and the alternative Halmstad-Grenaa routes discussed in the HAZID workshop. Also, fishing vessels and pleasure crafts will be largely affected by the Hesselø OWF. Most of the hazards identified in the HAZID were medium risk hazards, and mainly related to potential ship-turbine collisions from ships sailing in the routes in vicinity of Hesselø OWF; Route T, Route 3 (route south of Hesselø OWF) and the old Route D (here split into Route D1/D2).

Ship-turbine collision risk during operation

Due to that the Stena Line route between Halmstad and Grenaa needs to relocate, two scenarios for modelling the ship traffic in the area were considered in the quantitative risk assessment: One with the Stena Route relocated north of the OWF (scenario 1) and one with the Stena Route relocated south of the OWF (scenario 2). Both scenarios quantify the complete navigational risk for all ship traffic in the area, and the only difference between the scenarios is the different relocation of the Stena route. A scenario with potential sailing corridor for Stena Line through Hesselø OWF is not quantified in this study.

The resulting frequency of ships striking the wind turbines is 0.0053 and 0.0052 for scenario 1 and 2, respectively. These frequencies equal a return period of about 200 years. The routes that contribute most to the ship-turbine collision frequencies are Route T and Route D1/D2. There are twice as many ships passing along Route T compared to Route D1/D2, so even though Route D1/D2 is located closer to the OWF the actual frequency contribution is lower. Route 3 also contributes to the ship-turbine collision frequency, however the low number of ships passing through this route results in a smaller contribution compared to the above-mentioned routes.

Ship grounding risk

It is calculated that the total grounding frequency after establishment of Hesselø OWF is 0.29 for scenario 1 and 0.3 for scenario 2, which equals to a return period of 3 years. Compared to today's situation these numbers indicate a decrease in frequency of 5.8% and 3.2% for scenario 1 and 2 respectively. This may be largely due to the fact that vessels sailing in proximity of the OWF will be more likely to collide with a turbine instead of drifting on ground in case of loss of steering or power. Further, the traffic distribution along Route 3 is narrower in the revised condition, resulting is less probability of powered grounding at Lysegrund.

Ship-ship collision risk

The ship-ship collision frequency after establishment increases with approximately 12.8% in both scenarios. After establishment, the ship-ship collision frequency is 0.066, which yields a return period of 15 years. In both scenarios, the densification of ship traffic along Route 3 is contributing to the increased ship-ship collision risk, as well as an increased risk for collision at the 'bends' between legs along the revised Stena routes which have slightly more turns than the original route.

Ship transits to and from the OWF, typically CTVs, are not included in the analysis, and the potential further increase in ship-ship collision frequency due to these vessels crossing or merging with other routes should be investigated when the CTV port and operational patterns are decided.

Construction, decommissioning and cable laying operations risks

The number of vessels that operate in construction and decommissioning phases is expected to cause a negligible risk addition to current traffic. However, a procedure for safe voyages will be made for the construction work in dialogue with relevant stakeholders such as pilots. This is especially relating to navigational hazards for when constructions and cable laying vessels may need to cross deep-water routes and major traffic flows, e.g., Route T or Route S.

Cumulative risk effects

Galatea/Kattegat Syd OWF and Stora Middelgrund OWF in Swedish waters are both in the project development phase. In case these OWFs are established, assuming also establishment of Hesselø OWF, the ship traffic in the Kattegat will be restricted and concentrated along the main routes. This will potentially result in a slightly higher collision risk based on the densification of commercial traffic along Route T and Route S. Further, there are both fishing vessels and pleasure crafts sailing in the area. These vessels may have to sail closer to or along the main routes which also may increase the collision risk. Further, three OWFs located within the same region will naturally also introduce a higher risk for ship-turbine collisions.

Risk of wind farm cable interaction with ship traffic

Based on VMS data from 2010 to 2020, a significant amount of bottom trawling activity was identified in the area of the planned export cable corridor, as well as within the offshore wind farm area itself. Generally, no bottom trawling is allowed inside the cable protection zone, which covers an area equal to 200 meters on each side of all cables, both the export cable and cables inside the OWF. The risk of bottom trawling damaging the export cable will thus be low. Further, power cables will be clearly marked in charts and be buried to a sufficient depth to avoid being uncovered, which also reduces the risk of damage to the cable from erroneous trawling or dropped anchors.

Direct impacts on ships and maritime activities not covered by the frequency analysis

Fishery

After establishment of Hesselø OWF, a part of the area will potentially become unavailable for fishing using bottom-impacting gear, like trawling. As mentioned, there is a strict no-fishing zone within the 200 meters protection zone around all the cables. Fishing activities inside the OWF area, at allowed distances from the power cables, are however not prohibited. Whether or not the amount of fishing activities will be significantly reduced is not certain. Though, it was mentioned in the HAZID workshop that the region will become less attractive for fisheries after establishment of the OWF, particularly if the OWFs in the Swedish EEZ are established as well. If the unavailable area becomes too large, it could be expected that fishing activities in the area would decrease significantly or cease to exist. This would in turn, naturally, decrease the navigational risk itself as the total ship traffic volume would decrease.

Search and Rescue

No significant disruption of Search and Rescue (SAR) operations at sea is expected, as the spacing between the turbines (approx. 1500 m) and the minimum distance between the Highest Astronomical Tide (HAT) and the lower wing tip (approx. 20 m) will allow for rescue boats to sail in between turbines and through the wind farm.

Pleasure crafts

These smaller vessels may have to sail closer to or along the main transit routes and major traffic flows which may increase the collision risk.

Assessment of required sailing corridor for main ship routes

When designating shipping corridors for Danish waters, DMA used the general calculation principles as described in a Dutch white paper for IMO [2] [3]. Based on the calculation principles by DMA, DNV has calculated the indicative minimum area for the routes that are close to the Hesselø OWF.

The calculations show that indicative area required for Route T does not overlap with the Hesselø OWF area. Route 3 overlaps partly with the OWF area, some of the turbines in the proposed layout, in the south-east corner of the OWF. However, this is based on a conservative assumption that the centreline of Route 3 does not change after the establishment of the OWF. Old Route D1/D2 overlaps with parts of the planned Hesselø OWF area *if* the direction of the route compared to today's sailing pattern is not changed. However, both the Marine Spatial Plan for Denmark (*Havplan*) and this assessment show that a slight adjustment of the sailing direction can avoid overlap between this route and the OWF area.

ABBREVIATIONS AND TERMS

Abbreviations

AIS	Automatic Identification System
AtoN	Aids to navigation
DEA	Danish Energy Agency
DMA	Danish Maritime Authority
EIA	Environmental Impact Assessment
ETA	Estimated time of arrival
FSA	Formal safety Assessment
GT	Gross tonnage
HAT	Highest Astronomical Tide
HAZID	Hazard Identification
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IMO	International Maritime Organisation
ISO	International Organization for Standardization
IWRAP	IALA Waterways Risk Assessment Program
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MMSI	Maritime Mobile Service Identity
NM	Nautical mile
PEC	Pilot exemption Certificate
SAR	Search and Rescue
SPS	Significant Peripheral Structure
SWIFT	Structured What-If Technique
TSS	Traffic separation scheme
VMS	Vessel monitoring system
VTS	Vessel Traffic Services

Risk terminology

Collision	Ship-ship collision: Striking or being struck by another ship, regardless of whether under way, anchored or moored. Ship-turbine collision: Ship striking the wind turbine or offshore substation (powered or drifting vessel). Collision with a fixed object may also be defined as 'allision'.
Grounding	Powered grounding: Grounding while under power, due to navigational error or technical fault. Drift grounding: Grounding while not under control, typically due to loss of propulsion and/or power in adverse weather.
Hazards	Physical situations which have the potential to cause harm. The word "hazard" does not express a view on how likely it is that the harm will occur. A major hazard is a hazard with potential to cause significant damage or multiple fatalities.
Likelihood	May be expressed either in terms of a frequency (the rate of events occurring per unit time) or in terms of a probability (the chance of the event occurring in specified circumstances).
Consequence	Refers to the expected effects of an event occurring.
Safety	The inverse of risk. The higher the risk of any level of harm from an activity, the lower is its safety. Complete safety, as implied by the colloquial definition of safety as "the absence of risk", is a worthwhile goal for engineers, but is practically impossible in an intrinsically hazardous activity. A realistic target is to reduce the risk of accidents until the safety of the activity is acceptable, bearing in mind the benefits which it brings.
Risk	Combination of likelihood and consequence of accidents. More scientifically, it is defined as the probability of a specific adverse event occurring in a specific period or in specified circumstances. The distinction between "hazard" and "risk" is important, although in colloquial use, and in popular dictionaries, risk and hazard are treated virtually as synonyms.
Risk Management	The systematic application of management policies, procedures and practices to the tasks of analysing, evaluating and controlling risk. This is equally applicable to technological and other risks.

1 INTRODUCTION

1.1 Background

With the Energy Agreement 2018, all parties in the Danish parliament decided to establish three new offshore wind farms in Denmark before 2030. On June 22nd, 2020, the parties agreed on a ‘Climate agreement for energy and industry, etc. 2020’. In the agreement, it is decided that farm 2 (from the Energy Agreement 2018) will be moved forward in relation to an original plan and established so that it is completed in 2027. The new offshore windfarm is planned to be located in the central Kattegat approx. 32 km north of Gilbjerg Hoved on the north coast of Zealand. The farm will be named Hesselø Offshore Wind Farm (Hesselø OWF) after the small uninhabited island of Hesselø, which is located southwest of the area. The offshore wind farm will be a minimum of 800 MW and a maximum of 1,200 MW, with a maximum capacity at the connection point of 1,000 MW.

In order to complete the establishment in 2027 and fulfil the political goals from the Energy Agreement 2018, reconfirmed in the Climate Agreement 2020, the minister of Climate, Energy and Utilities, by order to Energinet, has decided to initiate the preliminary studies for Hesselø Offshore Wind Farm, i.e. strategic environmental assessment and relevant benthic surveys, etc. for Hesselø Offshore Wind Farm, so that these can be completed before the tenderers submit their tenders.

In accordance with the order from the Ministry of Climate, Energy and Utilities [10]. Energinet must prepare the following:

- A strategic environmental assessment (SEA) of the plan for Hesselø Offshore Wind Farm. The environmental assessment of the plan must include the entire project, both offshore and onshore.

For the offshore part:

- Geotechnical and geophysical surveys
- Providing information on and measurements (LIDAR) of wind, wave and current conditions, etc. (MetOcean)
- Supplementary marine environmental studies

For the onshore part:

- Environmental impact assessment (EIA) for the onshore area
- Establishment of plan basis for onshore facilities

For network connection:

- Indication of main connection point and voltage level as well as establishment of main connection point

As described in the order from the Ministry of Climate, Energy and Utilities (ref1), Energinet is obligated, among other things, to carry out supplementary environmental studies in addition to the requirements for the strategic environmental assessment. The purpose is to provide critical data and information in a baseline mapping that the concession winner can use during the later actual environmental impact assessment (EIA) pursuant to section 15 of the Environmental Assessment Act (“Miljøvurderingsloven”) and the environmental impact report, cf. section 20 of the Environmental Assessment Act concerning the specific project at sea (i.e. up to the coastal zone). The purpose of the supplementary marine environmental surveys is also to function as a risk-minimizing measure for tenderers for the offshore wind farm. The supplementary marine environmental surveys will cover several topics, including the topic of maritime traffic and navigational risks.

NIRAS is hired by Energinet to assist with the SEA and environmental baseline studies, and DNV is subcontracted by NIRAS to perform the Navigational Risk Assessment (NRA).

1.2 Objective

The objective of this navigational risk assessment is to assess how, where, and how much the plan for Hesselø OWF impacts the maritime traffic, and to assess the potential changes in risk of collisions and groundings caused by the OWF.

1.3 Scope and boundary limits

The scope of work includes a navigational risk assessment for the plan for Hesselø OWF. The project in this study includes the wind turbines, support structures, any substations with topside and support structure and power cables.

The assessment reviews the following phases:

- Operation
- Construction and decommissioning

The following is not part of scope for this study:

- Occupational hazards such as: falls, burns, poisoning, suffocation and asphyxiation during maintenance, and/or during crew transfers to/from the turbine.
- Detailed consequence modelling following turbine impact from ships or leisure boats (e.g. injuries/fatalities, loss of material asset, environmental damage and /or loss of production.
- Detailed anchor drops, and dragging anchor and bottom gear, calculations and impact assessments.
- Structure impact analysis (e.g. finite element modelling)
- Assessment of implications on marine navigation and communication equipment (e.g. radar)
- Terrorist or deliberate acts of sabotage are unpredictable and difficult to include in a quantified study and is therefore not included.
- Emergency preparedness evaluations and assessment.
- Assessment of rules and standards concerning navigation in the area.

1.4 Introduction to Hesselø Offshore Wind Farm

The location of Hesselø Offshore Windfarm is based on a detailed screening of multiple installation areas for wind farms in Danish waters carried out for the Danish Energy Agency during spring 2020 ([11]).

The plan definition for Hesselø Offshore Wind Farm is described in a memorandum from the Danish Energy Agency ([12]) and in a draft to the scoping report for the environmental assessment of the plan ([13]), which was issued in connection with the first public phase in the period February 12th to March 19th, 2021. The plan for Hesselø OWF includes the following:

Political decision/analysis	Content of decision/analysis
Energy Agreement of June 29th 2018	The conciliation parties decided that in 2021 a new offshore wind farm of at least 800 MW will be offered. If technically and economically possible, larger parks will be built.
Detailed screening 2020 (COWI) of May 2020	Detailed screening 2020 is an update in relation to Detailed screening 2018 of selected areas in Danish waters for establishment of offshore wind, partly because the area for “Hesselø” is slightly smaller and differently placed compared to the areas which was screened in 2018. The detailed screening confirms that it is possible – practical and in relation to nature, environment, planning and economic conditions – to establish an offshore wind farm of 1,000 MW with a specific location in the selected area in the screening.

Political decision/analysis	Content of decision/analysis
Climate agreement for energy and industry etc. of June 22nd 2020	The agreement group decided that farm 2 of the Energy Agreement 2018 will be established at Hesselø. The group also decided that the farm should be moved forward and completed in 2027, and that the farm at Hesselø should be based on the principles from the Energy Agreement 2018, which states that future offshore wind as far as possible should be market-led without public support.
Decision in the climate agreement group	The agreement group behind Climate Agreement 2020 decided that farm 2 of the Energy Agreement 2018 will be placed in Hesselø Bay and will be named Hesselø Offshore Wind Farm. Concession winner builds the offshore wind farm, transformer station(s) and export cables to the point of connection on land. Permitted size range for the park is 800-1,200 MW, of which up to 1,000 MW can be delivered to the grid, while the extra up to 200 MW can be used for overplanting. At the same time, it was decided that the possibilities for connecting PtX or battery systems on land or at sea to the offshore wind farm are sought to be improved, including that Energinet, as a part of the preliminary investigations, enters dialog with the relevant municipalities concerning reservations of areas for batteries or PtX systems on land, without an existing political decision on connection of batteries or PtX systems or their specific locations.
Administrative decision of October 23rd 2020 to choose Gilbjerg Hoved as point of connection	The Danish Energy Agency decided that the point of connection for Hesselø Offshore Wind Farm will be at Gilbjerg Hoved. Energinet has analysed two alternative solutions for exporting the power from Hesselø Offshore Wind Farm: one at Kyndby (through Isefjord) and the other at Gilbjerg Hoved west of Gilleleje Harbour. For both solutions, the point of connection is at Hovegård high voltage station. The Danish Energy Agency assessed that export at Gilbjerg Hoved collectively is the best solution. This is primarily due to the fact that Energinet assessed that this solution entails significant economic benefits, while at the same time the technical solution and consideration for nature and environment are at least as good as in the alternative.

1.5 Scenarios for Hesselø OWF

In addition to the political and administrative decisions and detailed screening, it is defined in the memorandum from the Danish Energy Agency ([12]), that the environmental assessment of the plan for Hesselø Offshore Wind Farm must include a description of the possible designs of a future project. These possible designs are not a part of the plan itself and will therefore not be limiting for a future project. However, they express the immediate expectations in terms of design and dimensions. The following are therefore used as bases for the assessments:

- Turbines founded in the seabed (800-1,200 MW), meaning for example 40-60 turbines of 20 MW each, 54-80 turbines of 15 MW each or 100-150 turbines of 8 MW each, with a total height of 310, 280 and 190 meters.
- A grid of inter-array cables in the seabed between the turbines.
- One (two) offshore transformer platform(s).
- 2-3 export cables.
- Technical facilities and cables on land, including a connection point that can receive 1,000 MW.

Wind turbines with a capacity in the range of 8-20 MW are expected to be installed. The minimum turbine capacity of 8 MW corresponds to the installation of up to 150 turbines, and the maximum turbine capacity of 20 MW corresponds to the installation of up to 60 turbines.

The technical parameters for Hesselø OWF included in this report are listed in Table 1-1.

Table 1-1 Technical parameters for the scenarios for Hesselø OWF.

Technical parameters			
Offshore wind turbines			
	8 MW turbine	15 MW turbine	20 MW turbine
No. of WTGs	100 - 150	54 – 80	40 - 60
Rotor diameter, meter	170	260	280
Hub height, meter	105	150	170

Tip height, meter	190	280	310
Nacelle (length, width, height), meter	20x8x8	29x13x13	32x15x15
Fundaments			
Monopile diameter, meter	10	13	15
Pile driving; hammer size, blow strength and blow rate	IHC S-4000, 6000kJ, 7000 blows. Rate: 4 seconds for 'soft start-procedure' thereafter 2 seconds.		
Scour protection	15 – 20 meter in diameter		
Offshore transformer platform*			
Dimensions (length/width), meter	40/25		
Inter array cables			
	66 kV	66 kV	66 kV
Export cables			
No. of cables	2-3		
Voltage level	220 kV – 345 kV (AC)		
Investigated cable corridor (offshore), meter	1.000		
Distance between cables in Natura 2000 sites/other areas, meter	50/150-200		
Depth of cable trench, centimeter	60-100		
Length of directional drilling (at landfall), meter	Up to 1,500		

* A platform is expected to be established, but two possible locations are included in the preliminary investigations and in the strategic environmental assessment.

The parts of the project that take place on land are described in the technical project description that forms the basis for the environmental impact assessment for the project on land.

As previously described, the layout of the offshore wind farm and turbines is not decided at present, as this will be determined by the future concessionaire. The completed assessments have therefore been made at an overall level, taking into account the different variation possibilities in the size of the farm, different sizes of turbines and the consequent difference in the number of turbines and installation patterns. Thus, several different layouts are included in the plan for Hesselø Offshore Wind Farm, which can result in the final, specific project. An environmental impact assessment will be prepared for the specific project at a later point.

2 GENERAL METHODOLOGY

The methodology applied when estimating the navigational risk is a standard risk assessment approach, schematically indicated in Figure 2-1, based on the guidelines of the International Maritime Organisation (IMO) for Formal Safety Assessment (FSA). 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’ are excluded from scope of work.

Figure 2-1 Risk assessment process.

2.1 Hazard identification

2.1.1 Objective

A comprehensive identification of hazards is critical since hazards that are not identified will be excluded from further assessment. The objectives of the hazard identification are:

- To identify hazards associated with the defined operations(s), and to assess the sources of the hazards, events or sets of circumstances which may cause the hazards and their potential consequences.
- To generate a comprehensive list of hazards based on those events and circumstances that might lead to possible unwanted consequences within the scope for the risk assessment process.

2.1.2 Method

Hazard Identification (HAZID) is a systematic process to identify accidental events. The hazard identification is a qualitative review of possible accidents that may occur in order to select failure cases for quantitative modelling.

The HAZID was based on the SWIFT (Structured What-If Technique) and involved a series of keywords/guidewords for the systematic identification of potential hazards and major incidents. DNV used a combination of guidewords from industry guidelines (ISO 17776) and our experience to generate the guideword list. The detailed methodology to be applied in the HAZID workshop follows the steps outlined below:

- Identification of HAZID nodes (ship routes).
- Node briefing (traffic composition).
- Identification of hazards, their causes and consequences.
- Identification of preventive and mitigating measures.
- Determination of severity, likelihood and risk.
- Identification of potential recommendations.

A semi-quantitative risk evaluation using a risk matrix was performed to highlight the specific hazards and areas where the Risk Assessment should have particular focus. The risk ranking also cover hazards that may be difficult to quantify in the quantitative risk assessment.

A full method description, including the frequency and consequence classes for risk ranking, are provided in the HAZID report for Hesselø OWF (DNV Report No.: 2021-0483 /1/).

2.1.3 HAZID team

The HAZID workshop was held by videoconference on Microsoft Teams on the 5th of May 2021. The composition of the HAZID team reflected the different stakeholders in the field, as well as different professions, so that the team covered as broadly as possible in order to ensure that all relevant risks were identified. The attendants are listed in Table 2-1. DNV Maritime Advisory facilitated the workshop. The participants from the Danish Maritime Authority (DMA) and Danish Energy Agency attended the workshop as observers.

Table 2-1 Workshop participants.

Name	Company / organization
Henrik Lund	Danmarks Fiskeriforening
Hans Anders Pedersen	DanPilot
Sabina Fobian	Dansk Natursejler
Kasper Ullum	Danske havne
Morten Glamsø	Danske rederier/færgerederierne
Christian Lerche	Dansk Sejlunion
Hans Jørgen Johnsrud	DNV
Christine Krugerud	DNV
Pernille Skyt	Energinet
Randi Lucie Aliaga	Energistyrelsen
Søren Keller	Energistyrelsen
Carsten Nordahl	Gilleleje havn
Lars Mohr Christensen	Grenaa havn
Thomas Gissel	Grenaa havn
Betina Heron	NIRAS
Winnie Holdt	NIRAS
Mikael Bach	Royal Danish Navy
Frederik Lindberg	Sveriges Fiskares Producentorganisation (SFPO)
Mikael Lindgren	Stena Line
Mikael Stamming	Svenska seglarförbundet
Peter Ronelöv Olsson	Sveriges Fiskeras Producentorganisation
Flemming Sparre Sørensen	Danish Maritime Authority (DMA)
Morten Bækmark	Danish Maritime Authority (DMA)

2.2 Modelling of risk and input data

The objective of this stage is to assess the probability/frequency of initiating events occurring. The initiating events to be analysed are determined by the hazard identification as specified in the previous chapter. The frequency analysis is based on acknowledged mathematical models typically used for such analyses and with input based on Automatic Identification System data (AIS data), supplemented by Vessel Monitoring System (VMS) data.

Ship traffic nearby and through the planned offshore wind farms is modelled by using the IALA Waterways Risk Assessment Program (IWRAP) software. The analysis is based on AIS data collected for 2020 from July 1st to December 31st.

2.2.1 IWRAP tool

The applied calculation tool IWRAP MKII (hereinafter referred to as IWRAP) is a part of the IALA Recommendation [IALA O-134] on risk management. This tool has been used in numerous ship traffic and navigational risk assessments in Northern Europe (North Sea, Baltic and Øresund).

IWRAP calculates the probability of collision or grounding for a vessel operating on a specified route. The applied model for calculating the frequency of grounding or collision accident involves the use of a so-called causation probability that is multiplied onto a theoretically obtained number of grounding or collision candidates. 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 – alternatively – on grounding course).

A description of the ship traffic constitutes the central input for a navigational risk assessment. AIS data provides a detailed geographic and temporal description of the ship traffic in a region and has been used as the primary data basis.

Because the predominant part of the ship traffic is following navigational routes – which can be more or less well defined – the modelling of the ship traffic and the associated models of the risk of collisions and groundings usually adopts a route-based description of the traffic. The ship traffic description based on AIS is thus subsequently used as basis for definition of the routes in the probabilistic model in IWRAP.

A full method description of IWRAP can be found on the IWRAP Mk2 Wiki site [5]. In this project, IWRAP Mk2 version 6.4.4 was used, and the settings and parameters for the model are found in Appendix A.

2.2.2 AIS data

AIS is used as base data to quantify ship movements within the analysis area. Together with ship data, it is the most important data source for the risk calculations. High-resolution AIS data has been used, meaning that the resolution of the data corresponds to a new registered AIS point every 30 seconds.

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

A large portion of smaller fishing vessels and pleasure crafts do not carry AIS transceiver. These vessels will therefore be omitted from the risk quantification. However, an increasingly share of the larger pleasure crafts carry the low-cost alternative of AIS transceiver type B. This type does not transmit as often as the class A type (for commercial ships) and the coverage is also reduced. Due to that so many pleasure craft owners are now using type B makes this a valuable dataset for risk assessments, enabling to make representable traffic patterns and routes for recreational activities.

New routing measures in Kattegat from July 1st,2020, (further described in chapter 3.1.4) makes it not feasible to utilize AIS data for the entire year of 2020 for the risk modelling. Therefore, AIS data for the period July 1st to December 31st was used in the analysis. The extracted traffic was multiplied with a factor of 2 to estimate traffic throughout the entire year.

2.2.3 VMS data

Vessel Monitoring Systems (VMS) automatically collect positional data from fishing vessels above 12 meters long. It is a satellite-based monitoring system which at regular intervals provides data to the fisheries authorities on the location, course and speed of vessels. VMS is nowadays a standard tool of fisheries monitoring and control. VMS data for the analysis area has been collected from the period 2010-2020.

The VMS data is not added to the AIS data, because ships movements can both be registered in the AIS and the VMS data, potentially doubling the dataset. Mapping and filtering unique ship movements would be a lengthy process and may not give so much added value compared to its additional cost. Therefore, the VMS data is utilised as an additional source of information for fishery activities.

2.2.4 Ship data and ship classification

Ship movement data from AIS is combined with ship particulars data from DNV ‘s ship database. For some ships there will still be a lack of information after this automatic process, for instance lack of; IMO number, vessel type, length, width or depth. Review of the data has shown that vessels with unknown vessel type are predominantly pleasure crafts. That is why unknows are generally placed in the pleasure craft vessel category.

Where data is still missing, new data has been entered manually based available information on online ship traffic directories. In the dataset with ship information for this study area there are 6,040 ships with registered trips. The proportion of vessels with a lack of information was small, only 0.4% missing. It is therefore considered a reasonable assumption that missing information in the dataset for ship information has an insignificant effect on the accident frequency.

Classification of ships into main ship types are shown in Table 2-2. Classification of ships into size categories are shown in Table 2-3.

Table 2-2 Classification of ship types.

Main ship type	Sub ship types – Lloyds Type 5
Oil tankers	Bunkering Tanker, Crude Oil Tanker, Shuttle Tanker, Tanker (unspecified), Crude/Oil Products Tanker, Products Tanker, Oil Tanker, Inland Waterways, Coal/Oil Mixture Tanker, Asphalt/Bitumen Tanker
Product/chemical tankers	Beer Tanker, Molten Sulphur Tanker, Molasses Tanker, Chemical Tanker, Inland Waterways, Alcohol Tanker, Edible Oil Tanker, Inland Waterways, Chemical Tanker, Glue Tanker, Caprolactam Tanker, Edible Oil Tanker, Latex Tanker, Chemical/Products Tanker, Vegetable Oil Tanker, Wine Tanker, Vegetable Oil Tanker, Inland Waterways, Chemical/Products Tanker, Inland Waterways
Gas tankers	CO2 Tanker, Combination Gas Tanker (LNG/LPG), LPG Tanker, LNG Tanker, LPG/Chemical Tanker
Bulk carriers	Ore Carrier, Ore/Oil Carrier, Cement Carrier, Bulk Carrier, Bulk Carrier, Self-discharging, Laker, Bulk Carrier, Self-discharging, Bulk Dry Storage Ship, Wood Chips Carrier, Aggregates Carrier, Bulk Cement Carrier, Inland Waterways, Powder Carrier, Bulk Cement Storage Ship, Refined Sugar Carrier, Bulk Carrier, Laker Only, Urea Carrier, Bulk/Oil Carrier (OBO), Bulk Carrier (with Vehicle Decks), Limestone Carrier
General cargo/roro ships	Pulp Carrier, Refrigerated Cargo Ship, Nuclear Fuel Carrier (with Ro-Ro facility), Heavy Load Carrier, Barge Carrier, General Cargo Ship, Self-discharging, Yacht Carrier, General Cargo Ship (with Ro-Ro facility), Livestock Carrier, General Cargo/Tanker, General Cargo/Passenger Ship, Inland Waterways, Landing Craft, General Cargo, Inland Waterways, Ro-Ro Cargo Ship, Inland Waterways, General Cargo/Tanker (Container/oil/bulk - COB ship), Palletized Cargo Ship, Ro-Ro Cargo Ship, Deck Cargo Ship, Heavy Load Carrier, General Cargo Ship, Rail Vehicles Carrier, Vehicles Carrier, Open Hatch Cargo Ship, Nuclear Fuel Carrier, Container/Ro-Ro Cargo Ship
Container ships	Container Ship (Fully Cellular), Inland Waterways, Passenger/Container Ship, Container Ship (Fully Cellular with Ro-Ro Facility), Container Ship (Fully Cellular)
Passenger ships	Passenger Ship, Passenger Ship, Inland Waterways, Passenger/Landing Craft, General Cargo/Passenger Ship
Passenger/Roro	Passenger/Ro-Ro Ship (Vehicles), Passenger/Ro-Ro Ship (Vehicles), Inland Waterways, Passenger/Ro-Ro Ship (Vehicles/Train), Inland Waterways, Passenger/Ro-Ro Ship (Vehicles/Rail)
Cruise ships	Cruise ship and expedition ships
Offshore supply ships	Platform Supply Ship, Crew/Supply Vessel, Anchor Handling Tug Supply, Offshore Tug/Supply Ship
Other offshore ships/units	Supply Platform, jack up, Maintenance Platform, Gas Processing Vessel, Drilling Rig, Cable Layer, Diving Support Platform, Pipe Burying Vessel, Pipe Layer Crane Vessel, Offshore Construction Vessel, jack up, Pipe Layer, Pipe layer Platform, semi-submersible, Offshore Support Vessel, FSO, Oil, Crane Platform, jack up, Support

Main ship type	Sub ship types – Lloyds Type 5
	Platform, jack up, Standby Safety Vessel, Accommodation Platform, jack up, Diving Support Vessel, Drilling Ship, Pipe Carrier, Drilling Rig, jack up, FPSO, Oil, Pumping Platform, Well Stimulation Vessel, Production Testing Vessel, Trenching Support Vessel
Live fish carriers	Live Fish Carrier (Well Boat), Fish Carrier
Tugs	Articulated Pusher Tug, Tug, Pusher Tug
Fishing vessels	Seal Catcher, Factory Stern Trawler, Trawler, Fishing Vessel, Whale Catcher, Stern Trawler
Pleasure Crafts	Sailing Vessel, Houseboat, Yacht (Sailing), Yacht
Other service vessels	Training Ship, Bucket Ladder Dredger, Effluent carrier, Water Tanker, Hospital Vessel, Icebreaker/Research, Fish Farm Support Vessel, Fishery Support Vessel, Crane Vessel, Mining Vessel, Accommodation Ship, Incinerator, Buoy & Lighthouse Tender, Salvage Vessel, Naval Auxiliary, Fishery Patrol Vessel, Pearl Shells Carrier, Salvage Ship, Grab Hopper Dredger, Log Tipping Ship, Cutter Suction Dredger, Hopper/Dredger (unspecified), Suction Dredger, Fishery Research Vessel, Kelp Dredger, Pile Driving Vessel, Dredger (unspecified), Water Tanker, Inland Waterways, Tank Cleaning Vessel, Research Survey Vessel, Mooring Vessel, Search & Rescue Vessel, Work/Repair Vessel, Bucket Hopper Dredger, Fire Fighting Vessel, Trans Shipment Vessel, Suction Hopper Dredger, Fish Factory Ship, Icebreaker, Diving Vessel, Naval Auxiliary, Crew Boat, Research Vessel, Naval Auxiliary, Supply Tender, Utility Vessel, Naval Small Craft, Lighthouse Tender, Grab Dredger, Hopper, Motor, Crew Boat, Naval Auxiliary, Buoy Tender, Pollution Control Vessel, Patrol Vessel, Waste Disposal Vessel, Pilot Vessel, Stone Carrier
Other	Exhibition Vessel, Theatre Vessel, Sail Training Ship, Mission Ship
Unknown	Vessel (function unknown), Unknowns

Table 2-3 Classification of ship size.

Length category
0-30
30-70
70-100
100-150
150-200
200-250
250-300
300-350
>350

2.2.5 Bathymetry data

Bathymetry data (depth data) is important for the calculations of grounding risk. These data are produced based on available nautical charts. All grounds and shallow waters below 10 meter in vicinity of the proposed offshore wind farm is included in the dataset. These data are imported into the IWRAP model as polygons representing the depth contours.

2.2.6 Risk scenarios

Installation of an offshore wind farm will introduce obstacles that the ship traffic has to avoid. If not successful in doing this a collision with a wind turbine will be the result. However, the deviations required of the ship traffic to avoid the wind turbines may also increase the potential for ship-ship collisions and/or grounding. The navigational risk analysis therefore covers the following risk contributions:

- Ship-turbine collision risk for powered vessels (i.e., typically human error).
- Ship-turbine collision risk for drifting vessels (e.g., vessel with technical error).
- Changes in ship-ship collision risk due to increased traffic density around the offshore wind farm.
- Changes in ship grounding risk due to changes in ship routes due to the offshore wind farm.
- Impact on export cable from anchoring and fishing.

2.3 Risk evaluation

The ship traffic before and after the construction of the wind farm is modelled in order to compare the impact of the offshore wind farm on the navigational risk. Ship-ship collision and grounding of ships will thus be modelled in cases predicting before (i.e. existing conditions) and after construction of the wind farm.

Table 2-4 Calculated scenarios

Scenario	Existing routes	Relocated routes	Turbines included
1 – Before	X		
2 – After	X	X	X

All risk results are presented in terms of annual accident frequency, which is the expected number of accidents per year. For some of the key figures, the return period is also given. The higher the return period, the less frequently an event is estimated to occur. A higher average return period indicates an expectation that a longer period of time will pass between events.

There are no governing quantitative risk acceptance requirements for the establishment of offshore wind farms. In Denmark the approval of the navigational risk level is done on a case-by-case process by the Danish Maritime Authority (DMA). Risk evaluation towards any defined acceptable limits can therefore not be made, but the report presents the accident frequencies, discuss the results, explain any potential changes in risk and propose risk reducing measures

In addition, an evaluation of the wind farm location in relation to DMA’s guiding calculation principles for area requirements for transit routes and major traffic flows has been made. Based on the accident frequencies and the area calculations, DMA will assess whether the navigational risk associated with wind farm is acceptable.

3 ANALYSIS BASIS

This chapter describes the basis for the navigational risk assessment.

3.1 Hesselø OWF

3.1.1 Location

Hesselø OWF will be located in Kattegat, north of Hesselø. The outline of the OWF and the proposed export cable corridor is shown in Figure 3-1. The potential area for offshore wind turbines is approximately 247 km^2. The closest distance between the OWF area and the island Anholt is approximately 20 km.

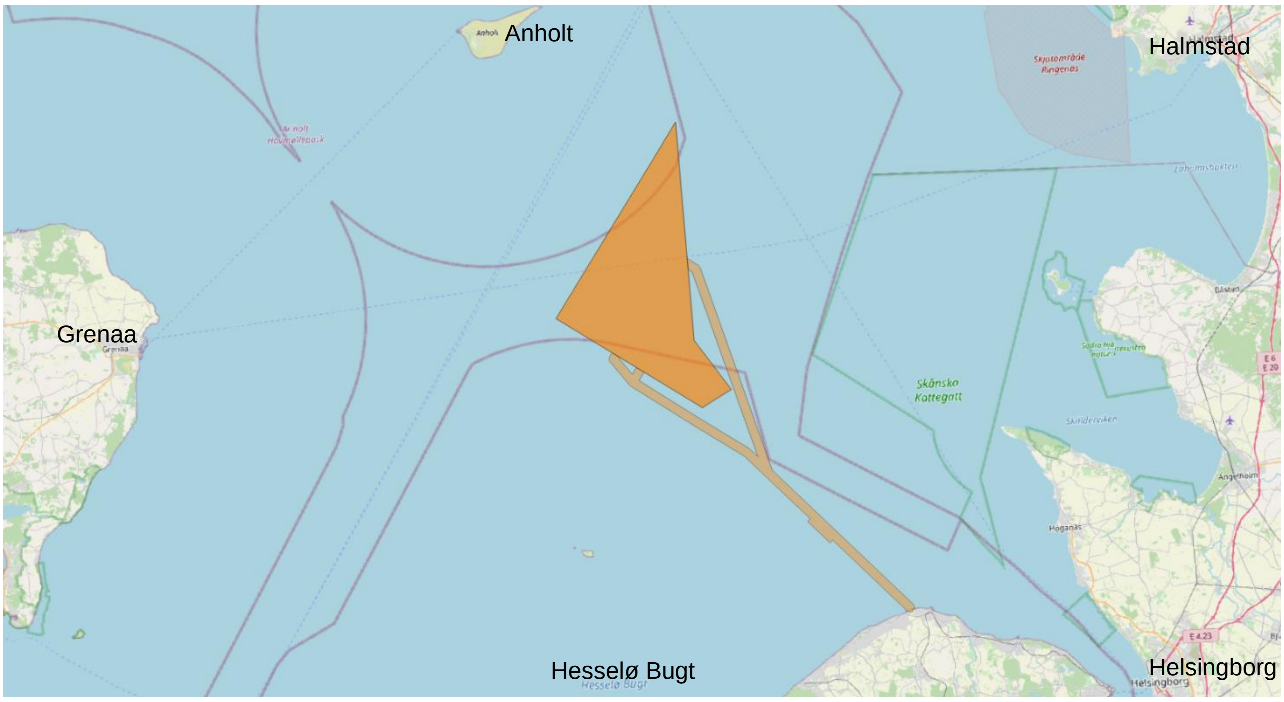


Figure 3-1 Proposed layout and location of Hesselø OWF, showing the turbine park (dark orange) and cable corridor (light orange).

The export cable corridor from Hesselø OWF makes landfall at Gilbjerg Hoved on the north coast of Zeland, and the offshore part of the corridor covers an area of approximately 70 km^2. This corridor area is shown in light orange in the figure.

3.1.2 Technical specification and layout

It is specified that Hesselø OWF will have a capacity of 800-1,200 MW, and different turbine sizes are considered for the project. Three potential turbine sizes are 8 MW (100-150 turbines), 15 MW (54-80 turbines) and 20 MW (40-60 turbines).

Figure 3-2 illustrates the potential number of turbines within the OWF area with two different turbine sizes: 8 MW and 15 MW. Both configurations accumulate to a capacity of 1,200MW. The left figure consists of 150 turbines of 8 MW, and the figure to the right consists of 80 turbines of 15 MW, which are the maximum number of turbines considered for each configuration. Figure 3-2 shows proposed potential turbine layout within the OWF area for 60 turbines of 20 MW.

DNV

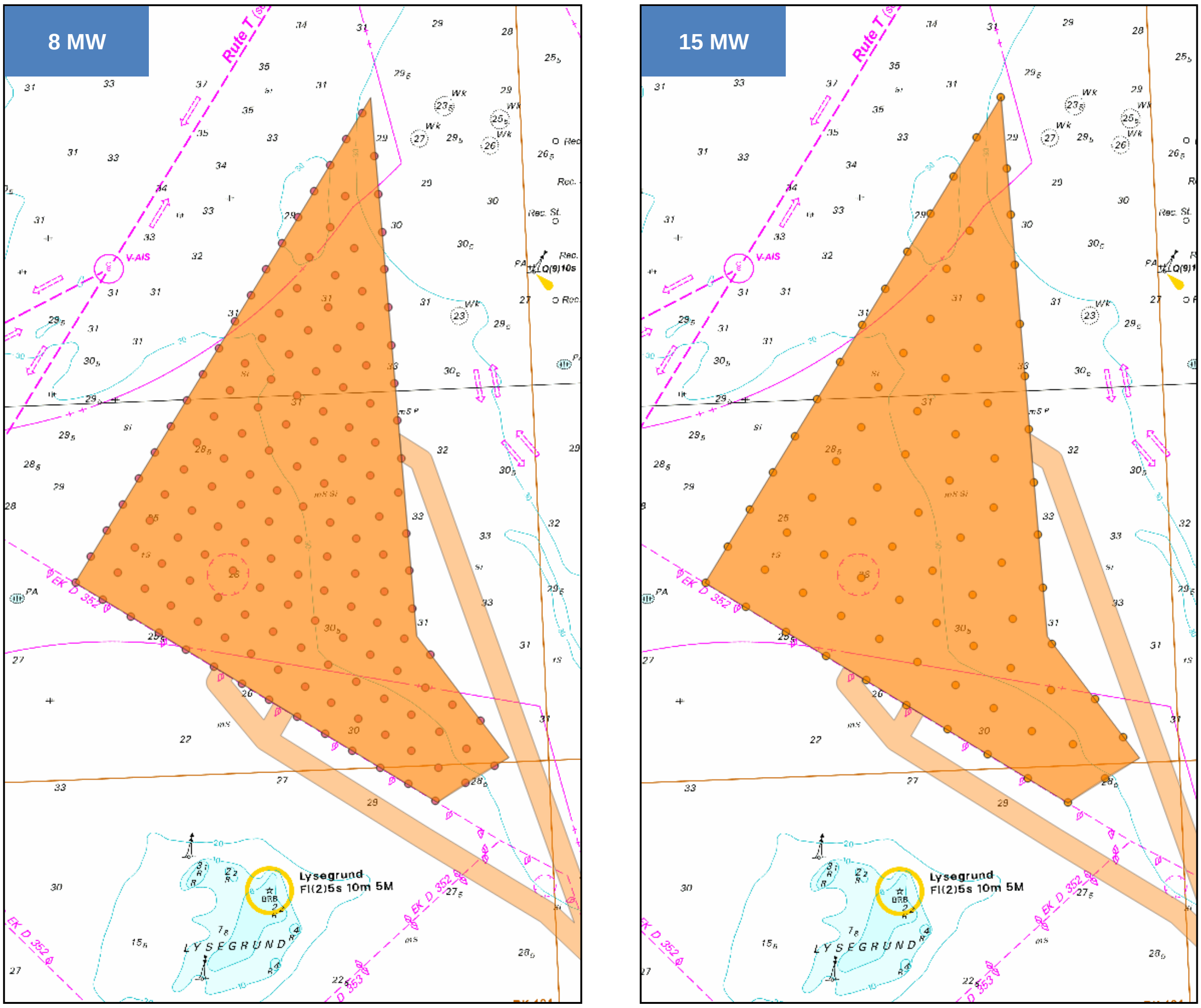


Figure 3-2 Potential turbine layouts for Hesselø OWF for total capacity of 1,200 MW. Left: layout for 8 MW turbines. Right: layout for 15 MW turbines.

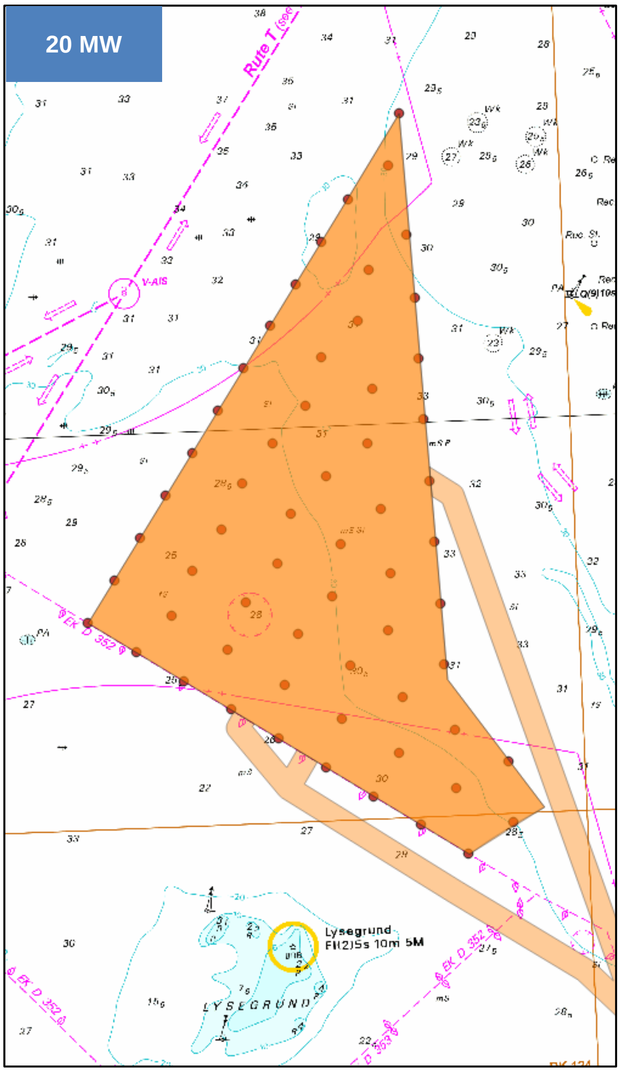


Figure 3-3 Potential turbine layout for Hesselø OWF for total capacity of 1,200 MW with 20 MW turbines.

It is expected that an offshore substation will be installed within the Hesselø OWF area. It will be located in-between the turbines, and exact location will be decided when the winning concessionaire has fine-tuned the layout with the chosen turbine size.

3.1.3 Metocean characteristics

Table 3-1 shows the Metocean characteristics for Hesselø OWF. The table also briefly explains how this is incorporated in the risk model using IWRAP.

Table 3-1 Metocean characteristics for waters around Hesselø OWF.

Data	Characteristics	Modelling in IWRAP
Prevailing wind direction	Prevalent wind direction from west-southwest. See wind rose in appendix A.	The prevalent wind direction has been applied in IWRAP and will affect the drift direction (drift grounding and ship-turbine drift collisions).

Data	Characteristics	Modelling in IWRAP
Ice	The Kattegat and the passages leading south to the Baltic Sea lie close to the boundary between the mild winters of the Northwest Atlantic and the cold winters of North Europe [4]. During some winters, mild west weather prevails, and the entire area remains ice free [4]. During other winters, cold eastern weather dominates the area, and ice sufficiently thick to restrict navigation for several weeks, is formed [4]. When the formation of ice, in combination with drift ice from the Baltic Sea, fills the greater part of the Kattegat, navigation is possible using assistance of an icebreaker [4].	IWRAP does not have capability to model navigation in ice or effect of ice on drifting ship. Hence, ice is not modelled in IWRAP.
Visibility (fog, precipitation)	During the HAZID, poor visibility was not identified as a particular hazard for this area. Similar to other areas in Kattegat.	Errors due to human factors (and/or combined with external factors) are part of the default IALA causation factors in IWRAP, see appendix A.
Current	The direction of the currents is north and southbound. The speed of the current should not pose any additional risks compared to other similar areas.	Current is not modelled in IWRAP.
Waves	Waves in this area are judged to not cause any disturbance to the commercial traffic. Smaller vessel will be more affected by waves, as in any other locations.	Waves are not modelled in IWRAP.

3.1.4 Waterway characteristics

As of July 1st, 2020, new routing measures were implemented in Kattegat. These new routes are illustrated in Figure 3-4, and the changes from previous routing are presented in Figure 3-5.

At route T, two deep water routes – “Kattegat North” and “Kattegat South” – are established. These routes are recommended for all ship traffic between Skagen and the Great Belt, and for ships with a draught of 10 meters or more. The minimum water depth along the route T is 19 meters. Beginning at TSS Skagen East, Route T leads in a south-east direction to the Precautionary Area located just east of Kummel Bank [4]. Route T continues, through and past the Precautionary Area. Along this stretch of the route lies the Kattegat North Deep-Water Route. Continuing south-southeast, Route T passes east of Anholt Island, after which it changes direction and runs in a southwest direction. Route T passes the east end of Route D just to the south of Anholt Island [4]. Along this stretch of the route lies the Kattegat South Deep-Water Route, passing the planned Hesselø OWF on port side.

Route S, the route between Skagen and the entrance to the Sound, is recommended for ships with a draught of 10 meters or less. The route leads between the west coast of Sweden and Zealand and forms the shortest route to the Baltic Sea.

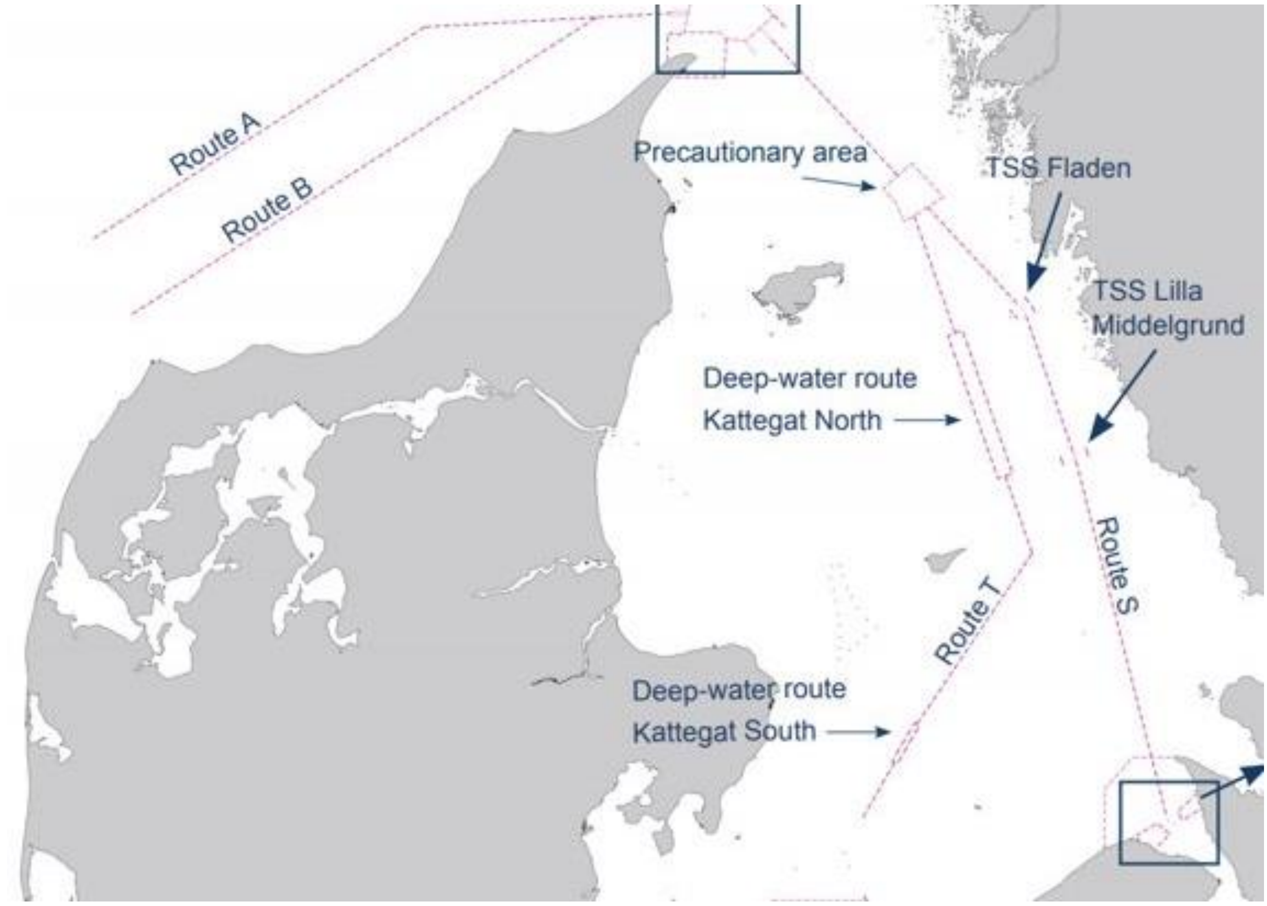


Figure 3-4 Routing measures per July 1st, 2020.

Route D is located south of Anholt Island and connects Route T to Route C at No. 4 Lighted Buoy [4]. Note that this is a new route, as the old route D, as seen in Figure 4-3, was located between the newly established Route S and Route T.

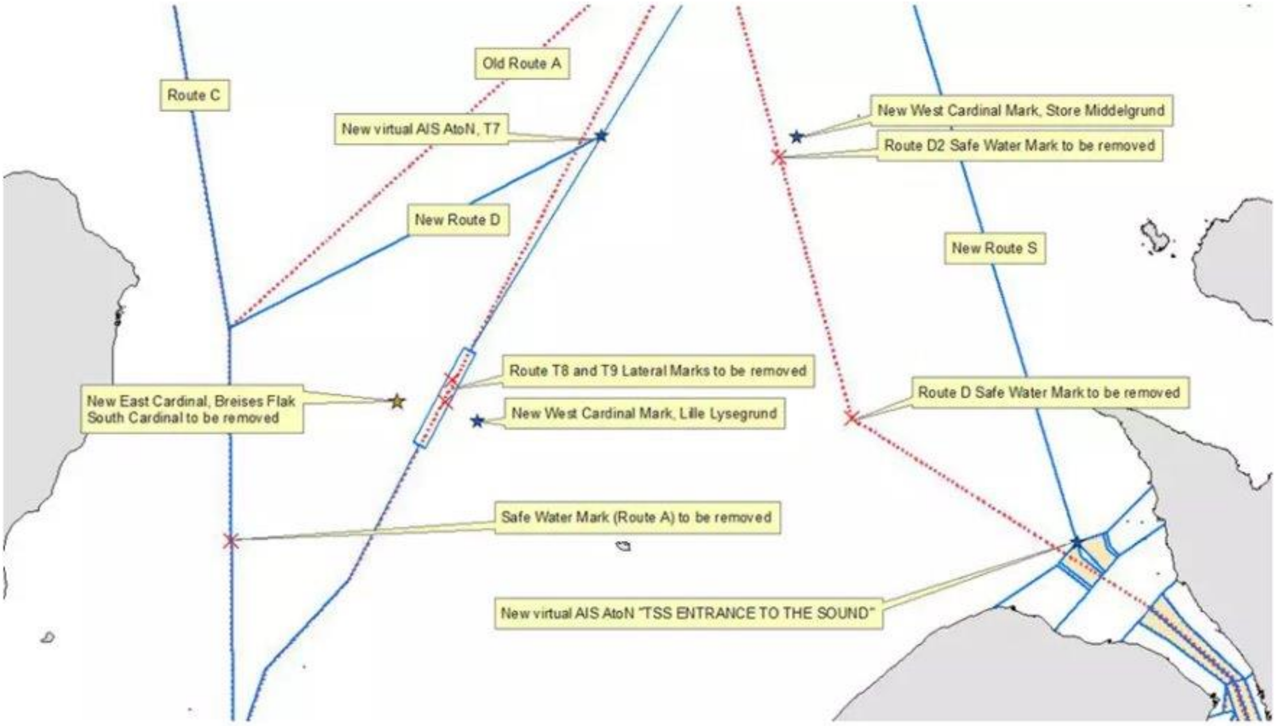


Figure 3-5 Changes to routing measures in Kattegat around Hesselø from July 1st 2020.

Route C is relatively far away from the Hesselø OWF. From the precautionary area at Skagen, Route C leads south and intersects Route D at No. 4 Lighted Buoy [4]. From the lighted Buoy, Route C leads south to No. 13 Lighted Buoy, where it joins Route T [4].

The water depth in the Hesselø OWF area is between 20 and 30 meters. The island Anholt is located northwest of the OWF, with shallow waters (10 meters and less) to the east, southwest, west, and northwest. A shallow area east of the OWF area is Store Middelgrund. There are also some shallow areas south and southwest of Hesselø OWF: Lysegrund, Lille Lysegrund and Briseis Flak. South of Lysegrund lies Hesselø (small island).

The nautical chart with the recommended routes and shallow waters in proximity to the OWF is presented in Figure 3-6.

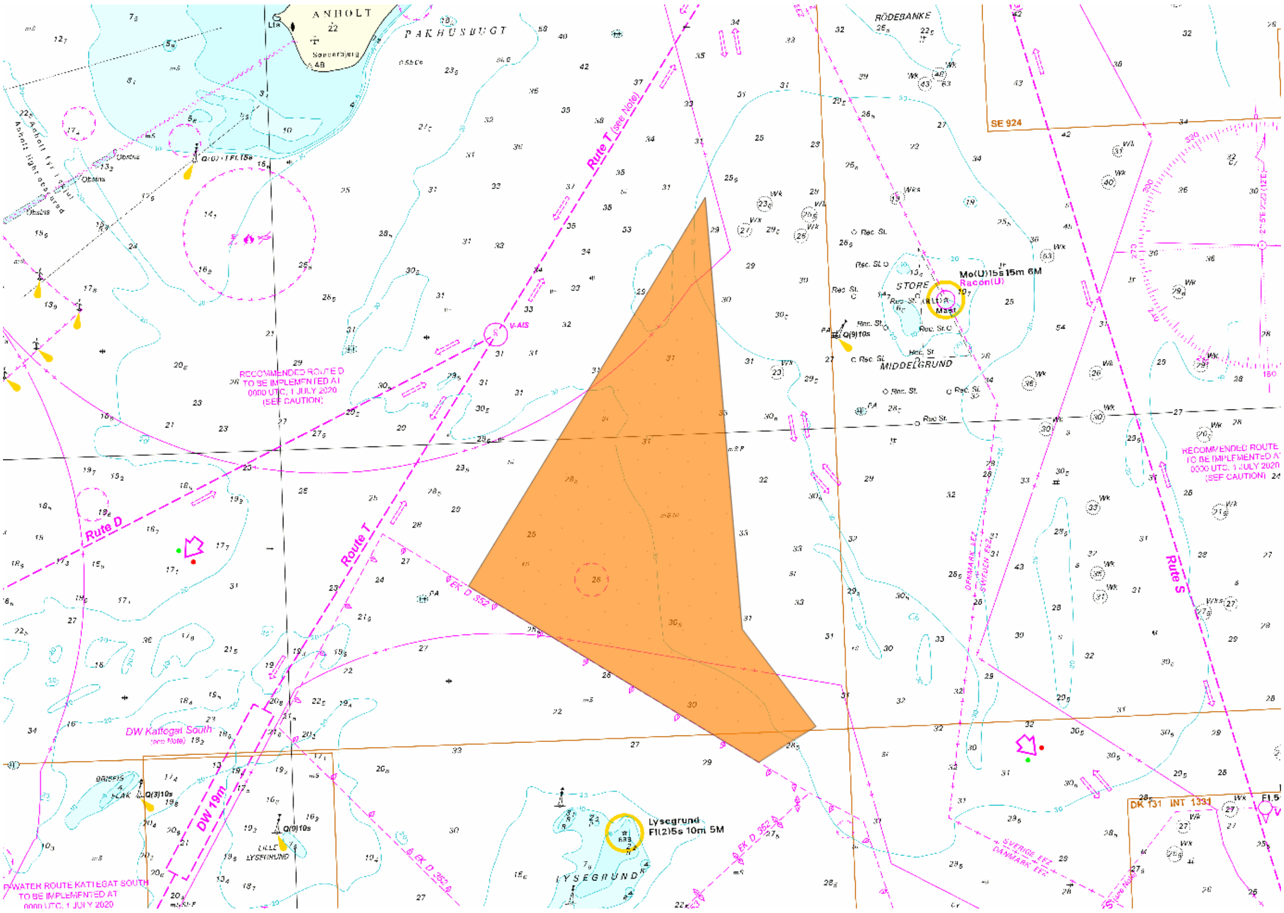


Figure 3-6 Nautical chart, with recommended routes, and layout of Hesselø OWF.

As seen in Figure 3-6, there are no nautical marks or lights directly located within the OWF area. However, further considerations and investigations should and will be carried out in order to determine whether the establishment of the OWF will affect the line of sight of nautical marks, and thus whether relocation of markings will be necessary.

South of Hesselø OWF there is also a military and live firing area (EK D 352 Lysegrund N and EK D 353 Lysegrund S). In the case of live firing events in these areas, a temporary caution area is established. The areas are however not closed off to ship traffic, but seafarers are encouraged to show careful consideration and caution while navigating in or close to the live firing area.[1]

There are no emergency tugs in the area close to Hesselø, and the nearest tugs for emergency assistance are located in the ports of Malmö and Copenhagen. However, commercial tug services are available in the area.

A summary of the waterway characteristics is shown in Table 3-2, including a description of the modelling in IWRAP.

[1] Skydeområder på søterritoriet (soefartsstyrelsen.dk)

Table 3-2 Waterway characteristics for Hesselø OWF.

Site characteristic	Summary	Modelling in IWRAP
Water depth	The water depth in the area of the planned establishment is 20-30 m.	Bathymetry data based on updated nautical charts has been applied in IWRAP, this will affect powered and drift groundings.
Nautical charts	Nautical chart for area around Hesselø.	Nautical charts, in combination with ship traffic data, has been used to define the routes in the study area.
Vessel Traffic Service (VTS)	There is no VTS in the near vicinity of the study area.	Not applicable.
(Emergency) tugs	There are no tugs with home harbour in any ports close to Hesselø OWF, and the tug capacity available in the area is commercial. Emergency tugs are located in Malmö and Copenhagen.	Not included in the model due to the relatively long distance to the emergency tugs, as well as not knowing whether the commercial service will be available at all times. Not including tugs in the model will result in a somewhat more conservative risk assessment.
Traffic Separation Scheme (TSS)	There are no defined TSS in near vicinity of the planned wind farm. However, there are deep-water routes with separation of traffic on each side of marked light boys.	All major traffic flows are modelled in IWRAP, including effects of routing measures.
Pilotage and Pilot exemption Certificate (PEC)	Mandatory pilotage (deep-water and harbour pilotage) according to Danish law.	Pilotage plays an important role to ensure the safety of navigation. DNV recognises that there are estimated up to 50% effect on reduction in accidents. The effect of pilotage is indirectly included in the way that ships navigate in the area, as the AIS tracks includes tracks where pilots have been onboard.

3.1.5 Ship traffic

The Danish Straits are made up from three channels: the Øresund channel (the Sound), the Great Belt and the Little Belt. The straits and mentioned channels interlink the North Sea and the Baltic Sea and are some of the world's main trafficked channels. The north- and southbound routes around Hesselø OWF are consequently heavily trafficked. Figure 3-7 shows the ship traffic density plot in the Hesselø OWF area, based on AIS data from July 1st to December 31st, 2020.

The three blue lines in the figure was used to count passing ships for the three main routes in total, in both north- and southbound direction. The "left" passage line counts the traffic to/from the Great Belt and the Little Belt, while the "middle" and "right" passage line counts traffic to/from the Sound. Figure 3-8 and Figure 3-9 graphically presents the number of passing ships from July 1st to December 31st, 2020, in north and south direction, respectively, distributed by ship type and ship length. Approximately 8,660 northbound ships and 8,750 southbound ships passed through these routes in the period, resulting in 17,410 ships passing in total. This indicates that through the entire year (doubling the 6-month number), a total of 34,820 ships have passed through these routes close to Hesselø OWF. Cargo/roro-ships accounts for almost 50% of the total ship traffic, followed by chemical/product tankers (18%) and bulk carriers (10%). Ships in all length-categories are registered, however the vast majority of the ships are between 70 and 250 meters long.

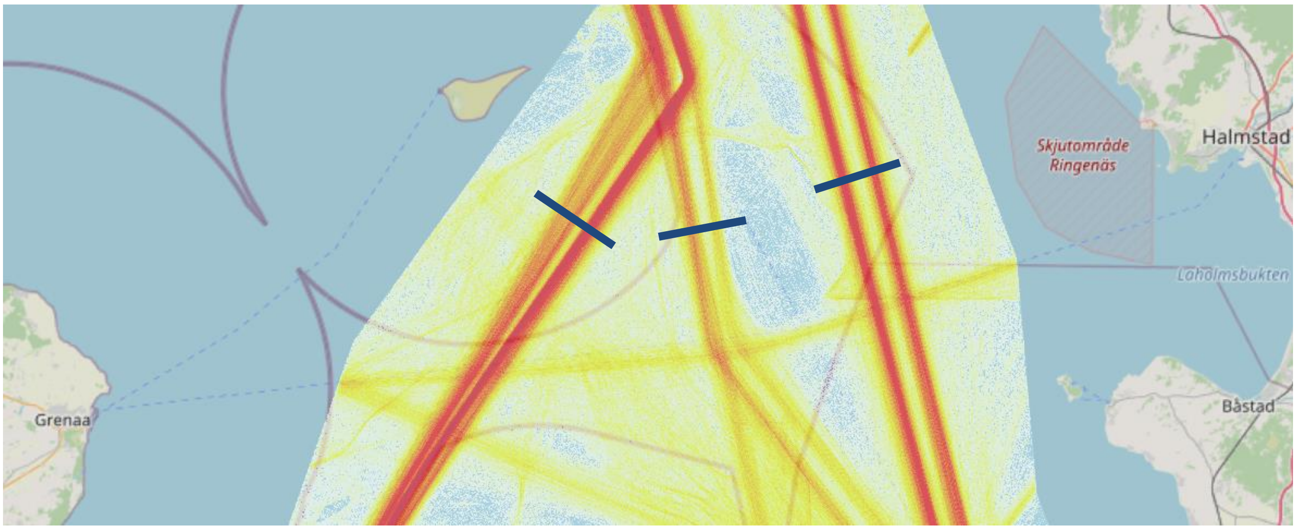


Figure 3-7 Ship traffic density plot based on AIS data from July 1st to December 31st, 2020.

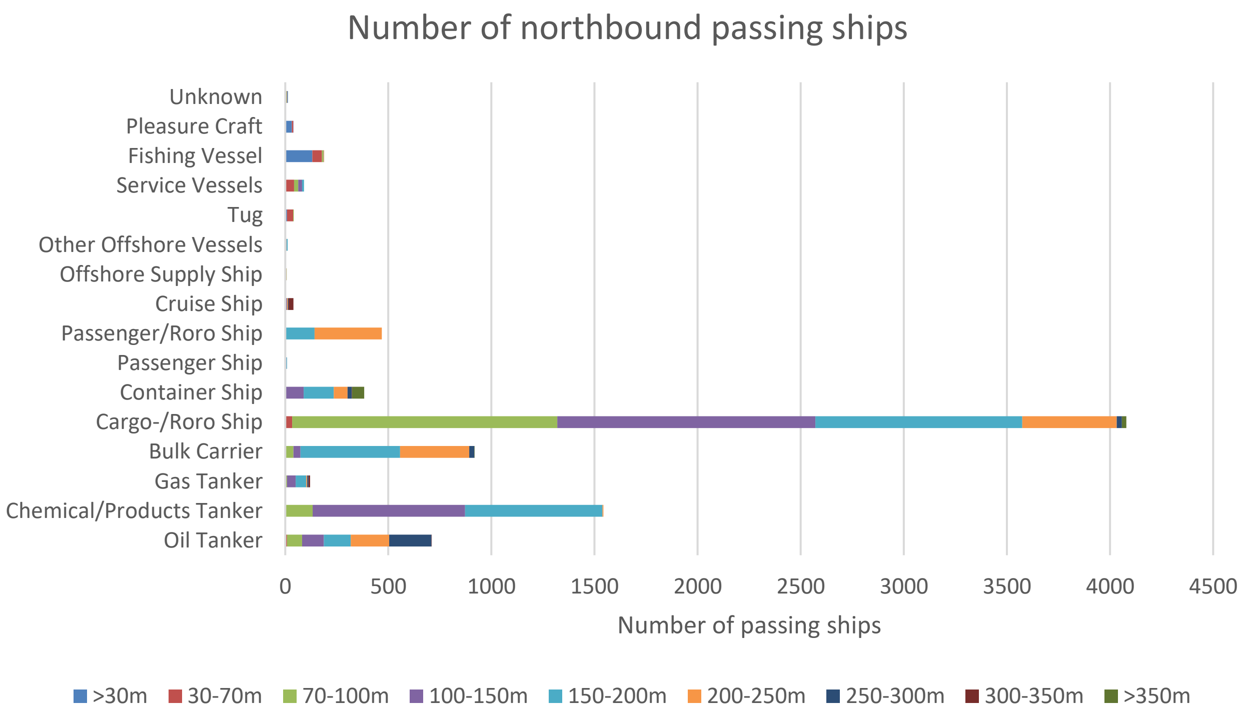


Figure 3-8 Number of northbound passing ships in the three main routes per ship type, categorised by ship length, in the period July 1st to December 31st, 2020.

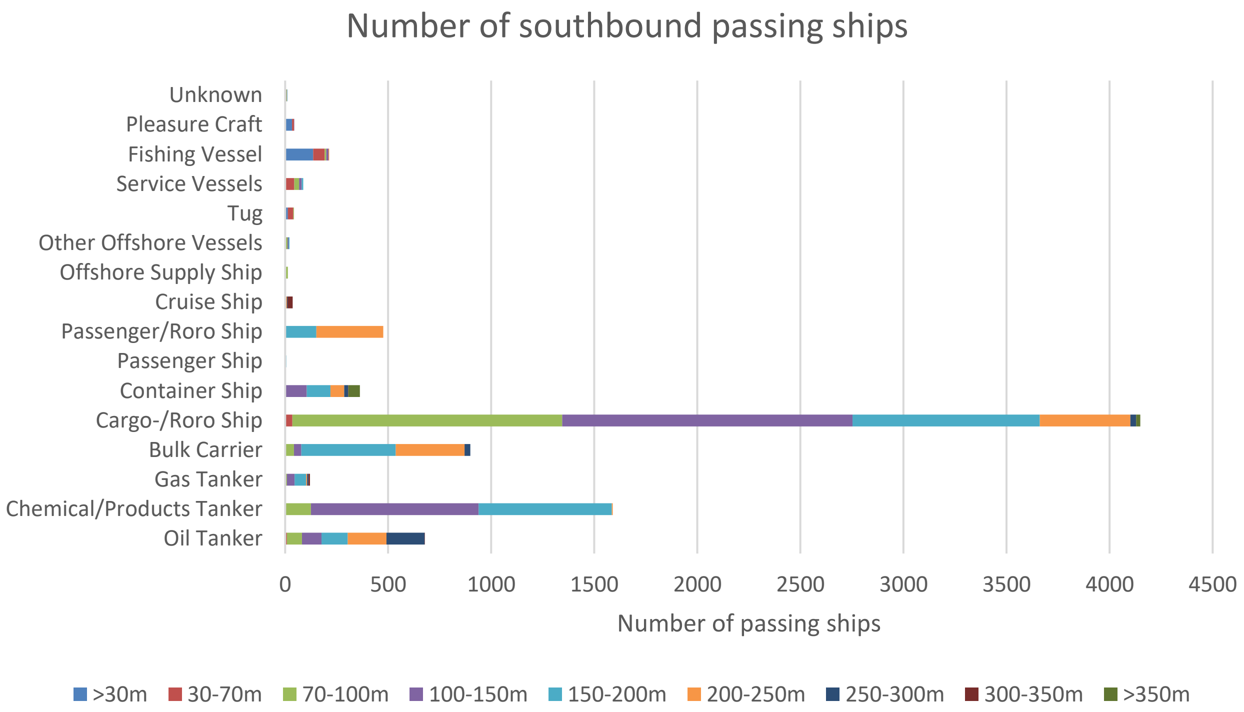


Figure 3-9 Number of southbound passing ships in the three main routes per ship type, categorised by ship length, in the period July 1st to December 31st, 2020.

A more detailed presentation of the ship traffic and composition along each route in proximity of Hesselø OWF, also including less trafficked routes, is provided in chapter 4.1. It should also be noted that Stena Line is optimistic regarding the route between Halmstad and Grenaa and has communicated that this route may be serviced by two ships in the future. Due to the uncertainties regarding if and when this will take place, no sensitivity study related to potential additional Stena-vessel has been included in this assessment.

In addition to the commercial ship traffic, there are significant fishing activities and some pleasure craft sailings in the area. Separate traffic density plots for each ship type, such as pleasure crafts and fishing vessels, are included in Appendix B. It is important to note that pleasure crafts are not required to carry AIS-transponders, and the density plot enclosed in the appendix includes only pleasure crafts that have such a transponder installed onboard. The ratio of yachts and sailing vessels that carry AIS-transponders versus those who do not, is however not known.

As mentioned above, there is a lot of fishing activities in Kattegat, also at the location of the planned OWF. Many of these fishing vessels are not required to carry AIS transponders. However, vessel monitoring systems (VMS) automatically collect positional data from fishing vessels above 12 meters long. Fishing activities and potential implications from the establishment of the OWF are discussed in chapter 4.5.7.

Lastly, the covid-19 pandemic has impacted the maritime industry. It is well known that the cruise and tourism industry was significantly affected, with worldwide cruises completely stopped in parts of 2020. Shipping was however affected to a lesser extent. As part of this project, DNV received a comparison of both port calls and number of passing ships in Øresund, Skagen and the Great Belt for the complete year of 2019 and 2020 from the DMA. These numbers indicate the amount of port calls for January to July 2020 was lower than in 2019, but the port calls for the last six months of 2020 was actually higher compared to 2019. Further, the number of transit ships for Skagen and Øresund were observed as very stable. As the basis for this assessment is AIS data from July 1st to December 31st, 2020, it is not considered to be any need for adjusting the commercial shipping traffic.

Based on the above paragraph, the ship traffic volumes will be adjusted for cruise and passenger ships. The method for adjusting these numbers is described in chapter 4.1.1.

3.1.6 Accidents

According to the HELCOM[2] database there has not been any accidents *within* the area of the planned Hesselø OWF during the period 1989 to 2017 [6]. However, there have been registered a contact accident and a collision very close to the area as shown in Figure 3-10. Further, several groundings have occurred close to Grenaa and Anholt, as well as ship collisions both in the vicinity of Anholt, Halmstad and the entrance to the Sound. All accidents registered in the HELCOM database in the area of interest are visualized in Figure 3-10. The symbols in the visualization represents different accident types as shown in the legend in the figure.

Figure 3-10 Visualisation of registered accidents in HELCOMs database (1989-2017) [6].

The dataset is constructed by the HELCOM Secretariat and has been compiled by the HELCOM Contracting Parties[3]. The actual location of the accidents, as presented in the map, may therefore deviate from the “real” location. However, it is reasonable to assume that the real locations are not far off from the locations reported by HELCOM. Accident statistics has been used to roughly compare the calculated frequencies in IWRAP towards the historical accidents in the area.

[2] The Baltic Marine Environment Protection Commission – also known as the Helsinki Commission (HELCOM).

[3] According to the decision of the HELCOM SEA 2/2001 shipping accident data compilation will include only so called conventional ships according to the Regulation 5, Annex I of MARPOL 73/78 - any oil tanker of 150 GT and above and any other ships of 400 GT and above which are engaged in voyages to ports or offshore terminals under the jurisdiction of other Parties to the Convention.

3.2 Analysis and assumptions

3.2.1 Design and layout

The turbines in Hesselø OWF is expected to have an individual capacity of 8 to 20MW, depending on the type. The foundation design can be based on monopile, jacket or other bottom-fixed foundation types. Monopile foundation is currently planned for the turbines, with an example shown in Figure 3-11.

Since the final layout of the turbines in the offshore wind farms is not known at present, the navigational risk assessment is performed such that it will represent a conservative assumption for all possible turbine layouts i.e. both with regards to turbine size and location of the turbines within the offshore wind farm area. The conservative approach is intentionally chosen to overestimate uncertain risks in order to be confident that we are not underestimating them.

The risk assessment is therefore based on a layout of turbines that, in the context of navigational risk, is considered as the most conservative. This layout is the configuration with the smallest sized turbines, i.e. 150 turbines with 8 MW capacity.

Figure 3-11 Photo of typical wind turbine in operation with monopile foundation

The chosen layout consists of 150 8MW turbines since this is assumed to result in the highest likelihood of ship-turbine collision. It is noted that a layout with 80 15MW turbines or 60 20MW turbines would extend over approximately the same area, however the lower number of turbines would present fewer obstacles to the ship traffic, which would lead to a reduced potential of ship-turbine collisions. The smaller turbine types are in the conservative scenario located over the entire offshore wind farm area since this represents the case where the existing ship traffic will be disturbed the most.

The diameter of the monopiles for the smaller turbines is 10 meters and is relevant for the ship-turbine collision risk. Each turbine is modelled in the risk assessment as a round structure at the water surface with this diameter. In case the foundation design would change at a later stage in the project, for instance to a four-legged jacket or a tripod, the ship-turbine collision risk could potentially be slightly impacted. Unless the diameter at or close to the water surface increases, the ship-turbine collision risk is however not expected to increase.

The wind farm will have a crew transfer vessel for maintenance of the turbines. There will be a 200 meters safety zone around the power cables on the seabed. No safety zone is defined around the wind turbines in the operational phase, however the entire or parts of the OWF area will be closed during the construction phase.

The wind turbines will be marked in accordance with industry best practice and/or statutory standards, likely to be yellow up to 15 meters above sea level. There will be at least 20 meters clearance from the tip of turbine blades to sea level based on the Highest Astronomical Tide (HAT).

3.2.2 Marking and lighting

The following assumptions are used in this risk assessment, see Figure 3-12 for example.

- For offshore wind turbines, it is assumed that these will be marked in nautical charts with an appropriate legend, such as 'turbine' and/or danger circle. This may include ID number.
- Power cables are marked (e.g., prohibited to carry out fishing activity with bottom contacting gear).
- Requirements from the DMA for Racon[4] may be expected, depending on the exact location of the wind turbines.
- The marking with light on the turbines in relation to shipping and navigation is expected to comply with the requirements by the DMA.
- Typically, all turbines placed in the corners and at sharp bends along the peripheral (significant peripheral structures = SPS) of the wind farm, will be marked with a yellow light. Additional turbines along the peripheral will be marked, so that there will be a maximum distance between SPS defined turbines on 2 nautical miles.
- The yellow light will be visible for 180 degrees along the peripheral and for 210-270 degrees for the corner turbines (typically located around 5-10 m up on the transition piece). The light will be flashing synchronously with 3 flashes per 10 second and with an effective reach of at least 5 nautical miles.
- A part of the top part of the foundation (e.g., the transition piece) will be painted yellow from sea surface to 15 m above mean sea level. Indirect light will illuminate the part of the yellow painted section with the turbine identification number.
- During construction the complete construction area will be marked with yellow lighted buoys with a reach of at least 2 nautical miles. Details on the requirements for the positions and number of buoys will be agreed with the DMA.
- In relation to shipping and navigation the marking and lighting requirements are independent of wind turbine size.

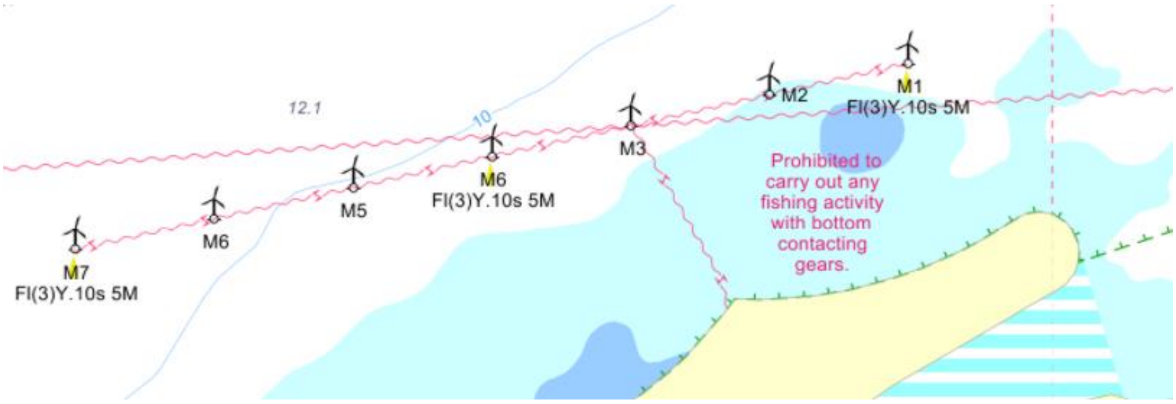


Figure 3-12 Example charting of offshore wind farm where three of the turbine have light flashing synchronously. All turbines are marked with ID, and the power cable grid is also shown in the chart.

[4] 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."

3.2.3 Crew transfer vessels trips

Hesselø OWF will be serviced and maintained throughout the life of the wind farm from a local port in the vicinity of the wind farm. However, the exact port is not yet decided and will be part of the developer's responsibility. Further assessment should therefore include the additional ship traffic in the area due to CTV transits, including specific route, operational pattern and expected number of transits to and from the OWF.

Figure 3-13 shows an example CTV.

Figure 3-13 Example CTV from the Lillgrund OWF; M/V Bringer is a 20 m multipurpose service vessel, designed for supporting offshore wind farms. The vessel has a capacity of 12 Pax + Crew.

4 RISK ASSESSMENT

4.1 Modelling of ship traffic through/around wind farm

An overall introduction to the ship traffic in the area surrounding the planned Hesselø OWF was described in chapter 3.1.5. The various ship traffic routes modelled in IWRAP are shown in Figure 4-1, for the existing situation (i.e., before establishment of the wind farm). The main routes have been identified and provided with a unique identifier (name/ID) as listed in Table 4-1, for easy reference in the assessment. A high-level description of the traffic composition within each route is included Table 4-1. Full details of the traffic composition for each route are included in Appendix D.

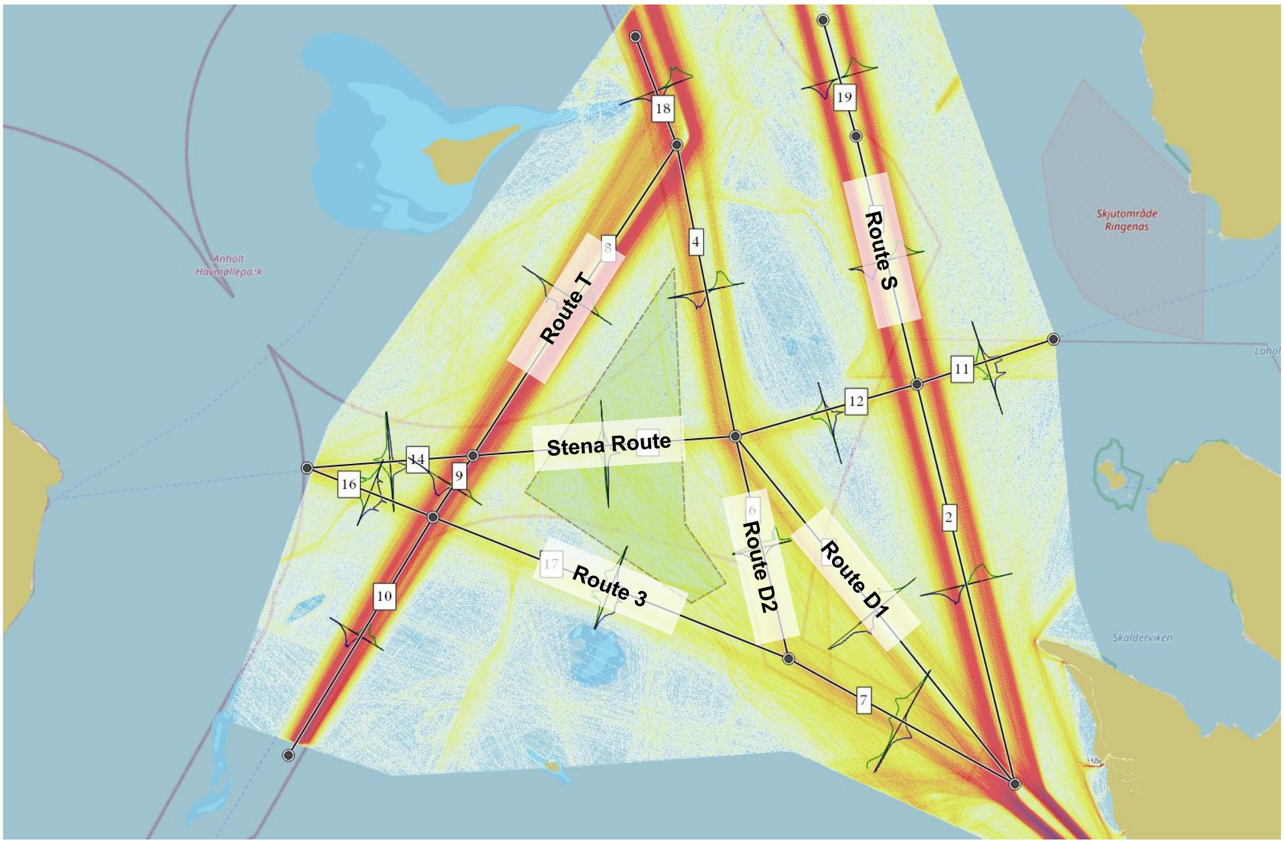


Figure 4-1 Modelling of routes for existing situation, based on AIS data from July 1st to December 31st 2020. Note that the outline of Hesselø OWF only is included for reference in this case.

Table 4-1 Routes in vicinity of Hesselø OWF and traffic composition

ID	Route name	Route description	Traffic composition (most dominating ships listed)
Route T	Deep-water recommended route	Deep-water route west of Hesselø OWF	Cargo/Roro ships (34%), Chemical/Gas Carriers (20%), Bulk Carriers (14%), Oil Tankers (12%)
Route S	Route between Skagen and the Sound	Recommended route between Store Middelgrund and the Swedish shore (Halmstad)	Cargo/Roro ships (62%), Chemical/Gas Carriers (17%)
Route 3	Route south of Hesselø	Traffic south of Hesselø OWF to/from the Sound	Cargo/Roro ships (62%), Bulker Carriers (11%)
Old Route D1	Part of old Route D	Traffic between route T and the Sound, east of Hesselø OWF	Cargo/Roro ships (44%), Chemical/Gas Tankers (15%), Bulk Carriers (9%)

ID	Route name	Route description	Traffic composition (most dominating ships listed)
Old Route D2	Part of old Route D	Traffic between route T and the Sound, east of Hesselø OWF	Cargo/Roro ships (35%), Fishing vessels (17%), Bulk Carriers (17%), Chemical/Gas Tankers (16%)
Stena Route	Halmstad-Grenaa	Main route for cargo and passenger transport by Stena Line	Passenger/Roro ships (75%), Service vessels (10%)

Note that Route 3 is not a marked route in the nautical charts, but used by some ships, mostly cargo, roro and bulk carriers.

Number of passing ships and traffic composition in terms of ship types and length categories for each route is graphically illustrated in Figure 4-2 and Figure 4-3, respectively.

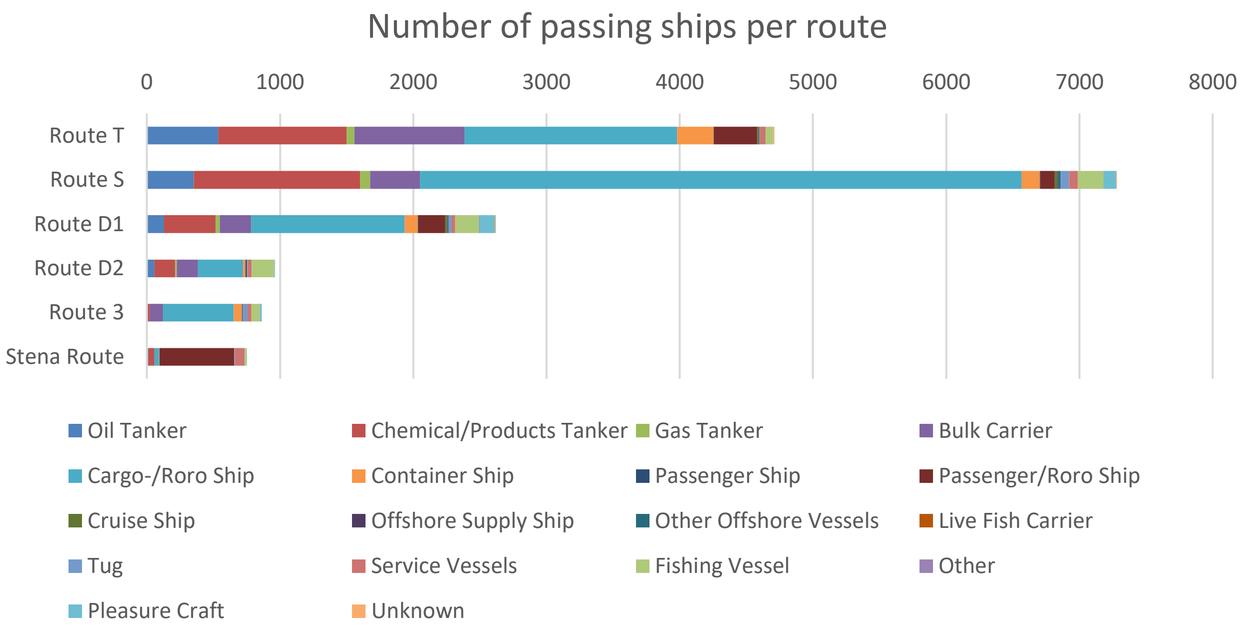


Figure 4-2 Number of passing ships per route in the period July 1st to December 31st 2020, both in north- and southbound direction, categorised by ship type.

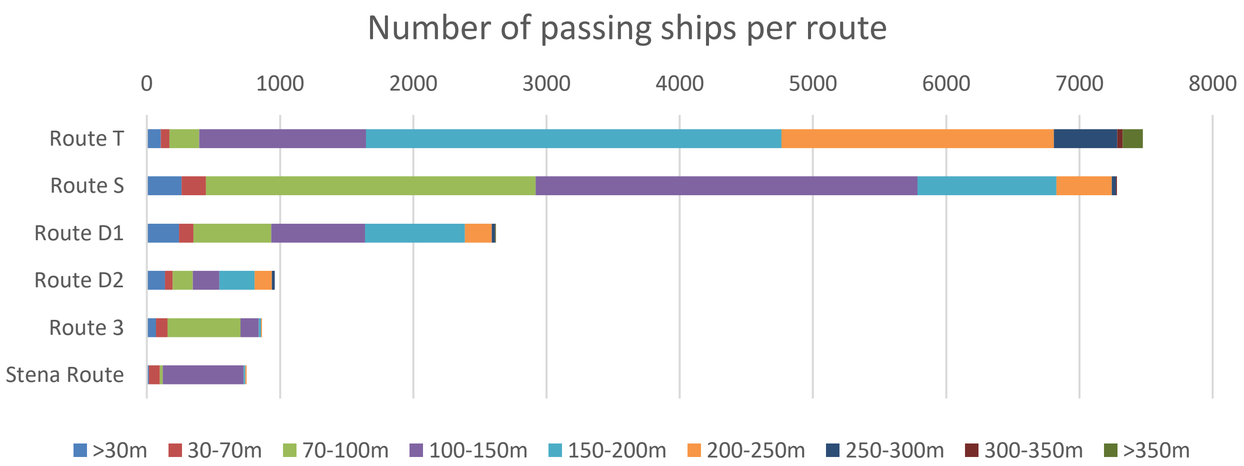


Figure 4-3 Number of passing ships per route in the period July 1st to December 31st 2020, both in north- and southbound direction, categorised by ship length.

Prior to the new routing measures and establishment of Route S from July 1st, 2020, route D was the recommended route for ships sailing to the Sound (Øresund). Now, Route S is recommended for ships with draught of 10 meters or less. However, as seen from the traffic density plot and the graphics illustrating passing ships per route, the old route D1/D2 are still used by several ships. Some of these tracks may be due to "habits", i.e., that the ships are navigating based on previous experience (prior to the new routing measures) or that the nautical charts onboard these ships have not yet been updated. The intention of the new routing system is to move all ships from Old Route D to Route S, while large oil tankers to/from the oil terminal in Malmö will still need to use this old route due to larger draughts (>10m).

To ensure a conservative risk assessment with regards to potential ship-turbine collisions, as route D1/D2 is closer to the OWF than Route S, the ship traffic along route D1/D2 is kept based on the actual AIS data from 2020. However, the development of traffic in old route D1/D2 should be monitored along the Hesselø OWF project development, as this will inform a more precise and site-specific risk assessment.

Due to the fact that AIS data for the period July 1st to December 31st, 2020, is used in the risk analysis, the traffic volume along each route (i.e., each leg in the model) has been multiplied by 2 to simulate a full year of ship traffic.

4.1.1 Adjusted passenger and cruise traffic due to covid-19

As addressed in chapter 3.1.5, it is well known that the covid-19 pandemic had a major impact on the cruise and passenger ship traffic in 2020. In order to account for the lower cruise and passenger ship activity than what was expected in the area in 2020, a comparison of AIS data between 2019 and 2020 was carried out. The same passing lines as shown in Figure 3-7 were used for the comparison. Figure 4-4 presents density plot cut-outs with passing lines for 2020 (to the left) and 2019 (to the right). AIS data from July 1st to December 31st, 2019, was used to generate the density plot for 2019 to ensure correct comparison to the 2020 AIS data set.

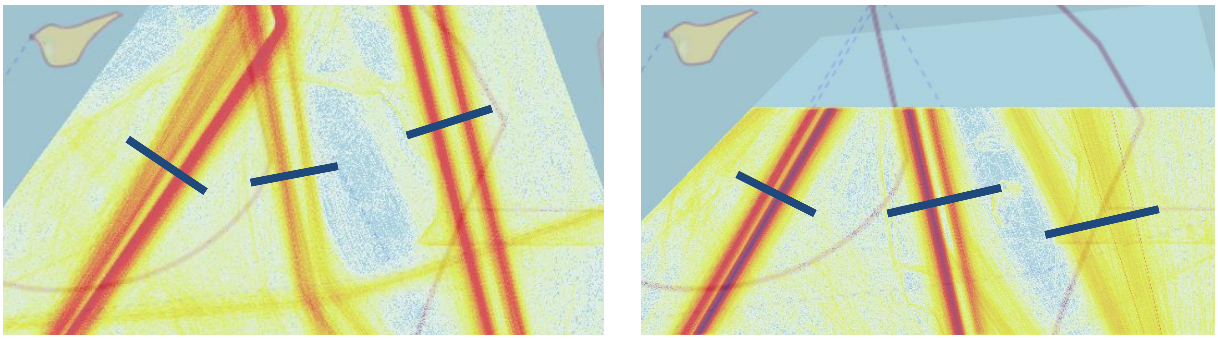


Figure 4-4 Focused density plot in a smaller area with passing lines used for comparison of cruise and passenger ship traffic in 2020 and 2019. The left cut-out shown the density plot from 2020 while the cut-out to the right shows the density plot in the same area for 2019.

Comparison of total transits through the indicated lines reveals that approximately 200 cruise ships transited the area in 2019, compared to 76 cruise ships in 2020, as shown in Table 4-2. Further, the transits of passenger and passenger/roro ships in 2020 were approximately 11% and 85%, respectively, of the registered transits in 2019. Based on these differences, the cruise and passenger ship traffic in the analysis according to 2020 AIS-data were adjusted with a factor as shown in the last row in Table 4-2. Full details of the traffic composition for each route after this adjustment can be found in Appendix C. This is the traffic composition used for the period July 1st to December 31st, 2020, in the risk assessment.

Table 4-2 Comparison of cruise and passenger ship transits for 2020 and 2019.

	Cruise ships	Passenger ships	Passenger/Roro ships
2019	200	114	1109
2020	76	13	944
% 2020 vs 2019	38 %	11 %	85 %
Factor	2,6	8,8	1,2

4.1.2 Modelling of revised ship traffic due to establishment of Hesselø OWF

It is assumed that some of the ship traffic will reroute to avoid passing through the Hesselø OWF. The routes used to model these components of the ship traffic in the risk analysis must be adjusted accordingly based on the assumed future behaviour of this traffic – i.e., how far the traffic will tend to relocate.

The revised routeing pattern following construction of the wind farm has been estimated based on the review of impact on navigation. It is assumed that ships will revise their voyage plans in advance of encountering the wind farm due to effective mitigation in the form of information distribution about the development to mariners through Notices to Mariners, updated charts, liaison with ports, etc.

The route that will be most and directly affected by the establishment of Hesselø OWF is the Stena Route sailing between Grenaa and Halmstad. Based on discussions prior to and during the HAZID workshop, two potential routes identified for Stena Line are routes either north or south of the OWF. These two options are implemented in the after-establishment scenarios as respectively Alternative Stena Route 1 and 2 and are described in the following two sections. In addition, a sailing corridor through the wind farm was proposed and discussed in the HAZID, but this route option is not quantified in this study.

Scenario 1

Figure 4-5 shows the IWRAP model after establishment of Hesselø OWF in scenario 1. In this scenario, the Stena Route is relocated north of Hesselø OWF (alternative no. 1).

The main changes to the complete ship traffic model compared to the model before establishment of the OWF are:

- Old Leg 17 (part of Route 3) is split into three parts, where the traffic distribution along the legs have changed to normal distribution for Leg 31 and 30 as the traffic spread along the route will be limited due to the presence of the PWF. The centreline of Route 3, and these three legs, are similar to the model before establishment of Hesselø OWF.
- The route passing directly through the OWF area, Stena Route, has been relocated north of Hesselø OWF. The traffic along this route (Leg 20, 29, 21, 27, 24 and 22) are assumed normally distributed, with a mean of 100 meters for both west and east direction, and a standard deviation of 600 meters. The traffic composition is identical to the initial model (before OWF establishment), with some commercial traffic as well as the Stena Line ship.
- The width of Leg 26 has been decreased slightly to ensure no direct overlap between the traffic distribution and the turbines. The traffic distribution itself has not been modified.

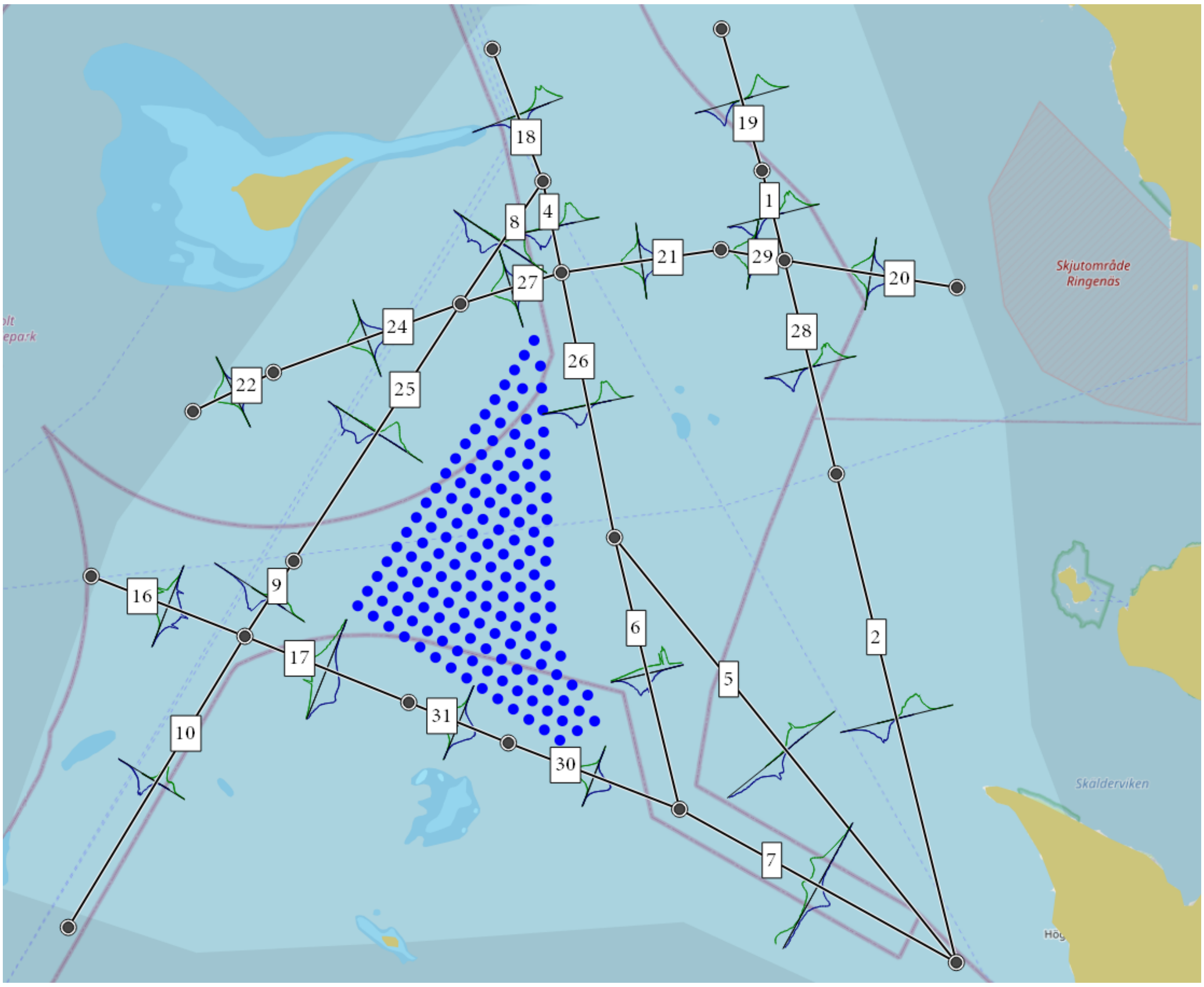


Figure 4-5 Revised ship traffic model due to establishment of Hesselø OWF in scenario 1. The potential new OWFs Galatea/Kattegat Syd (northern green area) and Stora Middelgrund (southern green area) is also shown in the figure for reference only.

Route 3 is not a heavily trafficked route, and it can also be discussed whether the centreline of this route will be relocated closer to Lysegrund, i.e. in the middle between Lysegrund and the closest turbines. This would probably decrease the risk of ship-turbine collision; however, the potential grounding risk could increase as ships would sail closer to Lysegrund.

Scenario 2

In scenario 2, the Stena Route is relocated south of Hesselø OWF (alternative no. 2). The IWRAP model after establishment of Hesselø OWF in scenario 2 is shown in Figure 4-6.

The main changes to the ship traffic model compared to the model before establishment of the OWF are:

- Old Leg 17 (part of Route 3) is split into three parts, where the traffic distribution along the legs have changed to normal distribution for Leg 31 and 30 as the traffic spread along the route will be limited due to the presence of the PWF. The centreline of Route 3, and these three legs, are similar to the model before establishment of Hesselø OWF.

- The route originally passing directly through the OWF area, Stena Route, has been relocated to the south of Hesselø OWF. The traffic along the first part of this route (Leg 32, 34, 36 and 38) are assumed normally distributed, with a mean of 100 meters for both west and east direction, with a standard deviation of 600 meters. The traffic composition is identical to the initial model (before OWF establishment) for this part of the route, with some commercial traffic as well as the Stena Line ship. For the latter part, the ship traffic along the original Stena Route has been added to the existing traffic in Route 3 where the routes intersect (for Leg 30, 31, 17 and 16).

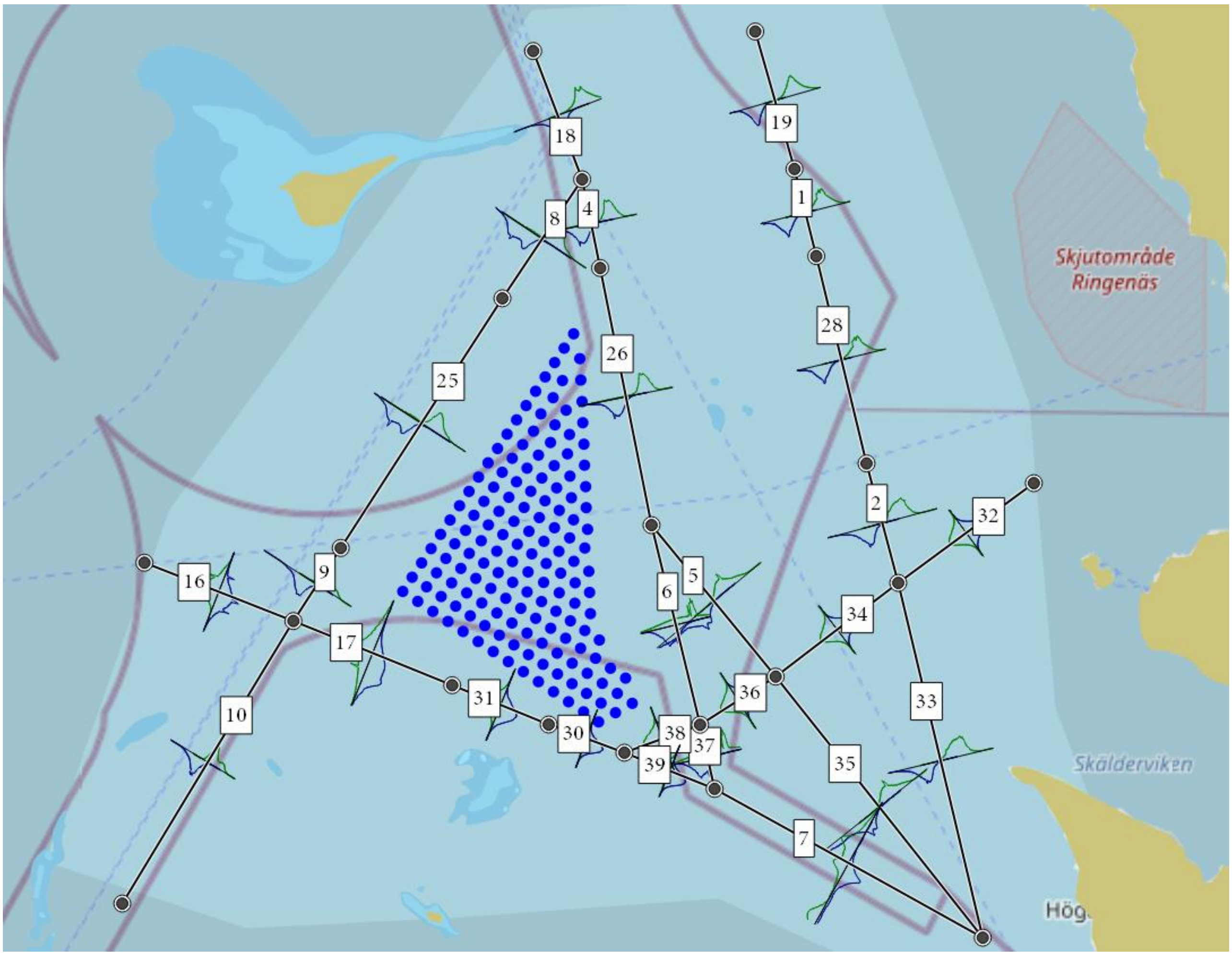


Figure 4-6 Revised ship traffic model due to establishment of Hesselø OWF in scenario 2.

4.2 Hazard identification

A total of 65 hazards were identified and discussed in the HAZID workshop. The complete HAZID log sheet with all 65 hazards, their causes, consequences, and existing safety measures, as well as any identified recommendations, is documented in DNV Report no. 2021-0483 [1].

The hazards ranked in the high-risk area (red area) are mainly related to the Stena Line route between Halmstad and Grenaa (which will be "blocked" by the OWF) and the alternative Halmstad-Grenaa routes discussed in the workshop. Also, fishing vessels and please crafts will be largely affected by the Hesselø OWF. Most of the hazards identified in the HAZID were medium risk hazards, and mainly related to potential ship-turbine collisions from ships sailing in the routes in vicinity of Hesselø OWF, e.g., Route T, Route 3, and old Route D.

Recommendations and follow-up actions were identified and discussed in the workshop and are listed in chapter 5.

4.3 Frequency analysis

4.3.1 Existing conditions (before establishment)

The existing condition represents the case where the Hesselø OWF is not established and is meant as a base for comparison in order to assess the impact the wind farm will have on the navigational risk. Figure 4-1 showed the IWRAP model for existing routes (current situation).

As seen from Table 4-3, grounding is the dominating risk contributor with a calculated frequency of 0.31 groundings per year. This equals to about one grounding every 3.5 years.

From the HELCOM database we found several registered groundings in the period 1989 to 2017. 13 groundings were observed within the complete area (not limited to the AIS-area), as shown in chapter 3.1.6, which equals to one grounding every 2 years (frequency of 0.46). Comparing IWRAP with real accidents we see that IWRAP is calculating a lower grounding frequency than has been observed the last decades, but still in the same order of magnitude. The higher historical number of groundings compared to results from IWRAP may also be due to the fact that a limited extent of ship traffic is included in the analysis, and several of the registered groundings took place very close to port of Grenaa where the ship traffic is not modelled.

Although there is a difference between the IWRAP results and accident statistics registered in HELCOM, this has no practical implications for this study. It is the risk evaluations, comparing the 'before' and 'after' situation (the "delta risk") of the wind farm establishment that is key, i.e., the percentage potential increase in accident frequency. Therefore, the significantly increased modelling and calculating time resulting from including all AIS data in the complete area is not considered to be feasible in this case.

Detailed risk results are provided in Appendix D.

Table 4-3 Calculated accident frequencies for current situation (before establishment) within the study area. Frequencies are calculated in IWRAP.

Accident type	Before establishment
Powered grounding	9.0E-04
Drift grounding	3.1E-01
Total grounding	**3.1E-01**
HeadOn ship-ship collisions	4.6E-03
Overtaking ship-ship collisions	2.1E-02
Crossing ship-ship collisions	2.0E-02
Merging ship-ship collisions	2.8E-03
Bend ship-ship collisions	1.1E-02
Total ship-ship collisions	**5.9E-02**
Ship-turbine powered collision	--
Ship-turbine drift collision	--
Total ship-turbine collision	**--**

The frequency of ship-ship collisions is calculated to be 0.059, which is about one collision every 17 years. The accidents statistics reveal that there have only been a few collisions within the study area, i.e., within the AIS data area. Four ship collisions were found relevant for the study area during 1989 to 2017, which would equal to one collision every seven years. However, this is not considered as enough data to make any sufficient comparison with IWRAP values. The main routes (route T and route S) have relatively low overlap between the southbound and northbound ship traffic, which explains the low head-on ship-ship collision frequency. There is also not much merging traffic, which is also indicated by the low merging ship-ship collisions frequency.

4.3.2 Revised condition (after establishment)

Given the project location, no significant disruption of the major commercial shipping lanes is expected. However, the traffic that today goes through the wind farm area will need to be re-located. This means in that the Stena Route and the ship traffic that was sailing along this route needs to be relocated.

Scenario 1

In this scenario, the Stena Route is relocated to the north of Hesselø OWF as described in chapter 4.3.2. The accident frequencies for scenario 1, including all ship traffic in the area and a relocation of the Stena Route, were calculated in IWRAP, and are summarised in Table 4-4. Detailed risk results are provided in Appendix D.

The risk evaluation of the accident frequencies, before versus after establishment of Hesselø OWF, are presented in chapter 4.5.

Table 4-4 Calculated accident frequencies for revised situation (after establishment) in Scenario 1 within the study area. Frequencies are calculated in IWRAP.

Accident type	After establishment
Powered grounding	7,5E-04
Drift grounding	2,9E-01
Total grounding	**2,9E-01**
HeadOn ship-ship collisions	4,8E-03
Overtaking ship-ship collisions	2,1E-02
Crossing ship-ship collisions	2,4E-02
Merging ship-ship collisions	3,4E-03
Bend ship-ship collisions	1,3E-02
Total ship-ship collisions	**6,6E-02**
Ship-turbine powered collision	5,4E-04
Ship-turbine drift collision	5,1E-03
Total ship-turbine collision	**5,7E-03**

Scenario 2

In this scenario, the Stena Route is relocated to the south of Hesselø OWF as described in chapter 4.3.2. The accident frequencies for scenario 2, including all ship traffic in the area and a relocation of the Stena Route, were calculated in IWRAP, and are summarised in Table 4-5. Detailed risk results are provided in Appendix D.

The risk evaluation of the accident frequencies, before versus after establishment of Hesselø OWF, are presented in chapter 4.5.

Table 4-5 Calculated accident frequencies for revised situation (after establishment) in Scenario 2 within the study area. Frequencies are calculated in IWRAP.

Accident type	After establishment
Powered grounding	4,8E-05
Drift grounding	3,0E-01
Total grounding	**3,0E-01**
HeadOn ship-ship collisions	5,1E-03
Overtaking ship-ship collisions	2,1E-02
Crossing ship-ship collisions	2,5E-02
Merging ship-ship collisions	3,0E-03
Bend ship-ship collisions	1,3E-02
Total ship-ship collisions	**6,6E-02**
Ship-turbine powered collision	6,4E-04
Ship-turbine drift collision	5,2E-03
Total ship-turbine collision	**5,9E-03**

4.4 Consequence analysis

There are several potential consequences should a ship-turbine collision occur. The most severe consequences would be either a ship drift impact in severe weather or powered striking. In a drifting vessel scenario, it is likely that personnel and crew should have sufficient time to prepare for impact and thereby ensure all persons are in safe locations onboard the ship or being evacuated. It may also be sufficient time to be assisted by other ships or tugs. However, in severe weather conditions and/or combined with short distance to the turbines, it may not be sufficient time to avoid a major accident.

The severity of a striking event 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 speed. A powered striking (i.e., occurring at speed) would likely result in the most severe consequences for both the vessel and the turbine. Worst-case scenario of a powered striking 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.

Although potential consequences have the possibility of being severe, it is important to also consider the frequency of powered striking when considering the risk. Resulting frequency of powered wind turbine striking, as presented in Table 4-4 and Table 4-5, is 0.00054 and 0.00064 for scenario 1 and 2, respectively. These frequencies equal a return period of 1,851 and 1,562 years. However, drifting ship-turbine collision has a higher frequency, resulting in a return period of approximately 200 years in both scenarios.

4.5 Risk evaluation

Table 4-6 summarises the calculated accident frequencies, before and after establishment of Hesselø OWF. The following chapters discusses the results of each of the accident types; grounding, ship-ship collision and ship-turbine collision. The evaluations focus on the numerical outputs from the model, i.e., the accident frequencies.

Table 4-6 Accident frequencies, before and after establishment of Hesselø OWF.

Accident type	Before	After Scenario 1	After Scenario 2	Difference Scenario 1 (after vs before)		Difference Scenario 2 (after vs before)	
Powered grounding	9,0E-04	7,5E-04	4,8E-05	-1,5E-04	-16,8 %	-8,5E-04	-94,6 %
Drift grounding	3,1E-01	2,9E-01	3,0E-01	-1,7E-02	-5,5 %	-9,0E-03	-2,9 %
Total grounding	**3,1E-01**	**2,9E-01**	**3,0E-01**	**-1,8E-02**	**-5,8 %**	**-1,0E-02**	**-3,2 %**
HeadOn ship-ship collisions	4,6E-03	4,8E-03	5,1E-03	1,7E-04	3,7 %	5,0E-04	10,8 %
Overtaking ship-ship collisions	2,1E-02	2,1E-02	2,1E-02	-1,0E-04	-0,5 %	2,0E-04	1,0 %
Crossing ship-ship collisions	2,0E-02	2,4E-02	2,5E-02	4,4E-03	22,3 %	4,8E-03	24,4 %
Merging ship-ship collisions	2,8E-03	3,4E-03	3,0E-03	6,0E-04	21,3 %	1,4E-04	5,0 %
Bend ship-ship collisions	1,1E-02	1,3E-02	1,3E-02	2,4E-03	22,2 %	1,9E-03	17,6 %
Total ship-ship collisions	**5,9E-02**	**6,6E-02**	**6,6E-02**	**7,5E-03**	**12,8 %**	**7,5E-03**	**12,8 %**
Ship-turbine powered collision	--	5,4E-04	6,4E-04	--	--	--	--
Ship-turbine drift collision	--	5,1E-03	5,2E-03	--	--	--	--
Total ship-turbine collision	**--**	**5,7E-03**	**5,9E-03**	**--**	**--**	**--**	**--**

The consequences of a ship-ship collision or grounding event are the same regardless of the wind farm establishment. The consequence of a collision with the wind turbine is dependent on collision angle, the vessel type, size of vessel and the vessel speed. The qualitative consequence descriptions were given in the previous chapter (chapter 4.4).

4.5.1 Grounding risk

It is calculated that the total grounding frequency after establishment of Hesselø OWF is 0.29 for scenario 1 and 0.3 for scenario 2, which equals to a return period of 3 years. Compared to today's situation these numbers indicate a decrease in frequency of 5.8% and 3.2% for scenario 1 and 2 respectively. This may be largely due to the fact that vessels sailing in proximity of the OWF now could collide with a turbine instead of drifting on ground in case loss of steering or power. Further, the traffic distribution along Route 3 is narrower in the revised condition, resulting is less probability of powered grounding at Lysegrund.

4.5.2 Ship-ship collision risk

The ship-ship collision frequency after establishment increases with approximately 12.8% in both scenarios. After establishment, the ship-ship collision frequency is 0.066, which yields a return period of 15 years. In both scenarios, the densification of ship traffic along Route 3 is contributing to the increased ship-ship collision risk, as well as an increased risk for collision at the 'bends' between legs along the revised Stena routes which have slightly more turns than the original route. At such an intersection ('bend') a ship can become a collision candidate if the course is not changed at the intersection.

Ship transits to and from the OWF, typically CTVs, are not included in the analysis, and the potential further increase in ship-ship collision frequency due to these vessels crossing or merging with other routes should be investigated when the CTV port and operational patterns are decided. However, the relative ship traffic increase based on number of CTV transits to and from the OWF is assumed to be small given the significant amount of total ship traffic in the area, and the additional risk contribution would probably be small as well.

4.5.3 Ship-turbine collision risk during operation

The presence of the offshore wind farm is assumed to result in that some of the ship traffic will relocate to avoid passing through the offshore wind farm. The routes used to model these components of the ship traffic in the frequency analysis are adjusted accordingly based on the assumed future behaviour of this traffic, i.e., how the traffic will tend to relocate. In the analysis it is assumed that ship traffic will not travel through the farm.

The accumulated results for the entire offshore wind farm are presented in Table 4-6. It shows the frequency for the two scenarios (powered/drifting collision), as well as the combined sum for the two, for both revised situation scenarios.

The ship-turbine accident frequencies are the lowest of all the accidents, with an annual frequency of 0.0053 and 0.0052 for scenario 1 and 2 respectively. This is equivalent to a collision happening once in every 200 years. It is noted that the calculated collision frequencies cover all cases of collision, i.e., both minor collisions as well as severe collisions where repair of ship is needed before the ship can continue its planned journey.

The routes that contribute most to the ship-turbine collision frequencies in the revised condition scenario 1, are Route T (55%) followed by Route D1/D2 (27%). There are twice as many ships passing along Route T compared to Route D1/D2, so even though Route D1/D2 is located closer to the OWF the actual frequency contribution is lower. Route 3 also contributes to the ship-turbine collision frequency (9%), however the low number of ships passing through this route results in a smaller contribution compared to the above-mentioned routes.

For the revised condition scenario 2, Route T (54%) and D1/D2 (24%) still contribute most to the frequency. However, the contribution from Route 3 (and the Stena Route) is higher in this scenario (12%). This also results in a slightly higher total ship-turbine collision frequency for scenario 2 compared to scenario 1. The increased frequency in this scenario follows directly from relocating the Stena Route traffic to the south of Hesselø OWF and along parts of Route 3.

The ship types that have the highest contribution (10% or more) to the ship-turbine collision frequency in scenario 1 are: General Cargo/ Roro-ships (41%), Chemical/Product Tankers (17%) and Bulk Carriers (13%). In scenario 2, the ship types with the highest contribution are: General Cargo/ Roro-ships (39%), Chemical/Product Tankers (17%), Bulk Carriers (13%) and Passenger/Roro-ships (10%). Approximately 90% of the frequency contribution stems from ships between 70 and 250 meters in length in both scenarios.

Another risk contributor to the ship-turbine collision frequency, which is not modelled in this assessment, could be the crew transfer vessels when they sail to and from the wind farm turbines. The latest ship-turbine collision accident in Danish waters was in April 2020 when a CTV hit a turbine in the North Sea, seriously injuring one crew member and harming another two. The risks should be mitigated with good operating procedures and crew training, however further assessment of this risk should be carried out when the home port of the CTVs, and number of CTV, are decided.

The closest distance between the wind turbines and the vast majority of ships (90%) sailing north in Route T and south in D1/D2 is indicated in Figure 4-7.

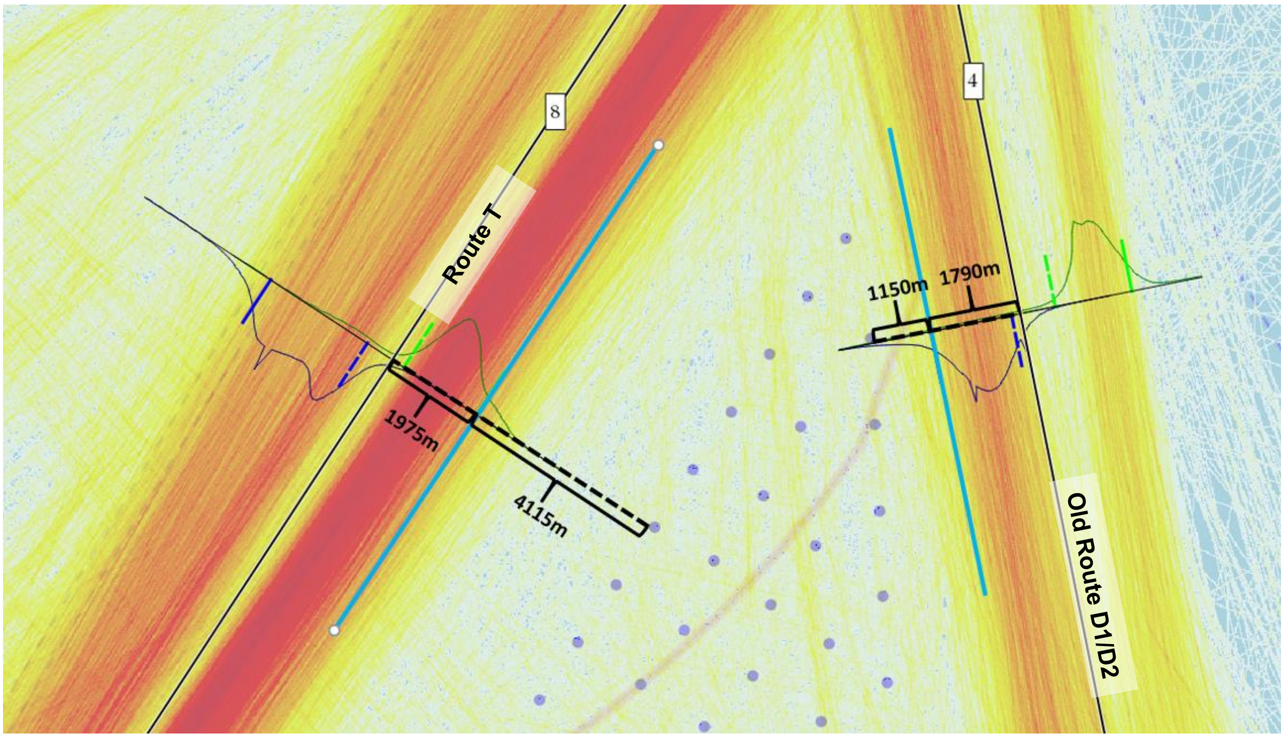


Figure 4-7 Traffic density plots showing the lateral traffic distribution for the ship traffic along Old Route D1/D2 and Route T. The blue lines indicate the 90% traffic distribution limit along each route.

4.5.4 Risk during construction and decommissioning

The number of vessels that operate in construction and decommissioning phases is expected to be a negligible risk addition to current traffic. However, a procedure for safe voyages will be made for the construction work in dialogue with pilots. This is especially relating to navigational hazards for when constructions and cable laying vessels may need to cross deep-water routes and major traffic flows, i.e., Route T or Route S.

The vessels that are anticipated to be present during construction include construction barges, support tugs, heavy-lift vessels, jack-up rigs, supply/crew vessels and cable laying vessels. These vessels will also be present in the region during decommissioning. It is likely that approximately 10-15 vessels (including support vessels) may be on site at any time during the construction phase. Construction vessels are anticipated to be sailing at very low speeds through the construction zone. The construction phase is currently estimated to last about two years, from 2025 to 2027, however depending on the OWF developer.

The highest navigation risks during construction will be:

- Cable laying barges crossing major traffic flows.
- Smaller vessels operating in close proximity to construction and work vessels during construction. This risk is mitigated by safety zones that is anticipated to be implemented during construction operations. The safety zones are expected to prohibit “third party vessels” from entering into, transiting through, mooring, or anchoring within safety zones.

It is assumed that 500 meters safety zones will be established during construction around each location where the towers, nacelles, blades and subsea cables will be installed in navigable waters. However, the exact safety zone radius will be agreed with the DMA prior to construction. The intention of establishing safety zones is to safeguard mariners from the hazards associated with construction of the wind farm.

Further, it is expected that the complete construction area will be marked with yellow lighted buoys with a sufficient reach. Details regarding the requirements for positions and number of buoys will be agreed with the DMA.

4.5.5 Qualitative assessment of cumulative effects

The previous evaluations have considered the proposed project in isolation. Under this section the potential cumulative and in-combination impacts on shipping (of any nearby developments in the area) will be reviewed. This will include any proposed developments not yet constructed, but scoped, within the area. An increased navigational risk due to cumulative effects in the area has been assessed qualitatively.

There is already one existing wind farm in the area: Anholt OWF. Further, several other OWFs are currently in the development phase or identified as potential OWF areas: Kattegat I, Treå Møllebugt, Kattegat II, Stora Middelgrund, Galatea/Kattegat Syd and Galene. These areas are shown in Figure 4-8.

Based on information received from Energinet, the Kattegat I and Kattegat II OWF areas are only potentially planning areas and whether offshore wind farms will be developed is uncertain. The locations of Treå Møllebugt and Galene are considered to have no or minimal impact to the traffic pattern in proximity of Hesselø OWF. These locations are therefore not further assessed with regards to potential cumulative effects.

The presence of the existing Anholt OWF is not considered to have any direct implications on the establishment of Hesselø OWF.

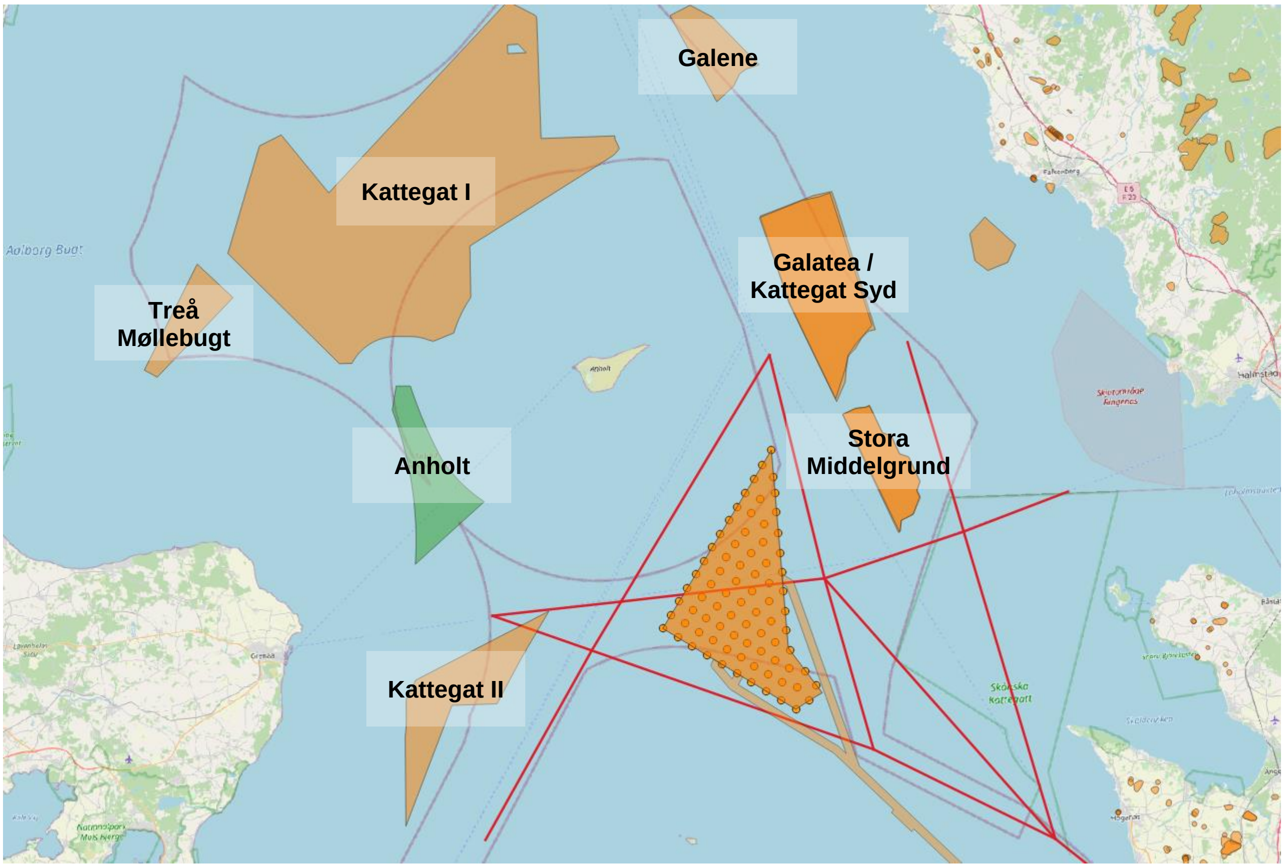


Figure 4-8 Visualisation of existing wind farms (green) and potential wind farms (orange) in the area around Hesselø OWF. The red lines in the illustration represent the existing main ship traffic routes.

Galatea / Kattegat Syd OWF and Stora Middelgrund OWF are in the project development phase, and the establishment of these wind farms should thus be addressed. In case these two OWFs are established, assuming also establishment of Hesselø OWF, the ship traffic in the area will be restricted and concentrated along the main routes. This will potentially only result in a slightly higher collision risk based on the densification of commercial traffic along Route T and Route S. Further, there are both fishing vessels and pleasure crafts sailing in the area. These vessels will have to sail closer to or along the main routes which also increases the collision risk. Lastly, three OWFs within the area will naturally also introduce a higher risk for ship-turbine collisions.

In this assessment, one alternative route for the Halmstad-Grenaa Stena Line route is north of Hesselø OWF. This implies transit between the potential OWFs Galatea / Kattegat Syd and Stora Middelgrund. Further assessment of this risk will be required for the navigational risk assessments of Galatea/Kattegat Syd and Stora Middelgrund should the route north of Hesselø OWF be a feasible option.

4.5.6 Direct impacts on ships and maritime activities not covered by the frequency analysis

Fishing vessels

AIS data from 2020 and VMS data from Fiskeristyrelsen for the years 2010 to 2020 are used to assess the fishing activities in both the planned offshore wind farm area and the corresponding cable route.

The VMS data[5] was filtered to only include data points where the vessels have been sailing with a speed equal to or below 5 knots, as this is assumed the threshold for trawling and net activities. Note that a complete study related to fishing vessels will be carried out separately by NIRAS, and the topic is therefore only briefly included in this risk assessment.

A visual representation of the VMS data points is shown in Figure 4-9.

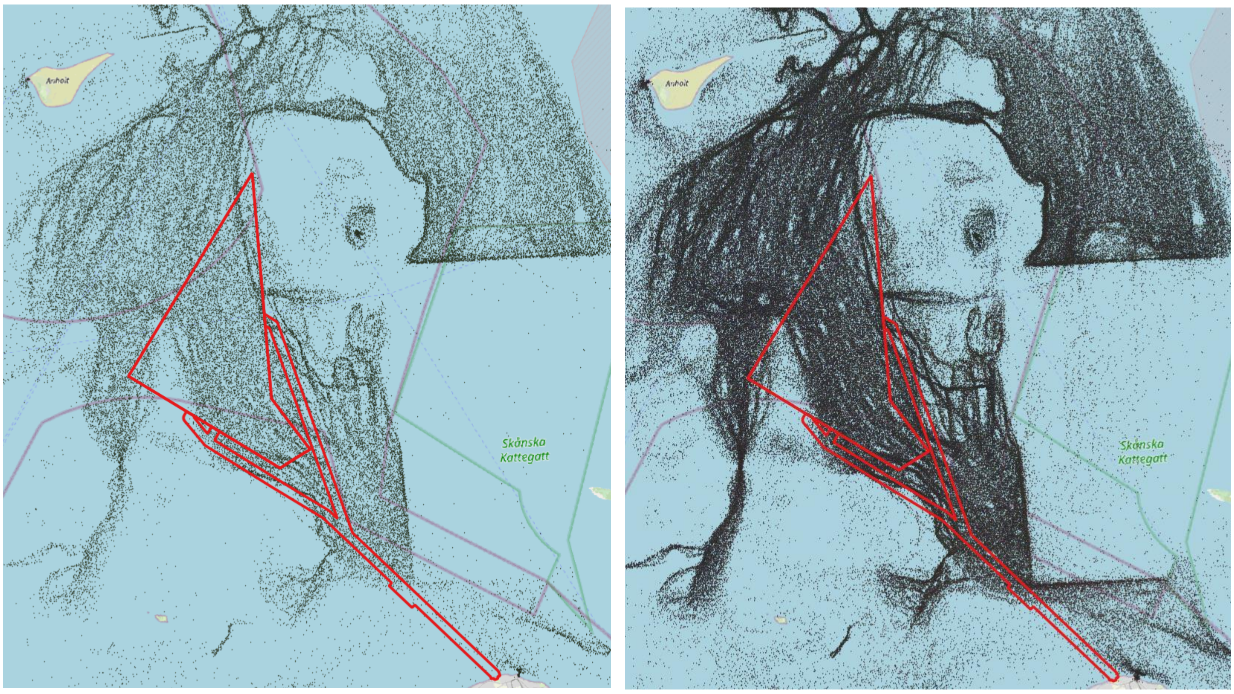


Figure 4-9 Fishing activity in the project area. Left picture: VMS data points from 2019 and 2020. Right picture: VMS data points from 2010 to 2020.

[5] Note that for VMS data: For the years 2010 and 2011 vessels of length 15 meters or longer are included, while for the data points from 2012 to 2020 vessels from 12 meters are included.

VMS data plots for different types of fishing activities, such as bottom trawling, pelagic trawling, fishing with net, and other fisheries, are shown in Figure 4-10 and Figure 4-11.

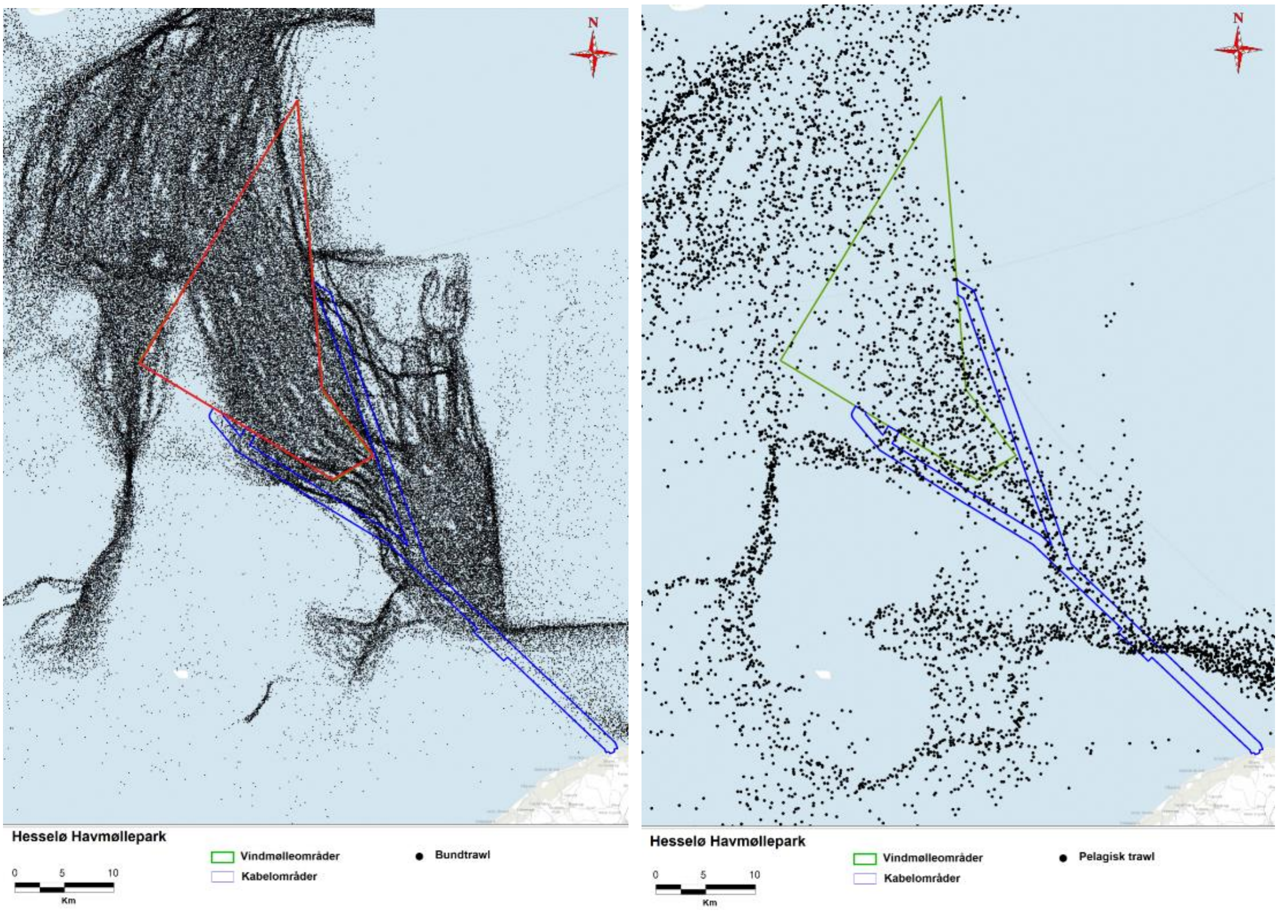


Figure 4-10 VMS data for bottom trawling (left) and pelagic trawling (right) from 2010 to 2020.

It is evident that this area in Kattegat is an important fishing area. Bottom trawling is the dominant fishing activity, as seen from Figure 4-10. The areas southwest, northeast, east and northwest of Hesselø OWF, as well as the OWF area itself, are currently exposed to lots of fishing.

After establishment of Hesselø OWF, a part of the area will potentially become unavailable for fishing using bottom-impacting gear, like trawling. There is a strict no-fishing zone within the 200 meters protection zone around all cables, both the export cable and cables inside the OWF. Whether or not the amount of fishing activities will be significantly reduced is not certain. Though, it was mentioned in the HAZID workshop that the region will become less attractive for fisheries after establishment of the OWF, particularly if the OWFs in the Swedish EEZ are established as well. If the unavailable area becomes too large, it could be expected that fishing activities in the area would decrease significantly or cease to exist. This would in turn, naturally, decrease the navigational risk itself as the total ship traffic volume would decrease.

An AIS density plot of fishing vessels and their operational pattern is included in Appendix B. Even though the smaller fishing vessels are not required to carry AIS transponders, and thus some fishing vessels may be missing from the AIS data, the AIS density plot and the VMS data plot show similar operational patterns.

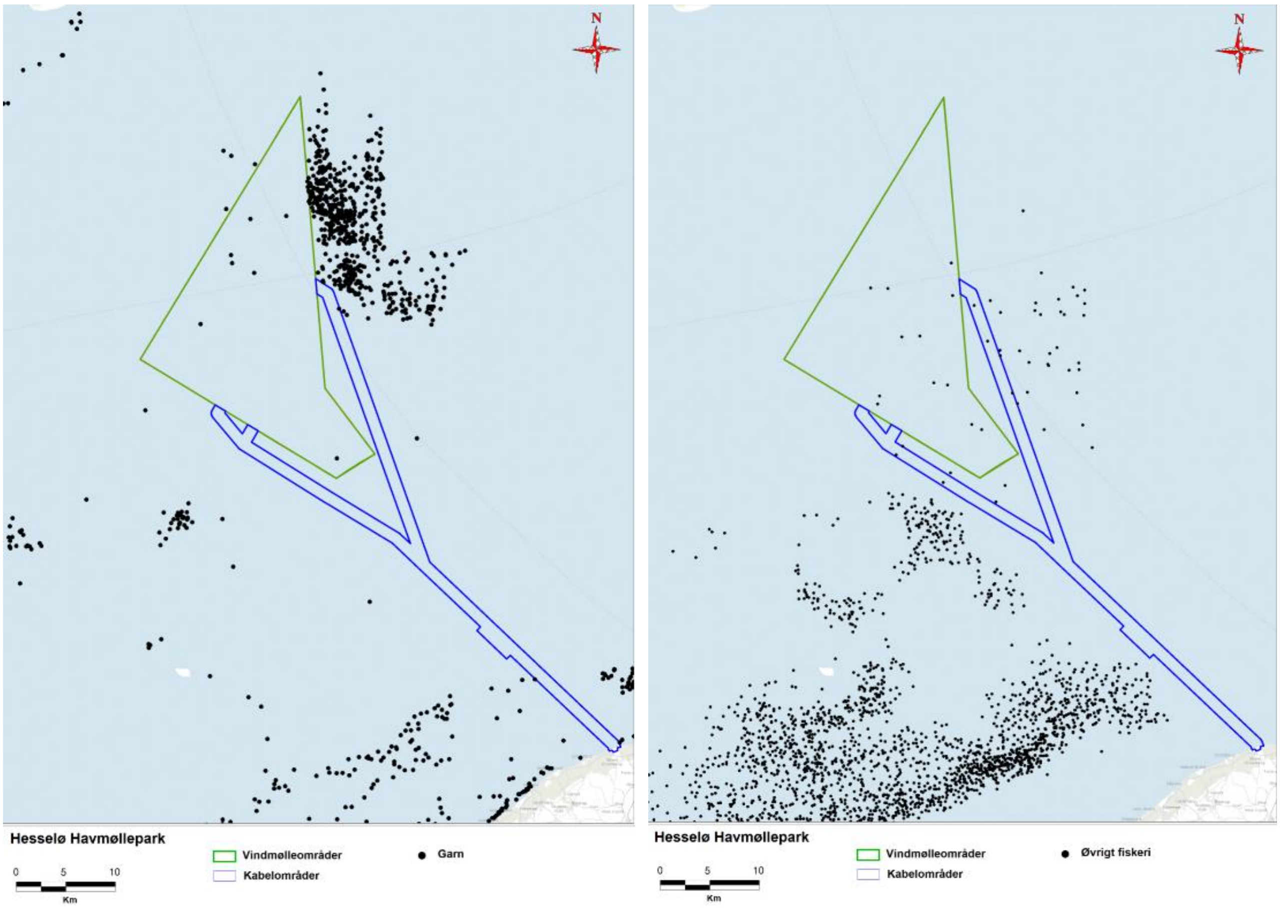


Figure 4-11 VMS data for fishing with net (left) and other fishing activities (right).

Search and rescue operations

No significant disruption of Search and Rescue (SAR) operations at sea is expected, as the spacing between the turbines (approx. 1500 m) and the minimum distance between the Highest Astronomical Tide (HAT) and the lower wing tip (approx. 20 m) will allow for rescue boats to sail in between turbines and through the wind farm.

Pleasure crafts and leisure activity

In addition to the significant fishing activities in the area, the area is also trafficked by pleasure crafts. The ship tracks / density plot of pleasure crafts, such as yachts, motorboats and sailing vessels, are shown in Figure 4-12. Highest density is observed at the entrance to / exit of the Sound. Further, several ship transits are observed to and from Anholt Island, as well as some tracks along Route S.

As mentioned in the Analysis Basis chapter, pleasure crafts are not required to carry AIS-transponders and the traffic density plot only shows the pleasure crafts that have such transponders installed. An expert guesstimate on the ratio of yachts and sailing vessels with AIS-transponders versus those who do not would be 1 out of 50-100, i.e., 1-2%.

The density plot gives an indication of typical sailing pattern for the pleasure crafts but does however not show the complete picture of leisure activity.

A not quantified contribution to the navigational risk after establishment of Hesselø OWF is the relocation of pleasure craft transits closer to the main shipping routes. These vessels may have to sail closer to or along the main routes which may increases the collision risk. The difference in terms of grounding risk is not expected to increase, as the OWF area is situated far from land.

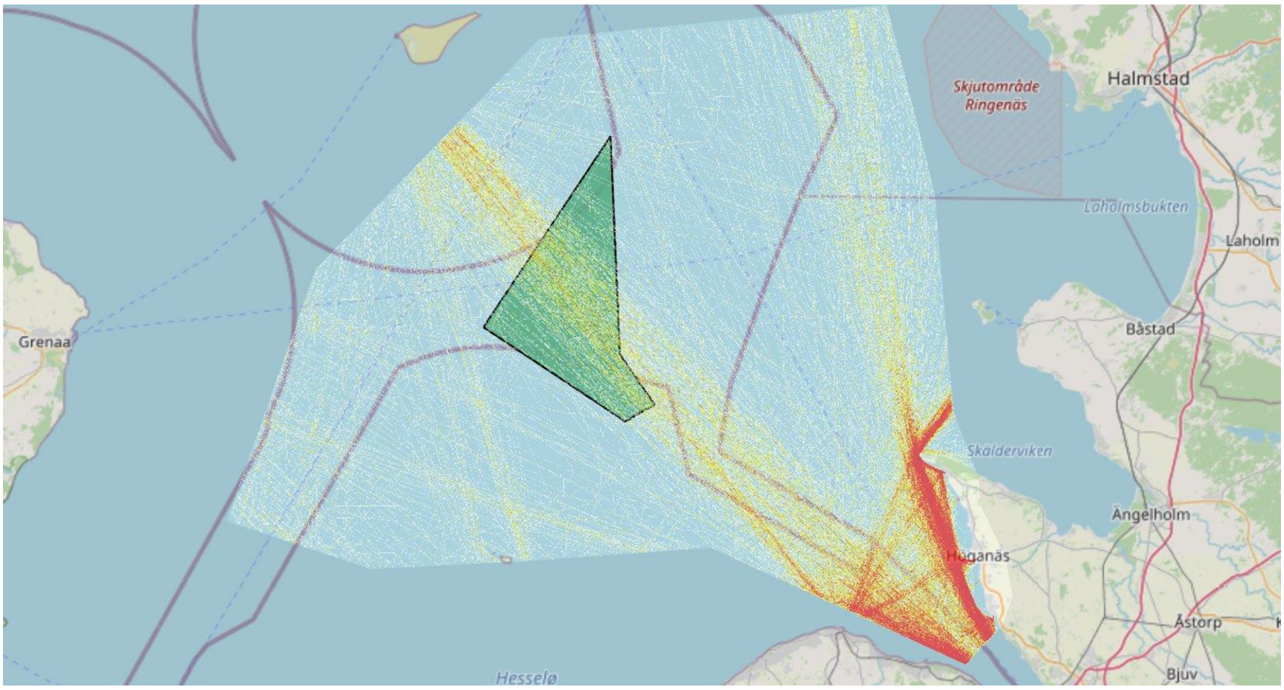


Figure 4-12 Density plot of pleasure crafts based on AIS data from July 1st to December 31st, 2020.

4.5.7 Assessment of wind farm cable interaction with ship traffic

Anchoring, emergency anchorage or trawling activity with bottom gear near proposed cable route(s) could potential interaction with the power cable. Therefore, a high-level review of potential cable impacts from was carried out using the available AIS and VMS data covering the proposed cable route.

Dropped or dragged anchor

Figure 4-13 shows the density of traffic above the power cable. Typical cable interaction hazards related to the ship traffic are:

- Sinking vessels
- Dragged anchors
- Dropped anchors
- Dropped objects (e.g., containers).
- Grounding vessels

Sinking vessels, dropped anchor or object directly above the power cable is a very unlikely event, thus considered negligible risk contribution. The probability that a ship will sink is equal to 5.1E-9 per sailed nautical mile [9]. The export cables from the Hesselø OWF to land (Gilbjerg Hoved) will be buried approximately 1 meter into the seabed. It is thus assumed that the risk of grounding/contact to the cables is negligible.

The dragged anchor scenario could result as a consequence of two events:

- Anchoring in an emergency situation (emergency dragged anchor).

- Uncontrolled drop of the anchor (accidental dragged anchor).

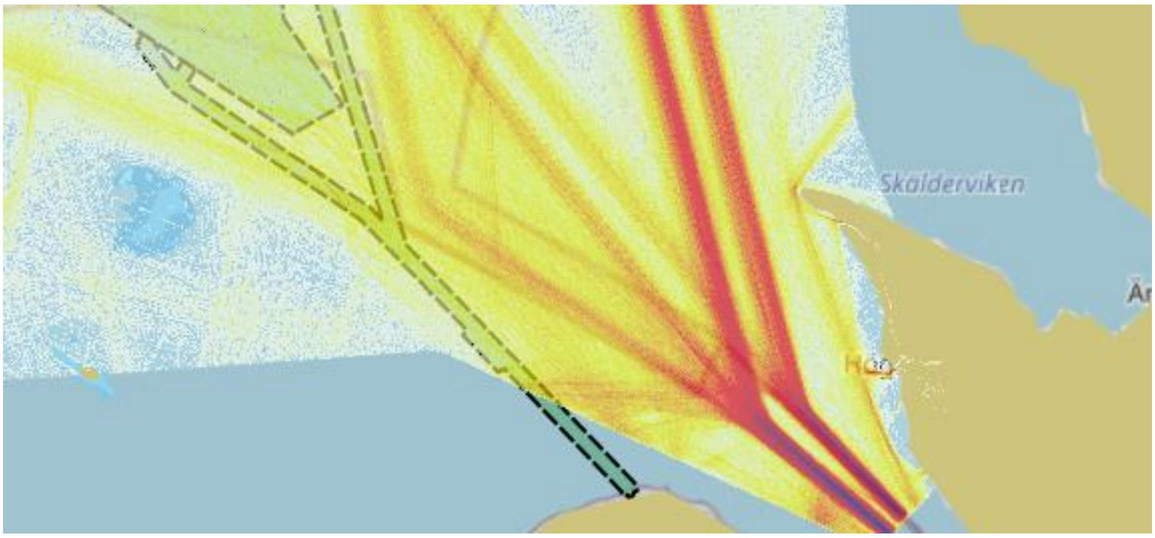


Figure 4-13 Ship traffic density plot above and surrounding the proposed cable corridor.

Power cables will be clearly marked in charts. However, in emergency situations a vessel drifting towards shore or a turbine may attempt to anchor to reduce the risk of collision or grounding. Cables should therefore be buried to a sufficient depth to avoid being uncovered. Where power cables cannot be sufficiently buried, it is important that alternative types of cable protection are considered. The cable burial depth will be at least 1 meter, according to the requirements from the DMA.

Di Padovaa et.al. found, based on [7] and [8], that the frequency of anchors lost (events/ship/year) vary between 0.01 to 0.005 events/ship/year [9]. A frequency of 0.005 corresponds to 1 anchor lost every 150 ship per year. This must therefore be considered as a 'low frequency event'.

Trawling activity

The fishing activities in general in the complete study area was described in chapter 4.5.6. Figure 4-14 shows a cut-out from the VMS data plot filtered to only include bottom trawling, focused around the planned cable corridor. Generally, no bottom trawling is allowed inside the cable protection zone, 200 meters on each side of the cable. However, access can be granted on a case-by-case basis if the cables are considered safe.

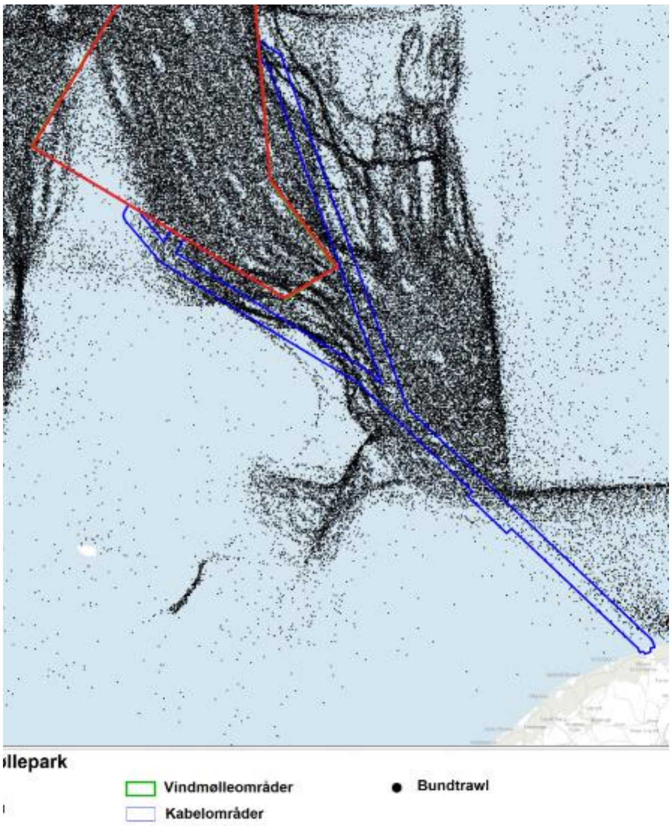


Figure 4-14 VMS data for bottom trawling from 2010 to 2020.

4.6 Assessment of required sailing corridor for main ship routes

When designating shipping corridors for the Danish Maritime Spatial Plan (MSP), DMA used the general calculation principles as described in a Dutch white paper for IMO [2] [3]. The paper provides guidance for calculation of area requirements for transit routes and major traffic flows.

The calculation ensures that ships in the normal traffic flow can perform normal deviation manoeuvres, i.e., determines the space required for safe navigation [2]. Normal traffic flow will in principle mean that ships can overtake at a distance of two ship lengths, and otherwise can manoeuvre in accordance with international maritime rules (COLREGS) [2]. If the traffic intensity is high, there may be an additional need for several ships to be able to overtake each other at the same time [2].

In addition to normal traffic flow, there is a need for an additional safety margin from the outer edge of the traffic flow to, for example, an offshore wind farm. This space - often called the buffer zone or the safety margin - is an area where ships can make emergency manoeuvres, e.g., if a vessel comes across from the offshore wind farm. An emergency manoeuvre consists of a normal deviation to starboard of 0.3 nautical miles followed by a 360-degree turn. A 360 degree turn usually takes up six times the ship length.

With knowledge of the ship's length and traffic intensity, the indicative minimum area for a given ship's corridor (path and safety margin) can be calculated using the following formula:

$$\left((2L * X) + 0.3nm + 6L\right) * 2$$

L is the standard ship length[6] in a given traffic flow and X is between 2 and 4. X is determined in relation to the traffic intensity as follows [2]:

- X = 2 for less than 4,400 passages per year,
- X = 3 for more than 4,400 but less than 18,000 passages per year, and
- X = 4 for more than 18,000 passages per year.

Since traffic flows usually consist of two opposing traffic lanes, it is necessary to multiply by 2, to make room for the entire ship corridor in both directions [2].

Based on the calculation principles by DMA, DNV has calculated the indicative minimum area for the routes that are close to the Hesselø OWF. The calculations are based on the inputs provided in Table 4-7.

Table 4-7 Input values for calculation of area requirements for transit routes and major traffic flows.

Route	Standard ship length	Traffic intensity (number of passages)
Route T	400m	Approx. 15,500
Route 3	200m	Approx. 1,700[7]
Old Route D1/D2	300m	Approx. 7,200

Table 4-8 Indicative area requirements for transit routes and major traffic flows.

Route	Complete route width	Space required on each side of the route centerline
Route T	10.7km (~5.8nm)	5.4km (~2.9nm)
Route 3	5.1km (~2.8nm)	2.6km (~1.4nm)
Old Route D1/D2	8.3km (~4.5nm)	4.2km (~2.2nm)

The indicative minimum area for the routes is plotted in Figure 4-15. Route T does not overlap with the planned area for Hesselø OWF. Route 3 overlaps with parts of the area, and some of the turbines in the modelled layout, in the south-east corner of the OWF. However, this is based on a conservative assumption that the centreline of Route 3 does not change after the establishment of the OWF. It may be that ships sail further away from the turbines, and still keep sufficient distance to the shallow waters around Lysegrund. Note that Route 3 is not a marked route in the nautical charts, but used by some ships such as cargo ship, roro-ships and bulk carriers. The centreline therefore relates to the centre of the traffic intensity.

[6] Standard ship length defined as: 98,5% of the ships are no larger than the standard ship.

[7] In case relocation of Stena Route south of Hesselø, the total number of passages will increase to approximately 3,200. This is still below 4,400 passages (and no change to X in the equation for calculating the sailing corridor). The standard ship length will also be the same.

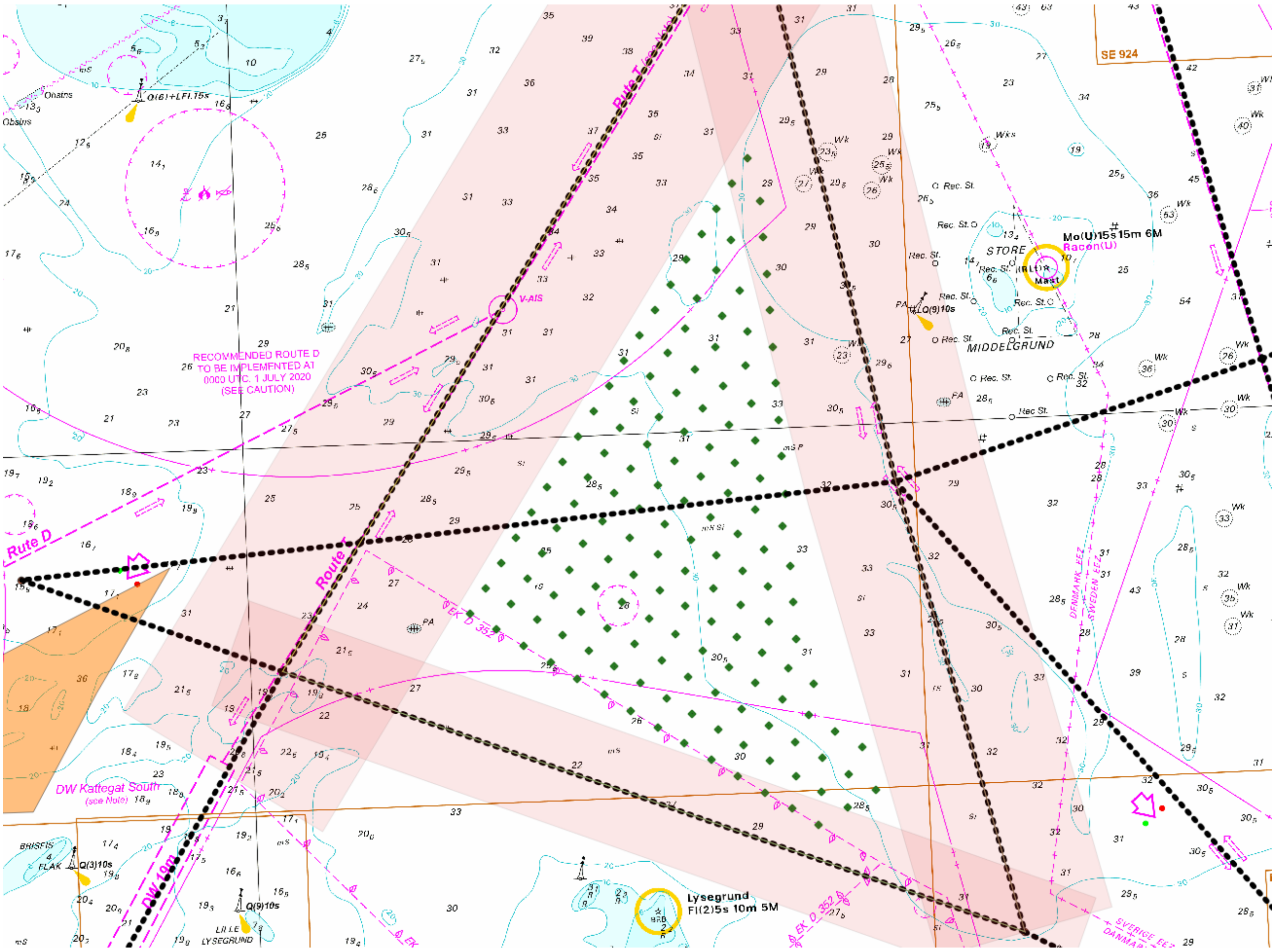


Figure 4-15 Safe sailing corridors for ship Route T, Route 3 and Old Route D1/D2 (no change in centreline position/direction). Small green squares represent the wind turbines.

As can be seen from the above figure, old Route D1/D2 overlaps with parts of the planned Hesselø OWF area in the northeast corner of the OWF in the case that the centreline (or the direction) of the route is not modified. There is a cardinal mark west of Store Middelgrund that ensures ships keep a safe distance to the shallow waters. However, as also indicated in the Marine Spatial Plan (Havplan), the route can be safely 'tilted' to the east and thus providing more space between the centreline of the route and the OWF. Further given the uncertainty related to the actual number of passages through Old Route D1/D2, as a result of the new routing system settling with the aim of moving all ships from Old Route D to Route S, number of transits / passages through this route should decrease. Figure 4-16 illustrates the sailing corridor width for Old Route D1/D2 calculated based on the assumption of less than 4,000 yearly ship passages along this route and with the route centreline slightly relocated east at the northern part close to the OWF.

As can be seen from Figure 4-16, it is possible to obtain minimal overlap between the sailing corridor and the OWF area after slight relocation of the sailing direction and with fewer than 4,000 yearly passages.

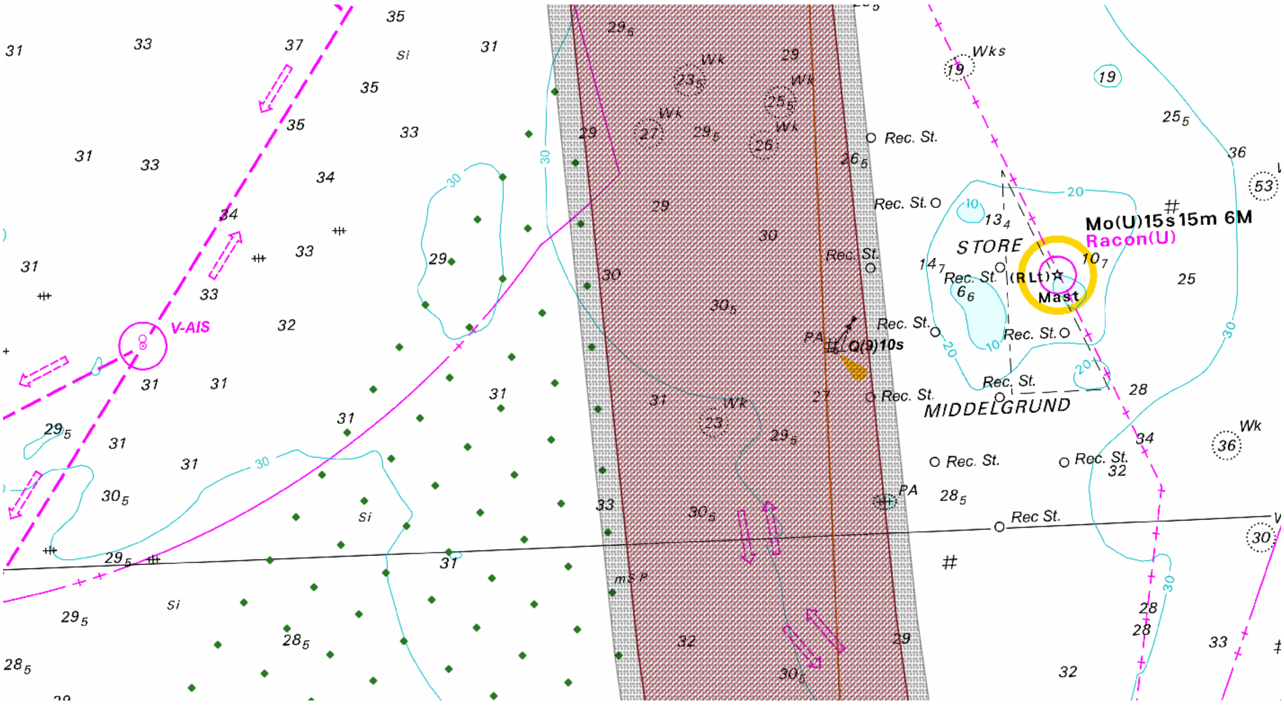


Figure 4-16 Revised sailing corridor based on the assumption that the direction is slightly changed and there will be less than 4,000 yearly passages along Old Route D1/D2 in the future. Red area indicates the revised width, while the grey area represents the width for more than 4,000 yearly passages. Small green squares represent the wind turbines.

Figure 4-17 presents a scenario where the centreline of Route 3 is slightly relocated southwards, then there is no overlap with the turbines nor the shallow waters around Lysegrund.

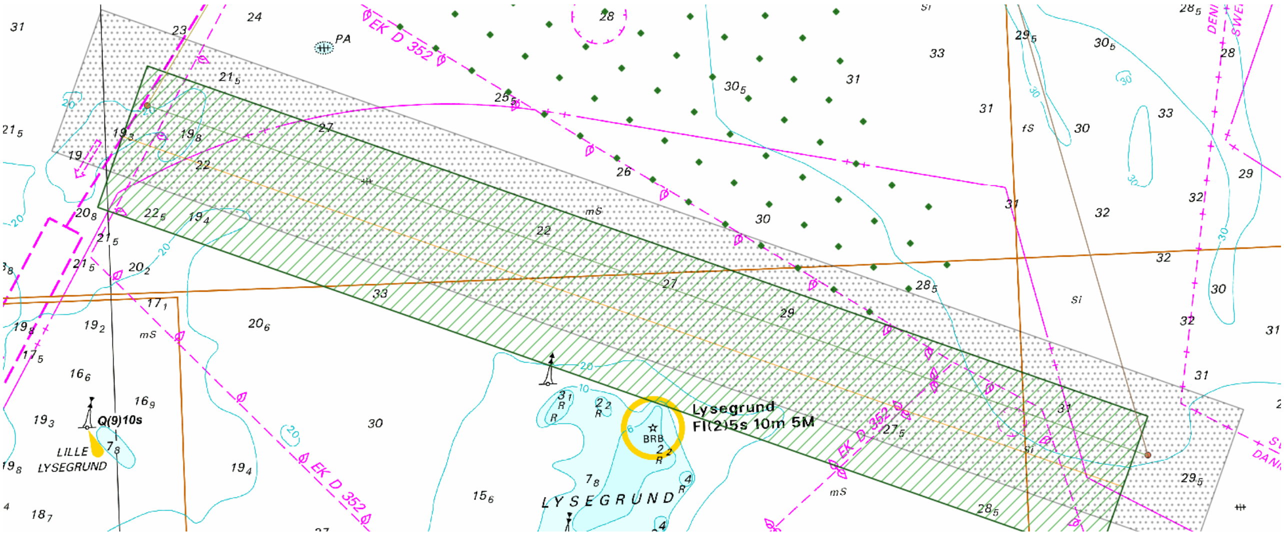


Figure 4-17 Safe sailing corridor after relocation of centreline of Route 3 (green area). Grey area represents the sailing corridor shown in Figure 4-15. Small green squares represent the wind turbines.

5 RECOMMENDATIONS

Several recommendations should be considered in the further development or project phase for Hesselø OWF, based on the navigational risk assessment in this report and HAZID carried out:

- Further considerations and evaluation should be carried out to ensure safe ship passing distance between Old Route D1/D2 and the northeast part of the OWF. As one of the objectives of the new routing in Kattegat is to move ships with less draft than 10m to Route S, the commercial ships remaining in the old Route D will be mainly oil/product/chemical tankers sailing to Malmö oil terminal. As such, the ships sailing in this route in the following years will be mainly larger ships with limited manoeuvrability.
- Establishment of Hesselø OWF will require relocation of the Halmstad-Grenaa Stena Line route if no sailing corridor through the OWF will be made. Close dialog between the developers of Hesselø OWF, Galatea/ Kattegat Syd OWF and Stora Middelgrund OWF as well as both Danish and Swedish authorities is recommended to evaluate the combined effects on ship traffic in Kattegat. Stena Route to be especially considered, as this route will be affected by the OWFs. A joint working group (or similar) could be established. In case the north Stena Route is a feasible option, additional risk reducing measures should be considered by relevant parties and national authority (e.g., sufficient route with between Galatea/ Kattegat Syd OWF and Stora Middelgrund OWF, marking, lighting, traffic surveillance/VTS, routing measures, etc.).
- Investigate whether or to what extent Hesselø OWF will hinder the line-of-sight to existing navigational lights. This can be considered together with the marking of the wind farm, potentially looking at marking of recommended routes and other lights/marks in the area.
- Synchronization and harmonization of lighting with respect to other existing and planned offshore wind turbines in the region should also be considered. Different arrangement of lighting on the different offshore wind farms in the area may confuse mariners. It should also be ensured to minimize the disturbing effect of unsynchronized lighting. This will of course also need to consider aviation lighting.
- Radar interference, radar shadow, false echoes, lost echoes, etc. (contributing to lack of surveillance and insufficient situational awareness) to be investigated by separate study. Radar interference can only be assessed with sufficient accuracy when the final decision has been made on the design and layout of the park (number of turbines, location, height, etc.) when allocating establishment permits.
- Evaluate if measures should be taken to compensate/mitigate for potential increased risk for pleasure crafts and smaller vessels (e.g., fishing vessels) that may need to sail closer to deep-water routes and major traffic flow due to establishment of the OWF. Measures could be information campaigns, dedicated or recommended routes for pleasure/leisure crafts and smaller ships, additional aids to navigation etc.
- Recommendation related to the construction and cable-laying phase:
    - Consider creating a common working group with applicable stakeholders prior to initiation of the construction work, to ensure common understanding of construction work, plans, phases etc. and to align plans.
    - Consider establishment of a sailing corridor for the construction vessels to provide a predictable traffic pattern and limit the potential navigational risks. Will be marked in the charts.
    - Consider carrying out the OWF construction in stepwise phases with "step-by-step" sub-areas, to avoid the entire OWF area being closed off at the same time.
    - Publish information to sailors and pleasure crafts in the area regarding planned construction and cable laying activities (Notice to Mariners).

- Consider protection boats / guard vessels during construction of the OWF. This depends however on developer specification.

- AIS data for the period July 1st to December 31st, 2020, was used in this assessment. As the new routing measures in Kattegat was in force from July 1st, a large portion of the ships registered along Old Route D1/D2 may have used the route based on “habit” or lack of updated nautical charts. Therefore, the number of transits along this route may be significantly reduced in the future, when the new routing system has settled. When updating the Navigational Risk Assessment for the final OWF design, ensure to apply updated AIS data to see if there are any new trends with respect to ships relocating from old Route D to Route s.

6 REFERENCES

/1/ DNV (2021). *Navigational Risk Assessment of Hesselø Offshore Wind Farm – HAZID report*. Report no. 2021-0483, Rev A. Dated: 2021-05-20

/2/ Email from Peter Dam (Danish Maritime Authority) sent 22/06/2021.

/3/ Council of the European Union (2015) Amendment to the General Provisions on Ships' Routeing (resolution A.572(14)) on establishing multiple structures at sea – Assessment Framework for Defining Safe Distances between Shipping Lanes and Offshore Wind Farms. W. Doc. 2015/99. Information paper by the Netherlands.

/4/ National Geospatial Intelligence Agency (2020). Sailing directions (enroute) – Skagerrak and Kattegat. Publication is corrected through 3 April 2021.

/5/ IALA IWRAP Mk2 Wiki site https://www.iala-aism.org/wiki/iwrap/index.php/Main_Page

/6/ Helcom Map And Data Service https://maps.helcom.fi/website/mapservice/

/7/ DNV GL, Gard and The Swedish Club. “Anchor loss - technical and operational challenges and recommendations”, DNV GL AS, 2016.

/8/ A. Di Padovaa*, C. Zuliania, and F. Tallonea (2018). Dragged anchors interaction scenario: Detailed frequency analysis for pipeline design. Probabilistic Safety Assessment and Management PSAM 14, September 2018, Los Angeles, CA.

/9/ Enersea (2018). D12-B to D15-FA-1 Pipeline. D12-B to D15-FA-1 Risk Assessment and dropped object analysis.

/10/ Klima-, Energi- og Forsyningsministeriet (2020). Pålæg om gennemførelse af forundersøgelser og om etablering af nettilslutningspunkt til Hesselø Havvindmøllepark. 02.07.2020.

/11/ COWI (2020). Miljø- og planmæssige forhold for Nordsøen I, Hesselø og Krigers Flak II.

/12/ Energistyrelsen (2021). Udkast til plan for Hesselø Havvindmøllepark til brug for strategisk miljøvurdering (SMV). 12.02.2021.

/13/ Energistyrelsen (2021). Udkast til udtalelse om afgrænsning af miljørapport (SMV) for planen for Hesselø Havvindmøllepark. 12.02.2021.

APPENDIX A
IWRAP settings and parameters

The following default IALA values have been selected in IWRAP:

Causation factors:

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
Powered Grounding	1,600 E-4
Powered Allision	1,600 E-4
Area moving:	0,500 E-4
Area stationary:	0,500 E-4

Default Causation Reduction Factors

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

Mean Time Btw. Checks:	180 s

Tug assistance:

Preparation time:	30 min
Success probability:	0.85
Average speed	12.00 knot
Max range:	No limit
Max ship length:	300 m

Drift parameters:

Blackout Frequency

RoRo and Passenger	0.10 per year
Other vessels	0.75 per year

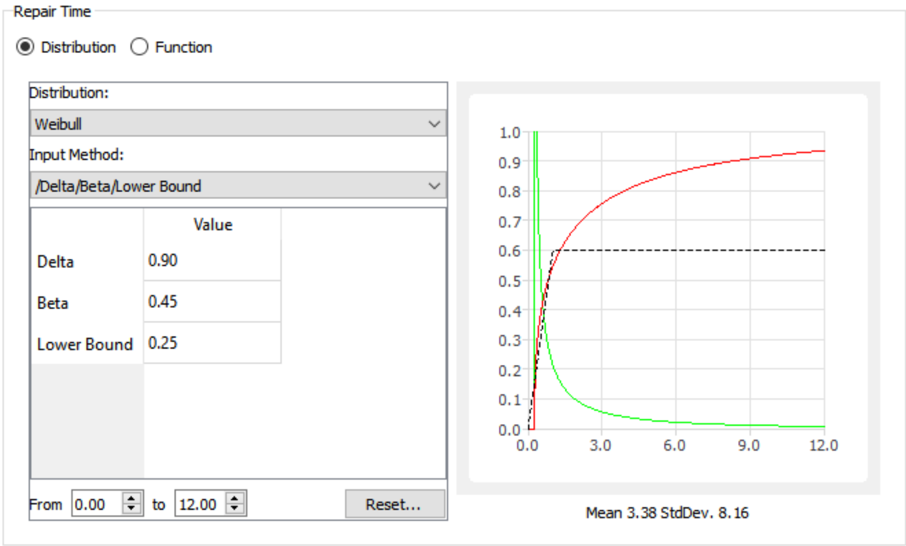
Drift Speed

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:



Wind rose, ref. MScThesisReport_GydeOhlsen_revised_03_2019.pdf (dtu.dk). The wind rose is in line with what has been commented in the HAZID workshop and other reports from nearby areas.

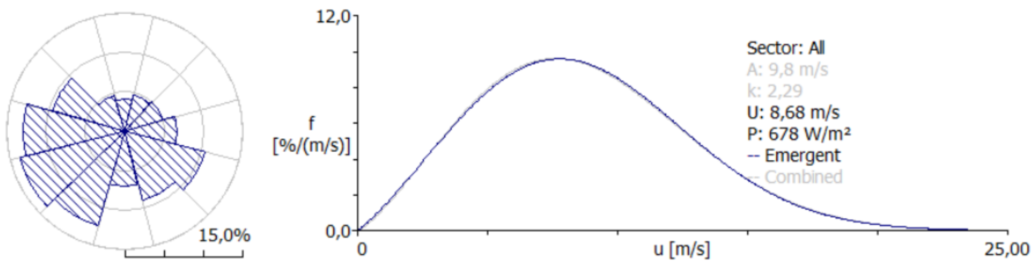
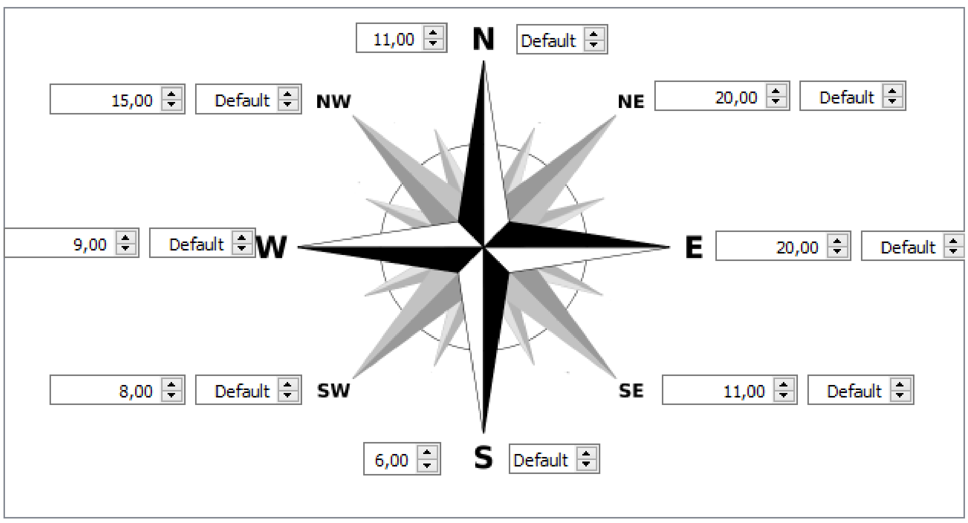


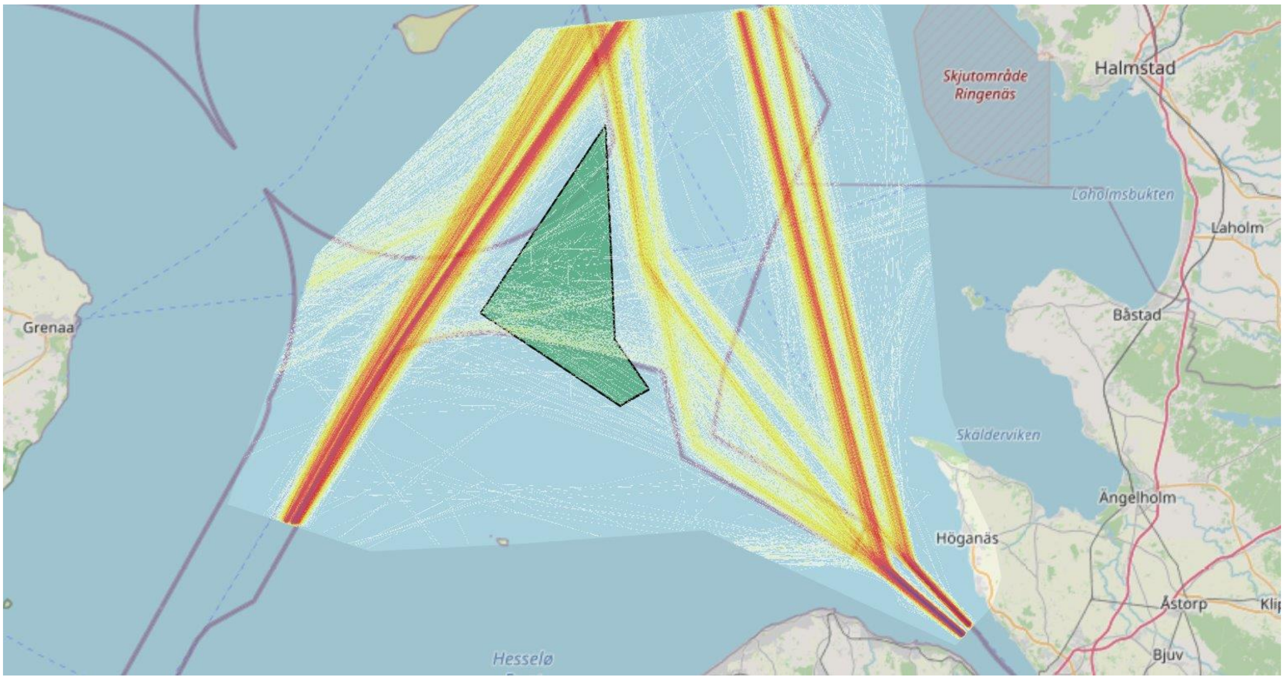
Figure 5.13: Hesselø wind rose (left) and Weibull probability density function (right) at 100 m height (WAsP derived).



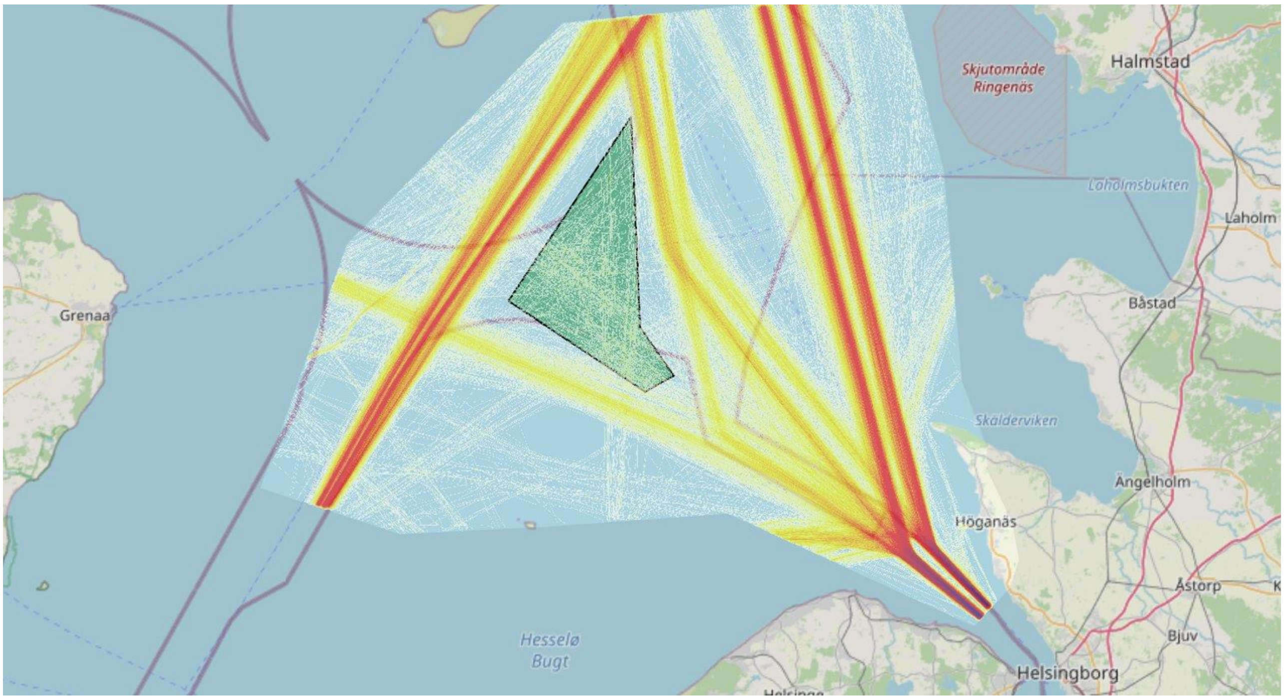
Note that the drift direction in IWRAP is specified for directions where vessels most likely will drift *towards*, while the wind rose itself indicates the dominant wind direction where the wind is coming *from*.

APPENDIX B
Traffic density plots per ship type

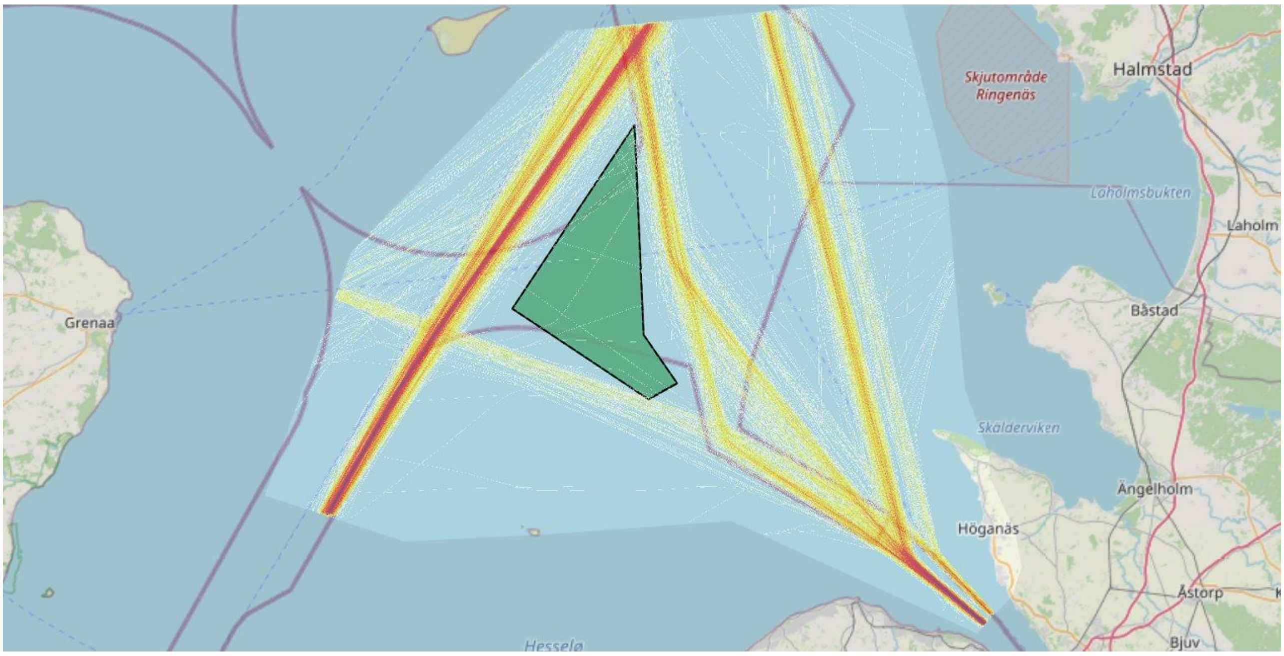
OIL, GAS & CHEMICAL/PRODUCTS TANKERS



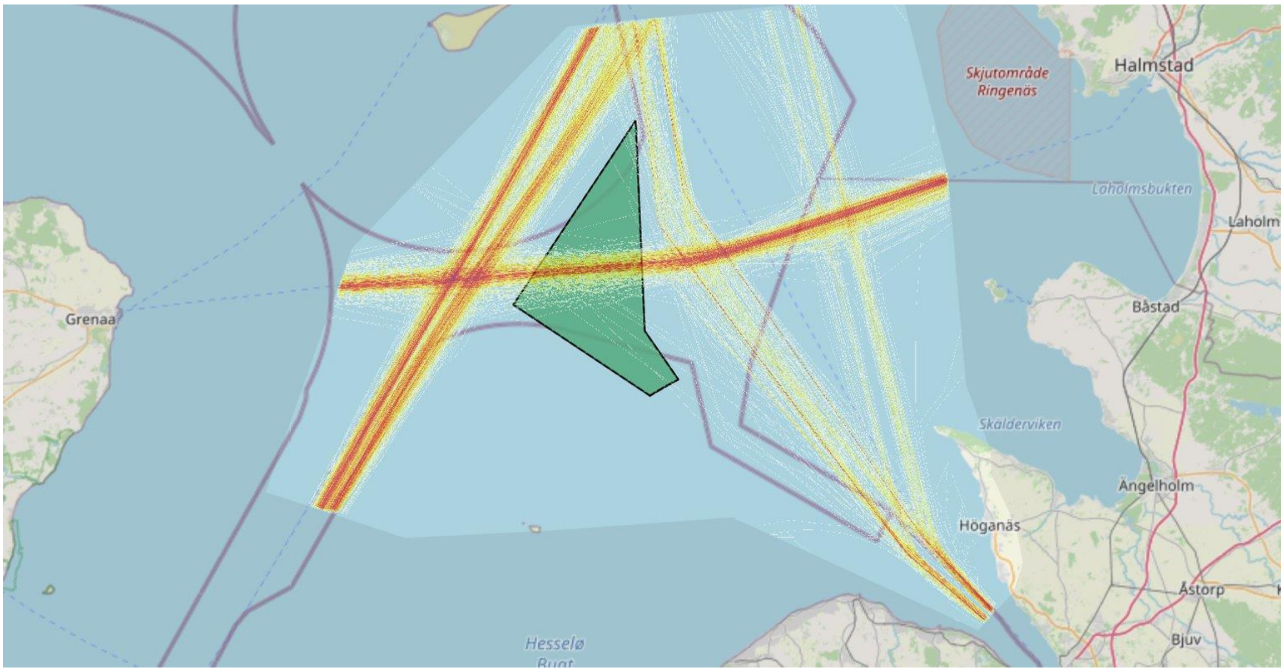
CONTAINER SHIPS AND CARGO/RORO-SHIPS



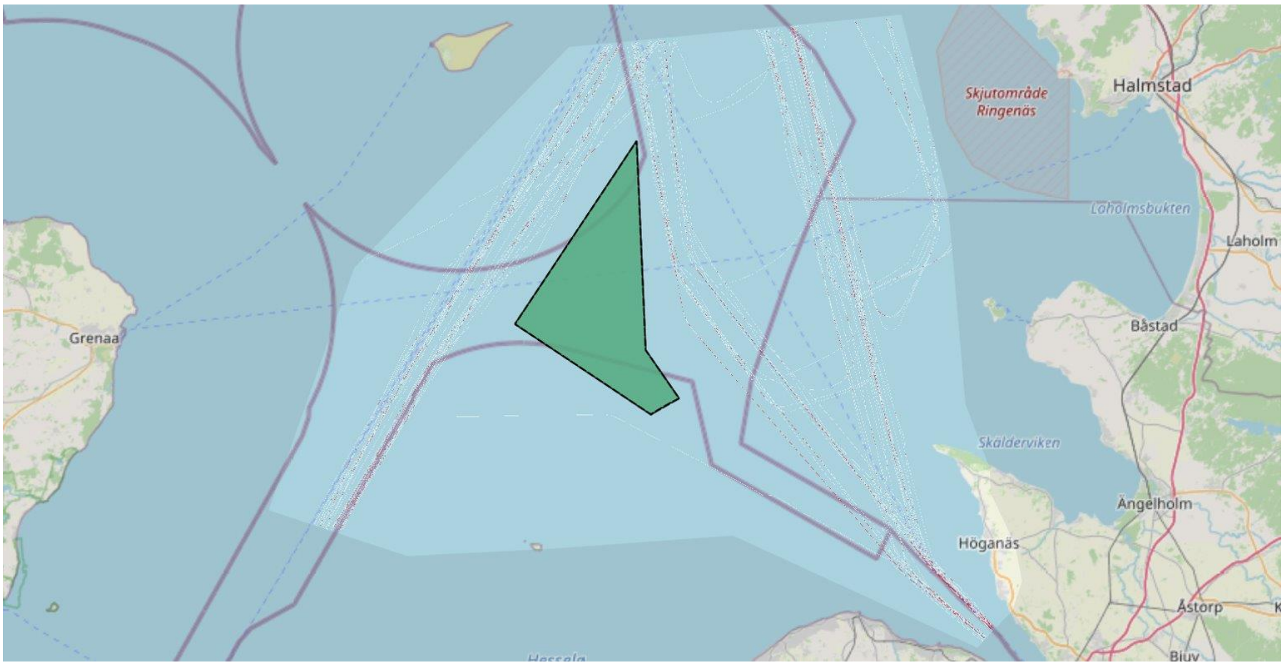
BULK CARRIERS



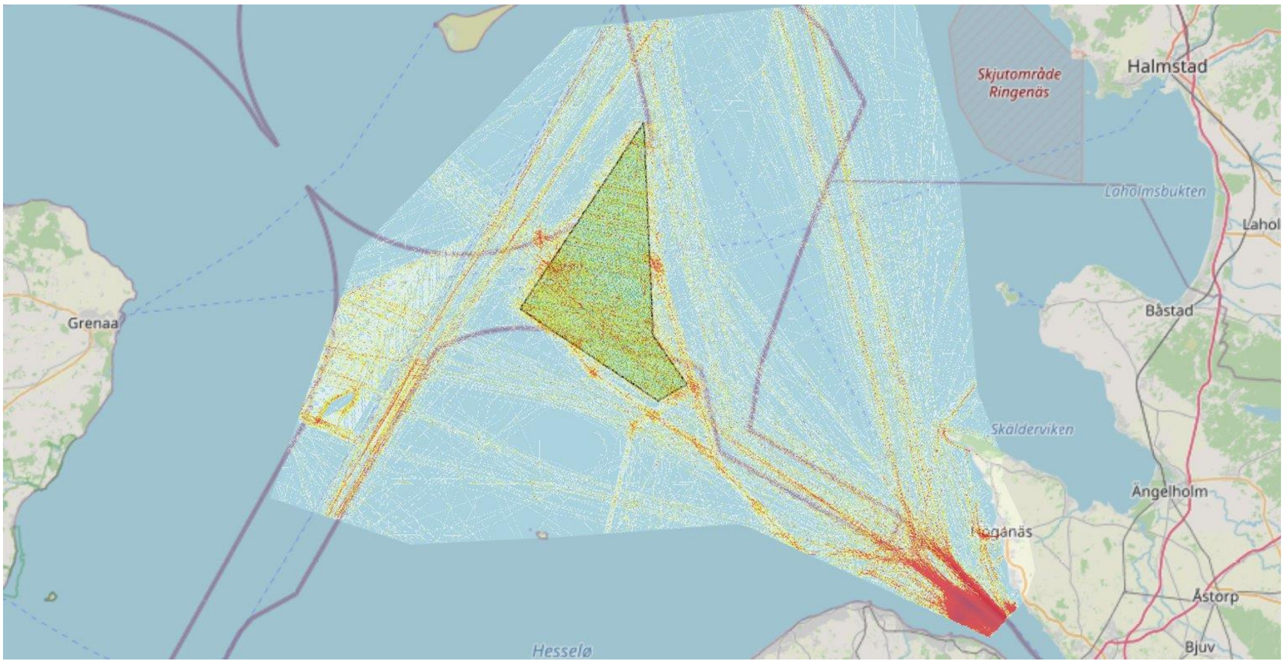
PASSENGER/RORO SHIPS (ROPAX) AND PASSENGER SHIPS



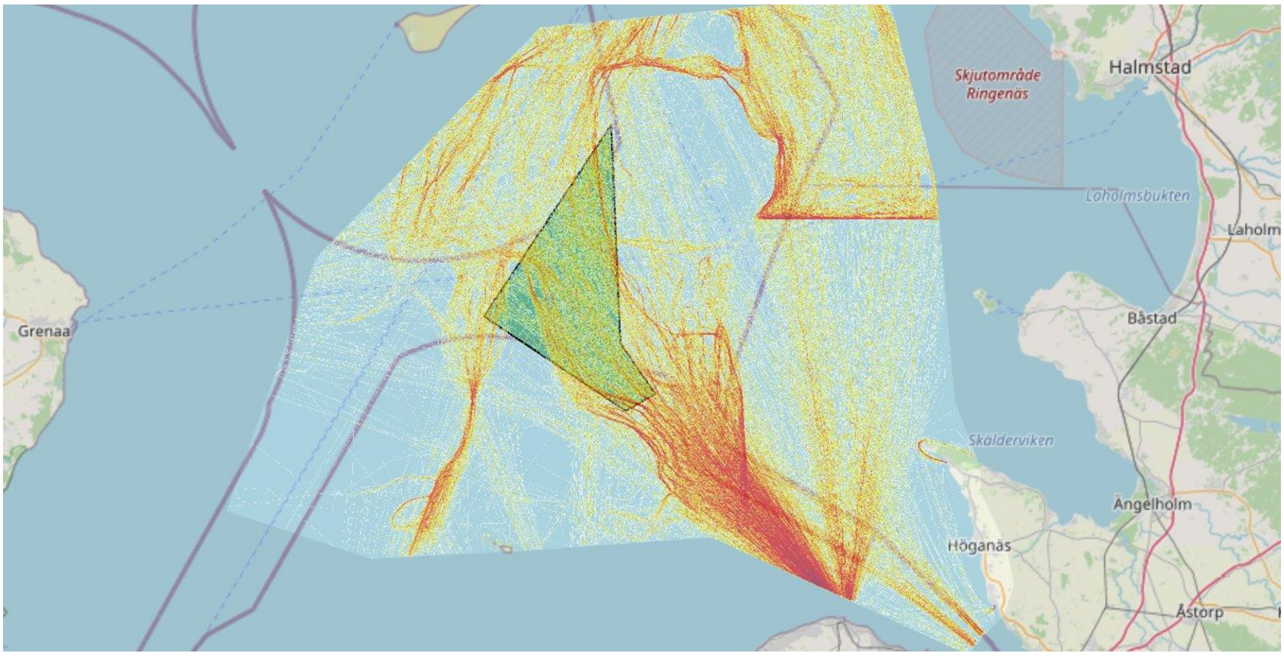
CRUISE SHIPS



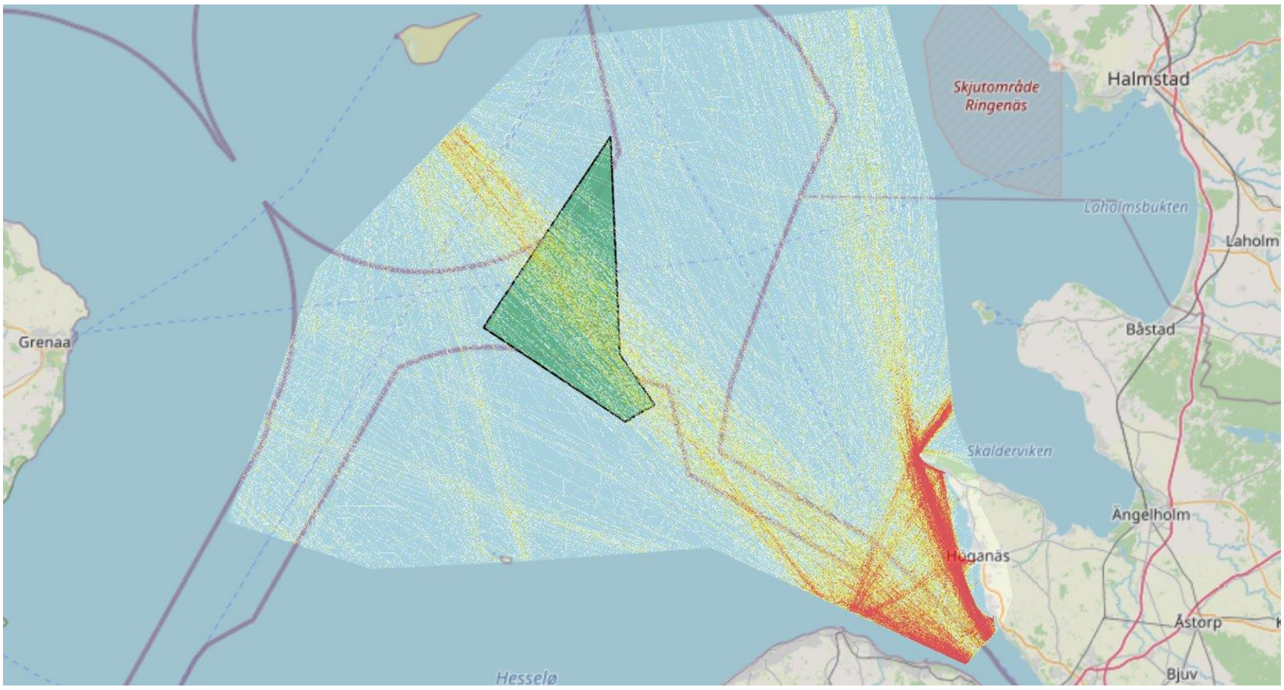
TUGS, OFFSHORE SUPPLY VESSELS, OTHER OFFSHORE SERVICE SHIPS, AND OTHER SERVICE VESSELS



FISHING VESSELS



PLEASURE CRAFTS



APPENDIX C
Traffic composition (before establishment)

TRAFFIC COMPOSITION ALONG EACH ROUTE BEFORE ADJUSTMENT OF CRUISE AND PASSENGER SHIP TRAFFIC IN THE PERIOD JULY 1ST TO DECEMBER 31ST, 2020

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo- /Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
Route T																		
0-30	0	0	0	0	0	0	0	0	0	0	0	1	0	97	8	0	**106**	**1 %**
30-70	2	0	0	0	6	0	0	0	0	2	0	5	35	1	3	9	**63**	**1 %**
70-100	24	55	1	0	117	0	0	0	0	6	2	1	16	2	0	0	**224**	**3 %**
100-150	44	627	23	24	482	28	2	0	0	0	1	0	17	0	1	3	**1252**	**17 %**
150-200	184	781	42	619	1285	186	0	0	0	0	4	0	17	0	0	1	**3119**	**42 %**
200-250	280	6	4	396	576	131	0	651	0	0	0	0	0	0	0	0	**2044**	**27 %**
250-300	342	0	13	30	49	37	0	0	4	0	0	0	0	0	0	0	**475**	**6 %**
300-350	2	0	16	0	0	2	0	0	21	0	0	0	0	0	0	0	**41**	**1 %**
350-	0	0	0	1	36	116	0	0	0	0	0	0	0	0	0	0	**153**	**2 %**
Sum	**878**	**1469**	**99**	**1070**	**2551**	**500**	**2**	**651**	**25**	**8**	**7**	**7**	**85**	**100**	**12**	**13**	**7477**	**100 %**
%	**12 %**	**20 %**	**1 %**	**14 %**	**34 %**	**7 %**	**0 %**	**9 %**	**0 %**	**0 %**	**0 %**	**0 %**	**1 %**	**1 %**	**0 %**	**0 %**	**100 %**	
Route S																		
0-30	0	0	0	0	1	0	0	0	0	3	1	25	9	137	86	0	**262**	**4 %**
30-70	14	0	0	0	47	0	1	0	0	2	2	37	23	44	10	1	**181**	**2 %**
70-100	93	160	13	68	2098	0	0	1	0	3	4	4	24	4	0	4	**2476**	**34 %**
100-150	117	761	36	26	1771	130	3	4	2	0	4	0	8	4	0	0	**2866**	**39 %**
150-200	56	325	23	147	375	7	2	102	1	0	5	0	0	0	0	0	**1043**	**14 %**
200-250	49	3	3	128	220	0	0	0	8	0	0	0	1	2	0	0	**414**	**6 %**
250-300	23	0	0	6	2	0	0	0	2	0	0	0	0	0	0	0	**33**	**0 %**
300-350	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	**6**	**0 %**

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo-/Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**352**	**1249**	**75**	**375**	**4514**	**137**	**6**	**107**	**19**	**8**	**16**	**66**	**65**	**191**	**96**	**5**	**7281**	**100 %**
%	**5 %**	**17 %**	**1 %**	**5 %**	**62 %**	**2 %**	**0 %**	**1 %**	**0 %**	**0 %**	**0 %**	**1 %**	**1 %**	**3 %**	**1 %**	**0 %**	**100 %**	
Old Route D1																		
0-30	0	0	0	0	0	0	0	0	0	0	0	7	3	115	113	3	**241**	**9 %**
30-70	4	0	0	0	12	0	0	0	0	1	3	16	12	54	6	1	**110**	**4 %**
70-100	31	65	4	18	442	0	0	0	1	1	3	0	10	7	0	2	**584**	**22 %**
100-150	39	184	9	20	401	36	3	0	5	0	1	0	3	1	0	0	**702**	**27 %**
150-200	13	137	16	110	207	59	3	201	2	0	1	0	1	0	0	1	**751**	**29 %**
200-250	30	0	2	78	85	1	0	0	3	0	0	0	0	1	0	0	**200**	**8 %**
250-300	12	0	0	10	1	2	0	0	0	0	0	0	0	0	0	0	**25**	**1 %**
300-350	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	**2**	**0 %**
350-	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	**6**	**0 %**
Sum	**129**	**386**	**31**	**236**	**1154**	**98**	**6**	**201**	**13**	**2**	**8**	**23**	**29**	**178**	**119**	**7**	**2621**	**100 %**
%	**5 %**	**15 %**	**1 %**	**9 %**	**44 %**	**4 %**	**0 %**	**8 %**	**0 %**	**0 %**	**0 %**	**1 %**	**1 %**	**7 %**	**5 %**	**0 %**	**100 %**	
Old Route D2																		
0-30	0	0	0	0	0	0	0	0	0	0	0	1	3	126	6	1	**137**	**14 %**
30-70	0	0	0	0	4	0	0	0	0	0	1	5	19	27	2	0	**58**	**6 %**
70-100	5	14	0	0	119	0	1	0	0	2	1	0	4	3	0	0	**149**	**16 %**
100-150	17	53	10	3	105	3	0	0	0	0	1	0	2	6	0	0	**200**	**21 %**
150-200	4	87	3	72	76	14	0	7	0	0	0	0	1	0	0	0	**264**	**27 %**
200-250	18	0	0	77	33	0	0	0	0	0	0	0	0	2	0	0	**130**	**14 %**
250-300	14	0	0	7	2	0	0	0	0	0	0	0	0	0	0	0	**23**	**2 %**
300-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**58**	**154**	**13**	**159**	**339**	**17**	**1**	**7**	**0**	**2**	**3**	**6**	**29**	**164**	**8**	**1**	**961**	**100 %**

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo- /Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
%	6 %	16 %	1 %	17 %	35 %	2 %	0 %	1 %	0 %	0 %	0 %	1 %	3 %	17 %	1 %	0 %	100 %	
Route 3																		
0-30	0	0	0	0	0	0	0	0	0	0	0	9	2	44	15	0	**70**	**8 %**
30-70	0	0	0	0	17	0	0	0	0	1	4	24	21	19	0	0	**86**	**10 %**
70-100	6	6	0	81	445	0	0	0	0	4	0	0	4	0	0	1	**547**	**63 %**
100-150	1	9	0	7	57	61	0	0	1	0	0	0	1	0	0	0	**137**	**16 %**
150-200	0	2	0	5	11	0	0	0	0	0	0	0	0	0	0	0	**18**	**2 %**
200-250	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	**5**	**1 %**
250-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
300-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**7**	**17**	**0**	**97**	**531**	**61**	**0**	**0**	**1**	**5**	**4**	**33**	**28**	**63**	**15**	**1**	**863**	**100 %**
%	**1 %**	**2 %**	**0 %**	**11 %**	**62 %**	**7 %**	**0 %**	**0 %**	**0 %**	**1 %**	**0 %**	**4 %**	**3 %**	**7 %**	**2 %**	**0 %**	**100 %**	
Stena Route																		
0-30	0	0	0	0	1	0	0	0	0	0	0	0	0	14	1	0	**16**	**2 %**
30-70	0	0	0	0	1	0	0	0	0	2	0	4	73	0	1	0	**81**	**11 %**
70-100	1	9	0	0	12	0	0	0	0	0	0	0	1	0	0	0	**23**	**3 %**
100-150	10	35	0	0	1	1	0	559	0	0	0	0	0	0	0	0	**606**	**81 %**
150-200	0	1	0	1	11	0	0	0	0	0	0	0	0	0	0	0	**13**	**2 %**
200-250	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	**11**	**1 %**
250-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
300-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**11**	**45**	**0**	**1**	**37**	**1**	**0**	**559**	**0**	**2**	**0**	**4**	**74**	**14**	**2**	**0**	**750**	**100 %**
%	**1 %**	**6 %**	**0 %**	**0 %**	**5 %**	**0 %**	**0 %**	**75 %**	**0 %**	**0 %**	**0 %**	**1 %**	**10 %**	**2 %**	**0 %**	**0 %**	**100 %**	

TRAFFIC COMPOSITION ALONG EACH ROUTE AFTER ADJUSTMENT OF CRUISE AND PASSENGER SHIP TRAFFIC IN THE PERIOD JULY 1ST TO DECEMBER 31ST, 2020

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo-/ Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
Route T																		
0-30	0	0	0	0	0	0	0	0	0	0	0	1	0	96	8	0	**105**	**1 %**
30-70	2	0	0	0	6	0	0	0	0	2	0	5	35	1	3	9	**63**	**1 %**
70-100	24	55	1	0	117	0	0	0	0	6	2	1	16	2	0	0	**224**	**3 %**
100-150	44	627	23	24	484	28	18	0	0	0	1	0	17	0	1	1	**1268**	**17 %**
150-200	184	781	42	619	1286	172	0	0	0	0	4	0	17	0	0	14	**3119**	**41 %**
200-250	280	6	4	396	576	131	0	781	0	0	0	0	0	0	0	0	**2174**	**28 %**
250-300	342	0	13	30	49	37	0	0	10	0	0	0	0	0	0	0	**481**	**6 %**
300-350	2	0	16	0	0	2	0	0	55	0	0	0	0	0	0	0	**75**	**1 %**
350-	0	0	0	1	36	116	0	0	0	0	0	0	0	0	0	0	**153**	**2 %**
Sum	**878**	**1469**	**99**	**1070**	**2554**	**486**	**18**	**781**	**65**	**8**	**7**	**7**	**85**	**99**	**12**	**24**	**7662**	**100 %**
%	**11 %**	**19 %**	**1 %**	**14 %**	**33 %**	**6 %**	**0 %**	**10 %**	**1 %**	**0 %**	**0 %**	**0 %**	**1 %**	**1 %**	**0 %**	**0 %**	**100 %**	
Route S																		
0-30	0	0	0	0	1	0	0	0	0	3	1	25	9	137	86	0	**262**	**4 %**
30-70	14	0	0	0	47	0	9	0	0	2	2	37	23	44	10	1	**189**	**3 %**
70-100	93	160	13	68	2097	0	0	1	0	3	4	4	24	4	0	4	**2475**	**34 %**
100-150	117	761	36	26	1770	130	18	6	5	0	4	0	8	4	0	0	**2885**	**39 %**
150-200	56	325	23	147	375	7	18	122	3	0	5	0	0	0	0	0	**1081**	**15 %**
200-250	49	3	3	128	220	0	0	0	21	0	0	0	1	2	0	0	**427**	**6 %**
250-300	23	0	0	6	2	0	0	0	5	0	0	0	0	0	0	0	**36**	**0 %**
300-350	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	**16**	**0 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**

Sum	**352**	**1249**	**75**	**375**	**4512**	**137**	**45**	**130**	**49**	**8**	**16**	**66**	**65**	**191**	**96**	**5**	**7371**	**100 %**
%	**5 %**	**17 %**	**1 %**	**5 %**	**61 %**	**2 %**	**1 %**	**2 %**	**1 %**	**0 %**	**0 %**	**1 %**	**1 %**	**3 %**	**1 %**	**0 %**	**100 %**	
Old Route D1																		
0-30	0	0	0	0	0	0	0	0	0	0	0	7	3	115	113	3	**241**	**9 %**
30-70	4	0	0	0	12	0	0	0	0	1	3	16	12	54	6	1	**110**	**4 %**
70-100	31	65	4	18	442	0	0	0	3	1	3	0	10	7	0	2	**586**	**21 %**
100-150	39	184	9	20	400	36	27	0	13	0	1	0	3	1	0	0	**733**	**27 %**
150-200	13	137	16	110	208	59	27	241	5	0	1	0	1	0	0	0	**818**	**30 %**
200-250	30	0	2	78	85	1	0	0	8	0	0	0	0	1	0	0	**205**	**8 %**
250-300	12	0	0	10	1	2	0	0	0	0	0	0	0	0	0	0	**25**	**1 %**
300-350	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	**5**	**0 %**
350-	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	**6**	**0 %**
Sum	**129**	**386**	**31**	**236**	**1154**	**98**	**54**	**241**	**34**	**2**	**8**	**23**	**29**	**178**	**119**	**6**	**2729**	**100 %**
%	**5 %**	**14 %**	**1 %**	**9 %**	**42 %**	**4 %**	**2 %**	**9 %**	**1 %**	**0 %**	**0 %**	**1 %**	**1 %**	**7 %**	**4 %**	**0 %**	**100 %**	
Old Route D2																		
0-30	0	0	0	0	0	0	0	0	0	0	0	1	3	126	6	1	**137**	**14 %**
30-70	0	0	0	0	4	0	0	0	0	0	1	5	19	27	2	0	**58**	**6 %**
70-100	5	14	0	0	119	0	0	0	3	2	1	0	4	3	0	0	**151**	**16 %**
100-150	17	53	10	3	105	3	0	0	0	0	1	0	2	6	0	0	**200**	**21 %**
150-200	4	87	3	72	76	14	0	8	0	0	0	0	1	0	0	0	**265**	**28 %**
200-250	18	0	0	77	33	0	0	0	0	0	0	0	0	2	0	0	**130**	**13 %**
250-300	14	0	0	7	2	0	0	0	0	0	0	0	0	0	0	0	**23**	**2 %**
300-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**58**	**154**	**13**	**159**	**339**	**17**	**0**	**8**	**3**	**2**	**3**	**6**	**29**	**164**	**8**	**1**	**964**	**100 %**
%	**6 %**	**16 %**	**1 %**	**16 %**	**35 %**	**2 %**	**0 %**	**1 %**	**0 %**	**0 %**	**0 %**	**1 %**	**3 %**	**17 %**	**1 %**	**0 %**	**100 %**	
Route 3																		
0-30	0	0	0	0	0	0	0	0	0	0	0	9	2	44	15	0	**70**	**8 %**

30-70	0	0	0	0	17	0	0	0	0	1	4	24	21	19	0	0	**86**	**10 %**
70-100	6	6	0	81	445	0	0	0	0	4	0	0	4	0	0	1	**547**	**63 %**
100-150	1	9	0	7	57	61	0	0	3	0	0	0	1	0	0	0	**139**	**16 %**
150-200	0	2	0	5	11	0	0	0	0	0	0	0	0	0	0	0	**18**	**2 %**
200-250	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	**5**	**1 %**
250-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
300-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**7**	**17**	**0**	**97**	**531**	**61**	**0**	**0**	**3**	**5**	**4**	**33**	**28**	**63**	**15**	**1**	**865**	**100 %**
%	**1 %**	**2 %**	**0 %**	**11 %**	**61 %**	**7 %**	**0 %**	**0 %**	**0 %**	**1 %**	**0 %**	**4 %**	**3 %**	**7 %**	**2 %**	**0 %**	**100 %**	
Stena Route																		
0-30	0	0	0	0	1	0	0	0	0	0	0	0	0	14	1	0	**16**	**2 %**
30-70	0	0	0	0	1	0	0	0	0	2	0	4	73	0	1	0	**81**	**9 %**
70-100	1	9	0	0	12	0	0	0	0	0	0	0	1	0	0	0	**23**	**3 %**
100-150	10	35	0	0	1	1	0	671	0	0	0	0	0	0	0	0	**718**	**83 %**
150-200	0	1	0	1	11	0	0	0	0	0	0	0	0	0	0	0	**13**	**2 %**
200-250	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	**11**	**1 %**
250-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
300-350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**11**	**45**	**0**	**1**	**37**	**1**	**0**	**671**	**0**	**2**	**0**	**4**	**74**	**14**	**2**	**0**	**862**	**100 %**
%	**1 %**	**5 %**	**0 %**	**0 %**	**4 %**	**0 %**	**0 %**	**78 %**	**0 %**	**0 %**	**0 %**	**0 %**	**9 %**	**2 %**	**0 %**	**0 %**	**100 %**	

APPENDIX D
Accident frequencies

GROUNDING FREQUENCIES BEFORE OWF ESTABLISHMENT

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo-/ Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
>30m	0,0E+00	0,0E+00	0,0E+00	0,0E+00	1,2E-05	0,0E+00	1,3E-05	0,0E+00	0,0E+00	2,6E-05	1,2E-05	3,5E-04	7,4E-05	3,9E-03	1,6E-03	4,2E-05	**6,0E-03**	**2 %**
30-70m	4,6E-04	0,0E+00	0,0E+00	0,0E+00	1,9E-03	0,0E+00	2,2E-04	0,0E+00	0,0E+00	1,0E-04	1,9E-04	2,2E-03	1,5E-03	2,1E-03	4,9E-04	7,2E-05	**9,3E-03**	**3 %**
70-100m	2,9E-03	5,1E-03	3,6E-04	2,5E-03	6,4E-02	0,0E+00	0,0E+00	3,1E-05	7,0E-05	2,2E-04	1,7E-04	1,7E-04	7,9E-04	2,3E-04	0,0E+00	1,5E-04	**7,7E-02**	**25 %**
100-150m	3,4E-03	2,6E-02	1,0E-03	1,2E-03	4,8E-02	3,6E-03	7,3E-04	2,6E-03	3,3E-04	0,0E+00	1,2E-04	0,0E+00	4,2E-04	1,5E-04	2,0E-05	3,4E-05	**8,7E-02**	**28 %**
150-200m	3,2E-03	2,4E-02	1,1E-03	1,7E-02	2,1E-02	2,2E-03	4,8E-04	4,3E-03	1,2E-04	0,0E+00	2,2E-04	0,0E+00	1,3E-04	0,0E+00	0,0E+00	2,5E-04	**7,4E-02**	**24 %**
200-250m	7,2E-03	1,9E-04	1,2E-04	1,3E-02	1,4E-02	1,6E-03	0,0E+00	5,5E-03	5,8E-04	0,0E+00	0,0E+00	0,0E+00	2,3E-05	7,1E-05	0,0E+00	0,0E+00	**4,2E-02**	**14 %**
250-300m	7,2E-03	0,0E+00	1,9E-04	1,0E-03	9,1E-04	5,7E-04	0,0E+00	0,0E+00	3,7E-04	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**1,0E-02**	**3 %**
300-350m	2,3E-05	0,0E+00	2,1E-04	0,0E+00	0,0E+0 0	2,6E-05	0,0E+00	0,0E+00	1,4E-03	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**1,6E-03**	**1 %**
>350m	0,0E+00	0,0E+00	0,0E+00	1,1E-05	5,2E-04	1,6E-03	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**2,1E-03**	**1 %**
Sum	**2,4E-02**	**5,5E-02**	**3,0E-03**	**3,5E-02**	**1,5E-01**	**9,6E-03**	**1,4E-03**	**1,2E-02**	**2,8E-03**	**3,5E-04**	**7,2E-04**	**2,8E-03**	**3,0E-03**	**6,4E-03**	**2,1E-03**	**5,4E-04**	**3,1E-01**	**100 %**
%	**8 %**	**18 %**	**1 %**	**11 %**	**49 %**	**3 %**	**0 %**	**4 %**	**1 %**	**0 %**	**0 %**	**1 %**	**1 %**	**2 %**	**1 %**	**0 %**	**100 %**	

SHIP-SHIP COLLISION FREQUENCIES BEFORE OWF ESTABLISHMENT

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo- /Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
Oil Tanker	4,5E-04	6,2E-04	8,0E-05	5,6E-04	2,0E-03	4,0E-04	2,2E-05	1,0E-03	6,7E-05	4,0E-06	4,8E-06	1,1E-05	4,5E-05	3,6E-05	6,1E-06	1,8E-05	**5,4E-03**	**9 %**
Chemical/ Products Tanker	8,2E-04	1,0E-03	1,5E-04	1,0E-03	3,5E-03	6,7E-04	4,7E-05	1,9E-03	1,1E-04	6,6E-06	8,4E-06	2,0E-05	7,1E-05	6,2E-05	1,0E-05	3,1E-05	**9,5E-03**	**16 %**
Gas Tanker	4,9E-05	6,7E-05	6,0E-06	6,6E-05	1,7E-04	3,3E-05	2,2E-06	1,0E-04	5,5E-06	4,0E-07	5,0E-07	1,4E-06	3,8E-06	3,9E-06	6,9E-07	1,3E-06	**5,1E-04**	**1 %**
Bulk Carrier	6,8E-04	8,8E-04	1,1E-04	7,5E-04	2,8E-03	5,4E-04	3,0E-05	1,4E-03	8,9E-05	5,8E-06	7,5E-06	1,7E-05	6,1E-05	5,5E-05	9,8E-06	2,7E-05	**7,4E-03**	**13 %**
Cargo-/Roro Ship	1,9E-03	3,0E-03	3,2E-04	2,6E-03	7,3E-03	1,2E-03	1,2E-04	3,8E-03	1,9E-04	1,6E-05	2,0E-05	4,6E-05	1,3E-04	1,5E-04	2,4E-05	4,3E-05	**2,1E-02**	**36 %**

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo- /Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
Container Ship	2,1E-04	3,0E-04	2,0E-05	2,8E-04	6,0E-04	7,9E-05	4,8E-06	2,7E-04	1,5E-05	1,7E-06	2,2E-06	5,5E-06	1,4E-05	1,5E-05	3,3E-06	4,0E-06	**1,8E-03**	**3 %**
Passenger Ship	8,5E-06	1,5E-05	1,8E-06	1,2E-05	4,2E-05	7,9E-06	7,5E-07	1,7E-05	1,3E-06	6,5E-08	1,2E-07	1,4E-07	8,1E-07	8,2E-07	1,5E-07	1,7E-07	**1,1E-04**	**0 %**
Passenger/ Roro Ship	6,5E-04	1,1E-03	6,9E-05	8,9E-04	2,6E-03	2,2E-04	5,0E-06	4,4E-04	3,2E-05	4,6E-06	8,6E-06	1,6E-05	4,6E-05	6,7E-05	7,4E-06	1,0E-05	**6,2E-03**	**11 %**
Cruise Ship	4,8E-05	9,7E-05	1,1E-05	6,2E-05	2,7E-04	3,3E-05	4,7E-06	6,5E-05	4,6E-06	3,6E-07	7,5E-07	6,7E-07	4,0E-06	4,0E-06	6,7E-07	1,1E-06	**6,0E-04**	**1 %**
Offshore Supply Ship	1,3E-05	2,0E-05	1,8E-06	1,6E-05	4,8E-05	7,9E-06	3,9E-07	1,5E-05	1,2E-06	5,7E-08	1,4E-07	2,2E-07	9,1E-07	7,0E-07	1,7E-07	3,3E-07	**1,3E-04**	**0 %**
Other Offshore Vessels	1,5E-05	2,9E-05	2,9E-06	2,2E-05	7,9E-05	1,1E-05	1,1E-06	2,3E-05	1,6E-06	1,4E-07	2,0E-07	4,0E-07	1,4E-06	1,7E-06	4,1E-07	3,4E-07	**1,9E-04**	**0 %**
Tug	5,4E-05	1,2E-04	9,5E-06	7,6E-05	3,0E-04	2,8E-05	4,1E-06	5,7E-05	5,3E-06	5,0E-07	1,2E-06	1,1E-06	4,5E-06	5,6E-06	1,5E-06	1,1E-06	**6,7E-04**	**1 %**
Service Vessels	6,5E-05	9,5E-05	8,9E-06	8,5E-05	2,3E-04	4,2E-05	2,8E-06	1,2E-04	5,9E-06	5,0E-07	6,6E-07	1,4E-06	4,0E-06	4,5E-06	8,2E-07	1,6E-06	**6,8E-04**	**1 %**
Fishing Vessel	3,9E-04	6,6E-04	5,6E-05	4,8E-04	1,6E-03	2,0E-04	1,9E-05	4,0E-04	4,6E-05	2,6E-06	7,0E-06	8,2E-06	2,4E-05	2,0E-05	7,0E-06	1,0E-05	**3,9E-03**	**7 %**
Pleasure Craft	4,6E-05	9,2E-05	8,7E-06	6,2E-05	2,5E-04	3,0E-05	5,4E-06	5,7E-05	5,3E-06	4,2E-07	9,6E-07	8,4E-07	3,9E-06	4,6E-06	6,9E-07	1,1E-06	**5,7E-04**	**1 %**
Unknown	1,4E-05	2,2E-05	2,0E-06	2,0E-05	5,5E-05	9,6E-06	8,3E-07	2,2E-05	1,9E-06	1,8E-07	2,8E-07	4,8E-07	1,1E-06	1,6E-06	3,9E-07	2,0E-07	**1,5E-04**	**0 %**
Sum	**5,4E-03**	**8,2E-03**	**8,7E-04**	**6,9E-03**	**2,2E-02**	**3,5E-03**	**2,7E-04**	**9,7E-03**	**5,8E-04**	**4,4E-05**	**6,4E-05**	**1,3E-04**	**4,2E-04**	**4,3E-04**	**7,4E-05**	**1,5E-04**	**5,9E-02**	**100 %**
%	**9 %**	**14 %**	**1 %**	**12 %**	**37 %**	**6 %**	**0 %**	**17 %**	**1 %**	**0 %**	**0 %**	**0 %**	**1 %**	**1 %**	**0 %**	**0 %**	**100 %**	

SHIP-TURBINE COLLISION FREQUENCIES AFTER OWF ESTABLISHMENT, SCENARIO 1

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo- /Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
>30m	0,0E+00	0,0E+00	0,0E+00	0,0E+00	1,2E-07	0,0E+00	1,7E-11	0,0E+00	0,0E+00	6,7E-08	3,1E-08	5,0E-06	2,0E-06	8,4E-05	1,7E-05	8,7E-07	**1,1E-04**	**2 %**
30-70m	3,9E-06	0,0E+00	0,0E+00	0,0E+00	2,8E-05	0,0E+00	5,7E-07	0,0E+00	0,0E+00	3,2E-06	7,5E-06	4,0E-05	5,8E-05	5,0E-05	8,4E-06	3,2E-06	**2,0E-04**	**4 %**
70-100m	3,8E-05	7,0E-05	3,0E-06	5,7E-05	7,6E-04	0,0E+00	0,0E+00	1,9E-08	3,2E-06	8,2E-06	3,4E-06	8,4E-07	1,8E-05	6,2E-06	0,0E+00	2,0E-06	**9,7E-04**	**17 %**
100-150m	5,1E-05	4,4E-04	2,1E-05	2,8E-05	5,8E-04	6,8E-05	2,0E-05	5,8E-05	8,6E-06	0,0E+00	2,1E-06	0,0E+00	1,1E-05	3,7E-06	7,6E-07	6,0E-07	**1,3E-03**	**23 %**
150-200m	8,9E-05	4,6E-04	2,5E-05	3,9E-04	6,4E-04	8,6E-05	1,1E-05	9,3E-05	2,3E-06	0,0E+00	2,8E-06	0,0E+00	5,7E-06	0,0E+00	0,0E+00	5,7E-06	**1,8E-03**	**32 %**
200-250m	1,5E-04	2,5E-06	1,8E-06	2,6E-04	2,8E-04	4,5E-05	0,0E+00	2,4E-04	4,6E-06	0,0E+00	0,0E+00	0,0E+00	5,3E-08	1,6E-06	0,0E+00	0,0E+00	**9,8E-04**	**17 %**

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo- /Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
250-300m	1,5E-04	0,0E+00	5,3E-06	2,3E-05	2,0E-05	1,3E-05	0,0E+00	0,0E+00	7,6E-06	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**2,2E-04**	**4 %**
300-350m	8,7E-07	0,0E+00	5,7E-06	0,0E+00	0,0E+00	5,8E-07	0,0E+00	0,0E+00	2,7E-05	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**3,4E-05**	**1 %**
>350m	0,0E+00	0,0E+00	0,0E+00	2,8E-07	1,3E-05	3,6E-05	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**4,9E-05**	**1 %**
Sum	**4,8E-04**	**9,8E-04**	**6,2E-05**	**7,5E-04**	**2,3E-03**	**2,5E-04**	**3,1E-05**	**3,9E-04**	**5,4E-05**	**1,1E-05**	**1,6E-05**	**4,6E-05**	**9,5E-05**	**1,5E-04**	**2,6E-05**	**1,2E-05**	**5,7E-03**	**100 %**
%	**9 %**	**17 %**	**1 %**	**13 %**	**41 %**	**4 %**	**1 %**	**7 %**	**1 %**	**0 %**	**0 %**	**1 %**	**2 %**	**3 %**	**0 %**	**0 %**	**100 %**	

SHIP-TURBINE COLLISION FREQUENCIES AFTER OWF ESTABLISHMENT, SCENARIO 2

	Oil Tanker	Chemical/ Products Tanker	Gas Tanker	Bulk Carrier	Cargo- /Roro Ship	Container Ship	Passenger Ship	Passenger/ Roro Ship	Cruise Ship	Offshore Supply Ship	Other Offshore Vessels	Tug	Service Vessels	Fishing Vessel	Pleasure Craft	Unknown	Sum	%
>30m	0,0E+00	0,0E+00	0,0E+00	0,0E+00	3,1E-07	0,0E+00	1,7E-11	0,0E+00	0,0E+00	9,6E-08	3,1E-08	5,1E-06	1,9E-06	8,7E-05	1,6E-05	6,5E-07	**1,1E-04**	**2 %**
30-70m	4,0E-06	0,0E+00	0,0E+00	0,0E+00	2,7E-05	0,0E+00	7,9E-07	0,0E+00	0,0E+00	4,3E-06	6,3E-06	3,8E-05	8,8E-05	4,7E-05	8,5E-06	3,3E-06	**2,3E-04**	**4 %**
70-100m	3,8E-05	7,4E-05	3,2E-06	5,0E-05	7,4E-04	0,0E+00	0,0E+00	2,6E-08	3,1E-06	7,7E-06	3,2E-06	1,0E-06	1,8E-05	6,1E-06	0,0E+00	1,9E-06	**9,4E-04**	**16 %**
100-150m	5,5E-05	4,6E-04	2,1E-05	2,7E-05	5,8E-04	6,3E-05	2,0E-05	2,4E-04	8,3E-06	0,0E+00	2,1E-06	0,0E+00	1,1E-05	3,5E-06	8,0E-07	6,0E-07	**1,5E-03**	**25 %**
150-200m	8,9E-05	4,6E-04	2,5E-05	3,8E-04	6,4E-04	8,5E-05	1,0E-05	8,7E-05	2,0E-06	0,0E+00	2,9E-06	0,0E+00	5,6E-06	0,0E+00	0,0E+00	5,7E-06	**1,8E-03**	**31 %**
200-250m	1,5E-04	2,6E-06	1,8E-06	2,5E-04	2,8E-04	4,5E-05	0,0E+00	2,4E-04	4,7E-06	0,0E+00	0,0E+00	0,0E+00	5,2E-08	1,6E-06	0,0E+00	0,0E+00	**9,8E-04**	**17 %**
250-300m	1,5E-04	0,0E+00	5,3E-06	2,2E-05	1,9E-05	1,3E-05	0,0E+00	0,0E+00	7,8E-06	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**2,2E-04**	**4 %**
300-350m	8,7E-07	0,0E+00	5,7E-06	0,0E+00	0,0E+00	5,8E-07	0,0E+00	0,0E+00	2,9E-05	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**3,6E-05**	**1 %**
>350m	0,0E+00	0,0E+00	0,0E+00	2,8E-07	1,3E-05	3,6E-05	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**4,9E-05**	**1 %**
Sum	**4,9E-04**	**9,9E-04**	**6,2E-05**	**7,3E-04**	**2,3E-03**	**2,4E-04**	**3,1E-05**	**5,6E-04**	**5,5E-05**	**1,2E-05**	**1,5E-05**	**4,4E-05**	**1,2E-04**	**1,5E-04**	**2,5E-05**	**1,2E-05**	**5,9E-03**	**100 %**
%	**8 %**	**17 %**	**1 %**	**13 %**	**39 %**	**4 %**	**1 %**	**10 %**	**1 %**	**0 %**	**0 %**	**1 %**	**2 %**	**2 %**	**0 %**	**0 %**	**100 %**	

DNV

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