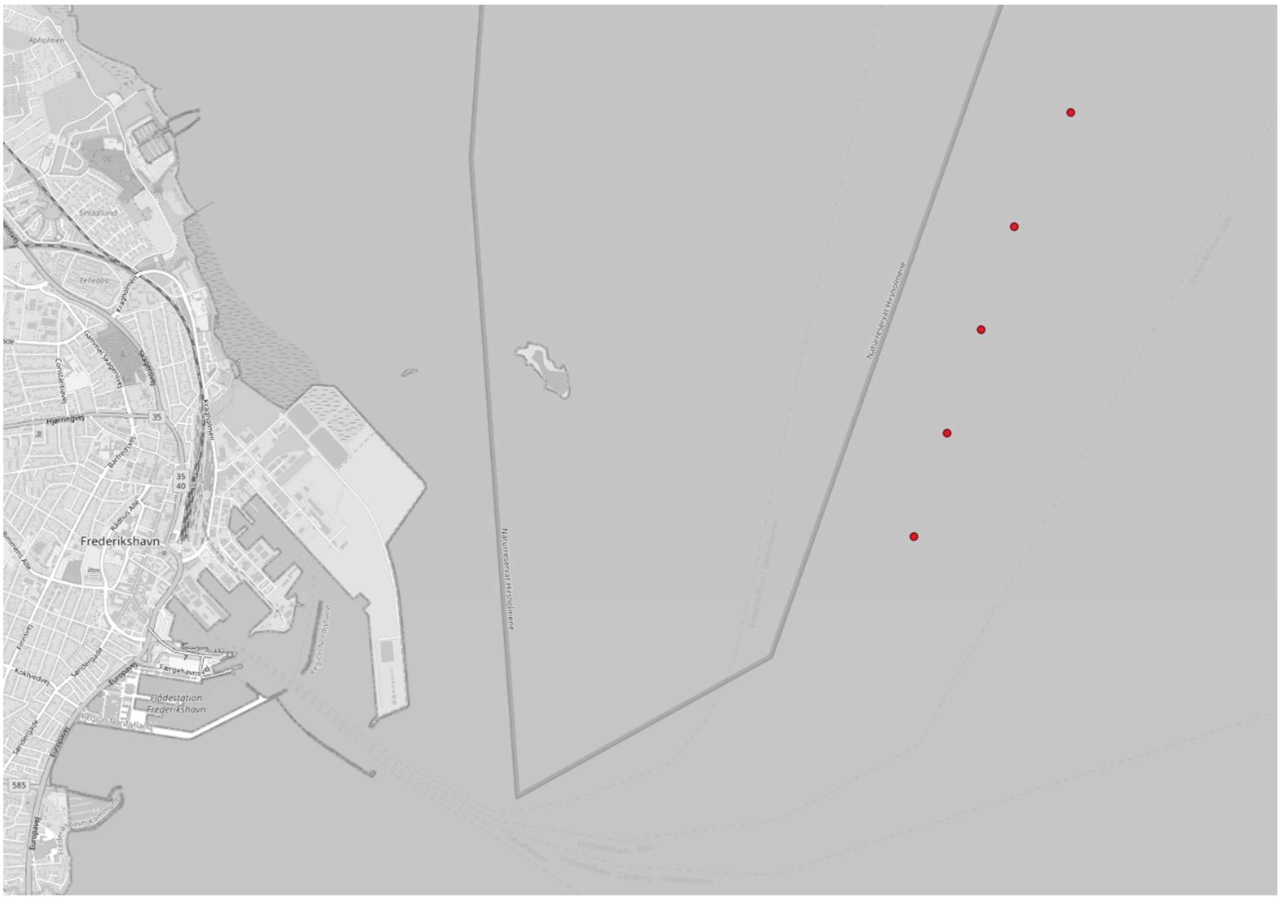
Final report

NAVIGATIONAL RISK ANALYSIS OF FREDERIKSHAVN OWF

Navigational Risk Assessment of Frederikshavn offshore wind farm

NIRAS A/S

Document No.: 11HYS6W7
Date: 2021-02-03



Project name:	Navigational Risk Analysis of Frederikshavn OWF	DNV GL AS Maritime Safety, Risk & Reliability
Report title:	Navigational Risk Assessment of Frederikshavn offshore wind farm	
Customer:	NIRAS A/S	
Customer contact:	Rikke Holm	
Date of issue:	2021-02-03	
Project No.:	10246326	
Organisation unit:	Safety, Risk & Reliability	
Report No.:	Rev. E	
Document No.:	11HYS6W7	

Prepared by:	Verified by:	Approved by:
Audun Marius Aasen Consultant	Johnsrud, Hans Jørgen (Digitally signed by Johnsrud, Hans Jørgen Date: 2021.02.18 13:04:19 +01'00') Hans Jørgen Johnsrud Senior consultant	Digitally signed by Hoffmann, Peter Nyegaard Date: 2021.02.18 13:18:44 +01'00' Peter Hoffmann Head of Section Safety Risk & Reliability
Digitally signed by Krugerud, Christine Date: 2021.02.18 12:43:06 +01'00' Christine Krugerud Consultant		

DNV GL Distribution:

☒ OPEN. Unrestricted distribution, internal and external.

☐ INTERNAL use only. Internal DNV GL document.

☐ CONFIDENTIAL. Distribution within DNV GL according to applicable contract.

☐ SECRET. Authorized access only.

Keywords:
Navigational risk, safety, offshore wind farm, Frederikshavn, ship collision

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	2020-11-16	Draft issue	MAASEN	HAJOH	
B	2020-12-07	2nd draft issue	MAASEN	HAJOH	
C	2021-01-21	Final issue	MAASEN	HAJOH	
D	2021-02-01	Final issue (editorial changes)	MAASEN	HAJOH	
E	2021-02-03	Final issue (editorial changes)	MAASEN	HAJOH	PHOFF

Table of contents

SUMMARY

This study presents the navigational risk assessment for the proposed offshore wind farm located east of Frederikshavn. The objective of this navigational risk assessment is to assess how, where and how much the offshore wind farm impact the maritime traffic.

The navigational hazards have been evaluated through modelling of ship traffic around the offshore wind turbines, both the traffic before establishing the wind farm and after establishment. Modelling both scenarios provides information on the change in accident frequency for ship-ship collisions, grounding and ship-turbine collisions due to the establishment of the turbines.

This study replaces the navigational risk assessment that was carried out in February 2008. The assessment is based on updated AIS-data from 2019, use of VMS fishery data, updated HAZID evaluations and using new improved software for frequency calculations (IALA Waterway Risk Assessment programme software - IWRAP).

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). Therefore, the risk evaluation cannot make a definite conclusion on whether the risk is within any defined acceptable limits. Instead, accident frequencies are presented and discussed. Based on this it can be judged by DMA if the navigational risk associated with the wind farms is readily acceptable.

Based on the results of the HAZID and the quantitative risk assessment, several risk reducing measures for Frederikshavn OWF are proposed, see chapter 5.

Main findings

No significant disruption of the normal commercial traffic patterns is expected during construction, operation, or decommissioning. The traffic that will be most affected by the offshore wind farm is pleasure crafts and fishing vessels. These vessels will need to keep safe distance by re-routing around the wind farm.

The accident frequency, prior to OWF establishment, for ship-ship collision is calculated to be 1.08E-2 (equivalent to a return period of 92.4 years). The change in ship-ship collision frequency due to the wind farm establishment is calculated to be low; 2.9 % increase, which means that the return period changes from one accident every 92.4 years to one accident every 90 years. The small increase is due to that the collision type "merging"; which has increased because the traffic originally transiting through the OWF has been redirected around, merging with an existing route.

The accident frequency, prior to OWF establishment, for ship grounding is calculated to be 9.82E-2 (equivalent to a return period of 10.2 years). The change in grounding frequency due to the wind farm establishment is calculated to be low; 5.0 % increase, which means that the return period changes from one accident every 10.2 years to one accident every 9.7 years. The small increase is due to that some of the pleasure craft traffic will be forced to sail in shallower waters, on the west side of the turbines.

The ship-turbine accident frequency is calculated to be 3.6E-3. This is equivalent to a ship-turbine collision happening 1 in every 276 years. It is estimated that power collision with a turbine will contribute to the largest part of accidents with the wind turbines. The drift collision is very low, although reasonable as there are tugs located in Frederikshavn port and the wind direction is also favourable for the commercial traffic east of the turbines in drift scenarios.

ABBREVIATIONS AND TERMS

Abbreviations

AIS	Automatic Identification System
AtoN	Aids to navigation
CTV	Crew Transfer Vessel
DEA	Danish Energy Agency
DMA	Danish Maritime Authority
EIA	Environmental Impact Assessment
FSA	Formal safety Assessment
HAZID	Hazard Identification
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IMO	International Maritime Organisation
IWRAP	IALA Waterway Risk Assessment Programme (software)
OWF	Offshore Wind Farm
SAR	Search and Rescue
SPS	Significant Peripheral Structure
SWIFT	Structured What-If Technique
VMS	Vessel Monitoring System

Risk terms

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 (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

The Danish Energy Agency (DEA) has granted permission to conduct a feasibility study for an offshore wind project located east of Frederikshavn. The results of the feasibility study will be compiled in an Environmental Impact Assessment (EIA). Part of the EIA is a navigational risk assessment. In relation to the scoping of the EIA for Frederikshavn Offshore Wind Farm the Danish Maritime Authority and Danish Energy Agency has identified the need to update the assessment of safety of navigation.

This risk assessment report is based on the updated HAZID report for Frederikshavn offshore wind farm (OWF) (DNV GL report no. 2020-0708) /2/. The previous HAZID for this wind farm was conducted in 2007 /9/. Hazards identified in earlier process (2007-report) were included in the update and supplemented with new hazards.

This risk assessment report replaces the navigational risk assessment that was carried out in February 2008 (Report no. 646046-REP-02) /8/, hereinafter referred to as the 2008-report. The most important updates from the previous report are:

- Use of improved modelling software (IALA Waterway Risk Assessment programme software - IWRAP). IWRAP is today used widely for similar projects, particularly among Nordic countries and within the Baltic region. The tool is superior when it comes to functionality, geographical user interface and calculation speed. IWRAP was endorsed by the IMO via SN.1/Circ.296.
- Use of new AIS-data from 2019.
- Use of VMS-data as complementary data (to AIS) for fishing activity.
- Update technical specifications for wind turbines and foundations.

Since this report replaces the 2008-report, no comparison of results between the two reports has been made. The EIA handling of safety of navigation should be based on this new report, supplemented by the updated HAZID report (DNV GL report no. 2020-0708) /2/.

1.2 Objective

The objective of this navigational risk assessment is to assess how, where and how much the offshore wind farm project impacts the maritime traffic, and to assess the potential changes in risk of collisions and groundings caused by the project.

1.3 Scope and limitations

The scope of work includes a navigational risk assessment for the offshore wind farm project east of Frederikshavn (hereinafter referred to as Frederikshavn OWF).

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.
- Structure impact analysis (e.g. finite element modelling)
- 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.

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 safety analysis (FSA). The FSA methodology is a process intended for rule making purposes. For this study rule making is not the objective, therefore are the steps 'risk control options' and 'cost benefit assessment' 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, because hazards that are not identified will be excluded from further assessment. The objectives of the hazard identification process 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. 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 Frederikshavn OWF (DNV GL Report No.: 2020-0708) [2].

2.1.3 HAZID team

The previous HAZID workshop for the 2008-report was carried out on the 30th of August 2007 in Frederikshavn, Denmark. 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. Table 2-1 lists the participants as well as their organization.

Table 2-1 Workshop participants (HAZID team).

Name	Organisation
Svend Erik Andersen	Strandby havn og fiskeriforening
Erik Nielsen	Strandby havn og fiskeriforening
Peter Frey	Søfartsstyrelsen
Jesper Thomsen	Frederikshavn Havn A/S
Flemming S. Sørensen	Farvandsvæsnet
Søren A. Nielsen	NearshoreLAB
Ole Riis	Lods
Peter Have	Skov og Naturstyrelsen
Christian Muff	Frederikshavn Marina
Ole Beck	Stena Line Denmark A/S
Kim Møller Pedersen	Søværnets Operative Kommando
Tommy Pedersen	Flådestationen Frederikshavn
Luis Sørensen	A7S Em Z. Svitser
Claus Christensen	DNV Hazid leader
Pernille Holm Skyt	Dong Energy
Tove Kjær Hansen	Dong Energy

This HAZID has been updated in 2020 by a DNV GL team, which specialise in maritime safety and risk management [2]. The HAZID was updated based on traffic data from 2019. The updated HAZID report was sent on hearing to the following stakeholders mirroring the stakeholders also invited in August 2007:

- Søfartsstyrelsen
- DanPilot
- Frederikshavn Havn A/S
- Færgeselskabet Læsø K/S
- Frederikshavn sejlklub

- Dansk Sejlunions Nordøstjyske kreds
- Søsportens Sikkerhedsråd
- Dansk Havfisker forbund
- Danmarks Fiskeriforening
- Strandby Fiskeriforening
- Strandby lystbådehavn
- Stena Line
- DFDS A/S
- Flådestation, Frederikshavn
- Søværnets Operative Kommando (SOK)
- Svitzer
- Rohde Nielsen A/S
- Frederikshavn marina
- Energistyrelsen

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 is 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 historical Automatic Identification System data (AIS data).

Ship traffic nearby and through the wind turbines is modelled by using the IALA Waterways Risk Assessment Program (IWRAP) software.

2.2.1 IWRAP tool

The applied calculation tool IWRAP MKII version 6.4.0 (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 [3]. Important settings and parameters for the model is 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. The analysis is based on AIS data collected for the whole calendar year of 2019. Year 2019 was been used, since this provides the most relevant and up-to-date traffic patterns in the area. High-resolution AIS data has been used, meaning that the resolution of the data corresponds to a new registered AIS point every 30 seconds.

Only ships carrying AIS-transponders are included in the risk quantification. 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.

2.2.3 VMS data

Vessel monitoring system (VMS) 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 [4]. VMS data for the analysis area has been collected from the period 2015-2019.

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 data.

2.2.4 Ship data and classification

Ship movement data from AIS is combined with ship particulars data from DNV GL'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 craft. That is why unknows are placed in the pleasure craft ship category.

Where data is still missing, new data has been entered manually based available information from online ship traffic directories. In the dataset with ship information for this study area there are 8,278 ships. The proportion of vessels with a lack of information was small, only 2-4% 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. Inspection of the trip list for Frederikshavn shows that only vessels that had insignificant number of trips through the model area categorized as "missing". When calculating accident rates, IWRAP only takes into account those vessels where all the necessary information is in place.

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	Example sub ship types
Oil tankers	Asphalt/Bitumen Tanker, Bunkering Tanker, Crude Oil Tanker, Coal/Oil Mixture Tanker, Shuttle Tanker.
Product/chemical tankers	Products Tanker, Alcohol Tanker, Molasses Tanker, Vegetable Oil Tanker, Chemical Tanker, Edible Oil Tanker, Latex Tanker, Chemical/Products Tanker, Vegetable Oil Tanker.
Gas tankers	LPG/Chemical Tanker, CO2 Tanker, LNG Tanker, LPG Tanker.
Bulk carriers	Bulk Cement Storage Ship, Bulk Carrier, Self-discharging, Bulk Cement Carrier, Urea Carrier, Laker Only, Ore/Oil Carrier, Ore Carrier.
General cargo ships	General Cargo/Tanker, General Cargo Ship, Self-discharging, General Cargo/Tanker (Container/oil/bulk - COB ship), Heavy Load Carrier.
Container ships	Container Ship (Fully Cellular), Container Ship (Fully Cellular with Ro-Ro Facility).
Passenger/Roro	Passenger Ship, Passenger Ship Inland Waterways, General Cargo/Passenger Ship, Passenger/Ro-Ro Ship (Vehicles), 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	Well Stimulation Vessel, Crane Platform, jack up, FPSO, Oil, Diving Support Vessel, FSO, Semi-Submersible, Drilling Rig, Supply Platform, jack up, Support Platform, Standby Safety Vessel, Cable Layer, etc.
Tugs	Articulated Pusher Tug, Tug, Pusher Tug
Fishing vessels	Stern Trawler, Whale Catcher, Trawler, Seal Catcher, Fishing Vessel, Factory Stern Trawler
Pleasure Crafts	Yacht, Motorboats, Houseboat, Sailing Vessel
Other	Stone Carrier, Suction Hopper Dredger, Utility Vessel, Pilot Vessel, Mooring Vessel, Fire Fighting Vessel, Work/Repair Vessel, Fish Factory Ship, Hopper/Dredger, Pollution Control Vessel, Salvage Ship, Crew Boat, Fishery Research Vessel, Mining Vessel, Fish Farm Support Vessel, Supply Tender, Lighthouse Tender, Fishery Patrol Vessel, Training Ship, Buoy & Lighthouse Tender, Patrol Vessel, Icebreaker, Hospital Vessel, etc.

Table 2-3 Classification of ship size by length.

Length category (metres)
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 accidents. These data are produced based on available nautical charts. All grounds and shallow waters below 20 m in vicinity of the proposed offshore wind farms are 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 to 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 OWF.

Table 2-4 Calculated scenarios.

Scenario	Existing routes	Relocated routes	Turbines included
1 (Before)	x		
2 (After)	x	x	x

Accident frequencies are presented in terms of:

- Annual accident frequency: Expected number of accidents per year.
- Return period: 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 specific 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). Therefore, the risk evaluation cannot make a definite conclusion on whether the risk is within any defined acceptable limits. It will instead present the accident frequencies, and return periods, and discuss the results and explain any potential changes in risk. Based on this it can be judged by DMA if the risk associated with such scenarios is acceptable.

3 ANALYSIS BASIS

This chapter describes the basis for the navigational risk assessment.

3.1 Location

The Frederikshavn OWF is planned to be established east of Frederikshavn, just south-east of Naturreservat Hirsholmene, see Figure 3-1. The total study area is approx. 350 km^2, of which the potential area for offshore wind turbines amounts to approx. 1 km^2. The distance between the coast and the nearest potential offshore wind turbines is 3 km.

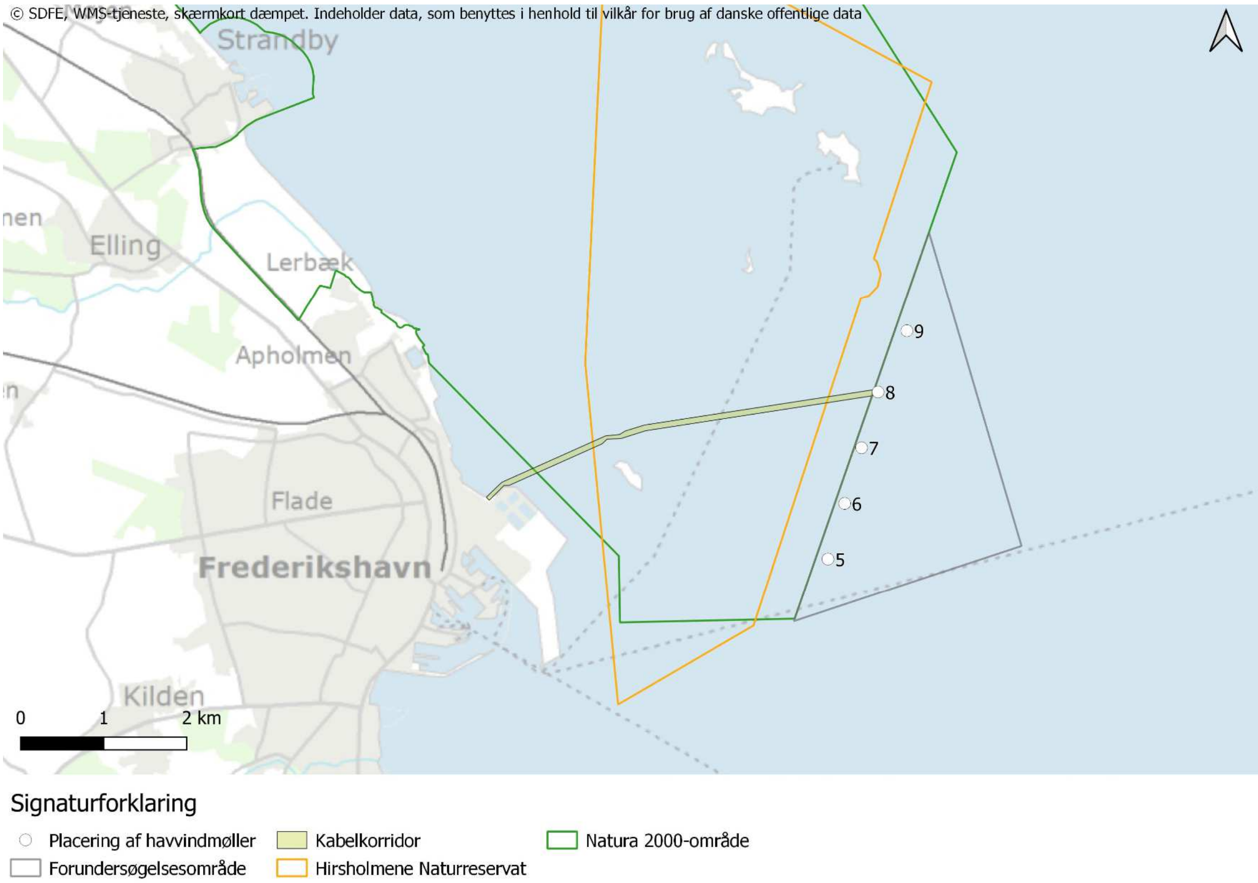


Figure 3-1 Proposed location of Frederikshavn OWF, showing location of cable route (light green) and turbine park (white points).

The cables for grid connection of the wind farm will be installed in a project corridor connecting to the facilities of Nordhavn station as the connection point for Frederikshavn OWF. The offshore project corridor for grid connection is approximately 5 km long.

3.2 Technical specification and layout

Frederikshavn OWF will comprise of five turbines with a combined capacity of maximum 80 MW, and minimum 25 MW. The turbines will be positioned in a north-south line with a separation distance of 680 – 820 meters between the foundations, see Figure 3-1.

3.3 Metocean characteristics

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

Table 3-1 Metocean characteristics.

Data	Characteristics	Modelling in IWRAP
Prevailing wind direction	Prevalent wind direction from south-west.	The prevalent wind direction has been applied in IWRAP, and will affect the drift direction (drift grounding and ship-turbine drift collisions)
Ice	The area is in the northern part of Kattegat and therefore close to Skagerrak. Skagerrak is mainly prune to drifting is and the water never fully freezes.	Ice is not modelled in IWRAP.
Visibility (fog, precipitation)	Fog, where the visibility is less than 1 km, can occur all year around. But is most frequent in the start of the year.	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 is judged to not cause any disturbance to the commercial traffic. Smaller vessel will be more affected by waves, as in any other locations. Waves in the area normally have a significant wave hight of less than 1m, although larger waves can occur.	Waves are not modelled in IWRAP.

3.4 Waterway characteristics

The area around Frederikshavn is relatively shallow. The OWF proposed position is also directly east of a nature reserve where the water depth is only 5-7 meters. Larger vessels will therefore only transit on the east side of the OWF.

The navigational channel into Frederikshavn is 14 meters deep, whereas the water depth outside the channel is around 7-9 meters deep. Larger vessels must therefore follow the channel which brings the vessels clear of the Frederikshavn OWF before altering their course North-bound.

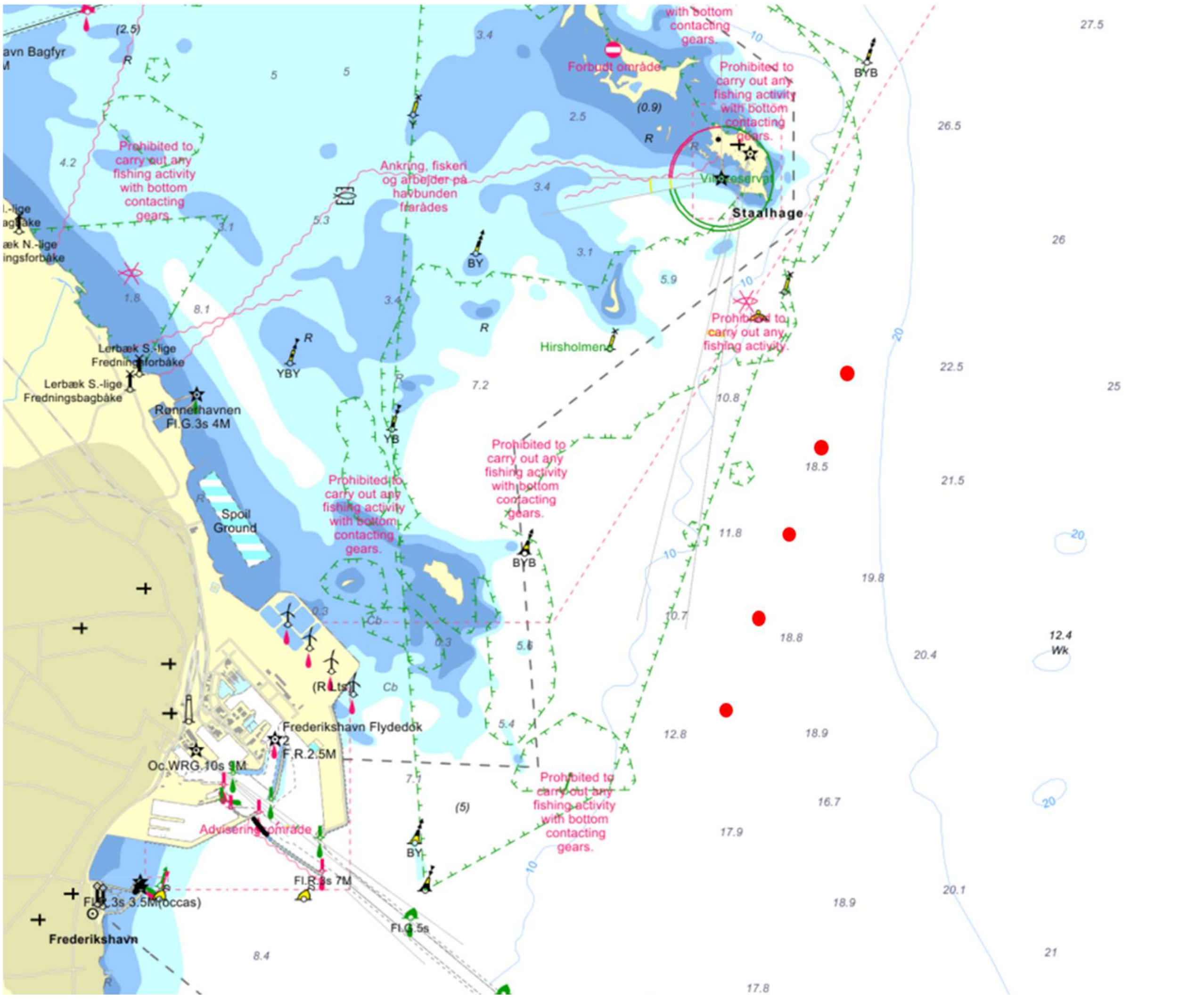


Figure 3-2 Nautical chart for area around Frederikshavn.

A summary of the waterway characteristics and what is modelled in IWRAP is shown in Table 3-2.

Table 3-2 Waterway characteristics

Site characteristic	Summary	Modelling in IWRAP
Water depth	Relatively shallow waters around Frederikshavn.	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 Frederikshavn.	Nautical charts, in combination with ship traffic data, has been used to define the routes in the study area.
VTS	The great belt Vessel Traffic Service (VTS) is to be used.	VTS plays an important role to ensure the safety of navigation. DNV GL recognise that there are estimates from 5 % effect on reduction in accidents and up to 50 % (in combination with TSS) /7/. Effect of VTS is indirectly included in the way that the ships navigate in the area, as the AIS could potentially look different if there were no VTS.
Emergency tugs	Located in Frederikshavn	Applied in the model, with default IALA "tug parameters", see Appendix A.
TSS	There are no TSS in the study area	TSS is not included in IWRAP.
Pilotage and Pilot exemption Certificate (PEC)	Pilotage is compulsory for the following vessels calling or departing from Frederikshavn, or any of the nearby ports: - Carrying oil or have uncleaned cargo tanks. - Carrying chemicals - Carrying gases - Have more than 5,000 tonnes of bunker oil on board - Carrying radioactive material. Offshore support vessels are exempt from these rules in accordance with the international definitions.	Pilotage plays an important role to ensure the safety of navigation. DNV GL recognise that there are estimates up to 50% effect on reduction in accidents /7. However, it is difficult to make a generic quantification of the pilot effect for groundings and ship collisions. Similar to VTS, this effect is also "indirectly" part of the risk model.

3.5 Accidents

According to the HELCOM[1] database there has been four grounding accidents and five collisions within the study area in the period 1989 to 2017. There have been additional accidents in the area, most being contact accidents in Frederikshavn port. In total, there have been 11 accidents within the study area between 1989 and 2017. Figure 3-3 shows the locations of the accidents, groundings marked in blue, contact in red and collisions marked in green.

The dataset is constructed by the HELCOM Secretariat and has been compiled by the HELCOM Contracting Parties[2]. The actual location of the accidents, as presented in the map in Figure 3-3, 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 compare the calculated frequencies in IWRAP towards the historical accidents in the area.

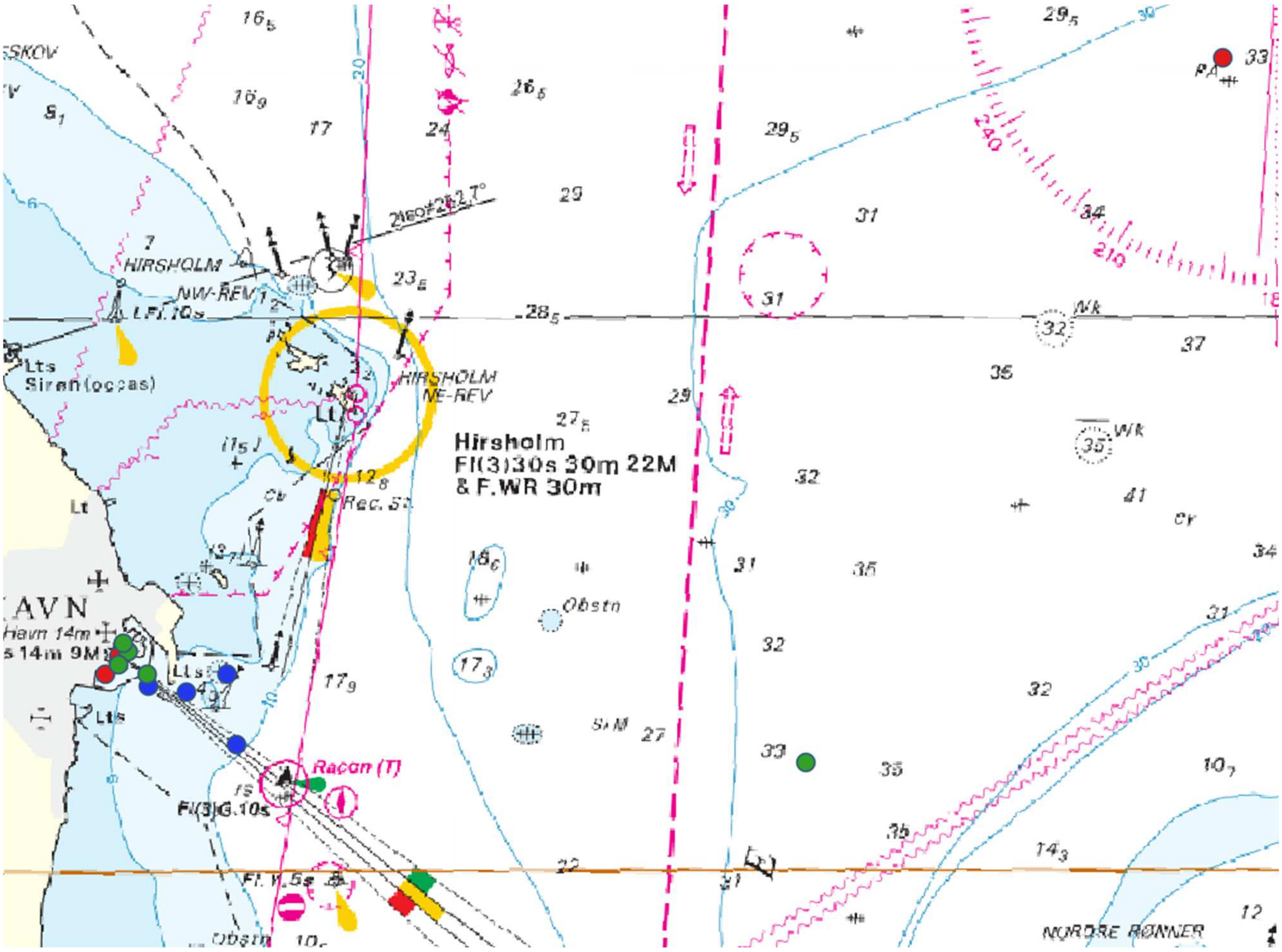


Figure 3-3 Location of accidents registered in the HELCOM database, from the period 1989-2017. Blue: Grounding, Green: Collision, Red: Contact.

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

[2] 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.

3.6 Analysis assumptions

3.6.1 Design and layout

The turbines on Frederikshavn OWF will have individual capacity of 5-16MW, depending on the type. The foundation of the turbines will be gravity-, suction bucket-, monopile- or a new tripod/gravity foundation, see Figure 3-4.

The diameter of the gravity base at the water surface, which is relevant for the ship-turbine collision is assumed to be 11 m. Gravity base is chosen as the conservative value, since this will give the largest diameter above the sea level.

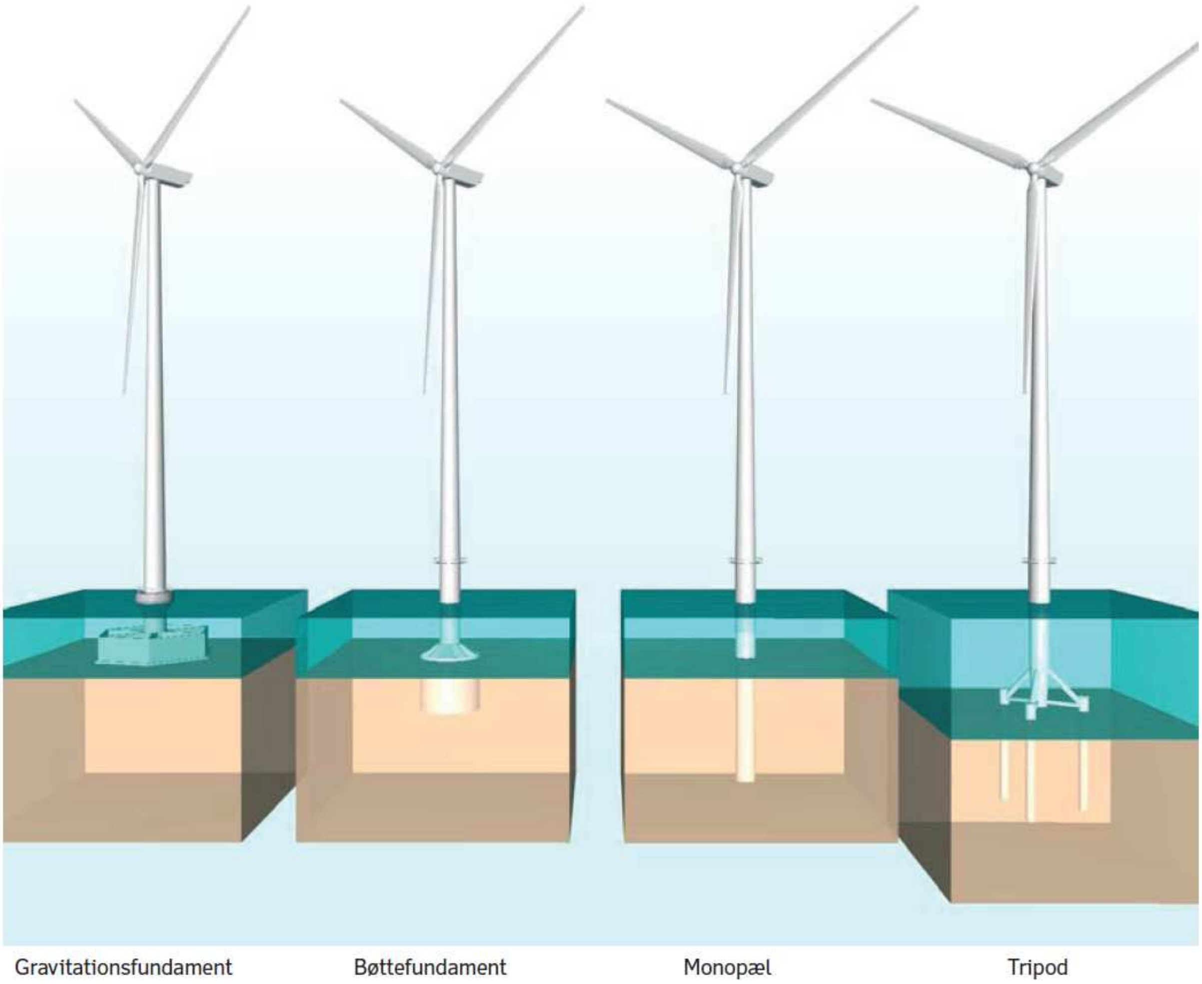


Figure 3-4 Different foundation types used in offshore wind farms (from left to right: gravity-, suction bucket -, monopile- and new tripod/gravity foundation).

Frederikshavn OWF will have a crew transfer vessel (CTV) for maintenance of the turbines. There will be a 200m safety zone around the power cables on the seabed. No safety zone around the wind turbines, expect during construction. The wind turbines will be marked in accordance with industry best practice and/or statutory standards, likely to be yellow up to 15 m above sea level. There will be at least 20m clearance from the tip of turbine blades to sea level.

3.6.2 Marking and lighting

The following assumptions are used in this risk assessment, see Figure 3-5 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 AIS and/or Racon[3] may be expected.
- 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 periphery (significant peripheral structures = SPS) of the wind farm, will be marked with a yellow light. Additional turbines along the periphery will be marked, so that there will be a maximum distance between SPS defined turbines of 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.

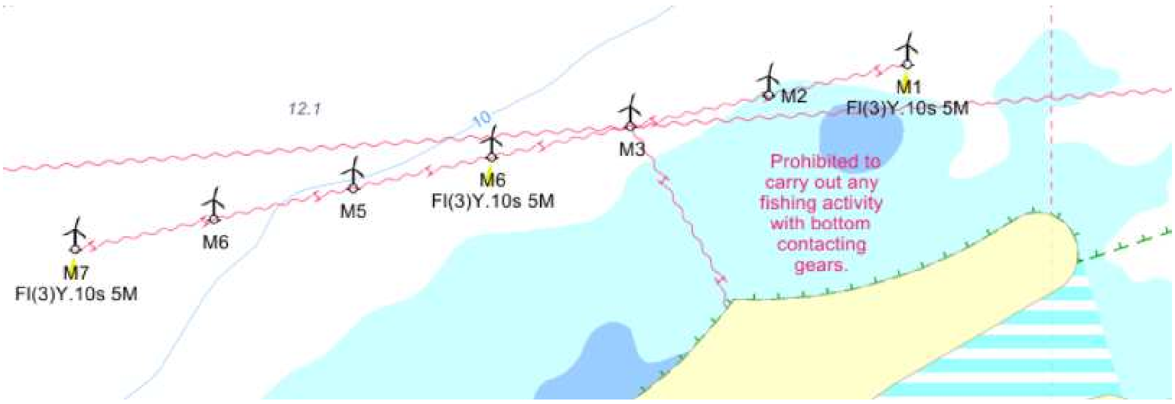


Figure 3-5 Example charting of offshore wind farm where three of the turbine have light flashing synchronously. All turbines are marked with ID, and the power cable grid is also shown in the chart.

[3] 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."

4 RISK ASSESSMENT

4.1 Modelling of ship traffic

A traffic density plot for the whole region around the planned offshore wind farm is shown in Figure 4-1. The study area for the navigational risk assessment concerned with the wind turbines are shown inside the map. The risk evaluation of the power cables to shore is handled in chapter 4.5.5.

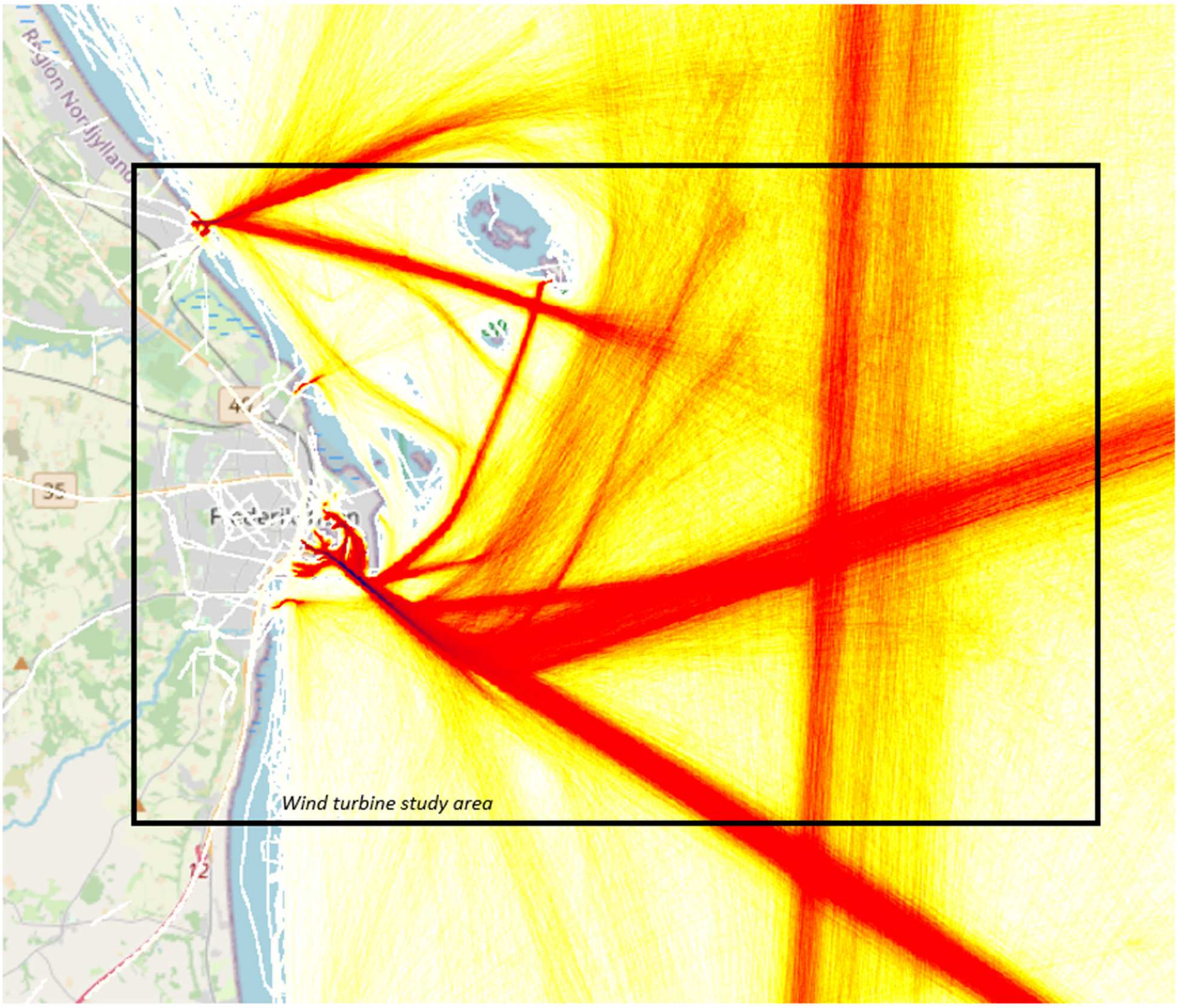


Figure 4-1 Density of traffic around Frederikshavn, based on AIS-data from 2019.

The ship traffic within the study area comprises a route model, as presented in Figure 4-2. The main routes (including those for fishing and pleasure crafts) have been identified and given a route ID, as listed in Table 4-1. Note that only routes with substantial traffic are given a unique identifier, but that does not exclude routes with less traffic from the model.

The routes with the most traffic in closest vicinity of the planned turbines are route 1A and 1B. 1A traffic is currently transiting directly through the planned OWF. The traffic composition here is mostly tugs (40%), oil tankers (22%), other (13%), pleasure crafts (12%) and general cargo (8%). Route 1B is further east of the OWF, and will be less affected, by the OWF. The traffic composition here consists of mainly of passenger/Ro-Ro ships (49%), tugs (25%) and general cargo (10%).

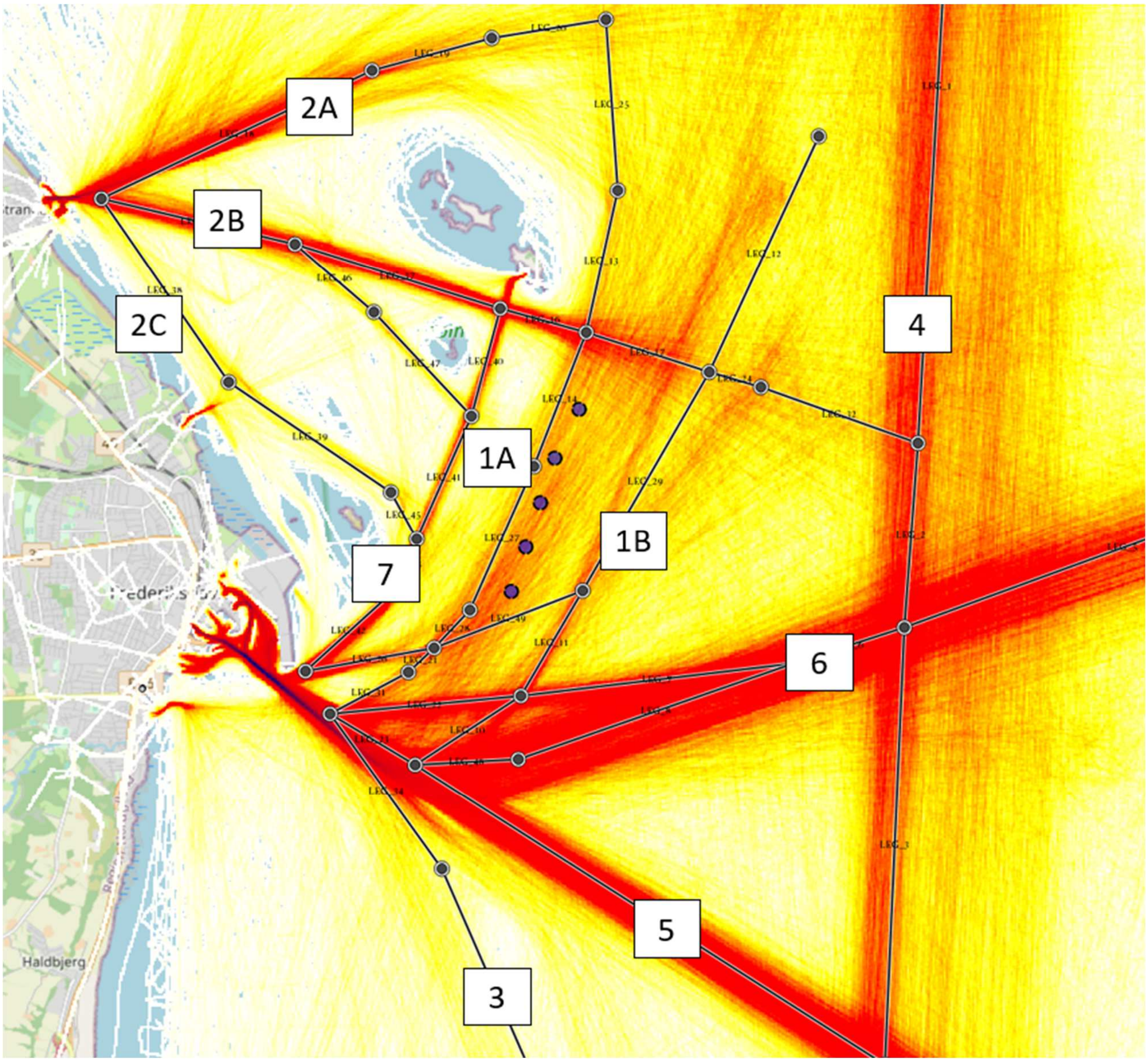


Figure 4-2 Modelling of routes for existing situation, based on AIS-data from 2019. Layout of the planned wind farm is indicated on the map.

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

ID	Route	Traffic composition (most dominating ship types)
1A	North/South-going inner route. The closest to the OWF, some of the route goes through the preliminary study area for the OWF. Dominated by Service vessels, Tugs and Oil tankers	Tugs (40%), oil tankers (22%), other (13%), pleasure crafts (12%) and general cargo (8%).

ID	Route	Traffic composition (most dominating ship types)
1B	North/south-going outer route. Dominated by Service vessels, Passenger ships and Tugs	Passenger/Ro-Ro ships (49%), tugs (25%) and general cargo (10%).
2A	Strandby – East/West going routes north of Hirsholm. This route is dominated by Fishing vessels and service vessels	Fishing vessel (92%), other (5%) and pleasure crafts (2%).
2B	Strandby – East/West going routes south of Hirsholm crossing the OWF. Dominated by fishing vessels and Pleasure crafts.	Fishing vessel (94%), Pleasure crafts (5%)
2C	Strandby – North/South going route south of Hirsholm, west of the OWF. Inner route between Skagen and Frederikshavn. Dominated by fishing vessels and Pleasure crafts	Pleasure crafts (38%), fishing vessel (33%) and other (25%).
3	North/South going route south of the OWF. This route is dominated by cargo vessels, tugs and service vessels.	Passenger/roro ships (29%), tugs (24%), general cargo (19%).
4	North/South going transit route between Læsø and Nordjylland. Dominated by cargo ships.	General Cargo (67%) and fishing vessels (7%)
5	Frederikshavn – Læsø route. Dominated by passenger vessels to/from Læsø.	Passenger/roro vessels (99%)
6	Frederikshavn-Gøteborg route. Dominated by the ferry to and from Gøteborg.	Passenger/roro vessels (96%)
7	Frederikshavn – Hirsholm route. Dominated by passenger vessels to and from Hirsholm.	Passenger vessels (67%), tugs (20%), pleasure crafts (7%).

Figure 4-3 shows the number of passing ships per route, grouped by ship type. Full details in the traffic composition can be found in Appendix B.

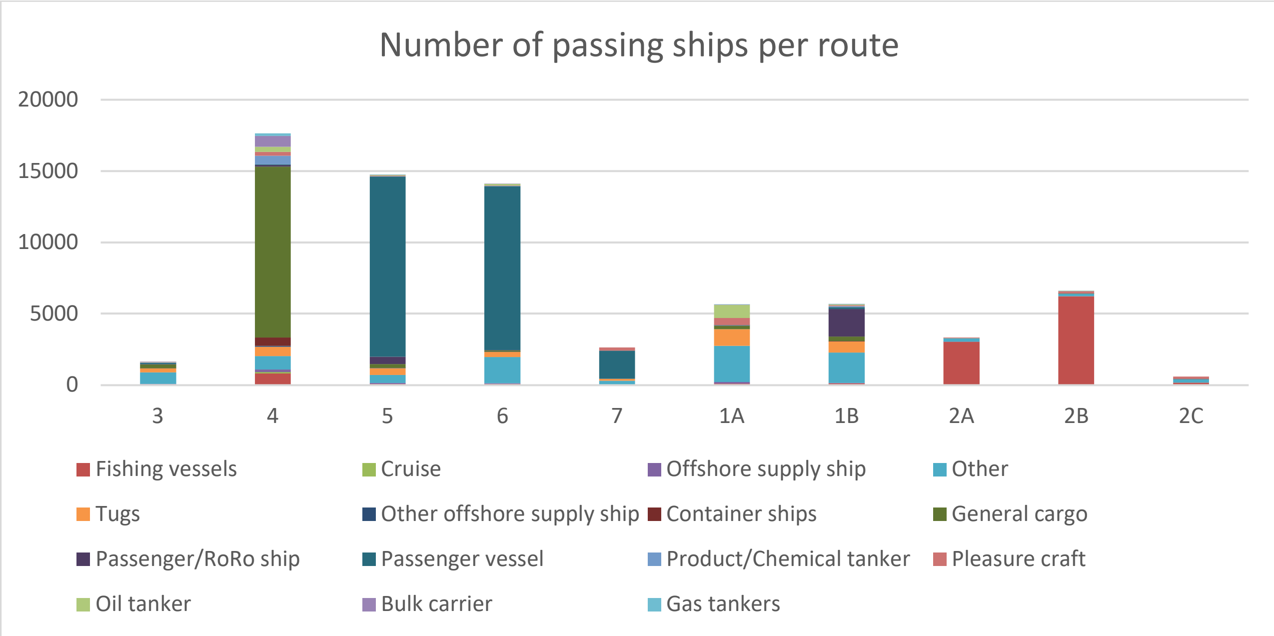


Figure 4-3 Number of passing ships per route in 2019, grouped by ship type.

Route 1A and 1B are the main routes which will be affected by the OWF. Most of the ships in route 1A are relatively small, in fact 94% of the transits are completed by vessels below 70 meters. However, for route 1B, the size distribution is altered towards larger vessels and 40% of the transits are completed by vessels between 150 – 200 meters. Although vessels under 70 meters still equate for 48% of all transits in this route.

4.2 Hazard identification

The key findings from the hazard identification study are listed in the bullet points below. For full details of the HAZID results we refer to HAZID report for Frederikshavn offshore wind parks (DNV GL Report No. 2020-0708 /2/).

- The key findings are: Risk of injuries to personnel while transferring from service vessel to wind turbine platform.
- Risk of ship-turbine collision, especially for ferries where potential consequences are high.
- Risk of personnel injury and material damage during construction, where the waves from frequent ferry transitions close to the wind farm area can create unsafe working environment at times where environmental conditions are vital for the installation process.

General recommendations proposed in the HAZID workshop are part of the safety recommendations in chapter 5.

4.3 Frequency analysis

4.3.1 Existing conditions (before establishment)

The existing condition represents the case where the OWF is not established and is meant as a base for comparison in order to assess the impact the OWF will have on the navigational risk. Figure 4-2 showed the IWRAP model for existing routes (current situation).

The results from the modelling of the current situation (before establishment) are shown in Table 4-2. As seen from the table, grounding is the dominating risk contributor with a calculated frequency of 0.098 groundings per year. This equals to about one grounding every 10 years.

From the HELCOM database we found 4 registered groundings in the period 1989 to 2017, which equals to one grounding every 7 years (frequency of 0.142). Comparing IWRAP with real accidents we see that IWRAP is calculating a slightly lower grounding frequency than was has been observed the last decades, but still in the same order of magnitude. Thus, the results of the IWRAP model are considered reasonable.

Table 4-2 Calculated accident frequencies for current situation (before establishment) within the study area. Frequencies are modelled in IWRAP.

Accident type	Before establishment	
	Frequency	Return period
Powered grounding	9.22E-02	10.8
Drift grounding	5.94E-03	168.2
Total grounding	**9.82E-02**	**10.2**
Head-On ship-ship collisions	2.90E-03	345
Overtaking ship-ship collisions	9.14E-04	1,094
Crossing ship-ship collisions	6.16E-03	162
Merging ship-ship collisions	3.32E-04	3,008
Bend ship-ship collisions	5.22E-04	1,917
Total ship-ship collisions	**1.08E-02**	**92**
Ship-turbine powered collision	--	--
Ship-turbine drift collision	--	--
Total ship-turbine collision	**--**	**--**

The frequency of ship-ship collisions is calculated to be 0.0108, which is about one collision every 92 years. The accidents statistics reveals that there have been more collisions then IWRAP predicts. Five collisions have been registered in the area from 1989 until 2017. However, reading the comments written about the collisions, most of these have been within Frederikshavn port and been categorized as contact and only one was in the open sea. Therefore, the collision estimations from IWRAP can also be considered as reasonable.

4.3.2 Revised condition (after establishment)

The presence of the offshore wind farm will require that some of the ship traffic must be relocated to avoid passing through the 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.

Given the project location, no significant disruption of the major commercial shipping lanes (not including commercial fishing), is expected. However, the traffic that today goes through the wind farm area will need to be re-located. The traffic composition in these routes consist mainly of tugs, service vessels, pleasure crafts, fishing vessels and the ship type category 'other' as well as small oil tankers. This traffic must be relocated to other routes in the model.

The following bullet points summarizes the revised routing system, as modelled in IWRAP:

- Traffic that transits along route 1A (see Figure 4-2) is assumed to re-locate to the outer route, 1B. Additionally, a new leg is introduced between the north end of route 1B and the east end of route 2A. The magnitude of traffic for the new leg is equivalent to the number of vessels that were originally transiting along route 1A and destine for Strandby. Vessels that are bound for the inner route between Frederikshavn and Hirsholm will be kept as is.
- The wind farm will be serviced and maintained throughout the life of the wind farm from Frederikshavn. Thus, traffic with crew transfer vessels (CTV) between a Frederikshavn port and the offshore wind farm has been added in the model. It is assumed that 50 trips to and from the turbines is required per year.

Table 4-3 Accident frequencies, after establishment of Frederikshavn OWF.

Accident type	After establishment	Return period
Powered grounding	9.71E-02	10.3
Drift grounding	6.00E-03	166.7
Total grounding	**1.03E-01**	**9.7**
HeadOn ship-ship collisions	2.92E-03	342.0
Overtaking ship-ship collisions	9.27E-04	1,078.2
Crossing ship-ship collisions	6.16E-03	162.3
Merging ship-ship collisions	5.31E-04	1,881.8
Bend ship-ship collisions	5.67E-04	1,764.0
Total ship-ship collisions	**1.11E-02**	**90.0**
Ship-turbine powered collision	3.6E-03	278.9
Ship-turbine drift collision	3.2E-05	31,666.8
Total ship-turbine collision	**3.6E-03**	**276,4**

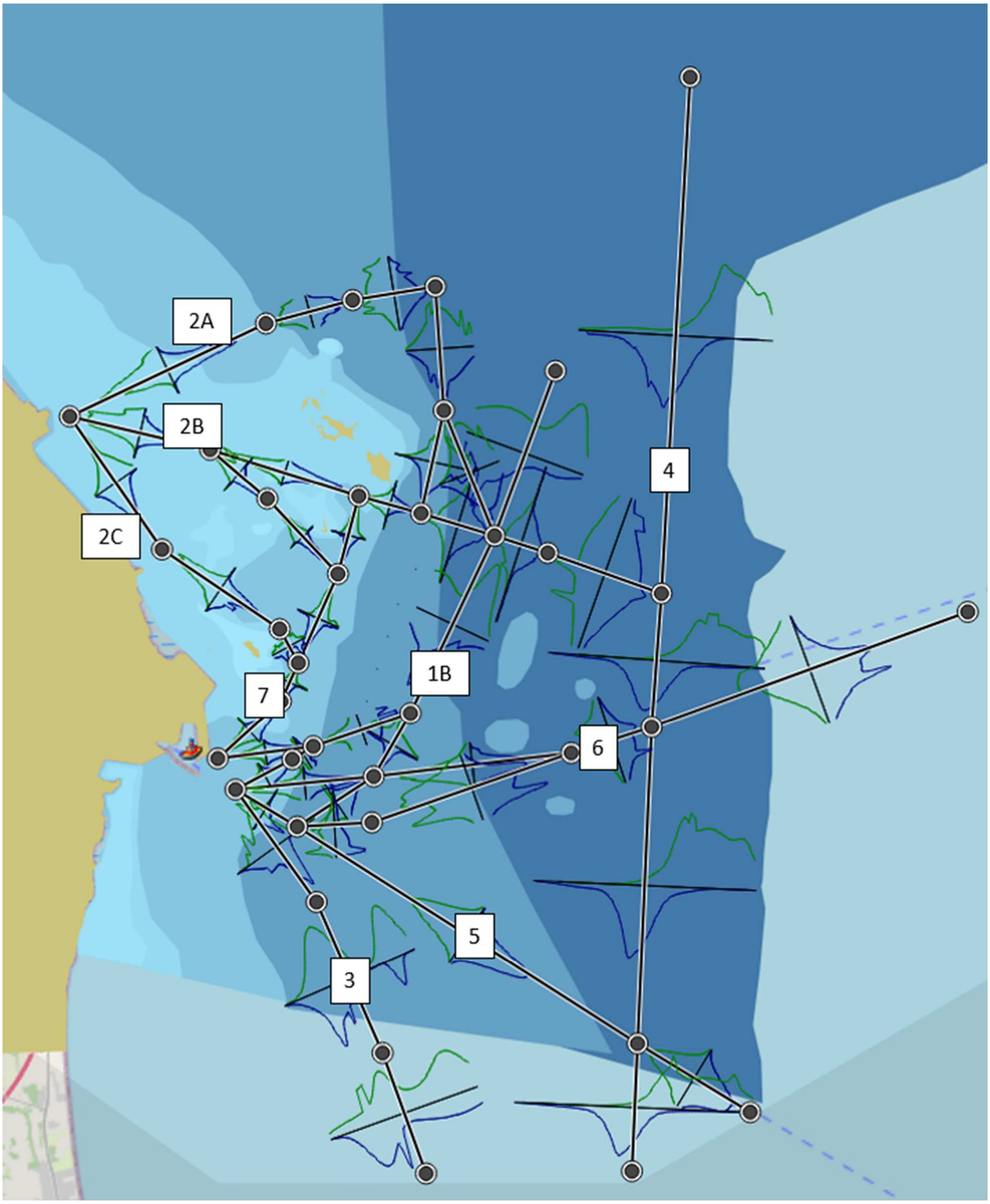


Figure 4-4 Revised routes due to wind farm, showing each leg ID and the lateral distribution of the traffic for each leg.

4.4 Consequence analysis

There are several potential consequences should a ship-turbine collision occur. The least severe consequence is that a drifting vessel grazes a wind turbine. In this event, there may be minor damage to both the vessel and the turbine. It is likely that all personnel and passengers, and the structures, would not experience any injury or damage. Personnel and crew should in this event have sufficient time to prepare for impact and thereby ensure all persons are in safe locations.

The severity of 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 any wind turbine striking is 3.6E-03. This event has a return period of 1 in every 276 years.

4.5 Risk evaluation

Table 4-4 summarises the calculated accident frequencies, before and after establishment of Frederikshavn OWF. The following chapters discuss 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.

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 size of vessels involved and the speed of the vessels.

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

Accident type	Before establishment		After establishment		
	Frequency	Return period	Frequency	Return period	Difference (%)
Powered grounding	9.22E-02	10.8	9.71E-02	10.3	5.3%
Drift grounding	5-94E-03	168.2	6.00E-03	166.7	0.9%
Total grounding	**9-82E-02**	**10.2**	**1.03E-01**	**9.7**	**5.0%**
HeadOn ship-ship collisions	2.90E-03	344.9	2.92E-03	342.0	0.9%
Overtaking ship-ship collisions	9.14E-04	1093.5	9.27E-04	1078.2	1.4%
Crossing ship-ship collisions	6.16E-03	162.4	6.16E-03	162.3	0.1%
Merging ship-ship collisions	3.32E-04	3007.9	5.31E-04	1881.8	59.8%
Bend ship-ship collisions	5.22E-04	1917.4	5.67E-04	1764.0	8.7%
Total ship-ship collisions	**1.08E-02**	**92.4**	**1.11E-02**	**90.0**	**2.7%**
Ship-turbine powered collision	--	--	3.6E-03	278.9	--
Ship-turbine drift collision	--	--	3.2E-05	31,666.8	--
Total ship-turbine collision	**--**	**--**	**3.6E-03**	**276.4**	**--**

4.5.1 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 4-4. It shows the frequency and return period for the two scenarios (powered/drifting collision), as well as the combined sum for the two.

The ship-turbine accident frequency is calculated to be 3.6E-3. This is equivalent to a ship-turbine collision happening 1 in every 276 years. It is estimated that power collision with a turbine will contribute to the largest part of accidents with the wind turbines. This is due to a relatively complex traffic situation on the outskirts of Frederikshavn. There are many routes that are either nearby the OWF or have a course that is perpendicular to the OWF. The drift collision is very low, although reasonable as there are tugs located in Frederikshavn port and the wind direction is also favourable for the commercial traffic east of the turbines in drift scenarios.

Vessels will need to keep safe distance, but hazards affecting visibility (e.g. fog, precipitation) may cause them to sail too close and accidentally hit the turbine. From the metocean data in chapter 3.3 we see that poor visibility is expected, especially in the beginning of each year. The risks should be mitigated with good seamanship and updated navigational charts. Most pleasure craft owners use electronic charts and plotter, even also now available on mobile devises. The operator of the wind farm will also ensure notification of the development to the recreational craft community is widespread and effective throughout all phases.

A risk contributor to the ship-turbine collision frequency is also the crew transfer vessels when they sail to and from the wind farm turbines. IWRAP is not able to model the patterns of the CTV in-between the wind turbines, but the voyages to/from port to the wind farm are included in the model. The latest ship-turbine collision accident 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.

For the remaining routes, not mentioned above, it is evident that the vessel traffic is largely undisturbed by the presence of the wind farm with regards to risk of ship-turbine collision.

4.5.2 Ship grounding risk

The accident frequency, prior to OWF establishment, for ship grounding is calculated to be 9.82E-2 (equivalent to a return period of 10.2 years). The change in grounding frequency due to the wind farm establishment is calculated to be low; 5.0 % increase, which means that the return period changes from one accident every 10.2 years to one accident every 9.7 years. The small increase is due to that some of the pleasure craft traffic will be forced to sail in shallower waters, on the west side of the turbines.

The added risk can be mitigated or reduced by following measures for the waters west of the planned wind farm:

- Improved marking of the area
- Establish ‘recommended route(s)’
- Improved depth measurements (if needed)

4.5.3 Ship-ship collision risk

The accident frequency, prior to OWF establishment, for ship-ship collision is calculated to be 1.08E-2 (equivalent to a return period of 92.4 years). The change in ship-ship collision frequency due to the wind farm establishment is calculated to be low; 2.9 % increase, which means that the return period changes from one accident every 92.4 years to one accident every 90 years. This increase in merging collision occurs on the south end of route 1A and 1B. Instead of vessels separating into two routes, these vessels will now transit in the same route (1B), increasing the merging frequency. However, it is important to note that the ship-ship merging collision frequency after the OWF establishment is still very low; frequency of 5.31E-04, corresponding to a return period of 1,882 years.

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. The vessels that are anticipated to be present during construction include construction barges, support tugs, jack-up rigs, supply/crew vessels and cable laying vessels. These vessels will also be present in the region during decommissioning. Construction vessels are anticipated to be sailing at very low speeds through the construction zone.

The highest navigation risk during construction will be 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 500m 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.

4.5.5 Assessment of cable interaction with ship traffic

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

Dropped or dragged anchor

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. Due to the shore power cable is suggested to be dredged into the seabed and the water depths in the area, grounding/contact to cables are also assumed 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).

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

Di Padovaa et.al. found, based on [1] and [5], that the frequency of anchors lost (events/ship/year) vary between 0.01 to 0.005 events/ship/year [6]. A frequency of 0.005 corresponds to 1 anchor lost every 150 ship per year). This must therefore be considered as a very 'low frequency event'.

Fishing activity

VMS data provided by Fiskeristyrelsen for the years 2015 to 2019 are used to assess the fishing activities in the area around the offshore wind farm and the corresponding cable route.

The VMS data 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 activities. All vessels of 12 meters length or longer and reporting on VMS are included in the VMS data. A visual representation of the VMS data is shown in Figure 4-5.

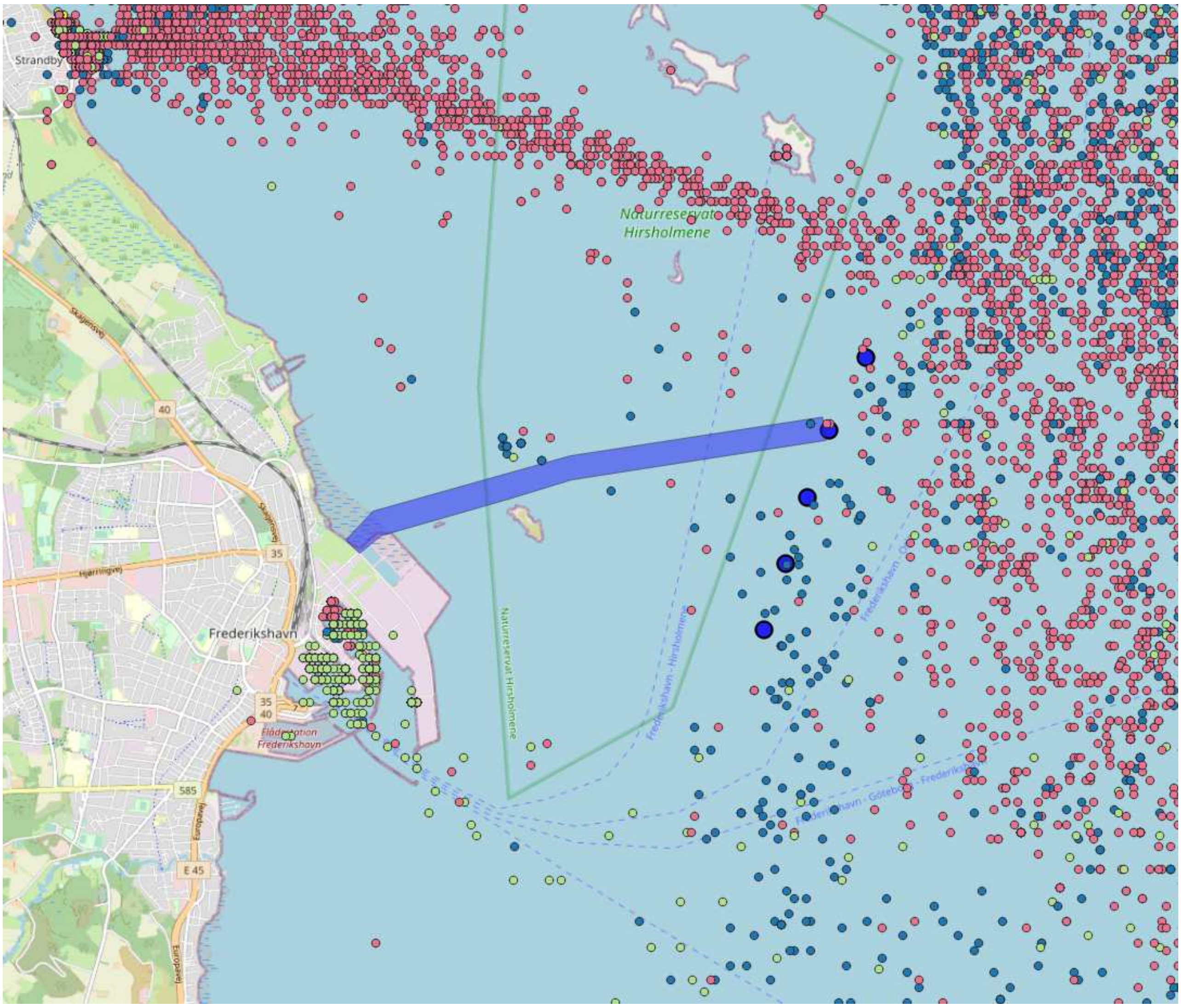


Figure 4-5 Visual representation of fishing activities from VMS data in Frederikshavn, from 2015 to 2019. Pink points: Bottom trawling. Blue points: Pelagic trawling. Green points: Unknown fishing equipment. Larger blue points represent the wind turbines and planned cable route in blue polygon.

From Figure 4-5, it can be observed a relatively low fishing and trawling activity directly above the proposed cable route. Considering the locations of the wind turbines, relatively high activity is seen east of the turbines, and some activity quite close to the turbines. Pelagic trawling dominates in the area closest to the turbines. High bottom trawling activity can be seen east of the wind farm area. Additionally, high density of points is observed north of the wind farm area, with fishing vessels traveling to and from Strandby. For the area in total, bottom traveling dominates the type of fishing activity.

Further, a simple analysis of the 2019 AIS data were performed to compare AIS data to the VMS data. In Figure 4-6, AIS tracks for the year 2019 from fishing vessels sailing with speed equal to or below 5 knots are presented. Proposed locations of the wind turbines and the cable corridor is indicated in dark blue in the figure.

It is evident that the filtered AIS data correspond well to the VMS data, with higher density of tracks north and east of the planned wind farm area. The VMS data is also presented for each year (by colour legend) in Figure 4-7, and the fishing activity for each year are quite similar to each other.

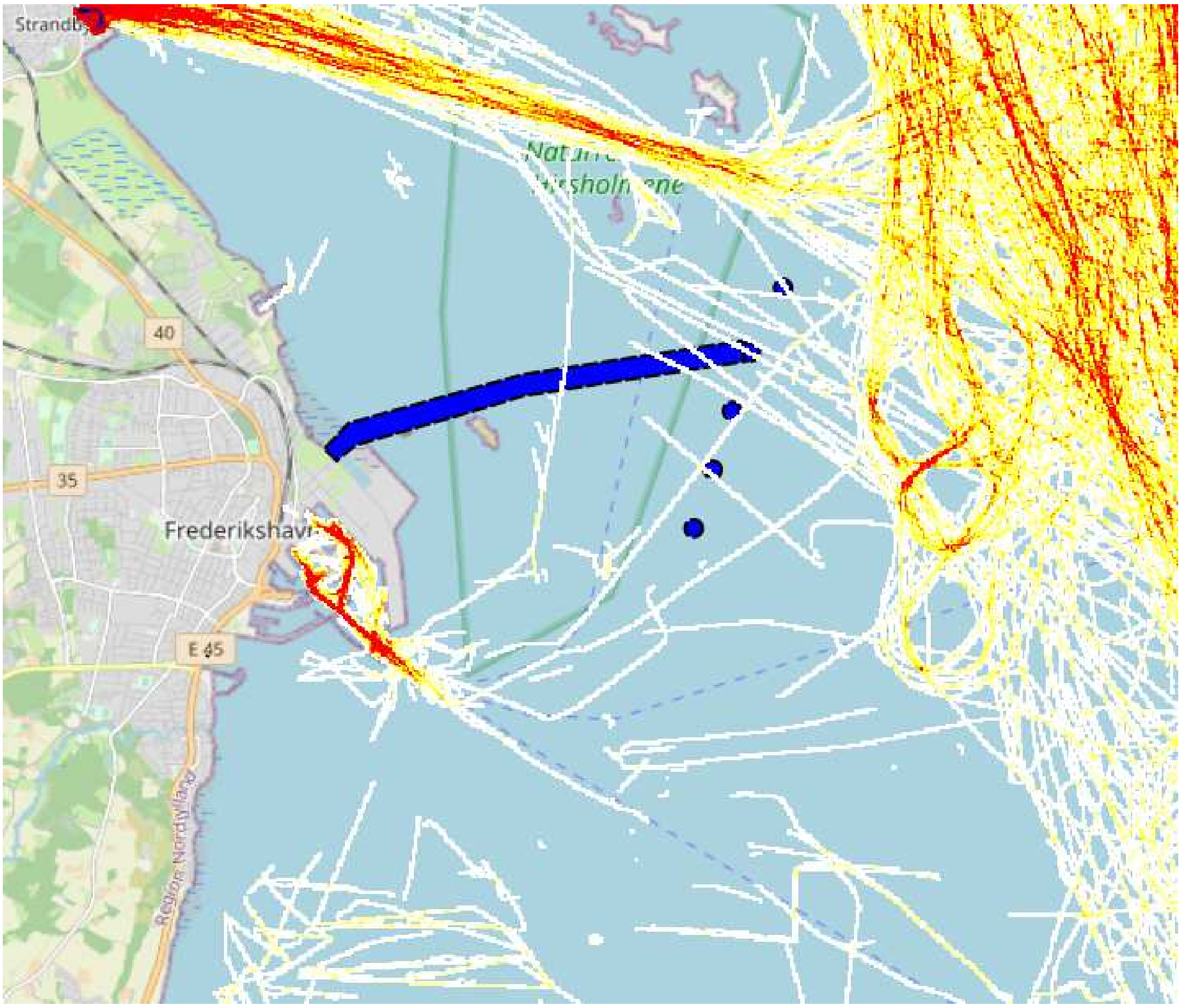


Figure 4-6 AIS tracks from fishing vessels traveling with a speed below 5 knots (2019).

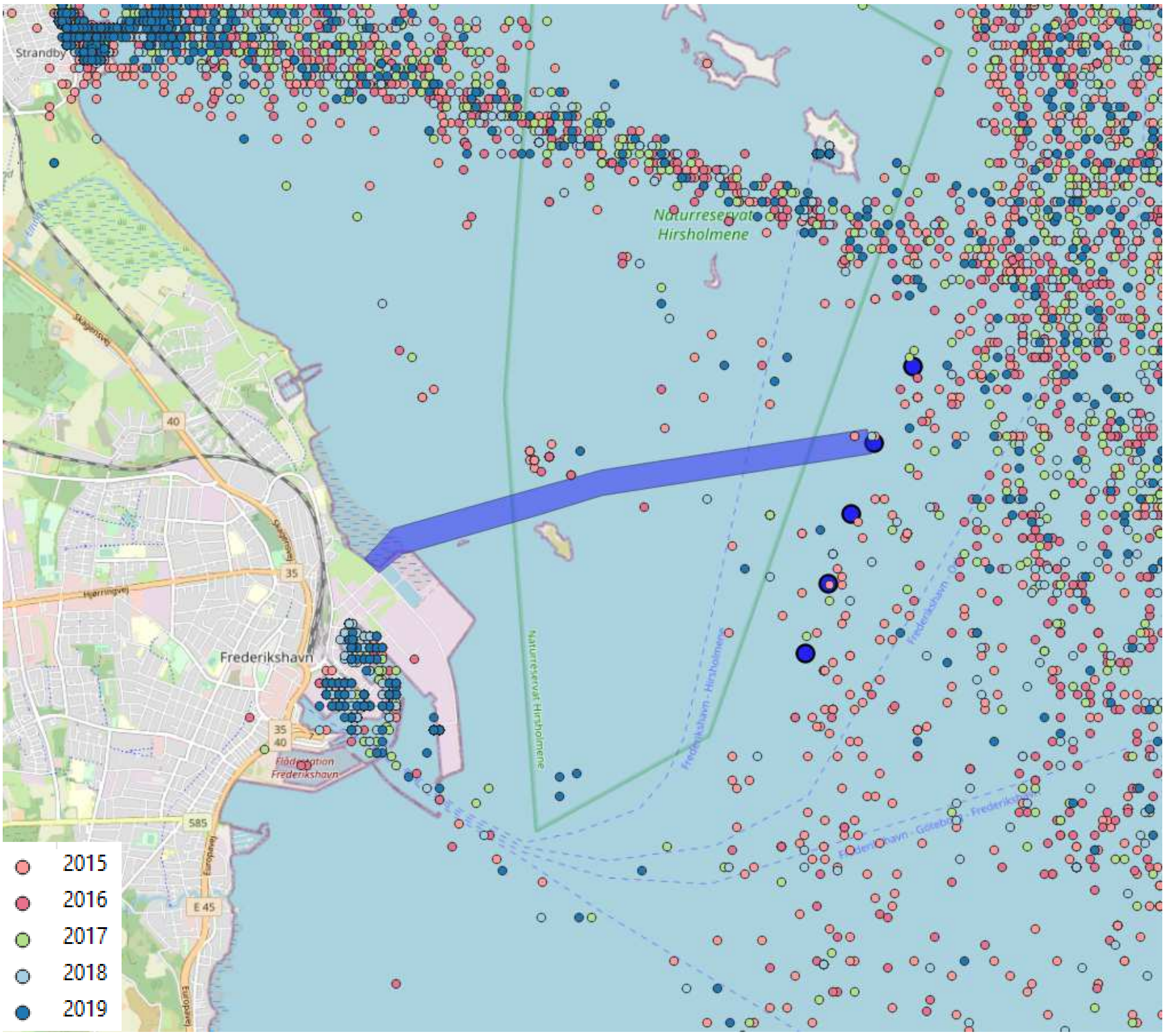


Figure 4-7 VMS data from 2015 to 2019, with colour legend representing each respective year.

4.5.6 Future port traffic

The extension of Frederikshavn is expected to give more port calls from larger vessels. According to the HAZID report for Frederikshavn OWF /2/, it was estimated that Frederikshavn will receive approximately 100 more port calls, mainly from larger vessels.

A sensitivity analysis has been completed to identify the effect the increase in port calls will have on the accident frequency. The increase in traffic is assumed to follow route 4 and 6 into Frederikshavn port and the overall increase in traffic is within these ship types: Bulk carrier, Gas tanker, Oil Tanker, General cargo and Offshore support vessels (Rigs). The increase amongst all vessel types is in the length category 100-150m and 150-200m.

The sensitivity analysis shows that the increase in traffic from larger vessels does not affect the ship-turbine accident type, but it increases the ship-ship collisions frequency marginally, whilst there is a modest increase in grounding frequency. The traffic is assumed to transit in routes relatively far away from the OWF before following the 'port approach route' into Frederikshavn port.

Table 5 Increase in accident frequency due to an increase in port calls for selected "large vessels"

Accident type	Frequency after establishment w/ standard traffic	Frequency after establishment w/ increased port traffic	Difference (%)
Powered grounding	9.71E-02	1.12E-01	15%
Drift grounding	6.00E-03	6.21E-03	4%
Total grounding	**1.03E-01**	**1.18E-01**	**15%**
HeadOn ship-ship collisions	2.92E-03	2.99E-03	2%
Overtaking ship-ship collisions	9.27E-04	9.78E-04	6%
Crossing ship-ship collisions	6.16E-03	6.31E-03	2%
Merging ship-ship collisions	5.31E-04	5.31E-04	0%
Bend ship-ship collisions	5.67E-04	5.67E-04	0%
Total ship-ship collisions	**1.11E-02**	**1.14E-02**	**3%**
Ship-turbine powered collision	3.60E-03	3.60E-03	0%
Ship-turbine drift collision	3.20E-05	3.20E-05	0%
Total ship-turbine collision	**3.60E-03**	**3.60E-03**	**0%**

5 RECOMMENDATIONS

The following measures are proposed during the HAZID and risk assessment:

- The turbines may create radar interference, radar shadow, false echoes, lost echoes, etc. - contributing to lack of surveillance and insufficient situational awareness. Radar interference can only be assessed with sufficient accuracy when the final decision has been made on the design of the turbines when allocating establishment permits.
- Aids to navigation (marking in charts, buoys, light etc.) around the construction areas should be established earlier than the actual start-up of the construction, in order to provide greater awareness and knowledge of the construction work. This may also counteract the lack of updating of charts on ships.
- In addition, there should be early notifications, including posters and send-outs about the construction work targeting fishing activity and leisure boats and marinas in all surrounding ports. Sailors have Facebook groups that can be informed in addition to notice to mariners.
- In relation to construction work, a procedure should be made for safe construction vessel (incl. cable laying vessels) voyages/routes sailing in the area. This should be prepared in dialogue with VTS and local pilots.
- Measures should be taken to compensate for increased grounding risk for pleasure crafts and smaller vessels sailing through on the inner route between Frederikshavn and Hirsholm. More accurate depth charts (if needed), improved navigational marking (e.g. lateral marking) or routeing measures, such as recommended routes/tracks for small ships should be evaluated.
- From the HAZID it was pointed out that recognized industry standards should be followed for personnel transfers to/from the turbines; e.g. "IMCA Guidance on the transfer of personnel to and from offshore vessels and structures", "ISO 29406 Offshore wind energy - Personnel transfer systems" and "DNV GL Walk to Work (W2W) Guidance".
- Recognized industry standards should be followed for the marking and lighting of the turbines; e.g. IALA Recommendation O-139 The Marking of Man-made Offshore Structures, DNVGL-SE-0176 Certification of navigation and aviation aids of offshore wind farms.
- AIS and Racon should be considered if lighting is not considered adequate.

6 REFERENCES

/1/ DNV GL, Gard and The Swedish Club. "Anchor loss - technical and operational challenges and recommendations", DNV GL AS, 2016.

/2/ DNV GL (2020) Opdateret HAZID rapport. Hazard identifikation og kvalitativ risiko evaluering af sejladssikkerhed – Frederikshavn vindmølleparker, Report No.: 2020-0708, Rev. B, Document No.: 11HYS6W6.

/3/ IWRAP Mk2 Wiki site: https://www.iala-aism.org/wiki/iwrap/index.php/Main_Page

/4/ EC (2020) Vessel monitoring system (VMS). https://ec.europa.eu/fisheries/cfp/control/technologies/vms_en

/5/ GARD, "Loss of anchors and chain. A selection of articles previously published by Gard AS", Gard News 201, pp. 5 – 7, (2014).

/6/ 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.

/7/ DNV GL (2015) Vurdering av forebyggende sjøsikkerhetstiltak. Rapport Nr.: 2014-1402, Rev. F, Dokument Nr.: 1908Z31-6, Dato: 2015-05-20.

/8/ DNV (2008) 6 vindmøller ved Frederikshavn - Vurdering af sejladssikkerheden i området. FEBRUAR 2008. REPORT NO. 646046- REP – 02 REVISION NO. 0.

/9/ DNV (2007) Hazard Identifikation og Kvalitativ Risiko Evaluering af Sejladssikkerheden for 6 Vindmøller ved Frederikshavn. Report No.: 646046-HAZ01. Date of this revision: 2007-10-05 Rev. No.: B.

APPENDIX A

Default IALA settings and parameters in IWRAP

The following default IALA values have been selected in IWRAP:

Causation factors:

Condition	Causation factor
Head on collisions	$0.5 \cdot 10^{-4}$
Overtaking collisions	$1.1 \cdot 10^{-4}$
Crossing collisions	$1.3 \cdot 10^{-4}$
Collisions in bend	$1.3 \cdot 10^{-4}$
Collisions in merging	$1.3 \cdot 10^{-4}$
Grounding – forget to turn	$1.6 \cdot 10^{-4}$
Mean time between checks after missed turn	180 seconds

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:

Repair Time

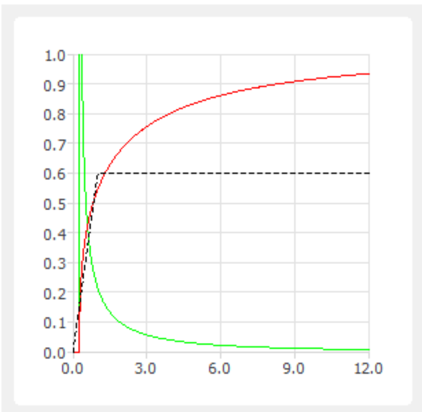
(●) Distribution ( ) Function

Distribution: Weibull

Input Method: /Delta/Beta/Lower Bound

	Value
Delta	0.90
Beta	0.45
Lower Bound	0.25

From 0.00 to 12.00 Reset...



Mean 3.38 StdDev. 8.16

APPENDIX B

Traffic composition for Frederikshavn (Before establishment)

	Oil tankers	Product/ chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/ Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum	%
Route 1A																
0-30	0	0	0	0	2	0	1	0	18	0	89	7	85	0	**202**	**28 %**
30-70	154	0	0	0	3	0	1	0	2	0	199	3	0	92	**454**	**63 %**
70-100	2	1	0	0	51	0	2	0	1	0	0	0	0	0	**57**	**8 %**
100-150	0	2	1	0	1	0	0	0	0	0	0	0	0	0	**4**	**1 %**
150-200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
200-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
250-300	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 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**156**	**3**	**1**	**0**	**57**	**0**	**4**	**0**	**21**	**0**	**288**	**10**	**85**	**92**	**717**	**100 %**
%	**22 %**	**0 %**	**0 %**	**0 %**	**8 %**	**0 %**	**1 %**	**0 %**	**3 %**	**0 %**	**40 %**	**1 %**	**12 %**	**13 %**	**100 %**	
Route 1B																
0-30	0	0	0	0	2	0	0	0	2	0	42	21	22	0	**89**	**9 %**
30-70	9	0	0	0	0	0	0	0	2	1	216	8	2	60	**298**	**29 %**
70-100	6	4	0	0	80	0	1	0	4	2	1	7	0	0	**105**	**10 %**
100-150	0	8	1	0	19	1	2	0	0	0	0	0	2	0	**33**	**3 %**
150-200	0	4	0	0	1	0	512	0	0	0	0	0	0	0	**517**	**50 %**
200-250	0	0	0	0	0	0	1	0	0	0	0	0	0	0	**1**	**0 %**
250-300	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 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**15**	**16**	**1**	**0**	**102**	**1**	**516**	**0**	**8**	**3**	**259**	**36**	**26**	**60**	**1 043**	**100 %**
%	**1 %**	**2 %**	**0 %**	**0 %**	**10 %**	**0 %**	**49 %**	**0 %**	**1 %**	**0 %**	**25 %**	**3 %**	**2 %**	**6 %**	**100 %**	

	Oil tankers	Product/ chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/ Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum	%
Route 2A																
0-30	0	0	0	0	0	0	0	0	1	0	9	1 485	29	0	**1 524**	**95 %**
30-70	0	0	0	0	0	0	0	0	0	0	0	0	2	82	**84**	**5 %**
70-100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
100-150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
150-200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
200-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
250-300	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 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**9**	**1 485**	**31**	**82**	**1 608**	**100 %**
%	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**1 %**	**92 %**	**2 %**	**5 %**	**100 %**	
Route 2B																
0-30	0	0	0	0	0	0	3	0	0	0	0	1 333	64	0	**1 400**	**99 %**
30-70	0	0	0	0	0	0	0	0	0	0	0	0	0	20	**20**	**1 %**
70-100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
100-150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
150-200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
200-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
250-300	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 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**1 333**	**64**	**20**	**1 420**	**100 %**
%	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**94 %**	**5 %**	**1 %**	**100 %**	

	Oil tankers	Product/ chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/ Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum	%
Route 2C (Leg38)																
0-30	0	0	0	0	0	0	7	0	0	0	1	74	85	0	**167**	**75 %**
30-70	0	0	0	0	0	0	0	0	0	0	0	0	0	55	**55**	**25 %**
70-100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
100-150	0	0	0	0	0	0	2	0	0	0	0	0	0	0	**2**	**1 %**
150-200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
200-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
250-300	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 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**0**	**0**	**0**	**0**	**0**	**0**	**9**	**0**	**0**	**0**	**1**	**74**	**85**	**55**	**224**	**100 %**
%	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**4 %**	**0 %**	**0 %**	**0 %**	**0 %**	**33 %**	**38 %**	**25 %**	**100 %**	
Route 3 (Leg34)																
0-30	0	0	0	0	0	0	10	0	0	0	40	7	10	0	**67**	**22 %**
30-70	5	0	0	0	1	0	24	0	1	0	31	7	1	24	**94**	**31 %**
70-100	1	0	0	0	45	0	2	0	18	2	2	0	0	0	**70**	**23 %**
100-150	0	4	0	0	13	0	23	0	0	0	1	0	0	0	**41**	**14 %**
150-200	0	1	0	1	0	0	29	0	0	0	0	0	0	0	**31**	**10 %**
200-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
250-300	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 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**6**	**5**	**0**	**1**	**59**	**0**	**88**	**0**	**19**	**2**	**74**	**14**	**11**	**24**	**303**	**100 %**
%	**2 %**	**2 %**	**0 %**	**0 %**	**19 %**	**0 %**	**29 %**	**0 %**	**6 %**	**1 %**	**24 %**	**5 %**	**4 %**	**8 %**	**100 %**	
Route 4																

	Oil tankers	Product/ chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/ Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum	%
0-30	0	0	0	0	1	0	2	0	2	0	87	234	24	0	**350**	**8 %**
30-70	4	0	0	12	89	0	3	0	16	8	44	61	18	107	**362**	**8 %**
70-100	27	46	42	90	2 103	0	2	0	42	13	4	14	5	3	**2 391**	**54 %**
100-150	13	102	1	45	639	140	7	2	3	5	0	0	8	1	**966**	**22 %**
150-200	10	19	0	30	115	3	97	3	0	0	0	0	0	0	**277**	**6 %**
200-250	13	0	2	4	4	0	0	18	0	0	0	0	0	0	**41**	**1 %**
250-300	21	0	1	1	0	0	0	0	0	0	0	0	0	0	**23**	**1 %**
300-350	8	0	0	0	0	0	0	0	0	0	0	0	0	0	**8**	**0 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**96**	**167**	**46**	**182**	**2 951**	**143**	**111**	**23**	**63**	**26**	**135**	**309**	**55**	**111**	**4 418**	**100 %**
%	**2 %**	**4 %**	**1 %**	**4 %**	**67 %**	**3 %**	**3 %**	**1 %**	**1 %**	**1 %**	**3 %**	**7 %**	**1 %**	**3 %**	**100 %**	
Route 5																
0-30	0	0	0	0	0	0	36	0	1	0	2	0	10	0	**49**	**2 %**
30-70	0	0	0	0	0	0	3 060	0	0	0	9	3	0	6	**3 078**	**98 %**
70-100	0	0	0	0	10	0	0	0	1	0	0	0	0	0	**11**	**0 %**
100-150	0	0	0	0	3	0	1	0	0	0	1	0	1	0	**6**	**0 %**
150-200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
200-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
250-300	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 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**0**	**0**	**0**	**0**	**13**	**0**	**3 097**	**0**	**2**	**0**	**12**	**3**	**11**	**6**	**3 144**	**100 %**
%	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**99 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**100 %**	
Route 6																
0-30	0	0	0	0	0	0	0	0	0	0	9	22	3	0	**34**	**1 %**

	Oil tankers	Product/ chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/ Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum	%
30-70	38	0	0	0	0	0	1	0	1	0	29	3	1	9	**82**	**2 %**
70-100	2	5	0	0	3	0	0	0	2	2	1	0	0	0	**15**	**0 %**
100-150	0	1	0	0	4	0	793	0	0	0	0	0	0	0	**798**	**24 %**
150-200	1	2	0	1	1	0	2 416	0	0	0	0	0	0	0	**2 421**	**72 %**
200-250	1	0	0	0	2	0	0	0	0	0	0	0	0	0	**3**	**0 %**
250-300	2	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	**0 %**
300-350	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 %**
Sum	**44**	**8**	**0**	**1**	**10**	**0**	**3 210**	**0**	**3**	**2**	**39**	**25**	**4**	**9**	**3 355**	**100 %**
%	**1 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**96 %**	**0 %**	**0 %**	**0 %**	**1 %**	**1 %**	**0 %**	**0 %**	**100 %**	
Route 7																
0-30	0	0	0	0	0	0	494	0	0	0	147	7	51	0	**699**	**95 %**
30-70	0	0	0	0	0	0	0	0	0	0	0	0	0	34	**34**	**5 %**
70-100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
100-150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
150-200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
200-250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
250-300	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 %**
350-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0 %**
Sum	**0**	**0**	**0**	**0**	**0**	**0**	**494**	**0**	**0**	**0**	**147**	**7**	**51**	**34**	**733**	**100 %**
%	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**0 %**	**67 %**	**0 %**	**0 %**	**0 %**	**20 %**	**1 %**	**7 %**	**5 %**	**100 %**	

APPENDIX C

Accident frequency for Frederikshavn

Table 6 Total grounding frequency before establishment

	Oil tankers	Product/chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum	%
0-30	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.4E-07	0.0E+00	2.1E-03	0.0E+00	1.5E-05	0.0E+00	3.9E-03	2.7E-02	4.5E-03	2.1E-02	**5.8E-02**	**59 %**
30-70	1.2E-03	0.0E+00	0.0E+00	1.4E-06	3.7E-05	0.0E+00	5.6E-03	0.0E+00	6.6E-05	2.4E-06	1.0E-03	9.9E-05	1.7E-05	1.7E-02	**2.5E-02**	**25 %**
70-100	2.2E-05	3.7E-05	5.3E-06	1.1E-05	1.1E-03	0.0E+00	7.9E-06	0.0E+00	3.1E-04	1.8E-05	1.6E-05	2.4E-05	5.6E-07	4.9E-05	**1.6E-03**	**2 %**
100-150	7.9E-06	6.9E-05	2.6E-06	5.0E-06	1.7E-04	1.4E-05	3.1E-03	1.8E-07	3.9E-06	3.3E-04	1.7E-04	0.0E+00	3.4E-04	2.5E-04	**4.5E-03**	**5 %**
150-200	1.5E-06	3.7E-04	0.0E+00	7.0E-04	1.4E-05	3.7E-07	8.7E-03	2.2E-07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**9.7E-03**	**10 %**
200-250	1.9E-05	0.0E+00	1.7E-07	5.3E-07	1.5E-06	0.0E+00	6.6E-06	1.5E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**2.9E-05**	**0 %**
250-300	2.0E-05	0.0E+00	2.4E-07	7.3E-06	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	**2.7E-05**	**0 %**
300-350	1.3E-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	0.0E+00	0.0E+00	0.0E+00	**1.3E-05**	**0 %**
350-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.2E-06	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	**5.2E-06**	**0 %**
Sum	**1.2E-03**	**4.8E-04**	**8.4E-06**	**7.2E-04**	**1.3E-03**	**1.4E-05**	**1.9E-02**	**1.9E-06**	**4.0E-04**	**3.5E-04**	**5.1E-03**	**2.7E-02**	**4.8E-03**	**3.8E-02**	**9.8E-02**	
%	**1 %**	**0 %**	**0 %**	**1 %**	**1 %**	**0 %**	**20 %**	**0 %**	**0 %**	**0 %**	**5 %**	**27 %**	**5 %**	**38 %**		

Table 7 Total grounding frequency after establishment

	Oil tankers	Product/chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum	%
0-30	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.8E-06	0.0E+00	3.2E-03	0.0E+00	4.4E-05	0.0E+00	4.3E-03	2.7E-02	4.6E-03	2.3E-02	**6.1E-02**	**59 %**
30-70	1.5E-03	0.0E+00	0.0E+00	1.4E-06	4.5E-05	0.0E+00	5.6E-03	0.0E+00	7.0E-05	2.5E-06	1.2E-03	1.1E-04	1.7E-05	1.7E-02	**2.6E-02**	**25 %**
70-100	3.4E-05	3.6E-05	5.3E-06	1.0E-05	1.4E-03	0.0E+00	8.0E-06	0.0E+00	3.1E-04	1.8E-05	1.6E-05	2.4E-05	5.6E-07	4.9E-05	**1.9E-03**	**2 %**
100-150	7.8E-06	6.8E-05	1.6E-05	5.0E-06	1.8E-04	1.4E-05	3.1E-03	1.8E-07	3.9E-06	3.3E-04	1.7E-04	0.0E+00	3.4E-04	2.5E-04	**4.5E-03**	**4 %**
150-200	1.5E-06	3.7E-04	0.0E+00	7.0E-04	1.4E-05	3.5E-07	8.7E-03	2.1E-07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**9.8E-03**	**9 %**
200-250	1.9E-05	0.0E+00	1.7E-07	5.1E-07	1.4E-06	0.0E+00	6.6E-06	1.5E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**2.9E-05**	**0 %**
250-300	2.0E-05	0.0E+00	2.2E-07	7.3E-06	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	**2.7E-05**	**0 %**
300-350	1.3E-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	0.0E+00	0.0E+00	0.0E+00	**1.3E-05**	**0 %**
350-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.2E-06	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	**5.2E-06**	**0 %**
Sum	**1.6E-03**	**4.8E-04**	**2.2E-05**	**7.2E-04**	**1.6E-03**	**1.4E-05**	**2.1E-02**	**1.9E-06**	**4.3E-04**	**3.5E-04**	**5.7E-03**	**2.7E-02**	**4.9E-03**	**4.0E-02**	**1.0E-01**	
%	**2 %**	**0 %**	**0 %**	**1 %**	**2 %**	**0 %**	**20 %**	**0 %**	**0 %**	**0 %**	**6 %**	**26 %**	**5 %**	**39 %**		

Table 8 Total ship-ship collision frequency, before establishment of OWF Frederikshavn

Striking/Struck	Oil tankers	Product/chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum
Oil tankers	1,7E-06	1,3E-06	2,2E-07	1,0E-06	1,6E-05	1,3E-06	8,5E-05	2,8E-07	7,2E-07	9,9E-06	4,2E-06	6,6E-06	1,2E-06	1,2E-05	**1,4E-04**
Product/chemical tankers	9,1E-07	7,5E-07	1,3E-07	6,1E-07	9,2E-06	1,2E-06	7,9E-05	2,9E-07	3,4E-07	4,0E-06	1,4E-06	2,1E-06	2,6E-07	4,4E-06	**1,0E-04**
Gas tankers	2,1E-07	1,9E-07	1,7E-08	1,4E-07	2,0E-06	3,5E-07	1,8E-05	8,3E-08	5,6E-08	7,7E-07	1,8E-07	4,6E-07	5,2E-08	8,6E-07	**2,3E-05**
Bulk carriers	8,6E-07	7,6E-07	1,3E-07	5,1E-07	8,6E-06	1,4E-06	7,7E-05	3,3E-07	2,6E-07	3,4E-06	9,0E-07	1,5E-06	2,2E-07	3,8E-06	**9,9E-05**
General cargo ships	1,8E-05	1,7E-05	3,7E-06	1,5E-05	1,5E-04	2,6E-05	1,3E-03	6,2E-06	4,3E-06	5,8E-05	1,6E-05	2,8E-05	3,8E-06	6,4E-05	**1,7E-03**
Container ships	5,3E-07	3,8E-07	5,8E-08	2,8E-07	4,2E-06	1,8E-07	5,7E-05	8,2E-08	1,6E-07	3,2E-06	5,0E-07	1,3E-06	1,5E-07	3,4E-06	**7,2E-05**
Passenger/Roro	8,5E-05	1,0E-04	2,0E-05	1,1E-04	1,6E-03	7,5E-05	3,9E-03	1,6E-05	4,2E-05	1,6E-05	1,9E-04	7,6E-05	3,0E-05	5,3E-05	**6,4E-03**
Cruise ships	2,8E-06	1,8E-06	6,9E-08	5,9E-07	1,3E-05	2,1E-07	2,6E-04	2,7E-08	2,7E-06	3,3E-05	1,6E-05	2,0E-05	1,4E-06	3,5E-05	**3,8E-04**
Offshore supply ships	8,7E-08	7,0E-08	1,2E-08	5,6E-08	8,6E-07	3,9E-08	8,6E-06	7,0E-09	2,6E-08	5,3E-07	8,6E-08	2,4E-07	3,0E-08	5,7E-07	**1,1E-05**
Other offshore ships	8,6E-07	6,7E-07	1,3E-07	5,3E-07	7,3E-06	6,7E-07	6,2E-05	1,4E-07	4,0E-07	3,9E-06	2,1E-06	1,5E-06	2,6E-07	4,4E-06	**8,5E-05**
Tugs	2,5E-07	3,0E-07	6,6E-08	2,6E-07	3,6E-06	3,3E-07	2,3E-05	7,3E-08	1,7E-07	1,3E-06	7,1E-07	3,8E-07	6,5E-08	1,5E-06	**3,2E-05**
Fishing vessels	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	0,0E+00	0,0E+00	0,0E+00	0,0E+00	**0,0E+00**
Pleasure Crafts	2,1E-06	1,1E-06	2,5E-07	1,1E-06	1,5E-05	1,1E-06	5,0E-05	2,7E-07	4,8E-07	1,4E-07	2,4E-06	6,8E-06	8,1E-07	6,6E-07	**8,2E-05**
Other	2,2E-06	1,2E-06	2,2E-07	1,0E-06	1,4E-05	1,2E-06	6,5E-05	3,1E-07	5,0E-07	1,5E-07	2,5E-06	6,4E-06	6,6E-07	6,9E-07	**9,6E-05**
Sum	**1,2E-04**	**1,3E-04**	**2,5E-05**	**1,3E-04**	**1,8E-03**	**1,1E-04**	**6,0E-03**	**2,4E-05**	**5,2E-05**	**1,3E-04**	**2,3E-04**	**1,5E-04**	**3,9E-05**	**1,8E-04**	9,2E-03

Table 9 Total ship-ship collision frequency, after establishment of OWF Frederikshavn

Striking/Struck	Oil tankers	Product/chemical tankers	Gas tankers	Bulk carriers	General cargo ships	Container ships	Passenger/Roro	Cruise ships	Offshore supply ships	Other offshore ships	Tugs	Fishing vessels	Pleasure Crafts	Other	Sum
Oil tankers	6.2E-06	1.6E-06	2.4E-07	1.1E-06	1.8E-05	1.3E-06	8.6E-05	2.9E-07	9.6E-07	1.3E-05	7.8E-06	8.7E-06	2.7E-06	1.7E-05	**1.7E-04**
Product/chemical tankers	1.1E-06	8.0E-07	1.4E-07	6.1E-07	9.3E-06	1.2E-06	7.9E-05	2.9E-07	3.6E-07	4.2E-06	1.6E-06	3.4E-06	3.4E-07	4.7E-06	**1.1E-04**
Gas tankers	2.2E-07	1.9E-07	1.7E-08	1.4E-07	2.0E-06	3.5E-07	1.8E-05	8.3E-08	5.6E-08	7.8E-07	1.9E-07	5.2E-07	5.5E-08	8.7E-07	**2.3E-05**
Bulk carriers	8.9E-07	7.6E-07	1.3E-07	5.1E-07	8.6E-06	1.4E-06	7.7E-05	3.3E-07	2.6E-07	3.4E-06	9.3E-07	1.5E-06	2.3E-07	3.8E-06	**9.9E-05**
General cargo ships	1.9E-05	1.7E-05	3.7E-06	1.5E-05	1.6E-04	2.6E-05	1.3E-03	6.2E-06	4.4E-06	6.0E-05	1.7E-05	3.3E-05	4.4E-06	6.7E-05	**1.7E-03**
Container ships	5.4E-07	3.8E-07	5.8E-08	2.8E-07	4.2E-06	1.8E-07	5.7E-05	8.2E-08	1.6E-07	3.2E-06	5.2E-07	1.4E-06	1.6E-07	3.4E-06	**7.2E-05**
Passenger/Roro	8.6E-05	1.0E-04	2.0E-05	1.1E-04	1.6E-03	7.5E-05	4.0E-03	1.6E-05	4.2E-05	1.6E-05	1.9E-04	9.7E-05	3.1E-05	5.4E-05	**6.4E-03**
Cruise ships	4.7E-06	2.3E-06	7.3E-08	5.9E-07	1.4E-05	2.1E-07	2.6E-04	2.7E-08	2.9E-06	3.6E-05	1.8E-05	4.0E-05	2.6E-06	4.0E-05	**4.2E-04**
Offshore supply ships	9.0E-08	7.0E-08	1.2E-08	5.6E-08	8.6E-07	3.9E-08	8.6E-06	7.0E-09	2.6E-08	5.3E-07	8.9E-08	2.4E-07	3.1E-08	5.8E-07	**1.1E-05**
Other offshore ships	1.3E-06	7.2E-07	1.3E-07	5.3E-07	7.5E-06	6.7E-07	6.2E-05	1.5E-07	4.3E-07	4.2E-06	2.4E-06	2.1E-06	4.4E-07	4.9E-06	**8.7E-05**
Tugs	2.7E-07	3.0E-07	6.6E-08	2.6E-07	3.6E-06	3.3E-07	2.3E-05	7.3E-08	1.7E-07	1.4E-06	7.4E-07	4.6E-07	7.3E-08	1.5E-06	**3.2E-05**
Fishing vessels	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	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**0.0E+00**
Pleasure Crafts	4.4E-06	1.4E-06	2.6E-07	1.1E-06	1.6E-05	1.2E-06	5.1E-05	2.7E-07	6.2E-07	1.4E-07	4.6E-06	8.2E-06	1.6E-06	1.6E-06	**9.3E-05**
Other	5.1E-06	1.5E-06	2.3E-07	1.0E-06	1.5E-05	1.3E-06	6.7E-05	3.2E-07	6.7E-07	1.6E-07	4.8E-06	8.6E-06	1.6E-06	2.4E-06	**1.1E-04**
Sum	**1.3E-04**	**1.3E-04**	**2.5E-05**	**1.3E-04**	**1.9E-03**	**1.1E-04**	**6.0E-03**	**2.4E-05**	**5.3E-05**	**1.4E-04**	**2.5E-04**	**2.0E-04**	**4.5E-05**	**2.0E-04**	**9.3E-03**

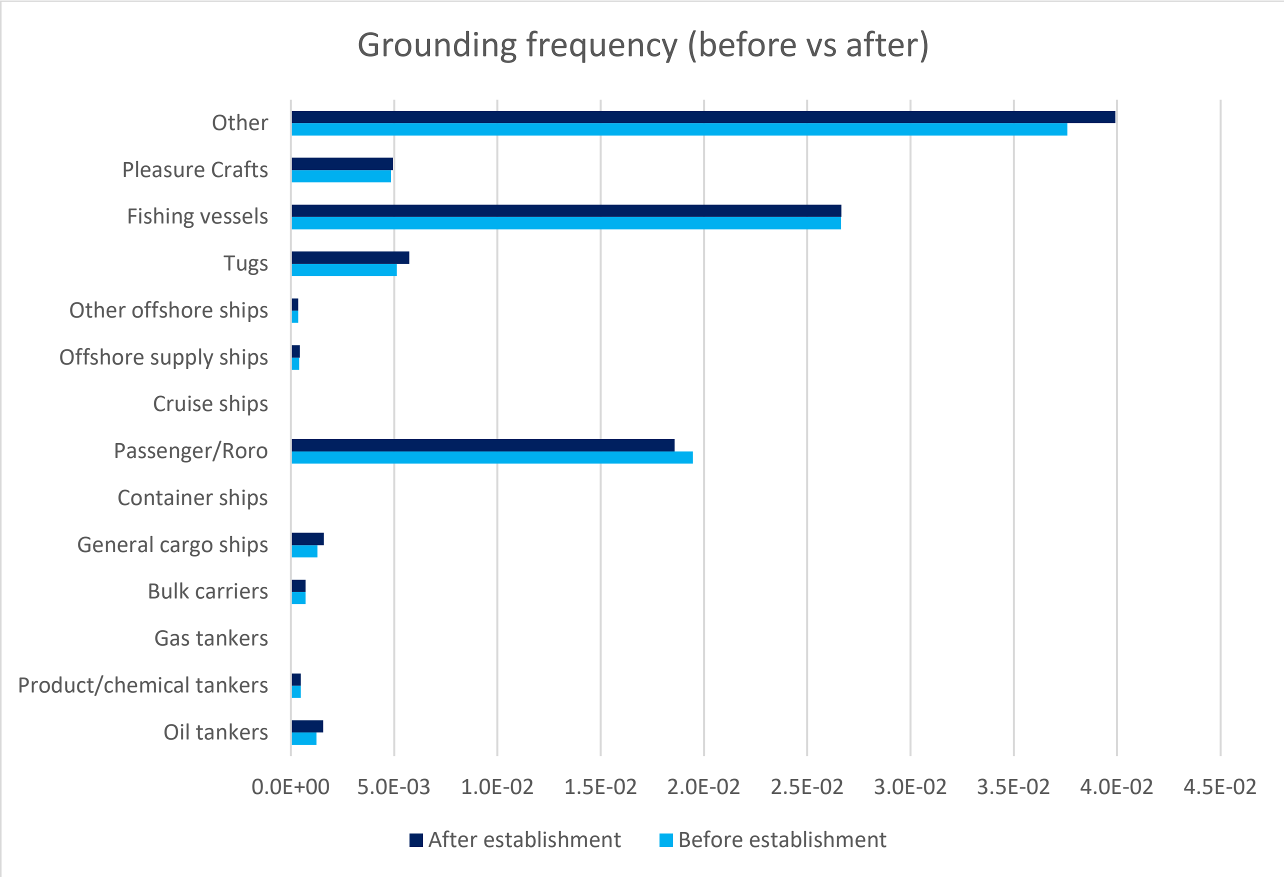


Figure 6-1 Grounding frequency Frederikshavn, before vs after establishment of OWF

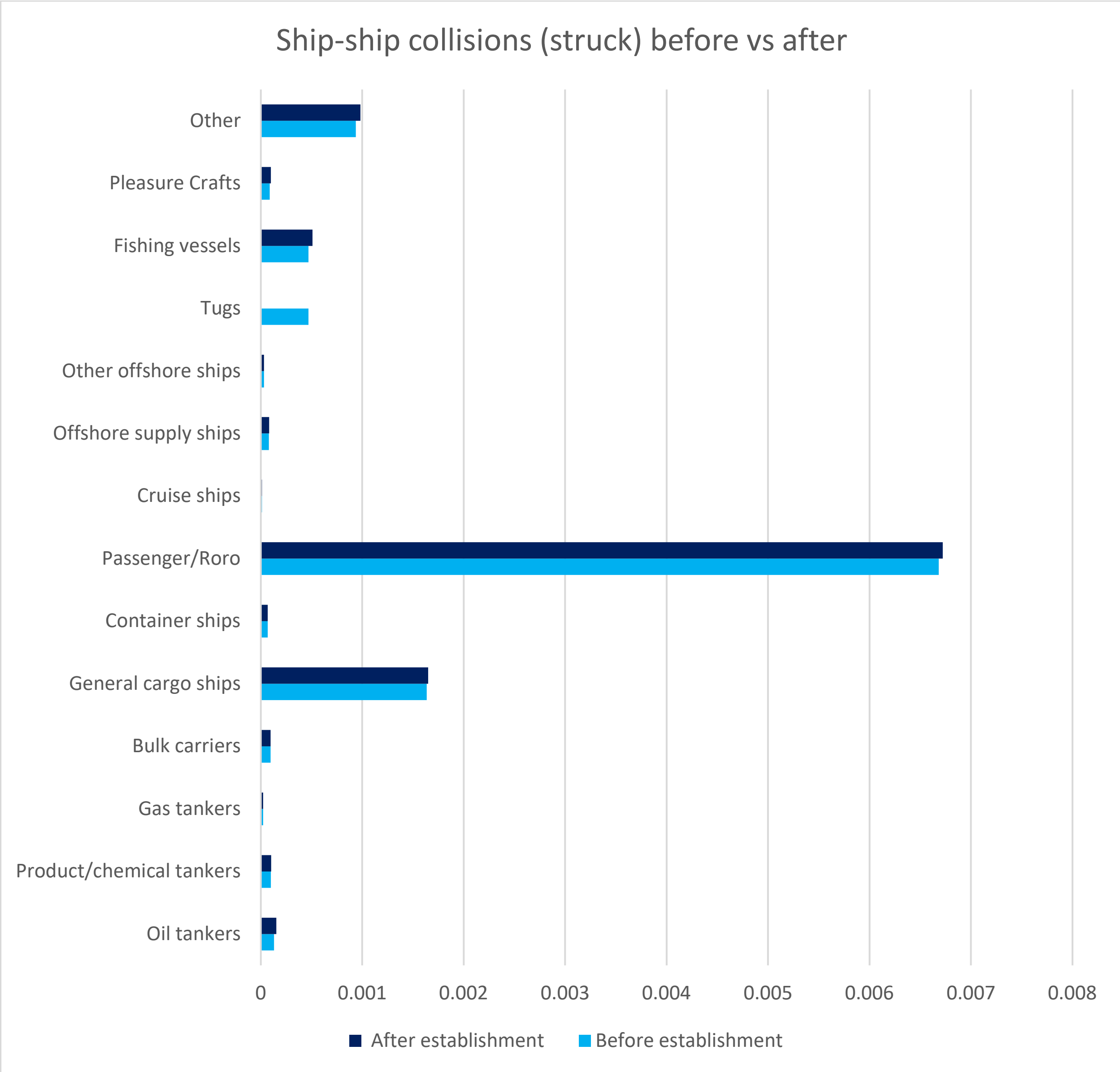


Figure 6-2Ship-ship collision frequency , before vs after establishment of OWF.

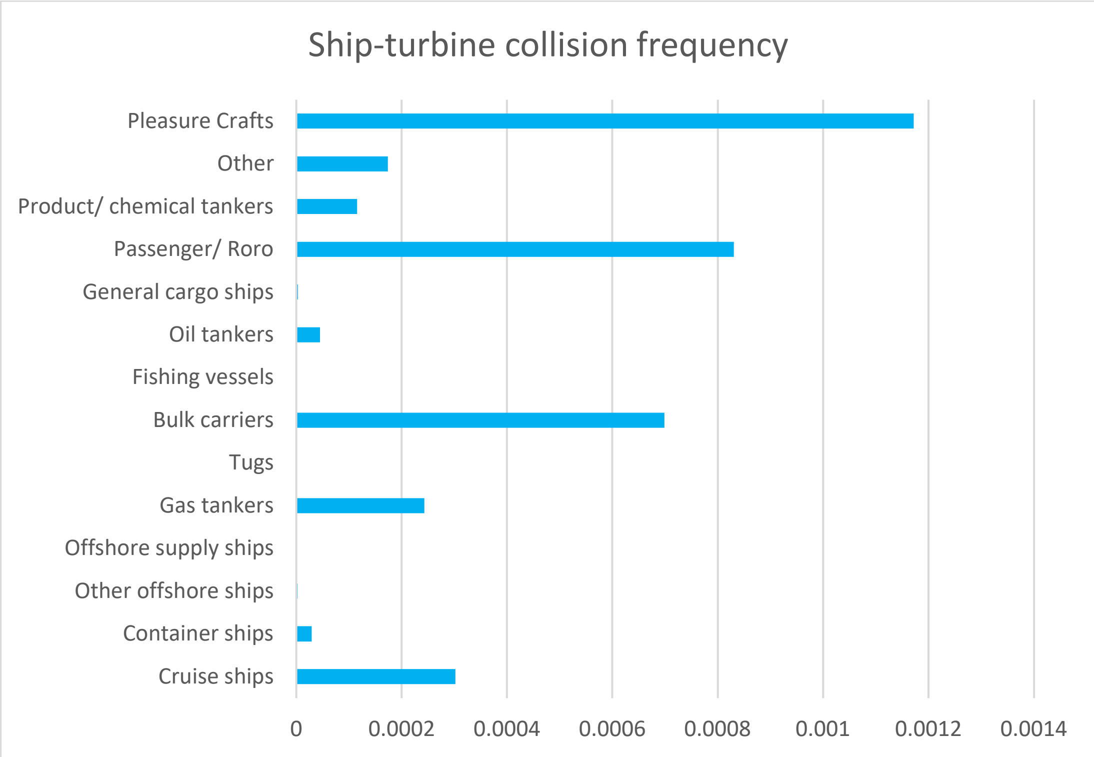
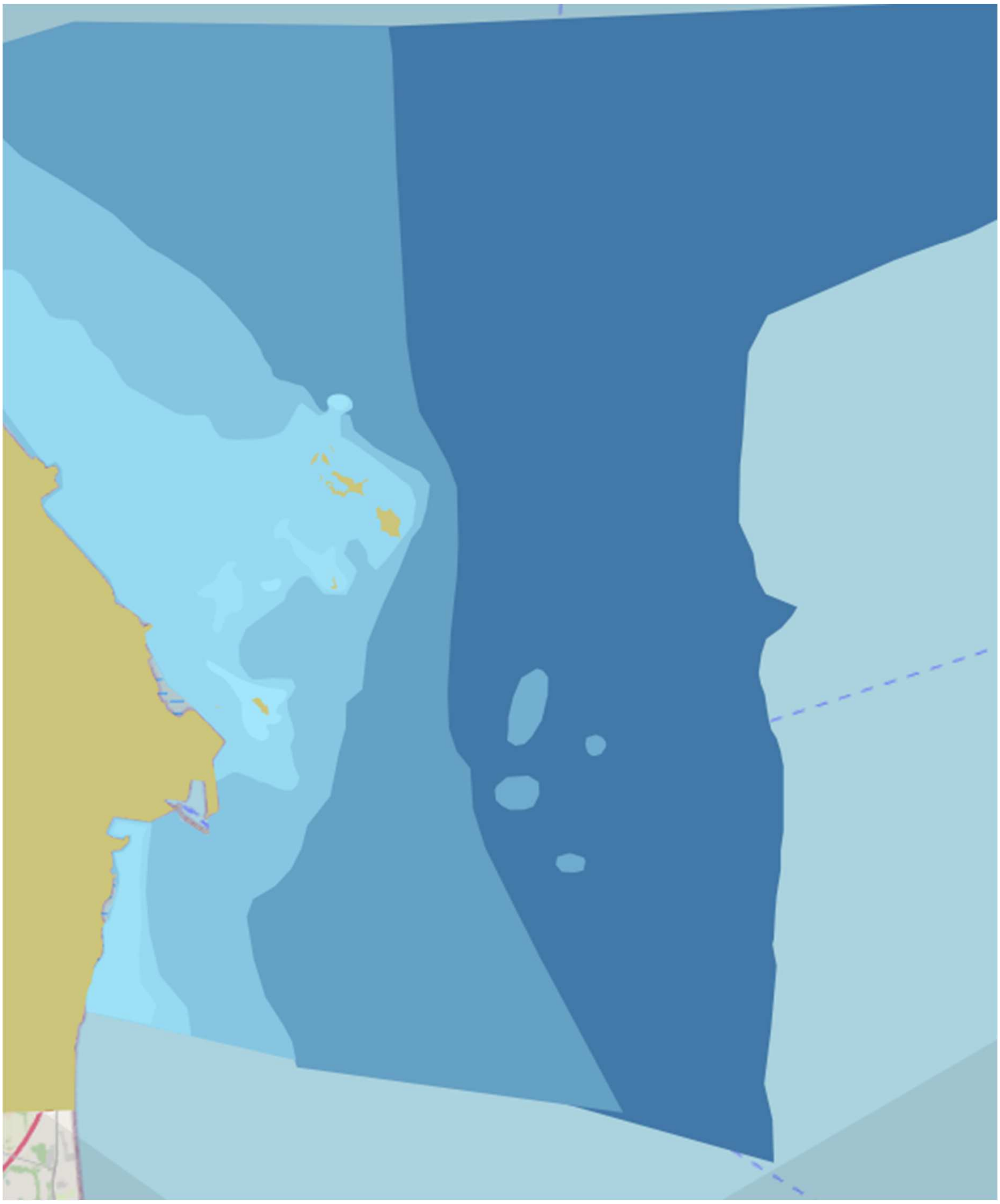


Figure 6-3 Ship-turbine collision frequency, after establishment of OWF.

APPENDIX C
Model of bathymetry

Frederikshavn model for bathymetry:



About DNV GL

DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.