NAVIGATIONAL RISK ASSESSMENT JAMMERLAND BUGT OWF

Jammerland Bay Nearshore Navigational Risk Assessment

WSP Danmark A/S

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Applicable contract(s) governing the provision of this Report:

Objective:

Assessment of the navigational risk associated with the Jammerland Bugt nearshore Wind Farm. Update of risk assessment performed in 2014/2015 with detailed farm layout

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A	2022-01-25	First issue	NJD	LSNI	JADS
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C	2023-09-26	Updated to incorporate 2022 traffic data	NJD	LSNI	JADS
D	2023-10-13	WSP comments incorporated	NJD	LSNI	LILS

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1 EXECUTIVE SUMMARY

This report presents the assessment of the impact of the planned Jammerland Bugt Nearshore Wind Farm on navigational safety, i.e., the impact on the likelihood for collisions and groundings for the shipping through the Great Belt. The study addresses five alternative layouts for the wind farm, denoted as Case 1, Case 2, Case 2a, Case 3 and Case 4, varying from a layout with 41 smaller wind turbines (Case 1) to a layout with 18 large wind turbines (Case 4).

The study covers a qualitative assessment by means of a HAZID workshop and a quantitative assessment using the IWRAP software tool.

The HAZID workshop addressed hazards both during the construction phase and the operational phase. The quantitative study does only address the changes in risk between the present situation (base case) and the operational phase, based on the shipping patterns from AIS data collected for 2019.

The quantitative study assumes that most commercial shipping that at present crosses the project area (where the wind turbines will be placed) will divert to a route circumventing the project area. This is the basis for the conclusions. Because the project area after establishing the wind turbines will be accessible for shipping, there is uncertainty to what extent some shipping, mainly recreational and fishing vessels but also incidentally other commercial vessels (e.g., small support and cargo ships), will remain to pass through the project area. This is addressed by sensitivity analysis and the outcome is reflected in the conclusions.

The study answers the questions:

- Does the wind farm lead to an intolerable number of collisions between ships and wind turbines?
- Does any rearrangement of the shipping lead to an increased and intolerable number of groundings?
- Does any rearrangement of the shipping lead to an increased and intolerable number of collisions between ships?
- From a point of view of navigational safety, is there a preference for one of the cases?

1.1 Conclusions

- There is a risk of collision between pleasure boats and wind turbines (in the order of an event occurring several times per 100 years, so it is expected to happen within the lifetime of the wind park). This is due to recreational shipping to continue to sail within the Offshore Wind Farm. This risk is ranked “Medium”, i.e., acceptable when reduced to As Low As Reasonably Practicable.
- The risk of collision between pleasure boats and wind turbines is lower for layouts with lesser wind turbines, the risk for collision for Case 4 is 42% lower than for Case 1. From a point of view of navigational safety, Case 4 is the preferred option.
- The risk of collision between commercial vessels and wind turbines is two orders of magnitude lower than the present risk of grounding or ship-ship collisions during passage of the Great Belt, and therefore in general to be considered low and broadly acceptable. Some events are ranked to have “medium” risk, viz., when smaller cargo and fishing ships that presently navigate through the location of the Wind Farm, continue to do so.
- The Offshore Wind Farm does not lead to an increase in the number of groundings.
- The Offshore Wind Farm does not lead to an increase in the number of ship-ship collisions.
- The quantitative study is based on shipping data for 2019. Shipping data for 2022 has been compared with the data for 2019, and no significant changes were observed, except an increase in recreational shipping. This increase has been accounted for in the first conclusion in this section. The study results are therefore representative for recent shipping data.

1.2 Recommendations

- It will be necessary to perform a study of the effect of the wind turbines on the radar systems used by the Great Belt Vessel Traffic Service (VTS). If the study concludes that the wind turbines cause shadowing, interference or hide reflections from ships, mitigating measures shall be implemented.

For the construction phase, the following is recommended:

- To ensure safe crossing of construction-related ship movements with the traffic along route T, it is recommended to coordinate such movements with the Great Belt VTS, and to concentrate such movements to few corridors.

To avoid unauthorised ships entering the construction area it is recommended:

- To apply a standby vessel to deflect intruding ships;
- To supplement the formally issued navigational information (Notices to Mariners) with information supplied through channels from e.g., Dansk Sejlunion, Danske Tursejlere, and Fiskeriforeningen:
- To place temporary light buoys on unfinished structures (foundations).

2 INTRODUCTION

Jammerland Bay Nearshore A/S is preparing for the installation of an offshore wind farm at Jammerland Bugt. As part of the Environmental Impact Assessment (EIA), a navigational risk assessment shall be carried out. WSP Danmark A/S supports Jammerland Bay Nearshore A/S with the preparation of the EIA and has requested DNV Denmark A/S to update the navigational risk assessment prepared in 2014/2015 (DNV GL, 2015) to incorporate the definite alternative park layouts (Cases) and more recent data on shipping in the area.

This report presents the results of the quantitative navigational risk assessment. Prior to the quantitative analysis, a hazard identification workshop was held, again to update an earlier workshop held in 2014. The overall approach for the navigational risk assessment follows hereby IMO's (International Maritime Organization) guidelines for evaluation of navigational safety assessment.

In principle, a stepwise approach needs to be adopted meaning that results are presented after each step and evaluated together with the Danish Maritime Authority (Søfartsstyrelsen) whether the next step needs to be executed.

- Step 1: A frequency analysis based on ship traffic and proposed offshore wind farm layout is executed and results are presented to the Danish Maritime Authority.
- Step 2: If the Danish Maritime Authority does not find it possible to conclude from the results of the frequency analysis that the navigational risks will be acceptable, a consequence analysis must be executed and combined with the frequency results. The navigational risk assessment will then be updated with the resulting risk derived by combining the frequency and the consequence analyses.
- Step 3: If the Danish Maritime Authority cannot approve the estimated risk, possible risk reducing measures have to be identified, analysed, and adopted if considered feasible. This risk re- duction process must continue until the risk reaches an acceptable level. Otherwise, it has to be concluded that the project will not be feasible when required to be associated with an acceptable ship collision risk.

This report presents the results of Step 1 for five alternative layouts of the wind farm, depending in the size of the finally selected wind turbine (i.e., the layouts range from 41 turbines with a rotor diameter of 164 m to 18 turbines with a diameter of 236 m. Masts will be so that the rotating turbine blades will be 20 m above sea at their lowest point).

The baseline of the quantitative analysis of Step 1 is the ship traffic observed in 2019. Ship traffic as per 2022 has also been analysed, and it has been assessed qualitatively how the changes in ship traffic between 2019 to 2022 affect the results.

The HAZID workshop (the HAZID report is attached as Appendix A to this report) concluded that the main hazard introduced by the wind farm is the collision of ships with the turbine structures. Due to slight changes in sailing patterns (routes), some increased risk of collisions between ships cannot be excluded, notably because smaller vessels, including pleasure boats, may come closer to the main commercial traffic route (route "T", "Tango" through the Great Belt).

Another critical issue mentioned during the HAZID workshop is the impact of the wind turbine structures on the RADAR used by the Vessel Traffic Support (VTS). If the wind turbines lead to shadowing, false reflections, or interference, the VTS will have a reduced overview of ship traffic. This issue requires separate assessment and measures can be taken to combat the negative consequences, eventually by installing additional RADAR. This issue will not be addressed further in this report.

The HAZID workshop also addressed the risk during installation of the wind turbines and other related works such as cable-laying. This aspect is not included in the quantitative study. The hazards related to the installations phase that were identified are:

- Increased vessel movements for constructions and crew transports; these movements are likely to cross route "T". The traffic is limited as compared to the existing traffic and crossings of local shipping and can be (should be) subject to procedures and communication via VTS as suggested during the workshop.
- Collision of vessels with construction vessels, turbine foundations and other floating objects in the construction area. During construction, the area will be marked with buoys and prohibited for non-attending vessels. This condition will be communicated via the formal navigational publication channels. It is advised to ensure wider publication via other channels aiming at pleasure boats and fishery (e.g. via Dansk Sejlunion, Danske Tursejlere, Danmarks Fiskeriforening). The use of law enforcement vessels will be considered. Therefore, it is assessed that collisions between commercial vessels and turbines under construction will be no higher than during the operational phase, and that collisions between pleasure boats and fishing boats will be less than during the operational phase, when the waters between the turbines are accessible again.

2.1 Objectives

The objective of the present navigational risk assessment is to evaluate how and to what extent the ship traffic in the area will be influenced by the Jammerland Bugt Offshore Wind Farm and to identify and estimate any associated increase in the navigational risk in the region near the wind farm. Hence, the study will answer the questions:

- Does the wind farm lead to an intolerable number of collisions between ships and wind turbines?
- Does any rearrangement of the shipping lead to an increased and intolerable number of groundings?
- Does any rearrangement of the shipping lead to an increased and intolerable number of collisions between ships?
- From a point of view of navigational safety, is there a preference for one of the alternative layouts (addressed as "cases" in this study)?

2.2 Abbreviations

AIS	Automatic Identification System	An AIS system transmits repeatedly the object's (e.g. a ship's) identification (MMSI), position, speed, direction, and other information via a VHF-radio transponder, to be used as a navigation and anti-collision tool, making the information visible to other ships and VTS. AIS is obligatory for ships over 300 gross tonnage, all passenger ships and for fishing vessels over 15 m. These ships require a "class A" transponder. AIS is voluntary for other ships that may use a "class B" transponder.
DMA	Danish Maritime Authority (Søfartsstyrelsen)	
EIA	Environmental Impact Assessment (Vurdering af Virkning på Miljø, VVM)	Environmental Impact Assessment is a process of evaluating the expected environmental impacts of a proposed project or development, considering inter-related socio-economic, cultural, and human-health impacts, both beneficial and adverse. EIA is mandatory for certain projects according to national and EU-legislation.

GIS	Geographical Information System	Digital system to represent data linked to a geographical position such as objects in maps. IWRAP allows to import data (e.g., location of structures) in GIS format.
HAZID	Hazard Identification	Method (typically using a workshop session with stakeholders) to identify possible hazards and risk for some activity.
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities	
IMO; IMO number	International Maritime Organization	The IMO ship identification number is a unique seven-digit number that is assigned to propelled, sea-going merchant ships of 100 GT and above upon keel laying except for: • Ships without mechanical means of propulsion • Pleasure yachts • Ships engaged on special service (e.g. lightships, SAR vessels) • Hopper barges • Hydrofoils, air cushion vehicles • Floating docks and structures classified in an analogous manner • Ships of war and troopships • Wooden ships
IWRAP	IALA Waterway Risk Assessment Program	IWRAP is a modelling tool useful for maritime risk assessment. IWRAP assist to estimate the frequency of collisions and groundings in each waterway based on information about traffic volume/composition, route geometry and bathymetry.
MMSI	Maritime Mobile Service Identity	A Maritime Mobile Service Identity (MMSI) is a series of nine digits which are sent in digital form over a radio frequency channel to uniquely identify ship stations, ship earth stations, coast stations, coast earth stations, and group calls.
OWF	Offshore Wind Farm (Offshore vindmøllepark)	
VMS	Vessel Monitoring System	Vessel Monitoring Systems (VMS) is a general term to describe systems that are used in commercial fishing to allow environmental and fisheries regulatory organizations to track and monitor the activities of fishing vessels. In Denmark VMS is based on Inmarsat-C transceivers and is obligatory for commercial fishing vessels over 12 m.
VTS	Vessel Traffic Service	Land-based service to assist navigation, typically in busy waters

3 PROJECT DESCRIPTION

3.1 Offshore Wind Park

Jammerland Bugt Wind Farm is a near shore wind farm. Figure 3-1 shows the area selected for the location of the wind turbines and the corridor used to lay the cables for the connection to shore. This Figure also indicates the former survey area. The former survey study considered two cases with 80 and 35 wind turbines within this survey area, respectively.

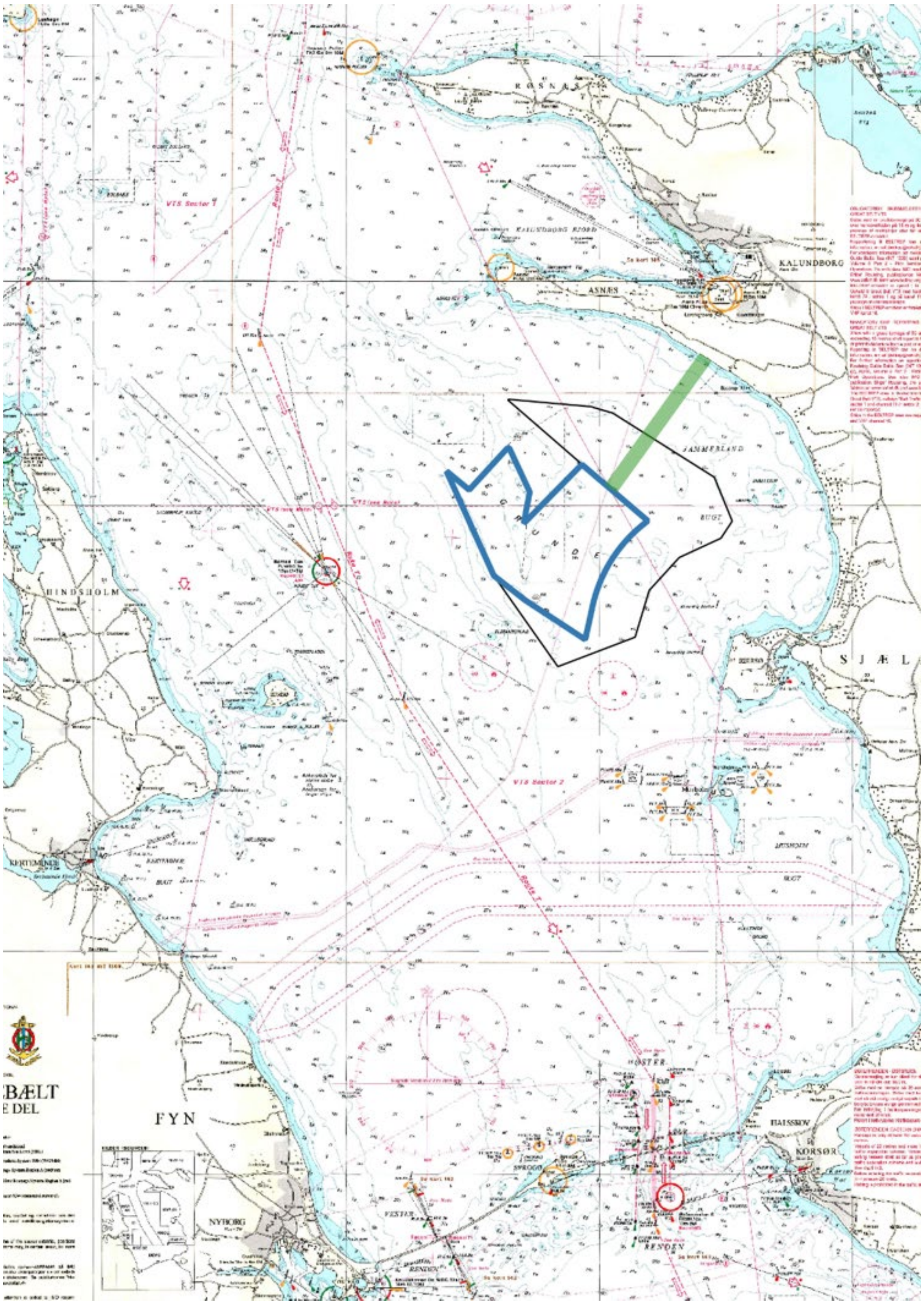

Figure 3-1 Project area marked in the navigational map. The thick blue marking is the extent to the layouts assessed in this report. The thin black marking is the survey area studied in 2014/2015. The green band indicates the cable corridor.

The wind park area is about 31 km^2. Water depths in the area vary between 4 and 20 m. Table 3-1 provides an overview of the five different lay-out cases with the number and size of the wind turbines. The power will be exported directly to land thus no offshore substation will be needed.

Table 3-1 Specification of the lay-out cases and turbine sizes

Case	Number of turbines	Rotor Diameter (m)	Hub Height (m)	Total Height (m)	Foundation Diameter 3 m above sea level (m)
1	41	164	102	184	10.5
2	27	174	107	194	11.5
2a	32	188	114	208	11.5
3	24	200	120	220	12.0
4	18	236	138	256	13.0

The layouts for the 5 cases are shown in Figure 3-2 to Figure 3-6, respectively. Note that the size of the dots indicating the positions are not to scale.

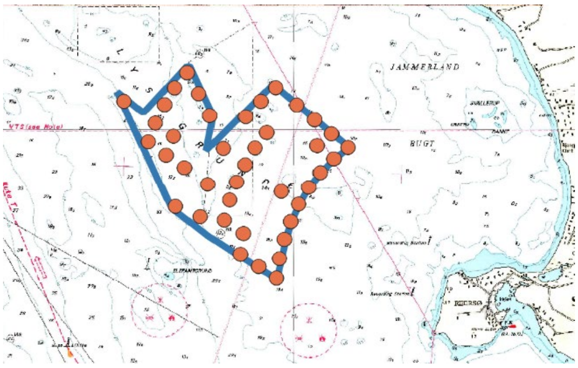

Figure 3-2 Case 1: 41 turbines with 164 m rotor.

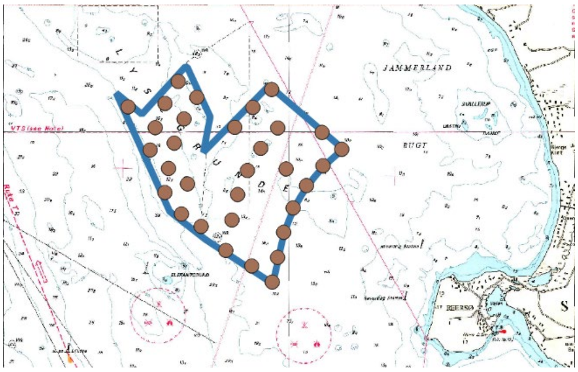

Figure 3-4 Case 2a: 32 turbines with 188 m rotor.

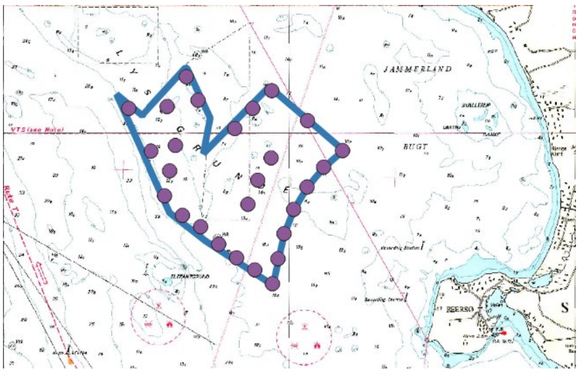

Figure 3-3 Case 2: 27 turbines with 174 m rotor.

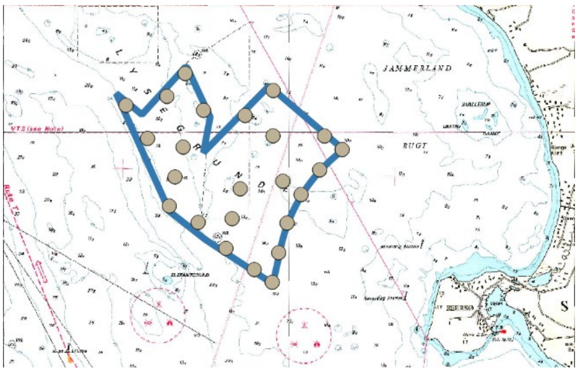

Figure 3-5 Case 3: 24 turbines with 200 m rotor.

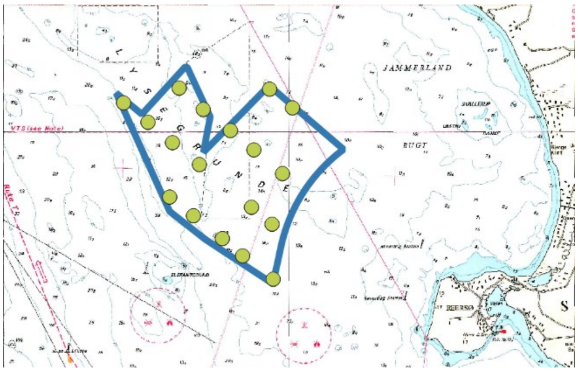

Figure 3-6 Case 4: 18 turbines with 236 m rotor.

4 MODEL DESCRIPTION AND DATA COLLECTION

The following describes the method for performing Step 1, the frequency analysis. The frequency analysis is based on acknowledged mathematical models typically used for such analyses and with input based on historical (statistical) data. The applied calculation tool IWRAP MKII is a part of the IALA Recommendation (IALA, 2009) on risk management.

4.1 Analysis tool

The IWRAP MKII software 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), see (Engberg, 2010) (IALA, 2014) for detailed theoretical model description. The probabilistic model assumptions are summarised in Appendix C and identical to the assumptions used in the previous study (DNV GL, 2015).

A description of the ship traffic constitutes the central input for a navigational risk assessment. Automatic Identification System (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, 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 MKII.

4.2 Data collection

4.2.1 AIS data

For the updated risk assessment AIS data was collected for 2019. The reason for this selection is that it is the most recent data, not being affected by the consequences of the COVID-19 pandemic on shipping.

The ship traffic is determined from the historical AIS data available at DMA (DMA, 2021), using all data (twelve months) for 2019. The AIS data handled in the analysis is within the following geographic bounds (the model area):

- Northerly bound: 55°48’ N
- Southerly Bound: 55°15’ N
- Westerly Bound: 010°30’ E
- Easterly Bound: 011°15’ E

The model area is shown in Figure 4-1 (the area within the slightly darker margin) and covers by-and-large the area shown in the nautical map of Figure 3-1. The area is chosen so that all relevant shipping that could reasonably interact with the wind farm (by drifting or on erroneous course) is included.

The AIS data exists of records for each transmitted AIS message. The messages are processed to select the following ships and ship positions:

- MMSI number starts with integer between 2 and 7 (i.e., only ship-related stations are included);
- AIS transmitter is Class A or Class B;
- Position is within the above boundaries;
- Speed Over Ground (SOG) is between 0.8 and 60 kn;
- Navigational status is neither “At Anchor” nor “Moored;”

The mapped AIS data and its extents are shown in Figure 4-1. Further detail on the processing of the AIS data follows in section 5. AIS data for selected ship types (passenger ships, tank ships, and pleasure boats and fishing ships) are presented in Appendix B.

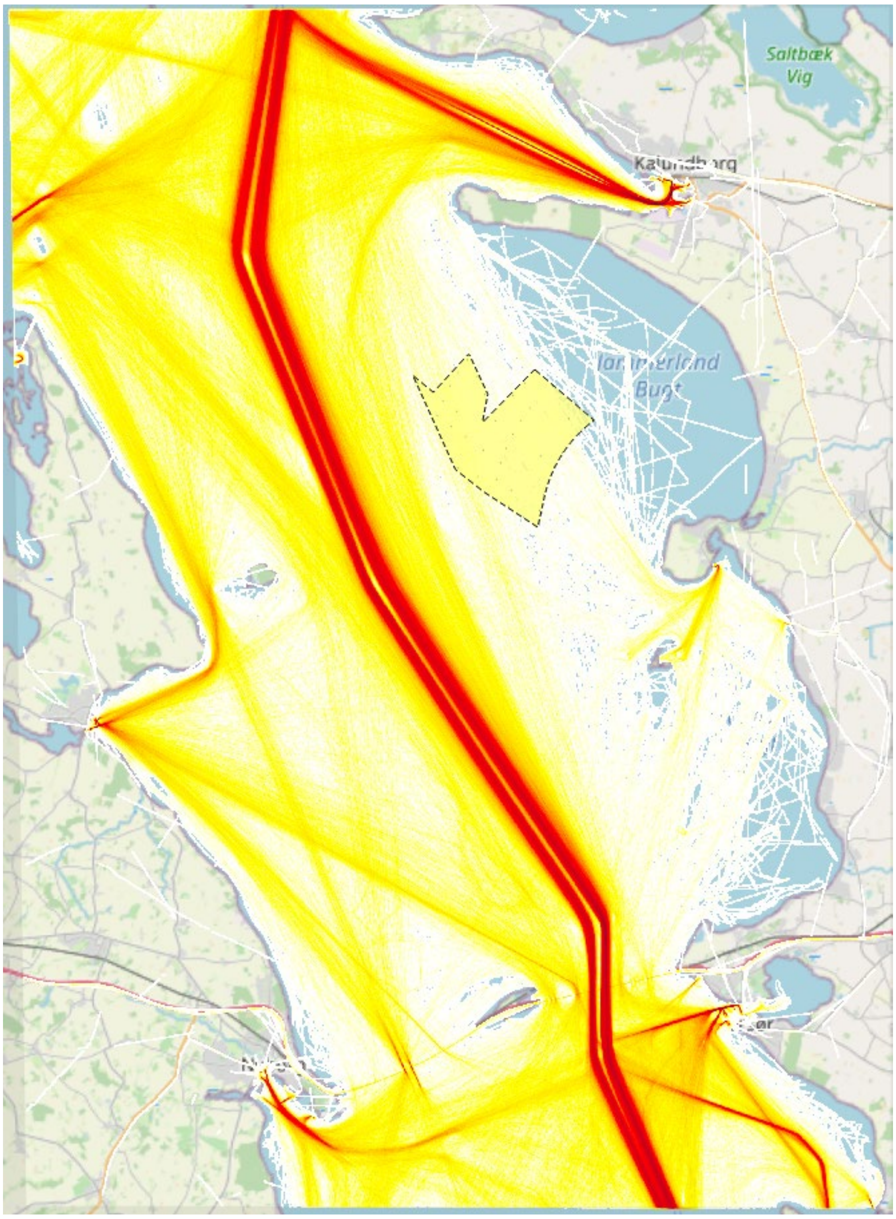

Figure 4-1 Ship traffic density based on AIS data from January 1 to December 31, 2019. The project area is shown for information only. Highest densitiy is dark red (up to black), single ship movements are shown as white tracks. The dense shipping along route "T" is clearly visible, with ships keeping at starboard side of the route centre line. The shipping along this route is about 10 000 vessels per year, both South-bound and North-bound.

4.2.2 VMS data

Because not all fishing ships (need to) use AIS, VMS data was also collected for 2019. VMS transponders are required for commercial fishing vessels longer than 12 m. (AIS is required for fishing vessels longer than 15 m). The VMS has been processed so it could be imported into the IWRAP MkII software in the same format as AIS data. VMS data is only transmitted once per hour and therefore the data needed to be interpolated to shorter time intervals to be compatible with AIS data. This was done by quadratic interpolation using position, speed, and direction from each VMS message. Figure 4-2 shows the fishing vessel density from the VMS data for 2019. A single track for one fishing vessel tour is also shown. The track does not end in the harbour because the VMS transponder was turned off within one hour from the last position outside the harbour.

As can be seen from Figure 4-2, there is little fishing activity in the project area, VMS-tracks are passing through the Western part of the project area, but this may just be passing vessels.

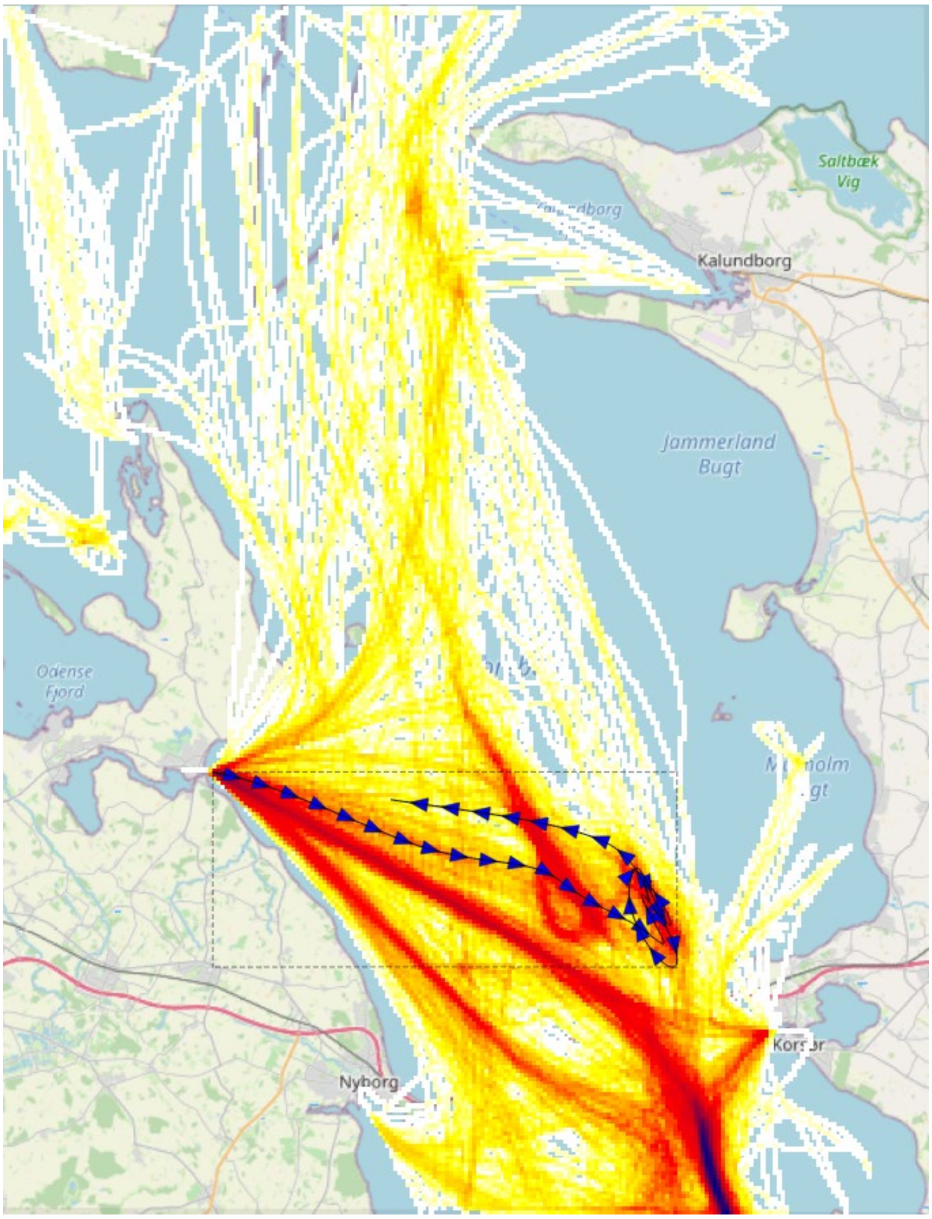

Figure 4-2 Fishing vessel density from VMS data for 2019. The arrows show a single track as example.

In the VMS database for 2019, 39 unique ships are recognized within the model area. In the AIS database, there are at least 49 vessels of the "Fishing ship" type within the model area. In the VMS database, fishing vessels are anonymised, and it is therefore not possible to check whether vessels appear in both databases. There are ships under 20 meters that do not have an IMO number and are classified as "Other Ship". There may be a few fishing vessels among them. As there are more fishing vessels in AIS data than in VMS, AIS data is also considered to be representative of fishing, and VMS data will not be used separately for the risk calculations.

4.2.3 Wind direction

The IWRAP MkII software requires input concerning the frequency of drift directions. Drift direction frequency is assumed to be the same as the wind direction frequency. Wind direction frequency is derived from data available from the online Global Wind Atlas (DTU Wind Energy, 2021), extracted at position 55° 31.02' N and 010° 55.2' E, which is almost in the centre of the model area. The frequencies are shown in Table 4-1. As expected, south-westerly and westerly winds (from 225° to 270°) are most frequent.

Table 4-1 Wind and Drift direction frequency.

Wind direction (°)	Frequency (%)	Drift direction
0	5.69	S
45	6.19	SW
90	10.19	W
135	12.00	NW
180	13.81	N
225	18.69	NE
270	20.94	E
315	11.50	SE

4.2.4 Bathymetry

The grounds in the area are as shown in Figure 4-3. The wind farm will be located at water depths ranging between 20 to 4 m in the bay of Jammerland Bugt. The wind farm will be partly shielded by the grounds "Lysegrunde" (Southbound traffic on route "T") and "Elefantgrunde" (Northbound traffic on route "T").

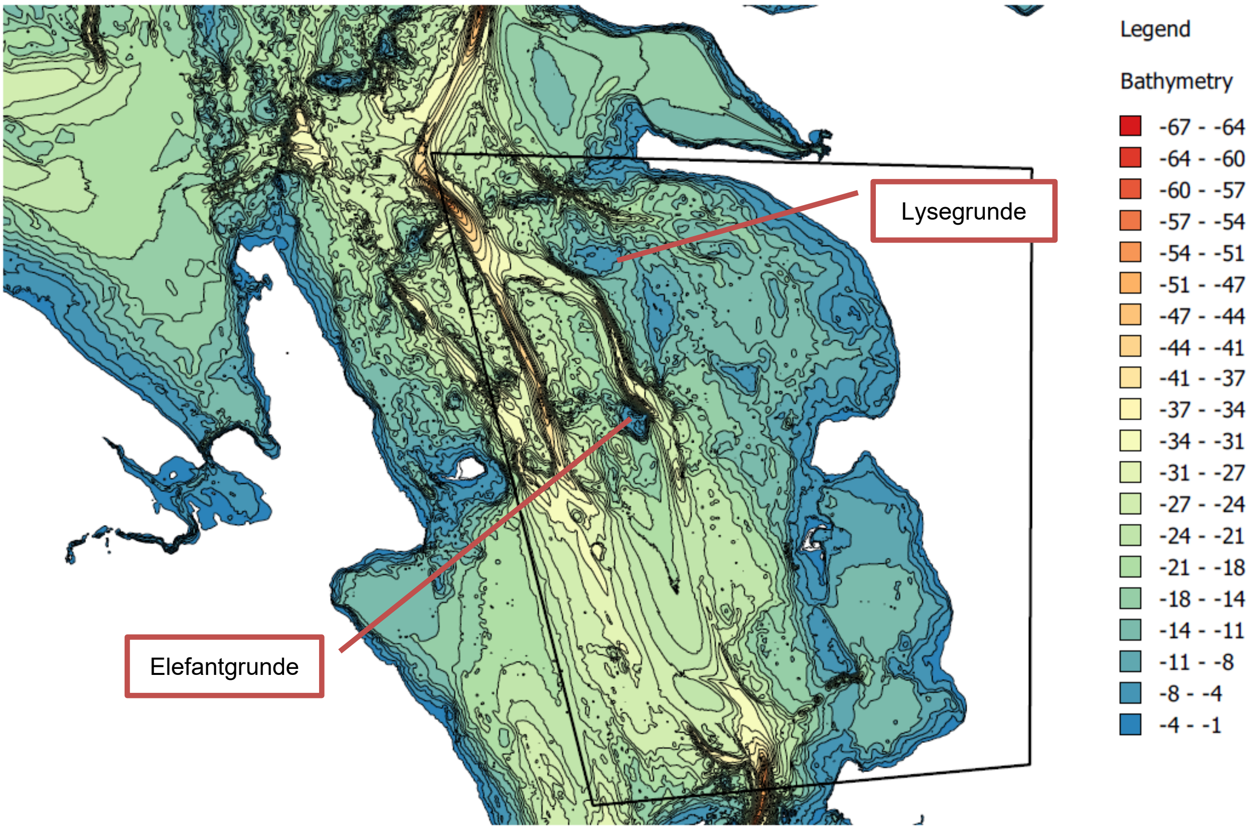

Figure 4-3 Bathymetry of the Great Belt, depth in meter. The data within the area marked with the black line is used in the analysis.

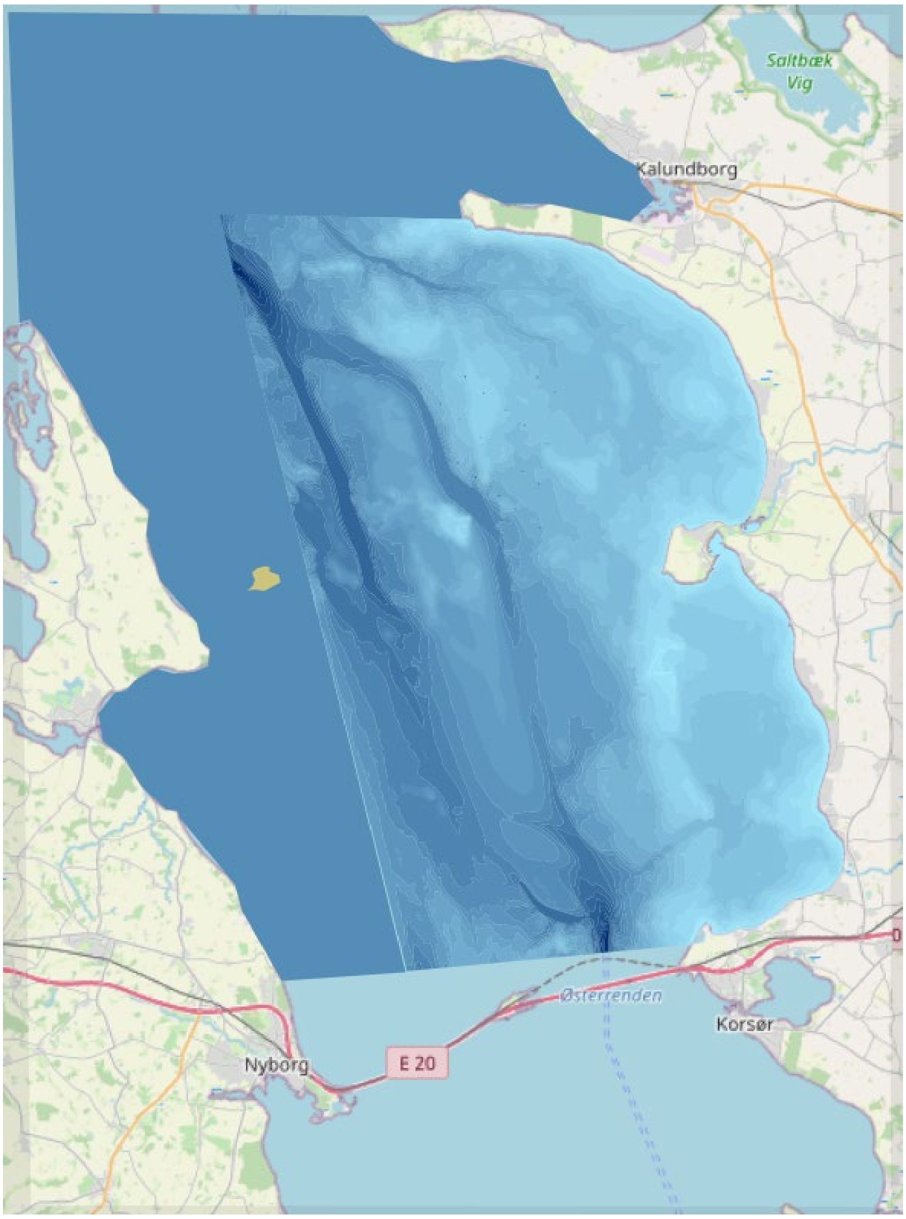

Figure 4-4 Bathymetry imported into the analysis. The part of the modelling area surrounding the detailed bathymetry that is shown in a darker blue defines a water depth of 25 m, which allows emergency anchoring in that area for all ships with a design draught over 3.6 m.

4.2.5 Wind turbine positions

Wind turbine positions are imported from data provided by WSP. WSP provided the centre positions of the wind turbines for the five cases (see Figure 3-2 to Figure 3-6). This data was transformed via GIS into hexagons with the distance between opposite corners to match the foundation diameter as in Table 3-1. These hexagons are imported into IWRAP as the individual wind turbine structures.

5 ANALYSIS OF AIS DATA

5.1 Ship types

When importing AIS data, the software assigns the ship type to the data available in the AIS message. The data obtained from DMA does not contain ship types for all AIS messages (ship type “undefined”). IWRAP maps this to the category “Other ship.”

The category “Other ship” is attempted to be minimized. For ships with IMO number, the ship type is assigned by:

- Applying data from a list issued by Lloyds, a list which also was used for the previous risk assessment, i.e., updated up to 2015
- Applying data from SeaWeb (IHS Markit, 2021) to the remaining “other ships”

For the remaining “Other Ships”, and ships without IMO number (e.g., naval vessels), data has been added manually using data from MarineTraffic (MarineTraffic, 2021). Such manual editing has been performed for all ships that have at least one trip in the model area.

A total of 42611 "trips" inside the model area have been registered for a total of 7440 unique ships. 2218 ships are “Pleasure boats”, 267 ships are “Other ship” (e.g., naval vessels, law enforcement, SAR, dredgers, lifting vessels, etc.).

The traffic distribution data in IWRAP separates ship length at 25 m. If the AIS data does not contain information about the length of the ship, the length is set to 50 m by default. This information has been adjusted manually for Pleasure Boats that made 3 or more trips (most of those pleasure boats are less than 25 m). However, there are left 125 Pleasure Boats with incorrect data (length by default 50 m). This is considered acceptable as being less than 6% of the number of Pleasure Boats (and even less when accounting for the number of trips).

Four vessels are by AIS assigned “Fast Ferries”, these have been manually inspected; one vessel is a US naval craft (moved to “Other Ships”), the other three are found to be high speed pleasure vessels without IMO number (moved to Pleasure Boats).

Figure 5-4 provides information about the numbers and type of ships passing through the Great Belt after further processing of data as discussed in the following sections.

5.2 Recreational shipping without AIS

AIS is not obligatory for pleasure vessels and fishing vessels smaller than 15m (although fishing vessels above 12m need to have a VMS transponder). The fraction of pleasure boats equipped with (and using) AIS is unknown. The issue was addressed during the HAZID workshop (see Appendix A). Estimates from participants range from 2% to 10%. In this study it is assumed that 5% of the sailing pleasure boats smaller than 15 m is using AIS, so where applicable, the amount of pleasure vessels < 25 m (as this is the distinction made in IWRAP) will be multiplied by 20 to represent the total amount of recreational shipping.

5.3 Traffic routes

The AIS data needs to be transformed into a “risk model.” The risk model assumes the ship traffic to follow several routes, made up of “legs” connected at waypoints. The routes and legs are assigned manually, based on a qualitative assessment of the AIS density distribution. Then, IWRAP selects the AIS data as trips and assigns the traffic to that leg that is both aligned (default within 10°) with the legs and within the manually set width. IWRAP calculates the lateral distribution of the traffic along the leg, which is the input to IWRAPs risk model.

5.3.1 Base case

For the base case, i.e., the situation before the construction of the wind farm, the routes are determined by the present (2019) ship density distribution. These routes are shown in Figure 5-1. The routes are selected that possibly have an impact on collision with or grounding close to the wind farm. Such routes are either parallel with the wind farm (with possible incidents from drifting due to predominant westerly winds) or pointing towards the wind farm (with incidents due to human error – forget to turn).

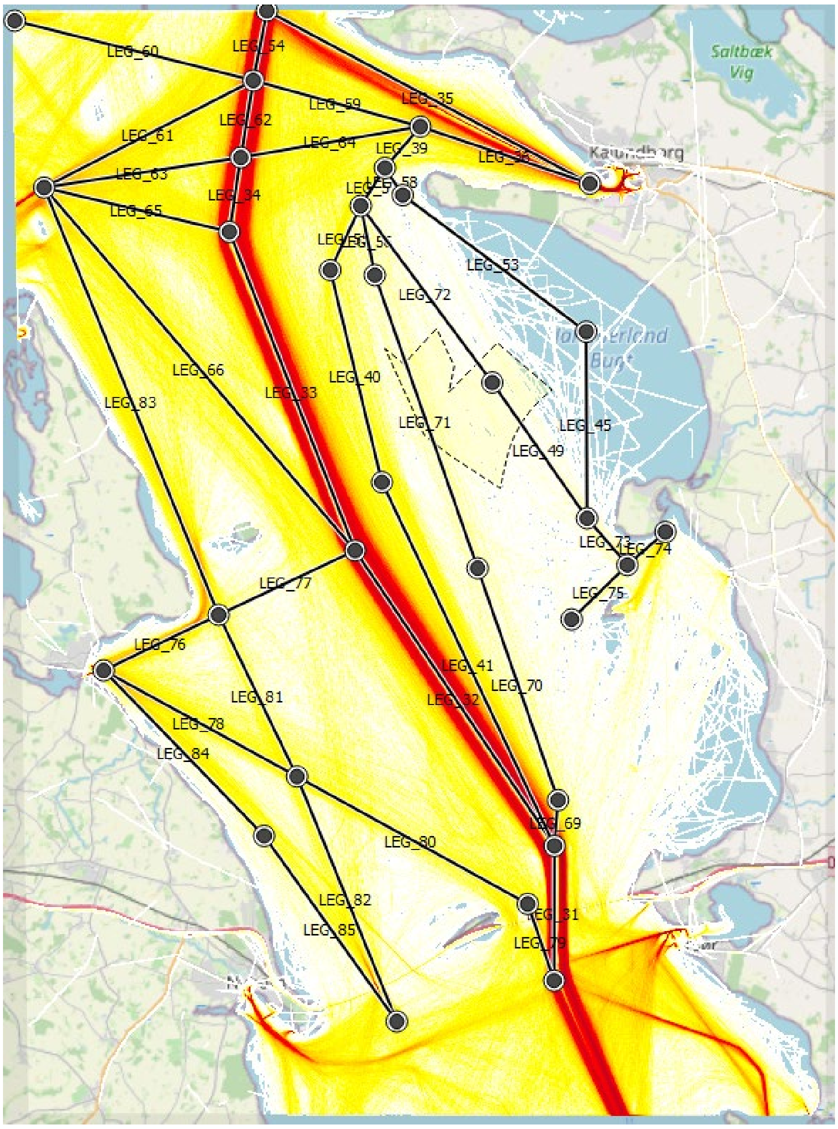

Figure 5-1 Routes, legs, and waypoints for the situation before construction of the wind farm (Base Case).

In the previous risk assessment (DNV GL, 2015) the "random" ship traffic not linked to a route (typically fishing and recreational shipping) was distributed over an area. Within the IWRAP model, random traffic in an area can be included to assess the ship-ship collision risk, but it is neither used to assess the possible groundings nor collision with structures. As the wind farm after construction is not restricted for (recreational) shipping, for the present study, the recreational shipping close to or though the wind farm is assigned to a special route, consisting of legs 49 and 72. The width of the legs is set to be very wide, covering the selected wind farm area, and the "alignment" criterion, default being 10°, is increased to 45°. This is supported by the analysis of traffic crossing two "passage lines" (Figure 5-2). From the crossing angles (not shown here) it appears that almost all ship movements are oriented along the NW-to-SE line, i.e., parallel with the coastline.

Figure 5-2 Analysis of ships passing two passage lines crossing the wind farm area

In anticipation of recreational ships taking a route East of the future wind farm along the coast, avoiding proximity to the heavy trafficked "route T", legs 45 and 53 have been included in the model set-up for the base case. This route has been treated differently too, similarly to legs 49 and 72, with the alignment criterion set to 30°. Both routes with the manually set width are shown in Figure 5-3. This Figure also shows the route of legs 69, 70, 71 and 56, which is used by smaller commercial vessels, and is likely to be relocated to be close to or overlapping with the route formed by legs 41, 40 and 55 once the wind farm is constructed.

The traffic intensity of pleasure boats and other ships < 25 m on the legs 49, 72, 45, 53 and 73 has been increased by a factor of 20 (see section 5.2) to account for recreational shipping not included in the AIS data as in Table 5-1.

Table 5-1 Adjustment of traffic intensity for non-AIS equipped pleasure vessels

	Pleasure boats < 25 m	
	Original (per year)	Adjusted (per year)
Leg_72 North Bound	90	1800
Leg_72 South Bound	53	1060
Leg_49 North Bound	77	1540
Leg_49 South Bound	46	920
Leg_73 North Bound	24	480
Leg_73 South Bound	19	380
Leg_53 West Bound	6	120
Leg_53 East Bound	1	20
Leg_45 North Bound	4	80
Leg_45 South Bound	0	0

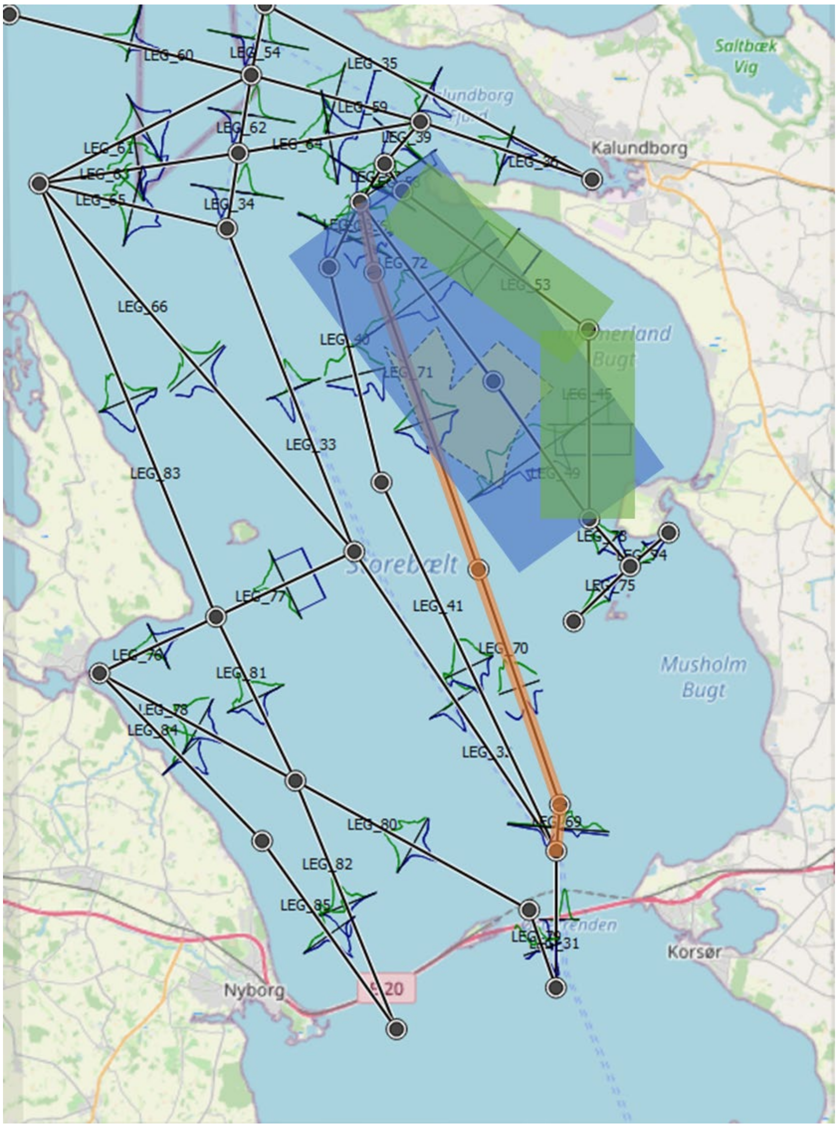

Figure 5-3 Shipping routes with lateral distributions. Routes through and around the wind farm are shown with the assigned width (in blue and green, respectively). The orange route is assumed to shift after construction of the wind farm.

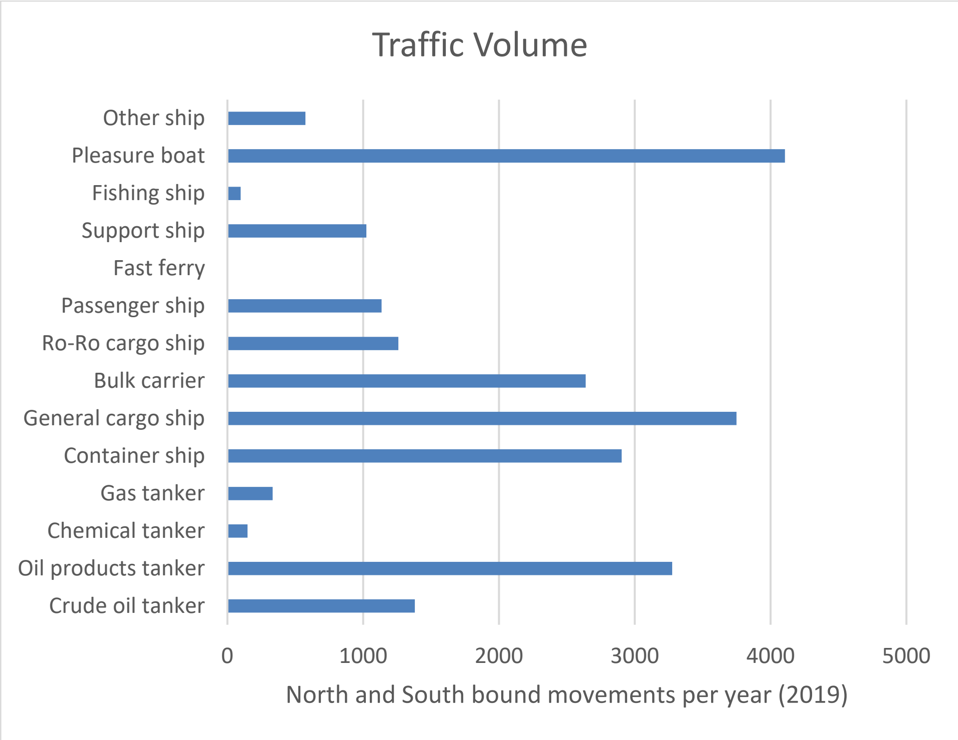

Figure 5-4 Traffic volume following legs 53, 72, 71, 40, 33, 66 and 83 after adjustment of recreational shipping for ships not using AIS.

The shipping in the model area, which potentially can interfere with, or may be influenced by, the future wind farm, exists mainly of the traffic passing through the Great Belt. The traffic volume passing through the Great Belt along the routes is shown in Figure 5-4. These volumes are the sums of the North bound and South bound traffic on legs (from East to West) 53, 72, 71, 40, 33, 66 and 83. Assuming that 5% of the pleasure boats are using AIS leads to an estimate of about 4100 recreational shipping movements. Note that the actually AIS-recorded pleasure boat movements over all legs count to about 1250 – only the traffic through and east of the windfarm has been compensated for missing AIS coverage by additional 2850 movements, see Table 5-1.

Figure 5-4 show that, assuming about 5% of the pleasure boats use AIS, pleasure boats dominate the shipping through the Great Belt close to the project area. Next to pleasure boats are general cargo ships and oil tankers. The sailing patterns of pleasure boats differs considerably from the routes taken by notably tankers and passenger ships, which stay close to the main route “T”, see Appendix B. There are some smaller General Cargo, Other, and Support ships that show patterns slightly more distributed than tankers, and at present take course through the project area.

5.3.2 Cases 1, 2, 2a, 3 and 4

The only change (apart from inclusion of the wind turbine structures) introduced for the risk assessment after construction of the wind turbines is the relocation of the route formed by the legs 69, 70, 71, and 56, which is now to pass West of Elefantgrunden, see Figure 5-5. In principle, ships can pass between Elefantgrunden and the wind farm, but Elefantgrunden is marked by a cardinal West buoy at the West side (not shown here but to be found on detailed nautical charts).

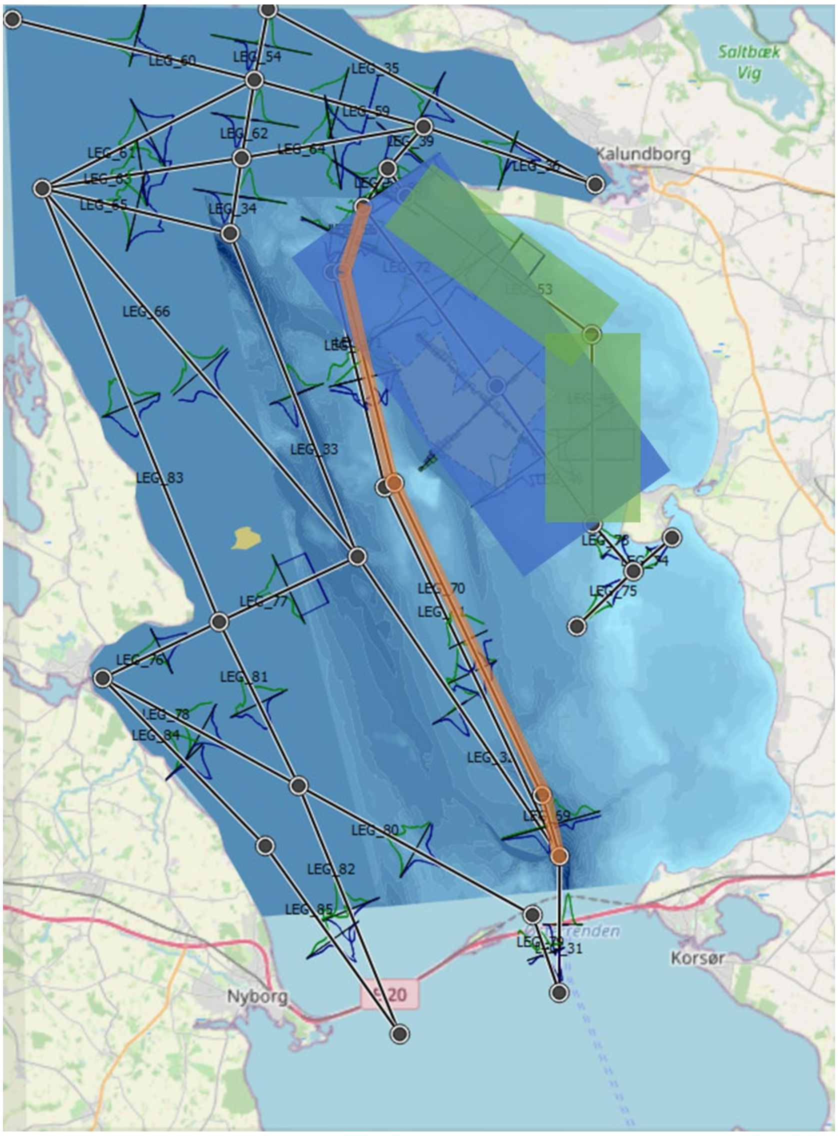

Figure 5-5 Shipping routes for the condition after construction of the wind farm. The orange route has been relocated to pass West of Elefantgrunden. The other routes are unchanged.

5.3.3 Sensitivity analysis – Relocation of recreational shipping

Two sensitivity studies are included. The aim of the first sensitivity studies is to address the uncertainty of the wind farm on the choice of pleasure boats either to pass through the wind farm or to pass around the wind farm. As discussed in the previous section, the primary assumption has been that the pleasure boats continue to use the same routes as before. At the HAZID workshop it was expressed that motor vessels are likely to continue to sail through the wind farm (shortest route) but sailing vessels would like to avoid the wind farm (foul winds, turbulence).

The effect of the recreational shipping only passing the wind farm to limited extent will be investigated by relocation of the “blue” route, legs 49 and 72. This route is relocated so that the centreline passes just South and West of the windfarm area. The width of the legs is decreased so the legs have limited overlap with the “orange” route. At the same time half of the recreational ships using this route are moved to the route following legs 45 and 53, see Table 5-2 and Figure 5-6. In this way only about one quarter of the ships will “pass” through the wind farm in the risk model. This is considered to represent a low estimate, appropriate for the sensitivity study.

Table 5-2 Adjustment of traffic intensity and relocation of pleasure vessels

	Pleasure boats < 25 m	
	Baseline assessment (per year)	Sensitivity assessment (per year)
Leg_72 North Bound	1800	900
Leg_72 South Bound	1060	530
Leg_49 North/West Bound	1540	770
Leg_49 South/East Bound	920	460
Leg_53 West Bound	120	1020
Leg_53 East Bound	20	550
Leg_45 North Bound	80	830
Leg_45 South Bound	0	460

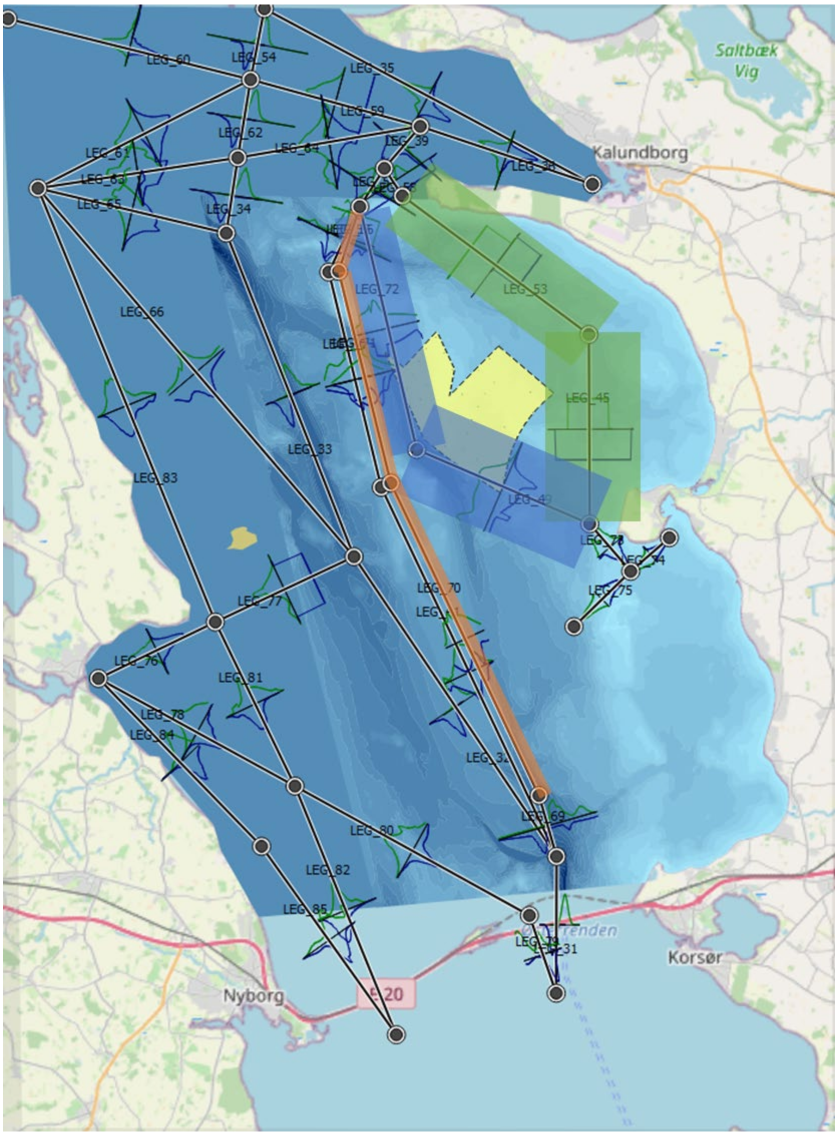

Figure 5-6 Relocation and adjustment of the route for recreational shipping originally passing completely through the wind farm.

5.3.4 Sensitivity analysis – Uniformly distributed traffic area

The second sensitivity study is performed to allow a comparison with the previous assessment (DNV GL, 2015). The previous assessment used traffic areas with uniformly distributed recreational and fishing traffic. Using this approach in IWRAP will not lead to prediction of collisions with structures or groundings of the traffic included by such traffic areas, only collisions between vessels. So, this sensitivity study will lead to a low number of collisions with wind turbines but may give higher collisions between vessels.

The analysis of the passage lines (Figure 5-2) concluded that the average shipping density at the site of the wind farm is about 0.001 vessel (equipped with AIS) per square nautical mile. An area for uniformly distributed traffic (with random direction and speed) is defined for the Base Case as indicated in Figure 5-7. The routes through the wind farm site and east of the site have been removed, as the area is intended to replace that traffic (note that in that process some other ship types' traffic has been removed, i.e., smaller vessels for general cargo and support ships). The area has an area of 252 km^2 or 74 NM^2 and the above-mentioned density corresponds to 1 vessel sailing in the area each day for 106 minutes. To account for the vessels without AIS, the number of vessels has been increased to 20 each day.

For the cases after construction of the wind farm, the area is shown in Figure 5-8. The area excludes the wind farm area and covers 217 km^2. The number of visiting vessels to the area is the same (20 vessels visiting the area each day for 106 minutes), so the shipping density is slightly higher (0.00116 ships per NM^2).

Figure 5-7 Area for uniformly distributed shipping for the Base Case.

Figure 5-8 Area for uniformly distributed shipping for the cases after construction of the wind farm.

6 UPDATED AIS TRAFFIC DATA FOR 2022

The AIS data for the year 2022 has been analysed in order to identify whether there are significant changes since 2019 and how this will affect the assessment.

6.1 Importing AIS data

A slight improvement has been made during the importing of the AIS data as compared to the description in section 4.2.1. The criteria are now:

- MMSI number shall have 9 characters and starts with an integer between 2 and 7 (i.e., only ship-related stations are included);
- Position is within the model area boundaries as described in section 4.2.1 ;
- Speed Over Ground (SOG) is between 0.8 and 100 knts (was 60 knts, the difference is not considered to be important);
- Navigational status is neither “At Anchor”, “Moored” nor “Aground;”
- In addition the following data has been processed to handle IWRAPs default ship dimensions when information is not contained in the AIS data: If transponder “Class B” or ship type “Pleasure boat” and no length, then length set at 15 m and width at 4 m

6.2 Ship types

Using SeaWeb (IHS Markit, 2021) and MarineTraffic (MarineTraffic, 2021), all unknown ships with unknown length with AIS transponder Class A having 1 or more trips in the area were identified and information was updated in IWRAP.

34 unknown ships with length at 15 m (hence class B transponder) and default type “Other Ships” were found. The 5 ships with the largest number of trips in the area (i.e. about 15%) were identified manually using MarineTraffic, and all found to be pleasure boats. Therefore, all these 34 ships were set to be pleasure boats.

A total of 30394 "trips" inside the model area have been registered for a total of 8844 unique ships. 3405 ships are “Pleasure boats”, 330 ships are “Other ship” (e.g., naval vessels, law enforcement, SAR, dredgers, lifting vessels, etc.).

This information is compared with the data from 2019 in Table 6-1.

Table 6-1 Comparison of overall data between 2019 and 2022

	2019	2022
Total number of trips	42611	30394
Total number of unique ships for these trips	7440	8844
Total number of pleasure boats for these trips	2218	3405
Total number of Other Ships for these trips	267	330

6.3 Traffic volume

The traffic intensity of pleasure boats and other ships < 25 m on the legs 49, 72, 45, 53 and 73 has been increased by a factor of 20 (see section 5.2 and 5.3.1) to account for recreational shipping not included in the AIS data as in Table 6-2. It is noted that the intensity of pleasure boating in the immediate vicinity of the planned wind farm has almost been doubled from 2019 to 2022. There may be random factors affecting pleasure boating from year to year (e.g. weather conditions), but travel restrictions during the COVID-19 epidemic may have increased the interest in pleasure boating, at least temporarily.

Table 6-2 Adjustment of traffic intensity for non-AIS equipped pleasure vessels, comparison between 2019 and 2022

	Pleasure boats < 25 m			
	2019		2022	
	Original (per year)	Adjusted (per year)	Original (per year)	Adjusted (per year)
Leg_72 North Bound	90	1800	157	3140
Leg_72 South Bound	53	1060	109	2180
Leg_49 North Bound	77	1540	145	2900
Leg_49 South Bound	46	920	91	1820
Leg_73 North Bound	24	480	46	920
Leg_73 South Bound	19	380	35	100
Leg_53 West Bound	6	120	17	340
Leg_53 East Bound	1	20	5	100
Leg_45 North Bound	4	80	11	220
Leg_45 South Bound	0	0	9	180
Total	320	6400	625	11900

Figure 6-1 Compares the numbers and type of ships passing through the Great Belt cf. the presentation in Figure 5-4.

The total number of commercial ships has remained at the same level, although there are some shifts for specific ship types (General cargo and Oil products tankers have increased while bulk carriers and container ships have decreased). The main significant change is the increase in pleasure boating, notably in the area of the planned wind farm. Fishing has almost halved.

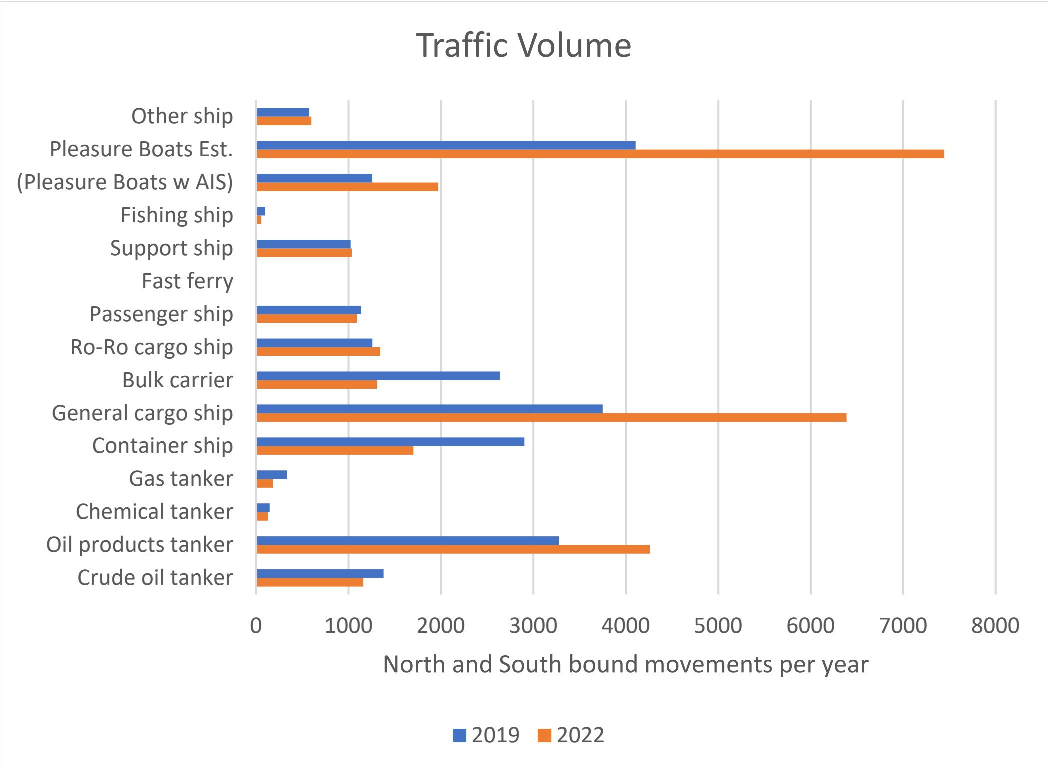

Figure 6-1 Comparison of traffic volume following legs 53, 72, 71, 40, 33, 66 and 83 from 2019 to 2022 (see Figure 5-1 for definition of legs). "Pleasure Boats Est" refers to the estimated movements of pleasure boats after adjustment for pleasure boats not equipped with AIS as per Table 5-2 and Table 6-2. "Pleasure Boats w AIS" refers to the actually observed movements of pleasure boats.

6.4 Traffic patterns

Observed traffic patterns are included in Appendix B. The data that has been used for the detailed assessment presented in Chapter 7 for 2019 is shown in Figure B-1 to Figure B-4 for all ships, passenger ships, tank ships and pleasure boats/fishing ships, respectively. Figure B-5 to Figure B-8 show the traffic patterns in 2022 for the same shipping categories.

The patterns for “all ships” do not show significant differences. There seems to be a slightly higher intensity on legs 71 and legs 49/72, which seems to represent pleasure boating.

Passenger ships show the same patterns with traffic concentrated along "route T" (legs 32/33). The same holds for tank ships, with some ships taking the "short cut" (slightly more in 2022 than 2019) on the route Kalundborg-Great Belt bridge via legs 41/40.

Pleasure boating/fishing ships also show by-and-large the same pattern, with a higher intensity in Jammerland Bugt and the area for the planned wind farm, in line with the observations from the traffic volume comparison in the above section.

An additional Figure B-9 has been included to show the (limited) fishing ship trips in the area in 2022. Most of the fishing ship trips seem trips in transit rather than fishing, notably through or close to the selected area for the planned wind farm.

7 RESULTS

7.1 Main study

Risk calculations are performed for the condition prior to construction of the wind farm ("Base Case") and for each of the cases 1, 2, 2a, 3 and 4 using the data as presented in sections 3.1, 5.3.1 and 5.3.2 (i.e. the ship traffic as observed in 2019). The total results in terms of groundings (powered and drifting) and collision with the wind turbine structures (powered and drifting) and ship-ship collisions (during overtaking, heads-on collisions, during crossing, merging, and bending) are presented in Table 7-1. The presence of the wind farm leads to a minor decrease in the number of groundings, probably due to the relocation of the "orange" route (Figure 5-5 and Figure 5-6). A considerable number of collisions with the wind turbines are predicted, in the same order of magnitude as the number of groundings. Most powered collisions happen for Pleasure Boats, and the data is included separately in Table 7-1. This is due to the "blue" route crossing the wind farm. The wind farm has no significant impact on the prediction of ship-ship collisions.

The number of collisions clearly decreases with the number of wind turbines as is expected, but not fully proportionally. While the number of wind turbines is reduced by 56% (from 41 for Case 1 to 18 for Case 4), the number of (powered) collisions decreases by 37% (non-recreational) to 42% (Pleasure Boats).

Note that this study does not address the potential impact of high ships (superstructures or masts) with rotor blades reaching down to 20 m above sea level. For ships reaching several meters above this level, the area to collide into, and thus the probability of hitting, will be larger compared to the turbine foundations with diameters from 10.5 to 13 m.

Table 7-1 Risk assessment results

Type of incident	Incident frequency per 1000 years					
	Base Case	Case 1	Case 2	Case 2a	Case 3	Case 4
Powered Grounding	3.63	3.40	3.40	3.40	3.40	3.40
Drifting Grounding	31.87	31.84	31.85	31.84	31.85	31.85
Total Groundings	35.50	35.24	35.25	35.24	35.25	35.25
Powered Structure Collisions/ Pleasure Boats	---	27.15	19.55	22.95	17.41	15.70
Powered Structure Collisions/ non-recreational	---	0.43	0.32	0.36	0.28	0.27
Drifting Structure Collisions	---	0.17	0.17	0.19	0.15	0.11
Total Structure Collisions	---	27.75	20.05	23.50	17.85	16.07
Overtaking	28.68	28.70	28.70	28.70	28.70	28.70
HeadOn	4.03	4.14	4.14	4.14	4.14	4.14
Crossing	2.35	2.27	2.27	2.27	2.27	2.27
Merging	1.22	1.22	1.22	1.22	1.22	1.22
Bend	69.96	69.96	69.96	69.96	69.96	69.96
Area	---	---	---	---	---	---
Total Ship-Ship Collisions	106.20	106.30	106.30	106.30	106.30	106.30

The distribution of structure collision over ship types is shown in Figure 6-1. Note that the numerical scale is logarithmic, the contribution of Pleasure Boats is two orders of magnitudes larger than the next largest contribution (Other ships).

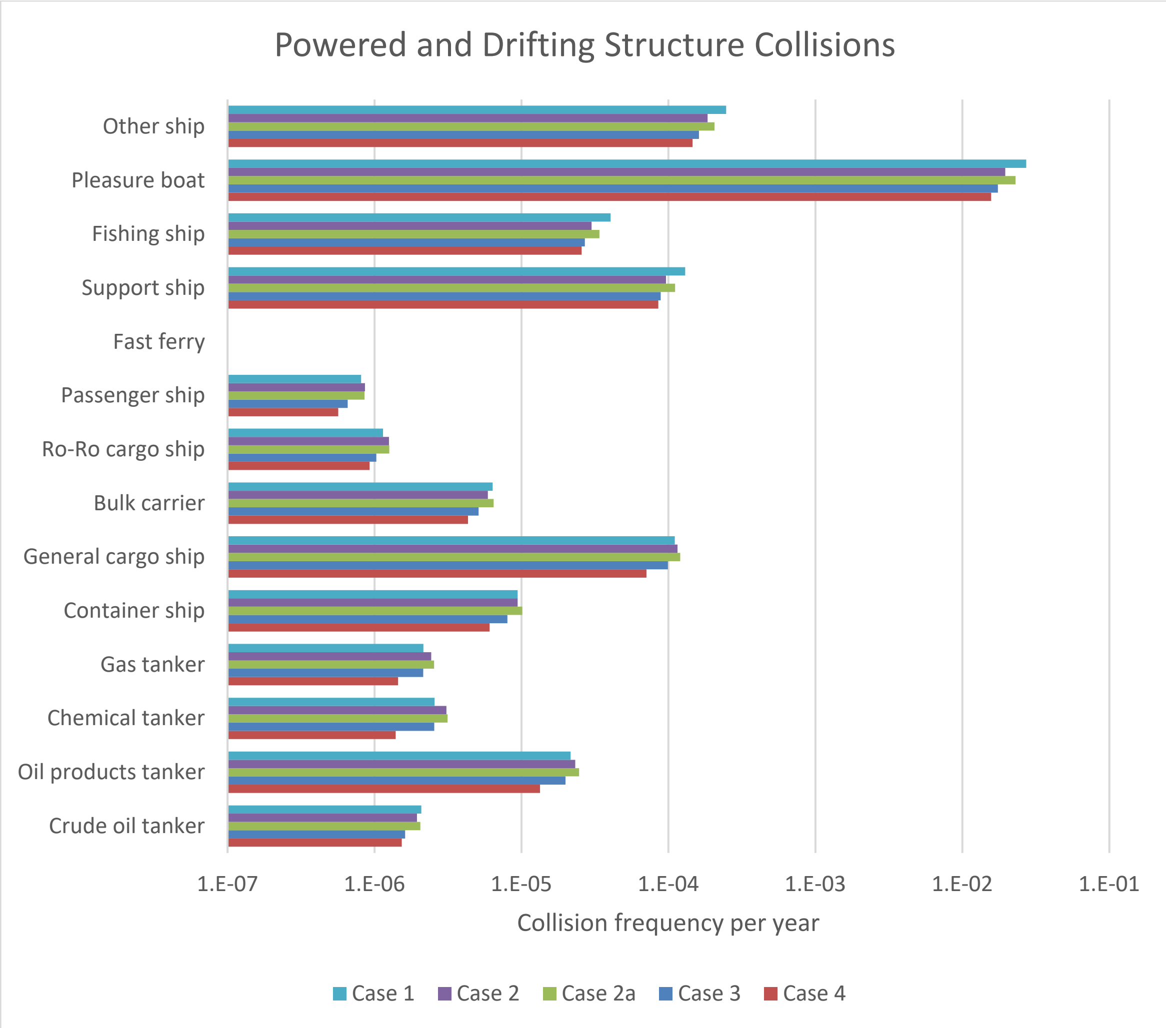

Figure 7-1 Contribution of ship types to collision with wind turbines.

Based on the results from the quantitative analysis, some scenarios from the HAZID study should be modified in terms of a changed expected frequency. These changes are shown in Table 7-2 The other scenarios of the HAZID remain unchanged, with unchanged risk ranking. With respect to definition of the modification factor and the frequency, severity and risk classes, reference is made to the HAZID study and the risk matrix therein. Note that the collision frequency class for passenger ships (Hazard IDs 2.8 and 2.9) has been set at "-6" which is below the range of the class definition, but considered to represent the results of the quantitative study (Figure 6-1, less than once per million years) best.

Table 7-2 Hazards identified during the HAZID workshop with updated frequency class (pink column) based on the quantitative risk assessment.

Hazard-ID	Ship type	Cause/Event	Hazard	Consequence	Frequency (class)	Modification Factor	Severity Persons	Severity Property	Severity Environment	Risk
1.2	Smaller ships	Changed sailing pattern, small ships closer to route "T"	Ship-Ship Collision	Fatality	-3	0.01	4	4	3	
1.4	Fishing ship	Human failure or technical fault	Powered collision with wind turbine	Injury, Damage, Oil spill	-4	2	3	4	3	
2.8	Passenger ship	Human failure or technical fault	Powered collision with wind turbine Turbine collapses on ship or rotor blade hits ship	Injury	-6	100	3			
2.9	Passenger ship	Human failure or technical fault	Powered collision with wind turbine	Damage to ship	-6	0.01		5		
3.3	Pleasure boat	Human failure or technical fault	Powered collision with wind turbine	Injury	-1	0.05	4			
3.4	Pleasure boat	Human failure or technical fault	Powered collision with wind turbine	Damage to ship	-1	0.01		4		
3.5	Pleasure boat	Human failure or technical fault	Powered collision with wind turbine	Oil spill	-1	0.2			0	
3.6	Pleasure boat	Masts above 20 m can be hit by rotor blade	Ship comes close to wind turbine	Damage to ship and rotor	-1	0.01	4	2	0	

7.2 Sensitivity analysis

As Case 1 leads to the highest number of structure collisions, this case has been taken for the sensitivity assessments.

The first study addresses the change of traffic through and around the wind farm as described in section 5.3.3, the second sensitivity the use of areas with uniformly distributed shipping as described in section 5.3.4. Note that in the latter case the shipping covered by the area is not assumed to be engaged in structure collisions of groundings, only in ship-ship collisions.

The results are presented in Table 7-3 and Figure 7-2. The “Base Case” and “Case 1” columns in Table 7-3 are identical to those in Table 7-1. In Table 7-3 the results from the previous study (DNV GL, 2015) are included next to the results for the assessment using uniformly distributed shipping (fishing and recreational), because this is the similar set-up.

Relocation of the route though the windfarm to pass the wind farm reduces the number of collisions by factor of 3, as could be expected.

Replacing the traffic through the wind farm by assuming an area with uniformly distributed shipping density, those ships now excluded from the calculated grounding and collisions with the wind turbines, drastically reduces the collision frequency, that now only covers the shipping on the remaining routes at larger distance from the wind farm.

Table 7-3 Results for the sensitivity analysis and comparison with the previous study. "Sensitivity" refers to the relocation and narrowing of the route through the wind farm, "Area" refers to the use of an area with uniformly distributed shipping, replacing the routes through and East of the wind farm.

Type of incident	Incident frequency per 1000 years					
	Base Case	Case 1	Case1 sensitivity 1	Base Case Area	Case 1 Area	Previous study
Powered Grounding	3.63	3.40	3.33	3.20	2.98	
Drifting Grounding	31.87	31.84	31.84	31.87	31.83	
Total Groundings	35.50	35.24	35.17	35.07	34.82	46
Powered Structure Collisions/ Pleasure Boats	---	27.15	7.85	---	0.05	
Powered Structure Collisions/ non-recreational	---	0.43	0.28	---	0.03	0.009
Drifting Structure Collisions	---	0.17	0.19	---	0.15	0.17
Total Structure Collisions	---	27.75	8.32	---	0.23	0.18
Overtaking	28.68	28.70	28.70	28.68	28.70	
HeadOn	4.03	4.14	4.10	4.03	4.03	
Crossing	2.35	2.27	2.29	2.35	2.26	
Merging	1.22	1.22	1.22	1.22	1.22	
Bend	69.96	69.96	69.96	69.96	69.96	
Area	---	---	---	0.026	0.026	
Total Ship-Ship Collisions	106.20	106.30	106.30	106.30	106.20	91

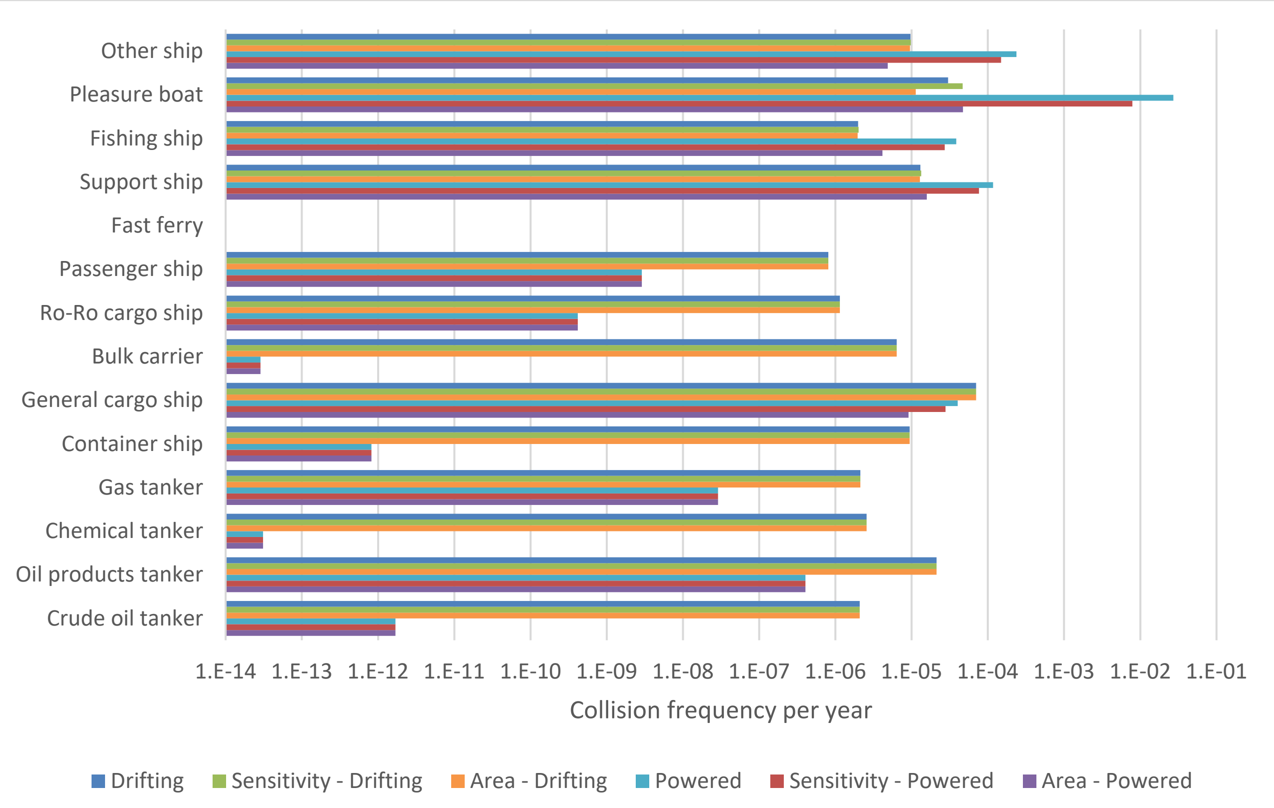

Figure 7-2 Distribution of Powered and Drifting collisions for Case 1, including the results of the sensitivity studies. "Sensitivity" refers to the relocation and narrowing of the route through the wind farm, "Area" refers to the use of an area with uniformly distributed shipping, replacing the routes through and East of the wind farm.

Figure 7-2 shows the distribution of powered and drifting collision for Case 1, both the baseline calculations and the two sensitivity studies. The sensitivity studies only affect the shipping originally heading through the wind farm area, which apart from the Pleasure Boats and Fishing ships also includes Other Ships, some smaller General Cargo ships, and Support ships.

7.3 Update for ship traffic in 2022

Chapter 6 describes the ship traffic intensity in 2022 and the comparison with the ship traffic in 2019. It is concluded that the overall ship traffic distribution has not changed. Also, the commercial ship traffic has not changed significantly in terms of total numbers. A noticeable increase of pleasure boating is observed, up to about a factor 2 in the area of the planned wind farm.

Given that the shipping patterns have not changed, the incident frequency for some ship type can be expected to change proportionally with the change of traffic intensity for that ship type. So the changes as presented in Figure 6-1 will change the results as in Figure 7-1 in the same proportion. This is insignificant for the commercial shipping, but it may be expected that incidents with pleasure boats will double as compared to the results in Table 7-1 and Table 7-3. So collisions between pleasure boats and wind turbine structures are expected to be between 2 and 6 per 100 years rather than 1 to 3 per 100 years.

7.4 Discussion of the results

The questions to be answered by this study are:

- Does the wind farm lead to an intolerable number of collisions between ships and wind turbines?
- Does the rearrangement of the shipping lead to an increased and intolerable number of groundings?
- Does the rearrangement of the shipping lead to an increased and intolerable number of collisions between ships?
- From a point of view of navigational safety, is there a preference for one of the alternative layouts (cases)?

7.4.1 Collisions between ships and wind turbines

The HAZID study (Appendix A) addresses the hazard of ships colliding with the wind turbines. The risk ranking, notably the estimated frequency of collision was based on the previous study (DNV GL, 2015). The results have been updated with the present results, see Table 7-2. The present results predict a relative high number of collisions, notably of Pleasure Boats, with wind turbines. This number is of the same order as the expected number of groundings or ship-ship collisions predicted in the model area in total. These collisions arise because the Pleasure Boats may remain to sail within the Wind Farm area. Depending on the change in sailing patterns and behaviour of recreational seafarers, as addressed by the baseline and sensitivity analysis, the expected frequency of collisions between Pleasure Boats and wind turbines is between 1 and 3 per 100 years (Table 7-3, based on the 2019 data, and between 2 and 6 per 100 years considering the 2022 data, see section 7.3). More collisions are predicted for the cases with more wind turbines (see Table 7-3). It shall be noted that the prediction is based on collision-causing factors (such as human-error rates and mechanical-fault rates) for professional shipping. If standards for Pleasure Boats are less, the number of collisions will be higher. The following scenarios are therefore estimated to be more frequent than assessed previously and change from risk ranking “green” (broadly acceptable) to “yellow” (Medium Risk, Acceptable if reduced to As Low As Reasonably Acceptable) see Table 7-2:

- Powered collision of Fishing ship with wind turbine (Hazard ID 1.4), considering property damage,
- Powered collision of Pleasure Boat with wind turbine (Hazard IDs 3.3, 3.4 and 3.6), considering personal risk (fatality) and property damage, and including the risk of wind turbine wings to hit masts over 20 m height.

This leads to the following set of collision scenarios that are to be ranked “yellow” (combine Table 7-1 with results from HAZID study):

- Fishing ship, powered collision, property damage,
- (General) Cargo, drifting collision, property damage and oil spill,
- (General) Cargo, powered collision, oil spill,
- Pleasure Boat, powered collision and/or wing hitting mast, loss of life and property damage.

With respect to the Cargo ships it is noted that the most likely collisions are with ships under 100 m length. The consequence severity is based on an oil spill of more than 100 ton. A small sample of ships in that size show that these ships indeed can have in the order of 100 tons of fuel oil on board but distributed over a several tanks (day-tanks, bunker tanks). The probability that all those tanks will leak, and thus the probability of leakage of 100 tons from such ships after collision, is small.

The probability of powered collision between a passenger ship and a wind turbine is extremely improbable, or even less than that, considering the frequency class definition used in the HAZID study. The expected frequency is less than 1 per 10 million years. On that basis it does not seem justified within the scope of this wind farm project to consider the possibility of the turbine falling on the passenger ship, the hazard as identified with ID 2.8 in the HAZID Study (Appendix A).

7.4.2 Change in number of groundings

The data in Table 7-1 and Table 7-3 show a very small decrease in the number of groundings after establishment of the Offshore wind Farm. This cannot be considered a significant change, and it is concluded that the Offshore Wind Farm and the related change of shipping patterns does not affect the risk of grounding.

7.4.3 Change in number of ship-ship collisions

The data in Table 7-1 and Table 7-3 show that there is no significant change in the number of ship-ship collisions. It is concluded that the Offshore Wind Farm and the related change of shipping patterns does not affect the risk of collision between ships.

7.4.4 Difference between layouts

As mentioned in section 7.1, the number of collisions decrease with the number of wind turbines as expected. The baseline study shows that the number of (powered) collisions decreases by about 37% for commercial (non-recreational) shipping and by 42% for Pleasure Boats when going from Case 1 to Case 4. From a point of navigational safety, fewer large wind turbines are to be preferred over more but smaller turbines. For commercial shipping, especially shipping along the main routes, the absolute risk of collision is small compared to the possibility for other accidents (ship-ship collision or grounding) during passage of the Great Belt, so for commercial shipping the number of wind turbines is not of utmost importance. With respect to Pleasure Boats, of which it is expected that some will remain to sail through the Wind Farm, there is a significant reduction in the risk of collision for Case 4 as compared to Case 1.

8 CONCLUSIONS

8.1 Conclusions from the quantitative risk assessment

- There is a risk of collision between pleasure boats and wind turbines (in the order of an event occurring several times per 100 years, so it is expected to happen within the lifetime of the wind park). This is due to recreational shipping may continue to sail within the Offshore Wind Farm and the uncertainty to what extent this will be the case. This risk is ranked “Medium”, i.e., acceptable when reduced to As Low As Reasonably Practicable.
- The risk of collision between pleasure boats and wind turbines is lower for layouts with lesser wind turbines, the risk for collision for Case 4 is 42% lower than for Case 1. From a point of view of navigational safety, Case 4 is the preferred option.
- The risk of collision between commercial vessels and wind turbines is two orders of magnitude lower than the present risk of grounding or ship-ship collisions during passage of the Great Belt, and therefore in general to be considered low and broadly acceptable. Some events are ranked to have “medium” risk, viz., when smaller cargo and fishing ships that presently navigate through the location of the Wind Farm, continue to do so.
- The Offshore Wind Farm does not lead to an increase in the number of groundings.
- The Offshore Wind Farm does not lead to an increase in the number of ship-ship collisions.
- The quantitative study is based on shipping data for 2019. Shipping data for 2022 has been compared with the data for 2019, and no significant changes were observed, except an increase in recreational shipping. This increase has been accounted for in the first conclusion in this section. The study results are therefore representative for recent shipping data.

8.2 Additional conclusions from the HAZID study

- It will be necessary to perform a study of the effect of the wind turbines on the radar systems used by the Great Belt Vessel Traffic Service (VTS). If the study concludes that the wind turbines cause shadowing, interference or hide reflections from ships, mitigating measures shall be implemented.

8.3 Recommendations for the construction phase

The construction phase has not been addressed in the quantified risk assessment, so the findings and recommendation originate from the HAZID study.

- To ensure safe crossing of construction-related ship movements (such as transport of personnel and components) with the traffic along route T, it is recommended to coordinate such movements with the Great Belt VTS, and to concentrate such movements to few corridors.

During construction, the area or sector where the construction will take place will temporarily be closed for other shipping note related to construction. Concerns were raised during the HAZID, that some ships, notably Pleasure Boats and Fishing ships, may violate the prohibition, not least due to a lack of awareness. Following recommendations were suggested during the HAZID:

- To apply a standby vessel to deflect intruding ships;
- To supplement the formally issued navigational information (Notices to Mariners) with information supplied through channels from e.g., Dansk Sejlunion, Danske Tursejlere, and Fiskeriforeningen:
- To place temporary light buoys on unfinished structures (foundations).

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APPENDIX A
HAZID study

NAVIGATIONAL RISK ASSESSMENT JAMMERLAND BUGT OWF

Hazard identifikation og kvalitativ risikovurdering af sejladssikkerhed

WSP Danmark A/S

Report No.: 1387975, Rev. B
Date: 2022-01-28

DNV

Project name:	Navigational Risk Assessment Jammerland Bugt OWF	DNV Denmark A/S Energy Systems
Report title:	Hazard identifikation og kvalitativ risikovurdering af sejladssikkerhed	Facilities, Equipment and Components E-NL-C
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Date of issue:	2022-01-28	
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Organisation unit:	Facilities, Equipment and Components E-NL-C	
Report No.:	1387975, Rev. B	

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Objective:

Prepared by:	Verified by:	Approved by:
Lasse Sahlberg-Nielsen Senior Engineer	Nijs Jan Duijm Principal Risk Specialist	Nijs Jan Duijm Principal Risk Specialist

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Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	2022-01-21	First Issue	LSNI	NJD	NJD
B	2022-01-28	Implemented WSP comments	LSNI	NJD	NJD

Table of contents

1 RESUME

DNV har fået til opgave at udføre en analyse af sejladssikkerheden i forbindelse med udarbejdelsen af miljøkonsekvensrapport for Jammerland Bugt Kystnær Havmøllepark.

Analysen følger IMO “Guidelines for Formal Safety Assessment” /1/, hvor det første step jfr. retningslinjerne er, at få identificeret de mulige hazards (mulige uheld), der kan medføre personskade, skade på miljøet eller økonomiske tab. Som baggrund for denne øvelse er skibstrafikken kortlagt i området baseret på AIS-data. AIS dataene dækker en periode af 12 måneder fra januar 2019 til december 2019.

HAZID’en (HAzard IDentification) blev udført virtuelt via TEAMS tirsdag d. 14. december 2021.

Hazard gruppen afspejlede de forskellige interessenter og fagområder, og bestod af personer med stor erfaring og kompetencer indenfor sejladssikkerhed. Hazard gruppen identificerede hazards relateret til skibstyperne fundet i AIS analysen. De fleste fartøjer er dækket af AIS og den eventuelle del af mindre fiskere og lystsejlere, der ikke er dækket af AIS, er vurderet ud fra VMS og et skøn fra deltagerne.

For de identificerede hazards er frekvenser og konsekvenser skønnet, og på baggrund af dette er risikoen evalueret ud fra den opstillede risikomatrice.

Endelig blev der i relation til de forskellige hazards identificeret forskellige mulige risikoreducerende tiltag (afværge- eller sikkerhedsforanstaltninger). Indførelsen af nogle af disse tiltag bør baseres på en cost-benefit evaluering, men dette arbejde udestår.

Hazards er vurderet ud fra fem mulige mølleopstillingsscenarier. Mølleopstillingsscenarier ændrer ikke på hvilke typer af hazards vil opstå men frekvensen (sandsynligheden) for at de forekommer, vil formentlig ændres. Deltagerne forventer, at opstillingsscenarier med færre møller vil mindske sandsynlighed for sammenstød med møller.

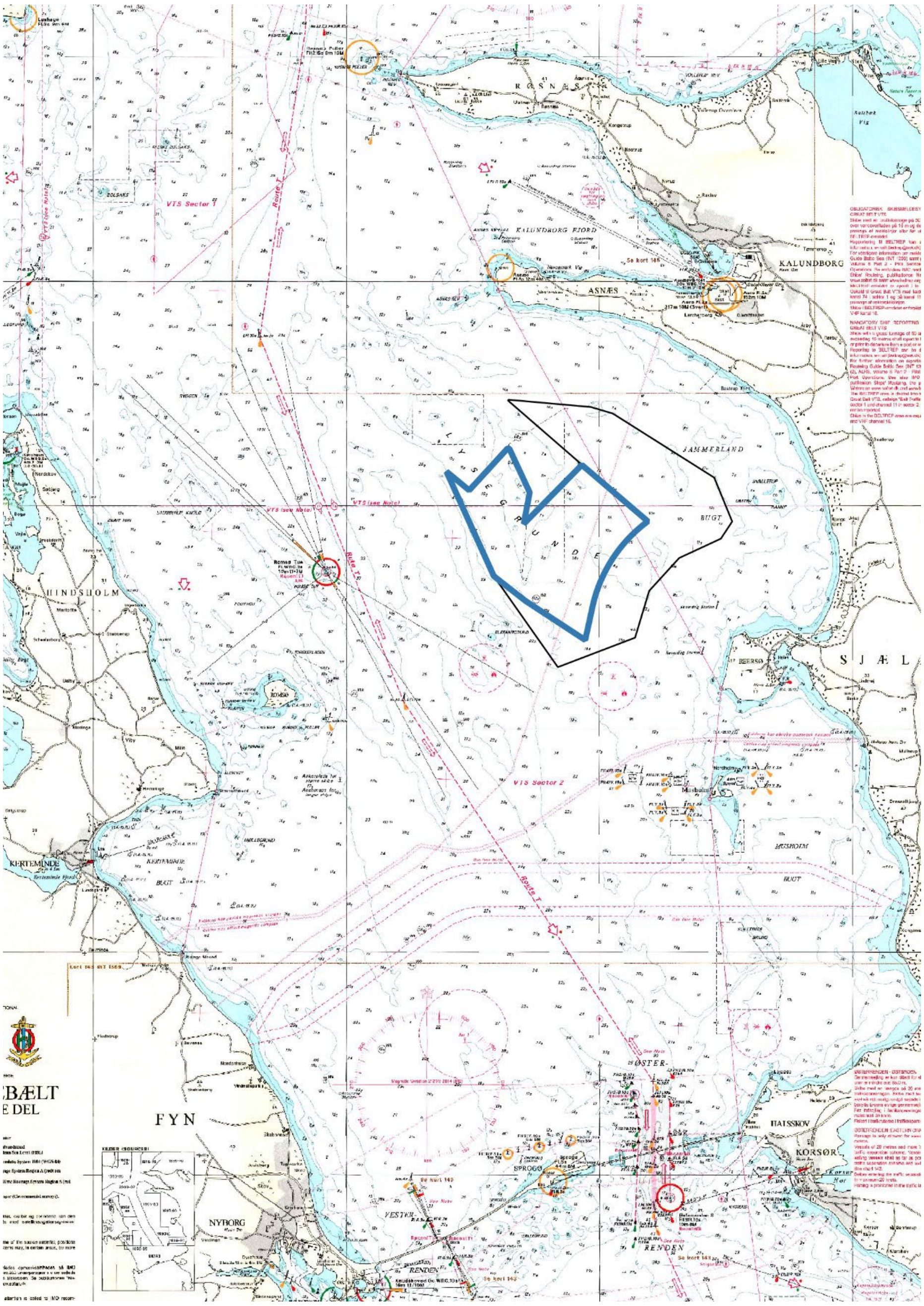
De hazards, hvor risikoen er skønnet til at være i ALARP området (As Low As Reasonably Practicable – gult område i risikomatrice) eller i det ikke acceptable område (rødt område i risikomatrice), vil blive analyseret nærmere sammen med de identificerede mulige risikoreducerende tiltag som en del af den efterfølgende sejladssikkerhedsanalyse.

2 BAGGRUND

I forbindelse med udarbejdelsen af miljøkonsekvensrapport for Jammerland Bugt OWF skal mølleparkens effekt på sejlads forhold og sejladssikkerhed vurderes. Der har i 2014 været afholdt en HAZID-workshop /2/. Forundersøgelsesområdet samt mulige mølleopstillinger er siden ændret hvorpå en ny workshop er afholdt for at afdække om tidligere hazards stadig er gældende samt hvis andre væsentlige forhold er opstået siden 2014.

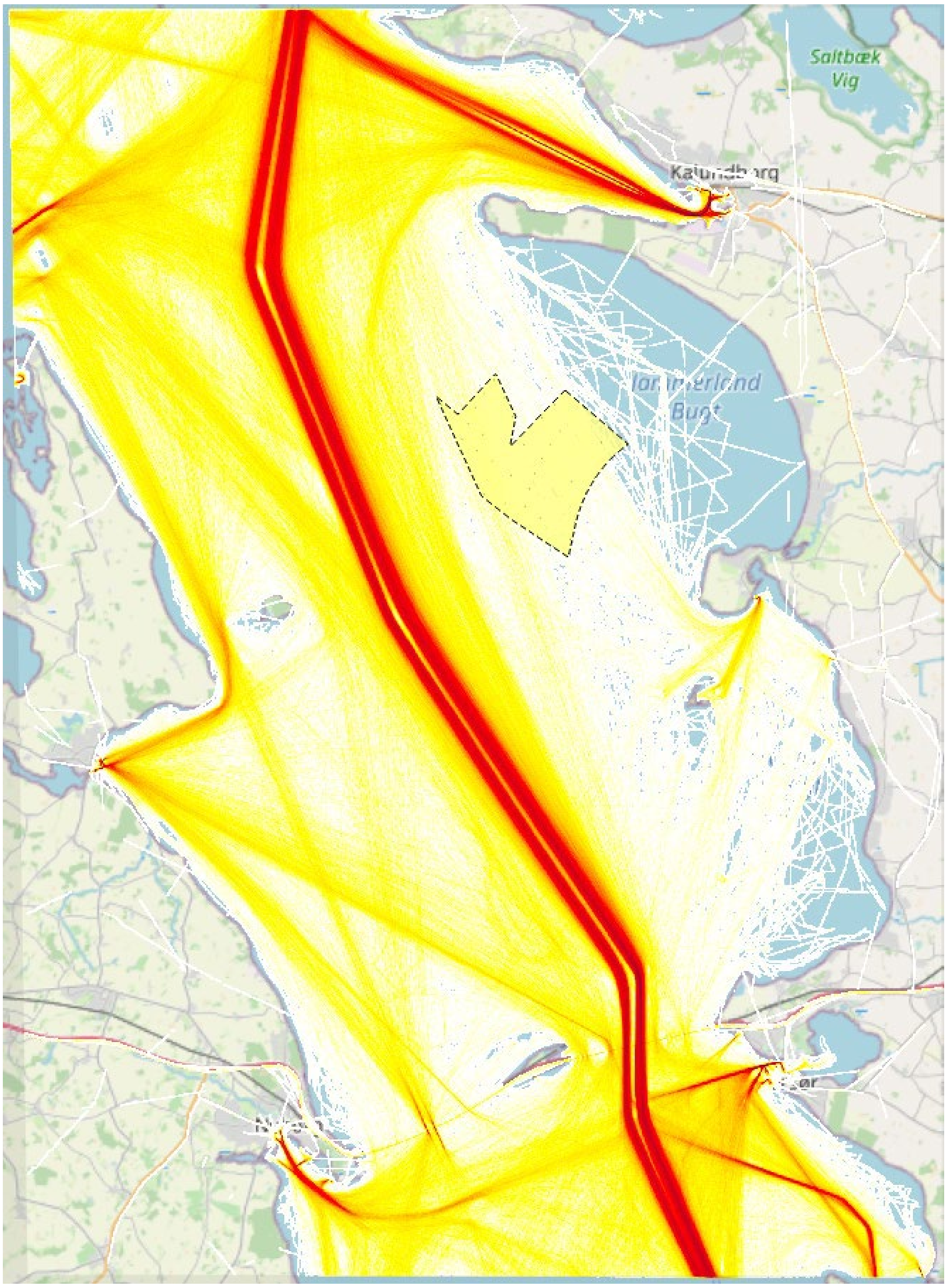
Formålet med HAZID-studiet er at sikre at alle relevante farer inkluderes i den endelige sejladssikkerhedsstudie. Denne rapport skal derfor betragtes som input.

Placeringen af projektområdet er givet i Figur 1. Mulige mølleopstillinger 1, 2, 2a, 3 og 4 er vist i Appendix A.



Figur 1 Projektområde. Den tykke blå markering er Projektområdet, den tynde sorte markering er den tidligere område, håndteret ved den første HAZID i 2014

De forskellige hazards er evalueret på baggrund af den kortlagte skibstrafik omkring projektområdet, som blev præsenteret på HAZID'en. Et plot af trafikintensiteten i området er vist i Figur 2, hvori det gælder at jo højere trafikintensiteten er des kraftigere er den røde markering.



Figur 2 Trafikintensitet i Storebælt for hele året 2019.

3 ORGANISERING AF STUDIET

3.1 HAZID mødet

HAZID workshoppen blev afholdt virtuelt via TEAMS tirsdag d. 14. december 2021. Deltagerne og deres fagområde er angivet i afsnit 3.2.

Hovedformålet var at identificere risiko scenarier, som vil være forårsaget af etablering af Jammerland Bugt Kystnær Havmøllepark. Den nuværende generelle sejladsrisiko i området er således ikke omhandlet, men kun den forøgede risiko forårsaget af etableringen af den nye møllepark.

Da der er tale om en overordnet vurdering af sejladssikkerhed i området, blev der ikke anvendt standard spørgeord som ofte anvendes i HAZIDs. I stedet blev der foretaget en “systematisk brain-storming”, hvor hver skibstype blev gennemgået for både anlægsfasen og driftsfasen. Deltagerne fik præsenteret lister med nøgleord til inspiration (se Appendix C). Nøgleord er opstillet på baggrund af DNV’s erfaring med andre lignende projekter. Herudover er generelle emner som møllernes indflydelse på navigation i området kort diskuteret.

Selvom der ikke vil være restriktioner for sejlads gennem vindmølleparkområdet, forventes det, at hele området automatisk vil blive friholdt af kommerciel trafik i driftsfasen, således at den mindre nuværende trafik gennem projektområdet får øget sejllængde og intensitet på de omkringliggende ruter. Dette forhold er også diskuteret.

3.2 HAZID Gruppen

Sammensætningen af HAZID gruppen afspejlede de forskellige interessenter på området, samt forskellige professioner, således at gruppen dækkede så bredt som muligt med henblik på at sikre at alle relevante risici blev identificeret.

I Tabel 1 er angivet deltagerne samt deres organisation og profession.

NAVN	FIRMA / ORGANISATION
Arne Rydahl	Kalundborg Havn
Tom Elmer Christensen	FLID - Foreningen for lystbådehavne i danmark
Christian Lerche	Dansk Sejlunion
Hans Jørgen Ellekilde	Kerteminde havn
Niels Bergmann Rasmussen	Danpilot
Leif Nielsen	Danske Tursejlere
Stig Prüssing	Fiskeristyrelsen
Dorthe Olbæk Hansen	VTS Storebælt
Jimmi Westermann	VTS Storebælt
Henrik S Lund	Danmarks fiskeriforening
Morten Glamsø	Danske rederier
Flemming Sparre Sørensen	Nautisk Konsulent, Søfartsstyrelsen, Sikre Farvande
Aino Rudebeck	Energistyrelsen (deltog kun i begrænset omfang)
Julie Andersen	Energistyrelsen (deltog kun i begrænset omfang)
Kristian Nehring Madsen	Jammerland Bay Nearshore
Birgitte Nielsen	Jammerland Bay Nearshore
Brian Bredal Kristensen	Jammerland Bay Nearshore
Andreas Karhula Lauridsen	Jammerland Bay Nearshore (deltog kun i begrænset omfang)
Anke Struve Olsson	WSP
Danni Junge Jensen	WSP
Claus Goldberg	WSP
Nijs Jan Duijm	DNV
Lasse Sahlberg-Nielsen	DNV

Tabel 1 HAZID deltagere og profession og / eller organisation

3.3 Risikovurdering

Konsekvenserne af en uønsket hændelse er inddelt i klasser i Tabel 2. Klasserne kombinerer de kategorier som foreslået i IMO's Guidelines /1/, Appendix 4, for effekter på personer, ejendomme og miljø i ét sæt således, at effekter på personer vægtes højere i forhold til økonomiske skader. Sammenhæng mellem personskade og økonomiske skader svarer til de klasser som blev benyttet ved den tidligere HAZID /2/, antal af klasser er reduceret for, at risikovurderingen i workshoppen kunne holdes overskueligt.

Betegnelse	Person	Ejendom	Miljø	Økonomisk	Klasse
Ubetydelig	Ubetydelig tilskadekommen	ubetydelige materielle skader	meget lille miljøpåvirkning, ubetydelig spild	under 10 000 DKK	0
Lille	Skibets besætning kommer til skade. Medarbejdere kommer til skade under installationen. Vedligeholdelsespersonale kommer til skade.	Skader på skibe og/eller vindmøller som kan repareres indenfor nogle måneder; eventuelle forlis af et mindre (lyst)fartøj	Miljøpåvirkning som er oprettelig indenfor ca. et år, oliespild 100 kg - 10 tons	10 000 til 1 million DKK	2
Stor	1 til 3 dødsfald under skibets besætning. 1 til 3 dødsfald under installationsmedarbejdere. 1 til 3 dødsfald under vedligeholdelsespersonale.	Tab af vindmølle eller mindre erhvervsfartøjer, alvorlige skader på store skibe eller tab af last.	Alvorlig miljøpåvirkning af stort område, som tager flere år at genoprette; oliespild over 10 - 1000 tons	1 - 100 millioner DKK	4
Katastrofal	Tab af hele skibets besætning. Tab af alle som arbejder med vindmøllens installation. Tab af alle som vedligeholder en vindmølle.	Tab af store del af parkens elementer, forlis af store skibe.	Uoprettelig miljøpåvirkning af følsomme områder (Natura 2000); oliespild mere end 1000 tons	Mere end 100 millioner DKK	6

Tabel 2 Konsekvensklasser

Sandsynligheden (frekvensen) er på samme måde inddelt i klasser som vist i Tabel 3. Definitionen af disse klasser er det samme som ved den tidligere HAZID /2/, dog er middelværdier (”Frekvens”) tilpasset for at matche definitionen.

Betegnelse	Definition	Frekvens (per år)	Klasse
ofte	Månedlig/årligt	3	1
meget sandsynlig	1-10 år	0.3	0
sandsynlig	10-100 år (I parkens levetid)	0.03	-1
mulig	100-1000 år (på verdensplan)	0.003	-2
usandsynlig	1000-10 000 år	0.0003	-3
meget usandsynlig	10 000-100 000 år	0.00003	-4
ekstrem usandsynlig	>100 000 år	0.000003	-5

Tabel 3 Sandsynlighedsklasser

Baseret på den skønnede konsekvens og frekvens kan risikoen for den evaluerede hazard bestemmes. En grov risikoscreening er foretaget ud fra risikomatricen givet i Tabel 4, hvor det afgøres om hazarden er uacceptabel, og risikoreducerende tiltag skal evalueres yderligere, eller om den er acceptabel uden at gøre mere, afhængig af de samlede omkostninger ved hændelsen. Det skal bemærkes, at nedenstående risikomatrice er noget strengere m.h.t. accept af store og katastrofale konsekvenser (idet antallet af konsekvensklasser er reduceret) end den risikomatrice som blev brugt ved den forrige HAZID /2/.

Følgende betegnelser er anvendt i nedenstående matrice:

- Rødt område: Uacceptabel risiko. Risikoen skal reduceres
- Gult område: Medium risiko. Skal overvejes ved hjælp af ALARP (As Low As Reasonably Practicable) - mulige risikoreducerende tiltag skal overvejes og implementeres når omkostningerne ikke er disproportioneret i forhold til sikkerhedsgevinsten.
- Grønt område: Acceptabel risiko. Ingen yderligere aktion påkrævet

Bemærk at risikoen angivet i tabellerne i Appendix B er under antagelse af at eventuelle foreslåede (nye) risikoreducerende tiltag (angivet i yderste kolonne) ikke er implementeret. Hvis de angivne tiltag indføres, vil risikoen reduceres – dog skal det bemærkes, at risikoestimaterne generelt er baseret på deltagernes subjektive vurderinger, og estimaterne skal derfor håndteres med forsigtighed.

				Konsekvens			
			Betegnelse:	***Ubetydelig***	***Lille***	***Stor***	***Katastrofal***
			klasse	0	2	4	6
			Mennesker:	Ubetydelige skader	Tilskade-komne	E t enkel dødsfald	Mange dødsfald
			Økonomi (MDKK):	< 0.01	0.01-1	1-100	> 100
	klasse	***Betegnelse***	*Gentagelsesperioden*				
Sandsynlighed	1	**ofte**	Månedlig/årlig	1	3	5	7
	0	**meget sandsynlig**	1-10 år	0	2	4	6
	-1	**sandsynlig**	10-100 år (I parkens levetid)	-1	1	3	5
	-2	**mulig**	100-1000 år (på verdensplan)	-2	0	2	4
	-3	**usandsynlig**	1000-10 000 år	-3	-1	1	3
	-4	**meget usandsynlig**	10 000-100 000 år	-4	-2	0	2
	-5	**ekstrem usandsynlig**	>100 000 år	-5	-3	-1	1

Tabel 4 Risiko matrice.

3.4 Hazard listen

Kernen af resultatet af HAZID workshoppen er tabellen med de identificerede hazards. Denne tabel er rapporteret og præsenteret i Appendix B i nærværende rapport.

Tabellen er opstillet under workshoppen. Senere tilføjelser af DNV er markeret med orange tekst. Tabellen, inklusiv DNV's tilføjelser, er sendt til alle mødedeltager for at sikre at tabellen fremstiller resultatet af workshoppen korrekt. Tabellen er derfor "låst" og skal betragtes "as-is".

Workshoppen tog udgangspunkt i HAZID-tabellen genereret i den forrige workshop i 2014. Denne tabel adresserede kun kollision mellem skibe og vindmøller. Forskellige skibstyper blev vurderet mht. mulighed for kollision (drivende eller under fremdrift) og konsekvenser: Mindre skibe, passagerskibe, tankskibe, fragtskibe, fiskeriskibe og lystfartøjer. Denne del af tabellen blev gennemgået og kun mindre ændringer gennemført.

Andre hazards blev tilføjet inspireret af de nøgleord præsenteret i Appendix C.

Tabellen indeholder også mulige aktionspunkter og risikoreducerende tiltag, som blev foreslået under workshoppen.

Generelt er risikoen ikke evalueret for de tilfælde, hvor nye, af deltagerne foreslåede, identificerede risikoreducerende tiltag. Dette vil blive gjort i forbindelse med den mere detaljerede sejladsanalyse.

3.5 Rapportering og væsentlige emner ikke dækket af hazard listen

Nedenfor er givet en række punkter og emner, der blev diskuteret og som ikke direkte indgår i hazard listen i Appendix B. Det er dog væsentlige punkter, som kan have indflydelse på sejladssikkerheden i området.

- VTS-Storebælt (Vessel Traffic Service) gjorde opmærksom på, at der kan vise sig at være radar-interferens, radar skygge, falske ekkoer, mistede ekkoer etc. – bidragende til dårligere overvågning og dårligere situationsoverblik. En evaluering af radarinterferens skal senest gennemføres, når der er truffet endelig beslutning om parkens udseende (antal møller, placering, højde osv.) ved tildeling af etableringstilladelser. SFS (Søfartsstyrelsen) oplyser som eksempel, at der er lavet radaranalyse for Sprogø Møllerne som resulterede i opstilling af ekstra radar for VTS Storebælt. VTS Storebælt pointerer yderligere, at det er væsentligt, at der foretages en fuld radardækningsanalyse, når mølleplaceringerne er kendt. Dette med henblik på at der, ifald analysen peger på forringet radardækning, kan træffes de nødvendige foranstaltninger til opretholdelse af radardækning af hensyn til varetagelse af VTS.
- Danpilot bemærker at store skibe med dybdegang over ~11m antageligt vil være stødt på grund inden de kommer ind i projektområdet.
- Valg af anlægshavn på Fyn (f.eks. Nyborg) vil medføre krydsende anlægstrafik med rute T.
- Der blev foreslået at information om igangværende konstruktionsarbejder, herunder periodiske afmærkninger og forbudte områder også (udover de formelle informationer via Efterretninger for Søfarende) kan formidles gennem informationskanaler af fx Dansk Sejlunion, Danske Tursejlere og Fiskeriforeningen.

3.6 Udestående aktiviteter og anbefalinger

3.6.1 Tankskibe med dobbelt skrog og beskyttelse af forbrugstanke

Ved fare ID 1.6 (se HAZID TABEL i Appendix B) er det bemærket, at sandsynlighed for olieudslip fra tankskibe vil være mindre når skibene har dobbelt skrog. På den baggrund blev modifikationsfaktoren MF (dvs. den betingede sandsynlighed for, at konsekvensen opstår efter hændelsen - i dette tilfælde sandsynlighed for stort olieudslip efter kollision med mølle) nedsat til 0.0005 ved sidste HAZID /2/. Ved diskussion af udslip fra forbrugstanke blev det på den nye workshop nævnt, at forbrugstanke på moderne skibe, dvs. skibe bygget efter august 2010, skal være forsynet med en lignede beskyttelse af forbrugstanke, i henhold til MARPOL Annex 1, Regulation 12A. Det gælder alle skibe (ikke kun tankskibe) med en samlet brændstofkapacitet over 600 m^3. Det blev aftalt, at DNV skulle vurdere hvor stor en andel skibe ville have beskyttede forbrugstanke,

DNV har undersøgt alderen på 50 råolietankskibe (Crude Oil Tankers), som passerede Storebælt i 2019 ifølge AIS analysen. Disse 50 skibe passerede Storebælt oftest, de udgør ca. 12% af alle råolietankskibe, som passerede Storebælt mindst én gang i 2019, men udgjorde ca. 37% af det totale antal passager af råolietankskibe. Af disse skibe er 58% (vægtet med det antal passager) bygget efter 2010, dvs. forsynet med beskyttelse af forbrugstanke.

På baggrund af denne stikprøve antages, at omtrent halvdelen af alle store skibe som passerede Storebælt i 2019, var forsynet med beskyttelse af forbrugstanke. Derfor er modifikationsfaktoren MF nedsat fra 0.2 til 0.1 for konsekvensen olieudslip (fra forbrugstanke) ved kollision af tankskibe, fragtskibe og passagerskibe med mølle. Dette medfører ikke en ændring i vurdering af risiko ifølge risikomatricen (rød, gul, grøn).

3.6.2 Andel af mindre skibe uden AIS

Der er stor usikkerhed vedrørende andelen af lystfartøjer og fiskefartøjer under 15 m, som har AIS og dermed er inkluderet i AIS opgørelsen, som er grundlag for det kvantitative studie. Estimater fra deltagerne, med ingen eller begrænset dokumentation, varierer mellem 2% og 10%. DNV har valgt at anvende 5%, dvs. at antal af mindre skibe (i

AIS opgørelsen[1] klassificeret at være mindre end 25 m) er 20 gange højere end det antal AIS registrerede skibe. Estimaterne vil blive anvendt i sejladssikkerhedsanalysen.

3.6.3 Konsekvens af møllekollaps

Der er usikkerhed med hensyn til konsekvens af møllekollaps, dvs. svigt af mølletårnet ved kollision med et stort skib. Enten bliver tårnet skubbet hen over fundamentet og vælter væk fra det kolliderende skib, eller tårnet knækker med mulighed for at nacellen vælter ned på det kolliderende skib. Det sidste vil medføre alvorlige personskader, hvis der er tale om et passagerskib, som nævnt ved farerne ID 2.6 og 2.8 ((se HAZID TABEL i Appendix B). Sidstnævnte scenario er ikke umuligt ifølge nogle analyser /3/. Fare 2.8 er vurderet ”gul”, der bør derfor overvejes at foretage en nærmere analyse om risikoreducerende tiltag, afhængigt af om resultatet af det kvantitative studie bekræfter den estimerede kollisionsfrekvens.

[1] AIS er opgjort i efter skibslængde og kategoriseret i 25m interval.

4 KONKLUSIONER

Den nuværende HAZID-workshop har bekræftet, med mindre tilpasninger, at resultaterne fra den tidligere HAZID /2/, og tilføjet enkelte nye farer med tilhørende risikovurdering, bl.a. herunder farer relateret til anlægsfasen, er gældende for de fem mulige møllescenarier.

Det vil være nødvendigt at udføre en analyse, som belyser på hvilken måde vindmøllerne vil interagere med radar fra VTS trafikovervågning. Idet analysen konkluderer, at vindmøllerne vil forårsage radarskygge, interferens eller skjuler ekkoer, skal der foretages afværgende foranstaltninger. Det er på nærværende ukendt om nødvendighed og omfanget af eventuelle afværgende foranstaltninger vil have indflydelse på valg af møllescenarie. Det anbefales at indhente en kvalificeret vurdering om denne analyse skal udføres for alle scenarier, eller om det kan afventes det endelige scenarie.

Udover dette er der ikke fundet andre forhold mht. Jammerland Bugt Kystnær Havmøllepark, som ud fra sejladssikkerheden er uacceptable. Workshop-deltagerne har ikke udtrykt præference for én af opstillingsscenarierne, men forventer, at scenarier med færre vindmøller vil medføre lavere risiko for kollision mellem skib og mølle.

I driftsfasen er der en række farer forbundet med kollision med møller samt forhøjet antal kollisioner mellem skibe pga. ændrede trafikmønstre, som er vurderet ”gule”, dvs. at det bør overvejes hvordan risiko kan mindskes (ALARP-princippet). Det anbefales at afvente det numeriske studie, som vil opdatere frekvensestimaterne for disse hændelser, som kan vise sig at være lavere (mindre risiko) end ifølge det kvalitative resultat fra workshoppen.

En række farer i forhold til anlægsfasen kræver opmærksomhed eller ekstra tiltag. For at sikre at afspærrede arbejdsområder respekteres, især af lystfartøjer og fiskefartøjer, anbefales det:

- At anvende et afviserfartøj;
- At benytte supplerende informationskampagner ved brug af informationskanaler af Dansk Sejlunion, Danske Tursejlere og Fiskeriforeningen m.fl.;
- At placere mindre lysafmærkninger på funderingspæle inden montering af overgangsstykke

I forbindelse med den ekstra trafik i anlægsfasen, og eventuelt under vedligehold i driftsfasen, og hvor rute ”T” skal krydses, anbefales det at sikre koordinering med VTS og etablering af korridorer.

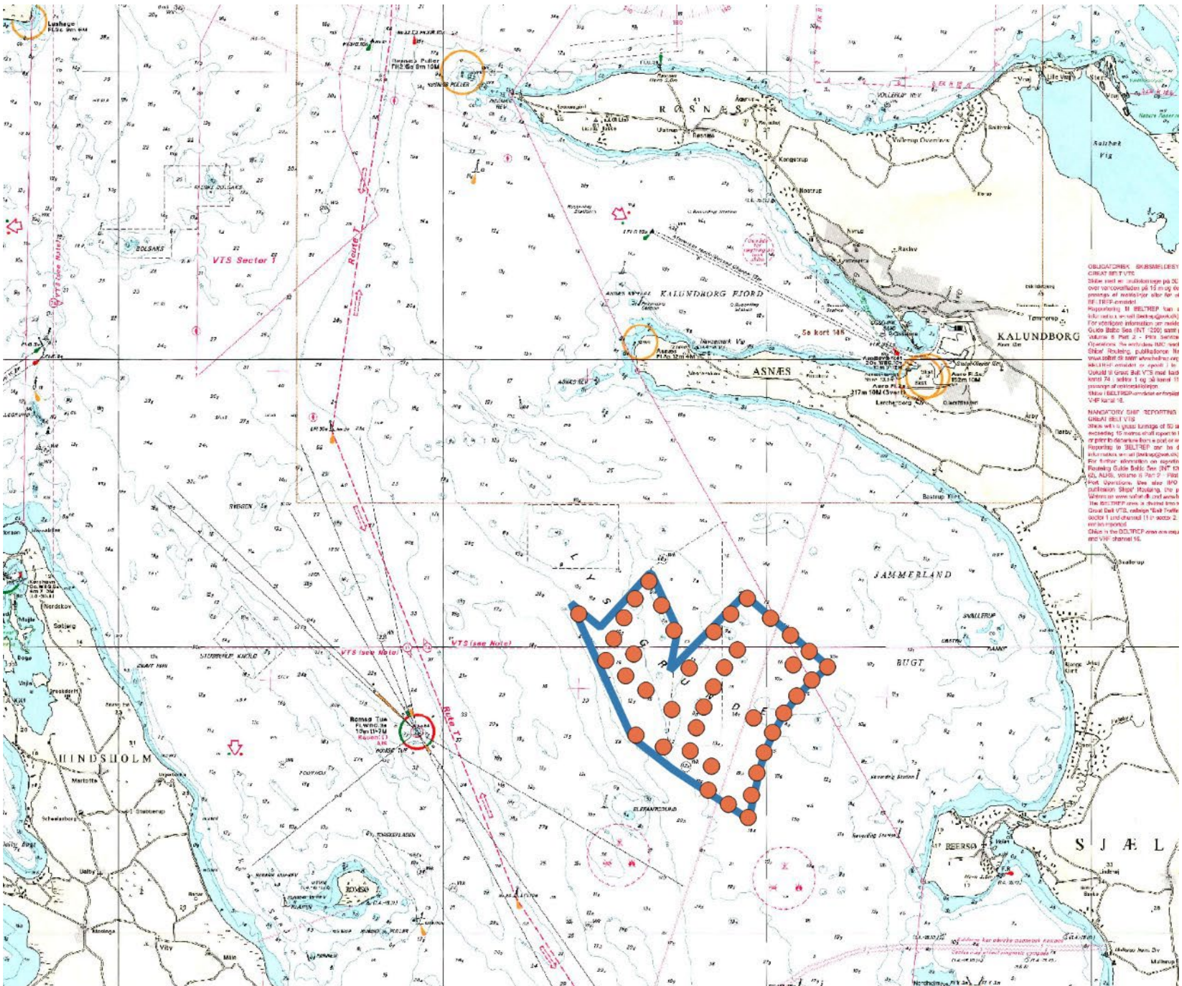
5 REFERENCER

/1/ IMO, 2018, REVISED GUIDELINES FOR FORMAL SAFETY ASSESSMENT (FSA) FOR USE IN THE IMO RULE-MAKING PROCESS, MSC-MEPC.2/Circ.12/Rev.2

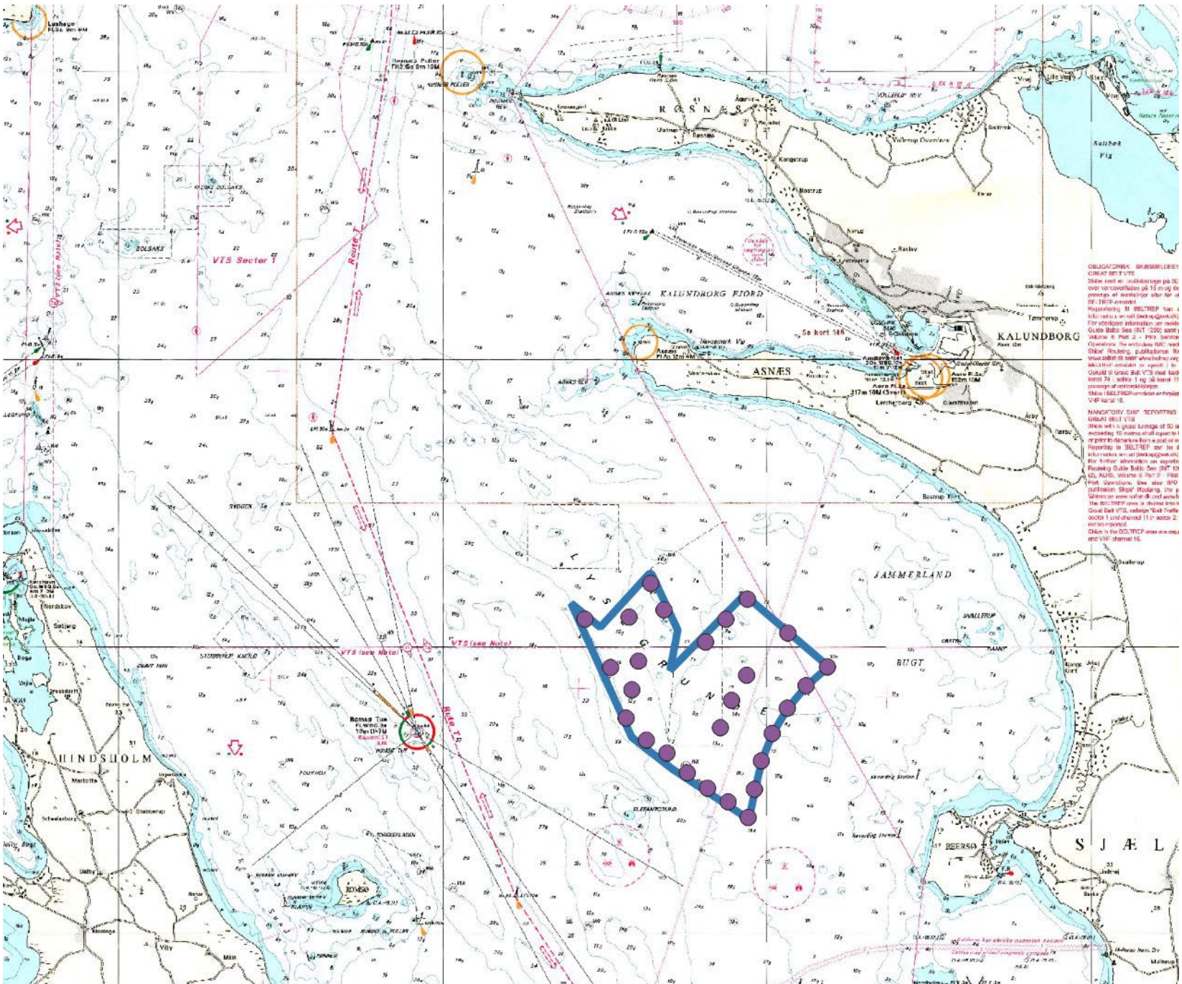
/2/ DNV-GL, 2015, Hazard Identification and Qualitative Risk Evaluation of the Navigational risk for the Jammerland Bugt Wind Farm, Report No.: 1KNPOEP-4, Rev. 0

/3/ Andreea Bela, Hervé Le Sourne, Loïc Buldgen, Philippe Rigo, 2017, Ship collision analysis on offshore wind turbine monopile foundations, Marine Structures, Vol 51, Pp. 220-241

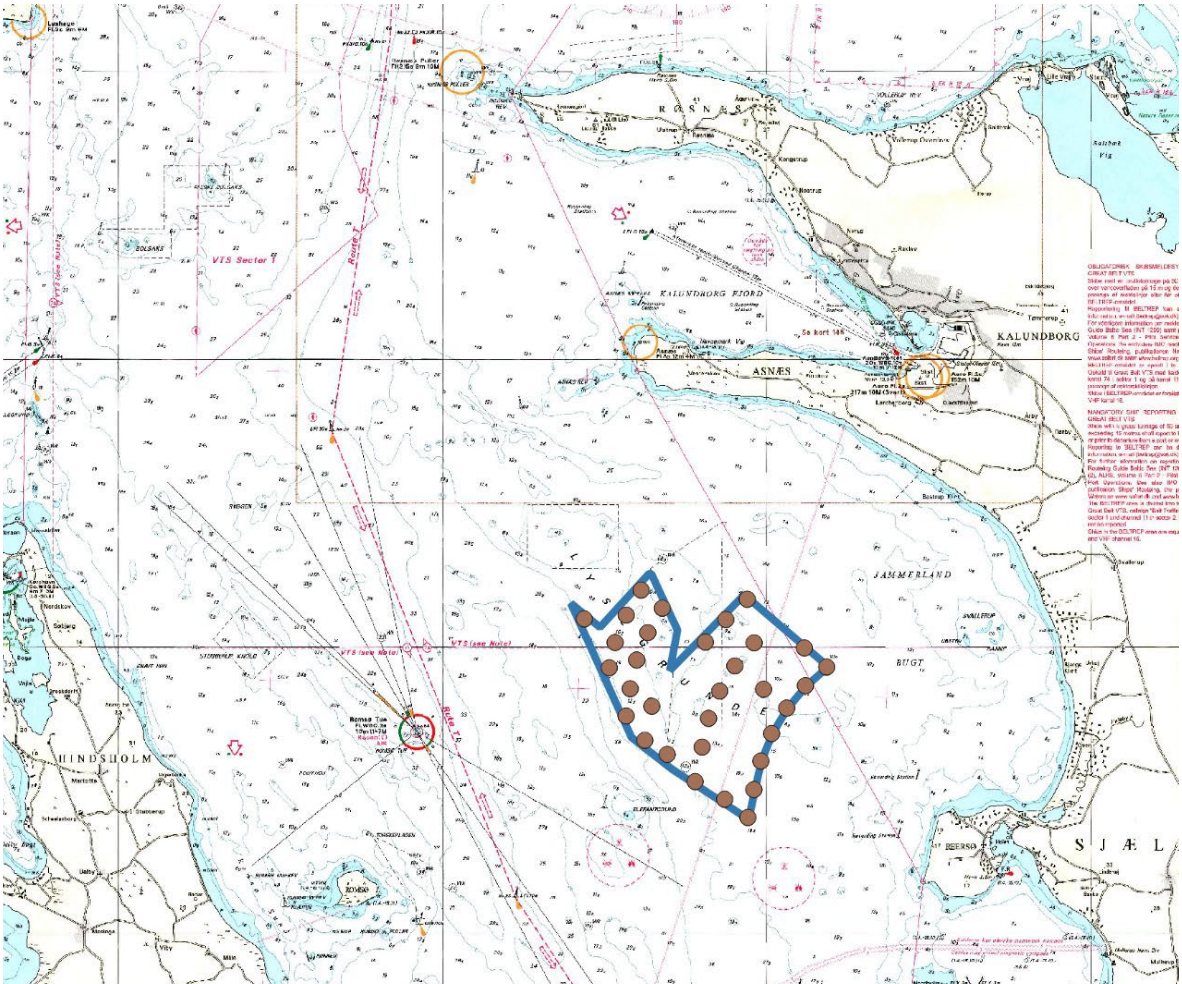
APPENDIX A
MØLLEOPSTILLINGER FOR DE FEM SCENARIER



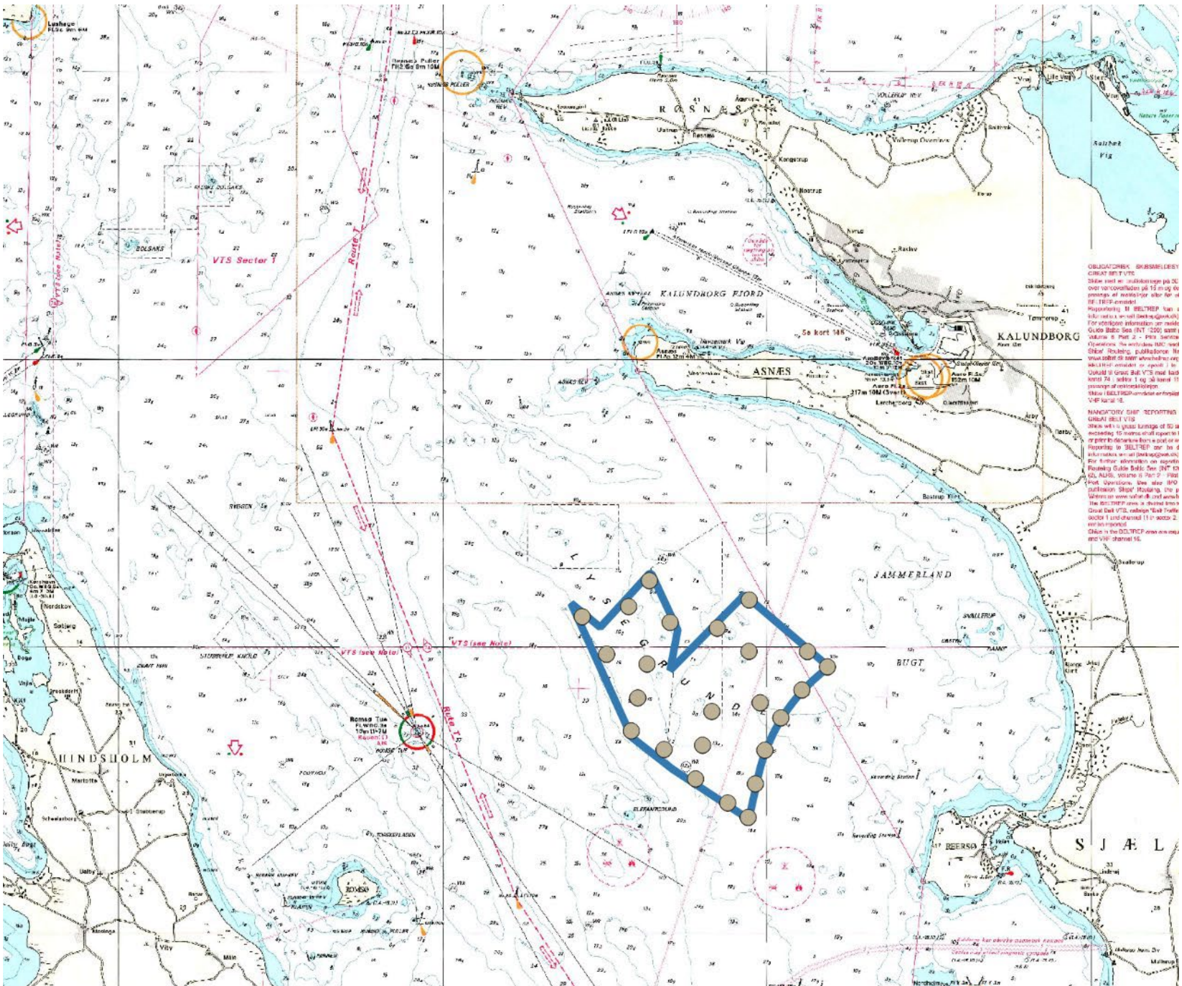
Figur 3 Scenarie 1: 41 møller med 164m rotor



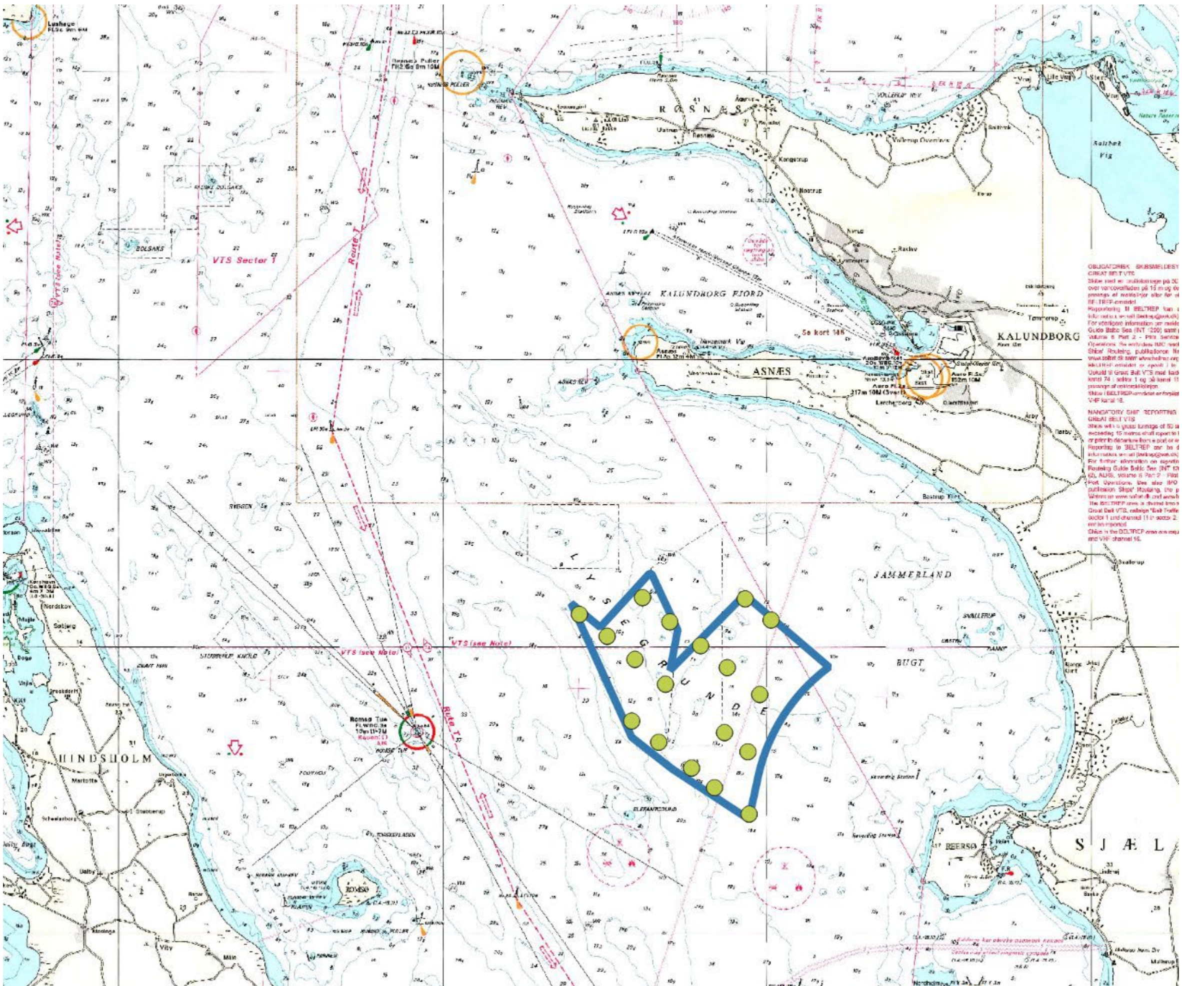
Figur 4 Scenarie 2: 27 møller med 174m rotor



Figur 5 Scenarie 2a: 32 møller med 188m rotor



Figur 6 Scenarie 4: 24 møller med 200m rotor



Figur 7 Scenarie 4: 18 møller med 236m rotor

APPENDIX B
HAZID TABEL

Tekst i tabellen med orange farve er indsat af DNV efter workshoppen. Det vedrører sandsynligheds- og alvorlighedsvurdering baseret på sammenlignelige hazard og væsentlig korrektur af noter fra workshoppen.

Fare-ID	Skibsrute	Skibstype	Årsag/hændelse	Fare/uheld	Konsekvens	Eksisterende sikkerhedsforanstaltninger	Frekv.	M.F.	Alvor - Person	Alvor - Ejendom	Alvor - Miljø	Risiko	Foreslåede sikkerhedsforanstaltninger	Kommentar/Aktioner	Aktions-ansvarlige
Dritsfase															
1,1	Alle	Alle	Radarskygge/interferens/manglende ekkoer forårsaget af parken. Mistende situationsoverblik for kystovervågningen	Øget sandsynlighed for skib-skib kollision									Interferensstudier, nye radarpositioner	Generelle forhold kan ikke risikovurderes. Er markeret rødt for at indikere at risikoreducerende tiltag skal gennemføres	
1,2	Alle	Mindre fartøjer	Ændret sejladsmønster. Mindre fartøjer kan komme tættere på rute T	Skib-skib kollision	Dødsfald		-2	0,01	4	4	3	0		Frekvensvurdering baseret på at det er en "mulig" hændelse. Konsekvens er vurderet at forekomme 1 ud af 100 gange	
1,3	Alle	Fiskeskib	Havari, Redskab i propel, Manglende manøvreringsevne ved fangst	Drivende kollision med mølle	Personskade, Skade på skib, Olieudslip		-5	2	2	3	3	-1,70		M.F. estimeret til 2 da ikke AIS ikke indeholder alle fartøjer	
1,4	Alle	Fiskeskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Personskade, Skade på skib, Olieudslip		-5	2	3	4	3	-0,70		M.F. estimeret til 2 da ikke AIS ikke indeholder alle fartøjer	
1,5	Alle	Tankskib	Havari, black-out	Drivende kollision med mølle	Personskade, Skade på skib		-4	0,01	2	3		-3		Konsekvensen vurderet at forekomme 1 ud af 100 gange	
1,6	Alle	Tankskib	Havari, black-out	Drivende kollision med mølle	Olieudslip fra last		-4	0,0005			6	-1,30		Mindre sandsynligt at tankskibe med dobbelt skrog vil skabe oliespild	

1,7	Alle	Tankskib	Havari, black-out	Drivende kollision med mølle	Olieudslip fra forbrugstank		-4	0,005			5	-1,30			DNV undersøger hvor stor andel af tankskibe er bygget efter 2010 som er med dobbeltskroget forbrugstank. Se MARPOL annex I regulation 12A. Det estimeres pga. en stikprøve blandt de passerede råolietankskibe, at ca. halvdelen af skibene er forsynet med beskytttelse af forbrugstanke. Derfor er Modifikations Faktoren MF nedsat fra 0.01 til 0.005
1,8	Alle	Tankskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Personskade		-5	0,1	3			-3		Konsekvensen vurderet at forekomme 1 ud af 10 gange	
1,9	Alle	Tankskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Skade på skib		-5	0,01		5		-2		Konsekvensen vurderet at forekomme 1 ud af 100 gange	
2	Alle	Tankskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Olieudslip fra last		-5	0,000 5			6	-2,30		Mindre sandsynligt at tankskibe med dobbelt skrog vil skabe oliespild	

2,1	Alle	Tankskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Olieudslip fra forbrugstank		-5	0,1			5	-1		Høj hastighed forbundet med direkte påsejling. Konsekvens estimeret at forekomme 1 ud af 5 gange. Skarpe kanter fra mølle kan skære skrog åbent	DNV undersøger hvor stor andel af tankskibe er bygget efter 2010 som er med dobbeltskroget forbrugstank. Se MARPOL annex I regulation 12A. Det estimeres pga. en stikprøve blandt de passerede råolietankskibe, at ca. halvdelen af skibene er forsynet med beskytttelse af forbrugstanke. Derfor er Modifikations Faktoren MF nedsat fra 0.2 til 0.1
2,2	Alle	Fragtskib	Havari, black-out	Drivende kollision med mølle	Personskade, Skade på skib, Olieudslip		-3	0,01	2	5	5	0		Konsekvensen vurderet at forekomme 1 ud af 100 gange	
2,3	Alle	Fragtskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Personskade		-4	0,1	3			-2		10 personer estimeret at blive påvirket	
2,4	Alle	Fragtskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Skade på skib		-4	0,01		5		-1		Konsekvensen vurderet at forekomme 1 ud af 100 gange	

2,5	Alle	Fragtskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Olieudslip		-4	0,1			5	0		Høj hastighed forbundet med direkte påsejling. Konsekvens estimeret at forekomme 1 ud af 5 gange. Skarpe kanter fra mølle kan skære skrog åbent	Det estimeres pga. en stikprøve blandt de passerede råolietankskibe, at ca. halvdelen af skibene er forsynet med beskytttelse af forbrugstanke. Derfor er Modifikations Faktoren MF nedsat fra 0.2 til 0.1
2,6	Alle	Passagers kib	Havari, black-out	Drivende kollision med mølle. Mølle falder ned på skib. Vinge rammer skib	Personskade	Varsling af kollision via højtaleranlæg	-5	100	2			-1	Ved forventet kollision, nødstopsordning via VTS så rotor står stille	100 personer estimeret vil blive påvirket	
2,7	Alle	Passagers kib	Havari, black-out	Drivende kollision med mølle.	Skade på skib, Olieudslip		-5	0,01		3	5	-2		Konsekvensen vurderet at forekomme 1 ud af 100 gange	
2,8	Alle	Passagers kib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle Mølle falder ned på skib. Vinge rammer skib	Personskade		-5	100	3			0		100 personer estimeret vil blive påvirket	
2,9	Alle	Passagers kib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Skade på skib		-5	0,01		5		-2		Konsekvensen vurderet at forekomme 1 ud af 100 gange	

3	Alle	Passagerskib	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Olieudslip		-5	0,1			5	-1		Høj hastighed forbundet med direkte påsejling. Konsekvens estimeret at forekomme 1 ud af 5 gange. Skarpe kanter fra mølle kan skære skrog åbent	Det estimeres pga. en stikprøve blandt de passerede råolietankskibe, at ca. halvdelen af skibene er forsynet med beskytttelse af forbrugstanke. Derfor er Modifikations Faktoren MF nedsat fra 0.2 til 0.1
3,1	Alle	Lystfartøj	Havari, black-out, Motorstop, Skrue sidder fast	Drivende kollision med mølle			-4	0,05	3			-2,30		Konsekvensen vurderet at forekomme 1 ud af 20 gange	
3,2	Alle	Lystfartøj	Havari, black-out, Motorstop, Skrue sidder fast	Drivende kollision med mølle			-4	0,01		3	0	-3		Konsekvensen vurderet at forekomme 1 ud af 100 gange	
3,3	Alle	Lystfartøj	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Personskade		-4	0,05	4			-1,30		Konsekvensen vurderet at forekomme 1 ud af 20 gange	
3,4	Alle	Lystfartøj	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Skade på skib		-4	0,01		4		-2		Konsekvensen vurderet at forekomme 1 ud af 100 gange	
3,5	Alle	Lystfartøj	Menneskelig fejl eller teknisk svigt	Direkte påsejling med mølle	Olieudslip		-4	0,2			0	-4,70		Høj hastighed forbundet med direkte påsejling. Konsekvens estimeret at forekomme 1 ud af 5 gange. Skarpe kanter fra mølle kan skære skrog åbent	

3,6		Lystfartøj	Master højere end 20m kan blive ramt af vinge.	Skib kommer tæt på mølle	Skade på skib og vinge		-3	0,01	4	2	0	-1		En ud af 10 vurderet at have 20m eller højere. Konskvensen er vurderat at forekomme 1 ud af 10.	
Anlægsfase															
2,1		Mindre fartøjer	Ændret sejladsmønster. Mindre fartøjer kan komme tættere på rute T	Skib-skib kollision	Skade på skib, personskade, olieudslip		-2	0,01	4	4	3	0		Frekvensvurdering baseret på at det er en "mulig" hændelse. Konsekvens er vurderet at forekomme 1 ud af 100 gange	
2,2		Lystfartøjer	Sejler ind i anlægsområdet. Overholder ikke begrænsninger under anlægsfasen. Mange nye sejlere og manglende bekendskab til projektet	Sammenstød med materiel og skibe	Skade på skib, personskade, olieudslip	Efterretninger for søfarende Afspærret arbejdsområde	-1	0,01	4	4	3	1	Afviserfartøj Supplerende informationskampagne lokalt og ved hjælp af dansk sejlunion. Mindre lysafmærkning på pæl inden montering af overgangsstykke	Frekvens vurderet ud fra at begrænsninger erfaringsmæssigt ikke overholdes. Konsekvens vurderet at forekomme 1 ud af 100 gange.	
2,3		Fiskefartøjer	Sejler ind i anlægsområdet	Sammenstød med materiel og skibe	Skade på skib, personskade, olieudslip	Efterretninger for søfarende Afspærret arbejdsområde	-1	0,01	4	4	3	1	Afviserfartøj Supplerende informationskampagne gennem kanaler rettet mod fiskeri.	Frekvens vurderet ud fra at begrænsninger erfaringsmæssigt ikke overholdes. Konsekvens vurderet at forekomme 1 ud af 100 gange.	

2,4		Mindre skibe i forbindelse med anlægsfasen, mandskab, daglig transport mv.	Krydser eller følger rute T	Kollision med anden trafik	Skade på skib, personskade, olieudslip		-3	0,01	4	4	3	-1	Koordinerer med VTS før krydsning. Etablering af korridor. Valg af udskibningshavn kan minimere risiko f.eks. Kalundborg. Skibe med lav dybdegang kan muligvis gå øst om. Alle involverede i projektet bærer AIS	Frekvens vurderet ud fra at det er erhvervsmæssigt sejlads koordineret med VTS. Konsekvens vurderet at forekomme 1 ud af 100 gange	
2,5		Anlægsfartøjer	Materel kan komme af søvejen og dermed øge trafikken til og fra anlægshavn	Kollision med anden trafik	Skade på skib, personskade, olieudslip		-3	0,01	4	4	3	-1		Frekvens vurderet ud fra at det er erhvervsmæssigt sejlads koordineret med VTS. Konsekvens vurderet at forekomme 1 ud af 100 gange	
2,6		Fiskefartøjer og lystfartøjer	Kabel krydser	Kollision med anlægsskib eller kabel	Skade på skib, personskade, olieudslip		-1	0,01	4	4	3	1	Afviserfartøj i kritiske (f.eks. sommer) perioder med øget trafik	Frekvens vurderet ud fra at begrænsninger erfaringsmæssigt ikke overholdes. Konsekvens vurderet at forekomme 1 ud af 100 gange.	
Andre forhold															
		Tank/kemikalie - farlig last	Kollision med mølle	Tage højde for fremtidig farlig transport										Ikke risikovurderet da møllen ikke har indflydelse på mønstret på farlig transport.	

		Alle	Nordgående skib i rute T som glemmer at dreje	Sammenstød med mølle										Risikovurderingen er håndteret i ovenstående farer for skib-mølle kollision. Den numeriske analyse tager eksplicit højde for dette scenarie.	
			Hvis manglende AIS - mest fiskeskibe og lystfartøjer.	Manglende datagrundlag i det numeriske studie											DNV vil foreslå en fornuftig andel af skibe som ikke er dækket af AIS.
			Dominerende vind fra vest - drivende skibe fra rute T	Sammenstød med mølle										Risikovurderingen er håndteret i ovenstående farer for skib-mølle kollision. Den numeriske analyse tager eksplicit højde for effekt af vindretning.	
		Support skib	Kollision med mølle		Skader på mølle									Ingen rapporterede kollisioner i danmark. Skader på mølle ikke relevant i forhold til sejladssikkerhed.	

APPENDIX C
NØGLEORD

Driftsfase	Skibsroute	Skibstype	OWT-del	Årsag/hændelse	Fare/uheld	Konsekvens
Drift	(iht. AIS)	Hurtigfærge	Flere turbiner	navigationsfejl	kollision skib-installation	skade på skib
Installation	Alle	Færge	Fundament	teknisk fejl	kollision skib-skib	forlis
Vedligehold		Fiskeri	Tårn	blackout/skib på drift	grundstødning	brand
Kabel-udlægning		Fragtskibe i transit	Vinge	interferens/radarskygge	bølgegang	skade på installation
Alle		Passagerskibe i transit	Nacelle	manglende AIS	rammer undersøisk kabel/rør	tab af installation
		Tankskibe /Skibe med farlig gods	Service vessel	manøvrer (undvige, …)	anker skader kabel/rør	tårn+ vinger vælter på skib
		lystbåde /lystsejlere	Kabeludlægger	trafik	anker skader fast installation	miljøudslip
		Øvrige skibe (service vessels)	Kranskib	vejr		tilskadekommen/dødsfald
		Små skibe	Transformer	strøm		
		Store skibe		Afstand/fart		
		Alle				

About DNV

(Final HAZID report will be included with final version)

APPENDIX B

AIS Ship traffic intensity

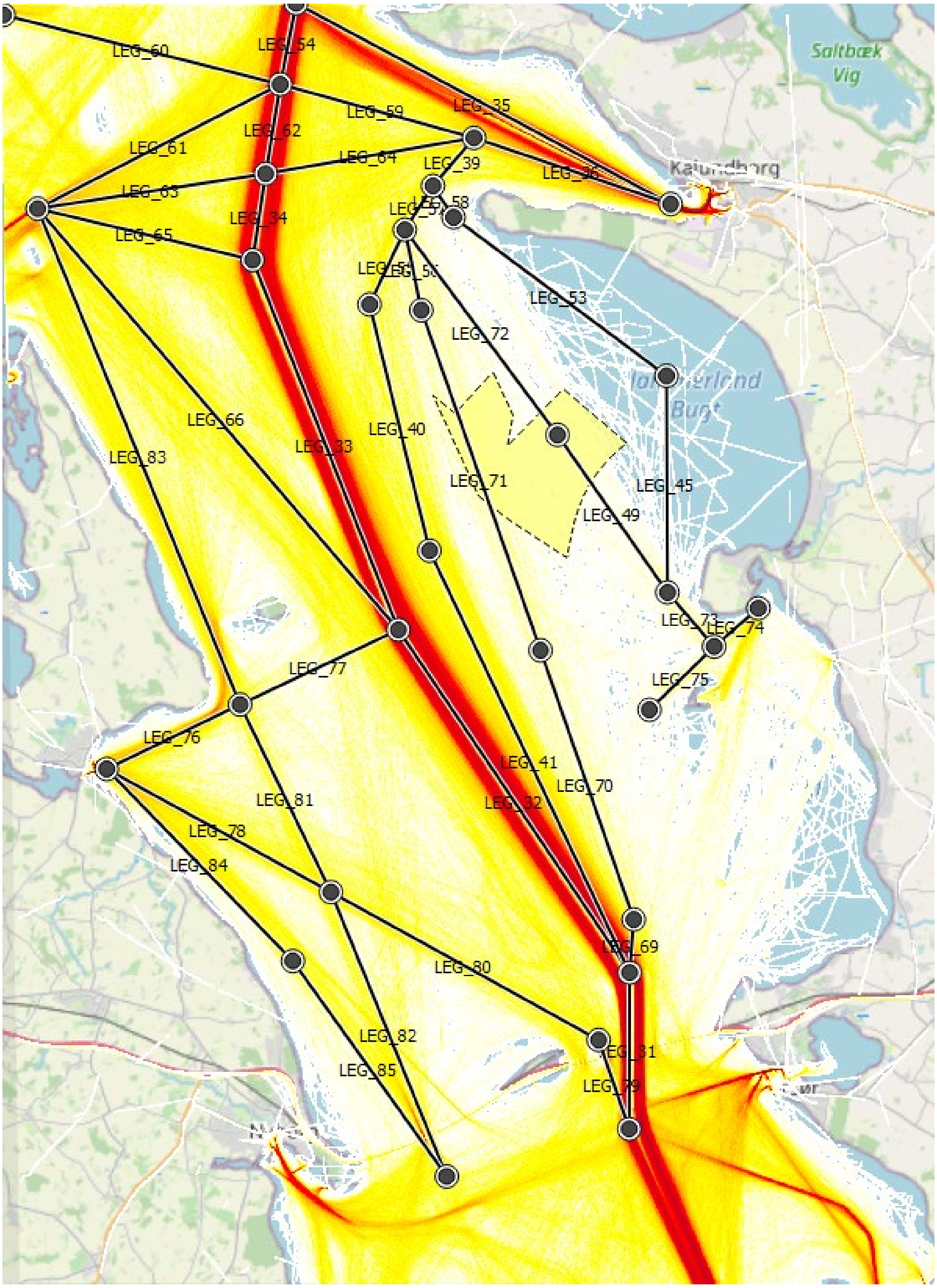


Figure B-1 Ship traffic intensity 2019 - all ships

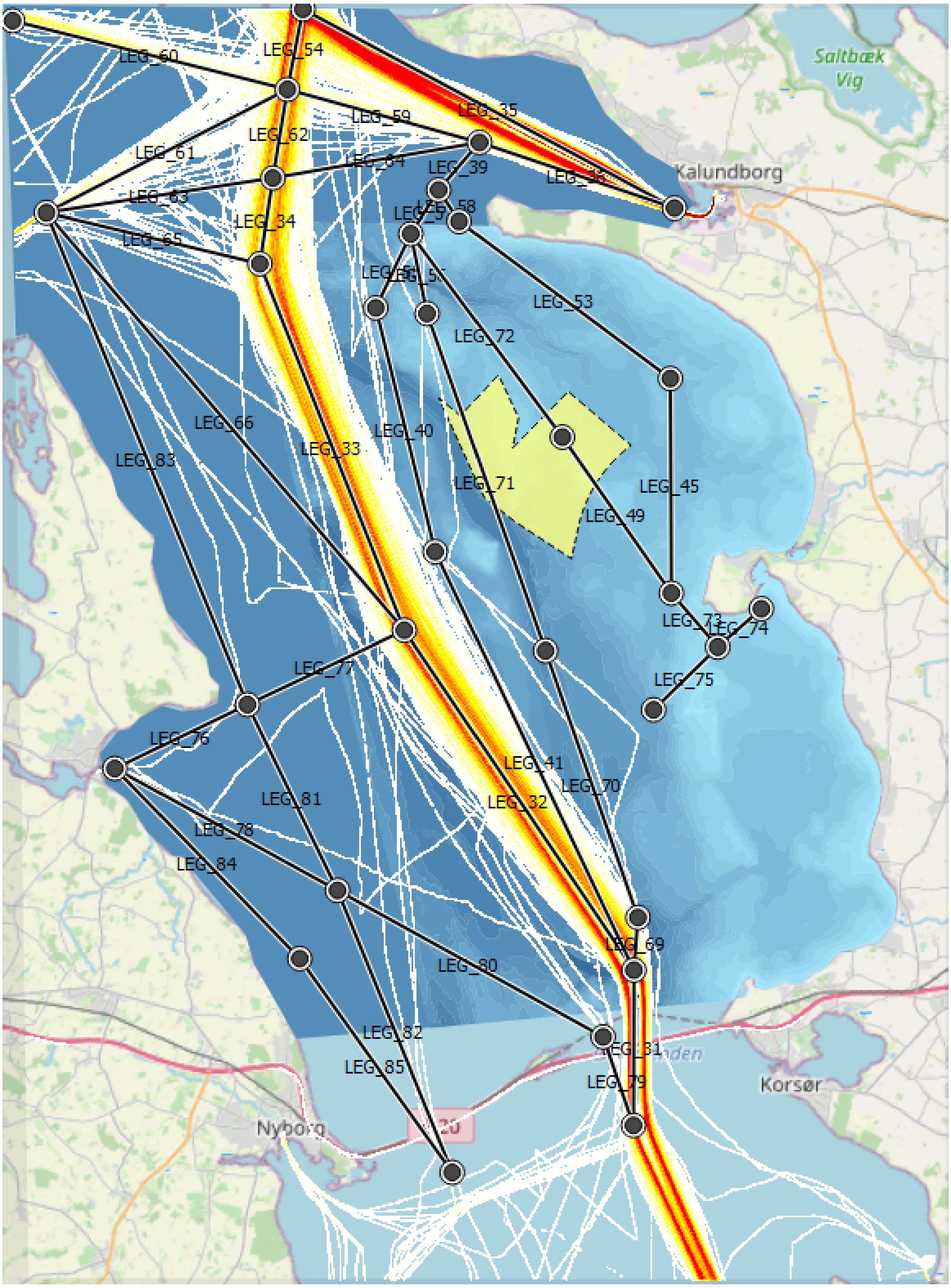


Figure B-2 Ship traffic intensity 2019 - Passenger ships

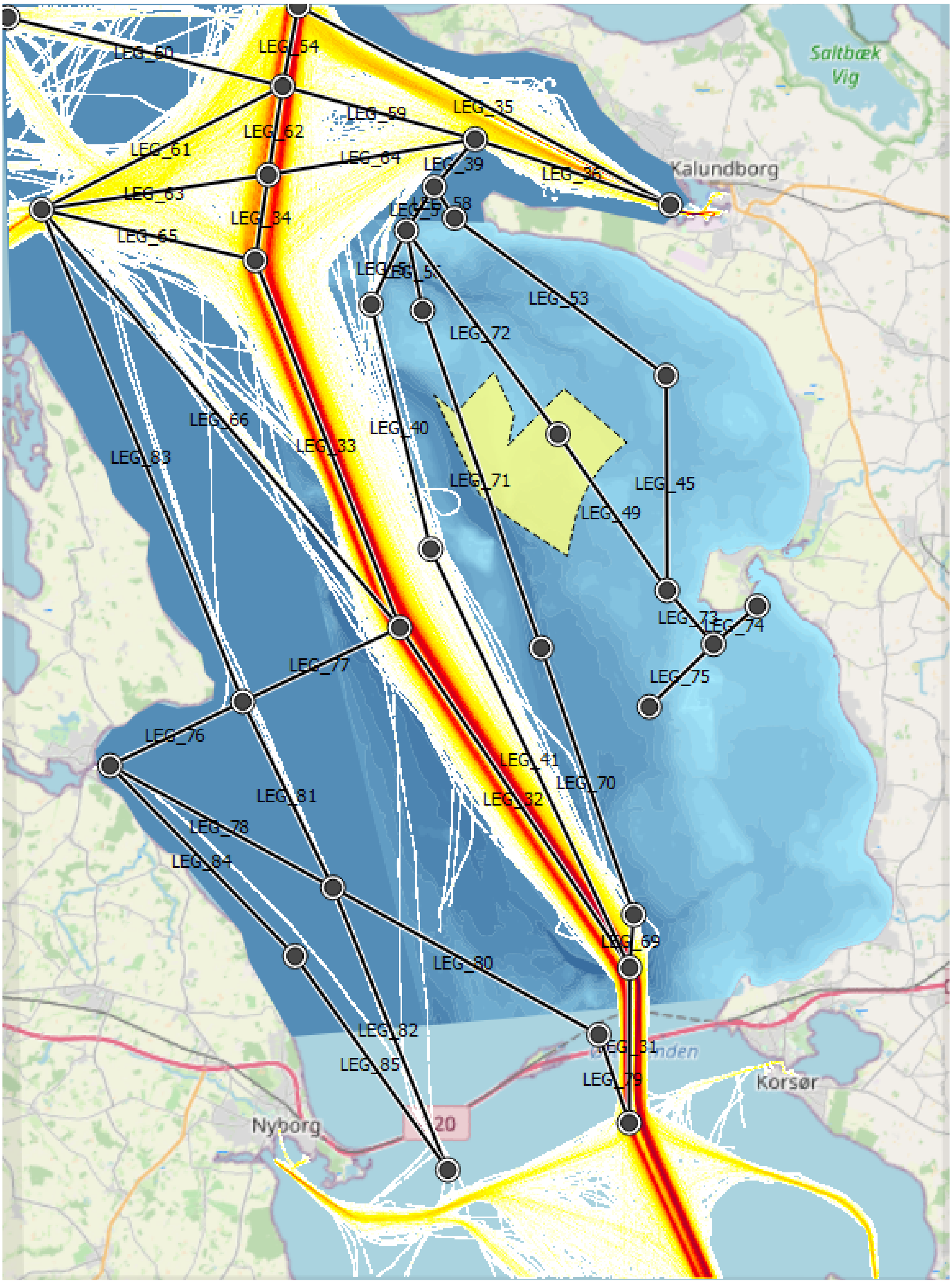


Figure B-3 Ship traffic intensity 2019 - Tank ships (crude oil, chemical and gas tankers)

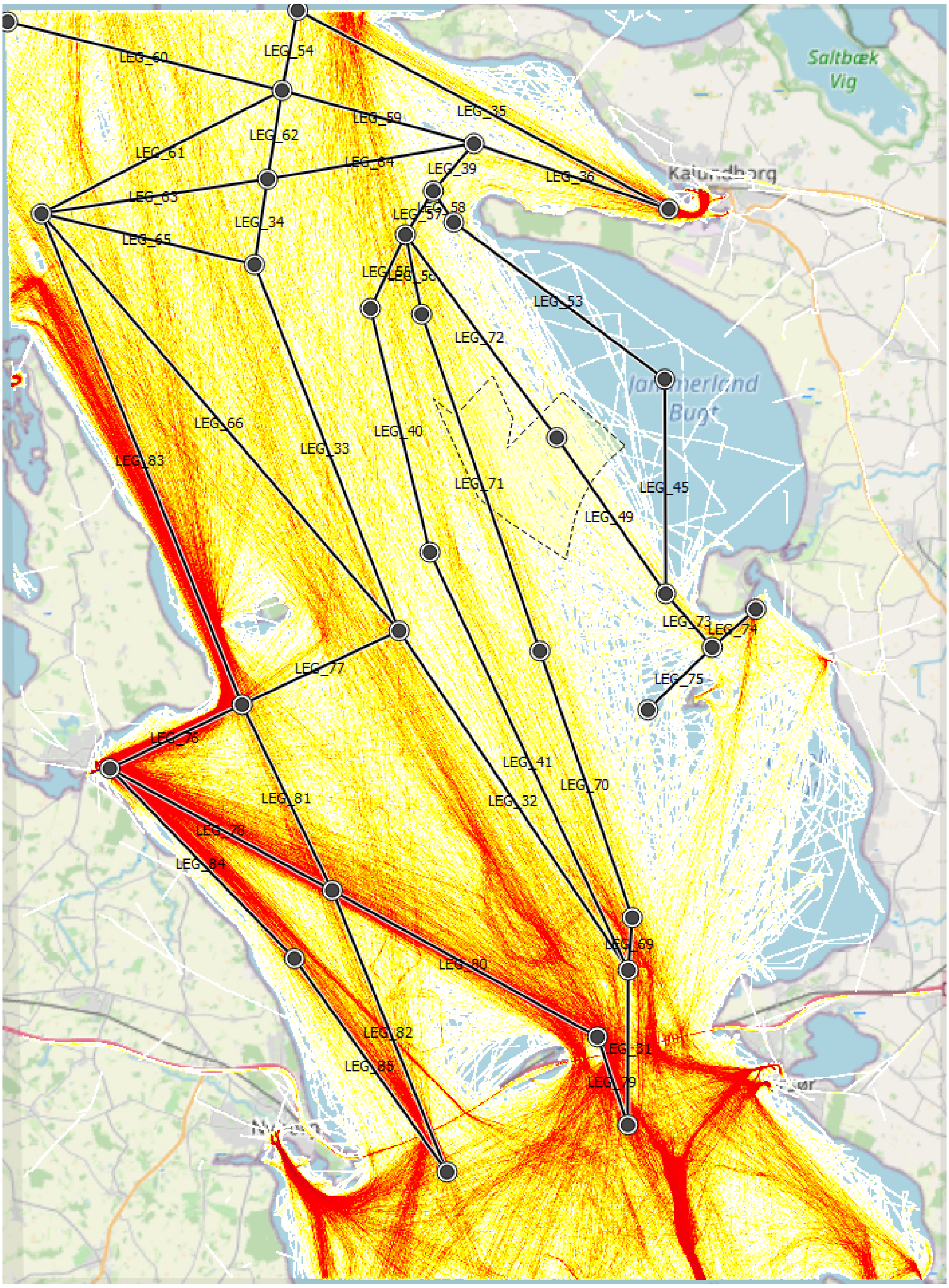


Figure B-4 Ship traffic intensity 2019 -Pleasure Boats and Fishing ships

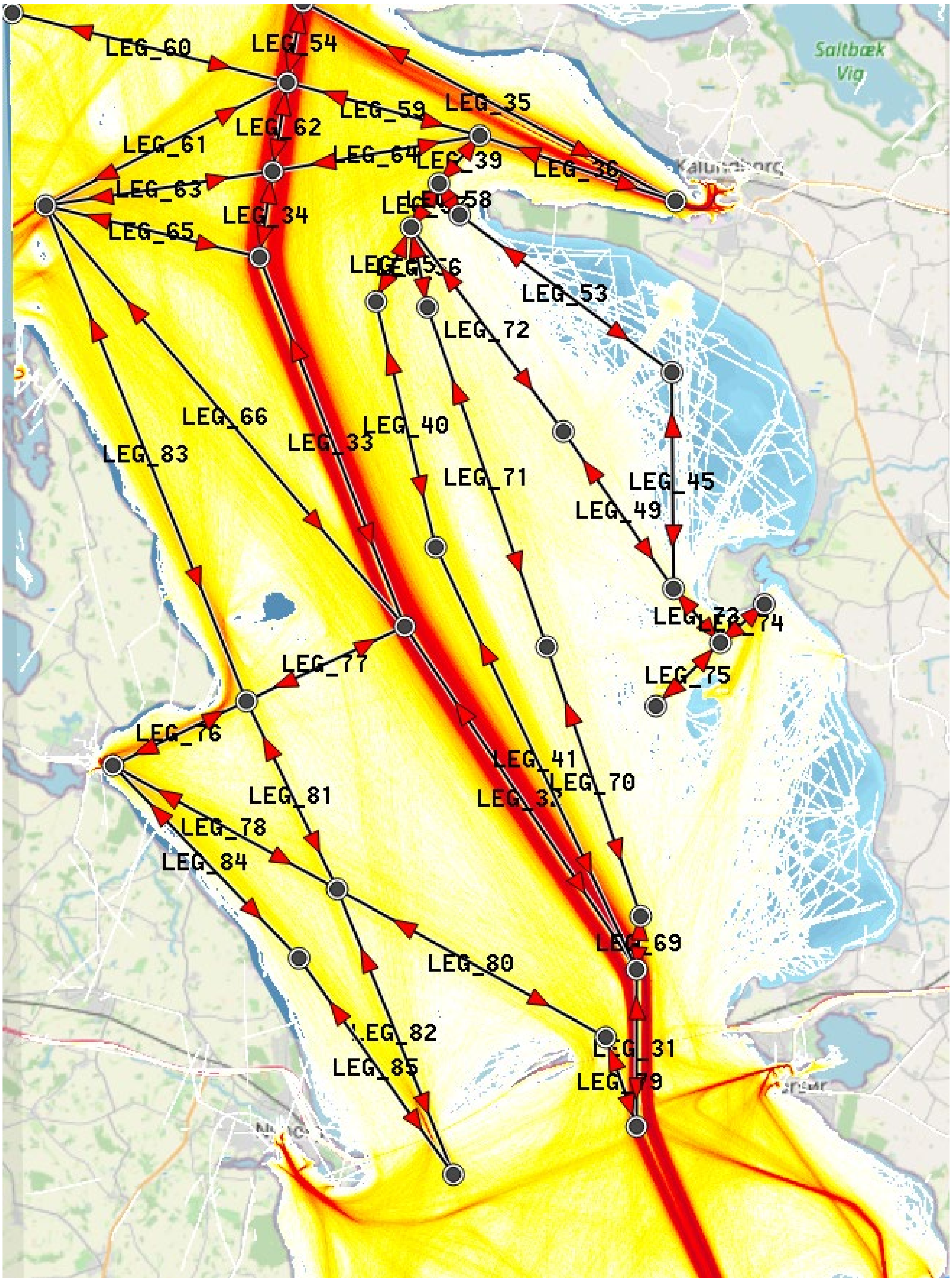


Figure B-5 Ship traffic intensity 2022 - all ships

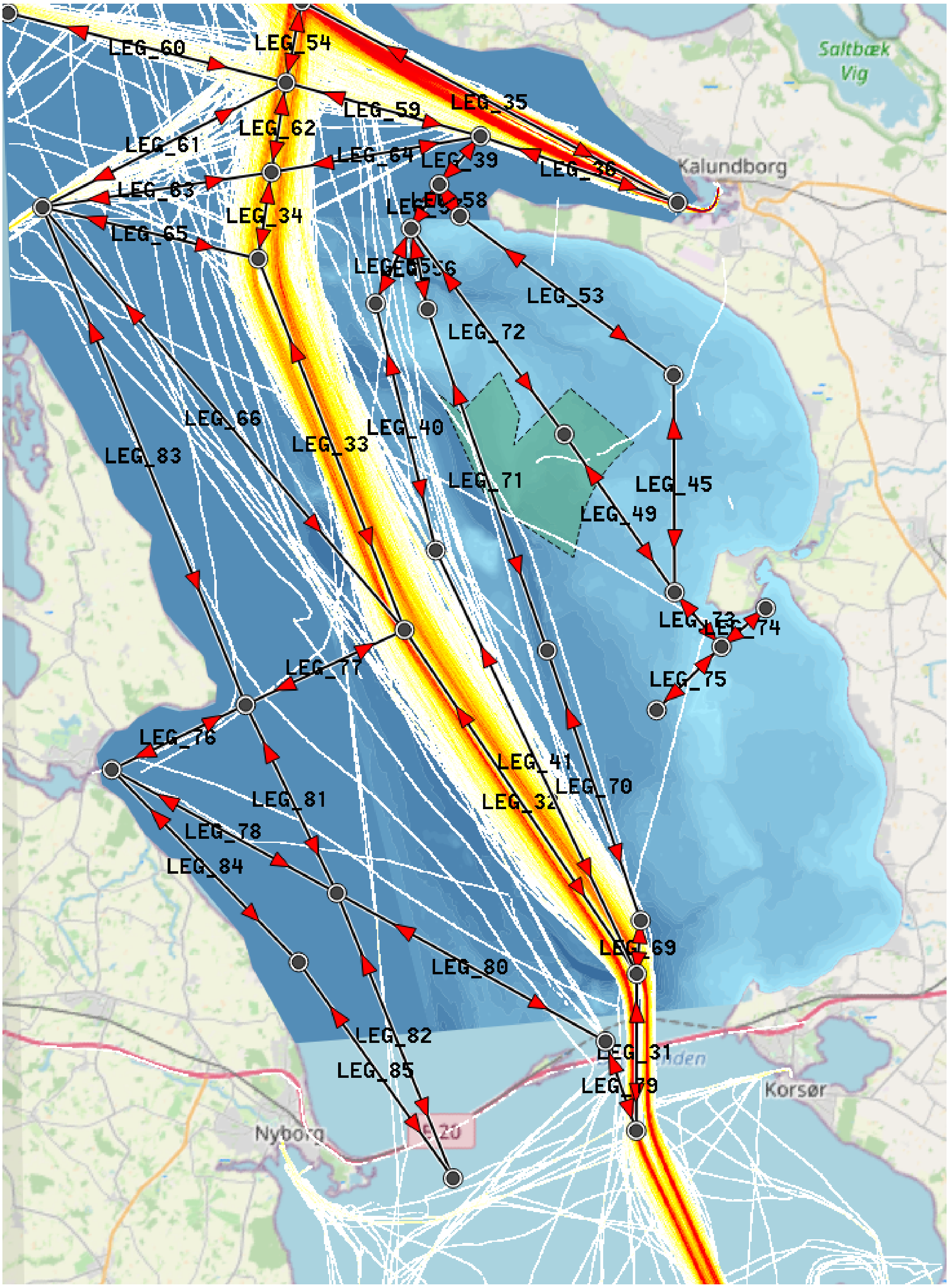


Figure B-6 Ship traffic intensity 2022 - Passenger ships

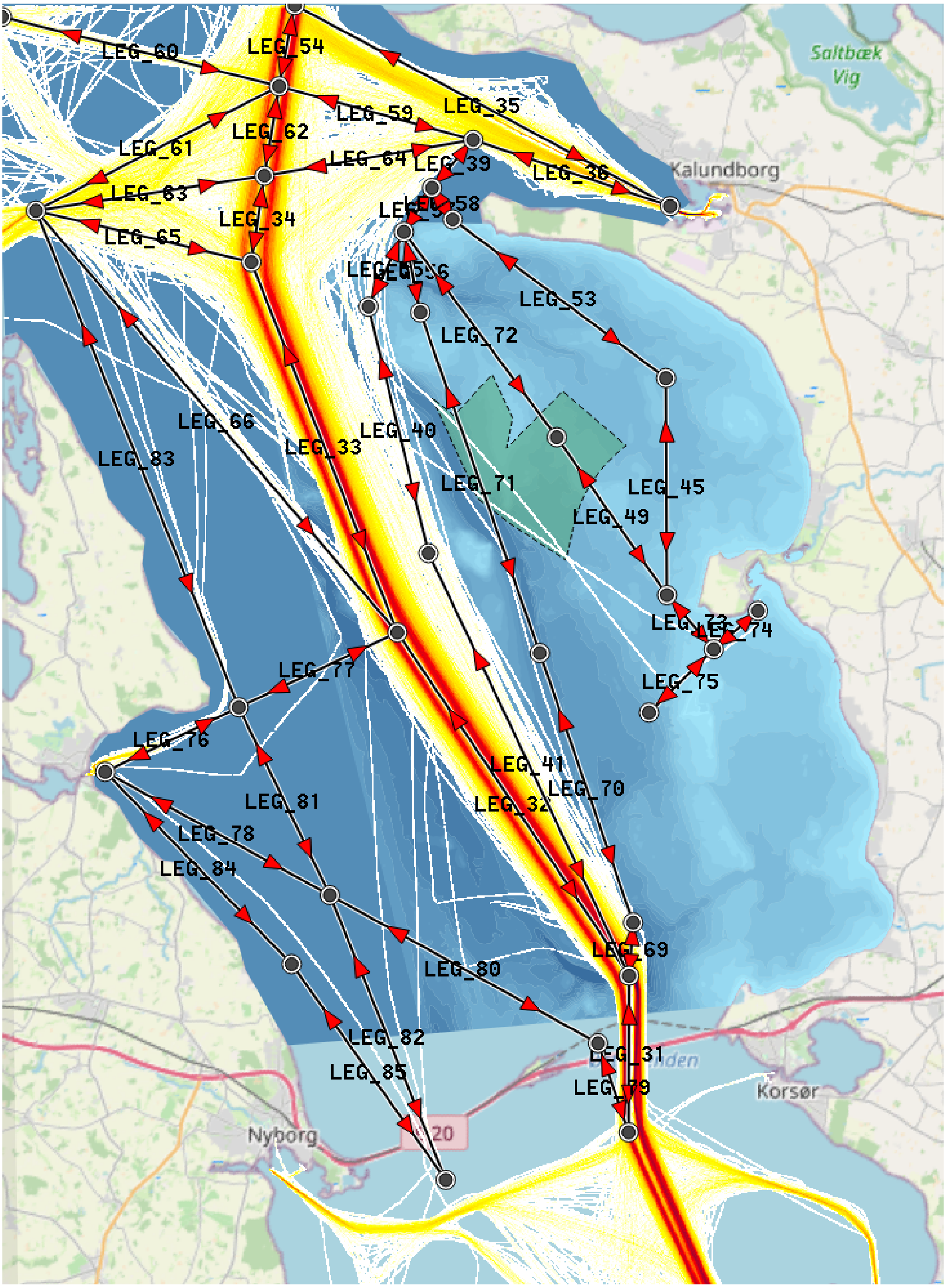


Figure B-7 Ship traffic intensity 2022 - Tank ships (crude oil, chemical and gas tankers)

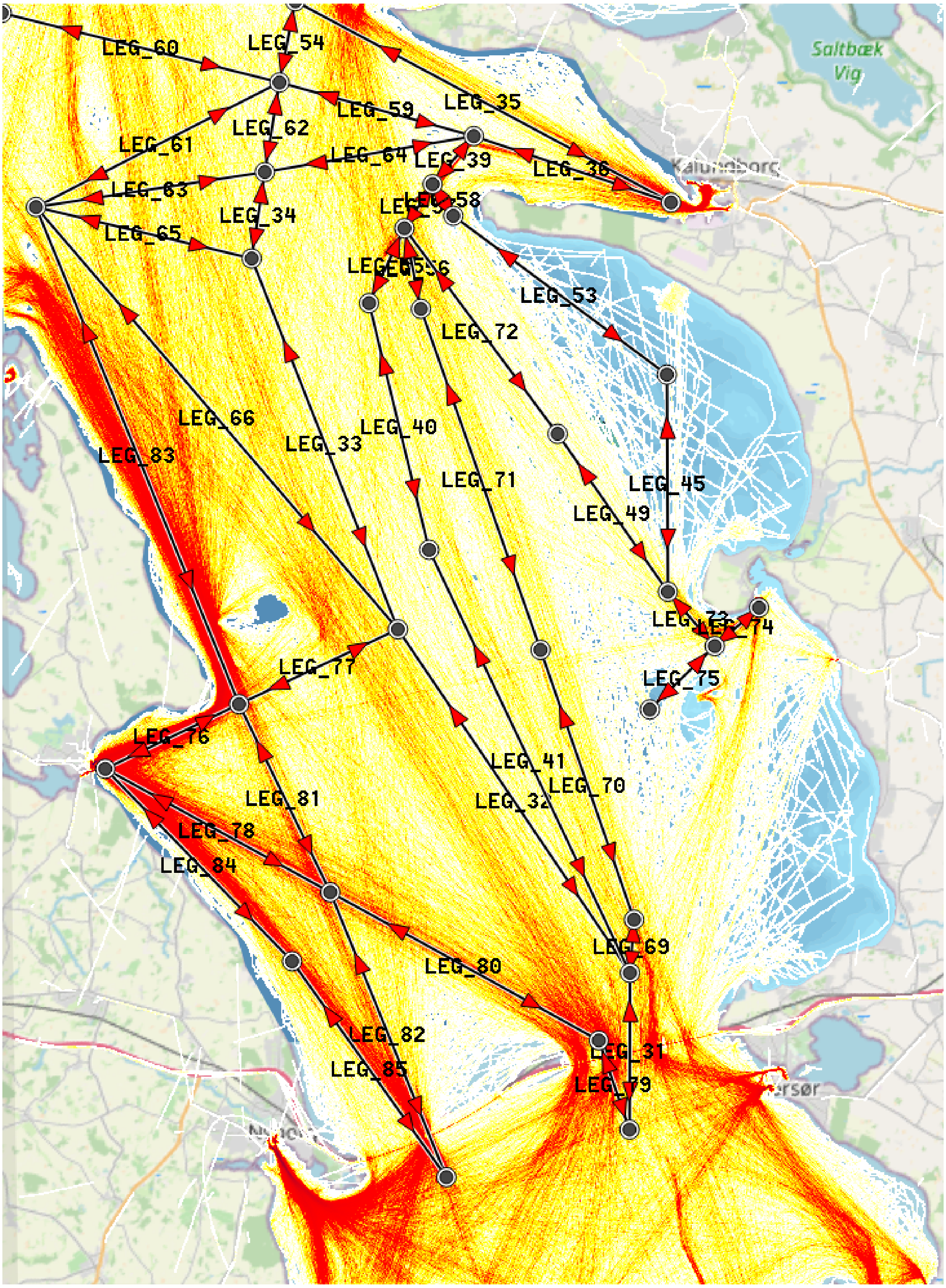


Figure B-8 Ship traffic intensity 2022 -Pleasure Boats and Fishing ships

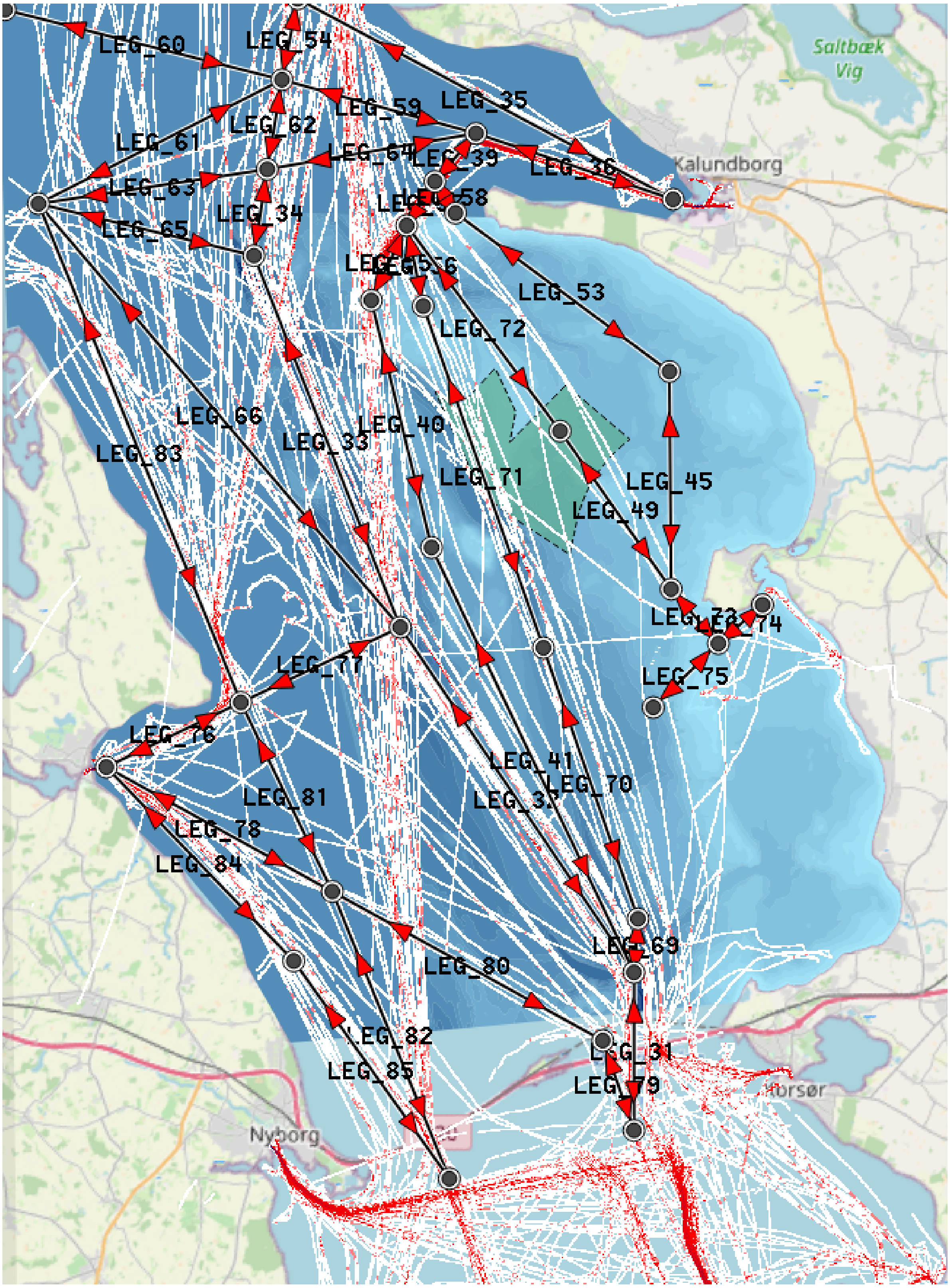


Figure B-9 Ship traffic intensity 2022 - Fishing ships only.

APPENDIX C
Probabilistic model assumptions

The IWRAP default values for human failure which have been applied are shown in Table 8-1. The assumed machine failure relevant parameters are reflected in Table 8-2.

Table 9-1 Human failure relevant parameters ***(IWRAP default)***

Ship-ship collision incidents	**Causation factors**
Merging	1.3E-4
Crossing	1.3E-4
Bend	1.3E-4
Headon	0.5E-4
Overtaking	1.1E-4
Area moving	0.5E-4
Area stationary	0.5E-4
Ship grounding incidents	
Grounding - forget to turn	1.6E-4
Ship-turbine collision incidents	
Collision - forget to turn	1.6E-4
Ship type specific reductions	**Causation reduction factors**
Passenger ships	20
Fast ferries	20

Table 9-2 Machine failure relevant parameters

Drift speed	1 knot(s) *(IWRAP default)*
Probability of successful anchoring	0.98 (*Assessment by Søfartstyrelsen based on seabed conditions*)
Max. anchor depth	7 times design draught *(IWRAP default)*
Min. anchor distance from ground	3 times ship length *(IWRAP default)*
Probability of self-repair	0 for t < 0.25 hour $1-\frac{1}{1.5(t-0.25)+1}$ for t > 0.25 hour
Blackout frequencies	
RoRo and passenger ships	0.1 per year *(IWRAP default)*
Other vessels	1.75 per year *(IWRAP default)*

DNV

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.