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THOR OFFSHORE WIND FARM
NAVIGATIONAL RISK ASSESSMENT

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THOR OFFSHORE WIND FARM
NAVIGATIONAL RISK ASSESSMENT

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CONTENTS

APPENDICES

Ver	Author	Checker	Approver	Date	Description
1.0	MASOE	TOJK	TOKJ	2022-10-04	First version for external review
2.0	MASOE	TOKJ	TOKJ	2022-10-31	Revised according to NIRAS comments and after presenting result for DMA

List of abbreviations:

AIS	Automatic Identification System
CTV	Crew Transfer Vessel
CWAS	Construction works at Sea
DMA	Danish Maritime Authority
DMI	Danish Metrological Institute
EIA	Environmental Impact Assessment
HAT	Highest astronomical tide
MSL	Mean Sea Level
OWF	Offshore wind farm
VHN	Vesterhav Nord
VHS	Vesterhavn Syd
RWE	RWE Renewables
TSHD	Trailer suction hopper dredgers
SEA	Strategic Environmental Impact Assessment
SOV	Service and Operations Vessel

1. INTRODUCTION

As part of the Environmental Impact Assessment (EIA) report for the Thor Offshore Wind Farm (OWF) Rambøll is performing a navigational risk assessment in relation to the construction, operation, and decommission of Thor OWF, which will be constructed and operated by Thor Wind Farm I/S, owned by RWE.

The present report is based on the in writing available project description /1/, the 2018 preliminary navigational safety study concerning the early project developments of Thor OWF and the related HAZID and hearing of users of the waters /2/. Like the previous study, the present report also includes AIS data from the Danish Maritime Authority but for 2021 instead of 2018 /3/. Further, information from the Danish Port Pilots guide available online /4/ and the Danish maritime spatial planning /5/ is also used.

The scope of the present analysis is limited to only consider hazards and related risk that are caused by accidents. Intentional actions to cause harm to others, humans or materials, is outside the scope of the present analysis.

1.1 Generic method for risk assessment of navigational safety

The navigational safety assessment is based on the standard method of the International Maritime Organisation (IMO). IMO publish a guideline to perform a formal safety assessment (FSA) that defines the framework of the risk assessment. A schematic illustration of the FSA process is shown in Figure 1-1. The FSA principles are followed in this project: thus, the HAZID identification, Risk Assessment, including evaluation of risk control options for the current stage of the project has been performed and is further developed as background for the EIA for Thor OWF concerning navigational safety.

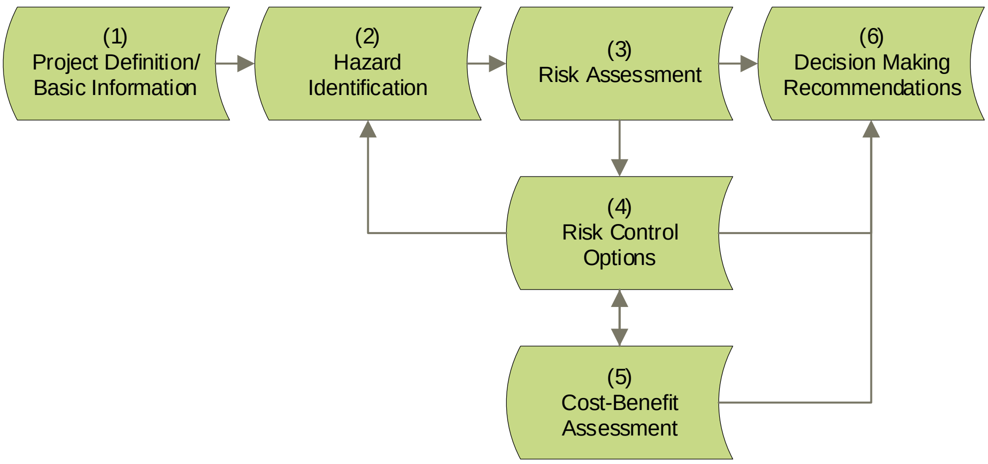

Figure 1-1: Schematic illustration of the steps leading to a risk assessment and a risk assessment-based decision.

1.1.1 HAZID Workshop

Rambøll did a written HAZID identification and consultation of users of the waters as background for the assessment of the consequences to the ship traffic and as input to the Strategic Environmental Impact Assessment (SEA) for the Thor OWF. The HAZID and consultation was for public health reasons done by letter and took place in May and June 2020.

The consultation and HAZID addressed primarily the construction and operational phases and assumed that the decommissioning phase of the project is to a large extent like the construction phase. The inputs and hazards received from the consultation are available in /2/ and are included into the present risk assessment.

The consulted users of the waters were presented with a letter asking for inputs concerning navigational safety in relation to the Thor OWF. Attached to the letter was a project description and a ship traffic analysis of the area. From the responses of the users of the waters Rambøll generated a list of 8 hazards; 7 of which are relevant during the operation phase and 2 in the construction phase. A few additional comments and concerns were received and addressed in the preliminary risk assessment in /2/.

1.1.2 Data and risk assessment

The navigational safety is investigated using AIS data, whereby it is possible to quantify the vessel activity in the interest area. AIS data together with the collected input from the consultation forms the data basis for the risk assessment. AIS is a maritime radio system for automatic identification of ships and other units of maritime transport. The system functions by vessels carrying an AIS VHF radio-transmitter and -receiver onboard. AIS is a requirement for all vessels above 300 gross tonnages, all passenger vessels, and fishing vessels above 15 m length overall /3/.

For military crafts there are no requirements regarding AIS thus their activity might not be observed. The same goes for smaller vessels such as pleasure boats, why only a smaller part of pleasure boats carry an AIS onboard, and thus are observed in the data set.

Not all vessels are careful in registering their vessel correctly on their AIS transmitter, thus these vessels have an unknow vessel type and are designated as other vessels.

The present report applies AIS-data from all of 2021 collected by and downloaded from DMA.

Modelling of the ship traffic and accident frequencies are done using the IALA-recommended software IWRAP MK2 extended 64bit v6.4.1. Accident frequencies calculated by IWRAP are ship-ship collisions, ship-wind turbine collisions, called allisions, and groundings.

The risk assessment is done as a comparative analysis where the risk between a basic scenario without Thor OWF and a scenario including Thor OWF in operation is compared. When modelling the basic scenario, OWFs operative in the area before Thor OWF are included.

Consequences of a collision are not estimated in detail in relation to damages to persons, equipment, or environment. Instead, a qualitative judgement based on the DMA schema Construction works at Sea (CWAS) is given. It classifies the consequences on a scale from 0 to 4 as indicative of the total cost of a consequence class, see Figure 1-2.

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

Figure 1-2: Danish Maritime Authority's risk assessment schema concerning Construction works at sea /6/.

The schema is not designed to be used in the operational phase but is here used as an indicator for the level of risk.

2. PROJECT DESCRIPTION AND AREA OF INTEREST

Following the Danish Parliament Energy Agreement of June 29th, 2018, the Danish Energy Agency agree to complete the construction of three 800-1000 MW offshore wind farms by 2030. One of these offshore wind farms is Thor OWF.

Once completed, Thor will have 67-72 wind turbines with effects between 14-15 MW each giving a total effect up to 1,000 MW. To the OWF will also be an offshore substation for current transformation, inter-array cables connecting the wind turbines to the substation and two export cables to transport the energy to the onshore power grid. The current project area is 220 km^2 which is a reduction from an initially 440 km^2 gross area during the preliminary screenings.

A wind turbine and related terminology are shown in Figure 1-1. For Thor OWF the wind turbines rotor diameter is expected to be approximately 236 m and a hub height of 143-148 m, with a total tip height of 261-266 m. The tip clearance then is expected to be 25 – 30 m above mean sea level (MSL).

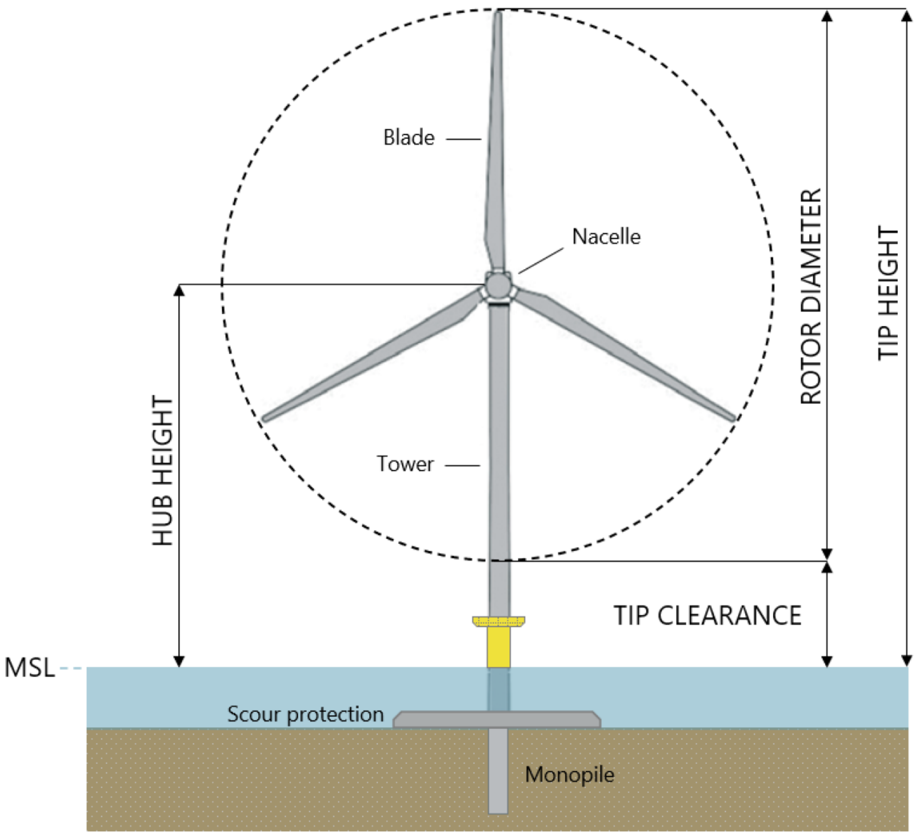

Figure 2-1: Illustration of an offshore wind turbine on a monopile construction. Note the terminology for difference numeric measures. Source: Niras /1/

A sea chart with the Thor OWF drawn in is shown in Figure 2-2. The park is situated approximately 22 km west of Thorsminde. Closer to shore, outside Thyborøn and Hvide Sande are two other OWFs named Vesterhav Nord (VHN) and Vesterhav Syd (VHS) respectively, which are expected to be operational ultimo 2023 /7/. South of VHS is the OWF Horns Rev where three OWFs are currently in operation. With a distance greater than 50 km Horns Rev is too far away to be considered impacting Thor OWF. The Thor OWF is indicated with the maximum of 72 turbines as basis for the current assessments.

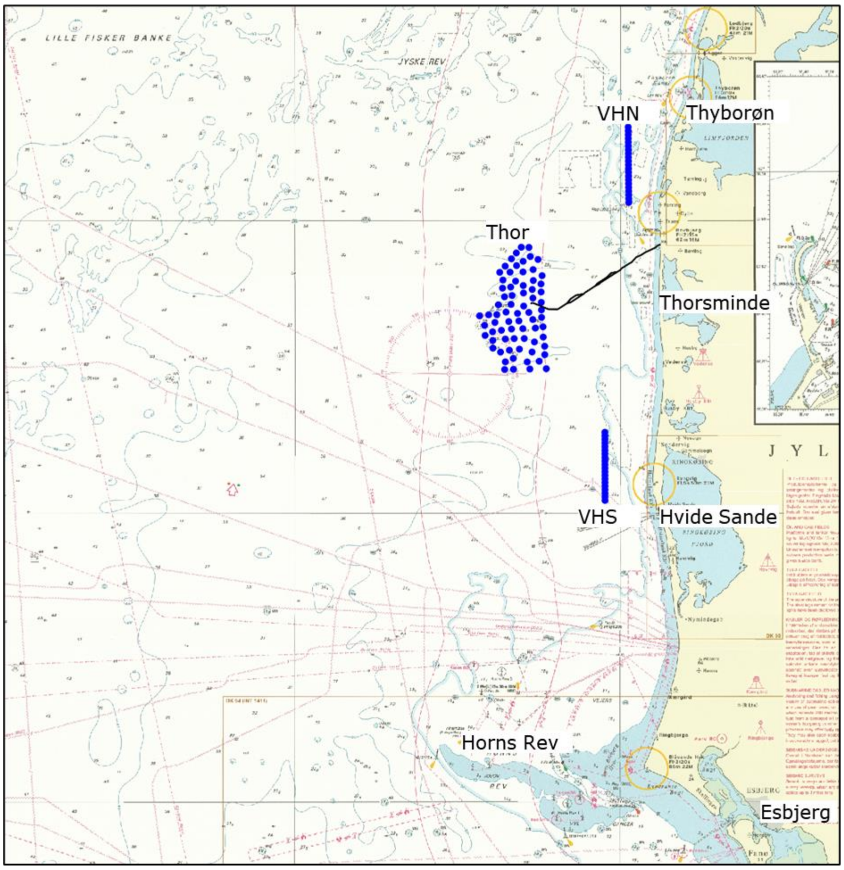

Figure 2-2: View of the seachart from the waters where Thor OWF will be constructed. Also seen are the cable corridor, the OWFs VHS and VHN, and names of relevant places and cities.

The primary harbours in the area are from north to south at Thyborøn, Thorsminde, Hvide Sande, and Esbjerg.

Thyborøn Port is at the entrance from the North Sea to Limfjorden in which Aalborg Port is placed and it is possible to pass through to Kattegat. The port activities range from import of goods, consumer and industry fishing, operation and maintenance of offshore activities, and shipyards with subcontractors.

Thorsminde is a smaller harbour with fewer activities. The harbour is anticipated to be used for some of the operations and maintenance activities during the operation of Thor OWF /1/.

Hvide Sande port services several maritime business' from OWF operation and maintenance, goods, and fishing.

Esbjerg port is the largest port along the Danish west coast with several thousand arrivals each year and is an active hub for the offshore industry in the Danish North Sea. It is relative far away from Thor but may be used for construction vessels or SOVs during maintenance as re-supply harbour, thus it is relevant to mention here.

From the sea chart, Figure 2-2, the overall water depth is read off to be below 10 m only about 1 km outside the coast and falls below 20 meters a few km off the coast. In the area of Thor OWF, the water depth is 20 m to 30 m in the sea chart. Geological surveys of the local bathymetry in the project area confirms the sea chart /1/.

The position of Thor OWF is within an area reserved for renewable energy according to the Danish maritime spatial planning and with more than 4 km to the largest maritime traffic corridor /5/. In Figure 2-3 the position of the Thor OWF wind turbines and the Danish national maritime traffic corridors are shown. Also seen are the two other OWF VHS and VHN. Numbers and black lines indicate distance measures from Thor to the ship traffic corridors. It is seen that Thor has about 4.3 km to the nearest ship traffic corridor.

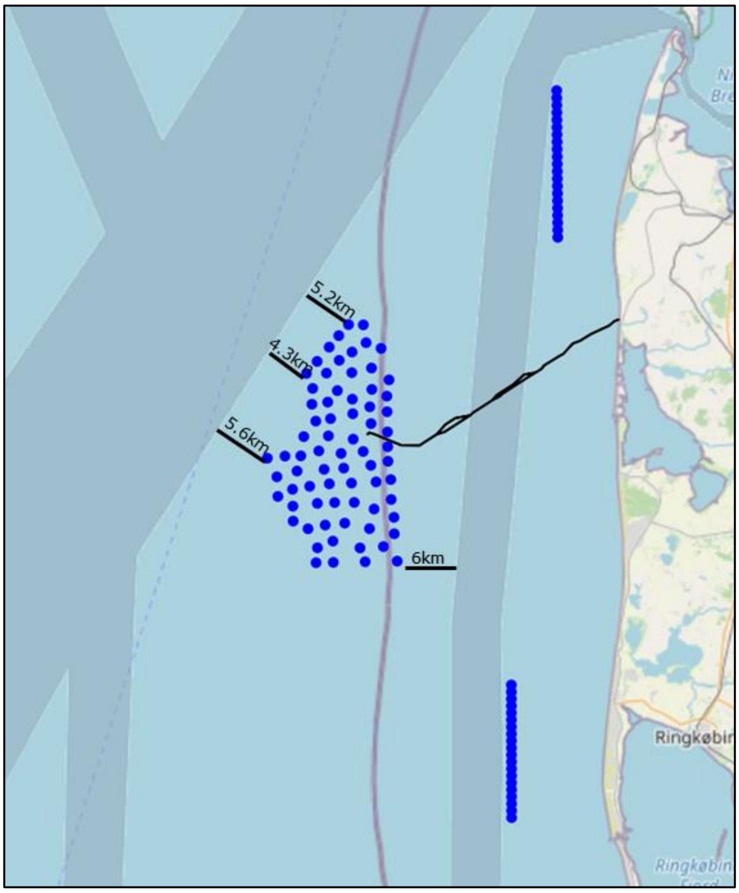

Figure 2-3: Position of Thor, VHS, and VHN, relative to the Danish national marine traffic corridors from the Danish maritime spatial plan /5/.

3. TRAFFIC ANALYSIS

Here traffic density maps for different vessel types are shown. A traffic density map indicates the traffic intensity through an area and highlights the main routes used by the ship traffic. The routes are defined in agreement with the routes analysed in the hazard identification and preliminary risk assessment /2/.

3.1.1 All vessel types

Figure 3-1 shows the ship traffic density in the area for all vessel types. Also shown are the project area and indications of the identified routes of the area, which are outlined below in chapter 4, indicates a broad band of traffic to the west of the project area which is the commercial ship traffic between the Netherlands and the Skagerrak. The width of the band is approximately 15 nm. The traffic is designated Route 1.

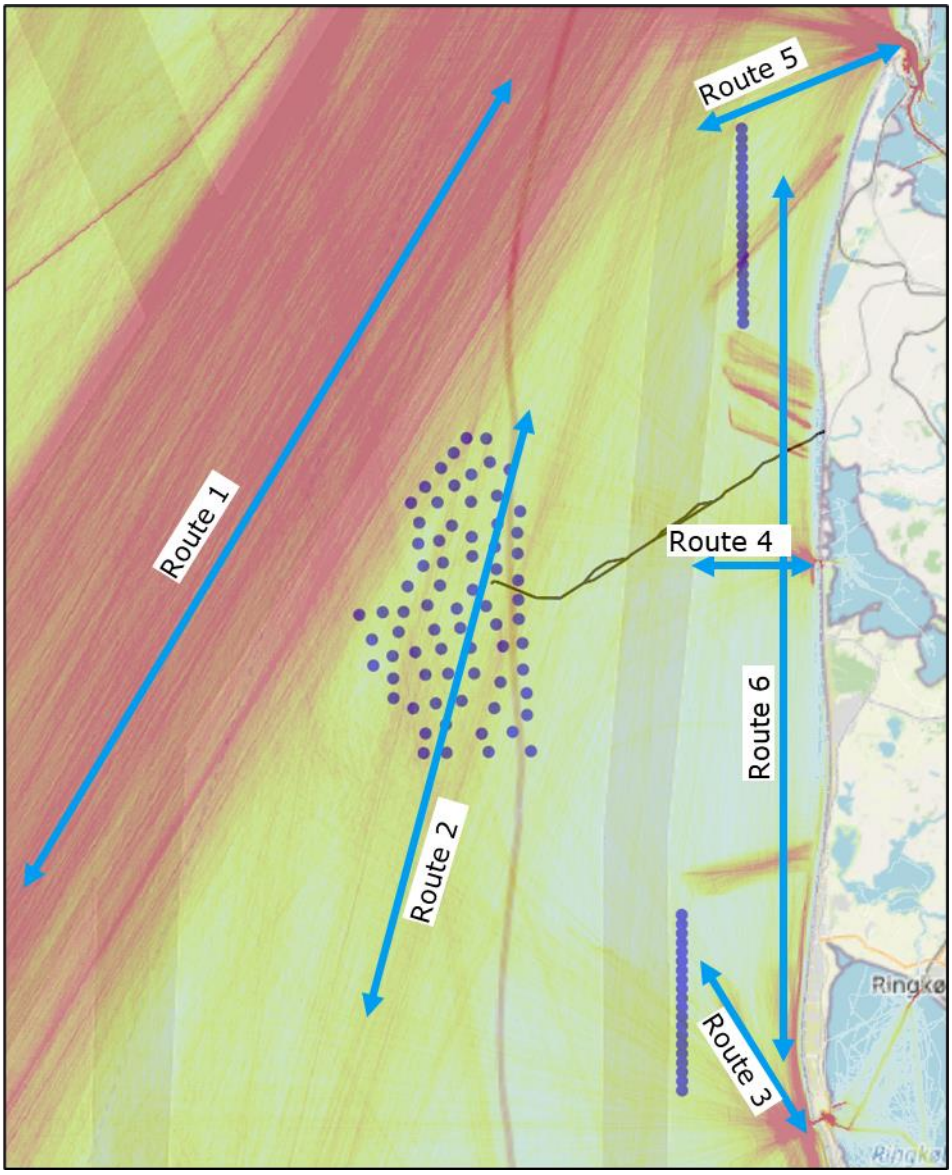

Figure 3-1: Traffic density map of the area from AIS data of 2021. Also shown are the project area and indications of identified ship traffic routes as well as shipping routes as defined in the Danish Maritime Spatial Plan (shaded blue).

Traffic to the harbours and fjords:
Traffic is observed to concentrate into harbours and fjord entrances or exiting from here in fan-like pattern.

Dredging operations and national coastal protection program:
Along the coast, several elongated east-west oriented areas of traffic are observed. These are areas where Trailing Suction Hopper Dredgers (TSHDs) are dumping dredged seabed material onto the coast as part of the national coastal protection program that continuously operates along the west coast of Jutland /12/.

3.1.2 Cargo, Tanker, and Container vessels

The traffic density map of cargo, container, and tanker vessels shown in Figure 3-2 clearly indicates that these vessels are primarily found west of the project area. Some traffic is also observed to pass through the project area and less activity is moving along the coast and crossing over the subsea export cable. It is also seen that no traffic is observed to pass in and out of Thorsminde, indicating that the traffic on Route 4 are other types of vessels like CTVs, fishing vessels and pleasure boats. To and from Hvide Sande, also little traffic is observed in Figure 3-2, while some traffic is observed to pass in and out of Limfjorden and to Thyborøn port.

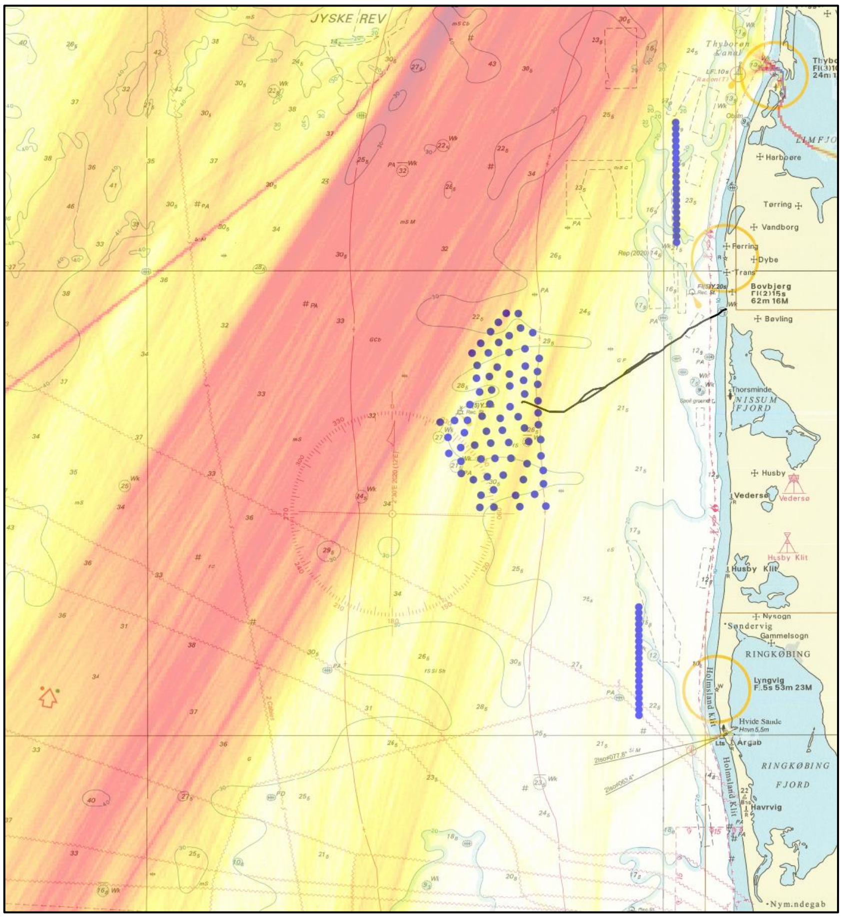

Figure 3-2: Traffic density map of the area around Thor OWF. Also seen are the cable alignment in black and OWFs VHN and VHS.

3.1.3 Fishing activities

The activity by fishing vessels can indicatively be observed by a traffic intensity map of fishing vessels with speed over grounds of 2 – 4 knots, and this is shown in Figure 3-3. Three characteristics are observed: 1) there is activity just outside the ports at Thyborøn, Thorsminde, and Hvide Sande, 2) the activity along the coast at Hvide Sande is the most intense region of traffic, and 3) most fishing activity offshore is west to south-west of the planned Thor OWF. Some fishing activity is seen inside the area where Thor OWF are placing wind turbines.

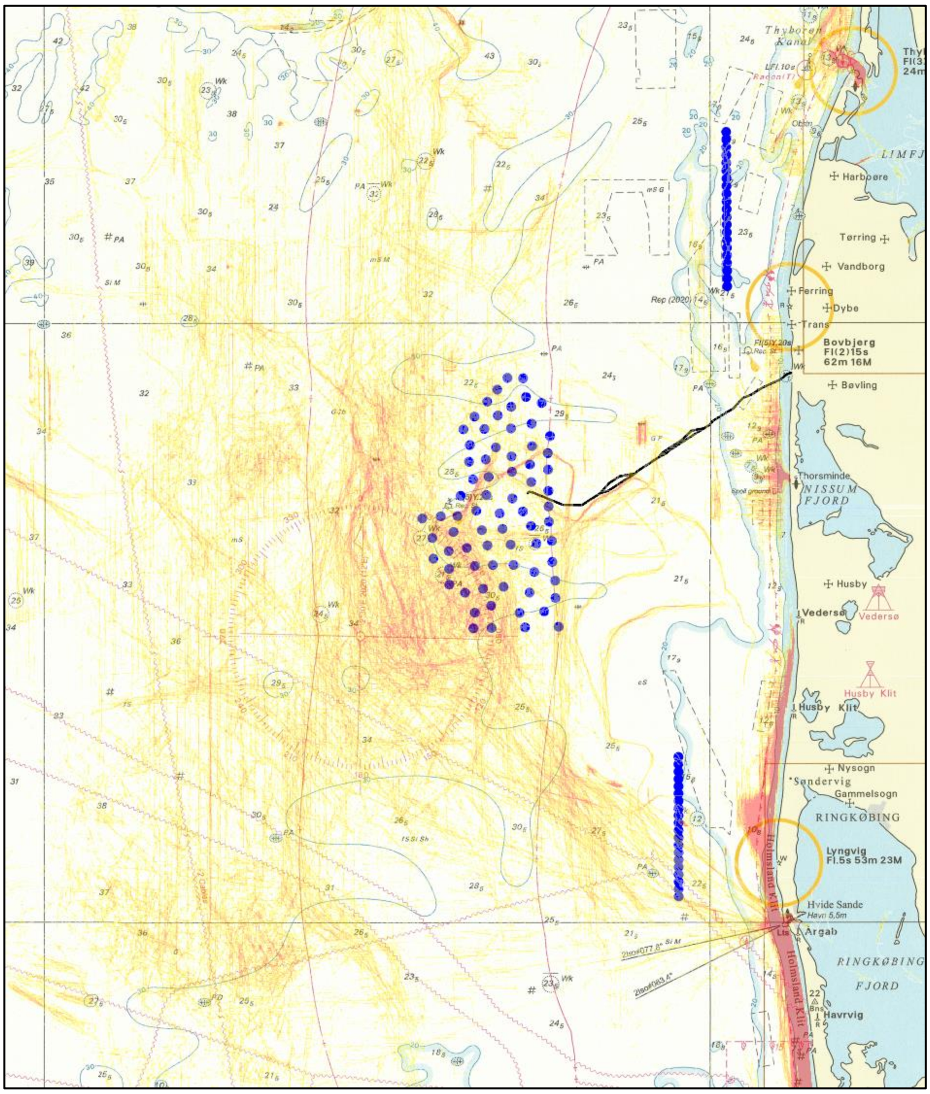

Figure 3-3: Traffic density map of fishing vessels at speed over ground interval of 2-4 knots.

3.1.4 Pleasure boats

Pleasure boats are also seen along the west coast of Jutland. However, most of the traffic is concentrated along the coast, and only few vessels are observed more than 20km from the coast near the planned Thor OWF. As mentioned in Section 1.1.2, pleasure crafts are not always registered in the AIS data set, and hence the representation of pleasure crafts may be underestimated. However, at larger distances to the shore, and with no nearby destinations and harbours west of Denmark, it is assessed that the density of pleasure crafts in the area of Thor

OWF will indeed be low. This is also confirmed from Figure 3-4 which shows the traffic density of pleasure crafts in the area. Also seen are many straight lines as well as areas previously identified as dredging activity. Indeed, it is confirmed that there are dredgers registered as pleasure crafts within the AIS data. It is assumed that the straight lines are also due to false ship type registrations within the individual ship's AIS transponder.

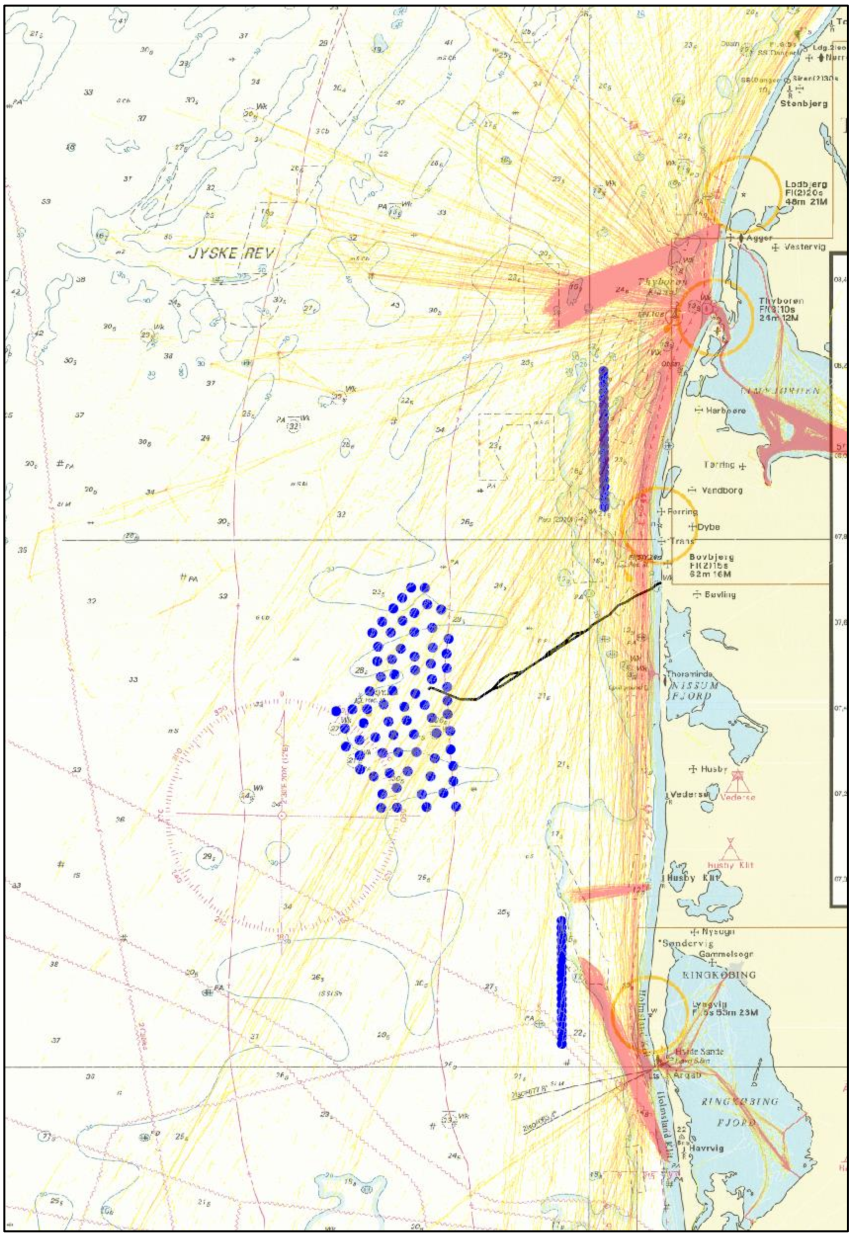

Figure 3-4: Traffic density map of pleasure crafts.

4. TRAFFIC ROUTES

The overall characteristic of each route is presented below. The route numbers are referenced to Figure 3-1 and defined in agreement with the routes analysed in the hazard identification and preliminary risk assessment /2/.

4.1 Route 1 – west of Thor OWF

Figure 4-1 presents the ship characteristics of traffic on Route 1 which is the broad band of traffic observed just west of the project area. The traffic is generated by vessels sailing to and from the Netherlands, from or to destinations in Skagerrak or east of Jutland further into Kattegat or the Baltic Sea. A total of 17806 vessels has used the route in 2021.

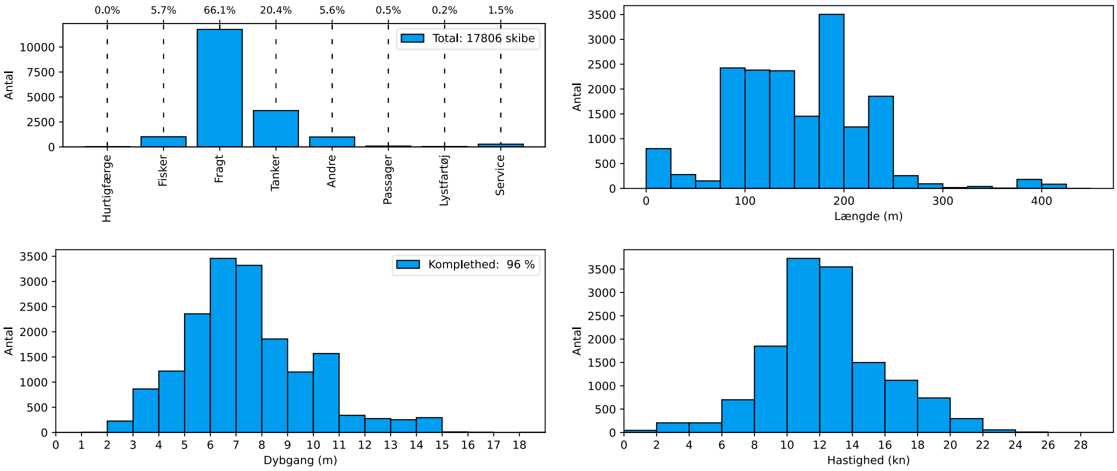

Figure 4-1: Route 1 ship traffic statistics. Top left is the counts per ship type. Top right is the counts per length in 25 m intervals. Bottom left is the draught in intervals of 1 m. Bottom right is the speed over ground in 1 kn intervals.

Looking at Figure 4-1 top left, it is evident that cargo vessels, which are different types of bulk and goods carriers and container ships, dominate the traffic. Secondly follows tankers while some fishing, support and other vessels are also frequent. Fast ferries, passenger ships and pleasure crafts are rarely found on Route 1.

The top right figure shows the length distribution of the traffic. This is dominated by vessels between 75 m and 250 m of length. Further it is observed that some vessels are around 400 m of length.

Bottom left figure displays the draught for the vessels and shows that most vessels are between 5 m and 11 m. The largest draught registered is 25.5 m and comes from a trawler fishing vessel and a tug. Most probably these are false depths, though it is possible that the trawler may have registered the depth of the trawling gear while fishing. Similarly, the tug may have dragged an object, e.g., a sinker line, through the water behind it.

The speed over ground distribution is shown in the bottom right corner of Figure 4-1 and follows a near normal distribution with a mean value around 12 kn.

4.2 Route 2 – through Thor OWF

Route 2 describes the traffic that crosses through the project area in a north/south direction. Those heading in a north going direction most probably have destinations in Skagerrak or east of

Jutland. Those heading in a south bound direction may be on course to the Netherlands or Germany, e.g., Bremerhaven or Hamburg. The destination may also be Esbjerg.

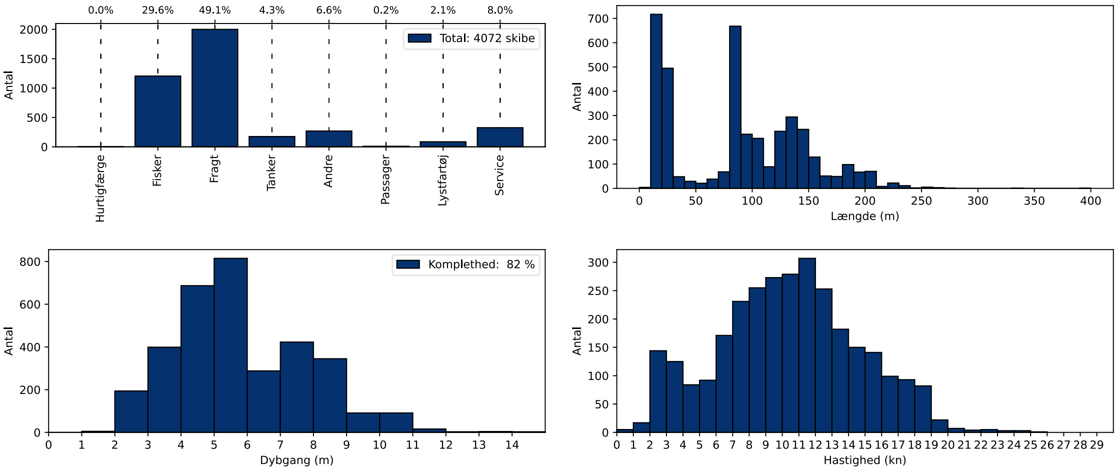

Figure 4-2: Route 2 ship traffic statistics. Top left is the counts per ship type. Top right is the counts per length in 25 m intervals. Bottom left is the draught in intervals of 1 m. Bottom right is the speed over ground in 1 kn intervals.

The traffic on Route 2 is less intense than Route 1. Still, it is dominated by cargo vessels. However, the second most abundant vessel type are fishing vessels. A total of 4072 vessels are registered on the route in 2021. The length distribution on Route 2 is dominated by two populations. First is a population of vessels between 10 m and 40 m which are fishing vessels and smaller other vessels like tugs or dredgers. The second population consist of cargo and tanker vessels and have lengths from 80 m to 400 m. Most of these are however between 80 m and 150 m. The draught for the traffic on Route 2 shows many vessels with draught below 1 m. These vessels most probably do not register a draught which is normal for small vessels, e.g., fishing vessels and pleasure boats. Most vessel for which the draught is known are in the range between 2 m and 11 m, with few vessels registering draughts as high as 25.5 m.

4.3 Route 3 – out of Hvide Sande

This route describes the traffic out of Hvide Sande with a general direction going towards or coming from the proposed Thor OWF.

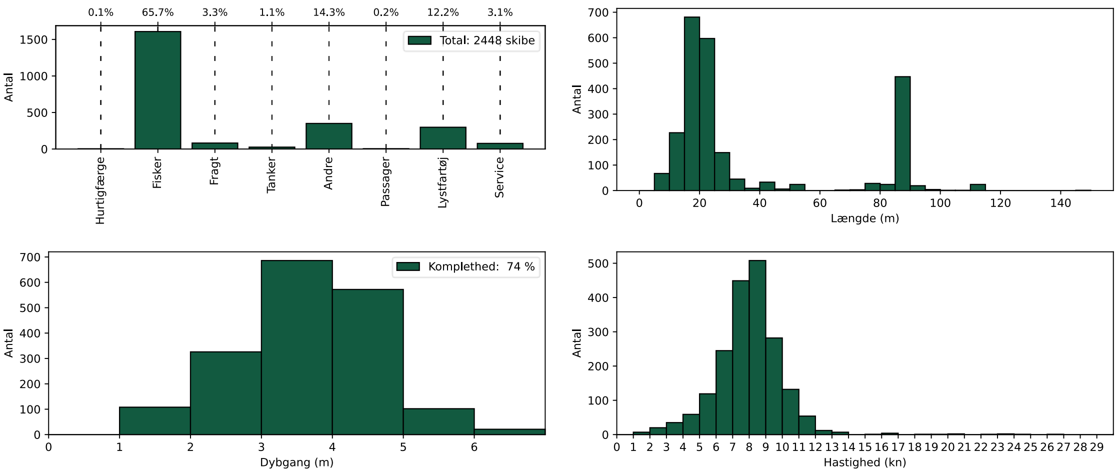

Figure 4-3: Route 3 ship traffic statistics. Top left is the counts per ship type. Top right is the counts per length in 5 m intervals. Bottom left is the draught in intervals of 1 m. Bottom right is the speed over ground in 1 kn intervals.

On Route 3, 2448 ships are reported to have passed. The traffic is dominated by fishing vessels, other vessels, and pleasure boats. Cargo and tanker vessels are very few as are passenger and fast ferries. The distribution of ship lengths of the traffic shows a population around 20 m of length and another smaller population around 90 m and is in line with most vessels being fishing vessels. The longer vessels are generally identified as other vessels and include dredgers. The draught distribution also shows a large fraction of the traffic to have no draught registered in the AIS data, and the remaining vessels to be between 1 m and 7 m. The speed over ground is almost normal distributed around 8 kn, but also captures vessels of speeds up to nearly 30 kn.

4.4 Route 4 – out of Thorsminde

This route describes the traffic out of Thorsminde with a general direction going towards or coming from an area near the proposed Thor OWF.

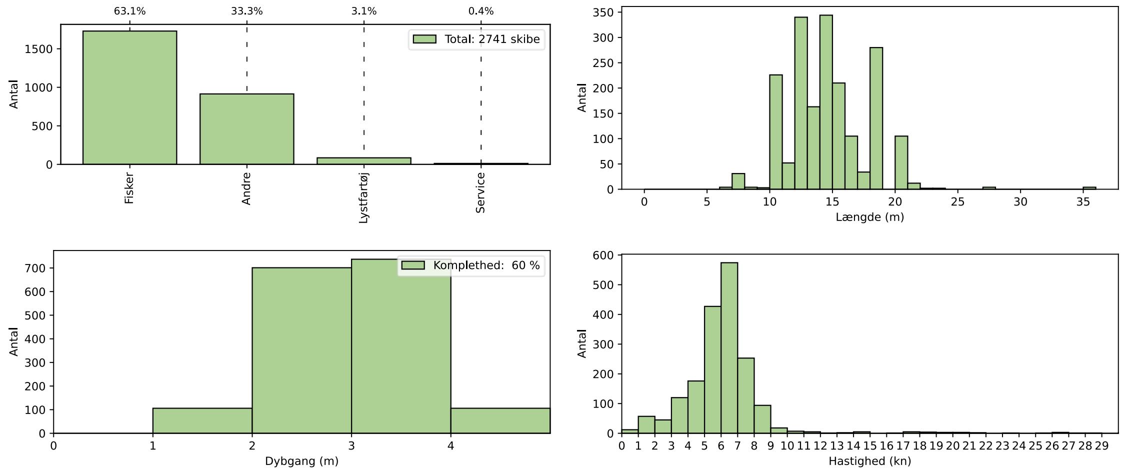

Figure 4-4: Route 4 ship traffic statistics. Top left is the counts per ship type. Top right is the counts per length in 1 m intervals. Bottom left is the draught in intervals of 1 m. Bottom right is the speed over ground in 1 kn intervals.

The traffic on Route 4 holds only fishing, other, pleasure and support vessels, with fishing vessels dominating the traffic. A total of 2741 ships are reported to pass. The ship length distribution of the traffic also indicates this by all vessels being below 40 m in length, with most being between 10 m and 20 m. The draught is also unknown for most vessels, while it is between 1 m and 6 m for those that do register a draught. The speed over ground between 1 kn to 9 kn, while some do go at high speeds up to 30 kn.

4.5 Route 5 – out of Thyborøn

This route describes the traffic out of Thyborøn with a general direction going towards or coming from an area near the proposed Thor OWF.

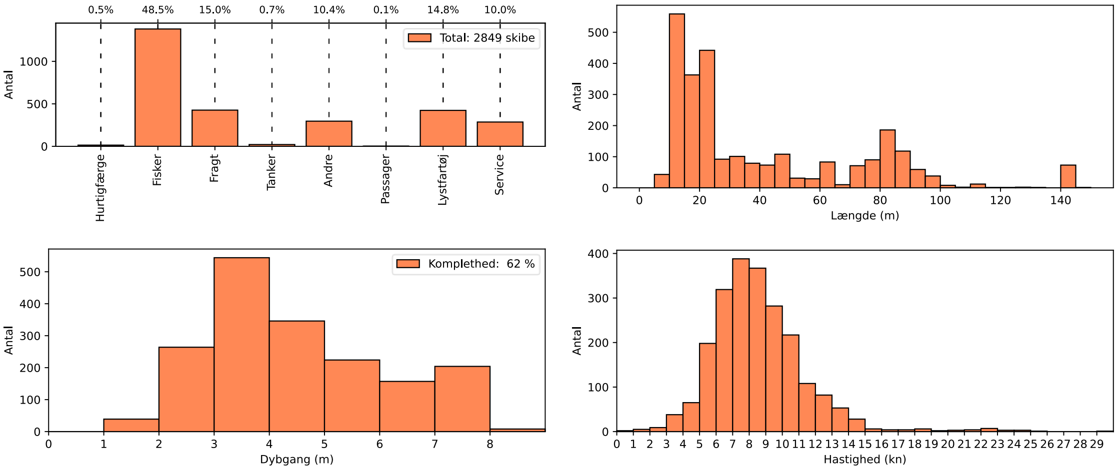

Figure 4-5: Route 5 ship traffic statistics. Top left is the counts per ship type. Top right is the counts per length in 5 m intervals. Bottom left is the draught in intervals of 1 m. Bottom right is the speed over ground in 1 kn intervals.

Route 5 is dominated by fishing vessels but also cargo vessels, pleasure crafts, other and support vessels are frequently observed. There is little activity from fast ferries, tankers and passenger vessels. The length distribution shows ship lengths between 10 m and 145 m with most vessels being between 10 m to 25 m. The draught is mostly unknown, but for registered vessels it is between 1 m and 9 m. The speed over ground has a near normal distribution with a mean value at 8 knots. Some vessels do show high speeds up to 30 kn.

4.6 Route 6 – coastal traffic

This route generally describes the coastal traffic moving in a north/south direction along the west coast of Jutland.

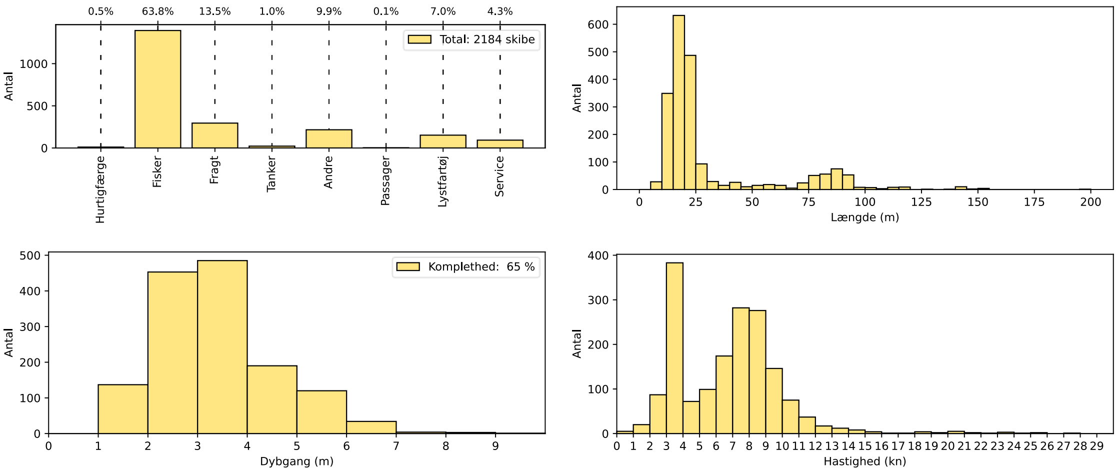

Figure 4-6: Route 6 ship traffic statistics. Top left is the counts per ship type. Top right is the counts per length in 5 m intervals. Bottom left is the draught in intervals of 1 m. Bottom right is the speed over ground in 1 kn intervals.

On Route 6, 2184 ships are registered to have passed. Primarily these are fishing vessels, some cargo, other, support, and pleasure crafts. Tankers, fast ferries, and passenger vessels show little activity. The length distribution shows vessels with lengths between 5 m and 200 m, with most vessels being between 10 m and 30 m, and a small sub population between 75 m and 95 m. The draught is for the most part unknown. Vessel that has a draught registered shows values between

1 m and 10 m. The speed over ground shows a peak between 3 kn and 4 kn, aside from which, is otherwise normal distributed with a mean value close to 8 kn. High velocities up 30 kn are also observed.

5. BASIS SCENARIO

Here the basis scenario is presented. Included in the basis scenario is the traffic as observed within AIS data year 2021 and the two wind farms VHS and VHN expected to be in operation from ultimo 2023. In consequence of the two OWFs the ship traffic will adapt why some rerouting of today's traffic is needed.

5.1 Modeling of ship traffic and collision scenarios

The modeling of the ship traffic and the collision scenarios is done using IWRAP. Specific details and settings for the modeling are described in appendix 1.

Three different accident scenarios are modelled

- Groundings
- Allisions, which are collisions between ships and fixed obstacles (turbines and platforms)
- Collisions between ships

The location of offshore structures will generally influence the way the ships in the area navigate, e.g., such that ships change sailing patterns, more ships follow the same main routes, etc. The presence of turbines is thus able to influence the navigational situation in an area and require that the traffic adapts to the new surroundings. The changes may cause ship collisions with the turbines themselves, as well as a change in the frequency of grounding and ship-ship collisions.

Grounding against land areas and collisions with fixed obstacles (e.g., offshore wind turbines or an offshore substation platform), known as allisions, can be caused by human error, where a ship continues at an unchanged speed until grounding or collision. In the event of engine failure or black out, on the other hand, a ship will begin to drift, and thus be exposed to wind and waves and at a lower speed could continue to run aground or collide with a turbine. The possibility of anchoring and restarting the machine before grounding or collision is considered in the modeling in IWRAP, just as the wind direction is considered when estimating the drift direction. The frequency of grounding will be influenced by the number of fixed obstacles along the modeled shipping routes, and the accident scenario could end up in a situation where ships hit or drift into one of the obstacles before the ships run aground.

Ship-ship collisions can occur within a single route in connection with the passage of oncoming traffic (head-on), or when overtaking other ships. In addition, collisions can occur in connection with crossing traffic, with route breaks and with intertwining traffic. Modeling scenarios as implemented in IWRAP are shown in Figure 5-1.

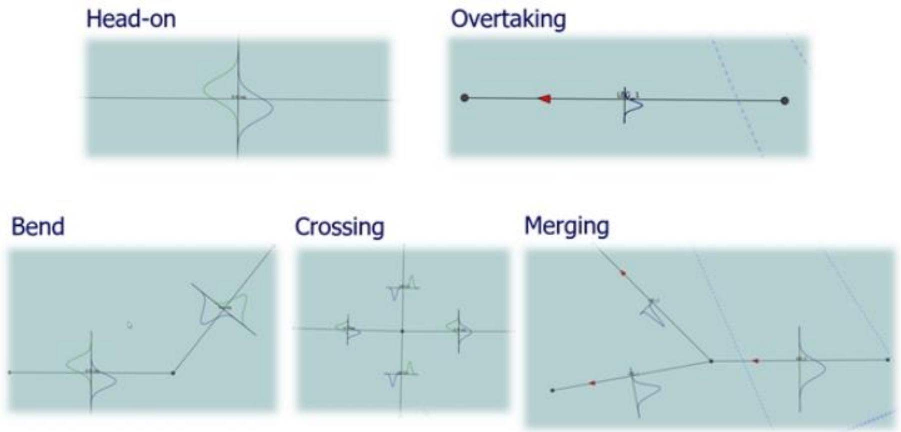

Figure 5-1: The different event types for ship-ship collisions modeled in IWRAP.

Figure 5-2 shows an example of the possibility of a frontal ship collision (head-on). Two statistical distributions describe the possible locations of ships moving in different directions along a route. Based on the ships' width and possible location across the route, the probability that two ships are on a collision course is calculated. If an evasive maneuver is not carried out in such a situation, a collision will occur. IWRAP includes causation factors to describe the likelihood that evasive maneuvers will not be performed correctly. Further details of the calculations performed in IWRAP are described in the tool's manual in ref. /9/.

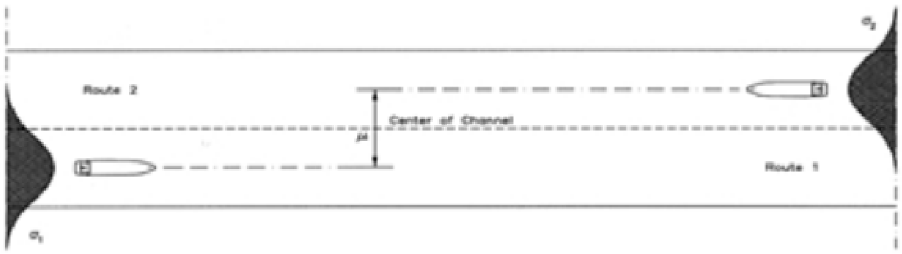

Figure 5-2: Example of the risk of head-on collision.

Head-on ship collisions occur most frequently on routes where the distribution of ship traffic overlaps in both directions, e.g., in narrow corridors. On the other hand, overtaking is more frequent on larger shipping routes, where ships of different sizes sail at different speeds, which gives rise to overtaking and an increased risk of a ship collision. The change in the frequency of head-on ship collisions can, among other things, be affected by the construction of new wind farms. The establishment of new wind farms can contribute to the rerouting of traffic and some routes will experience an increase in traffic. This may contribute to more collisions, especially on routes that pass past or between several wind turbine areas, where the ships sail closely in both directions. Shipping traffic on routes that are narrowed will experience a reduced ability to make evasive maneuvers, or the ability to stop a drifting collision with a wind turbine. Routes that change direction and break can give rise to collisions regardless of the type of shipping traffic. Crossing routes, merging and splitting routes correspondingly increase the risk of ship collisions and are also modeled and included in the calculations in IWRAP.

5.1.1 Area traffic modelling

In addition to the main traffic in the area, there may be additional traffic not following the main routes. This traffic will mainly consist of smaller fishermen and pleasure crafts. There are no restrictions in sailing in-between wind turbines, and hence such traffic will occur. However, explicit modelling of collisions frequencies based on deliberate manoeuvres within a wind farm area cannot be reliably performed. Moreover, many fishing activities using trailing gear are assumed to be difficult within a wind farm area and hence the fishing activities are in general assumed to move outside the areas. Finally, the most critical collision scenarios are related to larger vessels, and hence the ship traffic following the more well-defined routes in the area. Specific modelling of area traffic is therefore neglected, and the impacts on fishermen and pleasure crafts are separately assessed.

5.1.2 Drifting

In the event of a vessel losing the ability to propel itself it will begin to drift. The direction and speed of this drifting is dictated by a drifting rose, and the drifting rose is ideally a mix of currents and winds in the area. With the main ship traffic located west of the wind farms, and prevailing western winds, it is assumed that the drift directions are governed by the prevailing wind. The wind rose is taken from DMIs database /8/ and is shown in the Appendix 1 where also the drift parameters of IWRAP are presented.

5.1.3 Bathymetry

A final model parameter considered is the local bathymetry as observed in the sea chart, Figure 2-2. From here it is relevant to model the 10 m depth curve and the shoreline to include the risk for groundings. Lastly a -35 m depth curve is added to model the general water depth in the area and thereby allow the IWRAP model to include the probability for emergency anchoring in case of black out and uncontrolled drifting.

5.2 Traffic model anno 2021 before Vesterhav Syd and Vesterhav Nord

The traffic in the area is defined by a series of north-south and east-west going legs, see Figure 5-3. The detailed ship traffic as identified from the AIS data is extracted to each route leg, and the ship traffic following the legs is in the figure represented by blue and green histograms showing the ship traffic in each direction. Each circle in the plot indicates a “waypoint” where two or more route legs intersect, merge, or split. The network of route legs therefore represents ship traffic on all routes as well as intersecting points.

The route network is in line with the area being navigated by vessels going 1) from/to the southern North Sea east of Rotterdam or Bremen and sail into/from Skagerrak and 2) vessels going to and from the harbours situated at the fjord openings along the west coast of Jutland. Thus, the traffic has several crossings, but the open sea with no traffic regulations or guiding allows for the traffic to follow near straight lines as also remarked in the preliminary study /2/. Bends and turns are therefore limited.

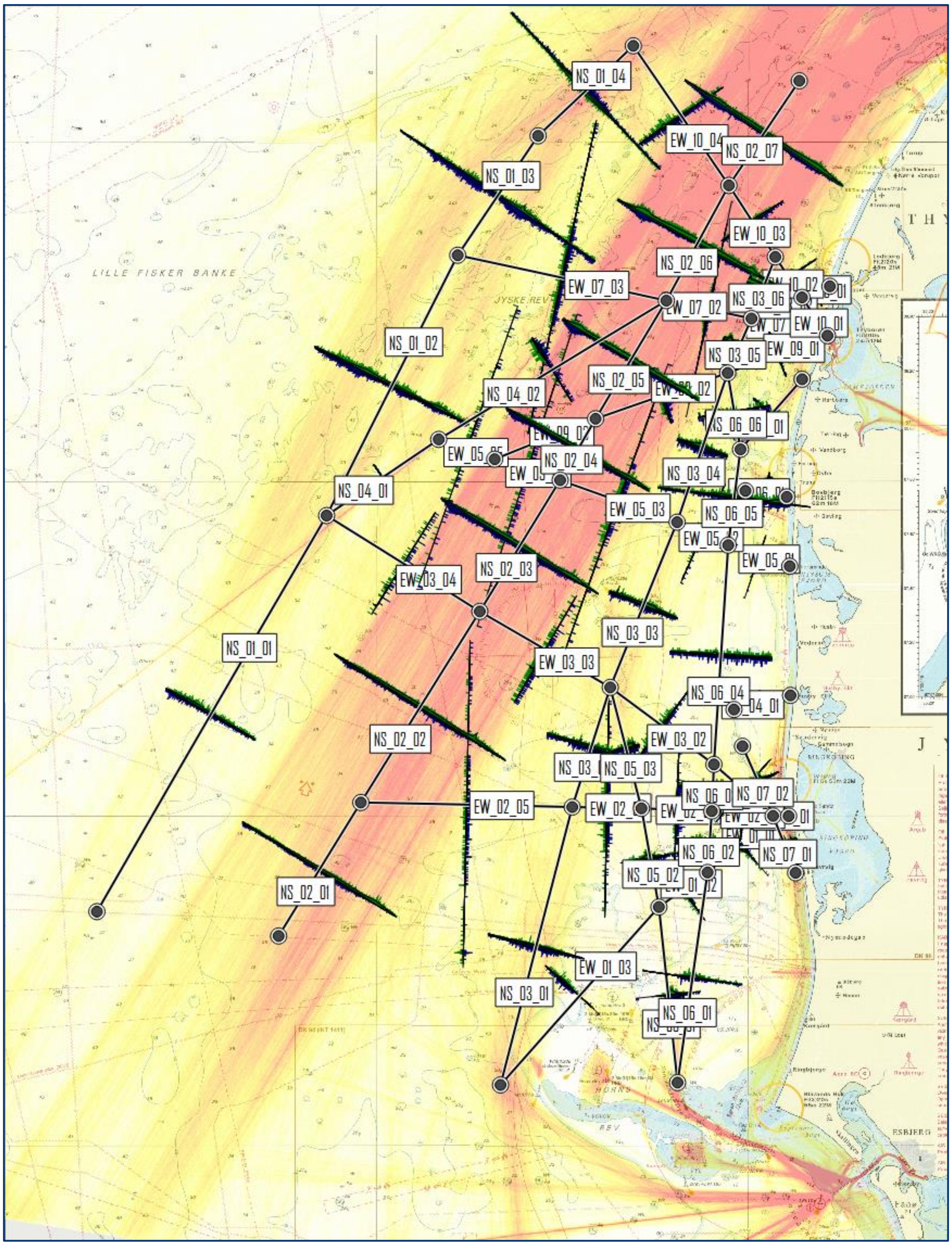

Figure 5-3: Traffic model based only on AIS data.

5.3 Basis scenario traffic model

The OWFs Vesterhav Nord (VHN) and Vesterhav Syd (VHS) are expected to become operational ultimo 2023 /6/. This will cause the ship traffic in the interest area to change and adapt relative to today, as the traffic needs to navigate around VHN and VHS. Relative to Figure 5-3, the new traffic is expected to be as shown in Figure 5-4. The related changes made to the traffic are outlined in the following subsections.

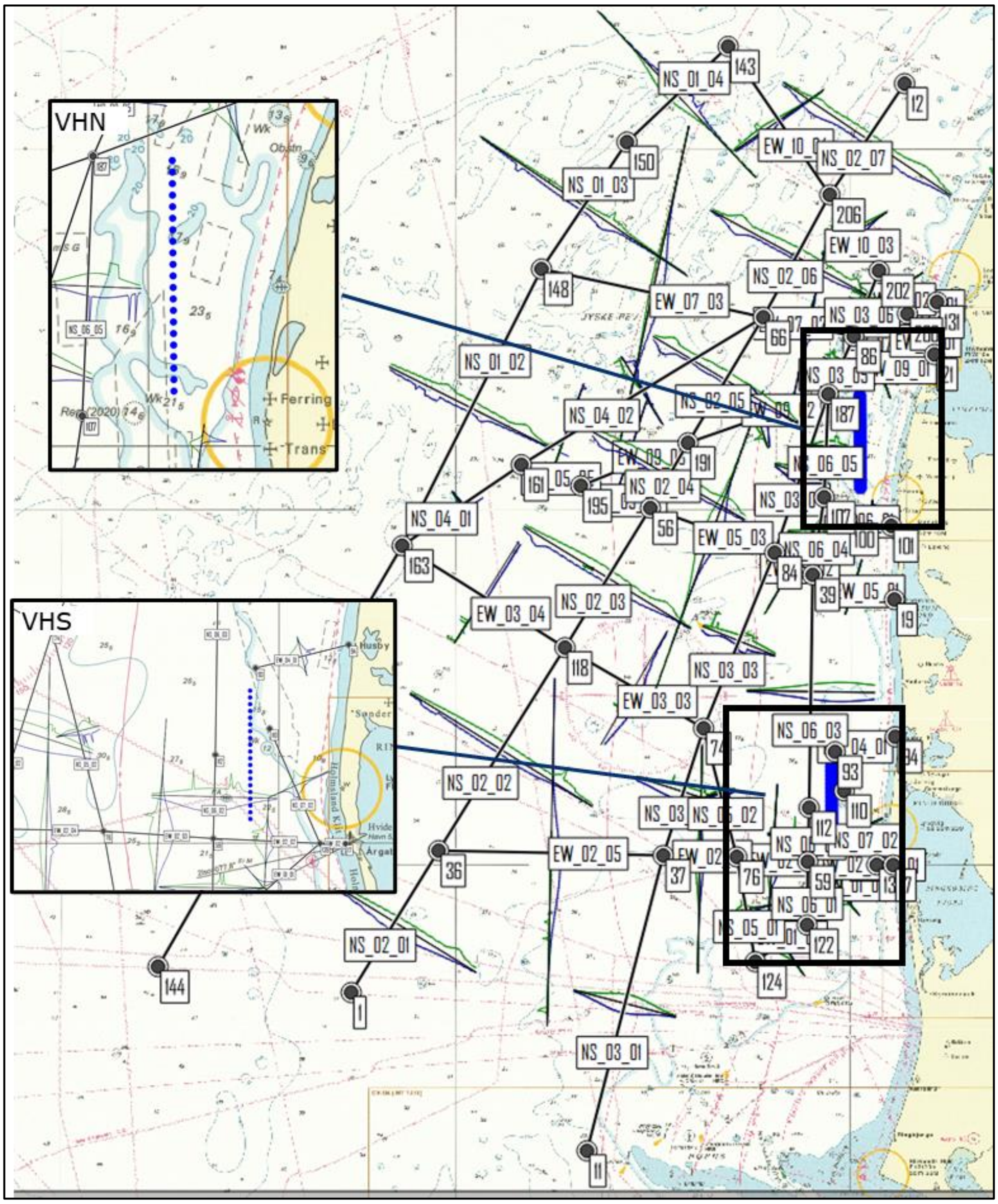

Figure 5-4: Traffic model based on AIS data and the presence of the OWFs Vesterhav Nord and Vesterhav Syd. Inserts are zoom in's on the areas near VHN and VHS respectively.

There are two changes due to VHS and VHN compared to the currently observed ship traffic. These are outlined below.

VHN: Traffic leg EW_11_01 removed:

At the shore-side of VHN dredging operations are observed to follow a well-defined route, defined as traffic leg EW_11_01 in Figure 5-5, will cross through VHN. However, in the future a dredger will not be allowed to use this route why the traffic on leg EW_11_01 is removed in the basis scenario. Further, waypoint 107 can be removed and traffic leg NS_06_06 becomes NS_06_05, which will now end in waypoint 187.

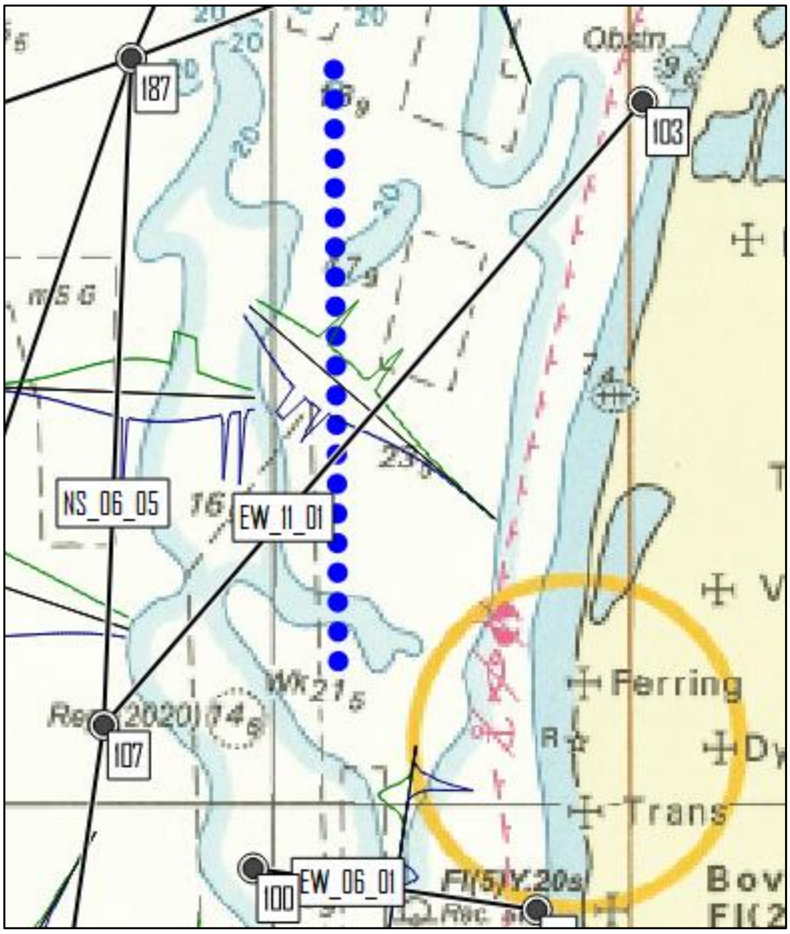

Figure 5-5: Traffic Leg EW_11_01 that cross through VHN shown with blue dots. Waypoints 103, 107, and 187 are also shown as are traffic legs NS_06_05 and NS_06_06.

<u>VHS: EW_03_01 and EW_03_02 moved to EW_02_02, EW_02_03 and NS_05_03:</u>
The traffic today observed to enter or exit Hvide Sande port in north-west direction is described by traffic leg EW_03_01 and EW_03_02 that go between waypoints 139, 112, and 74. See Figure 5-6. The traffic consists mostly of fishers. In the future the fishers will most likely change their route to go south around VHS, hence they will use traffic legs EW_02_02, EW_02_03 and NS_05_03, between waypoints 139, 59, 76, and 74. Hereby the following traffic movements are made:

1	EW_03_01	North/west	→	EW_02_02	North/west
2	EW_03_01	South/east	→	EW_02_02	South/east
3	EW_03_01	North/west	→	EW_02_03	North/west
4	EW_03_01	South/east	→	EW_02_03	South/east
5	EW_03_01	North/west	→	NS_05_03	North/west
6	EW_03_01	South/east	→	EW_05_03	South/east

Further, the traffic on the following legs is removed:

1	EW_03_01	North/west
2	EW_03_01	South/east
3	EW_03_02	North/west
4	EW_03_02	South/east

Traffic on route NS_06_02 must adapt to the VHS to avoid collisions. Therefore, traffic is expected to move westward relative to today. In principle, the traffic observed is wide why a split in the traffic could also be the result. However, with Thor OWF being northwest of VHS, it is conservatively assumed the all the traffic goes west around VHS.

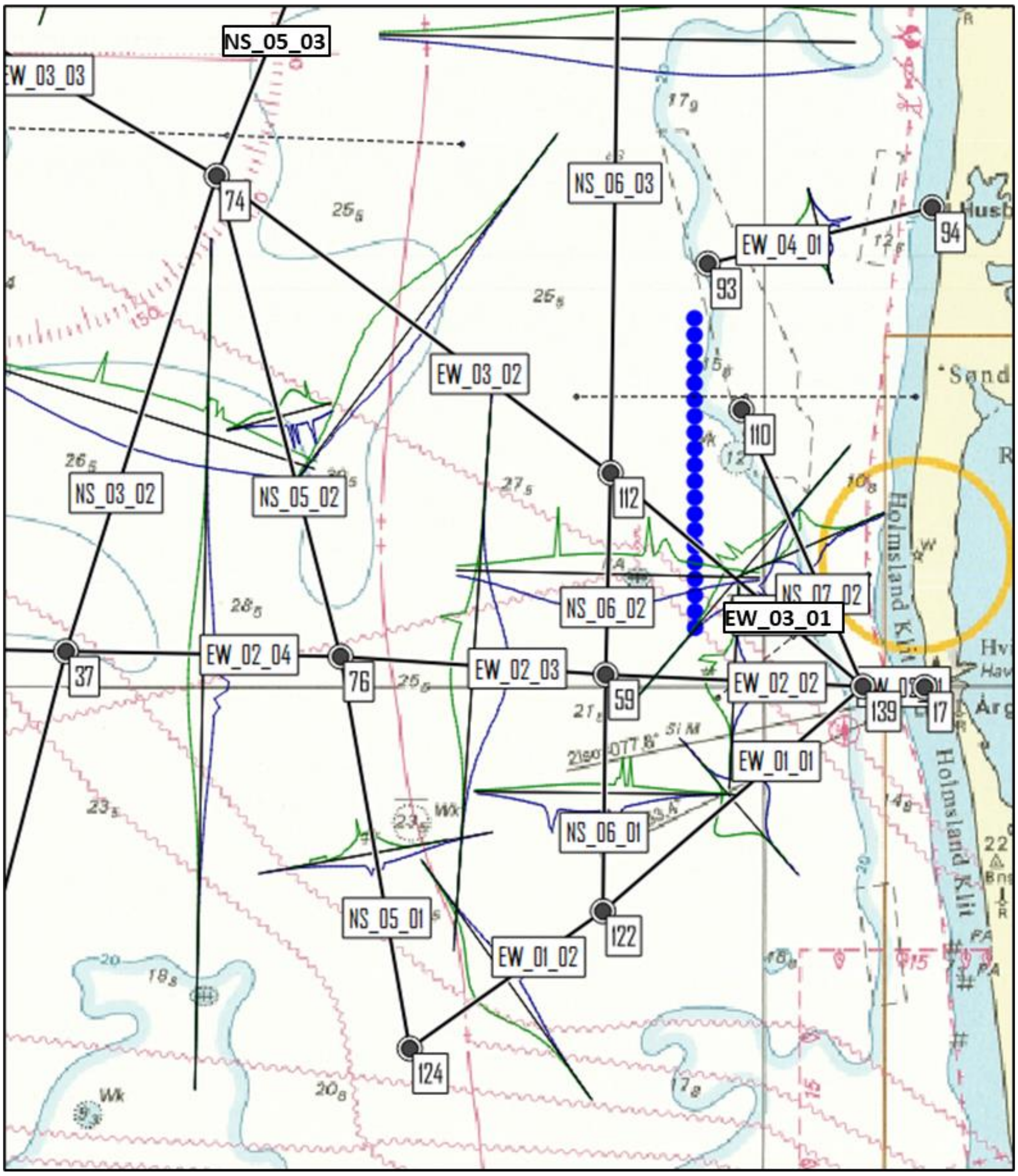

Figure 5-6: Traffic Leg EW_03_01 that crosses through VHS and continues EW_03_02. Waypoints 59, 74, 76, 112, and 139 are also shown, as are traffic legs NS_05_03, EW_02_01, EW_02_02, EW_02_03. The wind turbines of VHS are shown by blue circles.

5.4 Basis Scenario Frequency modelling

The frequency modelling was done with IWRAP MK2 extended 64bit version 6.4.1 and with IALA defined causation factors, see appendix for specific values or visit the IWRAP manual for details about how IWRAP models incident frequencies /9/.

The overall results of the frequency modelling are shown in Table 5-1 with years between incidents and the corresponding yearly frequency, which allow for comparison with the DMA construction works at sea schema shown in Figure 1-2.

Table 5-1: Overall frequency modelling results of basis scenario

	Years between incidents	Frequency (yr^{-1})
Powered Grounding	131.7	7.59E-03
Drifting Grounding	34.35	2.91E-02
Total Groundings	**27.25**	**3.67E-02**
Powered Allision	3275	3.05E-04
Drifting Allision	10590	9.44E-05
Total Allisions	**2501**	**4.00E-04**
Overtaking	436.4	2.29E-03
Head On	142.7	7.01E-03
Crossing	325.6	3.07E-03
Merging	23600	4.24E-05
Bend	1985	5.04E-04
Total Collisions	**77.43**	**1.29E-02**

For groundings, the estimated return period is around 27 years between incidents. For allisions, i.e., collisions between ship and obstacles, the return period is about 2500 years, while total ship-ship collisions are about once every 77 years.

Given the frequencies of Table 5-1 a frequency index relative to DMA Construction works at sea is given for each incident type and the score can be seen below in Table 5-2.

5.5 Consequences

Based on the Construction works at sea schema from DMA we here qualitatively judge the consequence and find the risk index. The overall judgement is given in Table 5-2.

5.5.1 Powered groundings

Most, 80 %, of powered groundings are due to vessels using the coastal route NS_06_02 that runs north south between VHS and VHN. Traffic here is observed to be widely distributed why some traffic will be close to shore and some of the traffic will be safely outside the coast, several kilometres. The traffic on this route is Route 6 described in section 4.6 and consists primarily of small vessels such as fishers. The lengths are short, below 25 meters. Other traffic observed here do include few cargo vessels, however, these are expected to be safely away from shore thus not causing the actual powered groundings. Thus, the consequence score is assessed to be 0-1.

5.5.2 Drifting groundings

Most drifting groundings, roughly 50 %, are modelled to come from the main routes, Route 1, northern part in the waters west of Thyborøn, where the main traffic comes closest to shore, hence in the event of a drifting ship, this is also the shortest distance to shore. 95% of the vessels, on Route 1, are less than 250 m and the traffic is dominated by cargo vessels, though tankers are also present. The shores and bottom conditions are made up of soft and loose material which reduces the degree of damage due to the grounding and it is assessed that the consequence index is 1-2.

5.5.3 Drifting allisions

When a ship is drifting in can hit a wind turbine, known as a drifting allision. Drifting ships are moving slowly at about 1 kn, so the impact will be slow and probably the ship will be drifting with the side facing in the forward direction. For smaller vessels probably the turbine will simply deflect the vessel or stop it. For very large vessels the consequences can be worse with the turbine being dealt serios damage and potentially needing a replacement. Thus, the consequence index is judged to be between 1 and 3. It is not considered that more than a one wind turbine is hit simultaneously.

5.5.4 Powered allisions

A vessel coming out of course can potentially collide with the wind turbine, so-called powered allisions. Relative to the above case of a drifting allision, the velocities hence impact energies are much higher. Hence, more material damage can be expected from the powered allision relative to the drifting allision, and the consequence index is judged to be 2 to 3.

5.5.5 Ship-ship collisions

The traffic in the area is unregulated why several observed routes are described as distributions with wide lateral dispersions. For instance, Route 1, the main route, is observed to be around 26 km wide independent on direction and it explains why head-on collisions dominates the ship-ship collisions. However, the diversity of the traffic and the large available space means the consequence index is not easily determined, why it is estimated to be 1-4.

5.5.6 Indicative risk index

An indicative risk index is given for each of the collision scenarios. It is assessed that the maximum possible consequence will not occur for all collisions. Indeed, most collisions will not involve the largest possible ships and the most critical damage scenario. Therefore, an average consequence index is assumed in combination with the estimated collision frequencies leading to indicative risk indices as given in Table 5-2 for the basis scenario.

Table 5-2: Assessed risk index in the basis scenario.

Incident	Frequency index	Consequence index	Risk index
Drifting groundings	5	1-2	6
Powered groundings	4	0-1	5
Ship-wind turbine-collision*), drifting	2	1-3	4
Ship-wind turbine-collision*), powered	3	2-3	5
Ship-ship collision	4	1-4	6

*) Incl. transformer station

For construction projects, a risk index value above five is considered an elevated risk that normally would require some form of mitigation to be lowered to an acceptable level, but since this risk index is "as is", the risk level is here primarily used for comparison to the situation with Thor OWF located in the area.

Moreover, we note that the highest contributors to the risk in the area are assessed to be drifting groundings (due to their assessed frequency being high) and ship-ship collisions involving the main ship traffic (due to a combination of frequency of occurrence and a potentially high consequence).

6. THOR SCENARIO

The scenario with Thor OWF located in the area is modelled in this section. Moreover, a comparison with the basis scenario is performed.

6.1 Result of HAZID and comments from the stakeholders

A consultation of the users of the water was conducted in May and June 2020 see /2/. The main risk related concerns addressed the location of the most western turbines close to the main ship traffic, and a concern that ships currently passing through the area of the Thor OWF would need to divert towards west and pass Thor OWF following the main traffic.

The planned location of the turbines does consider that the westernmost corner of the gross area posed a concern for the maritime users. Hence, the layout places the wind turbines nearly in the middle of the pre-investigation area, utilising only a part (220 km²) of the pre-investigation gross area which was 440 km². Further the positioning of the western most turbines follow a near parallel line with the traffic in Route 1, though the single most western turbine may seem exposed when viewed from above, but as revealed by Figure 2-3 it is further away from the traffic corridor compared to the turbines to the north.

The layout is such that a corridor to allow Route 2 to pass the area is not made. Hence traffic on Route 2 must reroute to the main traffic on Route 1 or potentially follow the coastal route, Route 6, whichever causes the least challenges to the shipping liners affected. The need of rerouting ship traffic on Route 2 to follow the main traffic west of the Thor OWF was also addressed in the consultation replies /2/.

Pleasure craft owners request to be informed during the construction and decommissioning phase where safety zones or irregular traffic can be observed in the area.

Danish Fishermen address that a simple layout of the wind turbines would make navigation in the area simpler and suggests coordination with the fishing areas in a future layout of the wind farm.

6.2 Traffic modelling and rerouting

Once Thor OWF is operational, traffic will adjust to navigate around the OWF. Therefore, we anticipate the following idealised changes can be observed post Thor OWF construction. The updated route network is shown in Figure 6-1.

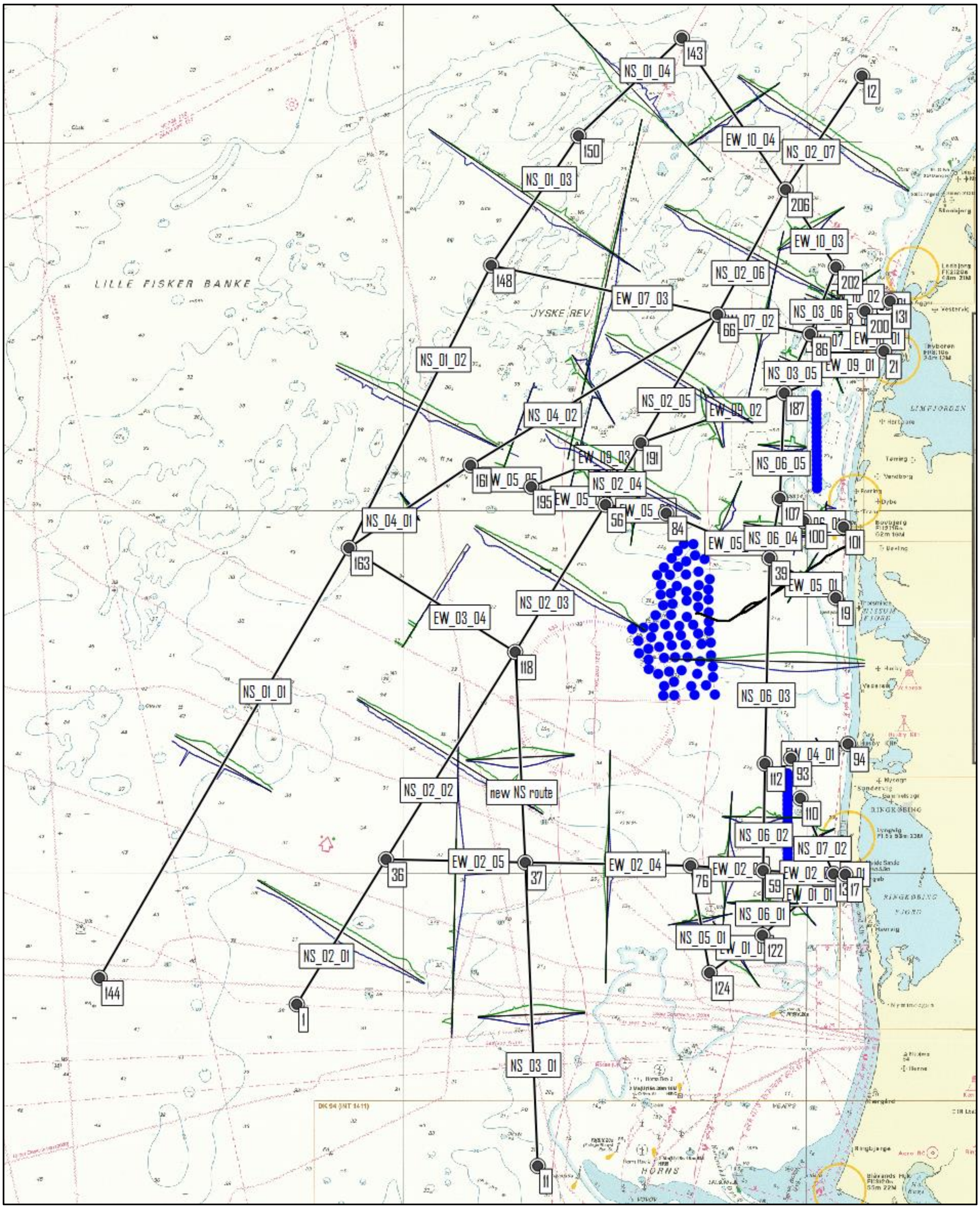

Figure 6-1: Route network as modelled after Thor is placed.

<u>New route to replace NS_03_XX</u>

It will no longer be possible to go via the route NS_03_XX as it traverses through the Thor OWF project area, Figure 6-2. This traffic will most probably go more west to navigate around Thor, hence it will merge with the main traffic route in the area described by legs NS_02_XX at waypoint 118.

The westward movement and merging are modelled by adding a new traffic leg between WP37 and WP118 named “New NS route”. Essentially this leg connects all traffic on NS_03_01 to NS_02_03-07 that runs to the west. Further WP37 is moved westward such that new NS route and NS_03_01 runs parallel and that the crossing of traffic from EW_02_04 and EW_02_05 originating from Hvide Sande port is moved westward.

In consequence of the new NS route, traffic on legs NS_03_02 → NS_03_04 is removed. Finally, traffic on NS_03_05 has its traffic to and from NS_03_04 withdrawn from it.

Another consequence of Thor is to traffic on leg NS_05_02 that used to merge with other traffic in WP74 and move onto leg NS_03_03. With Thor in operation traffic on NS_05_01 will move to the main route on NS_02_xx via legs EW_02_04 and new NS route. With the rerouting of NS_05_01 and NS_05_02, there is no longer traffic on EW_03_03 as this traffic originally originated from Hvide Sande port that moved northwest, i.e., though VHS. Overall, these changes lead to having only occasional traffic in the area south of Thor. This is because the east-west going traffic that could pass just south of Thor to and from Hvide Sande port is blogged by VHS.

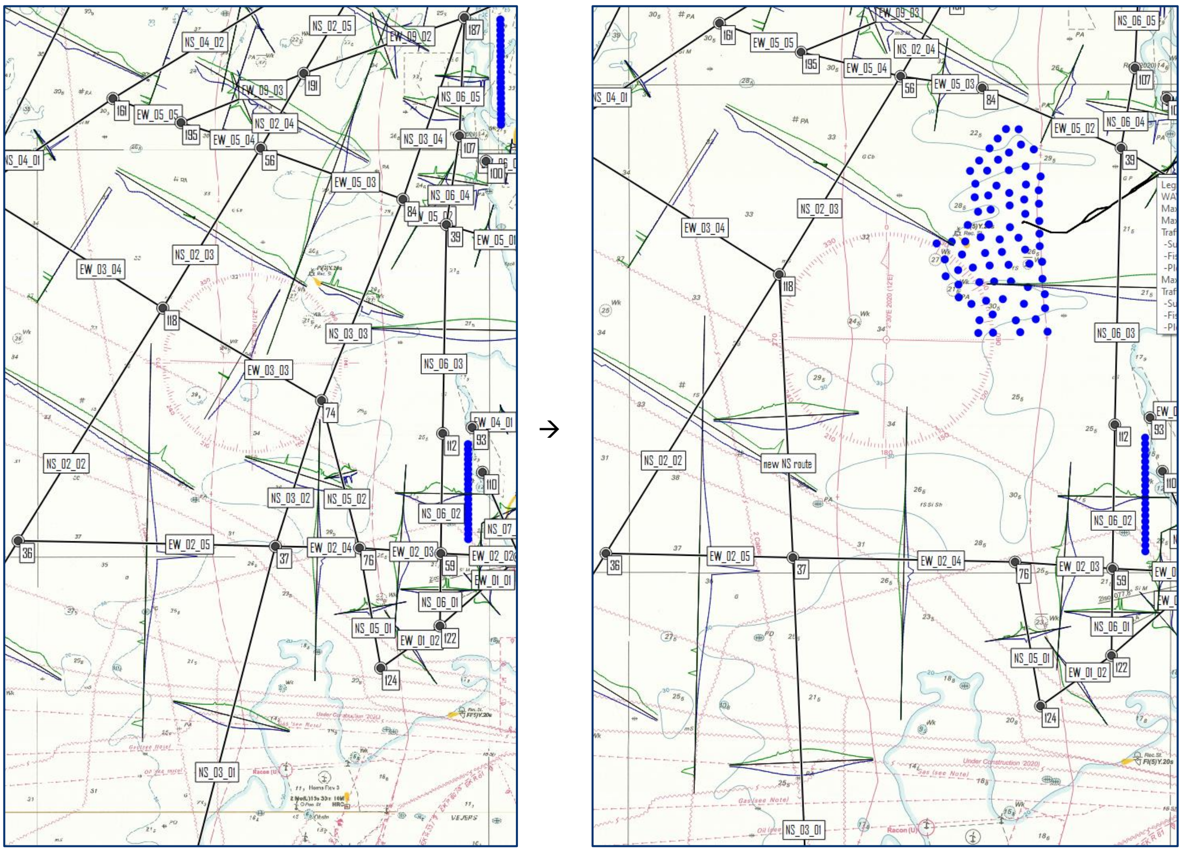

Figure 6-2: Consequence to shipping routes that would pass through or towards Thor. Left: prior to Thor. Right: after Thor is placed.

Traffic on legs EW_05_XX

Just north of Thor OWF traffic legs EW_05_XX describes traffic to and from Thorsminde port, see Figure 6-3. With Thor in operation this traffic must move northward to navigate around Thor and the traffic concentration will move northward relative to pre-Thor traffic. Overall, this is modelled by moving the WPs 39 and 84 westward and a little northward.

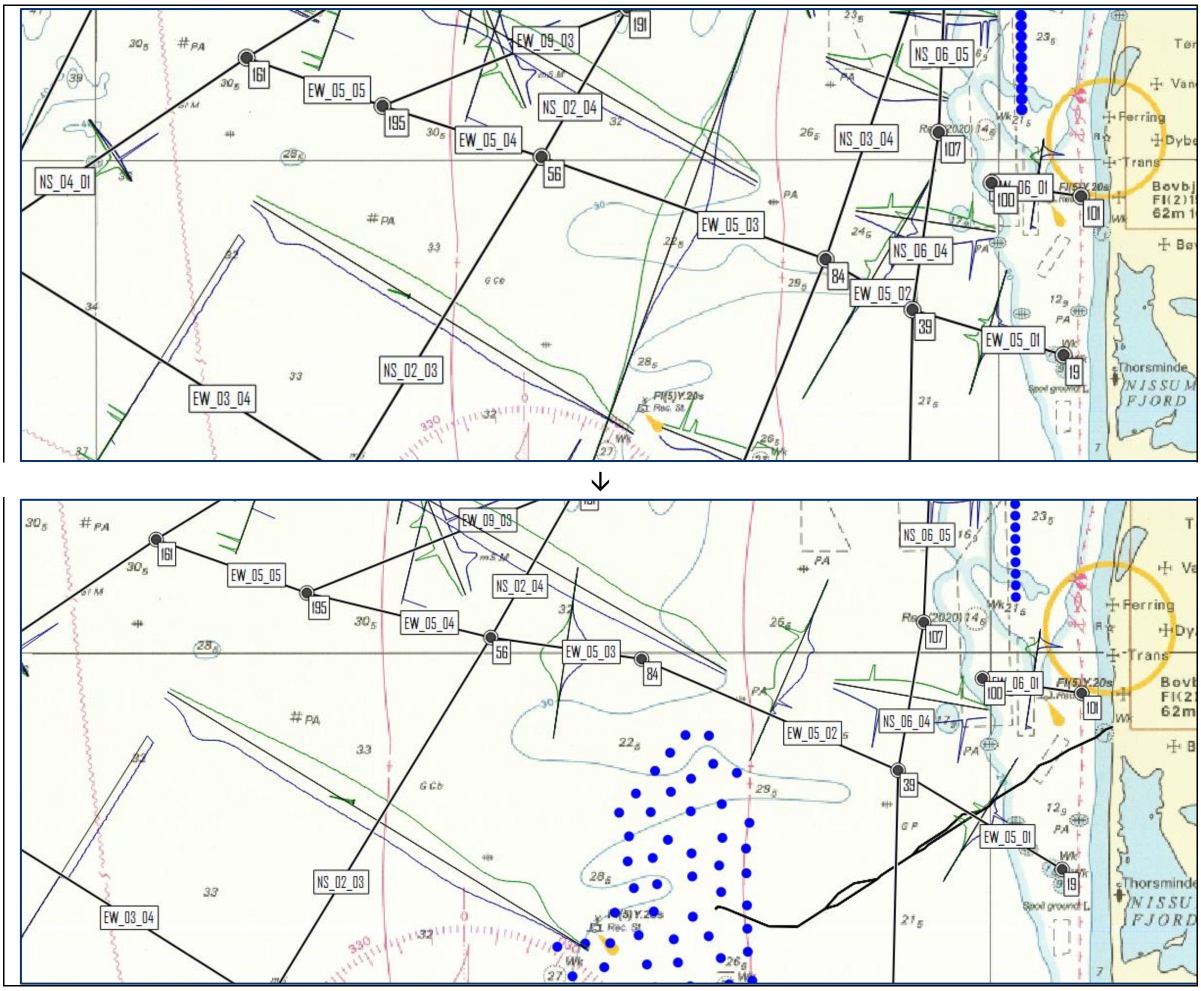

Figure 6-3: Changes to shipping routes north of Thor. Top: prior to Thor. Bottom: after Thor is placed.

<u>Adjustment of legs NS_02_03</u>

With Thor in operation, traffic moving on the main route, described by legs NS_02_XX will adjust their course to pass Thor at a safe distance, hence overall the traffic will concentrate slightly and probably not move much westward but be more concentrated as it passes the western side of Thor.

6.3 Frequency modelling in operational phase

Besides traffic rerouting the frequency modelling is performed with the exact same settings as in the Basis scenario described in chapter 5, and the result of the model is shown in Table 6-1.

Table 6-1: Overall frequency modelling results of scenario with Thor OWF in operation

	Years between incidents	Frequency (yr^{-1})
Powered Grounding	124.2	8.05E-03
Drifting Grounding	35.64	2.81E-02
Total Groundings	**27.69**	**3.61E-02**
Powered Allision	721.2	1.39E-03
Drifting Allision	12410	8.06E-05
Total Allisions	**681.6**	**1.47E-03**
Overtaking	415.5	2.41E-03
Head On	121.7	8.22E-03
Crossing	385.8	2.59E-03
Merging	17550	5.70E-05
Bend	1171	8.54E-04
Total Collisions	**70.8**	**1.41E-02**

Overall, the scenario with Thor in operation yields more collisions and groundings, but they are still comparable to the basis scenario and do not indicate much higher frequencies. For allisions however, there is a relatively large increase from an incident every 2500 years in the basis scenario to one incident every 680 years, equal to a frequency increase of a factor 3.7. But the total allision frequency is still small, i.e., about a decade smaller than the estimated frequencies for groundings and ship-ship collisions.

The primary contributing routes to powered and drifting allisions are shown in Table 6-2.

Table 6-2: Top 6 routes contributing to powered(left) and drifting allisions (right).

Route	Powered Allisions (%)
NS_02_03	55
NS_02_04	23
NS_06_03	8
NS_06_02	5
NS_02_05	4
NS_06_05	3
Total	**98**

Route	Drifting Allision (%)
NS_06_02	24
New NS route	13
EW_07_01	10
EW_07_02	9
EW_09_01	6
EW_02_02	5
Total	**67**

Powered allisions are dominated by the two routes NS_02_03 and NS_02_04, making up 78% of the total powered allisions. 98% of all powered allisions are found to come from the six routes in Table 6-1 and these are the main shipping routes in the area and is a result of Thor being in operation.

Drifting allisions is more equally distributed among the routes except for NS_06_02 which contributes with about a quarter of all drifting allisions. NS_06_02 is the route that passes up along VHS.

6.4 Comparison of scenarios

The overall change in incident frequencies between the basis and Thor scenario is shown with Table 6-3 where the right-most column gives the relative change from the basis scenario to the Thor scenario. A positive percentage means the frequency has increased, hence there are fewer years between incidents while negative percentages indicates that the frequency has decreased, hence there are more years between incidents.

Table 6-3: Comparison of the incident frequencies between the two scenarios.

	Years between incidents		
Incident type	**Basis Scenario**	**Thor Operational**	**Change in %**
Powered Grounding	131.7	124.2	6%
Drifting Grounding	34.35	35.64	-4%
Total Groundings	**27.25**	**27.69**	**-2%**
Powered Allision	3275	721.2	78%
Drifting Allision	10590	12410	-17%
Total Allisions	**2501**	**681.6**	**73%**
Overtaking	436.4	415.5	5%
Head On	142.7	121.7	15%
Crossing	325.6	385.8	-18%
Merging	23600	17550	26%
Bend	1985	1171	41%
Total Collisions	**77.43**	**70.8**	**9%**

6.4.1 Groundings

The total groundings frequency is decreased by 2%. The groundings are difficult to model with IWRAP due to dredging activity that takes place close to shore using dredger vessels that are designed to operate at small water depth and close to shore thus most probably the total groundings frequencies in both scenarios are overestimated. The overall reduction in grounding frequency is caused by some ship traffic moving further away from the coastline to pass west of Thor OWF.

6.4.2 Allisions

Allisions are the incident type that yields the highest change between the two scenarios. The change is due to the increased powered allisions frequency which is at 1/3275 years in the basis scenario and 1/721.2 years in the Thor scenario. This is explained by constructing the Thor OWF east of the main route of ship traffic in the area and is hence an expected result of placing additional offshore obstacles. The frequency for drifting allisions is reduced. This is due to some ship traffic being relocated to pass west of Thor OWF and hence no longer passing close to VHS and VHN where most drifting allisions are estimated to occur.

6.4.3 Collisions

A consequence of the rerouting of traffic has been to remove routes that would cross each other, and it is also observed that the frequency of collisions due to crossings are decreased by 18 %.

On the other hand, removing the crossing routes means that more bends must be made by each vessel, as well as more traffic being merged, which again increases the traffic intensity per area, hereby also increasing the number of overtaking and meetings from opposite sailing vessels. Combined, the number of incidents during overtaking, meetings (head on collisions), merging and bends increases. The total number of collision incidents is estimated to increase by 9 %.

6.5 Consequences

Again, the consequences of each incident type are evaluated using the DMA CWAS schema.

6.5.1 Powered groundings

There is neglectable changes from the basis scenario to the Thor scenario. The route NS_06_02 still contribute almost 80 % of powered groundings. Thus, the consequence index is unchanged at 0-1.

6.5.2 Drifting groundings

Like for powered groundings drifting groundings display the same behaviour. Thus, the consequence index is unchanged at 1-2.

6.5.3 Drifting allisions

Although the presence of Thor OWF overall increases the allisions frequency, the increase is almost entirely due to powered allisions. Thus, the consequence index is unchanged and remain to be between 1 and 3. It is not considered that more than a one wind turbine is hit per incident.

6.5.4 Powered allision

Powered allisions are the incident type with the largest change. However, the change is not so dramatic that it increases the frequency index nor is the consequences different.

6.5.5 Ship-ship collisions

The change in in ship-ship collisions from rerouting traffic increases the frequency a little but the consequence of an incident is the same and is 1-4.

6.5.6 Indicative risk index

The reasoning in evaluating the risk index is the same as for the basis scenario, see sect. 5.5.6. Between the two scenarios only the frequency index is changing, since the same type of incidents can be expected between the two scenarios, i.e., the consequences are the same. It was shown that the overall frequency is not changing significantly between the basis and Thor scenario and the frequency index remains the same. The powered allisions experienced the largest increase in frequency but not enough to offset the qualitative evaluation of the frequency index. A more subtle change of relevance between the basis and Thor scenario, not revealed in the index' in Table 6-4, is that the collision frequency was largest on VHN in the basis scenario and now it is largest to Thor OWF in the Thor scenario. This is again due to the rerouting between the two scenarios.

Table 6-4: Assessed risk index in the Thor scenario.

Incident	Frequency index	Consequence index	Risk index
Drifting groundings	5	1-2	6
Powered groundings	4	0-1	5
Drifting allisions*)	2	1-3	4
Powered allisions *)	3	2-3	5
Ship-ship collision	4	1-4	6

*) Incl. transformer station

6.6 Yearly maintenance traffic

With Thor OWF in operation, continued maintenance will also take place and generate some additional ship traffic to and from the OWF from nearby ports. Maintenance activities will be from a crew transfer vessel (CTV) vessel permanently stationed in Thorsminde port. During a yearly service period a SOV will visit each turbine for service and maintenance. Inspection of the substation, cables, and underwater inspections are also necessary. The anticipated traffic to and from the OWF is expected to be limited and not pose a detectable impact to the overall risk index of the area.

When operating outside the wind farm, the maintenance vessels are assumed to follow ordinary traffic and comply with COLREGS of the IMO /13/ with respect to navigating in waters with other vessels.

6.7 Construction and decommissioning phase

The construction of the OWF will make use of various construction vessels like SOV, jack-ups and CTV etc. A vessel fleet like for the construction phase is assumed to also be representative to the decommissioning phase.

To reduce the risk during construction and decommissioning, it is anticipated that safety zones are laid out, and that all offshore work areas are marked with Aids to Navigation (AtoN), which includes all types of objects physical or digital to mark work areas and aid the ships in the area to navigate safely through the area. Measures in place, communication and other activities must be in accordance with DMA to ensure that all vessels in the area are informed.

Collision frequencies and consequences, hence the risk, is not quantified during the construction and decommissioning phase. It is expected that construction vessels will follow the overall ship traffic pattern while in transit to and from between the offshore work area, and that they will act according to COLREGS when interacting with the normal ship traffic.

Overall, the risk from collisions between a third-party vessel and a construction vessel is assessed to be like ship-ship collisions and allisions of the operational phase.

6.8 Other risks

The above frequency analysis and risk assessment is primarily involving the commercial ship traffic. But there are other relevant aspects related to the navigational safety that qualitatively are assessed below.

6.8.1 Subsea cables

The anticipated alignment of the subsea cable from Thor OWF to shore is shown in Figure 3-1 together with the ship traffic intensity for 2021.
During the construction phase there will be subsea cable works to connect the substation with the transformer station on land. With the limited traffic up along the coast, Route 6, there will also be limited influence on the ship traffic from the construction works. But the traffic on Route 6 must cross the cable laying vessel, which is slow moving and with restricted manoeuvrability during cable operations, hence it is exposed for collision without the possibility to act in case of close encounters. A series of mitigating actions can be put in place to avoid collisions. First is to apply the DMA CWAS schema as part of planning and initiation of the constructions works and continue the planning of risk mitigations in dialog with DMA. Mitigations includes reporting to Notifications to Mariners about the constructions works, use of safety zones around the cable laying vessel, relevant navigational markings, lights on the construction's vessels, and potentially use of guard vessels.

During the operational phase the subsea cables will be at or below the bottom surface. The cable will be marked on a sea chart and a 200 m zone with bottom trawl and anchoring activities forbidden. The following hazards may still pose a danger to the subsea cable integrity:

- Lost object such as anchors or trawl equipment
- Anchors dragged along the ocean floor
- Sinking or grounding ships
- Fishing activity

Only a limited amount of traffic is using Route 6, and the subsea cable is judged to not be at significant risk of damages from ship traffic.

6.8.2 Fishing

Fishing activity might be affected by the Thor OWF.

During construction and decommissioning access restricted zones will surround the Thor OWF to avoid unauthorised trespassing of the area from e.g., fishers, pleasure crafts, or other crafts. Markings and communication of the construction and decommissioning must be coordinated between relevant authorities, contractors, and relevant harbours and sailing unions and clubs etc.

Within 200 m distance from the subsea cable there will be a restriction to use bottom trawl. Inside the OWF between the wind turbines there are no restrictions. Activities with pelagic equipment will however in principle be impossible to do within the OWF area.

It is Rambøll's experience that fishing activities may be undertaken inside an OWF if there is sufficient space between the wind turbines as the foundations may form the basis for new habitats for different species making the area relevant for fishers. However, fishing activities with extended trawling gear will probably be difficult or impossible between the turbines.

In consequence it can be anticipated that some types of fishers, even commercial ones, will enter the area for fishing purposes or follow the OWFs rim for fishing purposes.

6.8.3 Pleasure crafts

As mentioned, the area is marked as restricted during construction and decommissioning to avoid unauthorised trespassing of the area. The distance from shore and the work itself is believed to not cause an elevated risk to navigators in the area.

During operation the OWF will allow navigators incl. pleasure crafts to pass through the OWF area. With more than 1000 m between turbines this should allow for most pleasure crafts to navigate through. Even though the OWF is some 22 km offshore, it must be considered a potential attraction for pleasure crafts though it is not believed to be significant.

Vessels passing close by the wind turbines can collide with the turbine foundation, and if the vessel is high enough above the water surface, it can get hit by the tip of a blade. Therefore, the free space from at highest astronomical tide (HAT) must be at least 20 m according to the DMA. Further it is required by DMA that the foundation is constructed to minimize damage to a vessel in a collision. The currently proposed turbines have a tip clearance of 25-30 m, which is above the DMA tip clearance minimum requirement. Moreover, the proposed monopile foundations are assessed to fulfill the requirement to be "collision friendly."

The distance from shore and the space between the wind turbines and the construction of each turbine is therefore assessed to not significantly affect the pleasure crafts in the area.

6.8.4 SAR-operations

Per default the OWF area is not restricted and sailing between the wind turbines is permitted. There is more than 1000 m between each wind turbine, thus there will be sufficient space to perform search and rescue operations within the OWF area if relevant. It is also possible to navigate through the area during emergencies where the shortest route is through the park. It is also relevant to mention that the Joint Defence Command evaluated the impact of Thor OWF on the Thorsminde rescue station's function and activities as none to little impact as part of the consultation and HAZID process /2/.

6.9 Cumulative projects

The maritime spatial planning of Denmark has reserved large areas to investigate or construct renewable energy. Thus, it can be expected that in the future more offshore wind farms will be constructed close to Thor OWF. Especially since Thor is not taking up all space and only makes up a small fraction of the total area reserved for renewable energy, as is evident from the Danish Maritime Spatial Planning and reproduced in Figure 6-4. Here the red curve shows the overall project area of Thor OWF with related cable corridor as the black dashed lines. The orange and yellow areas are regions or development zones reserved for future renewable energy production and energy islands. One particular project to potentially affect the ship traffic or generate new traffic in the area is the North Sea Energy Island /11/ expected to be placed 50 km west of Thorsminde. Relative to Thor OWF which is just on the other side of the ship traffic corridor that runs up along the western rim of Thor. Thereby potentially creating a narrowing of the traffic flow as the traffic must pass in between Thor OWF and the Energy Island. However, the corridor, which is 10.5 nm wide, is wide enough to allow for traffic to flow. Further Thor OWF is at least 4 km away from the ship traffic corridor leaving sufficient space for the ship traffic to pass.

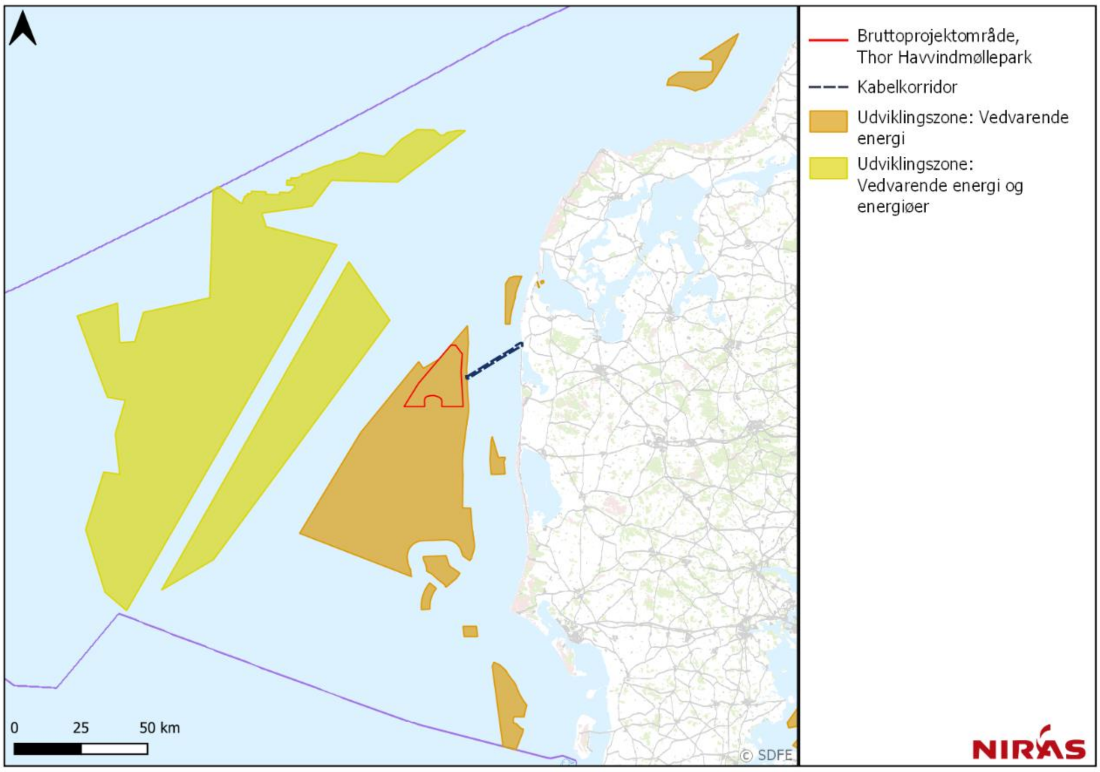

Figure 6-4: Danish Maritime Spatial Planning in the region around Thor OWF. Source: Niras.

If the ship traffic west of Thor is narrowed into a smaller region than today, there are measures to make sure the traffic flow continues with a minimum of congestions. One is a new navigational marking for the traffic in the area. This could be an AIS buoy west of Hanstholm and another one west of Esbjerg such that north and south going traffic is somewhat separated as they pass between Thor and the Energy Island. Potentially also an AIS buoy between Thor and the Energy Island in the middle of the ship traffic corridor could separate the traffic sufficiently to avoid congestion and lower the head-on ship-ship collision frequency.

Finally, the construction activities of Thor OWF will need to coordinate with other activities in the area, for instance sand feeding to the west coast of Jutland.

7. RISK REDUCING MEASURES

Here the risk reducing measures that can be applied during the construction, operation, and decommissioning phase are presented.

7.1 During construction and decommissioning

The primary hazard identified during the construction and decommissioning phase with respect to the navigational safety are due to the interaction of the construction vessels with the third-party ship traffic in the area. The actual routes used by the construction traffic is pending the decision of the work harbour. However, the construction vessels need not cross the main ship traffic on Route 1. Possible mitigations are:

- Work vessels will follow the primary routes in the area when transiting to and from the work area.
- Planning of the project must use the DMA CWAS schema and risk reducing measures must be planned in dialog with DMA.
- All construction works must be communicated via the Notice to Mariners. Additional communication to fishers and potentially also pleasure crafts should be considered.
- For vessels with limited manoeuvrability one or more risk reducing measures must be considered: Safety exclusion zones around the vessel, aids to navigation in the area, lights on the construction vessel, and the use of a guard vessel.
- During the construction phase, the DMA will establish a protective zone of 200 metres on both sides of the subsea export cable, which applies from its publication in Notices to Mariners. In the protective zone, anchoring, dredging, boulder fishing and using dragging gear are prohibited.

7.2 For the design and operation of the Thor OWF

The impact during operations of Thor OWF is more detailed, however, once the construction of Thor OWF commences, many of the changes will need to take place and the traffic situation will thereby have adjusted itself to Thor OWF as it begins its operation. The impacts are:

- Route 1 will adjust its overall distribution westward. Traffic on Route 2 will merge into Route 1 south and north of Thor OWF. Traffic on Route 3 will pass south around VHS and continue out to Route 1, leaving an empty pocket traffic intensity wise south of Thor. Traffic on Route 4 will adjust itself to go north around Thor. Route 5 will be unaffected while Route 6 will narrow itself to pass between VHS, VHN, and Thor.
- The wind turbines will be visible structures and be detectable by radars.
- Sailing in between the wind turbines is allowed. However, it is not assumed that larger vessels will attempt to pass through the area except if strictly necessary, i.e., SAR operations could pass through to save time, why it is also recommended that SAR vessel operators conduct relevant training to be able to navigate inside the OWF area.
- Fishers and pleasure crafts are expected to sail in the area to some extent.
- Vessels in the Route 1 traffic corridor must be aware of the OWF and position themselves to allow for evasive manoeuvres, which has sufficient with space.
- The consequence of collisions or allisions can be catastrophic given the type of vessels that passes Thor on Route 1. This includes material damage, loss of property, injuries or loss of life, and environmental damage from spills.
- In the event of a spill due to collisions or allisions, the consequences can have far reaching effects polluting and damaging the marine habitats and potentially also long segments of the west coast of Jutland. Though a small increase in the frequency of ship-ship collisions and allisions, the current traffic situation already can lead to such events.
- A permanent protective zone around the subsea cable is established by drawing the subsea cable into the sea chart. The protective zone is established in pursuance of order

no. 939 of 27 November 1992 on protection of submarine cables and submarine pipelines (the cable order).

In response to the impact Thor OWF has on the surrounding traffic the follow risk reducing measures are recommended:

- Markings of the OWF on the sea chart, marking of the wind turbines according to the IALA standard for markings at sea, and navigational light on the wind turbines. Further the wind turbine foundations must be designed to minimise damage during collision and an emergency procedure for closing a wind turbine due to a hazardous event must be created.
- It can be considered that the light markings on the wind turbines follow the same standard as VHS and VHN such that they visually appear similar in the area at night.
- Tip clearance of at least 20 m at highest astronomical tide (HAT). The wind turbines are planned to have a tip clearance with respect to mean sea level of 25-30 meters.
- The positions of the up to 72 wind turbines are placed away from the southwestern corner of the initial investigation area hereby limiting the risk of allisions between ship traffic in Route 1 and the westernmost turbines. Further the positions of the turbines are almost along the direction of motion of the ship traffic and near parallel with the ship traffic corridors. These design features help minimise the risk of allision and ship-ship collisions on Route 1.

  The placement of virtual buoys could be used to guide and contain more of the traffic into the ship traffic corridors and potentially separate the two traffic directions on Route 1.

8. CONCLUSIONS AND RECOMMENDATIONS

Overall, it is concluded that the establishment of the Thor OWF and related works is possible while upholding an acceptable level of navigational safety in the area. The frequency modelling shows that Thor OWF will require shipping routes in the area to adjust, so ships can navigate around Thor OWF, and it is also shown that there is an increase in the frequency of incidents in the area due to the presence of Thor OWF. When comparing the basis scenario with the Thor scenario, it is observed that the changes are relatively small and not enough to offset the qualitative assessment of the risk to navigational safety in the area. Moreover, the risk for ship-ship collisions and groundings is still assessed to be larger than the risk for allisions with wind turbines even after establishment of Thor OWF.

Besides the risk reducing measures that can be done in the design of the OWF with markings and lights etc. there are also identified measures to guide the ship traffic in its passing next to the Thor OWF that is worth further investigation. The actuality of such measures increases with increased use of the ocean surface for Energy Islands, OWFs or other uses of the area that challenge the unguided movement of ship traffic.

9. REFERENCES

/1/ Project basis and description from NIRAS

/2/ preliminary navigational safety study from Rambøll

/3/ AIS requirements, Danish Maritime Authority https://www.soefartsstyrelsen.dk/sikkerhed-til-soes/sejladsinformation/ais-data, dato: September 2022.

/4/ Den Danske Havnelods, visited August 2022

/5/ Danish Maritime spatial planning, https://havplan.dk/en/page/info, visited September 2022

/6/ https://dma.dk/safety-at-sea/safety-of-navigation/construction-works-at-sea, visited September 2022

/7/ Press release from Vattenfall concerning Vesterhav Nord and Vesterhav Syd, https://group.vattenfall.com/dk/nyheder-og-presse/nyheder/2022/vattenfall-begynder-at-klargore-havbunden-til-vesterhav-nord-og-syd, visited September 2022.

/8/ Observed Wind Speed and Direction in Denmark- with Climatological Standard Normals, 1961-90, https://www.dmi.dk/fileadmin/user_upload/Rapporter/TR/1999/tr99-13.pdf, visited September 2022

/9/ IWRAP Manual IWRAP Mk2. User manual. Per Engberg, project44. dato: August 2019.

/10/ IALA's wiki site on IRWAP Mk2. https://www.ialaaism.org/wiki/iwrap/index.php/Main_Page

/11/ Danish Energy Agency home page about the North Sea energy island, https://ens.dk/en/our-responsibilities/wind-power/energy-islands/energy-island-north-sea, visited September 2022

/12/ Danish Coastal Authority home, https://kyst.dk/english/coastal-protection-in-denmark/coastal-protection-on-the-west-coast-of-jutland/, visited September 2022

/13/ Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs), imo.org/en/About/Conventions/Pages/COLREG.aspx, visited September 2022

APPENDIX 1
IWRAP FREQUENCY MODEL SETUP

Modeling principles / collision models
The IWRAP tool is used for incident modeling for ship-ship and ship-wind turbine collisions. The method is purely probabilistic, i.e., based on statistics. IWRAP has been part of the IALA risk toolbox, mentioned by IMO SN Circular 296, since 2008.

The IWRAP model considers ship-ship collisions and allisions (ship-object collisions). IWRAP uses a geometric-statistical model in the sense that it considers ship traffic as moving along defined routes with statistical lateral distributions. IWRAP does not model the trajectory of the individual ships. The level of detail in the model input, e.g., bathymetry and the degree of detail in the interpretation of the results, must reflect this. For details on how the IWRAP model works, please refer to the IWRAP User Manual /9/ and to the IALA wiki page on IWRAP /10/. In the following, the settings used in the models are described.

In the model, a geometric calculation is made based on sailing speed and sailing direction, so that the frequency of a human error is scaled in relation to how long time a ship will be heading towards an obstacle, as well as the distance to the obstacle. The result of the modeling is therefore not based on random samples of human error per situation but on a probabilistic combination of all possible scenarios.

Technical errors are errors that lead to situations where the navigator cannot control the ship and thus avoid a potential collision. Basically, engine failure and steering failure are the two main types of technical failure. An engine failure will cause the ship to stop working, and a steering failure will cause the ship to go in circles. Generic frequencies of engine failure and steering failure are based on general statistical data for commercial vessels. The IWRAP tool includes engine failure/drifting ship modeling but does not implement the steering failure.

Causation factors
The causation factors indicate the probability that the officer on duty will not react, for example if the vessel is on a collision course with another vessel, or the vessel is about to run aground.

The causation factors are important to the results as they act as reduction factors on the calculated number of blind navigation collisions. In the specification of the causation factors, consideration should be given to whether navigators exhibit extraordinary awareness; possibly due to two navigators being present on the bridge.

For ferry routes, it is typically the case that the causation factor is lower than average due to the navigators' increased situational awareness and knowledge of the area. Therefore, causation reduction factors are used, e.g., the causation factor divided by the reduction factor of 20 for passenger ships and fast ferries are used as a default setting.

The default values that have been chosen in IWRAP are shown in Table A1 1 below. These settings for the causation factors are mainly rooted in the observations of Fujii and Mizuki (1998).

Table A1 1 IWRAP's standard cause parameters used for modeling ship collisions.

Merging routes	Crossing routes	Bend routes	HeadOn routes	Overtaking at routes	Groundings	Powered wind turbine collisions
1.3E-4	1.3E-4	1.3E-4	0.5E-4	1.1E-4	1.6E-4	1.6E-4

Drifting ships

In Figure A1 1, the operating parameters used are shown. In connection with an engine failure, it is possible that the error is rectified so that the ship can again be maneuverable before it drifts towards an obstacle. The repair time is modeled in IWRAP as a cumulative Weibull distribution. In addition, there will often be the possibility that a drifting ship will be able to drop anchor and thus prevent a collision or grounding. In the area of Thor OWF, the depth varies from 25 m to 30 m, and the probability of successful anchoring in case of engine failure is considered to be the default parameter for IWRAP of 70%. The anchoring parameters are also shown in Figure A1 1.

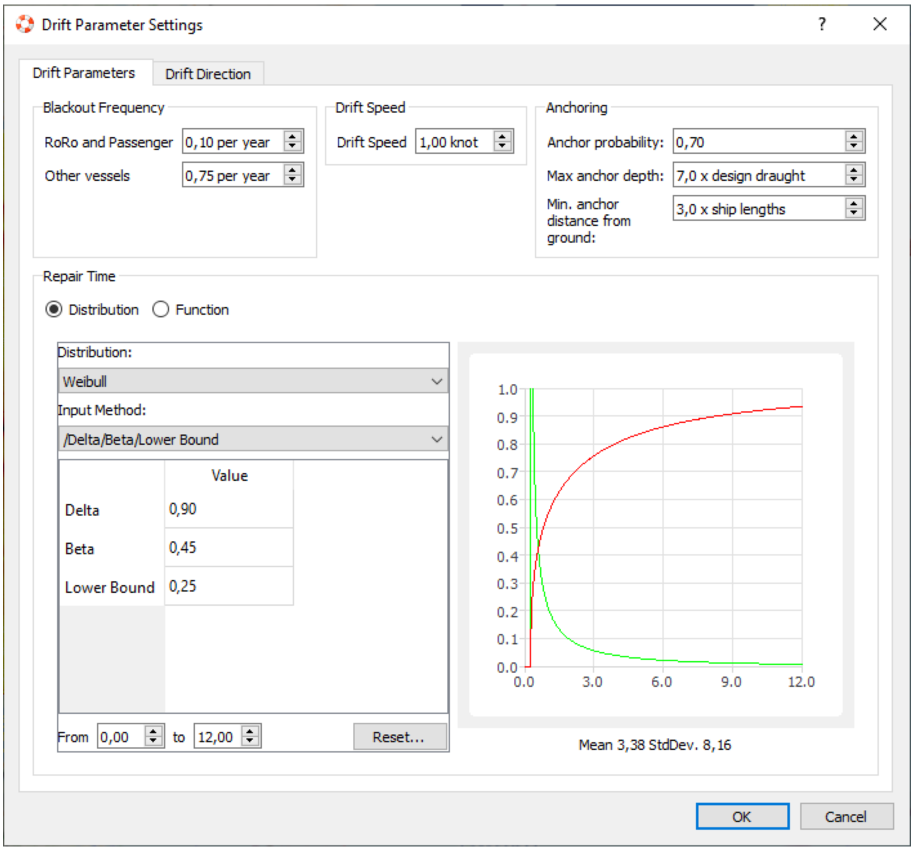

Figure A1 1 Operating parameters and settings for drifting ships where speeds of 1 knot are used.

Passenger ships have a lower blackout frequency than other ships. The relative scaling of the blackout frequency between passenger ships and other vessels is based on the standard scaling in IWRAP.

The probability of drift in each direction is assumed to be given by the distribution of wind directions measured at Thyborøn cf. ref. /8/; see Figure A1 2. In 3.1% of the time there is no wind and thus no direction in which drift is modelled. This is not supported by IWRAP. Here a ship will always drift. This is considered conservative in the model results.

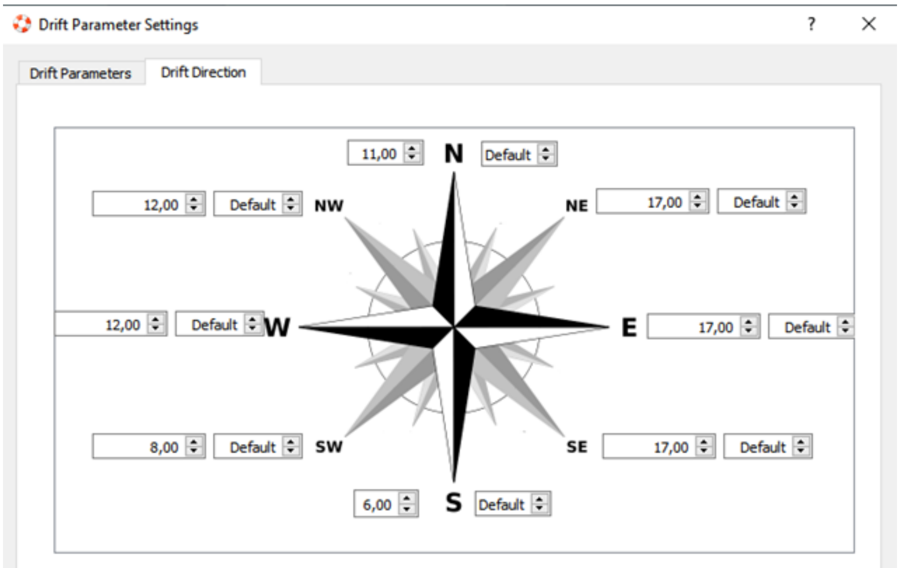

Figure A1 2 Probability of a ship drifting in a given direction, given as a percentage by the wind direction distribution from Thyborøn /8/.

Routes and waypoints

The sailing routes are modeled in IWRAP with routes and waypoints where the ship traffic has crossings. A route is given by a stretch and a width in which the ship traffic is counted. In addition, there is a limit on how far away each route is modelled. Figure A1 3 shows an illustration of a route modeled in IWRAP.

Figure A1 3 Illustration of a route modeled in IWRAP, ref. /9/.

In IWRAP, the routes are used to count ship traffic and the distribution on the route. The modeling in IWRAP therefore only includes ships sailing along each route and omits those sailing across. The maximum difference in the direction of the ship and the route is the default setting of 10 degrees deviation. Figure A1 4 below shows an example where the route has an angle of 80 degrees, in this example the angle is set to 5 degrees so the ship must have a direction between 75 and 85 degrees to be counted as having passed the two green transverse dotted lines.

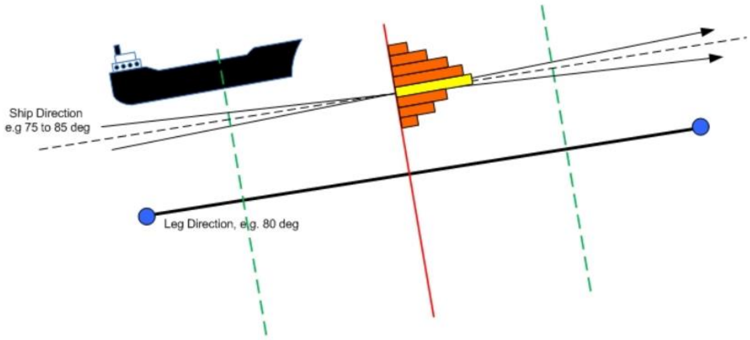

Figure A1 4 Routes and counting of ship traffic as well as distribution on the route.