ENERGINET - MARINE ENVIRONMENTAL STUDIES

Navigational Risk Assessment Kriegers Flak II

Energinet Eltransmission A/S

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Objective:

Environmental engineering consultancy services. The objective of the project is to perform marine environmental studies in order to describe the baseline conditions for offshore wind farms in the areas of Hesselø, Kriegers Flak II (North and South) and Kattegat in the Danish sector. The present report addresses the Navigational Risk Assessment for Kriegers Flak II (North and south) Offshore Wind Farm.

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1 EXECUTIVE SUMMARY

1.1 Conclusions

On the basis of both quantitative study and the HAZID workshop the following conclusions by this study are:

- The construction and operation of the Kriegers Flak II offshore wind farm (KF II OWF) leads to a noticeable increase in the expected number of allisions between ships and wind turbines. This is mainly related to vessels that intend to cross the OWF and may amount up to on average 1 incident per 100 years. For ships that remain within the fairways outside the OWF, the frequency will be a factor of ten lower. Such risk is acceptable if reduced to as low as reasonably practicable. The assessment is based on the OWF scenario with the most Wind Turbine Generators installed (the "overplanting" scenario). The frequency of allisions will be lower for the scenarios with fewer Wind Turbine Generators.
- The construction and operation of the Kriegers Flak II (North and South) offshore wind farms does not lead to a significant larger number of groundings in the area (less than 3%).
- The construction and operation of the Kriegers Flak II offshore wind farm leads to a significant increase in risk of ship/ship collisions, notably on the route from/to TSS "S of Gedser" to/from Trelleborg. Without mitigation this risk is considered unacceptable. Another significant increase in risk is noted east of Møn due to the increased amount and complexity of shipping related to Crew Transfer Vessels servicing the Kriegers Flak II (North and South) offshore wind farms.

1.2 Recommendations

On the basis of the studies, the following risk reducing measures are proposed:

1. Move the South-east corner of KF II OWF North further north so that the regular traffic between TSS "S of Gedser" and Trelleborg does not need to make another course change, and the shortest route for pleasure boats between Møn and Gislövsläge Marina does not cross the OWF and remains parallel with the commercial shipping route to Trelleborg.
2. Consider limiting the extent of the work zone during construction along the boundary on the south-side of the KF II OWF North or at least perform a more detailed analysis of such limitation on navigational safety.
3. Consider implementing work Vessel Coordination , both during the Construction Phase and Operational Phase, to minimize conflicts between work vessels or service vessels (CTVs) sailing out of Klintholm and commercial traffic east of Møn.
4. Consider other means of guidance or separation of ships east of Møn, or at least perform a more detailed analysis of such means on navigational safety, to mitigate the complex pattern of crossing ship movements (both commercial and recreational) and to minimize the risk of ship-ship collision at this position.
5. Ensure emergency response to stop WTGs when a drifting or uncontrolled ship threatens to collide with a OWF structure.
6. Investigate the need to establish additional coast-based Radar stations or AIS base-stations.
7. Consider the use of surveillance vessels to enforce the compliance with the prohibited work areas during the Construction Phase.
8. Exploit all possible communication channels to inform recreational sailors and fishermen about prohibited work areas and other temporary restrictions or arrangements.

9. Consider reserving or assign specific VHF channels for communication between work vessels, service vessels and Work Vessel Coordination.

2 INTRODUCTION

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

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

The area for Kriegers Flak II Offshore Wind Farm (OWF) consists of two sub-areas: North and South. The areas are located 25-50 km off the coast of South Zealand and Møn. Kriegers Flak II North is located approximately 15 km from the east coast of Møn, while Kriegers Flak II South is located approximately 30 km southeast of Møn. The area for the Kriegers Flak II OWF is approximately 175 km2, divided into 99km2 for North and 76km2 for South. The Kriegers Flak II OWF will be connected to land via subsea cables making landfall close to Rødvig on South Zealand.

Energinet has been requested by the Danish Energy Agency to perform a number of preliminary investigations on Kriegers Flak II (North and South) OWF east of Sjælland. As part of the studies, a navigational risk assessment shall be carried out.

This report presents the results of the quantitative navigational risk assessment. Prior to the quantitative analysis, a hazard identification workshop was held in November 2023. The overall approach for the navigational risk assessment follows hereby IMO's (International Maritime Organization) guidelines for evaluation of navigational safety assessment /6/.

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 (DMA, 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 DMA.
- Step 2: If the DMA 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 DMA cannot approve the estimated risk, possible risk reducing measures must be identified, analysed, and adopted if considered feasible. This risk reduction process must continue until the risk reaches an acceptable level. Otherwise, it must 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 Kriegers Flak II North and South, applying the preliminary layout with the largest number of wind turbines, which would lead to the largest risk of allisions.

The HAZID workshop (the HAZID report is attached as Appendix A to this report) is to be considered as an integrated part of this study. The results of the HAZID are transferred into the frequency analysis and addressed in the conclusions. Risk assessments from the HAZID are updated to the extent that this is possible within the frequency analysis.

An issue mentioned during the HAZID workshop is the impact of the wind turbine structures on the radar, both ship-based radar and the coastal Radar stations used for Vessel Traffic Service (VTS). This issue requires a separate assessment and is beyond the scope of this study.

2.1 Objectives

The purpose of the work package on maritime traffic and safety of navigation is to provide a description and mapping of the existing ship traffic in and around the areas of the future KF II OWF and based on this to undertake a navigational safety and risk assessment.

The navigational risk assessment will, to the extent applicable for this study, IMO’s guidelines for Formal Safety Assessment (FSA) /6/, particularly step 1, Identification of hazards and step 2, risk analysis. This will lead to recommendations, including proposals for risk reducing measures as covered by IMO’s FSA step 3, but without full re-analysis or a Cost Benefit Analysis (CBA).

The main questions to be answered by the navigational risk assessment are:

- Does the offshore wind farm (OWF) 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, including additional shipping in relation to construction and operation (maintenance) of the OWF lead to an increased and intolerable number of collisions between ships?

2.2 Limitations

The method to predict the frequency of allisions, collisions and groundings of ships is based on a probabilistic analysis. This is described in more detail in the model description in section 5.1. It shall be pointed out that the different scenarios to be analysed (the condition before establishment of the OWF and the condition after establishment of the OWF) is based on 1) the additional number of obstacles close to the shipping routes (the wind turbines) and 2) the redistribution of traffic routes in terms of number, width (lateral distribution), traffic density and waypoints. The probability of navigators not being able to avoid accidents in potentially hazardous situation is assumed not to be changed in the course of the assessments. But the OWF may have an effect on this probability (e.g. as identified during the HAZID). The probabilistic analysis does not account for these effects, neither positive nor negative. Such ignored effects are, but may not be limited to:

- The effects of the OWF on the situational awareness of navigators (e.g. the possibility of becoming confused or not expecting vessels to sail between the OWF structures).
- The effects of the OWF on the effectiveness of ship-based radar.
- The effect of an extension of, or changes in, coast-based traffic coordination (VTS, Work Vessel Coordination).
- The effect of surveillance ships or warnings issued by work vessels.
- The effect of additional navigational aids (buoys, virtual AIS).
- “Secondary” consequences, e.g. allisions with objects outside narrow fairways after performing evasive action to avoid collision.

As a consequence, this means that the probabilistic analysis cannot demonstrate the effectiveness of certain risk reducing measures, e.g. Work Vessel Coordination. It can only indicate that there may be waypoints (locations where fairways cross each other, merge, or change direction) with an increased risk of collision between crossing traffic, where such coordination may seem beneficial based on a qualitative assessment.

2.3 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.
CTV	Crew Transfer Vessel	Vessels used to transfer service personnel to OWF installations. Most CTV's are classified as High Speed Craft (HSC)
DEA	Danish Energy Agency (Energistyrelsen, ENS)	
DMA	Danish Maritime Authority (Søfartsstyrelsen, SFS)	
EC	Export Cable	
ECC	Export Cable Corridors	
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.
EPA	Environmental Protection Agency (Miljøstyrelsen, MST)	
FOU	Foundation (used to install wind turbine on)	
FSA	Formal Safety Assessment	Methodology for performing risk assessments. Within this report addressing the method following the IMO Guideline /6/
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.
HSC	High Speed Craft	Includes fast ferries and most CTV-s are classified as HSC
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities	
IDW	Inner Danish Waters	The three offshore wind farm projects: Kattegat, Hesselø and Kriegers Flak II (North and South)
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.
KA OWF	Kattegat Offshore Wind Farm	
KF II OWF	Kriegers Flak II Offshore Wind Farm (North and South)	
Landfall	Is where the cable transfers from sea to land	
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.
MSL	Mean Sea Level	

MSP	Marine Spatial Plan (Havplanen)	
NS1	North Sea I	The name of the offshore wind farm area (OWF) including all three subareas and the shipping corridors in between the three subareas
OSS	Offshore substation	Offshore structure (often a platform structure) collecting power connection from the individual wind turbines in an OWF, using a step-up transformer to enable a high voltage export of power to the coast.
OWF	Offshore Wind Farm (Offshore vindmøllepark)	
PA	Pre-investigation area	Gross area for the benthic survey. Within the pre-investigation area are the three wind farm areas (1-3), the three export cable routes (ERC's) and the shipping corridors between the three OFW areas.
Subareas		The wind farm area is subdivided into three subareas 1-3
TSS	Traffic Separation Scheme	A traffic separation scheme is a maritime traffic-management route-system ruled by IMO. It consists of two (outer) lines, two lanes with prescribed (opposite) sailing direction, and a separation zone inbetween.
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. In Danish waters, VTS is provided by the Danish Navy's Surveillance Unit (Søværnets Overvågningsenhed)
WTG	Wind Turbine Generator	

3 PROJECT DESCRIPTION

3.1 Description of area

The Kriegers Flak II OWF consists of two separate areas, "Kriegers Flak II North (Nord)" and "Kriegers Flak II South (Syd)". The wind farms are marked in Figure 1. The yellow areas mark "Kriegers Flak II (North and South)". The red areas are existing OWFs or OWFs under construction /7/,/8/.

Cumulative effects of planned future OWFs have been taken into account during the HAZID workshop (Appendix D) and the future planned wind farms are therefore marked in Figure 1 /7/. This concerns Kriegers Flak SE (in the Swedish sector). There are other planned OWFs with a greater distance to Kriegers Flak II (OWF where no cumulative effects are expected, i.e. Aflandshage; the area in the Swedish sector which includes Skåne wind farm, Triton and Arkona.

At present, there are various alternative scenarios for WTG locations /4/. For the present navigational risk assessment, the scenarios for "overplanting" are used, which with most WTGs will pose the greatest risk of collision, see Figure 3.

The most important shipping routes are marked in Figure 2. The intensity of traffic is derived from AIS registrations for 2022 which are made available via the Danish Maritime Authority (see section 4).

South of KF II OWF South is the route from the Baltic Sea to the Kattegat/North Sea via Kadetrenden to route "T" through the Great Belt, which includes a deep-water route. In continuation of the Kadetrenden and southeast of KF II OWF South is a Traffic Separation Scheme (TSS) ("North of Rügen"). In the eastern direction, this traffic merges with the traffic from/to the Baltic Sea via Øresund (separation zone "Bornholmsgat") /9//10/.

Commercial traffic via Øresund is routed via the TSS "Off Falsterbrorev" just north of the planned KF II OWF North. This TSS lies within an area which is controlled by VTS (Vessel Traffic Service) "Soundrep", where commercial vessels over 300 tons are required to report /9//10/.

In addition, there are several ferry routes, i.e. Rostock-Trelleborg and Travemünde-Trelleborg along Møn and west of KF II OWF; Travemünde-Malmø, also past Møn and via TSS Falsterbrorev; and Trelleborg Sassnitz and Trelleborg-Swinoujscie east of KF II OWF.

In the Marine Spatial Plan (MSP, Havplanen) for Danish waters some areas have been designated for other uses (extraction areas, landfill, aquaculture, fishing, etc.). At present, "Havplanen" has not been published. The areas are therefore identified based on available map material. From this, areas have been identified which are, or can be used, as material extraction areas. These are marked in Figure 3. For this study, the extraction areas between the existing Danish Kriegers Flak OWF are important. For these areas, known as areas 522-AC Kriegers Flak Southwest, 552-AB Kriegers Flak, and 552-AD Kriegers Flak Nord /7/, currently three (3) permits for extraction are valid, for Copenhagen City & Port (Lynetteholm) until 2026, Road Directorate in relation to Storstrømsbro until 2027 and Femern A/S until 2029. Extraction entails ship movements from this extraction area to and from the various projects, either past Møn or towards Copenhagen. New permits may be issued in the future.

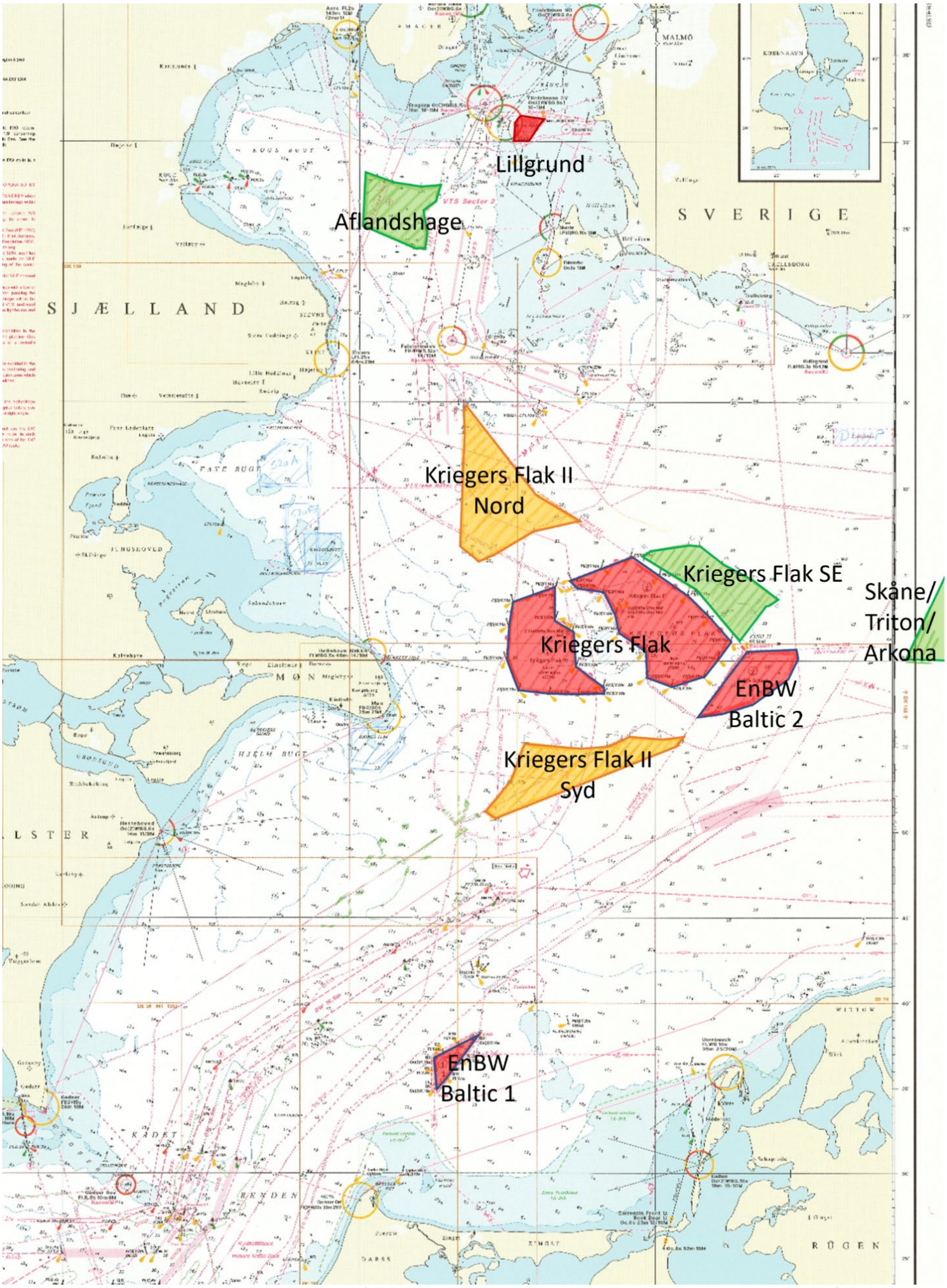


Figure 1 Position of existing and planned OWFs. The yellow areas are Kriegers Flak II (North and South) which this report is concerning, the red areas are existing or under construction, and green areas are future planned OWFs.

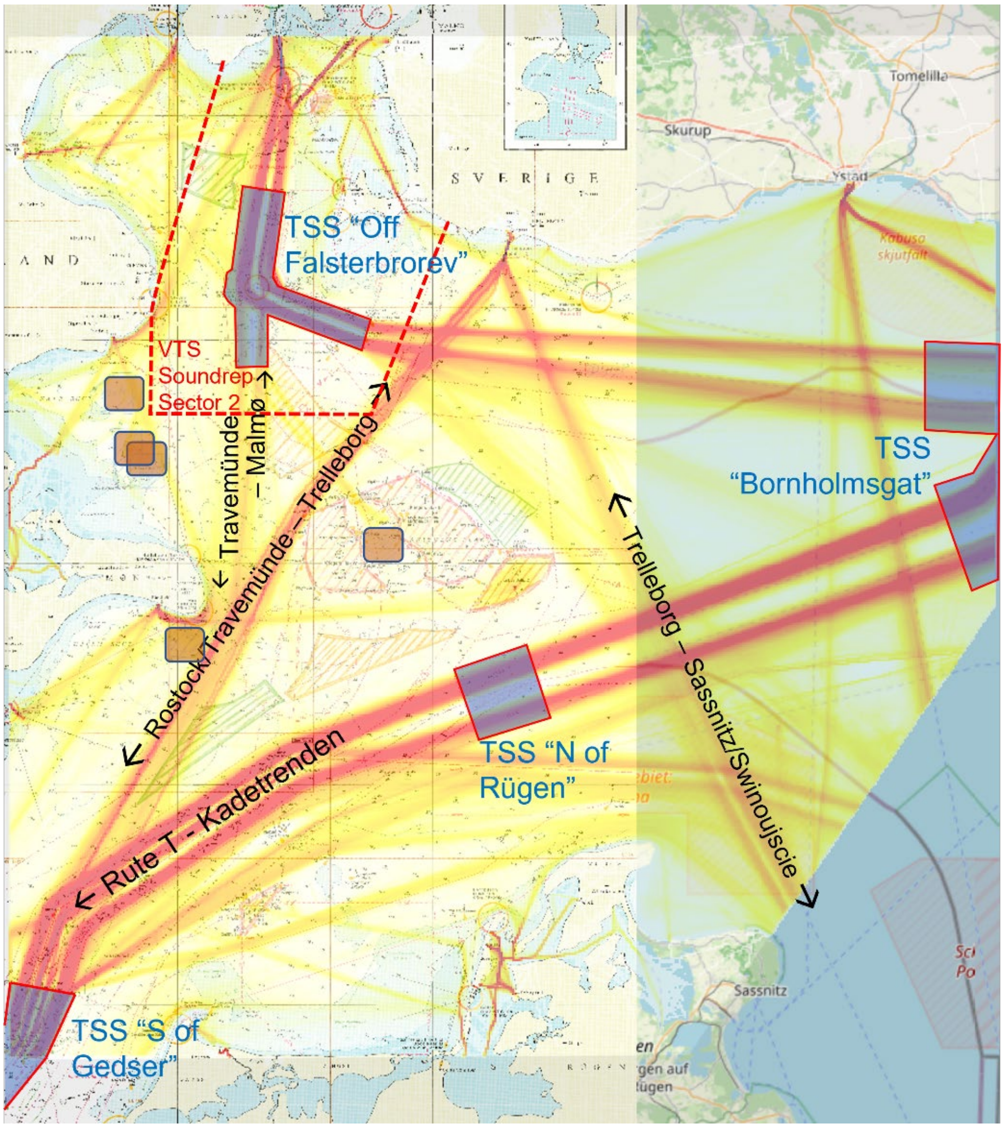


Figure 2 Traffic patterns based on AIS data and the most important ship and ferry routes. Blue with red outline marks Traffic Separation Zones (TSS); VTS area is marked with red broken line, Extraction areas are marked with brown /9//10//11/

3.2 Location of existing offshore wind turbine generators

The locations of existing Danish WTGs are obtained from DEA /13/. This covers the existing Kriegers Flak OWF in Danish waters (consisting of a western part with 24 WTGs and an eastern part with 48 WTGs).. The positions are listed in Appendix B.

The positions for Lillgrund (49 turbines inclusive OSS) and EnBW Baltic 1 (21 turbines) and 2 (81 turbines including OSS) are manually retrieved from nautical charts. Where positions were not provided in the chart and in case of doubt, a regular pattern was assumed. The positions are listed and shown in Appendix B.

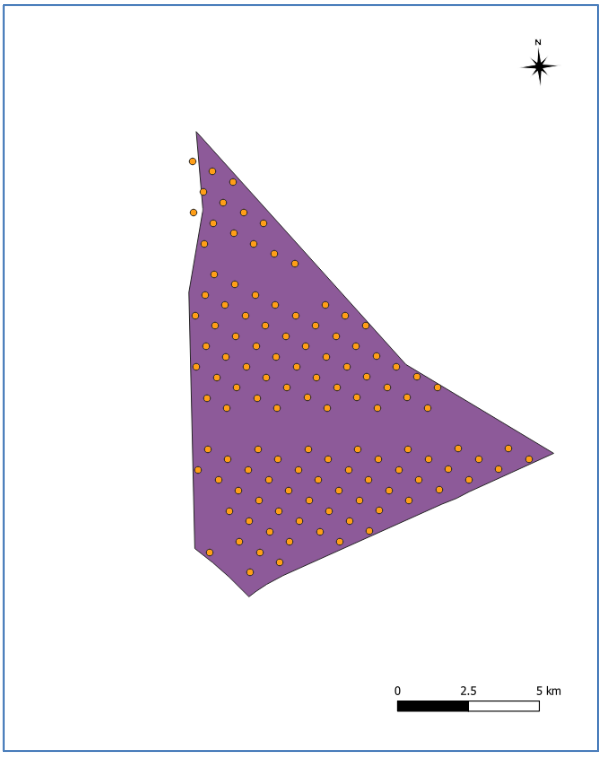
For the sake of the allision analysis, the single positions are transferred to small hexagons with a radius of 13 m (distance between opposite corners) at sea level.

3.3 Wind turbine generator locations for Kriegers Flak II OWF

At present, there are various alternative scenarios for WTG locations /8/. For the present navigational risk assessment, the scenarios for "overplanting" are used, because the largest number of WTGs will pose the largest risk of allision, see

Figure 3. Since the commencement of this analysis, the borders of KF II OWF North in the North-west corner have been slightly moved inwards to maintain a larger distance to the TSS “Off Falsterborev”, this means that these two WTGs shown outside the border (original positions KFN-1 and KFN-8) in Figure 3 are excluded from the study. The original number of 118 turbines for Kriegers Flak II North is thereby reduced to 116.

For the sake of allision analysis, the single positions are transferred to small hexagons with a radius of 13 m (distance between opposite corners) at sea level.



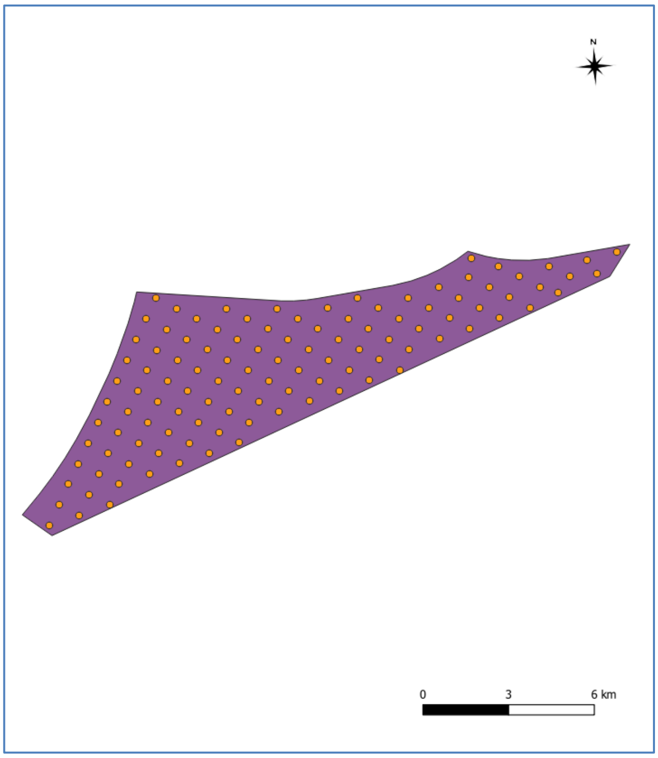


Figure 3 Kriegers Flak II, scenario “Overplanting”, 116 (Nord) og 112 (Syd) WTGs /8/. Note that the two turbines shown outside the updated borders of Kriegers Flak II North are not included in the analysis. Size of WTGs are not to scale.

3.4 Bathymetry

Bathymetry for the Baltic Sea has been obtained from the BALANCE project /12/. Bathymetry is available as a raster set with a resolution of 200 m horizontal and 1 m vertical. Data has been transferred to a vector format to be imported into the IWRAP model. Only bathymetry down to 46 m depth has been imported (no ships with such draught are expected, and effectiveness of emergency anchoring to avoid drifting will not be significantly worse if larger depth would have been included), see Figure 4.

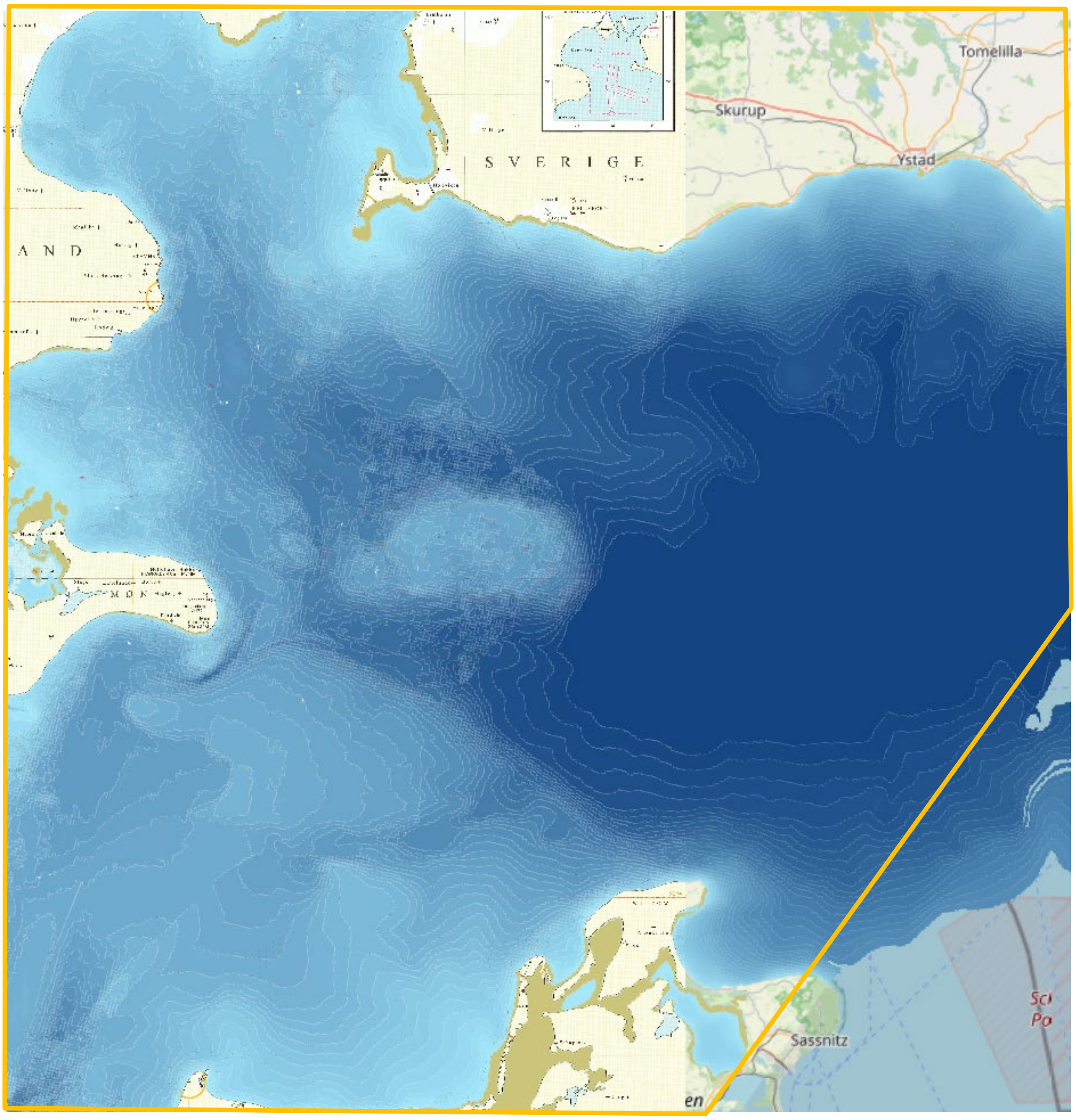


Figure 4 Bathymetry of Western Baltic within model area (marked by orange lines). Lightest blue: depth 1 m; darkest blue: depth 46 m; interval 1 m. Olive green: less than 1 m (effectively 0).

3.5 Wind direction

The IWRAP software requires input concerning the frequency of drift directions. Drift direction frequency is assumed to be the same as the wind direction frequency, see Assumption C.2, Appendix C.

4 SHIP TRAFFIC DATA

4.1 Ship data collection (AIS)

The ship traffic is determined from the historical AIS data available at DMA /1/, using all data (twelve months) for 2022. The AIS data handled in the analysis is within the following geographic bounds (the model area):

- Northerly bound: 55°35.500'N (line Dragør-Malmø)
- Southerly Bound: 54°26.565'N (Coast at Prerow)
- Westerly Bound: 12°10.100'E (Køge City)
- Easterly Bound: 14°6.455'E (Centre traffic separation zone TSS Off Bornholmsgat)
- The southeast corner is cut off through the locations 54°26.565'N, 13°30.549'E (Jasmunder Bodden) and 54°57.015'N, 14°6.455'E.

The model area is shown in Figure 2 (the area within the slightly darker margin). The area is chosen so that all relevant shipping that could reasonably interact with the KF II OWF (by drifting or on erroneous course) is included.

The AIS data exists of records for each transmitted AIS message. Before uploading the AIS data into the IWRAP tool, the messages have been pre-processed to select the following ships and ship positions:

- MMSI number of nine digits starts with integer between 2 and 7 (i.e., only ship-related stations are included);
- Position is within the above boundaries;
- Speed Over Ground (SOG) is between 0.8 and 100 m/s;
- Navigational status is neither “At anchor” nor “Moored” nor “Aground”;

Furthermore, records were adjusted to enable proper classification of ships in the IWRAP tool. If the transponder is Class B or ship type is “Pleasure”, and if the ship length unknown (empty data field) then the ship length is set at 15 m and width at 4 m. This allows identification of the unknown ship types after being imported in IWRAP. Unknown ship types will be assigned “Other Ships” in IWRAP, and unknown ship length is default assigned to 50 m. Class B transponders are limited to pleasure vessels and fishing vessels. IWRAP does not read the transponder class, but by selecting unknown ships with 15 m length, ships that are likely to be pleasure vessels can be identified.

4.2 Ship types

When importing AIS data, the IWRAP 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.” IWRAP applies ship categories (types) as in Table 1.

Table 1 Ship categories

IWRAP categories	Lumped categories in plots (e.g. as in Appendix A)
Crude oil tanker	Tankers
Oil products tanker	
Chemical tanker	
Gas tanker	
Container ship	Cargo
General cargo ship	
Bulk carrier	
Ro-Ro cargo ship	
Passenger ship	Passenger ships
Fast ferry	
Support ship	”Other”
Fishing ship	Fishing ships
Pleasure boat	Pleasure boats
Other ship	”Other”

Ships are assigned to length classes of 25 m each (so 0-25 m, 25-50 m, 50-75 m, etc.) up to 400 m, or longer than 400 m.

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 was used for the previous risk assessments, 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.

The AIS data analysis leads to identification of 13543 unique ships performing 167188 single trips[1] within the modelling area.

4.2.1 VMS data

Commercial fishing ships shorter than 15 m do not need to use AIS. Commercial fishing ships above 12 m length need to use a VMS transponder. In principle, VMS data could be used in addition to AIS data. However, from earlier studies DNV concluded that there is considerable overlap between AIS data and VMS data, but the overlap cannot be removed, because VMS data supplied by Danish authorities is anonymous. Also, the AIS registrations show that the total number of fishing ships is very small as compared to pleasure vessels, which have similar sailing patterns off the main fairways. Therefore, no attempt has been made to include VMS data.

4.3 Existing ship traffic patterns

The AIS data is imported into the IWRAP tool to provide a traffic density plot. The traffic density map shows the number of *passages* of ships through a small area (the cell size). It is not the same as a ship density plot (or heatmap): the traffic density does not depend on the ship’s speed, only on the number of passages or routes. (The *ship density* depends on

[1] IWRAP may break a factually single trip into several trips if there is too long time between consecutive AIS records from the ship, e.g. because of incomplete AIS (VHF) coverage. The DMA AIS data is based on coastal AIS receiving stations on Sjælland and Bornholm and coverage of these stations is not guaranteed to overlap. The accepted time lag (timeout) between consecutive AIS records has been increased to 20 min in the IWRAP tool to minimize the effect of limited coverage.

speed: a ship at half the speed contributes twice to ship density because it will be present twice as long in the same area).

Traffic density plots are provided in Appendix A for all ships and as plots for separate categories:

- Cargo ships (which includes Container ships, General cargo ships, Bulk carriers and Ro-Ro cargo ships).
- Tanker ships (including Crude oil tankers, Oil products tankers, Chemical tanker, and Gas tankers)
- Passenger ships (including ships classified as fast ferries or High Speed Craft, most of the Crew Transfer Vessels used to service OWF constructions are classified as HSC)
- Pleasure ships (both motor vessels and sailing vessels)
- Fishing ships.
- “Other ships” and Support ships. “Other ships” include e.g. naval (military) vessels, rescue craft and dredgers.

Figure A 2 and Figure A 3 show that cargo and tanker ships mainly follow the main shipping routes, as expected. Also, passenger ships mainly follow the main shipping routes, but Figure A 4 also shows that service vessels (CTVs) serving the existing Kriegers Flak OWF from Klintholm harbour, as well as EnBW Baltic 2 (which in 2022, as covered by AIS data, was under construction). EnBW Baltic 1 is served from the German Coast (Rügen).

Figure A 5 shows that the fishing activities are limited. Most fishing ships are in transit between Øresund and the Baltic east of Bornholm. There is some fishing activity from Klintholm Harbour that crosses the designated area for Kriegers Flak II South. Some fishing in Køge Bugt is not expected to be impacted by the Kriegers Flak II development.

Figure A 6 shows that the routes of pleasure boats differ substantially from the commercial shipping routes and indeed clearly avoids the busy shipping routes, notably the TSS-s. The pleasure boats typically follow the coastlines, but otherwise are rather randomly distributed, also through the existing Kriegers Flak OWF. Some crossings on open sea can be seen. Pleasure boats typically sail west of the main route between Møn and Øresund, crossings from Klintholm to Trelleborg and Ystad mainly pass north of the existing Kriegers Flak and there are routes from Klintholm both to the west and east-coast of Rügen. It shall be noted that the plot only shows movements of pleasure boats equipped with (and using) AIS. Section C.3 in Appendix C discusses the fraction of pleasure boats with AIS, but this does not affect Figure A 6 (the colours of the traffic density plots are relative to the maximum number of passage density of the ship category in question).

Figure A 7 shows the traffic density of “other ships”. In absolute numbers, the “other ships” do not count for much traffic and are hard to be distinguished in the plot for all ships (Figure A 1). The plot shows the activities of extraction from the extraction area between the existing Kriegers Flak West and East to the north. This is probably in connection with Lynetteholm works.

5 MODEL DESCRIPTION

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.

5.1 Analysis tool

The IWRAP MKII software calculates the probability of allisions (collisions with fixed structures), collisions between ships or groundings for vessels 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 /2/,/3/ for detailed theoretical model description. The probabilistic model assumptions are summarised in Appendix C (section C.1).

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 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.

5.1.1 Type of collisions

The assessment considers a number of possible accidents:

- Collisions between ships:
    - Within a straight route: *overtaking* and *head-on* collisions
    - collisions when two routes cross each other, merge, or intersect each other in a bend of a fairway.
- Groundings or allisions (collision with a fixed structure) (both are handled in the same way):
    - Powered groundings/allisions:
        - Ships following the ordinary direct route at normal speed. Accidents in this category are mainly due to human error but may include ships subject to unexpected problems with the propulsion/steering system that occur in the vicinity of the fixed marine structure or the ground.
        - Ships that fail to change course at a given turning point near the obstacle. For the simulations presented herein, when legs are extending within 10° of each other's direction, no such failures are assumed (the fairway is assumed to go straight on and no change of course is deemed necessary), This is done to have some freedom in definition of legs and waypoints to cover as much traffic as possible without too many legs and waypoints.
    - Drifting groundings/allisions

For a detailed description of the model theory, reference is made to /3/.

5.2 Definition of routes and waypoints

As stated above, the model applies traffic routes and ships assigned to those routes. Within the modelling concept, routes exist of straight “legs” between waypoints. At waypoints, legs can change direction and/or merge, and/or divide into several legs. The analyst has to assign ship traffic to legs, i.e. by describing the number movements per year of ships within a certain category and length class for that leg. Within this study the standard categories in the IWRAP tool are applied (Table 1):

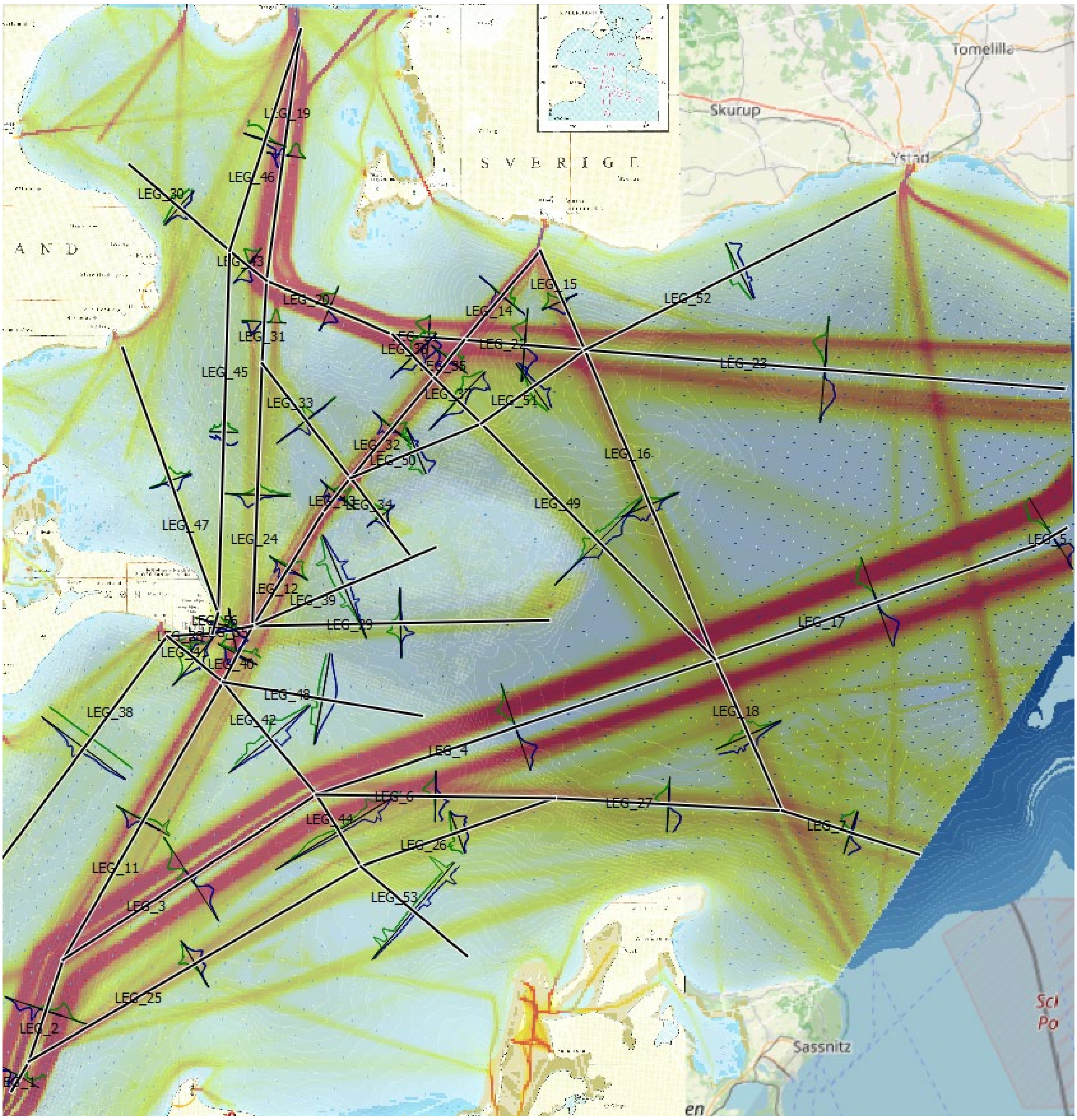


Figure 5 Definition of legs with lateral traffic distributions derived from AIS registrations.

The commercial version of IWRAP allows to use AIS data to automatically assign AIS registered ship movements to legs. That procedure has been used. The analyst has to define the waypoints, the legs between the waypoints and the width of the legs. Furthermore, the analyst can select to what degree the ship movements shall be aligned (have the same direction) with the leg, and the distance beyond the waypoint for which allisions and groundings are calculated (when the ship does not turn at the waypoint).

For this assessment, an alignment of 25 degrees for all legs have been applied, which is relatively wide, but this is done to ensure that directional traffic (e.g. CTVs sailing from one harbour to all WTGWTGs within an OWF) are captured within the leg.

There will be a part of the AIS registered ship movements that will not be assigned to a leg. Within the present version of the IWRAP tool, there is no information what fraction of the ship movements is assigned to legs and what fraction is not. This is a rather important information, because the fraction that is not captured will not be included in the analysis. This is another reason to apply the wide degree for alignment, to include as many movements as possible. It is noted that the model results herewith are sensitive to the selection (density and direction) of waypoints and legs, and the leg width. This shall be kept in mind when comparing results with other analyses for the same area.

Figure 5 shows the AIS traffic density for all ship categories (see Section 4.3 and Appendix A) and the definition of legs. Each leg has a number. These legs are selected and defined considering the traffic density of “all” ships and individual lumped categories, notably passenger ships (including CTV’s) and pleasure boats, to ensure that all relevant ship movements are covered. E.g. leg 45 runs parallel with leg 24 and represent pleasure boats sailing west of the commercial shipping route.

Where legs are crossing or come together (waypoints), ships may turn to another leg. The IWRAP tool collects the number of ships turning from one leg into another, thereby providing the data necessary to estimate the number of ships that inadvertently make a wrong (or no) turn.

In order to account for pleasure boats not equipped with AIS, the number of pleasure boats assigned to a leg has been multiplied by 6.7 for all legs as per Assumption C.3 (Appendix C).

5.2.1 Lateral distributions

The IWRAP tool calculates the lateral distribution of the ship traffic along the leg as a multimodal combination of (typical) normal and uniform distributions. Figure 5 shows the lateral distributions across each leg for North or West going ships (green) and for South or East going ships (blue) derived from the AIS registrations. The width of the distributions shows the selected width of the leg, used to select which ships from the AIS data belong to the leg. Assigned width as describes above is only used to limit the traffic assigned to the leg, the lateral (normal) distributions as used in the simulation can extend beyond the assigned width of the leg as visible in Figure 5. Note that the lateral distributions are normalized to the traffic along leg, so an equal height of the (peak of) the distribution does not indicate the same number of ships passing as along another leg.

5.3 Definition of simulation scenarios

Three simulation scenarios are defined, as described in the following sections. These scenarios are:

- Base case scenario (present condition with traffic from 2022 AIS data)
- Construction-phase scenario, i.e. the condition during the construction and construction of the KF II OWF
- Operational phase scenario, i.e. the condition when the KF II OWF is in operation.

All traffic intensities are based on the 2022 AIS data, that is, future trends in shipping intensity, apart from changes incurred by the operation of the KF II OWF, are not accounted for.

5.3.1 Base case scenario

The base case simulation is based on the 2022 AIS traffic data and definition of legs and way points as shown in Figure 5. Ship traffic from AIS data has not been adjusted apart from the general increase of pleasure boats by a factor of 6.7 as per Assumption C.3 (Appendix C) to account for pleasure boats not equipped with AIS. Inspection of the Crew

Transfer Vessels movements between Klintholm and existing Kriegers Flak OWF and EnBW Baltic 2 OWF show that these movements are in close agreement with the 5 return trips per WTG as per Assumption C.5 (Appendix C) and have not been modified.

Existing WTGs in Danish, Swedish and German OWFs are included in the simulation, i.e. there will be estimated allisions with these existing WTGs in the modelling area for the base case. This means that the scenarios for the Construction Phase and Operational Phase will cover the cumulative effects between the existing OWFs and the KF II OWF.

For later detailed comparison with the other scenarios, a number of routes are defined that are expected to be affected by the new KF II OWF, also considering the discussions from the HAZID workshops (Appendix D). The routes are indicated in Figure 6:

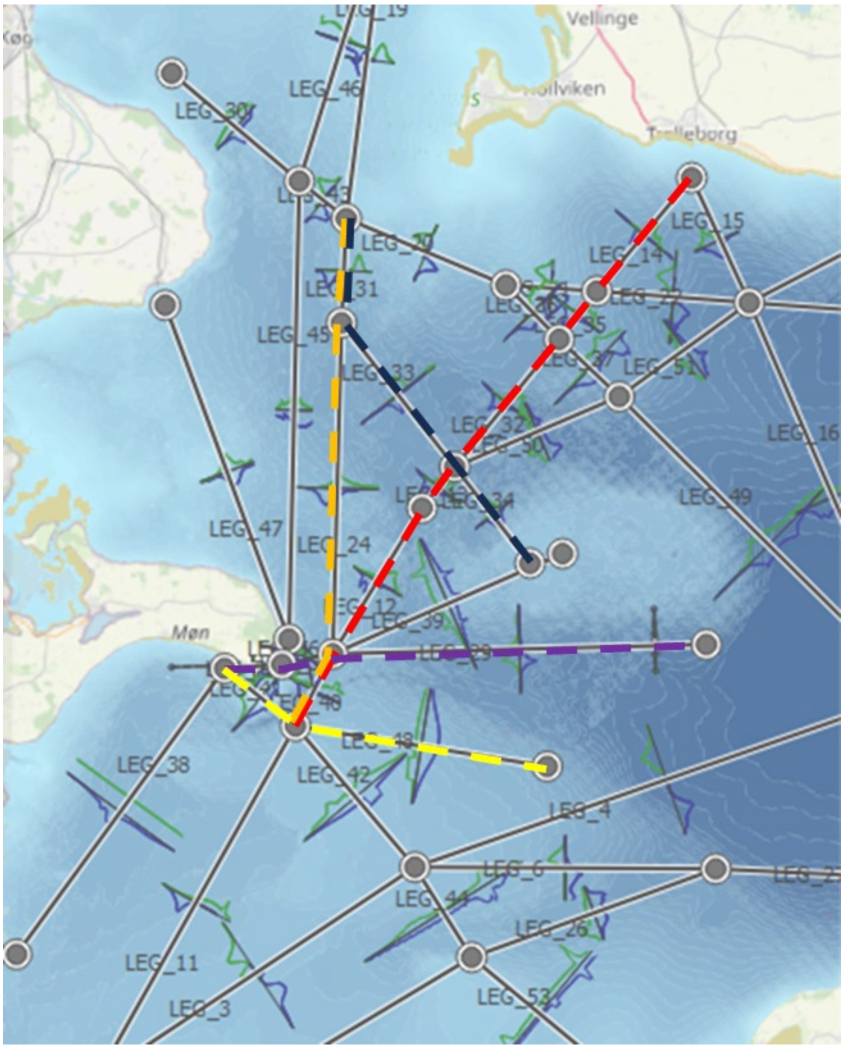


Figure 6 Base case, route definitions for further analysis. Red: Gedser-Trelleborg; Orange: Møn-Falsterbo; Yellow: Klinthom-North of Rügen; Black: Extraction to/from Copenhagen

A. Route from/to TSS “South of Gedser” to/from Trelleborg (this route will slightly change passing south of KF II OWF North) (Red in Figure 6)

B. Main commercial fairway from/to Møn to/from TSS "Off Falsterbrorev" (this route will become bounded on the east side due to KF II OWF North) (Orange)

C. Route from/to Klintholm to/from North of Rügen (rerouting of pleasure boats south of KF II OWF South) (Yellow)

D. Route from/to extraction area between existing OWF Kriegers Flak East and West to/from Copenhagen (rerouting passing south of KF II OWF North) (Black)

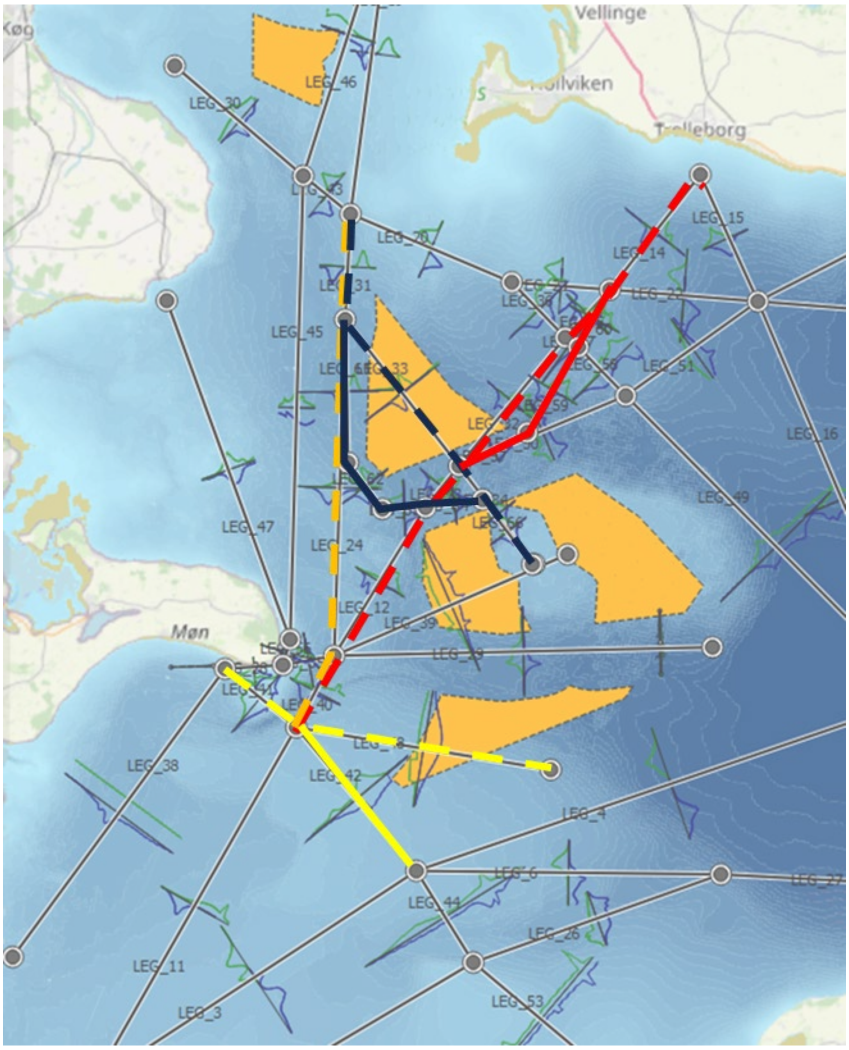


Figure 7 Construction phase. Solid lines represent re-routing of shipping routes

5.3.2 Construction phase scenario

For the construction phase, the WTGWTG structures of the KF II OWF are all included in the simulation (for the allision simulation, there is no difference between foundations or complete WTGWTG. This will provide a worst case scenario result.

The construction phase is characterized by the fact that the KF II OWF areas are work areas and non-attending vessels are not permitted to enter these areas. This means that all existing traffic has to pass around or outside the areas. This is modelled by the following changes made to the base case, see also re-routing on Figure 7:

A. Route from/to TSS "South of Gedser" to/from Trelleborg is completely routed south of KF II OWF North) (solid red in Figure 7), no traffic on the original route (legs 32 and 35). The traffic and lateral distributions of legs 32 and 35 have been copied to the (new) legs 57and 59, and leg 60, respectively.

B. Main commercial fairway from/to Møn to/from TSS "Off Falsterbrorev": the distribution of the traffic heading North is limited not to extend more than 2200 m east of the leg centreline (which is the distance to the western boundary of KF II OWF North from the leg centreline).

C. Route from/to Klintholm to/from North of Rügen (leg 42) is completely transferred to leg 48 (solid yellow); the existing lateral distribution of leg 48 has been changed as to avoid an overlap with the OWF.

D. Route from/to extraction area between existing OWF Kriegers Flak East and West to/from Copenhagen is re-routed passing south of KF II OWF North) (solid black). During the HAZID it was suggested that the route would pass East around KF II OWF North, but the detour via the Eastern entrance of TSS “Off Falsterbrorev” (buoy M43) is considerably longer. Leg 33 is copied (traffic and lateral distribution) to the new legs 62, and 63 (and traffic on legs 33 and 35 set to zero) and leg 34 is copied to the new legs 64 and 66 (and traffic on leg 34 set to zero). The traffic on this route fully crosses the route Gedser-Trelleborg (none of the ships on these two routes switch on to the other route at the crossing). Leg 62 joins the route between Møn and Øresund (leg 24) at a new waypoint.

The construction phase scenario does not consider any extra traffic for construction purposes, as there is no information about neither intensity nor route (construction harbour is not known).

5.3.3 Operational phase scenario

The operational-phase scenario is based on the construction phase scenario with the following changes (see Figure 8):

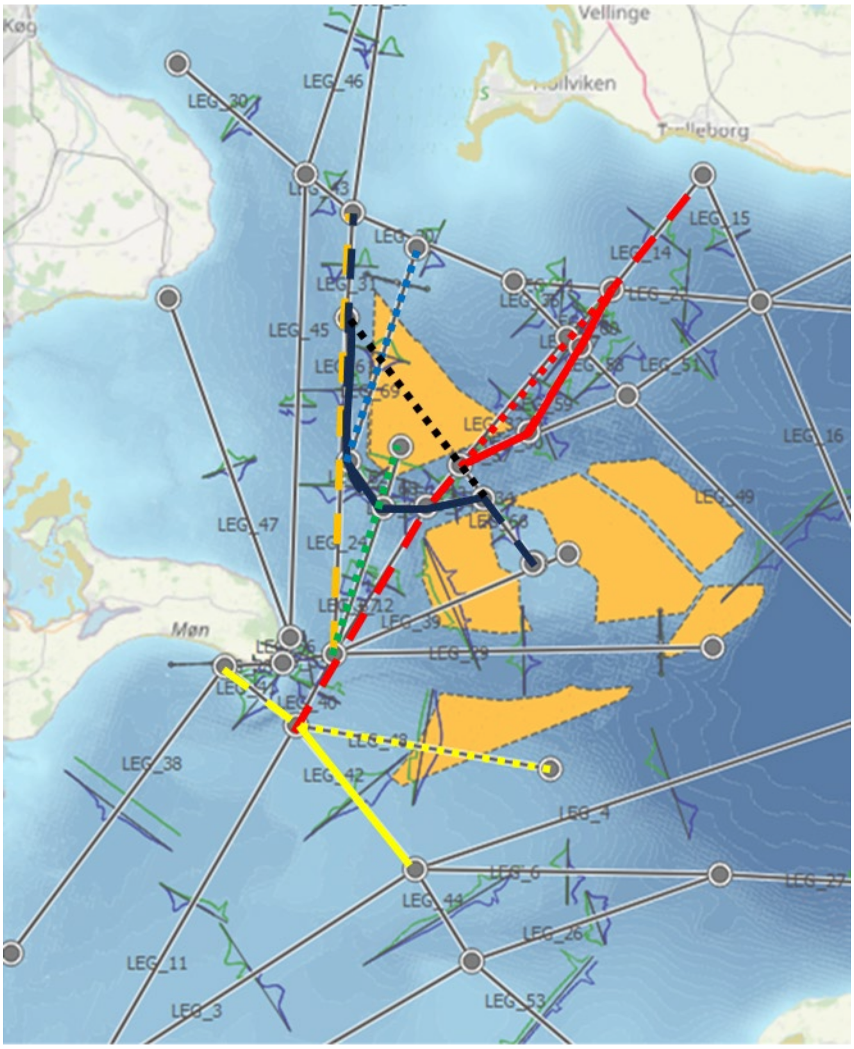


Figure 8 Operational phase. Solid lines represent re-routing of shipping, dotted lines (red, yellow and blue) are pleasure boats partially crossing KF II OWF, green dot-dash line is new CTV route to KF II OWF North.

A. Route from/to TSS “South of Gedser” to/from Trelleborg is routed south of KF II OWF North) (solid red in Figure 7). Some pleasure boats will use the straight route (red dotted line). The number of pleasure boats is based on the detour length as per Assumption C.4 (Appendix C). The detour length has been considered for the full distance Møn-Trelleborg (actually Gislövsläge Marina) or from the north-west corner of the existing Kriegers Flak West OWF to Trelleborg. These detour lengths are 0.6 and 0.8 km, respectively, corresponding to a relative detour of 1% and 2%, respectively. The highest relative detour leads to the largest fraction of pleasure boats expecting to cross the OWF, viz. 21%. So, 21% of the original number of pleasure boats sailing along legs 32 and 35 is retained on these legs, and the other 79% put on legs 57, 59 and 60 as per construction phase scenario (section 5.3.2).

B. Main commercial fairway from/to Møn to/from TSS "Off Falsterbrorev": No changes are made as compared to the construction phase scenario.

C. Route from/to Klintholm to/from North of Rügen (leg 42).

   a. Some pleasure boats will use the most direct route to the north of Rügen (actually heading just south of the TSS ”N of Rügen”). The detour length south of the KF II OWF South is 0.66 km or almost 1% relative to the total distance from Klintholm to the North of Rügen. As per Assumption C.4 (Appendix C), 15% of the pleasure boats is expected to take the route through the OWF. So 15% of the original number of pleasure boats sailing along 48 is retained on this leg, the other 85% is put on leg 42 as per construction phase scenario (section 5.3.2).

b. It is assumed that KF II OWF South will be serviced out of Klintholm. This will generate additional CTV traffic along the legs 41 and 48. This concern 112 WTGWTGs and as per Assumption C.5 (Appendix C), this would generate 560 return trips. Similar to the CTVs already operating from Klinthholm, this is equally shared between vessels up to 25 m and between 25 and 50 m length. These numbers are added to the CTV's already sailing along legs 41 and 48. No changes are made to the lateral distributions on these legs.

D. Route from/to extraction area between existing OWF Kriegers Flak East and West to/from Copenhagen is re-routed passing south of KF II OWF North) (solid black). No change as compared to the construction-phase scenario.

E. The KF II OWF North need to be serviced by CTVs and for this study this is assumed to be from Klintholm (as KF II OWF will have a single operator). Operation from Rødvig would be an alternative but in both cases the main fairway from Gedser to Falsterbrorev need to be crossed. Crossing at the spot with most traffic east of Klintholm would probably show the highest number of expected incidents, so this is considered a conservative assumption. KF II OWF North exists of 116 WTGWTGs and as per Assumption C.5 (Appendix C), this would generate 580 return trips. As described above for KF II OWF South, this is equally shared between vessels up to 25 m and between 25 and 50 m length. New legs (leg 67 and 68, green dash-dot in Figure 8) are created from the waypoint east of Møn to the OWF. The above traffic intensities are added to these legs as well as to the legs out of Klintholm (legs 28 and 55). Crossings at the waypoints are defined so that the above CTVs are fully routed from Klintholm to the OWF. The lateral distribution at leg 67 (south of the crossing with the black route) is set as a uniform distribution with width from – 1250m to +1250m in both directions, and for leg 68 (closest to the OWF) this distribution is widened to -2500m to +2500m, as it may be expected that the CTV sailing pattern will diverge as it is seen at Anholt (see Figure C.4-19).

F. In the traffic density plot for pleasure vessels (Figure A 6 in Appendix A) it can be seen that there are pleasure boats sailing directly from/to Klintholm (or East around Møn) to/from Skanör (West of Falsterbro). This was not separately captured by the original route definition but attempted captured by legs 24 and 31 (Møn – Malmø, yellow dashed in Figure 8). In order to capture pleasure boats still sailing straight through the KF II OWF North, a new leg 69 was defined (dotted blue in in Figure 8. The number of original pleasure boats along this route was analysed. The length of the detour along the North-west corner of KF II OWF North is 0.45 km or 0.8% of the total distance from Møn to Skanör. As per Assumption C.4 (Appendix C), 14% of pleasure boats are expected to sail through the OWF, this corresponds to 154 pleasure boats North-bound and 141 boats South-bound. The other legs (notably 24 and 31) have not been adjusted, so this is "extra" traffic added to the simulation. The lateral distribution of the new leg 69 is set as a normal distribution in both directions, centred on the leg, with a standard deviation of 750 m. The new leg does not cross the other fairways, so this is included only to assess the risk of allisions within the OWF.

6 RESULTS

The results of the assessment are presented as comparisons between the three scenarios. The absolute number of expected incidents or accidents depends heavily on the model assumptions (notably on the definition of legs and waypoints and also on the default causation factors), whereas the comparative results are less biassed by these assumptions.

The results are presented as total results for the modelling area. This provides a valid comparison with respect to the number of allisions with existing and/or new WTGWTGs, but when considering the impact on ship-ship collisions, results will be dominated by the fairways with most traffic, which will be away from the KF II OWF. Similar arguments hold for groundings. Therefore, detailed comparisons will be made for the routes affected by changes due to the KF II OWF (such as routing, crossings, traffic density or width)

A summary of results for the modelling area is presented in Table 2. The Table shows the absolute results for the modelling area and the changes as compared to the Base Case Scenario, both in absolute expected number of incidents per year, and the relative increase for the type of incident.

It can be concluded that the impact on groundings is limited, both in absolute and relative terms. In relative terms the number of allisions increases most (as can be expected by the increase of the number of WTGWTGs in the modelling area). In absolute terms the number of collision incidents increases most, notably incidents related to crossings, merging and bending, and amount up to three times the number of additional allisions in the operational phase.

The details of results per ship category and/or route will be discussed in the next sections.

Table 2 Summary of results for the modelling area

Type of incident	Expected number of incidents per year / *Expected averaged number of years between incidents*			Increase (incidents per year)		Relative increase	
	Base Case	Construction	Operational	Constr.	Oper.	Constr.	Oper.
Powered Groundings	1.40 / *0.71*	1.40 / *0.71*	1.41 / 0.71	0.005	0.008	0.4%	0.6%
Drifting Groundings	0.075 / *13.3*	0.078 / *12.8*	0.075 / 13.3	0.002	0.000	3.0%	0.0%
Total Groundings	1.47 / *0.68*	1.48 / *0.68*	1.48 / 0.68	0.006	0.007	0.4%	0.5%
Powered Allisions	0.010 / *100*	0.010 / *100*	0.022 / *46*	0.000	0.012	4%	125%
Drifting Allisions	0.0012 / *533*	0.0025 / *400*	0.0027 / *370*	0.001	0.002	106%	124%
Total Allisions	0.011 / *91*	0.012 / *83*	0.024 / *42*	0.002	0.013	15%	124%
Overtaking	0.085 / *12*	0.085 / *12*	0.085 / *12*	0.000	0.000	0.3%	0.6%
HeadOn	0.016 / *63*	0.016 / *63*	0.017 / *59*	0.001	0.001	3.9%	5.0%
Crossing	0.070 / *14.3*	0.074 / *13.5*	0.091 / *11.0*	0.004	0.021	6.0%	30%
Merging	0.031 / *32*	0.031 / *32*	0.040 / *25*	0.000	0.009	-0.2%	29%
Bend	0.263 / *3.8*	0.278 / *3.6*	0.269 / *3.7*	0.016	0.007	6.0%	2.5%
Total Collisions	0.464 / *2.2*	0.485 / *2.1*	0.502 / *2.0*	0.021	0.038	4.5%	8.2%

6.1 Allisions

The base case allisions relate to the existing OWF in the modelling area. Figure 9 shows the relative probability of allisions with the WTGWTGs of EnBW Baltic 2 and existing Kriegers Flak OWF. Summed over all ships categories, drifting allisions are about 10% of total allisions. The pattern of drifting allisions is different from the powered (and total) allisions and is related to passing vessels.

Note that this study does not address the potential impact of high ships (superstructures or masts) with rotor blades outside the foundation base of about 13 m diameter.

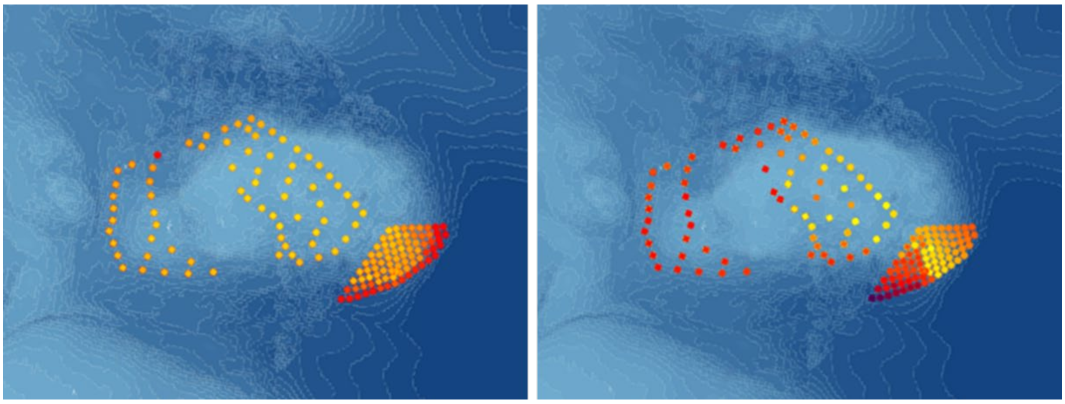


Figure 9 Base Case Scenario Allisions. Left: drifting allisions, right: powered allisions for existing Kriegers Flak OWF and EnBW Baltic 2

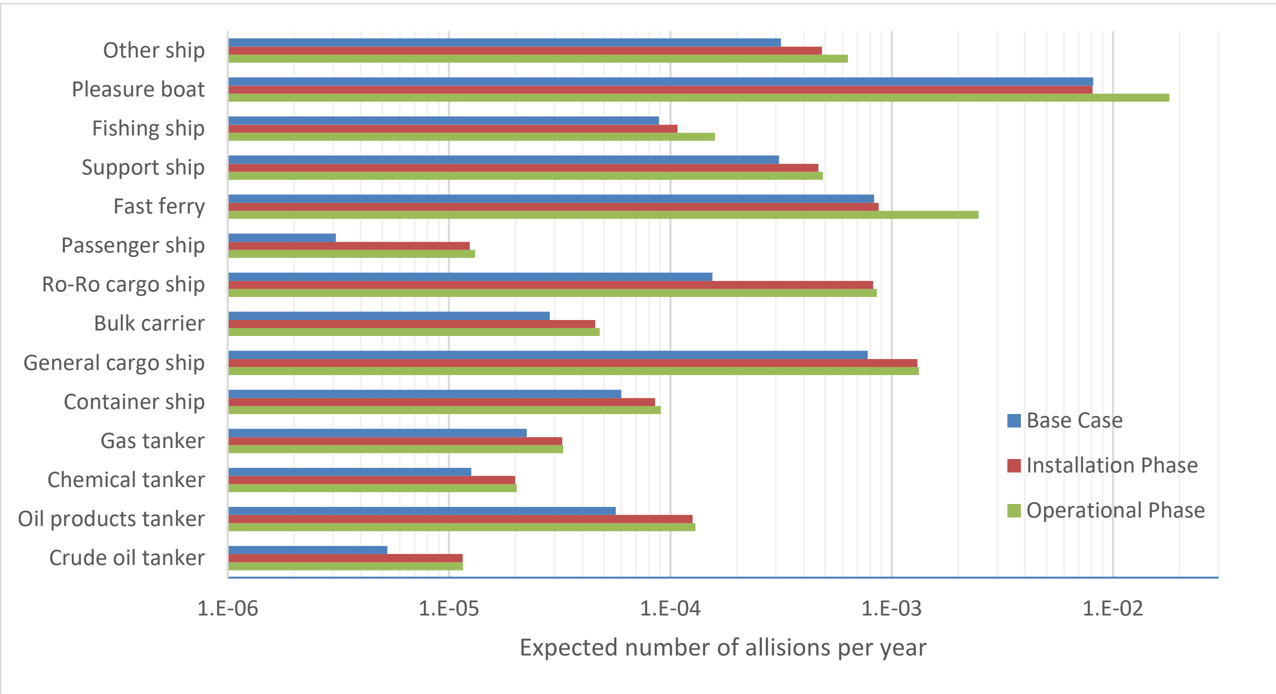


Figure 10 Total allisions

The comparison of the number of allisions is included in Table 3 and Figure 10. IWRAP expects for the existing OWFs in the modelling area (Danish Kriegers Flak, EnWB Baltic 1 and 2, and Lillgrund) about 1 allision per 100 years (probability 0.011 per year). Majority of such allisions will be pleasure boats (75% of total allisions) and most of these allisions from pleasure boats are powered allisions (98%). Next highest number of allisions are related to General Cargo and Fast Ferries. Allisions of pleasure boats and fast ferries (CTVs) are caused by the vessels sailing within the OWFs, General Cargo has both a high traffic intensity in general and diverse sailing patterns close to or crossing the OWFs.

There are large differences in the ratio between powered and drifting allisions. Apart from pleasure boats, Ro-Ro Cargo ships most often cause powered allisions (more than 95% of total allisions by Ro-Ro Cargo ships). At the other end, in the rare event of allision by a crude oil tanker, passenger ship or chemical tanker, it is most likely a drifting allision (99%, 93% and 87% respectively).

In Table 3 the highest number of allisions have been marked bold (Base Case column), and so have the largest absolute and relative increases from Base Case to Construction Phase and Operational Phase.

Table 3 Total (Powered and drifting) allisions in the modelling area

Ship category	Expected number of allisions per year/ *Expected averaged number of years between allisions*			Increase (incidents per year)		Relative increase	
	Base Case	Construction	Operational	Construction	Operational	Construction	Operational
Crude oil tanker	5.27E-06 / *190000*	1.15E-05 / *87000*	1.16E-05 / *87200*	6.25E-06	6.29E-06	119%	119%
Oil products tanker	5.66E-05 / *17700*	1.26E-04 / *7940*	1.30E-04 / *7690*	6.96E-05	7.33E-05	123%	130%
Chemical tanker	1.26E-05 / *79400*	1.99E-05 / *50300*	2.02E-05 / *49500*	7.28E-06	7.63E-06	58%	61%
Gas tanker	2.25E-05 / *44400*	3.25E-05 / *30800*	3.28E-05 / *30500*	1.01E-05	1.03E-05	45%	46%
Container ship	5.99E-05 / *16700*	8.54E-05 / *11700*	9.05E-05 / *11100*	2.55E-05	3.06E-05	43%	51%
General cargo ship	**7.81E-04 / *1280***	1.31E-03 / *763*	1.33E-03 / *752*	**5.27E-04**	**5.49E-04**	67%	70%
Bulk carrier	2.86E-05 / *35000*	4.58E-05 / *21800*	4.80E-05 / *20800*	1.73E-05	1.95E-05	61%	68%
Ro-Ro cargo ship	1.55E-04 / *6450*	8.25E-04 / *1210*	8.57E-04 / *1170*	**6.70E-04**	**7.02E-04**	**432%**	**453%**
Passenger ship	3.08E-06 / *325000*	1.24E-05 / *80600*	1.31E-05 / *76300*	9.31E-06	1.01E-05	**302%**	**326%**
Fast ferry	**8.32E-04 / *1200***	8.73E-04 / *1150*	2.47E-03 / *405*	4.06E-05	**1.63E-03**	5%	**196%**
Support ship	3.10E-04 / *3230*	4.67E-04 / *2140*	4.90E-04 / *2040*	1.57E-04	1.80E-04	51%	58%
Fishing ship	8.89E-05 / *11200*	1.08E-04 / *9260*	1.59E-04 / *6290*	1.88E-05	7.01E-05	21%	79%
Pleasure boat	**8.14E-03 / *123***	8.07E-03 / *124*	1.80E-02 / *56*	-7.44E-05	**9.84E-03**	-1%	**121%**
Other ship	3.16E-04 / *3170*	4.83E-04 / *2070*	6.33E-04 / *1580*	1.68E-04	3.18E-04	53%	101%
Total	1.08E-02 / *93*	1.25E-02 / *80*	2.43E-02 / *41*	1.65E-03	1.35E-02	15%	124%

Figure 11 shows the distribution of drifting and powered allisions during the construction phase. The South-side of KF II OWF Nord seems to be most exposed to allision, probably by the course changes of ships sailing to Trelleborg (of which many are Ro-Ro Cargo ships).

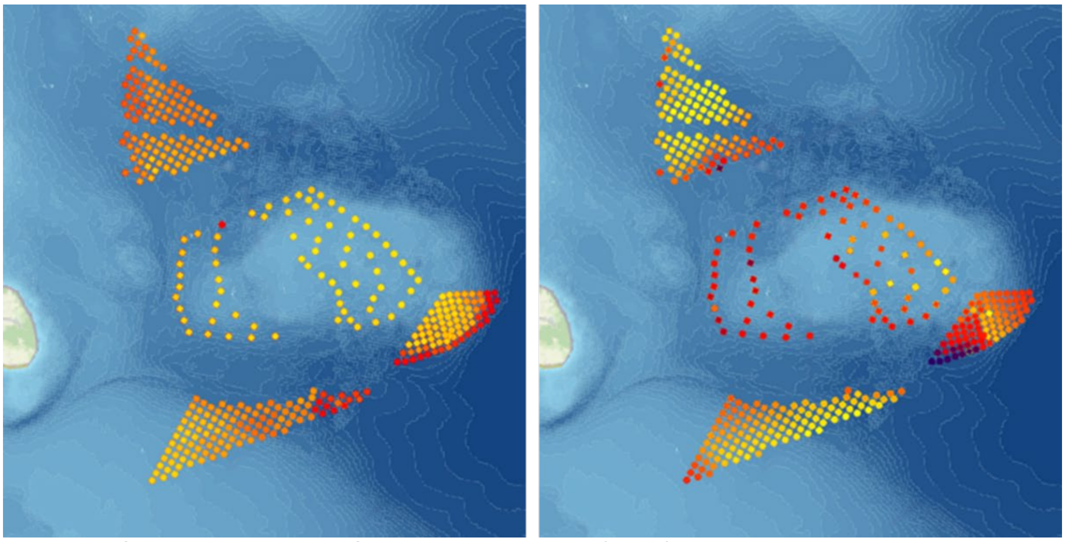


Figure 11 Construction Phase Scenario Allisions. Left: drifting allisions, right: powered allisions

During construction phase (and with all WTGs foundations installed) of KF II OWF the allisions risk in the modelling area increases by 15%, or the added probability (frequency) of allision during construction is 0.00165 per year. This can be fully contributed to the new OWF. Allision risk increases for all ship categories except pleasure boats (which may be an artefact due to routes through the new KF II OFW being closed). The increase is remarkable for Ro-Ro cargo ships (absolute and relative) and passenger ships (relative) and this is related to the change of the route to Trelleborg. This route has the highest traffic of Ro-Ro cargo ships. Ferries are normally classified as passenger ships, but it seems that the regular traffic on this route, some 7 ships in each direction each day, are registered as Ro-Ro cargo ships. Note that it is assumed (Assumption C.1, Appendix C) that the risk of incidents for passenger ships is reduced by a factor 20 as compared to other ship types. This may lead to some uncertainty (overestimation) of the absolute number of expected Ro-Ro cargo ship allisions.

Figure 12 shows the distribution of drifting and powered allisions during the operational phase. By comparison with Figure 11, it can be seen that the passing of Pleasure boats and attending by CTVs increases the powered allisions within the KF II OWF (both North and South).

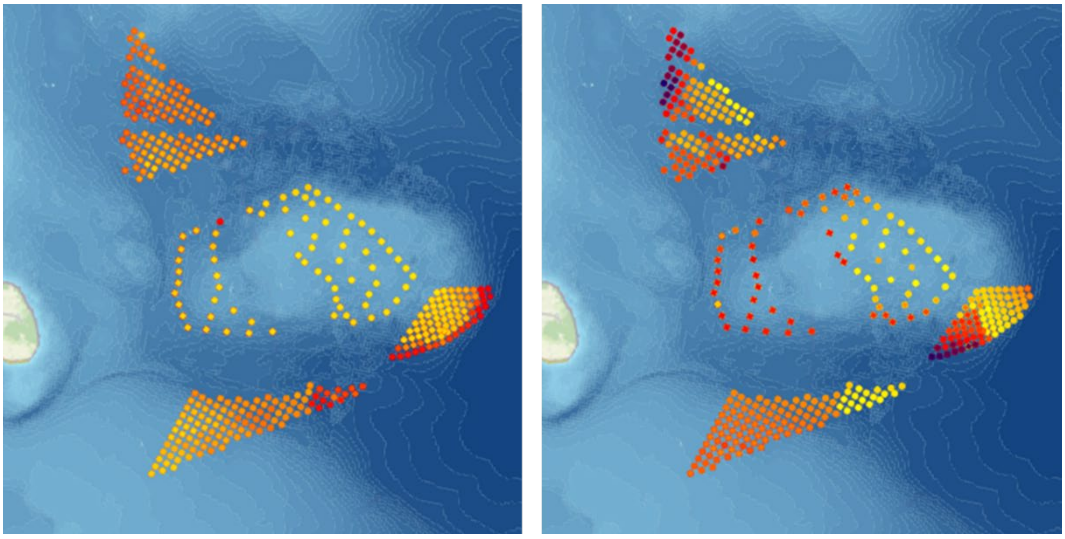


Figure 12 Operational Phase Scenario Allisions. Left: drifting allisions, right: powered allisions (Colours are scaled with the maximum incident frequency and therefore colours cannot be directly compared with Figure 11)

The number of allisions during the operational phase as compared to the construction phase is unchanged for most ship categories (small changes between the construction phase and operational phase for commercial shipping are likely to be artefacts due to small changes in waypoints between simulations). The exceptions (marked bold in Table 3) are, as can be expected from the changed assumptions, Fast Ferries or CTVs (because of increased activity) and Pleasure boats, Fishing ships and “other ships” (because these ships are partly “allowed” to sail through the KF II OWF).

Service trips for CTVs are added with 1140 return rips in total and this is forecasted to lead to an expected frequency of 0.0016 per year. Most of these allisions are powered allisions. This number may be questioned because the CTVs are deliberately attending the OWF and crews will be experienced to navigate within the OWF.

The largest increase in allisions in the operational phase as compared to the construction phase is due to Pleasure boats crossing the OWF. The expected frequency of allisions due to these crossings are estimated to be 0.01 per year, i.e. on average about one allision per 10 years is expected. Fishing ships are also expected to sail through the OWF, but because of the low number of Fishing ships, the additional expected frequency of allision remains low (0.00007 per year).

6.2 Groundings

Groundings occur mainly on the coasts surrounding the modelling area, with some groundings on the (relatively) shallow waters of Kriegers Flak, both sides of the Kadetrenden and the entrance to Øresund, see Figure 13.

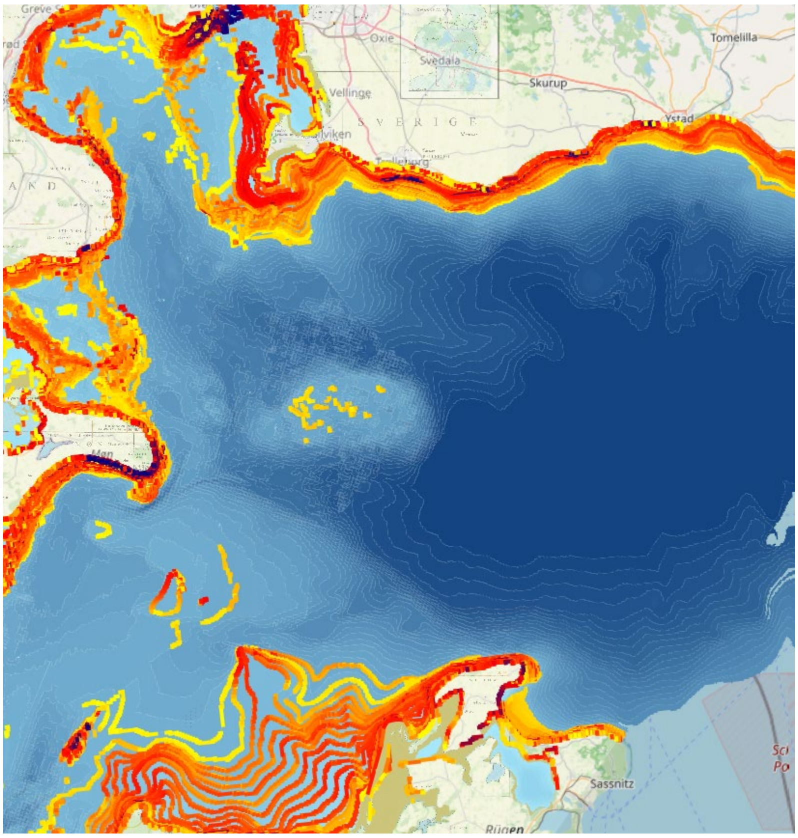


Figure 13 Base Case Scenario Groundings. Total groundings

The comparison of the number of groundings is included in Table 4.IWRAP expects one to two groundings in the modelling area per year, about 40% caused by pleasure boats followed by General Cargo ships (15%), Ro-Ro Cargo ships (14%) and Oil Product Tankers (13%).

The increase of the number of groundings during construction and operation of KF II OWF is predicted to be 0.5% on average. The largest increase is for Ro-Ro cargo ships (increase 2.1% from Base Case to Construction Phase and Operational Phase) and Fast Ferries (increase 200% from Construction Phase to Operational Phase), both increases marked bold in Table 4.

Most Ro-Ro Cargo groundings are powered groundings (more than 99%, whereas it is between about 80% and 95% for most other ship categories), and the volume of Ro-Ro Cargo ships on the re-routed Rostock-Trelleborg with an extra change of course may explain the increase in the number of groundings. The increase of groundings for Fast Ferries will be due to the increased number of CTV trips (a doubling as compared to the Base Case). A large proportion of Fast Ferry groundings are drifting groundings (35%).

Table 4 Total (Powered and drifting) groundings in the modelling area

Ship category	Expected number of groundings per year / *Expected averaged number of years between allisions*			Increase (incidents per year)		Relative increase	
	Base Case	Construction	Operational	Construction	Operational	Construction	Operational
Crude oil tanker	6.41E-02 / *16*	6.41E-02 / *16*	6.41E-02 / *16*	6.07E-05	-3.70E-06	0.1%	0.0%
Oil products tanker	**1.98E-01 / *5.1***	1.99E-01 / *5.0*	1.98E-01 / *5.1*	1.25E-03	-2.99E-05	0.6%	0.0%
Chemical tanker	3.16E-03 / *316*	3.16E-03 / *316*	*3.16E-03 / 316*	-5.42E-06	-5.93E-06	-0.2%	-0.2%
Gas tanker	7.26E-03 / *138*	7.30E-03 / *137*	7.25E-03 / *138*	4.19E-05	-5.71E-06	0.6%	-0.1%
Container ship	3.72E-02 / 27	3.73E-02 / 27	3.72E-02 / 27	1.01E-04	-3.29E-05	0.3%	-0.1%
General cargo ship	**2.23E-01 / *4.5***	2.24E-01 / *4.5*	2.22E-01 / *4.5*	1.07E-03	-2.70E-04	0.5%	-0.1%
Bulk carrier	6.21E-02 / *16*	6.23E-02 / *16*	6.21E-02 / *16*	1.82E-04	-1.70E-05	0.3%	0.0%
Ro-Ro cargo ship	**2.11E-01 / *4.7***	2.16E-01 / *4.6*	2.16E-01 / *4.6*	**4.44E-03**	**4.41E-03**	**2.1%**	**2.1%**
Passenger ship	3.83E-03 / *261*	3.83E-03 / *261*	3.83E-03 / *261*	3.55E-06	2.22E-06	0.1%	0.1%
Fast ferry	2.22E-03 / *450*	2.22E-03 / *450*	6.71E-03 / *450*	1.33E-06	**4.50E-03**	0.1%	**203%**
Support ship	2.60E-02 / *38*	2.59E-02 / *39*	2.59E-02 / *39*	-8.39E-05	-7.71E-05	-0.3%	-0.3%
Fishing ship	2.35E-02/ *43*	2.34E-02 / *43*	2.34E-02 / *43*	-6.31E-05	-7.22E-05	-0.3%	-0.3%
Pleasure boat	**5.94E-01 / *1.7***	5.94E-01 / *1.7*	5.93E-01 / *1.7*	-2.07E-04	-6.08E-04	0.0%	-0.1%
Other ship	1.74E-02 / *57*	1.72E-02 / *58*	1.73E-02 / *58*	-1.10E-04	-7.45E-05	-0.6%	-0.4%
Total	1.47 / *0.68*	1.48 / *0.68*	1.48 / *0.68*	6.68E-03	7.72E-03	0.5%	0.5%

6.3 Collisions

From Table 2 it appears that the KF II OWF has no or little effect on overtaking incidents and no significant effect on head-on incidents (at least in absolute terms), and the focus will therefore be on the incidents at waypoints (crossing, merging and bending). Figure 14 shows the relative incident frequency at waypoints for the three scenarios. Differences are hard to notice. The introduction of additional waypoints on the route to Trelleborg and the route between Copenhagen and the extraction area introduce new possibilities for incidents (see also Figure 7). The waypoint east of Møn shows slightly more incidents, probably due to crossing of more CTVs.

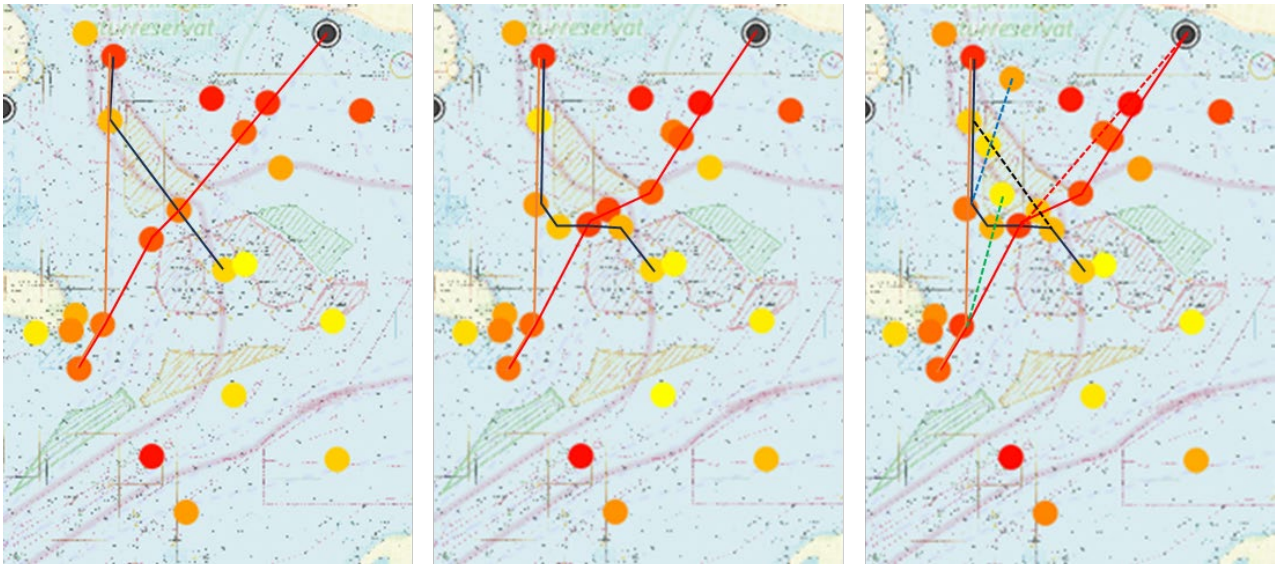


Figure 14 Waypoint collision incidents (crossing, merging, bending) close to KF II OWF. Left: Base Case Scenario, centre: Construction Phase Scenario, right: Operational Phase Scenario. Main routes and route changes are indicated, see also section 5.3. Note: the background is outdated and shows abandoned plans for other OWFs.

To address the increase of collision risk along affected shipping routes, two route segments are selected for detailed assessment, see Figure 15. These segments are on the route between TSS “Off Falsterborev” and TSS “S of Gedser” (orange in Figure 15) and the segment on the route between Trelleborg and TSS “S of Gedser” (red). The routes in Base Case are dashed, the changes in the Construction Phase and (partly) in operational Phase are solid lines.

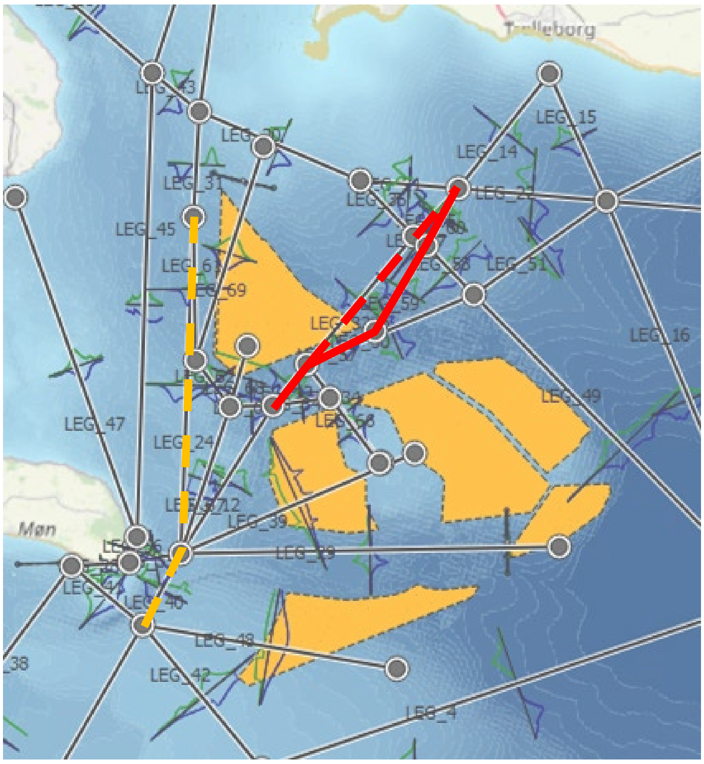


Figure 15 Route segments for assessment of increased waypoint incidents, cf. Figure 7 and Figure 8

The route segment between TSS “Off Falsterbrorev” and TSS “S of Gedser” has been selected because of increased crossing with CTVs East of Møn, a narrower lane west of the new KF II OWF North and the interaction with the shipping to/from the extraction area. The route to and from Trelleborg is selected because of the additional waypoints with crossings, merging traffic and course changes.

6.3.1 Waypoint incidents route to/from Trelleborg

The total number of incidents per ship category on the 4 (Base Case) to 5 (Construction Phase and Operational Phase) waypoints, i.e. points of crossings and/or course change for the route segment to Trelleborg are listed in Table 5. The highest number of incidents per ship category are marked bold for the Base Case as well as for the highest absolute and relative (over 200%) increases for the Construction Phase and Operational Phase. Given that the majority of ships on this route are Ro-Ro cargo ships, the highest number of incidents with this ship type is as expected. Also the increase of the number of incidents for the Construction Phase and Operational Phase is largest (in absolute terms) for the Ro-Ro cargo ships. About half of the increase of the incident frequency is related to the course change at the South-west entrance of the corridor between the existing Kriegers Flak OWF and KF II OWF North, the other half of the increase is mainly at the crossing with the fairway from TSS “Off Falsterborev” to the East.

There is also a considerable increase in incident frequency for General Cargo ships and pleasure boats.

The increase in incident risk along this route segment accounts for 70% to 75% of the total increase of collisions during construction and operation of the KF II OWF as per Table 2.

Table 5 Waypoint incidents route to/from Trelleborg

Ship category	Expected number of incidents per year / *Expected averaged number of years between incidents*			Increase (incidents per year)		Relative increase	
	Base Case	Construction	Operational	Construction	Operational	Construction	Operational
Crude oil tanker	1.42E-04 / *7040*	2.05E-04 / *4880*	5.36E-04 / *1870*	6.35E-05	3.94E-04	45%	**279%**
Oil products tanker	1.78E-03 / *562*	2.58E-03 / *388*	4.51E-03 / *222*	7.94E-04	**2.72E-03**	45%	153%
Chemical tanker	7.12E-05 / *14000*	1.05E-04 / *9520*	1.46E-04 / *6850*	3.43E-05	7.53E-05	48%	106%
Gas tanker	8.46E-05 / *11800*	1.45E-04 / *6900*	1.91E-04 / *5240*	6.00E-05	1.06E-04	71%	126%
Container ship	2.98E-04 / *3360*	4.49E-04 / *2230*	6.29E-04 / *1590*	1.51E-04	3.31E-04	51%	111%
General cargo ship	6.97E-03 / *143*	9.85E-03 / *102*	1.37E-02 / *73*	**2.88E-03**	**6.73E-03**	41%	97%
Bulk carrier	5.30E-04 / *1890*	7.62E-04 / *1310*	1.44E-03 / *694*	2.32E-04	9.11E-04	44%	172%
Ro-Ro cargo ship	**1.51E-02 / *66***	2.44E-02 / *41*	2.24E-02 / *45*	**9.26E-03**	**7.27E-03**	61%	48%
Passenger ship	8.72E-05 / *11500*	1.44E-04 / *6940*	1.83E-04 / *5460*	5.68E-05	9.53E-05	65%	109%
Fast ferry	7.02E-07 / *1420000*	2.22E-06 / *450000*	3.48E-06 / *287000*	1.52E-06	2.78E-06	**217%**	**396%**
Support ship	2.24E-04 / *4460*	4.09E-04 / *2450*	5.29E-04 / *1890*	1.85E-04	3.05E-04	83%	136%
Fishing ship	9.31E-05 / *10700*	1.38E-04 / *7250*	2.16E-04 / *4630*	4.48E-05	1.23E-04	48%	132%
Pleasure boat	2.21E-03 / *452*	4.24E-03 / *236*	8.63E-03 / *116*	**2.03E-03**	**6.42E-03**	92%	**291%**
Other ship	2.58E-04 / *3880*	8.52E-04 / *1170*	9.09E-04 / *1100*	5.95E-04	6.52E-04	231%	253%
Total	0.028 / *36*	0.044 / *23*	0.054 / *19*	0.016	0.026	59%	94%

DNV

6.3.2 Waypoint incidents route between TSSs “Off Falsterbrorev” and “South of Gedser”

The total number of incidents per ship category on the 4 (Base Case) to 5 (Construction Phase and Operational Phase) waypoints, i.e. points of crossings and/or course change for the route segment between TSSs “Off Falsterborev” and “S. of Gedser” are listed in Table 6. The highest number of incidents per ship category are marked bold for the Base Case as well as for the highest absolute and relative increases for the Construction Phase and Operational Phase. Ro-Ro cargo ships make up about 40% of the commercial traffic (pleasure boats and commercial traffic along this route are about 50% each), and this is reflected in the largest absolute expected number of incidents involving Ro-Ro ships. Most incidents in Base Case are expected to occur at the waypoint East of Møn. During construction, most incidents are expected to occur at the (new) waypoint where the traffic merges with the rerouted traffic South of KF II OWF North. During operation, the riskiest point again is East of Møn, involving Ro-Ro cargo ships and/or pleasure boats. The complexity of crossing traffic at this point also leads to relative increases for other large vessels (such as tankers).

CTV-incidents show an increase proportional to the increased operations, but not significant in absolute terms.

The increase in incident risk along this route segment accounts for 10% (Construction Phase) to 20% (Operational Phase) of the total increase of collisions during construction and operation of the KF II OWF as per Table 2.

Table 6 Waypoint incidents route between TSSs “Off Falsterbrorev” and “South of Gedser”

Ship category	Expected number of incidents per year/ *Expected averaged number of years between incidents*			Increase (incidents per year)		Relative increase	
	Base Case	Construction	Operational	Construction	Operational	Construction	Operational
Crude oil tanker	6.37E-07 / *1570000*	5.20E-07 / *1920000*	1.82E-06 / *549000*	-1.2E-07	1.19E-06	-18%	186%
Oil products tanker	6.48E-05 / *15400*	5.97E-05 / *16800*	2.18E-04 / *4590*	-5.2E-06	1.53E-04	-8%	**236%**
Chemical tanker	6.17E-06 / *162000*	4.77E-06 / *210000*	1.62E-05 / *61700*	-1.4E-06	1.01E-05	-23%	163%
Gas tanker	3.98E-07 / *2510000*	2.94E-10 / *3.40E+09*	2.78E-06 / *360000*	-4.0E-07	2.38E-06	-100%	**599%**
Container ship	3.38E-05 / *29600*	2.29E-05 / *43700*	8.33E-05 / *12000*	-1.1E-05	4.94E-05	-32%	146%
General cargo ship	6.81E-04 / *1470*	8.22E-04 / *1220*	1.74E-03 / *575*	1.41E-04	**1.06E-03**	**21%**	155%
Bulk carrier	3.63E-05 / *27500*	2.77E-05 / *36100*	7.88E-05 / *12700*	-8.5E-06	4.25E-05	-23%	117%
Ro-Ro cargo ship	**3.38E-03 / *296***	5.80E-03 / *172*	9.77E-03 / *102*	**2.42E-03**	**6.39E-03**	**72%**	189%
Passenger ship	9.25E-05 / *10800*	8.13E-05 / *12300*	2.26E-04 / *4430*	-1.1E-05	1.33E-04	-12%	144%
Fast ferry	6.74E-05 / *14800*	6.34E-05 / *15800*	1.41E-04 / *7090*	-4.1E-06	7.35E-05	-6%	109%
Support ship	3.47E-05 / *28800*	1.05E-05 / *95200*	4.25E-05 *23500*	-2.4E-05	7.88E-06	-70%	23%
Fishing ship	1.18E-05 / *84700*	6.17E-06 / *162000*	1.23E-05 / *81300*	-5.6E-06	5.07E-07	-48%	4%
Pleasure boat	**1.48E-03 / *676***	1.35E-03 / *741*	2.81E-03 / *356*	-1.3E-04	**1.34E-03**	-9%	90%
Other ship	1.24E-04 / *8070*	1.25E-05 / *80000*	3.58E-05 / *27900*	-1.1E-04	-8.80E-05	-90%	-71%
Total	0.006 / *167*	0.008 / *125*	0.015 / *67*	0.002	0.009	37%	153%

6.4 Updated risk table from HAZID workshop

During the HAZID workshop (the full report is included in Appendix D) the identified hazards were risk ranked. This risk ranking has been updated with the results from the quantified assessment as described in the sections above. The main columns from the HAZID sheet as included in Appendix D are copied into Table 7, and the column with expected event frequencies has been updated with the information from the quantified study to the extent possible (see for limitations section 2.2). The Risk Ranking (color coding "red, yellow, green") is updated as well. In Table 7, 4th column from left (frequency class), frequency estimates that have been unchanged from the HAZID assessment are coloured light blue. In case the updated frequency is lower, the cell is marked light green, and in case it has been increased, the cell is pink. In case the cell is white, it means that the quantitative study did not provide information to update the HAZID assessment.

Hazard IDs 16, 17, 18, 19, 24, 28, 31 and 35 have not been risk-ranked during the HAZID and have not been included in Table 7. These hazards relate e.g. to the impact of the WTGs on radar and other means of communication, and to service vessels, which are not covered by this general navigational safety study. Hazard 28 relates to the change in boundary at the North corner of the KF II OWF and is therefore no longer relevant.

The following hazards could not be updated:

- Hazard ID 4: The route from the extraction area to Femern has not been included in the simulation.
- Hazard ID 9 and 14: The allision with WTG wings has not been included in the simulation, only allision with the tower/foundation structure of about 13 m diameter.
- Hazard ID 20 and 21: the impact of limited visibility or radar coverage has not been quantified, see section 2.2 as well as the discussion in section 6.4.1 below.
- Hazard ID 26: The effect of the restricted work area of 500 m has not been quantified.
- Hazard ID 29, 33 and 34: The effect of surveillance ships or not complying with regulations has not been quantified, see section 2.2.
- Hazard ID 32: The risk of collision with a slowly moving working vessel crossing fairways has not been included in the simulation.

Table 7 Summary of updated HAZID hazard sheet (original HAZID sheet included in Appendix D). In the column "frequency", light blue indicates no change as compared to HAZID assessment, light green: the frequency has been lowered, and pink; the frequency has been increased.

Hazard-ID	Cause/Event	Hazard/Incident	Frequency	M.F.	Severity - Person	Severity – Property	Severity - Environment	Risk
	Operation Phase							
1	Tight distance to existing KF, necessary to go further east especially in bad weather.	Trelleborg-Rostock; corridor between KF and KF II N Collision of ferries/Ro-Ro ships with other traffic	4	1	4	4	3	8
2	Tight distance to existing KF, necessary to go further east especially in bad weather	Trelleborg-Rostock; corridor between KF and KF II N Collision of ferries/Ro-Ro ships with other traffic	3	1	3	3		6
3	Raw material extraction from Kriegers Flak (between the two existing OWFs) up to Copenhagen. Sand dredgers expected to sail east of KF II N	Sand dredger collides with other traffic	3	1	3	3		6

4	Raw material extraction from Kriegers Flak (between the two existing parks) to Femern. Unclear if sand dredgers are expected to sail southeast and down route T (Kadetrenden) or southwest (towards Møn/Falster). Northbound traffic back to the area will likely sail on route T/Kadetrenden up to buoys DW79 and DW80 and northwest into KF to avoid crossing traffic separation	Sand dredger collides with other traffic	3	1	3	3		6
5	Traffic west of KF North is at risk (wind from the west) of drifting into the park during blackout	Drifting allision with turbines	3	1	3	3		6
6	Maintenance traffic to both parks. Traffic will come from the west either Klintholm or Rødvig	Collision between service vessel and traffic on route	3	1	3	2	2	6
7	Fishing generally declining but there may be an increased likelihood of allision with wind turbine	Collision between fishing vessel and wind turbine	2	0.01	3	2	2	3
8	Passenger ship comes too close to the turbine	Passenger/cruise ship hits wind turbines	2	0.01	4	3	3	4
9	Passenger ship comes too close to the turbine	Blade hits passenger/cruise ship	3	1	4	3	0	7
10	Tanker hits turbine	Tanker hits turbine	3	0.01	3		4	5
11	Lack of space for existing north/southbound traffic east of TSS west of KF North	Leisure boats enter TSS zone with a higher likelihood of collision. Low speed, inability to react (updated frequency is based on all collisions in the modelling area)	4	1	3	2	2	7
12	Lack of space for existing north/southbound traffic east of TSS west of KF North	Leisure boats come too close to wind turbines. Low speed, inability to react, allision with turbines	3	1	2	2	2	5
13	Motor sailors may have increased interest in the turbine area. Sailing boats will generally stay away (spoiled wind)	Ship-turbine allision	3	0.1	3			5
14	Ship-turbine allision	Mast on large sailing ships higher than the free height to the blade	2	1	3			5
15	Rügen to Klintholm: Large number of both motor sailors and sailing boats will sail through the OWFs	Ship-turbine allision.	3	1	3	2	2	6
20	Ships coming from Trelleborg meet southbound traffic west of KF North. Possibility of not seeing ships if there is poor visibility along with poor radar coverage due to the park. Confusion between many information due to lanterns on turbines	Ship-ship collision	4	1	4	4	3	8
21	Ships coming from Bornholm meet NE-bound traffic south of KF South. Possibility of not seeing ships if there is poor visibility along with poor radar coverage due to the park. Confusion between many information due to lanterns on turbines	Ship-ship collision	4	1	4	4	3	8

22	Concentration of ships south of KF North of different types of ships with different speeds increases the possibility of collision	Ship-ship collision	4	1	3	3	3	7
23	Mixing of leisure craft and other ship traffic between KF north and KF increases the possibility of collision	Ship-ship collision	4	1	3	2	2	7
25	There are transformer platforms (expected only one in each park) between the turbines	Ship-Transformer allision	3	1	4	4		7
Construction Phase								
26	With a work zone of 500m, it will be narrow on ferry route.	Trelleborg-Rostock (TT/Stena-line) Collision with other traffic. E.g., lack of space for evasive manoeuvre.	5	1	4	4	3	9
27	With a work zone of 500m, it will be narrow on ferry route	Trelleborg-Rostock (TT/Stena-line), allision with turbines/foundation	3	1	3	3		6
29	Pleasure vessel-turbine allision	Large number of both motor sailors and sailing boats may attempt to sail through	3	1	3	2	2	6
30	Ship-ship collision	Large number of both motor sailors and sailing boats sail around	4	1	3	2	2	7
32	Cable laying vessel crosses main traffic west of OWFs	Collision between ship and cable laying vessel	2	1	4	3	3	6
33	Pleasure vessels do not respect work area	Collision between ship and work vessel	7	0.001	3	2	2	7
34	Ships do not respect work area	Collision between ship and work vessel	5	0.001	3	3	3	5

6.4.1 Risk of collision due to OWF structures masking ships on collision course

Hazards 20 and 21 address the possibility of OWF structures hiding ships sailing behind the OWF. In general, this is addressed by PIANC /14/, section 4.2.1 “COLREG 7c) Risk of collision", discussing ships departing an OWF, where ships on the main route may have difficulty to assess the collision potential (Closest Point of Approach) by radar's difficulty to discriminate between fixed and moving targets inside the OWF. PIANC /14/ recommends that ships should keep a distance of 1.5 NM from an OWF to have sufficient time to respond to ships departing from within or from behind an OWF. KF II OWF South is sufficiently apart from the main sailing routes. For KF II OWF North, there may be a concern for the ships from Møn to TSS "Off Falsterbrorev" as well as for the (rerouted) ships from Trelleborg to Gedser. With respect to ships from Møn to TSS "Off Falsterbrorev”, the distance of the route centreline to the OWF is about 1.2 NM. However, there is no transfer route through KF II OWF North (the commercial extraction shipping is expected not to pass the OWF, see section 5.3.3, route “D”) and the CTVs servicing the OWF will depart either on the southern corner or at a course parallel to the main shipping route. Rerouted ships from Trelleborg to Gedser can pass at sufficient distance south of KF II OWF North but may choose to pass close to the eastern corner for the shortest route. Potential conflicts may arise with pleasure boats choosing to pass through this corner, but these boats will follow a course almost parallel to the commercial ships heading in the same direction (from Trelleborg to Møn), and there will be more than 1.5 NM from departing the OWF to crossing the commercial ships.

With respect to the specific Hazards 20 and 21, it seems that there is sufficient free visual and radar range to take adequate action to avoid collision, see Figure 16. In both cases there is a waypoint (point where course has to be changed to remain in fairway) after free visual range has been reached. The hazard of not being able to anticipate in due time seems to be overestimated during the HAZID. However, the incident frequency at the waypoint east of Møn shows an increase of about 0.007 per year during operational phase (which is about twice the Base Case frequency).

This is not related to lack of awareness, but increased complexity at this point with different crossings. The initial assessment has therefore been retained in Table 7, but the risk does not arise from lack of visibility or radar coverage.

This means that after the updated frequencies, 4 hazards remain “red” (unacceptable without further risk reduction), 21 hazards are “yellow” (risk to be reduced to as low as reasonably practicable) and 2 hazards become “green” (risk is broadly acceptable.

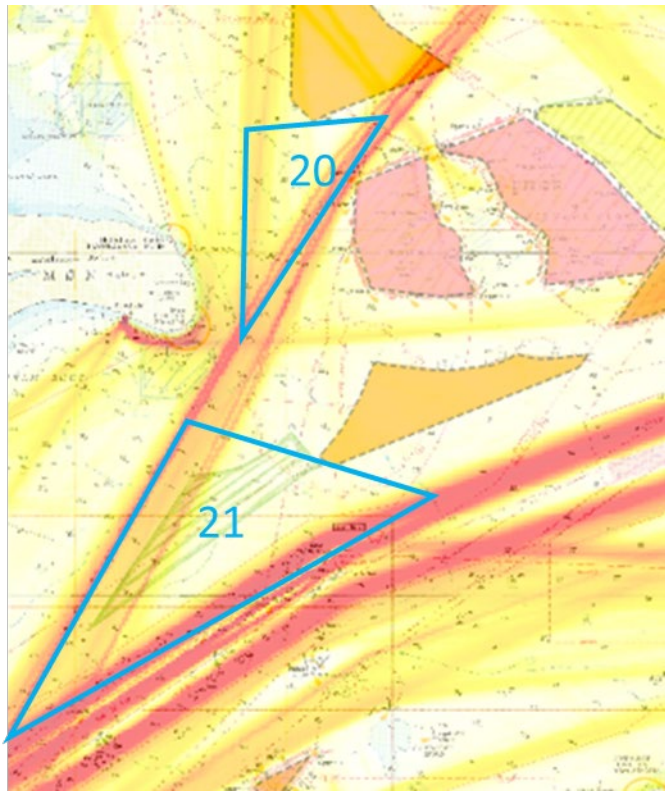


Figure 16 Hazards 20 and 21 (Table 7): free visual (and radar) range of ships sailing from Trelleborg merging with shipping towards Møn (Triangle 20) and of ships sailing from Bornholm through Kadetrenden merging shipping from Møn to TSS “S of Gedser”.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Discussion of the results

The questions to be answered by this study are:

- Does the wind farm lead to an unacceptable number of allisions 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?

7.1.1 Allisions between ships and offshore wind turbine generators

The HAZID study (Appendix D, Table 7) addresses the hazard of ships colliding into WTGs. The additional number of allisions during construction and operation of KF II OWF amounts to about 1 incident per 100 years, of which the majority involves pleasure boats. The present results predict a relative high number of allision of pleasure boats during the Operational Phase, mainly due to boats sailing across the KF II OWF. Ships remaining on fairways outside the OWF have lower risk of colliding: no more than 10% of allisions (both drifting and under power) involve Ro-Ro cargo ships or general cargo ships, and less for other large commercial ship types. These risks are considered acceptable if reduced to as low as reasonably practicable.

The probability of allision of a passenger ship remains improbable, in the order of 1 incident per 100 000 years.

7.1.2 Change in number of groundings

The data in Table 2 and Table 4 show a small decrease (no more than 3%) in the number of groundings during construction and operation of the KF II OWF. This cannot be considered a significant change, and it is concluded that the KF II OWF and the related change of shipping patterns does not affect the risk of grounding.

7.1.3 Change in number of ship-ship collisions

The data in Table 2 and section 6.3 show that the largest increase in risk is related to an increased frequency of ship-ship collisions. The largest increase is related to the ferry and Ro-Ro cargo route between TSS “S of Gedser” and Trelleborg. An extra change of course is required, and especially during operational phase, the alternative patterns of pleasure boats may lead to multiple crossings points. Also, the added traffic out of Klintholm leads to increased risk East of Møn.

Overall, the additional risk of ship-ship collisions is considered unacceptable without further risk reduction.

7.2 Recommendations

On the basis of both the HAZID workshop and findings from the quantitative study, the following four (4) recommendations are proposed:

1. Move the South-east corner of KF II OWF North further North so that the regular traffic between TSS “S of Gedser” and Trelleborg does not need to make another course change, and the shortest route for pleasure boats between Møn and Gislövsläge Marina does not cross the OWF and remains parallel with the commercial shipping route to Trelleborg. This will reduce the risk of hazard ID 1 (now rated unacceptable, see Table 7)
2. Consider limiting the extent of the work zone during construction along the boundary on the south-side of the KF II OWF North or at least perform a more detailed analysis of such limitation on navigational safety. This will reduce the risk of hazard ID 26 (now rated unacceptable, see Table 7)
3. Consider implementing Work Vessel Coordination, both during the Construction Phase and Operational Phase, to minimize conflicts between work vessels or service vessels (CTVs) sailing out of Klintholm and commercial

traffic east of Møn. This will reduce the risk of ship-ship collision at this position (now rated unacceptable, see section 7.1.3)

4. Consider other means of guidance or separation of ships east of Møn, or at least perform a more detailed analysis of such means on navigational safety, to mitigate the complex pattern of crossing ship movements (both commercial and recreational) and to minimize the risk of ship-ship collision at this position (risk now rated unacceptable, see section 7.1.3)

The following general recommendations were already identified during the HAZID study and are repeated for completeness (more details are included in Appendix D)

5. Ensure emergency response to stop WTGs when a drifting or uncontrolled ship threatens to collide with a OWF structure
6. Investigate the need to establish additional coast-based Radar stations or AIS base-stations.
7. Consider the use of surveillance vessels to enforce the compliance with the prohibited work areas during the Construction Phase.
8. Exploit all possible communication channels to inform recreational sailors and fishermen about prohibited work areas and other temporary restrictions or arrangements.
9. Consider reserving or assign specific VHF channels for communication between work vessels, service vessels and Work Vessel Coordination.

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APPENDIX A. **EXISTING SHIPPING PATTERNS**

(Note: the background chart used in this appendix is outdated and shows marking by pencil of other planned OWFs which have been abandoned).

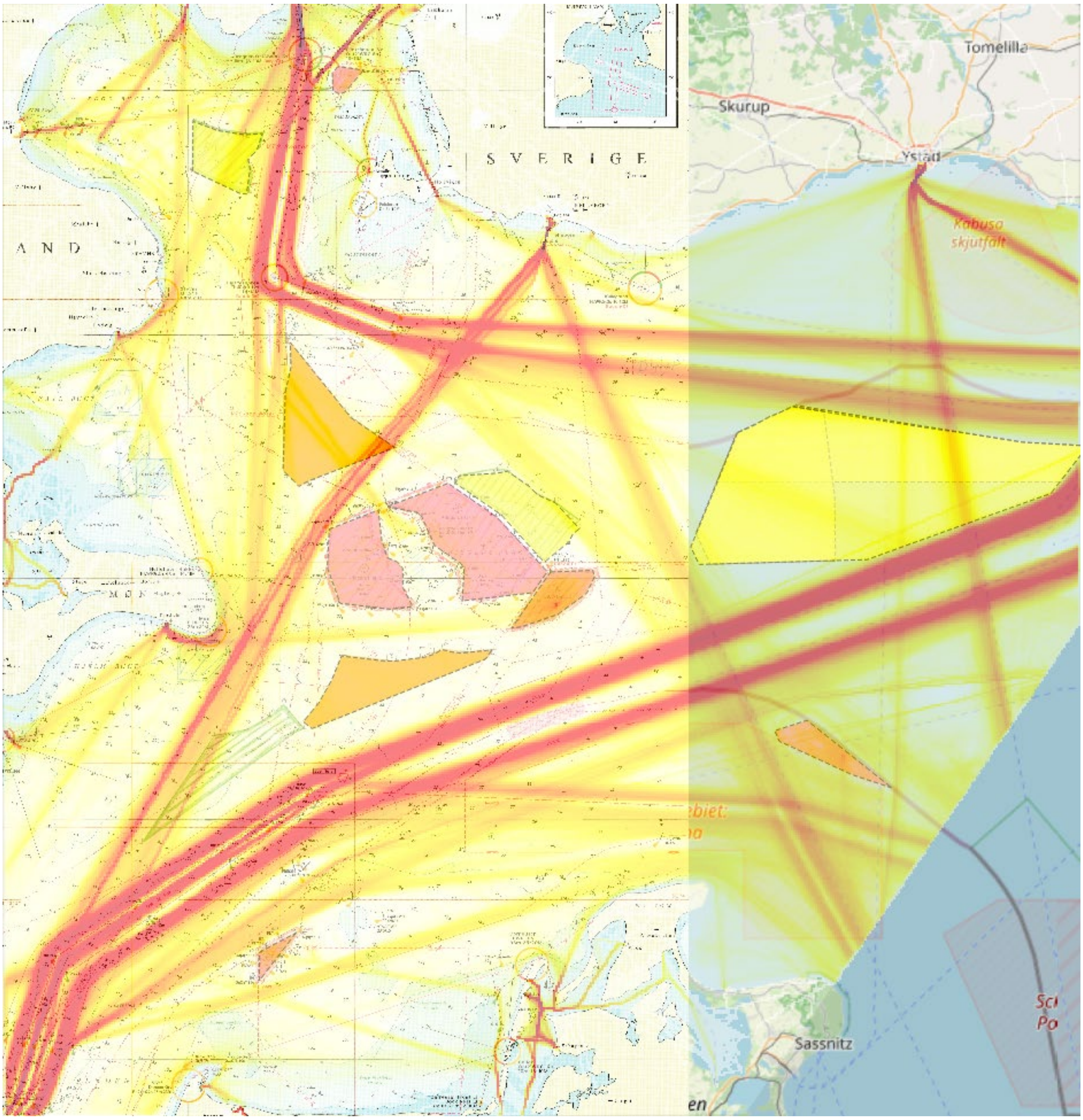

Figure A 1 Traffic density all ship types

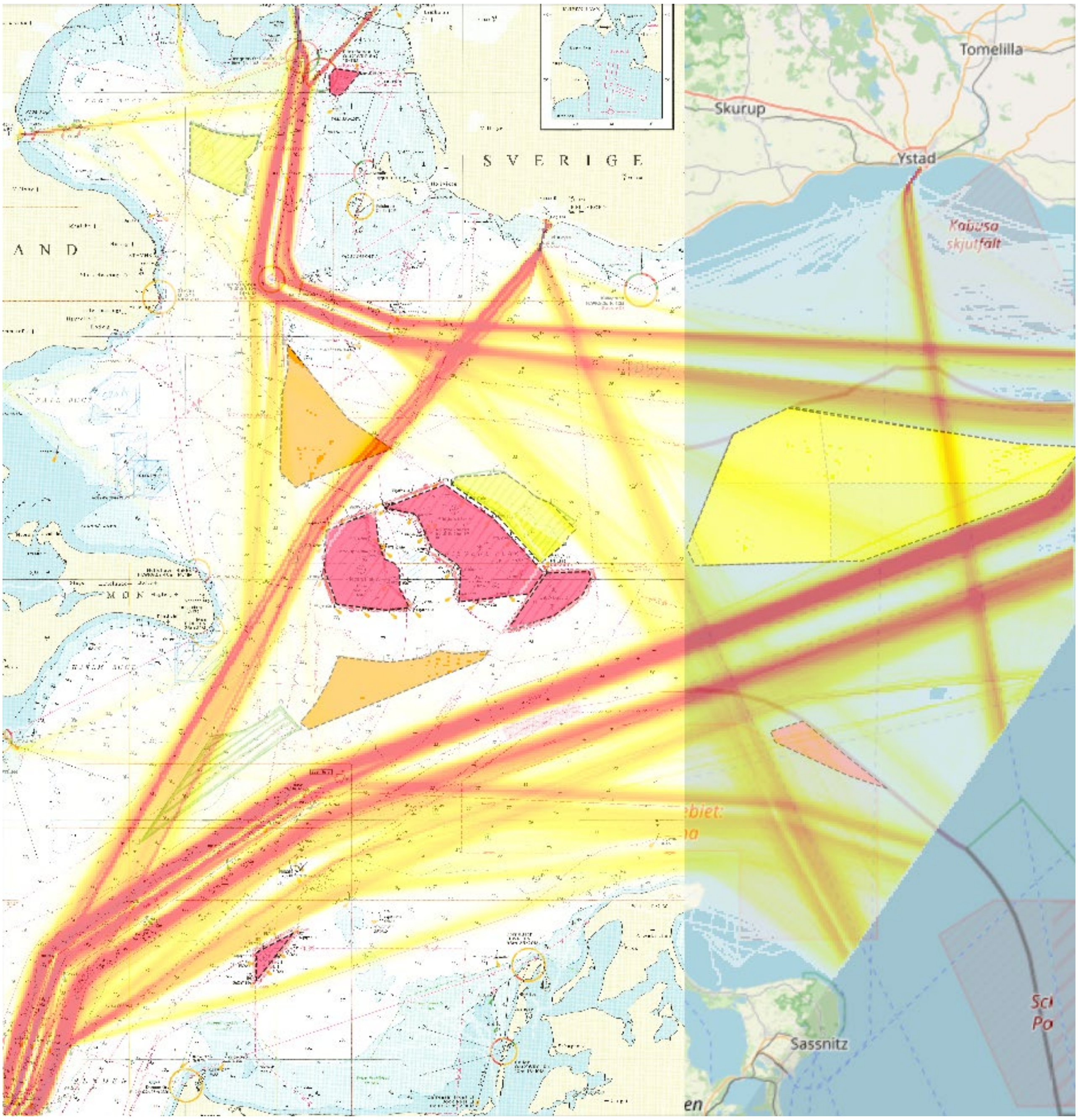

Figure A 2 Traffic density cargo ships (Container ship, General cargo ship, Bulk carrier, Ro-Ro cargo ship)

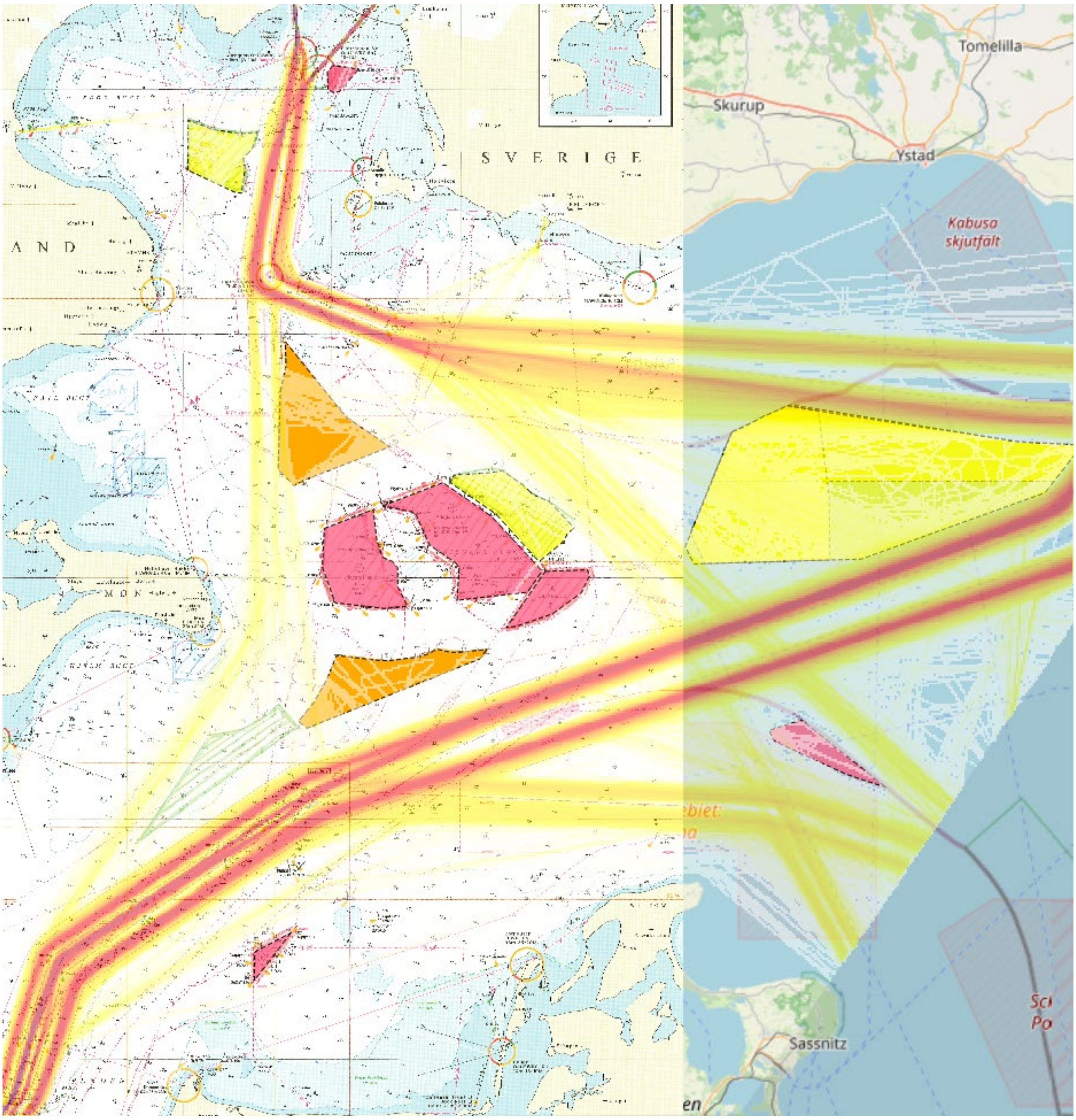

Figure A 3 Traffic density Tanker ships (Crude oil tanker, oil products tanker, Chemical tanker, Gas tanker)

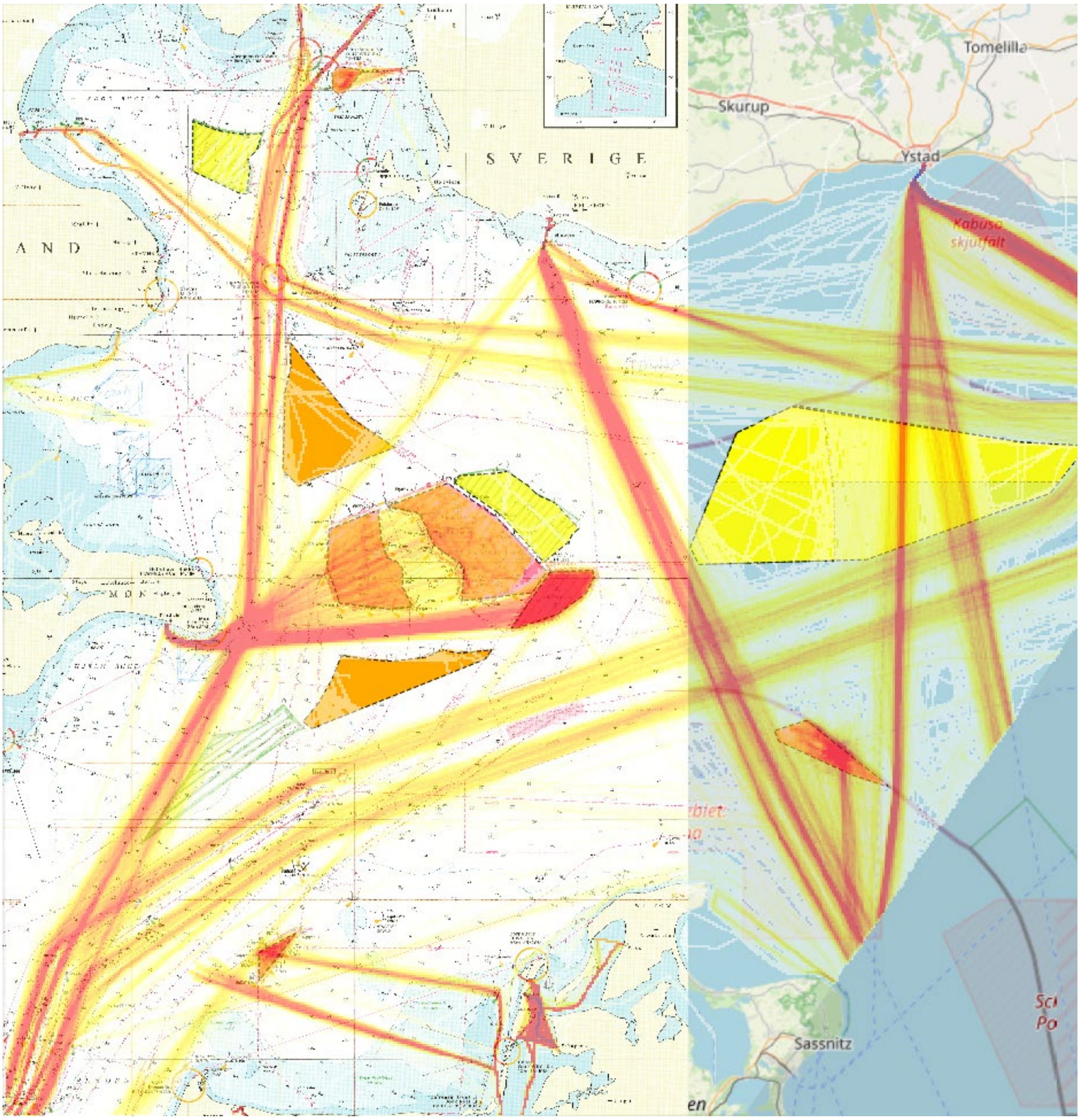

Figure A 4 Traffic density Passenger ships (Passenger ship, Fast ferry)

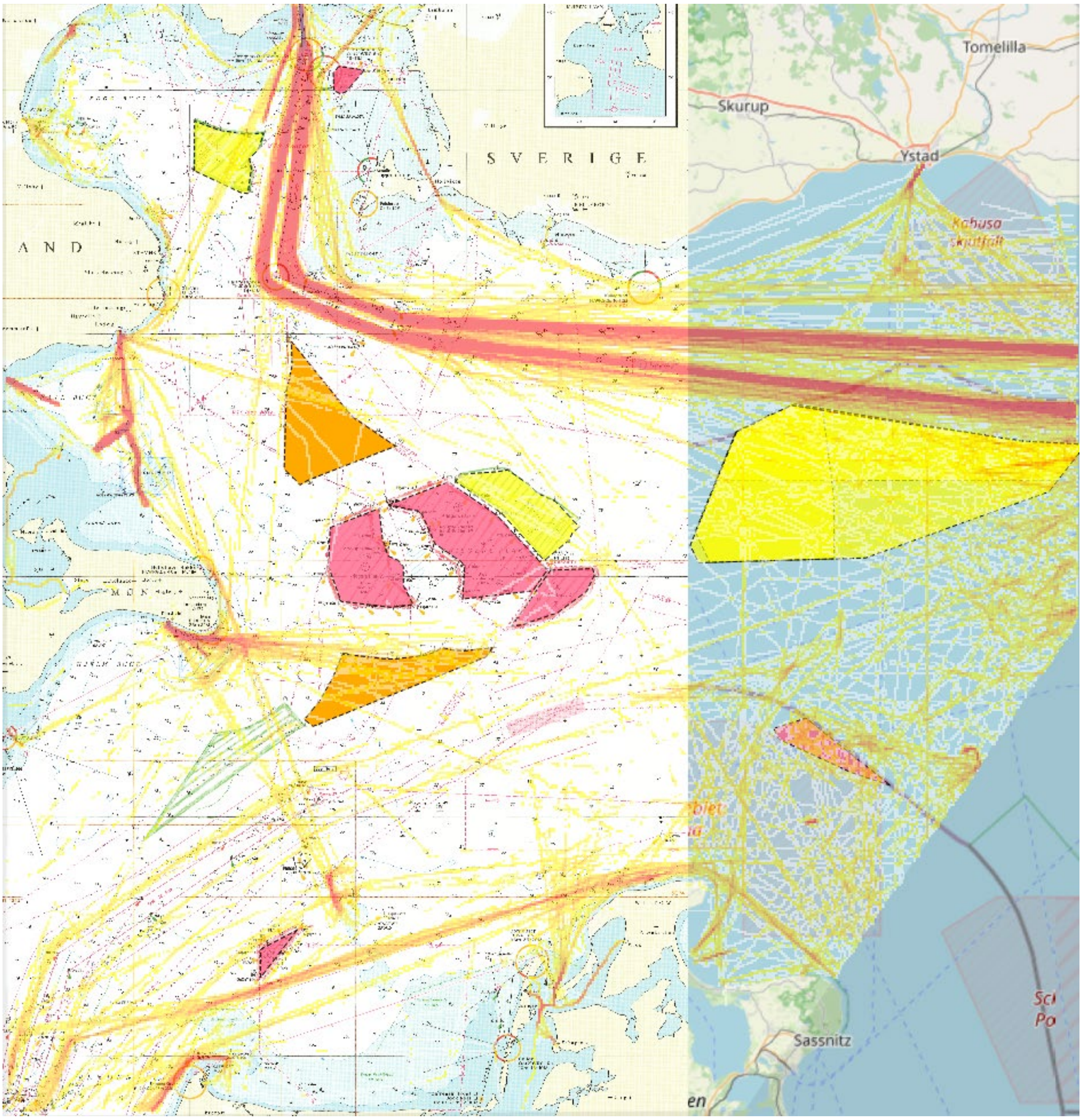

Figure A 5 Traffic density Fishing ships

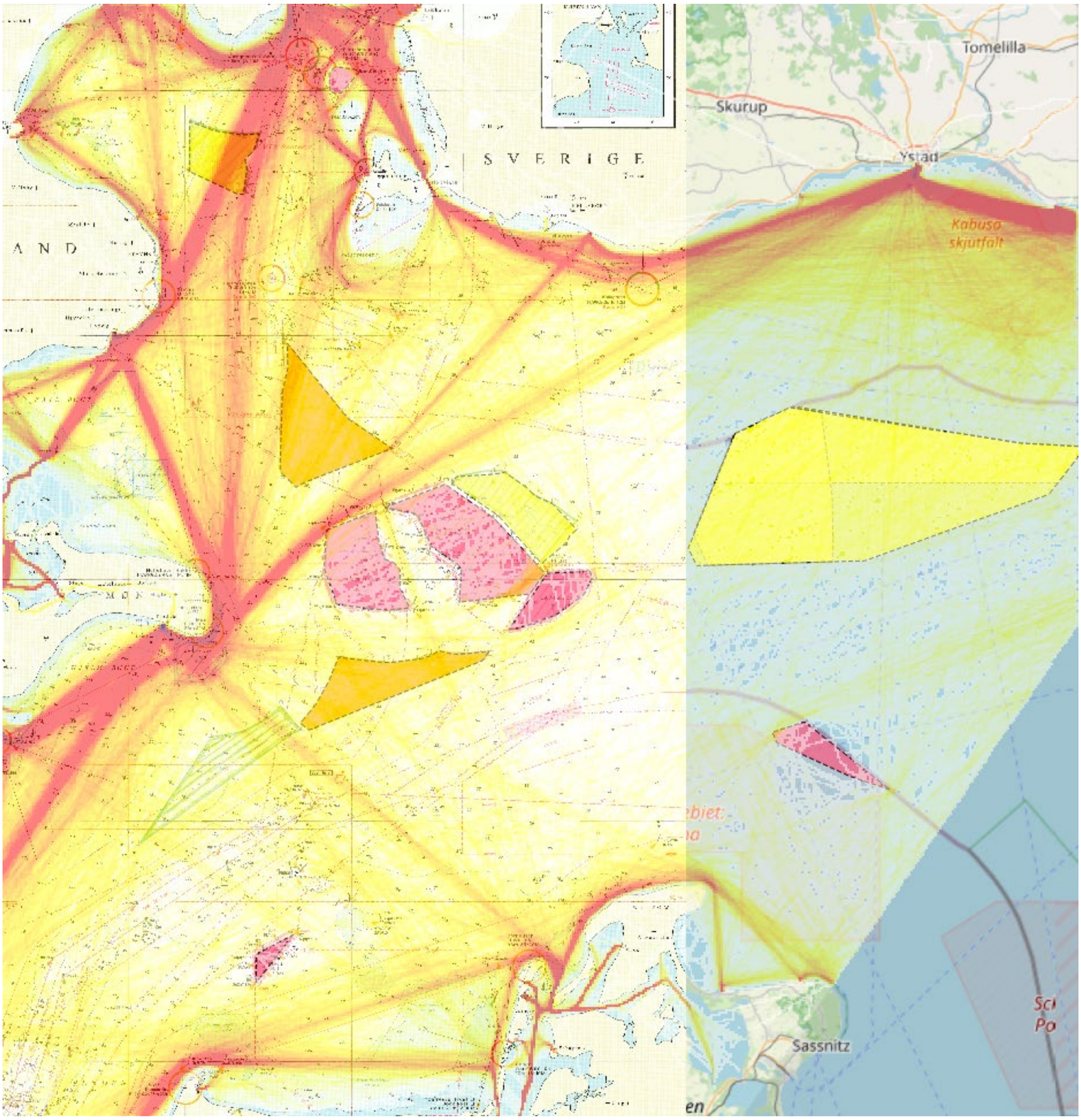

Figure A 6 Traffic density Pleasure boats

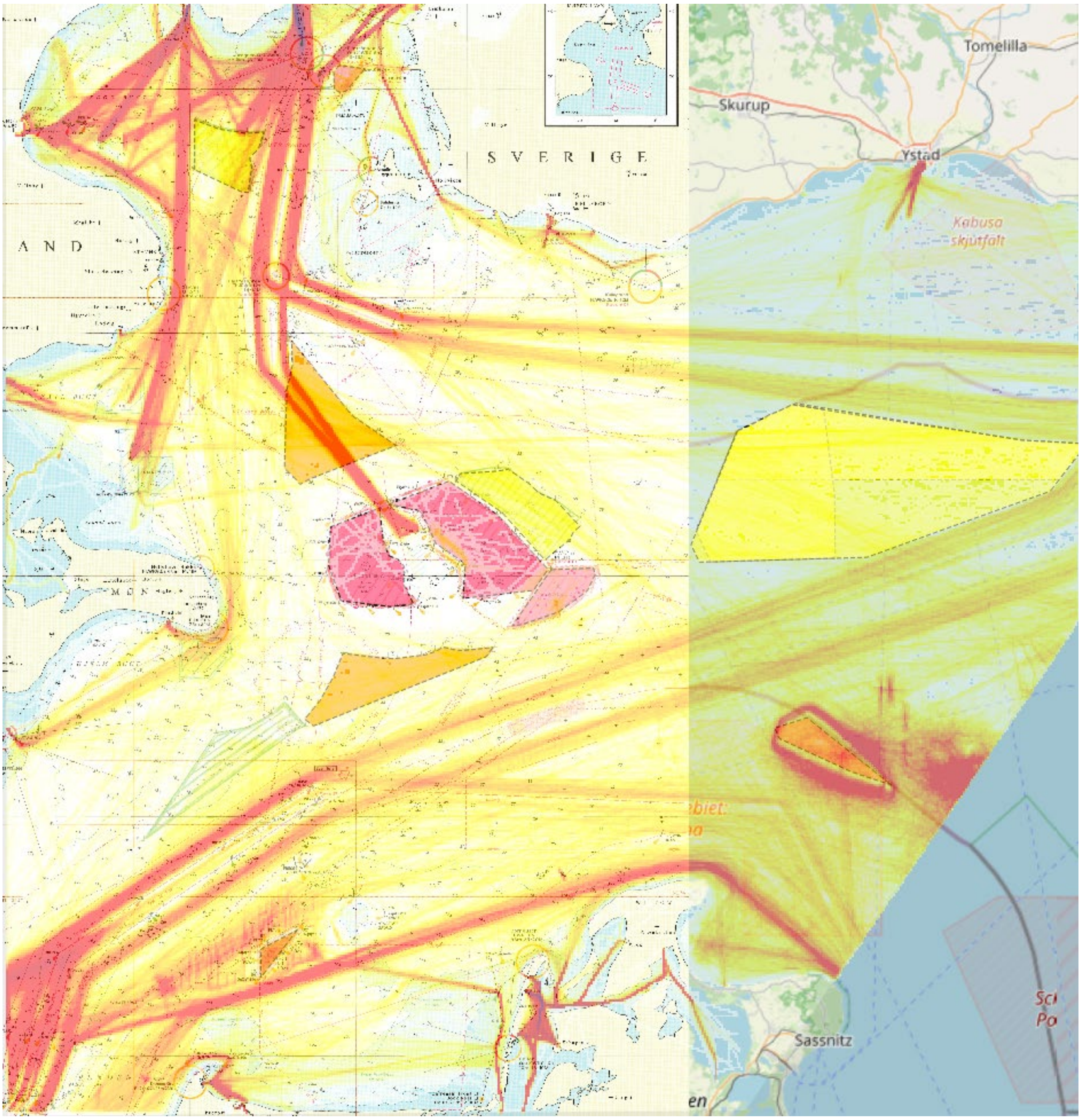

Figure A 7 Traffic density Other ships (Support ships, Other ships)

APPENDIX B. OWF TURBINE POSITIONS

Danish existing wind-turbine positions, position coordinates according to UTM 32 Euref89

Object ID	Easting	Northing
Ukendt 570715000000088650	625628	6135118
Ukendt 570715000000088674	625193	6135008
Ukendt 570715000000088681	624757	6134898
Ukendt 570715000000088698	624321	6134788
Ukendt 570715000000088704	623885	6134678
Ukendt 570715000000088711	623448	6134568
Ukendt 570715000000088728	623012	6134457
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Kriegers Flak 570715000001542595	741899	6107869
Kriegers Flak 570715000001542601	743789	6107689
Kriegers Flak 570715000001542618	740639	6107234
Kriegers Flak 570715000001542625	743609	6106429
Kriegers Flak 570715000001542632	740549	6105979
Kriegers Flak 570715000001542649	743789	6105169
Kriegers Flak 570715000001542656	740369	6104899
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Kriegers Flak 570715000001542670	744149	6103639
Kriegers Flak 570715000001542687	740459	6102739
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Kriegers Flak 570715000001542700	740189	6101749
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Kriegers Flak 570715000001542793	743429	6098419
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Object ID	Easting	Northing
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Uoplyst 570714700000013799	730662	6176293
Uoplyst 570714700000013805	730642	6176111

Existing Swedish and German wind-turbine positions, position coordinates according to UTM 32 Euref89

ID	Easting	Northing
EnBW Baltic 2 A1	377314	6090888
EnBW Baltic 2 B1	377894	6091719
EnBW Baltic 2 B2	378079	6090925
EnBW Baltic 2 C1	378472	6092514
EnBW Baltic 2 C2	378652	6091796
EnBW Baltic 2 C3	378819	6091075
EnBW Baltic 2 D1	379064	6093320
EnBW Baltic 2 D2	379230	6092634
EnBW Baltic 2 D3	379384	6091986

ID	Easting	Northing
EnBW Baltic 2 D4	379549	6091317
EnBW Baltic 2 E1	379614	6094064
EnBW Baltic 2 E2	379764	6093429
EnBW Baltic 2 E3	379915	6092794
EnBW Baltic 2 E4	380065	6092159
EnBW Baltic 2 E5	380215	6091524
EnBW Baltic 2 F1	380161	6094804
EnBW Baltic 2 F2	380307	6094199
EnBW Baltic 2 F3	380453	6093593

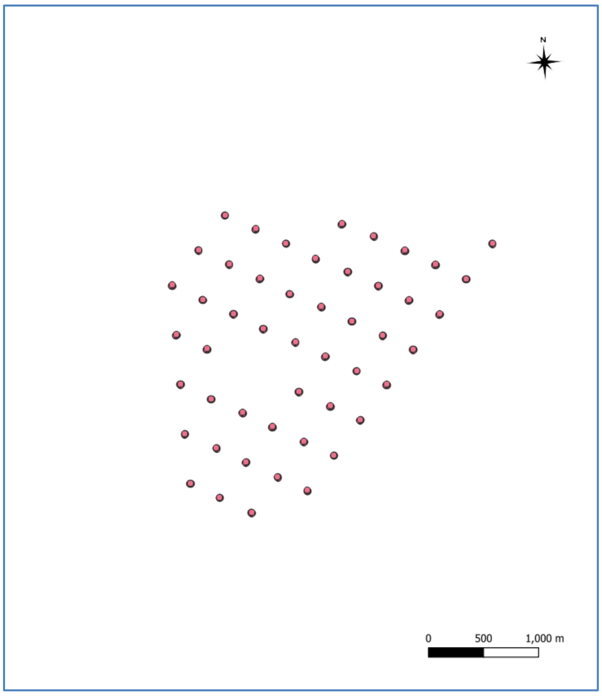
DNV

ID	Easting	Northing
EnBW Baltic 2 F4	380599	6092987
EnBW Baltic 2 F5	380745	6092381
EnBW Baltic 2 F6	380892	6091775
EnBW Baltic 2 G1	380691	6095520
EnBW Baltic 2 G2	380862	6094804
EnBW Baltic 2 G3	381032	6094088
EnBW Baltic 2 G4	381202	6093373
EnBW Baltic 2 G5	381373	6092657
EnBW Baltic 2 G6	381543	6091942
EnBW Baltic 2 H1	381255	6096265
EnBW Baltic 2 H2	381392	6095679
EnBW Baltic 2 H3	381529	6095092
EnBW Baltic 2 H4	381666	6094506
EnBW Baltic 2 H5	381804	6093919
EnBW Baltic 2 H6	381941	6093333
EnBW Baltic 2 H7	382078	6092746
EnBW Baltic 2 H8	382215	6092160
EnBW Baltic 2 I1'	381785	6096969
EnBW Baltic 2 I2	381946	6096319
EnBW Baltic 2 I3	382097	6095680
EnBW Baltic 2 I4	382248	6095041
EnBW Baltic 2 I5	382399	6094402
EnBW Baltic 2 I6	382550	6093763
EnBW Baltic 2 I7	382701	6093123
EnBW Baltic 2 I8	382852	6092484
EnBW Baltic 2 J1'	382589	6096520
EnBW Baltic 2 J2'	382444	6097125
EnBW Baltic 2 J3	382734	6095915
EnBW Baltic 2 J4	382879	6095310
EnBW Baltic 2 J5	383025	6094705
EnBW Baltic 2 J6	383170	6094100
EnBW Baltic 2 J7	383315	6093495
EnBW Baltic 2 J8	383461	6092890
EnBW Baltic 2 K1'	383163	6097142
EnBW Baltic 2 K2'	383315	6096509
EnBW Baltic 2 K3	383467	6095877
EnBW Baltic 2 K4	383619	6095244
EnBW Baltic 2 K5	383771	6094612
EnBW Baltic 2 K6	383924	6093979
EnBW Baltic 2 K7	384076	6093347
EnBW Baltic 2 L1'	383875	6097146
EnBW Baltic 2 L2'	384037	6096466

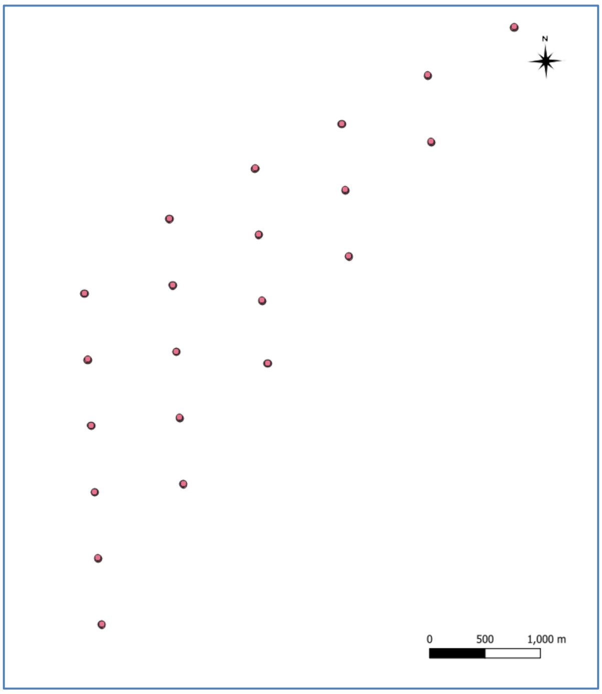
ID	Easting	Northing
EnBW Baltic 2 L3	384199	6095786
EnBW Baltic 2 L4	384361	6095105
EnBW Baltic 2 L5	384523	6094425
EnBW Baltic 2 L6	384685	6093745
EnBW Baltic 2 M1'	384582	6097138
EnBW Baltic 2 M2'	384762	6096397
EnBW Baltic 2 M3	384942	6095657
EnBW Baltic 2 M4	385122	6094917
EnBW Baltic 2 M5	385302	6094176
EnBW Baltic 2 N1'	385306	6097126
EnBW Baltic 2 N2'	385458	6096494
EnBW Baltic 2 N3	385609	6095862
EnBW Baltic 2 N4	385760	6095230
EnBW Baltic 2 N5	385912	6094599
EnBW Baltic 2 O1'	386147	6096609
EnBW Baltic 2 O2'	386016	6097160
EnBW Baltic 2 O3	386278	6096059
EnBW Baltic 2 O4	386410	6095508
EnBW Baltic 2 P1'	386718	6097183
EnBW Baltic 2 P2'	386894	6096457
EnBW Baltic 2 OSS	382322	6093242
EnBW Baltic 1 "1	346945	6054077
EnBW Baltic 1 "2	346925	6053477
EnBW Baltic 1 "3	346905	6052880
EnBW Baltic 1 "4	346885	6052279
EnBW Baltic 1 "5	346865	6051680
EnBW Baltic 1 "6	346844	6051081
EnBW Baltic 1 "7	347767	6054683
EnBW Baltic 1 "8	347747	6054082
EnBW Baltic 1 "9	347727	6053481
EnBW Baltic 1 "10	347707	6052882
EnBW Baltic 1 "11	347687	6052283
EnBW Baltic 1 "12	348578	6055071
EnBW Baltic 1 "13	348558	6054472
EnBW Baltic 1 "14	348538	6053873
EnBW Baltic 1 "15	348540	6053307
EnBW Baltic 1 "16	349391	6055406
EnBW Baltic 1 "17	349371	6054805
EnBW Baltic 1 "18	349351	6054206
EnBW Baltic 1 "19	350201	6055776
EnBW Baltic 1 "20	350181	6055174
EnBW Baltic 1 "21	351014	6056143

ID	Easting	Northing
Lillgrund ER S1	359870	6152751
Lillgrund ER S2	360137	6153050
Lillgrund ER S3	360403	6153348
Lillgrund ER S4	360670	6153647
Lillgrund ER S5	360936	6153945
Lillgrund ER S6	361203	6154244
Lillgrund ER S7	361469	6154543
Lillgrund ER S8 (OSS)	361736	6154841
Lillgrund 2R S1	359347	6152597
Lillgrund 2R S2	359612	6152897
Lillgrund 2R S3	359877	6153196
Lillgrund 2R S4	360143	6153496
Lillgrund 2R S5	360408	6153796
Lillgrund 2R S6	360673	6154095
Lillgrund 2R S7	360938	6154395
Lillgrund 2R S8	361203	6154695
Lillgrund 3R S1	359071	6152758
Lillgrund 3R S2	359337	6153056
Lillgrund 3R S3	359604	6153355
Lillgrund 3R S4	359871	6153653
Lillgrund 3R S5	360138	6153951
Lillgrund 3R S6	360404	6154250
Lillgrund 3R S7	360671	6154548
Lillgrund 3R S8	360937	6154846
Lillgrund 4R S1	358816	6152907
Lillgrund 4R S2	359081	6153206
Lillgrund 4R S3	359346	6153505
Lillgrund 4R S5	359875	6154103
Lillgrund 4R S6	360140	6154402
Lillgrund 4R S7	360405	6154701
Lillgrund 4R S8	360670	6154999
Lillgrund 5R S1	358807	6153361
Lillgrund 5R S2	359071	6153657
Lillgrund 5R S4	359598	6154248
Lillgrund 5R S5	359862	6154544
Lillgrund 5R S6	360126	6154840
Lillgrund 5R S7	360390	6155136
Lillgrund 6R S1	358806	6153812
Lillgrund 6R S2	359072	6154110
Lillgrund 6R S3	359338	6154408
Lillgrund 6R S4	359604	6154706
Lillgrund 6R S5	359870	6155005

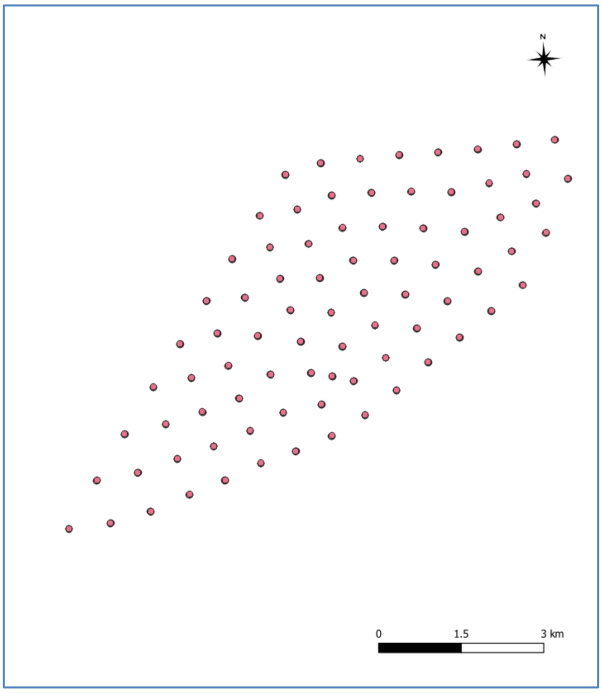
ID	Easting	Northing
Lillgrund 7R S1	358805	6154263
Lillgrund 7R S2	359072	6154561
Lillgrund 7R S3	359338	6154859
Lillgrund 7R S4	359605	6155158
Lillgrund 8R S1	358806	6154714
Lillgrund 8R S2	359072	6155011
Lillgrund 8R S3	359339	6155307



Wind turbine positions Lillgrund



Wind turbine positions EnBW Baltic 1



Wind turbine positions EnBW Baltic 2

APPENDIX C. ASSUMPTION REGISTER

C.1 Probabilistic Model Assumptions

<table>
<tr><td>Revision / Date</td><td>Cf. Earlier studies as per 2021, adopted for MH2030 studies 2024-01-10 (Fast Ferry causation reduction)</td></tr>
<tr><td>Purpose</td><td>Definition of the probabilistic parameters in the IWRAP tool</td></tr>
<tr><td>Description</td><td>
Human failure relevant parameters
<table>
<tr><th>Ship-ship collision incidents</th><th>Causation factors</th></tr>
<tr><td>Merging</td><td>1.3E-4 (IWRAP default)</td></tr>
<tr><td>Crossing</td><td>1.3E-4 (IWRAP default)</td></tr>
<tr><td>Bend</td><td>1.3E-4 (IWRAP default)</td></tr>
<tr><td>Head-on</td><td>0.5E-4 (IWRAP default)</td></tr>
<tr><td>Overtaking</td><td>1.1E-4 (IWRAP default)</td></tr>
<tr><td>Area moving</td><td>0.5E-4 (IWRAP default)</td></tr>
<tr><td>Area stationary</td><td>0.5E-4 (IWRAP default)</td></tr>
<tr><td>Ship grounding incidents</td><td></td></tr>
<tr><td>Grounding - forget to turn</td><td>1.6E-4 (IWRAP default)</td></tr>
<tr><td>Ship-turbine collision incidents</td><td></td></tr>
<tr><td>Collision - forget to turn</td><td>1.6E-4 (IWRAP default, as for grounding)</td></tr>
<tr><td>Ship type specific reductions</td><td>Causation reduction factors</td></tr>
<tr><td>Passenger ships</td><td>20 (IWRAP default)</td></tr>
<tr><td>Fast ferries</td><td>1 (IWRAP default is 20), see justification</td></tr>
</table>
Machine failure relevant parameters
<table>
<tr><td>Drift speed</td><td>1 knot(s) (IWRAP default)</td></tr>
<tr><td>Probability of successful anchoring</td><td>0.98 (Assessment by Søfartstyrelsen based on seabed conditions)</td></tr>
<tr><td>Max. anchor depth</td><td>7 times design draught (IWRAP default)</td></tr>
<tr><td>Min. anchor distance from ground</td><td>3 times ship length (IWRAP default)</td></tr>
<tr><td>Probability of self-repair</td><td>0 for t < 0.25 hour
$1-\frac{1}{1.5(t-0.25)+1}$ for t > 0.25 hour</td></tr>
<tr><td>Blackout frequencies</td><td></td></tr>
<tr><td>RoRo and passenger ships</td><td>0.1 per year (IWRAP default)</td></tr>
<tr><td>Other vessels</td><td>1.75 per year (IWRAP default)</td></tr>
</table>
</td></tr>
<tr><td>Impact</td><td>The calculated incident frequencies are linearly proportional with the causation factors</td></tr>
<tr><td>Justification/ References</td><td>/1/ IWRAP Mk II, Basic Modelling Principles for Prediction of Collision and Grounding Frequencies, (draft working document), Rev. 4, 2008.03.09, Peter Friis-Hansen, Technical University of Denmark.
/2/ IWRAP Mk2 Extended v6.6.0 (software)</td></tr>
</table>

	The causation reduction for Fast Ferries (High Speed Craft) has been reduced to 1 (i.e., no reduction) as the relevant HSC operations in the model areas (Kattegat and Western Baltic) are mainly limited to the Crew Transfer Vessels servicing the OWFs, normally transporting no more than 20 passengers. This assumption is supported by the preliminary conclusions of the Dutch Safety Board concerning the fatal accident involving Fast Ferry “De Tiger” and water taxi (comparable to Crew Transfer Vessel) “Stormloper”, 2023-10-21 near Terschelling, NL.
Prepared by	Nijs Jan Duijm
Review	Lasse Sahlberg-Nielsen

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C.2 Drift directions

Revision / Date	First Issue / 2024-01-16
Purpose	IWRAP requires probabilities for drift directions
Description	Drift directions are derived from wind data from the Global Wind Atlas /1/.

As likelihood and consequence of drifting is largest for high wind speeds (storm), the probabilities have been taken from the wind speed rose (showing the relative contribution to the averaged windspeed from each wind direction) rather than the wind frequency rose (the distribution of wind direction occurrence).

This data is distributed over 12 sectors, IWRAP uses 8 drift directions, so the data is redistributed:

Kriegers Flak (55.13493°N, 12.85675°E)						
Data from Global Wind Atlas			Transferred to 8 sectors			
12 sectors	Center (degr.)	Fraction of yearly averaged windspeed	8 sectors	Center (degr.)	Fraction of yearly averaged windspeed	Drift direction
1	0	0.03	1	0	0.05	S
2	30	0.02	2	45	0.05	SW
3	60	0.05	3	90	0.13	W
4	90	0.09	4	135	0.09	NW
5	120	0.08	5	180	0.12	N
6	150	0.06	6	225	0.19	NE
7	180	0.06	7	270	0.29	E
8	210	0.11	8	315	0.09	SE
9	240	0.17				
10	270	0.2				
11	300	0.09				
12	330	0.05				
Sum		101%	Sum		101%	

Kattegat (56.386543°N, 11.66748°E)						
Data from Global Wind Atlas			Transferred to 8 sectors			
12 sectors	Center (degr.)	Fraction of yearly averaged windspeed	8 sectors	Center (degr.)	Fraction of yearly averaged windspeed	Drift direction
1	0	0.04	1	0	0.06	S
2	30	0.02	2	45	0.04	SW
3	60	0.04	3	90	0.11	W
4	90	0.07	4	135	0.10	NW
5	120	0.08	5	180	0.14	N
6	150	0.07	6	225	0.21	NE
7	180	0.07	7	270	0.25	E
8	210	0.14	8	315	0.09	SE
9	240	0.17				

10	270	0.16				
11	300	0.1				
12	330	0.04				
Sum		100%	Sum		100%	

Impact	The distribution of drift direction affects the number of drifting allisions in relation to the location of the structure and the traffic leg
Justification/ References	/1/ https://globalwindatlas.info/en/ /2/ IWRAP Mk II, Basic Modelling Principles for Prediction of Collision and Grounding Frequencies, (draft working document), Rev. 4, 2008.03.09, Peter Friis-Hansen, Technical University of Denmark.
Prepared by	Nijs Jan Duijm
Review	Lasse Sahlberg-Nielsen

DNV

C.3 Fraction of Pleasure Vessels using AIS

Revision / Date	First Issue / 2023-03-16
Purpose	AIS is not obligatory for smaller vessels such as Pleasure Vessels (including smaller fishing vessels and other small commercial craft). In order to include a realistic number of pleasure vessel in the assessment, it is necessary to assume what fraction of pleasure vessels is using AIS
Description	According to the Lynetteholm report /1/, comparison of visual observations of Pleasure Vessel passages and AIS data for 6 days in August 2018 and September 2019 through channels close to Copenhagen, the number of visually observed vessels is 10.4 +/- 3.4 times the number of vessels observed by AIS. This number (10.4) will be applied for “domestic” Pleasure Vessels (Pleasure Vessels not registered in Austria, Belgium, Germany, Netherlands or Switzerland). For foreign pleasure vessels (from A, B, D, NL or S), a factor of 2.8 will be used following an analysis of foreign ships visiting Klintholm Harbour (See justification below) For the Kattegat model area, the AIS data as analysed by IWRAP shows 33478 pleasure Vessel Trips. According to the country code of the MMSI numbers, 10411 trips, i.e. 31%, have been by foreign vessels (Austria, Belgium, Germany, Netherlands, Switzerland). Therefore, it is estimated that the actual number of Pleasure Vessel trips in the Kattegat area is 0.31*2,8 + 0.69*10.4 = **8.0** times the number of trips as registered by AIS. The uncertainty range is between 5.6 and 10.4. For the Kriegers Flak model area, the AIS data as analysed by IWRAP shows 35006 pleasure Vessel Trips. According to the country code of the MMSI numbers, 17221 trips, i.e. 49%, have been by foreign vessels (Austria, Belgium, Germany, Netherlands, Switzerland). Therefore, it is estimated that the actual number of Pleasure Vessel trips in the Kattegat area is 0.49*2.8 + 0.51*10.4 = **6.7** times the number of trips as registered by AIS. The uncertainty range is between 4.8 and 8.4.
Impact	The number of Pleasure Vessel relate linearly to the number of incidents related to Pleasure Vessels.
Justification/ References	/1/ Ramboll, SEJLADSANALYSE FOR LYNETTEHOLM – BAGGRUNDSRAPPORT, Doc ID 1100038380-1940442988-101, 2020 /2/ Emails Rigo Jørgensen Klintholm havn, to DNV, dated 2024-01-10 8:28 and 9:59 *Justification on factor for foreign Pleasure vessels:* Klintholm Harbour is frequently visited by foreign guests from mainly Germany, but also Austria, Belgium, The Netherlands and Switzerland. For these countries, the Klintholm Harbour master has registered the overnight stays in 2022, being 7105 nights /2/. By comparing these numbers with the AIS registrations (using the country code as included in the MMSI number) of Pleasure Vessels visiting Klintholm Harbour, it can be estimated how many of the foreign ships apply AIS. Figure C.3-17 shows the passage line used for the analysis.

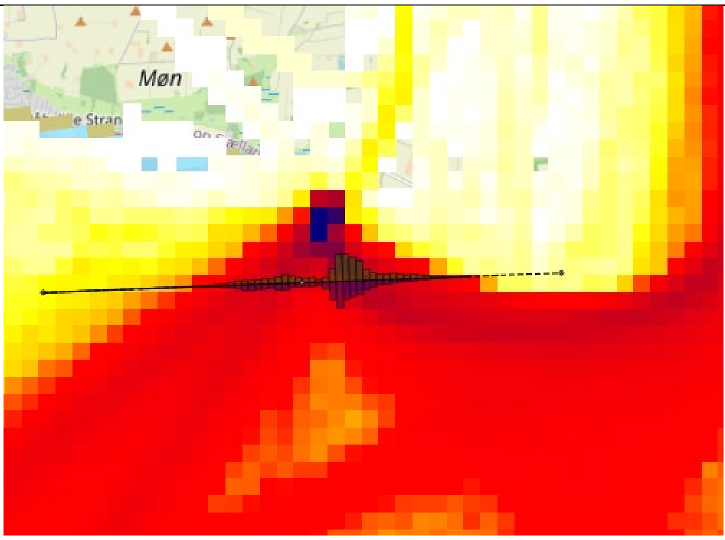


Figure C.3-17 Passage line South of Klintholm Harbour. The traffic density shows pleasure vessels, the distribution along the passage line shows all ships.

In order to relate the passages to the number of stays and nights, the passages of ships have been arranged, so arrivals (North going passage) and departures (South going passage) of single ships have been paired. For these pairs, the number of nights can be extracted on the basis of time of passage. Some passages could not be paired (e.g. because ships have kept close to coastline to the West, or had AIS turned off during arrival or departure, or AIS analysis did not identify passage). Results of the analysis is in Table C.3-8. An outlier of a stay duration of 44 days (Figure C.3-18) has been subtracted from the number of nights from paired arrivals and departures.

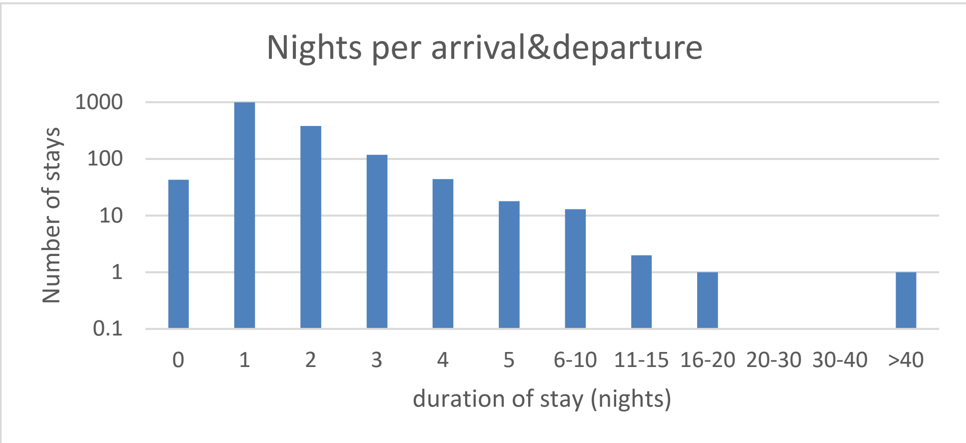


Figure C.3-18 Distribution of duration of stay per visit of AIS-equipped pleasure vessels (from A, B, D, NL or S). The duration of >40 days is considered erroneous (departure not registered correctly)

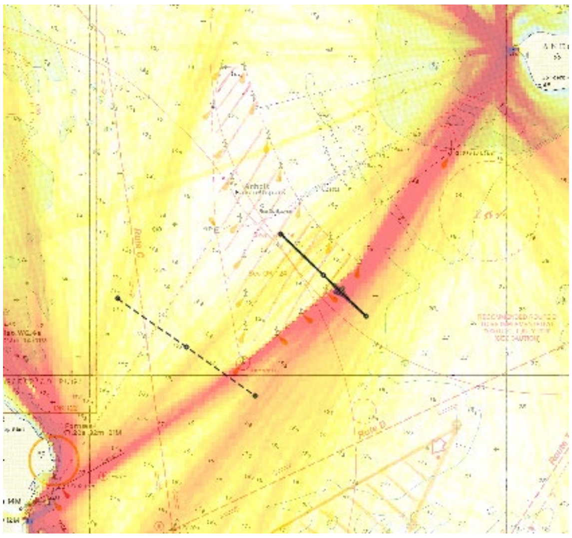
Table C.3-8 Analysis of AIS arrivals and departures at Klintholm Harbour in 2022

Total registered guest nights (Klintholm Harbour)	7105
Nights from paired arrivals and departures (AIS)	2510
Paired arrivals and departures (AIS)	1616

DNV

	Averaged nights per stay for paired arrivals and departures | 1.55 Unpaired arrivals or departures (AIS), sum | 230 Corresponding overnight stays of unpaired arrivals or departures | 357* Expected total overnight stays (AIS) | 2867 Ratio between registered guest nights and nights w/AIS Best estimate | 2.5* Highest estimate (conservative) | 2.8* ** *) It is assumed that the average duration of a stay of foreign pleasure vessels without AIS or unpaired visits with AIS is the same as for the vessels with paired visits with AIS, 1.55 night per stay. **) the highest estimate is based on paired arrivals and departures only. As it is not intended to underestimate the number of total pleasure vessels, a factor of 2.8 will be used for the foreign pleasure vessels (vessels from A, B, D, NL and S).
Prepared by	Nijs Jan Duijm
Review	Lasse Sahlberg-Nielsen

C.4 Number of Pleasure Vessels crossing OWF

Revision / Date	First Issue / 2024-01-09
Purpose	Estimating how many Pleasure Vessels will decide to cross an OWF rather than sail around
Description	The fraction of Pleasure Vessels that decide to cross though an OWF rather than sailing around the OWF is calculated based on the relative increase in sailing distance with this formula, where the extra sailing distance is the difference between the length of the route around the OWF and the shortest sailing distance through the OWF: $$Fraction = \left(\frac{extra\ sailing\ distance}{shortest\ sailing\ distance\ through\ OWF}\right)^{0.4135}$$
Impact	Sailing through an OWF will lead to more allisions with OWF structures
Justification/ References	From AIS data for 2022 for the Kattegat area it can be deducted how many ships are passing through the Anholt OWF rather than passing to the South of the OWF when sailing between the harbours of Grenaa and Anholt. The traffic was analysed using a "passage line", Figure C.4-19 and Figure C.4-20.  **Figure C.4-19 Traffic density plot between Grenaa Harbour and Anholt Harbour for the whole year 2022, showing most traffic (including ferries) passing South of the Anholt OWF. The black line indicates the passage line for which the analysis is made. Density plot shows Pleasure Vessels; passage line distribution shows all ships.**

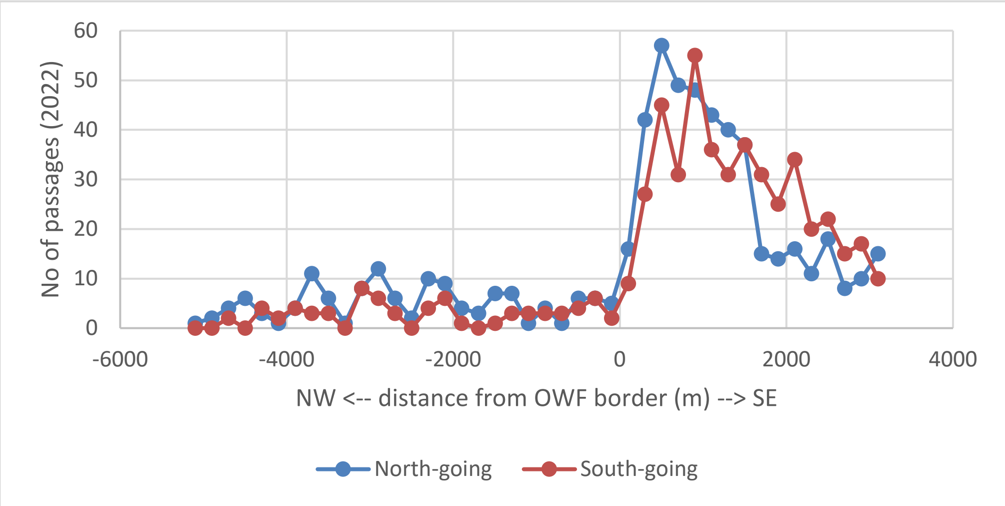


Figure C.4-20 Distribution of Pleasure Vessels crossing the passage line.

In total 130 and 71 Pleasure Vessels passed through OWF in northerly and southerly direction, respectively (between -5200 and 0 m in Figure C.4-20) against 361 and 327 vessels passing outside the OWF (between 0 and 2000 m). So, between 18% and 26% passed through the OWF.

It is expected that the longer the detour around the OWF, the more boats will decide to cross the OWF instead. There will be other factors determining this decision, including means of propulsion (sailing boats tending to avoid dirty wind inside the OWF) and sailing conditions (e.g., wind direction).

Detour length can be considered relative and absolute. The direct route from Grenaa to Anholt harbour crossing the OWF is 23.4 NM, whereas the route around the OWF would take 24.3 NM, i.e., an extra distance of 0.9 NM (absolute) or 3.8% (relative).

No other data is available, and further assumptions are speculative, but here it is assumed that when the sailing distance is doubled (relative), all boats will decide to cross. For this case, given a sailing speed of 5 to 10 knots, this would mean that a crossing of 3 to 5 hours would become 6 to 10 hours. These two points (a fraction of 26% with a relative increase of distance of 3.8% and a fraction of 100% at a doubling of the distance) are fitted with a power function with exponent 0.4135, Figure C.4-21

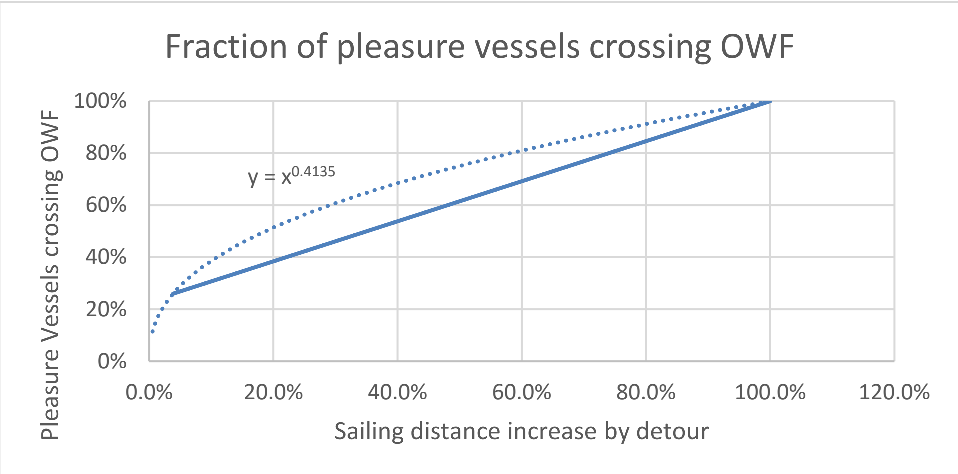
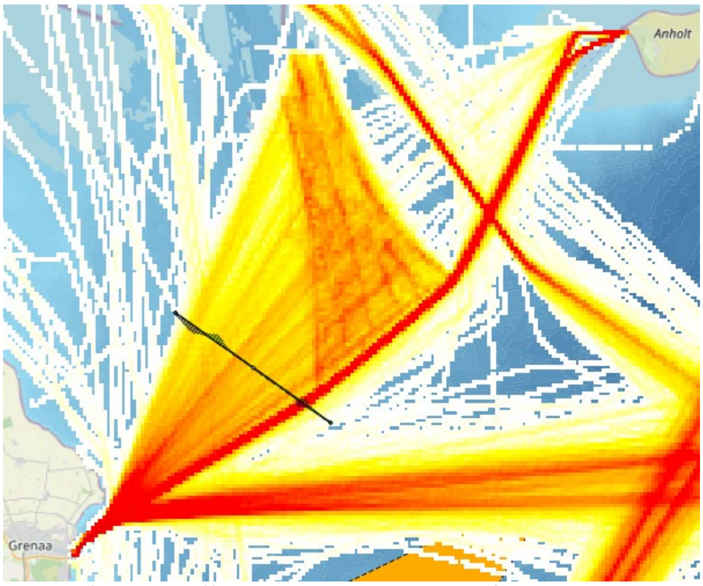


Figure C.4-21 relation between fraction crossing OWF and extra sailing distance.

Prepared by	Nijs Jan Duijm
Review	Lasse Sahlberg-Nielsen

C.5 Number of Crew Transfer Vessel operations for new OWF

Revision / Date	First Issue / 2024-01-09 Updated / 2024-02-22 – data from existing Kriegers Flak added
Purpose	Estimating additional service traffic generated by new OWFs
Description	Crew Transfer Vessels classified as "Fast Ferry" (HSC – High Speed Craft) are expected to perform 5 return trips per year per wind turbine. Average speed of a CTV during transit is 17 m/s
Impact	Additional ship traffic crossing existing shipping routes may cause additional incidents
Justification/ References	AIS data for 2022 in the Kattegat area show CTV's servicing Anholt OWF from Grenaa Harbour. This traffic was analysed across a "passage line",  **Figure C.5-22 Traffic density plot between Grenaa Harbour and Anholt OWF for the whole year 2022. The black line indicates the passage line for which the analysis is made. Density plot shows passenger ships (including HSC); passage line distribution shows all ships.** Three Crew Boats, with AIS classification "Fast Ferry" (HSC – High Speed Craft) were identified, performing 533 North going passages and 570 South going passages. It is assumed that the highest number corresponds with the number of visits, and representative for the service traffic (some of the outbound trips may have been passing outside the passage line) The OWF exists of 111 wind turbines of 3.6 MW each. This suggests that an OWF generates about 5 service trips per year per wind turbine. This will be used to estimate the additional service vessel traffic generated by new OWFs. There is quite some difference in average speed for outbound (North going) and inbound (south-going) service traffic, 11.9 and 16.6 m/s, respectively. For the new traffic, an average speed of 17 m/s will be assumed (high speed being more hazardous) *As additional evidence the study for Kriegers Flak shows that HSC to existing Kriegers Flak (Leg 39 in the IWRAP model) include 343 HSC trips West bound, and 346 trips East bound.*

	Given 72 turbines in the existing Kriegers Flak OWF, 360 trips would correspond to 5 trips per turbine.
Prepared by	Nijs Jan Duijm
Review	Lasse Sahlberg-Nielsen

C.6 Mapping trips to legs

Revision / Date	First Issue / 2023-03-16
Purpose	Generate traffic distribution along legs from AIS data, IWRAP Extract Model Data
Description	The width of legs is defined manually, attempting to ensure that all relevant traffic is covered by a leg. Parameters used for extracting model data: Season: not used (IWRAP default) Angle: 25 Degr (IWRAP default is 10 degr.) Bin size: 100 m Max time: 900 s (IWRAP default, maximum time between AIS records, if time is longer new trip is started) Min calculated speed: Disabled (IWRAP default) Max calculated speed: 100 kn (IWRAP default) Max distance: 4000 m (IWRAP default, maximum distance between AIS record, if longer new trip is started) Calculated geographical boundary used (IWRAP default) New algorithm disabled (IWRAP default)
Impact	The traffic assigned to legs will be used for the calculation of number of incidents. It is important to ensure that a maximum amount of traffic that can cause incidents is assigned to a leg, traffic not assigned to a leg will not be included in the calculations
Justification/ References	The angle is set at 25 degrees, so that also reasonable misalignment between leg direction and course still leads to assignment to that leg. Especially relevant to Pleasure Vessel traffic not aligned with leg definition.
Prepared by	Nijs Jan Duijm
Review	Lasse Sahlberg-Nielsen

APPENDIX D. **HAZID REPORT**

The HAZID report is provided as a pdf attachment within this pdf file.

About DNV

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