REPORT.

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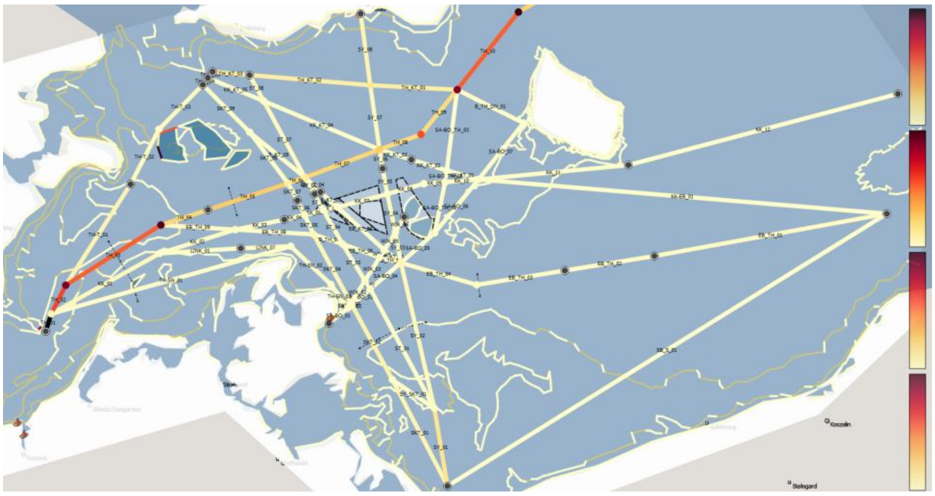
NORTH AND BALTIC SEA

Navigation Shipping Study

Expert's study on shipping traffic flows in the North and Baltic Seas and options to enhance the safety of shipping in the future

Work Package 4 – Analysis of EO2



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APPENDICES

1 EXECUTIVE SUMMARY

ABL performed a nautical risk study in the area of the Baltic, at the boundary between the Danish, German, Polish, and Swedish jurisdictions.

The traffic study was performed with a particular interest in the current and future offshore windfarm development areas, to inform the stakeholder nations as they undertake their maritime spatial planning. This work was commissioned by the German Federal Maritime and Hydrographic Agency.

The purpose of the study was to analyse from a navigational and risk perspective the Baltic Sea area around the German EEZ for possible areas for offshore wind development, with particular interest to examine the feasibility of the westward extension of area EO2 of the German MSP.

The study considered the existing offshore wind development in the area of relevance, between Kadetrenden and Bornholmsgat, and between Swinoujscie and Trelleborg, as well as windfarms at the pre-construction stage, that have already obtained permits. Also, based on engagement with other stakeholder nations – Denmark, Poland, and Sweden – the study considered the best current knowledge on the area allocated for future offshore wind development in their respective territorial waters and EEZs.

The current risk in the broader model, based on the 2019-2020 navigation routes and traffic, was calculated based on the GL guidelines. The analysis produced an annual frequency of 1.1210 vessel-to-vessel collisions, an annual frequency of groundings of 0.3617, and an annual frequency of allisions to OWFs of 0.0673. The calculated values exceed the actual figures extrapolated from the HELCOM accidents database for the same area, which suggest an annual vessel-to-vessel collision probability of 0.77. At the area of focus, to the west of future OWF Arcadis Ost 1, the vessel-to-vessel annual collision probability was calculated to be equal to 0.04776. This corresponds to just over 4% of the total risk in the broader model, and an anticipated return period between incidents of approximately 21 years.

Two different near-future scenarios were considered, addressing the introduction of the Arcadis Ost 1, and the Baltic Eagle OWFs to the maritime space. The “northern” scenario, which is expected to be the prevailing option for navigation, results in an annual vessel-to-vessel collision probability of 1.1100, approximately 1% lower than the current. Groundings remained constant, with the annual probability calculated to be 0.3611. The annual allision probability increased substantially with the introduction of the two OWFs, to a value of 0.3611 a 54% increase from the current. It is noted, however, that most of the rise is attributable to high strike probability from drifting vessels, which is irregularly augmented due to the large extent of the analysis model. Smaller models in line with the 15nm range around development would provide more modest results. At the area of focus, to the west of future OWF Arcadis Ost 1, the calculated vessel-to-vessel annual collision probability increased to 0.06010 (+25.8%). This corresponds to 5.4% of the total risk in the model, and a return period between incidents of approximately 17 years.

The final scenario considered the effect of nominating area EO2-West, which corresponds to the corridor between Arcadis Ost 1 and development area EO2, for offshore wind development. To run this scenario, the traffic currently using this corridor was diverted to the main route connecting Swinoujscie to The Sound and Trelleborg. The analysis produced an annual frequency of 1.1390 vessel-to-vessel collisions, which constitutes a 2.5% increase from the previous scenario, i.e., a 1.5% increase from the current risk levels. The model also yielded an annual frequency of groundings of 0.3611 which is identical to that of the previous scenario and marginally (<1%) lower than the current. The annual frequency of allisions to OWFs was calculated to be 0.09215, a decrease of 12.5% from that of the previous scenario. At the area of focus, to the west of future OWF Arcadis Ost 1, the vessel-to-vessel annual collision probability was calculated to be 0.06678, a further increase of 11% (+40% from current). This corresponds to 5.8% of the total risk in the model and a return period between incidents of approximately 15 years.

Finally, a mitigation scenario was considered analytically, to calculate the impact of extending the recommended route on the Swinoujscie route to The Sound and Trelleborg, to a point past the main SW-NE route (Kadetrenden-Bornholmsgat) and adjusting the traffic characteristics in line with this change. The mitigation proposed, was calculated to have the potential to improve the vessel-to-vessel annual collision probability by almost 3% compared to the previous scenario, and to a value 1.3% lower than the current risk in the system. A further benefit is a 2.5% reduction in allisions compared to the previous scenario (diversion of EO2-West traffic). At the area of focus, to the west of future OWF Arcadis Ost 1, the analysis yielded a vessel-to-vessel annual collision probability of 0.03481. This value constitutes a reduction of 48% compared to the previous scenario, and a reduction of 27% to the current risk in the area. The anticipated return period between incidents in the area post-mitigation increases to 29 years.

An additional analysis was undertaken to investigate the effect of increasing traffic and increasing vessel sizes on the risk in the model. The analysis was performed on the assumption of a 20% increase in transport demand projected for 2040, which is expected to convert to a 4% increase in traffic volume and a 5% increase in the dimensions of vessels. The re-run of the northern diversion risk model for the future demand scenario returned a collision probability increase of the order of 10%. The probability of groundings was found to increase by almost 8%, whilst allisions probability was found to rise by 5%, driven by an increase in powered allisions in excess of 8%.

As expected, the introduction of offshore wind developments in the maritime space leads to an increase in the overall risk in the model and generates areas where the majority of the introduced risk accumulates. Whilst the proposed changes constitute an increase in the collision probability in the affected area, this increase is not to an extent that converts the area into a risk hotspot, with risks that are difficult to manage. The cumulative risk in the area of focus which includes a crossing of the main SW-NE traffic route, remains lower than the risk attributed to any of the remaining crossings to the main route, thus being the safest point to cross from north to south.

Based on the above, the study sees no reason why the risk to navigation associated with the proposed changes cannot be managed, and therefore no reason for the changes not to be implemented.

It is however recommended, that the conditions associated with the management of risk in the area are periodically reviewed, and the evolution of risk is monitored as developments in navigation, traffic, and space allocation occur.

The report recommends the extension of the recommended route to a point to the North of the main SW-NE crossing, which appears to be beneficial in terms of reducing vessel-to-vessel collision risk, and secondarily allision risk in the area of interest. This mitigation measure appears to have the potential to reverse the introduction of risk to the current environment if implemented at the same time as the changes, or in the future control the risk escalation as a result of increasing traffic and vessel sizes.

It is noted that the content of this report is advisory, and the final decisions rest with the German authorities and stakeholders.

2 INTRODUCTION

2.1 General

The European Union "2030 Climate and Energy Framework" requires the member states' compliance with set EU-wide targets and policy objectives for the period from 2021 to 2030. This framework requires that by the year 2030:

At least 40% cuts are achieved in greenhouse gas emissions (from 1990 levels)

At least 32% share of the energy comes from renewable sources

At least a 32.5% improvement is achieved in energy efficiency

The achievement of these climate targets by the EU-member countries is expected to involve heavy investment in renewable energy, most of which is anticipated to come in the form of offshore wind turbines. To achieve the required output, the new offshore wind developments would have to cover a significant area in the maritime space off the coastline of European Union Member States.

Areas of interest include the North Sea and the Baltic Sea. In the North Sea, the east coast is already heavily trafficked by merchant and work vessels, and thus spatial demand is expected to become an important issue in achieving the balance between attributing space to offshore wind developments and maintaining safe and effective shipping traffic. The spatial demand may also increase due to other developments with spatial requirements, such as aquaculture. It is noted however that what is currently envisaged is that in most cases there can be an efficient overlap between offshore wind and aquaculture. In the Baltic, a similar picture is formed, as maritime space is expected to increasingly be claimed by offshore wind developments. This is of particular interest in narrow areas on the West side of the Baltic, including the North of Rugen area that is of interest to the study.

The Baltic Sea constitutes a major trade route for all countries on its coasts, through which the vast majority of exported and imported goods to and from those countries are being shipped. This traffic is then channelled to the North Sea or along the Norwegian coastline as part of the Northern Passage. It is therefore imperative that navigational safety and route efficiency is ensured in the aforementioned areas as new offshore windfarm and other offshore developments are planned.

2.2 Scope of ABL study

The scope of work for the study is split into five work packages:

- WP 1: Traffic analysis
- WP 2: Analysis of SN10

- WP 3: Analysis of EN13
- WP 4: Analysis of EO2
- WP 5: Ad-hoc analysis

The present report comprises Report one of Work Package 4, reporting the outcome of the traffic study for the area of interest around the German Baltic Sea.

2.2.1 Work Package 4

ABL was commissioned to perform an analysis of possible areas for offshore wind in the Baltic Sea, with particular interest to examine from a navigational risk perspective the feasibility of the westward extension of area EO2 of the German MSP.

The scope of the study includes a navigational risk assessment, the proposal of mitigation measures, and will be performed in close consultation with the neighbouring countries. The study is based on the routeing system of the Baltic Sea that influences the study area, including primary and secondary routes, TSS schemes, and other considerations relevant to navigation.

The present work package is based on the traffic analysis conducted as part of WP1 and will consider the possible impact of different scenarios of OWF development on the safety and efficiency of navigation. The study considers best nautical practices, whether the installation of OWFs is feasible given the spatial requirements for shipping, and whether certain areas are necessary for the safety and efficiency of navigation.

Focus is given to the existing offshore wind farms surrounding development plot EO2, i.e., the effect of existing permits for OWF and OWFs in coastal waters.

The outcome of the study will be informed by running TRANSAS simulations of the resulting scenario, to obtain the navigator’s perspective of the induced changes.

2.3 Assumptions and limitations

The analysis is based on the current maritime traffic situation based on Automatic Identification System (AIS) data.

Maritime traffic information was sourced through the availability of historic AIS data for the area of interest assessed in the study as defined in the following paragraphs of the present report.

Safety of Life at Sea (SOLAS) Convention requires all vessels of 300 gross tonnage or more employed in international voyages are equipped with an AIS transceiver since 2002. In recent years, given the improvement of technology and reduced cost of transmitter and receiver equipment, together with the introduction of an additional AIS class standard, several units with a gross tonnage <300 voluntarily became AIS-compliant.

The figures presented in the results of the traffic analysis include all the vessels for which AIS signals were picked up in the study area, SOLAS, and non-SOLAS.

However, a certain number of the latter vessels, such as pleasure craft, military operation involved units, fishing boats, etc.) are subsequently not included in the dataset for the risk study and will not be considered in the risk modelling. Although this is a limitation on the overall number of vessels, the erratic transit of a variety of smaller units would not be representative of the commercial marine traffic in the area of analysis, and thus are of no value to the present assignment.

2.4 Analysis software

The traffic and risk analyses will be performed using the IWRAP (IALA Waterway Risk Assessment Program) Mk2 Version 6.6.2.

IWRAP is a traffic analysis and collision/grounding frequency calculation tool recommended by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA).

2.5 Model development

This section intends to familiarise the reader with the modelling assumptions and parameters used in developing the environment for the present assessment.

2.5.1 Study area Boundaries, Baltic Sea

The study area in the Baltic Sea covers the area of the German jurisdiction to the North and East of Rugen and the area where the Swedish, Danish, Polish, and German EEZ meet. The study area is presented in Figure 1.

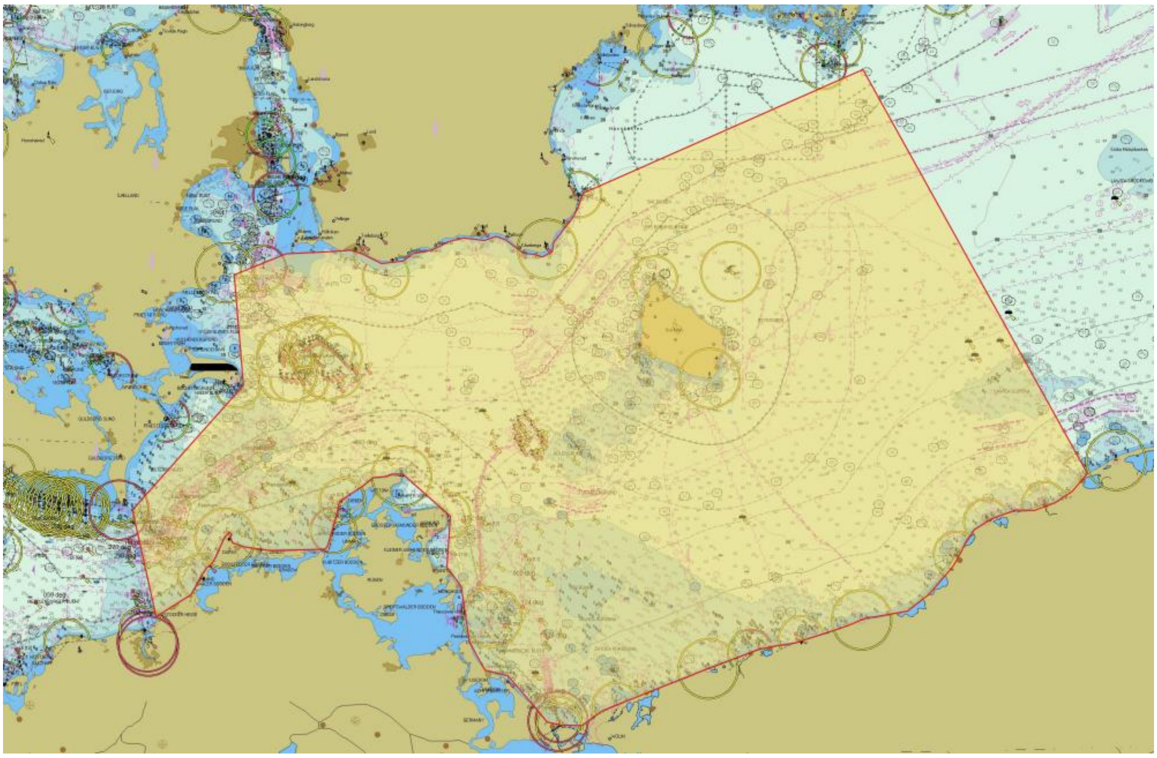

Figure 1: Area of study in the Baltic

The model area extends further to the east of Bornholm Island, to pick up the formation of W-E bound traffic that enters the main area of interest for the study. The same applies to the Kadet Rinne area to the west of Rugen. The study area excludes inland navigable waters as well as port approaches, harbours, anchorages, and roads. These particular areas are generally regulated by the pertinent port authorities. In addition, waters where pilotage is mandatory are subject to a regulatory regime which might differ from coastal and high sea waters, and as such, it might mislead the overall analysis of the marine traffic in said specific areas.

The study area also excludes the Greifswalder Bodden, Kubitzer Bodden, and the passage through Stralsund. These areas are primarily used by small vessels, that do not interfere with the traffic in the study area.

2.5.2 <u>Vessel Traffic and AIS datasets used</u>

ABL was provided with AIS terrestrial data for the years 2019 and 2020, from The Baltic Marine Environment Protection Commission (Helsinki Commission - HELCOM) database, maintaining records of the traffic in the Baltic Sea. Data was converted from the raw AIS NMEA sentence and provided in comma-separated values (csv) files (stored separated for each month) with position reports at an interval of approximately 5 minutes. Vessel size data was derived from the four coordinates present in the AIS message in relation to the location of the transducer antenna. Vessel type was therein included in text form. Because the latter form of reporting does not provide enough granularity in terms of the categories of cargo vessels, the values in the dataset were refined from databases and added to the model at a later stage, using a static list.

timestamp_pretty	timestamp	msgid	targetType	mmsi	lat	long	posacc	sog	cog	shipType	dimBow	draught	dimPort	dimStarboard	dimStern	month	week	imo	country	name	callsign
08/01/2019 01:06:21	1546909581000	3	A	111219504	55.696743	12.56694	0	0	348.5	SAR	1	NA	2	3	19	1	2	NA	SAR	NA	0
08/01/2019 00:31:40	1546907500000	1	A	111219504	55.674335	12.466971	0	102.2	75.9	SAR	1	NA	2	3	19	1	2	NA	SAR	NA	0
08/01/2019 00:25:37	1546907137000	1	A	111219504	55.59104	12.121021	0	11.1	207.4	NA	NA	NA	NA	NA	NA	1	2	NA	SAR	NA	NA
08/01/2019 00:31:35	1546907495000	1	A	111219504	55.6738	12.463239	0	102.2	75.8	SAR	1	NA	2	3	19	1	2	NA	SAR	NA	0
08/01/2019 00:37:45	1546907865000	1	A	111219504	55.69413	12.578887	0	50.3	296.8	SAR	1	NA	2	3	19	1	2	NA	SAR	NA	0
08/01/2019 00:37:35	1546907855000	1	A	111219504	55.69327	12.581877	0	52.1	297.2	SAR	1	NA	2	3	19	1	2	NA	SAR	NA	0
08/01/2019 00:26:39	1546907199000	3	A	111219504	55.593395	12.151878	0	102.2	54.1	SAR	1	NA	2	3	19	1	2	NA	SAR	NA	0
08/01/2019 00:25:34	1546907134000	1	A	111219504	55.59104	12.121021	0	11.1	207.4	NA	NA	NA	NA	NA	NA	1	2	NA	SAR	NA	NA
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08/01/2019 00:07:33	1546906053000	1	A	205093000	55.487034	10.549659	1	6.8	146	UNKNOWN	70	4.4	6	5	10	1	2	7508958	Belgium	NIJPTANGH	ORWE

Figure 2: Sample of HELCOM data.

ABL pre-processed the dataset to filter out irregularities in the form of Maritime Mobile Service Identity (MMSI)[1] duplication leading to vessels reported at a false location and AIS signal jumps.

Additional filtering was applied to MMSIs starting with 0 and 1 (denoting coast stations and search and rescue aircraft). Similarly, MMSIs starting with 8 (handheld devices) and 9 (freeform identity) were also purged from the dataset. A summary of the filtration process is presented in Table 1.

For the risk assessment, the requirement from [01], and [02] is that only SOLAS vessels, in excess of 500GT are considered in the quantitative risk assessment. The guideline however allows the inclusion of smaller vessels in the case the latter are of importance to navigation in the area and follow the standard shipping routes. In the present study, therefore, passenger and crew vessels exceeding 100 GT were kept in the dataset for risk analysis.

Table 1: Data filtering Summary

Total number of MMSI in identifiers in the set	15,898
Total number of MMSI in identifiers between 2xx and 7xx	15,643
Remaining vessels in the traffic model	15,643
Cargo and work vessels ≤ 500 GT, passenger vessels ≤ 100 GT, military, small fishing, and pleasure craft removed	7,100
Total considered in quantitative risk assessment	8,543

The final AIS data timeline loaded in the model is presented in Figure 3 below.

1 MMSI is a 9-digit number assigned by Administrations to each ship station as per Article 19 of ITU Regulations.

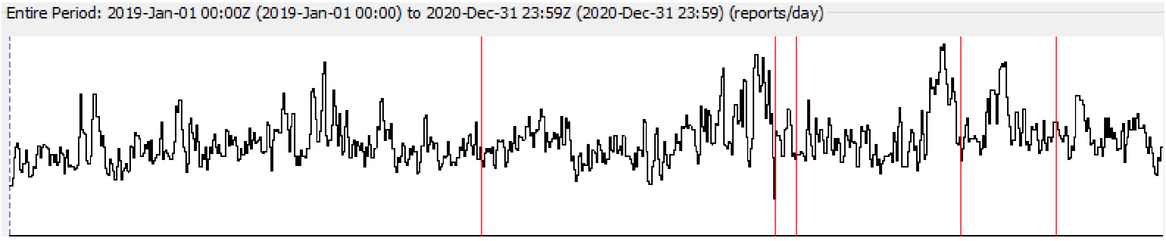


Figure 3: AIS data time distribution.

The sample consistency is of moderate uniformity, with roughly 135,000 reports/day, and a standard deviation of 33,350. Small gaps include the ones marked in red, where the number of samples appears to be missing for intervals of approximately 1-hour on three occasions. There is also a single occasion in April 2020, where data are missing between 22:00 hours on the 29 April and 16:00 hours on the 30 April (18 hours). The influence of those gaps is considered in the factor that converts traffic to an annuity.

2.5.3 Offshore windfarm development areas

As the baseline for the assessment is the current situation (traffic, risk), the existing OWF developments in the study area between 2019 and 2020 have been included in the model. They are incorporated into the model as polygon areas representing the footprint of the developments. The list of the OWFs that were included in the model for the benchmark case is presented in Table 2.

Table 2: Existing OWFs in the Baltic study area

Germany	Denmark
Arkona	Kriegers Flak A
Wikinger	Kriegers Flak B
EnBW Baltic 1	
EnBW Baltic 2	

The second stage of developing the model considers the addition of two OWFs that have currently obtained permits, are at the pre-construction stage, and their construction is expected to start in the near future. The list of the OWFs that were included in the second stage analysis is presented in Table 3.

Table 3: Existing OWFs in the Baltic study area

Germany	
Arcadis Ost 1	
Baltic Eagle	

This constitutes the baseline scenario for examining the effect of vessel traffic increase, based on the projections discussed in section 2.6.7.

The final stage of model development looks at the effect of redirecting the traffic of the corridor between area EO2 and the Arcadis Ost 1 OWF, to use the space as an extension to area EO2. This area will be onwards referred to as EO2-west (EP2W).

2.5.4 The layout of traffic corridors

The traffic corridors for the study were derived based on the AIS data for 2019 and 2020, and the algorithm used by the IWRAP Mk2. The latter composes individual AIS data points into a time series for each vessel. Subsequently, using proximity and speed criteria it extracts the pertinent trips for each vessel. Each trip is a complete and distinct track of the vessel's movement across the area of interest and contributes to qualitative and quantitative information for the assessment.

A density map was generated from the extracted trips, at a resolution of 200m x 200m and is presented in Figure 4.

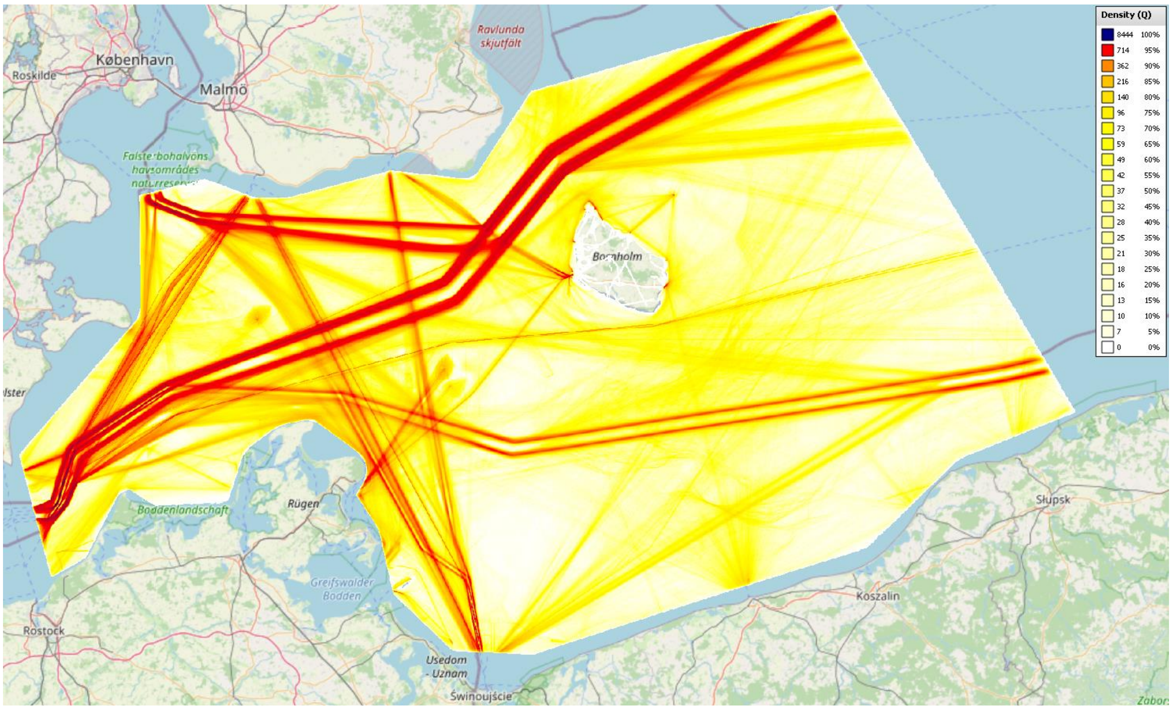


Figure 4: Density map generated for the Baltic Sea study area (resolution: 200m x 200m)

Based on the traffic distribution in Figure 4, a network of traffic corridors ("legs" in IWRAP Mk2) was developed to reflect the current system in place in the area of interest to the study. Each leg was attributed a specific width, reflecting the zone in which the software will look for vessel trips to attribute to it. This was chosen based on what appeared to be the requirement to cover the pertinent path as it is discernible on the density plot. A directional filter angle of 10 degrees was used as the alignment tolerance for each leg. This means that any vessel trip that intersects the leg in its width and has a heading deviating up to +/- 10 degrees from the direction of the leg axis, is added to the distribution for the leg. The network of legs comprising the analysis model is depicted in Figure 5.

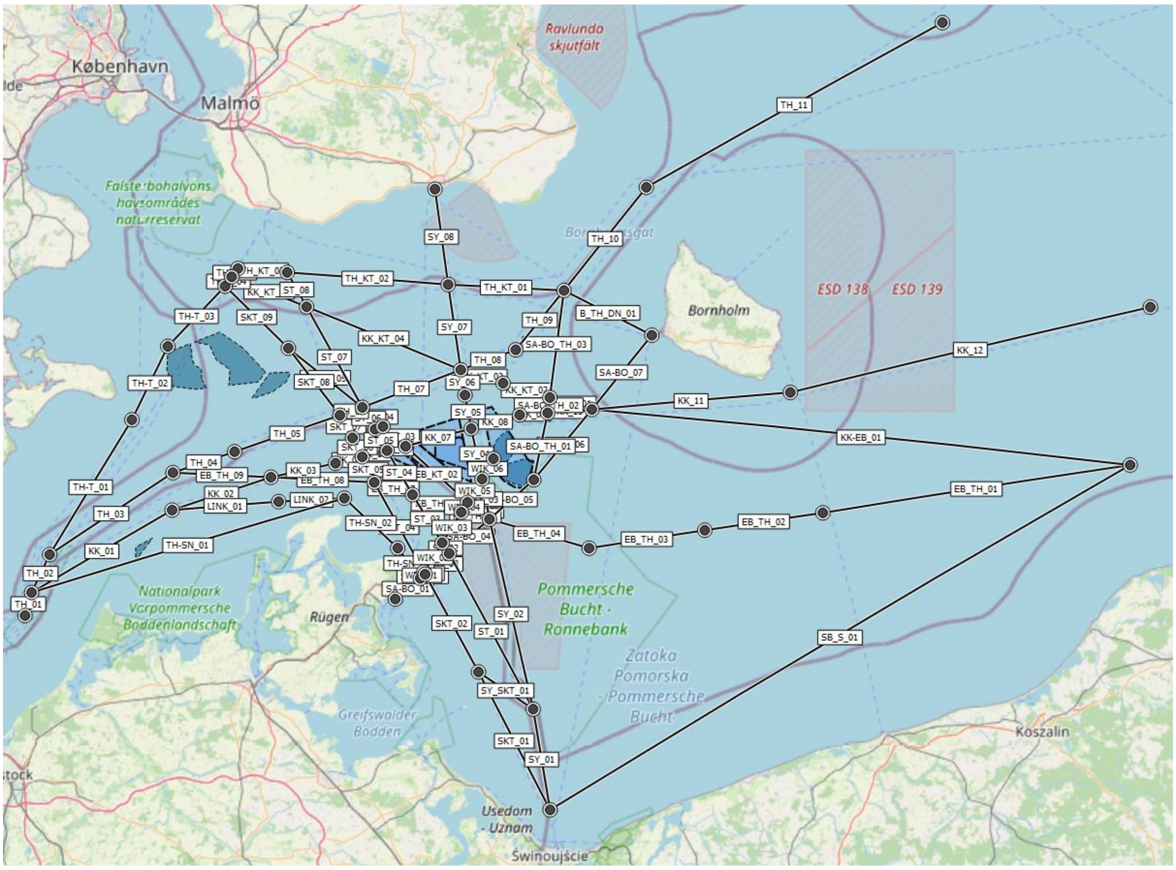


Figure 5: Network of traffic legs comprising the analysis model

To aid with referencing the paths comprising the model developed, names were assigned at each leg based on the routeing projection of the geographical locations these legs were joining. This is merely a referencing convention and does not imply that vessels identified by the software on the pertinent legs necessarily travel from/to these destinations. The reference names of the modelled legs are presented in Appendix B.

The coverage achieved by the assigned leg width is presented in Figure 6 overleaf.

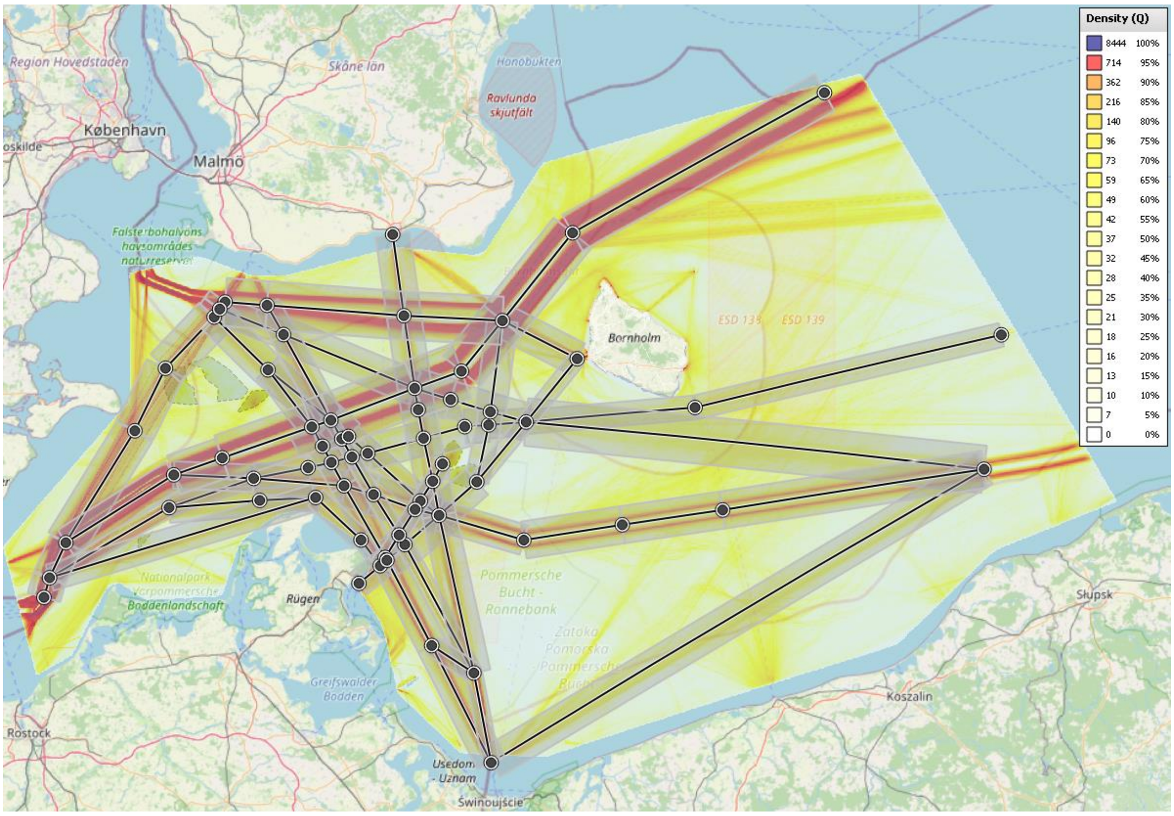


Figure 6: Coverage of tracks achieved by modelled legs

2.5.5 Lateral distribution of leg traffic

2.5.5.1 Existing conditions

The software used utilizes trips that are calculated as part of the traffic density analysis, along with the leg width and true heading of the vessels to assign vessel trips to the pertinent legs. To compute the lateral distribution of vessels in the lane, it also uses the distance of the path of the trip from the axis of each leg they are attributed to it. This is numerically expressed as a composition (summation) of different distributions, which in turn is used to perform risk calculations.

2.5.5.2 Following the introduction of changes

The introduction of changes in the model, whether in the form of channelling traffic from one route to another, or changing the alignment of a route, will require an adjustment to the lateral distribution of traffic on the altered routes. The approach used for the revised lateral distribution will be discussed later in the report.

2.5.6 Metocean conditions

The metocean conditions are important in terms of both determining the drifting parameters for vessels not under command (e.g., subjected to engine breakdown or blackout) following aberrant courses that can lead to a collision, as well as the potential of collision aversion through the intervention of tugs in the case of drifting vessels.

In the case of the former, the distribution of wind and current directions is important in determining the direction of drift, which takes part in the geometric probability calculation within the software. Metocean data are also significant in terms of determining the drifting speed of the vessels.

For the purpose of this project, two areas are considered:

- South Baltic Sea Area (Area 1)
- South-East North Sea Area (Area 2)

The metocean parameters were derived for each. These areas are presented in Figure 7.

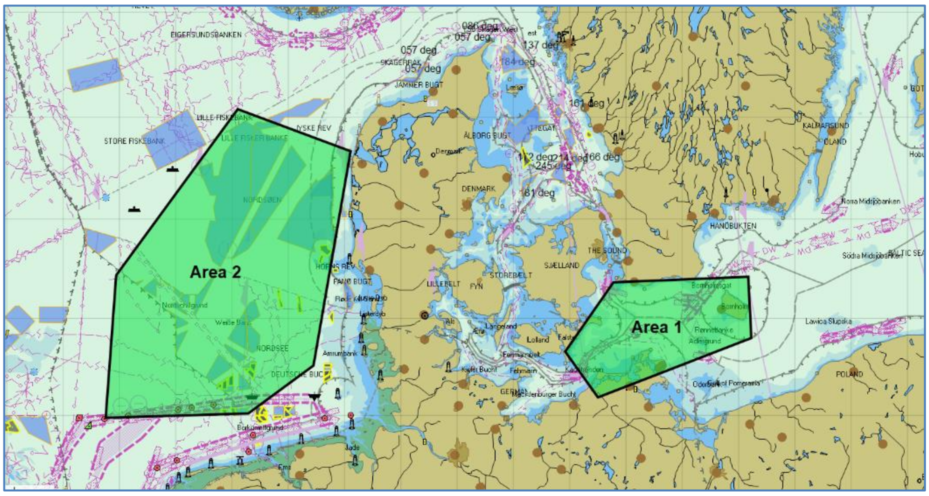


Figure 7: Area breakdown for metocean analysis

In both areas, long-term offshore wind and wave time series data were collected from the ECMWF-ERA5 database.

The ECMWF (European Centre for Medium-range Weather Forecasting) is an intergovernmental organization that uses state-of-the-art numerical models to deliver global weather forecasts in support of the national meteorological services. Both satellite and conventional data are daily collected from an extensive data collection network and analysed to set the initial conditions of the models. Wave data distributed by ECMWF are simulated by the spectral third generation WAM model coupled with the wind fields simulated by the global meteorological model. ERA-5 is a global atmospheric reanalysis from 1979, continuously updated up to the end of 2019. Data are provided on an hourly basis over a grid of 0.5° x 0.5°. This data is provided over a regular grid fully calibrated and homogenized against satellite data and (where available) in-situ buoy data. An example is presented in Figure 8.

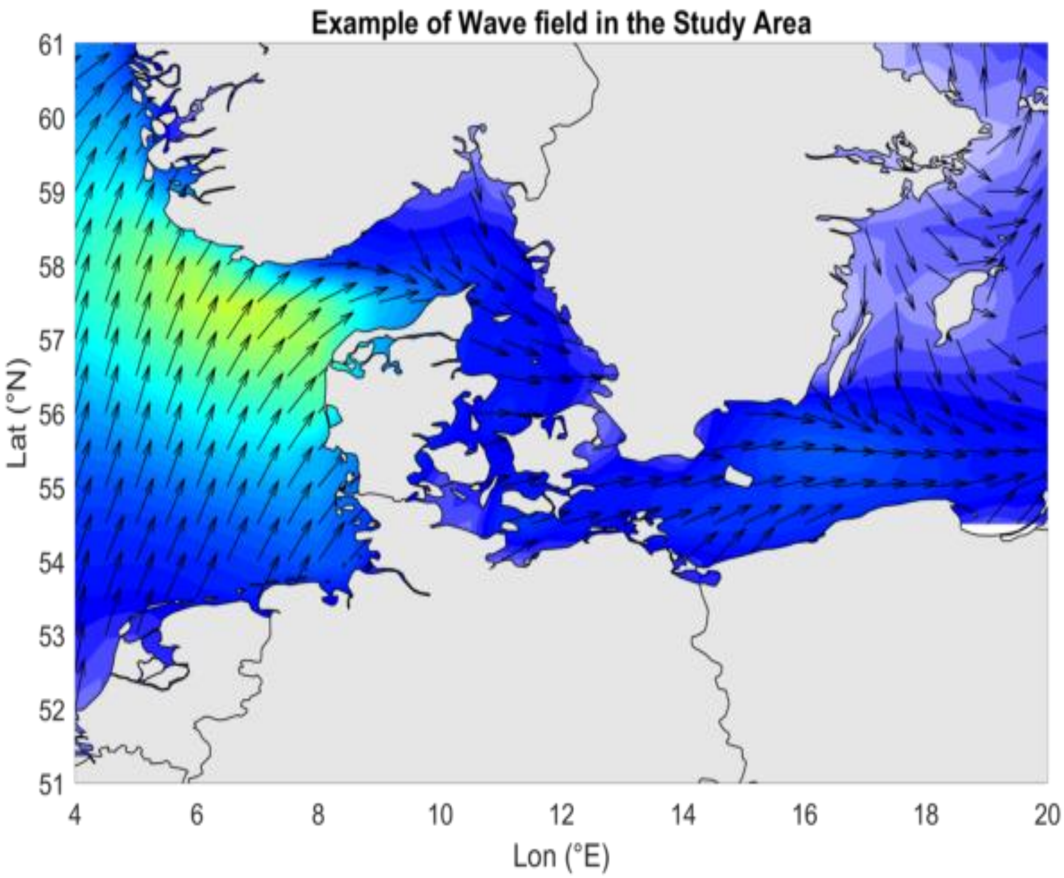


Figure 8: Example of Wave Field in the Study Areas.

Data on currents were obtained from historical archives of current data hindcasted by means of the HYCOM numerical model (Hybrid Coordinate Ocean Model) to assess the typical climate regime of the selected areas. The HYCOM consortium is a multi-institutional effort funded by the National Ocean Partnership Program (NOPP), as part of the U. S. Global Ocean Data Assimilation Experiment (GODAE). HYCOM is a primitive equation general circulation model which is isopycnal in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain following coordinates in shallow coastal regions, and to z-level coordinates in the mixed layer and/or un-stratified seas. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas. This results in the provision of a better representation of the upper ocean physics. The surface current climate is provided on the basis of data provided by the HYCOM database. An example of the currents field within the study areas is shown in Figure 9.

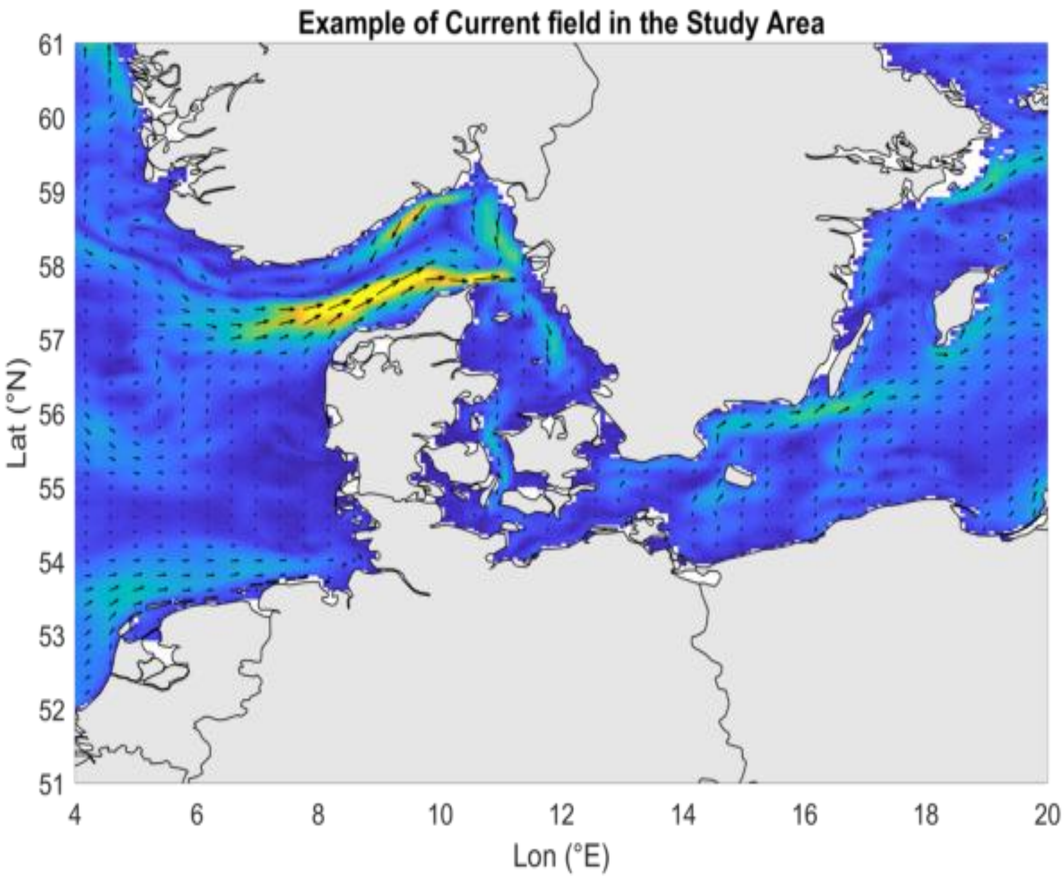


Figure 9*: Example of Instantaneous Currents Field in the Study Areas.*

Metocean parameters were analysed to provide seasonal statistics (in a table and graphical format), suitable for a correct drifting vessel assessment, at both Areas, South Baltic Sea Area, and South-East North Sea Area, respectively Area 1 and Area 2 in Figure 7. These derived statistics are presented in Appendix A.

2.3.3.1 South Baltic Sea Area

The Baltic Sea is an arm of the North Atlantic Ocean, extending northward from the latitude of southern Denmark almost to the Arctic Circle and separating the Scandinavian Peninsula from the rest of continental Europe.

Continental weather influences are predominant, giving periods of severe cold in winter and warm, dry weather in summer. Cloudy weather predominates, and fog is most frequent in spring and early summer. Winds tend to be variable and do not usually reach 15-20 m/s. Sea breezes commonly occur over coastal regions in summer.

Ice presence in the Baltic Sea influence the wave pattern, especially on the Northward side of the basin. To characterize the ice presence in the South Baltic Sea Area 1, which is also subject to sea ice, the Copernicus CMEMS database has been used. Ice concentration and thickness data have been gathered and used to identify potential periods of ice presence within the selected South Baltic Area.

In Figure 10 to Figure 12, maps of ice extension are provided for the most critical months, i.e., February, March, and April. These maps, obtained from the CMEMS database show that within the South Baltic Sea study area ice presence is negligible.

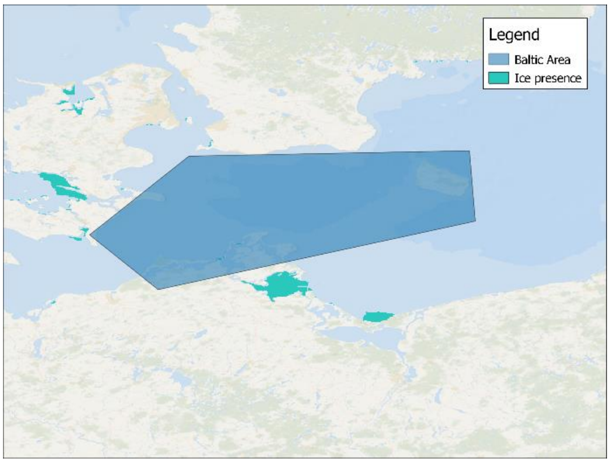


Figure 10: ***South Baltic Sea Area - Ice presence in February***

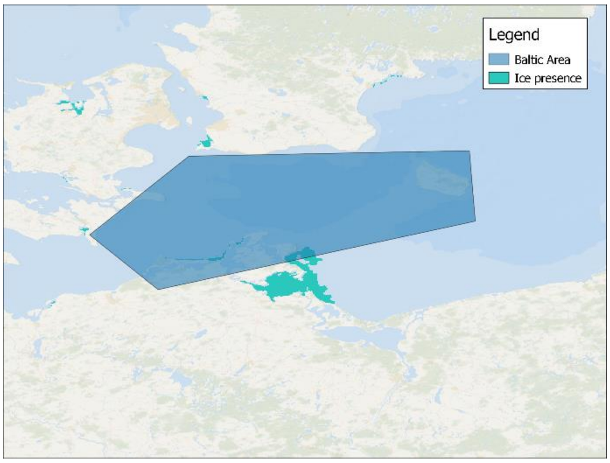


Figure 11: ***South Baltic Sea Area - Ice presence in March***

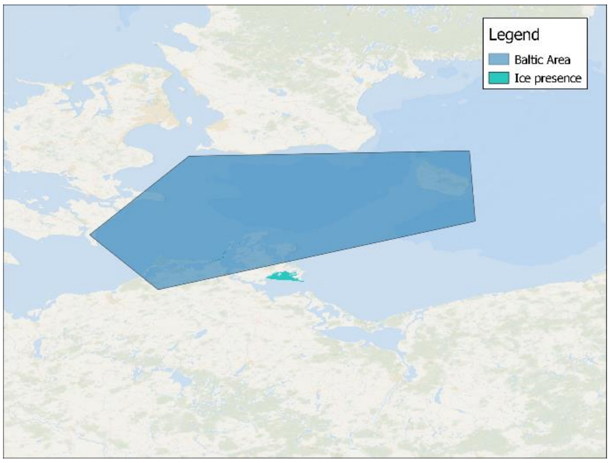


Figure 12: ***South Baltic Sea Area - Ice presence in April***

2.6 Risk assessment methodology and basic parameters

There are two main components to calculating collision risk.

The first is the geometrical probability (or frequency) which is related to the position of vessels in either direction of a traffic corridor (model leg), or route to a junction across each corridor, and the number of crossings. This expresses in effect the proportion of the total trips that would end in a collision if all vessels were navigating blindly (i.e., at their usual course with no reaction taken to avoid a collision). It shows the proportion of trips that would result in a collision if nobody could see one coming or act to avoid the other.

The second is the causation factor (or causation probability) which is related to the frequency in which a vessel will not take the necessary/correct action to avert a potential collision or will not diagnose the collision potential at all.

The overall collision risk is equal to the product of the two aforementioned parameters. The number of cases that would result in a collision if aversion were not possible, times the frequency of a vessel reacting to avert an incident fails.

2.6.1 Geometrical probability

IWRAP Mk2 uses the trip information extracted from AIS data to derive the lateral distribution of vessel traffic across the traffic corridors set up in the model. This distribution is converted to a summation of mathematical distributions for each leg and traffic direction, along with the geometric characteristics of each vessel in the model (length, width, draught) and the number of trips identified for each leg, it works out the geometrical probability.

For each leg, the identified number of collision candidates related to head-on, course alterations, and crossings is calculated for each vessel group and is subsequently multiplied by a causation factor.

2.6.2 Causation Factors

2.6.2.1 IALA approach

IWRAP Mk2 uses a set of default 'Causation Factor' values accepted by IALA for the different collision types described above. The values of these 'Causation Factors' correspond to the mean values of the range recommended by Fujii and Mizuki [11] and are presented in Table 25. Whilst different states/authorities may specify different values for the causation factors, internationally, the causation factors proposed by IALA (Table 4) are widely accepted.

Table 4: IALA Causation Factors

Collisions		Allisions		Grounding	
Merging	$1.30 \cdot 10^{-4}$	Powered	$1.60 \cdot 10^{-4}$	Powered	$1.60 \cdot 10^{-4}$
Crossing	$1.30 \cdot 10^{-4}$	Drifting	1.00	Drifting	1.00
Bend	$1.30 \cdot 10^{-4}$				
Head-on	$0.50 \cdot 10^{-4}$				
Overtaking	$1.10 \cdot 10^{-4}$				

2.6.2.2 GL approach

Germany, on the back of the Safety at Sea project that looked into the potential of a common approach to navigational risk studies for offshore wind, has assembled a group of experts to agree on risk acceptance criteria. The product of this initiative is report [01]. This document also forms the basis for the subsequent guideline document prepared by GL for the BSH [02] that defines the parameters for risk analyses in the approval procedure and the effectiveness of collision prevention measures pertaining to offshore wind developments.

The aforementioned documents specify a different set of causation factors, that are on the conservative side compared to the ones adopted by IALA. They consider a single causation factor of $3.0 \cdot 10^{-4}$ to express the probability of a ship identified on a collision course will not make a correction before it impacts the obstacle, due to technical or human causes.

2.6.2.3 Risk Reduction Factors

The presence of aids to navigation and other automated or non-automated risk mitigation systems and processes results in an improvement in the overall risk. Their effect on the reduction of overall risk is quantified and documented in guidelines and other scientific publications.

A risk reduction factor of 1.25 is considered for allisions to OWF installations, as a result of the latter being fitted with AIS transponders. This is endorsed by [01] and [02]. This factor will be applied to the OWF installation areas in the model.

The study area is covered by an integrated Vessel Traffic Service (VTS) extended also in the surrounding Danish, Swedish and Polish waters resulting in almost total coverage of the Northeast of Rugen Island jointly to a Ship Reporting System (SRS). This justifies the application of a risk reduction factor in line with references [01] and [02]. The system currently in place is manned and operational 24h/day monitoring AIS and Radar signals of navigating vessels in the area of interest, with the ability to contact and provide warnings/instructions to navigating vessels since these are requested to report their position at regular intervals, with reporting positions marked on the charts and to maintain a continuous watch on dedicated VHF channels. This justifies the use of the highest proposed reduction factor of 4.0 for the collision of manoeuvrable vessels, and a reduction factor of 1.1 for drifting vessels in the form of communicative support. The latter is applicable for 98% of drifting ships that can be detected by the VTS system. The combination of these factors will be applied in the model by factoring down powered and drifting allision probabilities respectively by:

- $3.0 \cdot 10^{-4} / (0.98 \times 4.0) = 7.65 \cdot 10^{-5}$ for powered allisions
- $1.0 / (0.98 \times 1.1) = 0.928$ for drifting allisions

The same factors will also be considered for powered and drifting groundings respectively.

The causation factors to be used in the risk analysis are summarised in Table 5:

Table 5: Model Causation Factors

Collisions		Allisions		Grounding	
Merging	$3.00 \cdot 10^{-4}$	Powered	$0.765 \cdot 10^{-4}$	Powered	$0.765 \cdot 10^{-4}$
Crossing	$3.00 \cdot 10^{-4}$	Drifting	0.928	Drifting	0.928
Bend	$3.00 \cdot 10^{-4}$				
Head-on	$3.00 \cdot 10^{-4}$				
Overtaking	$3.00 \cdot 10^{-4}$				

A further risk reduction factor of 1.15 is applied directly to the risk calculated for legs where there is a traffic-separation scheme in place, based on the work of MacDuff [12]. Where legs were only partially part of a TSS, this reduction is conservatively not considered.

Also, a risk reduction factor can be applied to the parts of the model where vessels are subject to pilotage. There is a plethora of studies that quantify the impact of pilotage, both in general and area-specific terms. Typically, the effect of pilotage reduces navigational risk to half.

IALA considers additional risk reduction factors for passenger ships and fast ferries. Based on the work of Fujii, the latter have smaller collision probabilities than ordinary merchant vessels. IALA recommends a reduction factor of 20 compared to ordinary merchant vessels, which means that ferries carry 5% of the collision risk of cargo vessels. This is because passenger ferries typically operate with two navigators on the bridge, and also follow standard repeated routes hence the navigators are more familiar with the risks in their area of operation compared to the navigators of cargo vessels. Furthermore, ferries are typically more manoeuvrable compared to cargo vessels and are thus much more effective in performing avoidance manoeuvres.

In debating this with the GDWS, the point was raised that whilst it is agreed that there are navigational and manoeuvrability benefits for passenger vessels compared to cargo vessels for the reasons mentioned above, these are not present when navigating under very severe weather or in excess of wind Beaufort Force (BF) 8. As we do not have accurate information on whether passenger vessel services are carried out or are suspended under BF8 conditions, the study conservatively assumes that the risk reduction factor of 20 is applicable only in the proportion of the time annually that the weather conditions are below BF8, with a factor of 1 (i.e., no reduction of risk) assumed for the proportion of time where conditions equal or exceed BF8. The impact of this adjustment is minimal since conditions overall exceed the limit of BF8 for 0.1% of the time. This results in a reduction factor of:

- 99.9%·20+0.01%·1 = 19.99

2.6.3 ETV stations and consideration in the study

Identifying Emergency Towing Vessel (ETV) stations in the area associated with the model and defining the available tugboats parameters allows the IWRAP software to consider tug intervention in cases of drifting vessels, to potentially avert allisions.

For the Baltic Sea, the study considers three tugboat stations, based on information obtained from research in the public domain and the information provided by the Coastal States. These are presented in Table 6.

Table 6: ETV availability in the study area

ETV	BP (t)	Max. Speed (kts)	Stationed	Stand-by location	BP Displ. (t)
BALTIC	127	11.2	Rostock	BF8: 5nm N of Heligendamm[2]	145,000
ARKONA	48	10.5	Rostock	BF8: 5nm E of Arkona lighthouse	13,000
BREMEN FIGHTER	104	11.6	Sassnitz	BF8: 5nm N of Dornbusch	106,000

[2] ‘nm’ stands for nautical mile equal to 1,852m.

We are aware that there are further emergency tug stations at Karlskrona (Sweden) and Gdynia (Poland), however, due to the increased distance from the study area, these stations will be conservatively not considered in the risk model. The same applies to the vessel Scharhörn which is based in Kiel.

From the information gathered, the three remaining vessels provided by Germany are the only active emergency response that can be considered for the study area. Predominantly with the presence of two ETVs, and a single multi-purpose vessel which can, at the occurrence, act as an ETV.

It is noted that the ETVs are deployed to their stand-by locations when weather conditions are equal or excess BF8. However, based on the required conditions to perform a successful tow discussed later in the report, the probability of ETVs successfully intercepting vessels ceases at BF8. Therefore, the station positions are used for the tugs in the model, vs the stand-by locations. It is noteworthy to mention that potential vessels' engine or steering failure can occur at any time and therefore ETV service would be required when these are stationing at their base port.

2.6.3.1 Tug availability and response time

In lack of more accurate information, the study assumes that the tug availability is 7 days per calendar week. However, the tug availability is conservatively assumed to be at 96% based on data from previous studies. This converts to a cumulative downtime of 15 days per year.

Report SO-ER2010.095 - Offshore wind farms - parameters for risk analyses in the approval procedure and effectiveness of collision prevention measures [02] advises that there is a 98% probability of a drifting vessel to be tracked by the authorities using a detective combination of AIS & Radar detection.

The study assumes a response time of 30 minutes, from the time the tug receives the call to the time it mobilises. This is a reasonable response time for an ETV to set off on a rescue mission.

2.6.3.2 Bollard pull capacity

The capacity of ETVs is measured by their rated bollard pull which is the tractor force a tug can exert at zero forward speed in calm water conditions, with the main engine running at 100% of the maximum power output the engine can safely generate continuously.

There are different factors affecting the capacity of a tug to tow a determined object. These are primarily related to the tug's propulsion system and design, then to the nature of the tow, its size and shape, and of course the prevailing weather conditions.

Using the bollard pull capacity above, the study set a limit to the largest vessel the tug can be effective against. This was hence used to work out the percentage of the model fleet each tug would be able to successfully intercept.

Requirements for the minimum bollard pull are defined by the Der Norske Veritas (DNV) Rule for planning and execution of marine operations 2015 [03] as the minimum towing force required for open sea towing to maintain zero speed under the following conditions:

- Wind 20 m/s
- Head current 1 m/s
- Significant wave height 5 m

For the present study, tugs are considered effective for the weather window that is equal to or milder than the above parameters.

As seen above there are several factors involved in a tow that requires an accurate assessment for a sound and safe result. However, it is possible to use a simplified formula for the approximate calculation of the required bollard pull as follows [04]:

Bollard Pull = (Displacement (t) x 60 /100.000) + 40

From the above formula, the maximum displacement of the tow at a given bollard pull as presented in Table 7 was calculated.

Table 7: Tug suitability as % of the fleet

Tug boat	Certified BP (t)	Max. Displacement (t)	Percentage of risk model fleet (%)
BALTIC	127	145,000	99.5
ARKONA	48	13,000	56.9
BREMEN FIGHTER	104	106,000	97.2

2.6.3.3 Tug intervention success probability

The success probability of each tug is calculated based on the following equation:

$P_{s.tug}$ = (% time availability) x (% Probability of identification of drifting vessel) x (% fleet it can intercept) x (% weather window)

The calculated success probabilities for the three tugs are:

- BALTIC: $P_{s.tug}$ = (96.0%) x (98.0%) x (99.5%) x (99.9%) = 93.5%
- ARKONA: $P_{s.tug}$ = (96.0%) x (98.0%) x (56.9%) x (99.9%) = 53.5%

- BREMEN FIGHTER: $P_{s.tug}$ = (96.0%) x (98.0%) x (97.2%) x (99.9%) = 91.4%

2.6.4 Lateral traffic distribution

As mentioned earlier in the report, the introduction of changes in the model, which can occur in the form of channelling traffic from one route to another, or altering the alignment of a route, will require an adjustment to the lateral distribution of traffic on the altered routes. This process is of high importance, as the result of the risk analysis regarding powered collisions, allisions, and groundings are heavily dependent on the position of the centreline of the route (leg axis) and the distribution of vessel traffic on either side of this axis. The position of the axis is determined empirically, based on the available space, shallow waters or other obstructions, navaids etc.

German guidelines for the approval of offshore windfarms issued in 2005 [01], and subsequently updated in 2010 [02], require that the lateral distribution of 98% of the traffic on a leg is performed based on a Gaussian distribution and 2% based on a uniform distribution. The reference value for the width of the uniform distribution is 6 times the standard deviation. The reference values for the standard deviation (in nm) of the Gaussian distribution at route end points are presented in Table 8.

Table 8: Reference values for the standard deviation to be considered in lateral traffic distribution

Fairway Type	Standard Deviation (nm)
Port approach	0.2 to 0.3
Approach points, e.g., navigation marks, buoys	0.3 to 0.4
Traffic separation areas	0.5
Waypoints in wide shipping lanes	0.5 to 1.0
Waypoints in open sea areas	2.0

At subsequent stages of the risk study, when changes to the current traffic are considered either in the form of channelling traffic to a different leg or re-routing it to a new track, the diverted traffic is laterally distributed across the leg in line with the recommendations of the aforementioned German guidelines. Traffic volumes and composition (vessel sizes and types) remain the same as in the leg that is replaced, only increased in cases where future risk is considered by a factor that captures the anticipated traffic increase.

2.6.5 Other considerations

2.6.5.1 Mechanical failure frequency

Mechanical failure frequency is an important parameter to consider in looking at drifting vessel allisions, as it determines how frequently a vessel is expected to be unable to navigate under her own powers and become a vessel not under command.

References [01], [02] tie the probability of a vessel becoming non-manoeuvrable to the failure rate of the propulsion and steering gear. The average failure rate assumed for all ship types is considered as $2.5 \cdot 10^{-4}$ per hour.

A window for adjustment is left however for ships with two or more propulsion units, in terms of using lower breakdown frequencies. These vessels are typically passenger vessels (cruise ships, ferries, high-speed craft, etc.) or special vessels fitted with Dynamic Positioning Systems that operate on a high degree of built-in redundancy in the engine room and hence they have a low frequency of mechanical failure that can leave the vessel out of control.

IALA considers a return period of 1 in 10 years for Ro-Ro and passenger vessels (failure probability per year of 0.1), and one in 1.3 years (failure probability per year of 0.75) for all other vessels. These are the default values in the IWRAP software, that consider the failure probability on an annual basis.

In the present study, the failure rate of the GL guidelines will be used for cargo vessels, and that proposed by IALA for passenger vessels. For the GL recommendation to be used in the model, it has to be converted to an annual failure rate. As a mechanical failure only leads to a drifting vessel during the time the vessel is sailing (ex. Not whilst in port, docked, or at lay-by), we have obtained the annual sailing hours of the non-passenger vessels in the analysis model dataset and obtained information on their total time spent at sea in the time interval of interest from the EMSA Thetis/MRV database[3]. The average time at sea of the non-passenger vessels in our model, weighted by the number of tracks of each in the model over the total extracted was calculated to be 4,572hrs. This suggests an annual failure rate of 1.14, 50% more conservative than the rate proposed by IALA.

For the present study, mechanical failure probabilities leading to a drifting vessel will be considered as:

- 0.10 failures per year for passenger vessels
- 1.14 failures per year for all other vessels

The selection of the lower failure of 0.1 incidents/vessel/year rate adopted for passenger vessels is generally in line with, and on the conservative side, of mechanical failure-related incidents in the HELCOM database for the period between 1989 and 2018.

2.6.5.2 Repair time distribution

[3] https://mrv.emsa.europa.eu/#public/emission-report

Repair time also constitutes a significant parameter in looking at the risk of accidents from drifting vessels. Mechanical failures that will be repaired in time, will constitute a drifting vessel navigable again, thus eliminating the risk. The time it will take for a failure to be repaired, is assumed on the basis of the Samson distribution (Figure 13), in line with the requirements of [01], [02].

For the first 15 minutes, the probability of a successful repair is zero.

From that point on, and up to the 24h mark from the time of the failure, the probability of the vessel stopping to drift as a result of a successful repair, is calculated from the formula:

$$1 - \left(\frac{1.0}{1.5 \times (t - 0.25) + 1}\right)$$

After the 24h mark, the vessel is no longer considered to be drifting, as if it has not collided or got stranded, it would have been intercepted and secured. The probability thus of the vessel exiting drift becomes equal to 1.

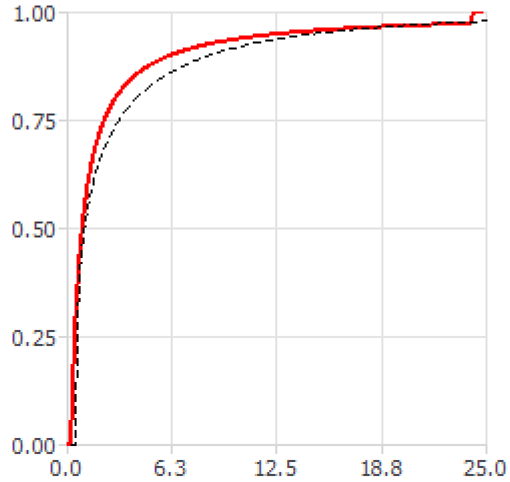


Figure 13:Samson distribution for the probability of successful repair vs time

2.6.5.3 Drifting vessel speed

The drifting speed of vessels is an important parameter in the risk analysis as it will determine the time interval between the time the vessel becomes out of control, and the time it may be intercepted by tugs, re-gain control following a repair, or be intercepted by tugs, before it collides or grounds.

For the purpose of the present analysis, the drifting speeds of the vessels in the set under conditions between BF3 and BF7 were calculated and weighted against the corresponding duration of these conditions in a year. Further, the weighted average for each vessel was weighted against the number of tracks of each vessel in the model over the total extracted. The drift speed for the model was thus calculated to be 1.48kts.

Drift speeds are also influenced by the intensity of the marine currents, which is added or subtracted from the drift speed vector depending on its direction of action on the vessel's hull. Currents in the study area are of speed lower than 0.38 kts for approximately 90% of the duration of the year, with the weighted average current speed calculated at 0.43 kts. The highest current speeds are noted in the easterly and westerly directions, however, the predominant speed of 0.38 kts component is almost equally distributed in all directions.

Considering the effects of the currents, the study conservatively assumes the global drift speed for the model to be at 1.48+0.5·0.43 = 1.70 kts.

It is noted that guidelines [01], and [02] impose a maximum value of 4kts for the drift speed.

2.6.5.4 Emergency anchoring to stop the drift

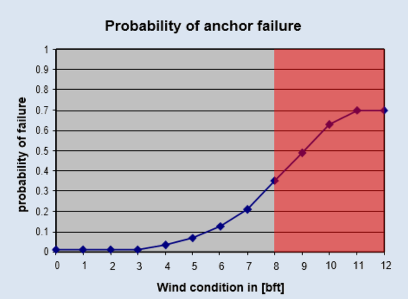
Apart from being intercepted by a tug, or being repaired whilst adrift, a drifting vessel may drop its anchors as a means of stopping if the water depth and seabed permit so.

As anchors do not descend directly under the ship, but some ship lengths away, the anchor needs to grip some distance before grounding or allision to a fixed object. As the length of anchor chains is determined based on the equipment number of a vessel, and thus its size, it is considered that the minimum reasonable value for this distance is 3 times the length between perpendiculars of the vessel.

For the anchor to be able to reach the seabed in this domain, the depth cannot exceed 7.0 times the design draught of the vessel. In waters deeper than that, the probability of successful emergency anchorage is considered zero.

Guidelines [01], [02] provide the following recommendations in terms of the probability of failure of emergency anchorage operations (Table 9):

Table 9: Emergency anchoring failure probability

Conditions	Anchor failure probability	Anchor success probability	
≤BF3	0.010	0.990	
BF4	0.035	0.965	
BF5	0.070	0.930	
BF6	0.126	0.874	
BF7	0.210	0.790	
≥BF8	1.000	0.000	

The above success probabilities, weighted against the annual duration of each set of the weather conditions in Table 9, result in an overall success probability for the analysis model of 0.93.

2.6.5.5 Visibility

Visibility constitutes an influencing parameter in navigational risk. Reducing the visibility from normal conditions to distances at and below 4000m, acts as a multiplier to collision risk, substantially increasing the probability of powered accidents. There are a number of references discussing the effects of poor visibility based on area-specific studies, however, the most useful in terms of quantifying its effects comes from the work of S. Kristiansen [10], which consolidates data from previous studies in the Dover Straight. The reference considers clear conditions to be when visibility exceeds 4 km, dense fog when visibility is limited to below 200m, and mist/light fog as the conditions in-between. The reference proceeds to quantify the effect of the aforementioned conditions as follows:

- Under Mist/light fog (4000m-200m), the collision probability is 10·nominal
- Under Dense fog (<200m), the collision probability is 300·nominal

Publicly available literature includes high-level references to the visibility in the area of interest but is not explicit enough for the purpose of quantitative assessment. The closest reference to visibility in the area is from the work of C. Lefebvre and G. Rosenhagen [05] on the climate in the North and Baltic Seas. The reference suggests that the frequency of occurrence of fog shows a distinct seasonal variation, peaking during winter when fog occurs on 6 to 8 days per month, and troughing during the summer when on average, there is only one day of fog in the months of July and August combined. It proceeds to note that fog at Rugen appears approximately 60 days per year. The reference does not relate the fog observation to visibility distance. Also, it does not provide information on the duration of the presence of the fog on the days it is noted.

To address the above issues, a hindcast dataset was procured for the area of interest [14] to extract accurate visibility information. The dataset includes information from 2008 to 2021, and a 13-year long period was used from the dataset, 15/12/2008 – 14/12/2021. The data is provided in hourly reports of kilometric visibility. The distribution of visibility distances in the period considered is presented in Figure 14.

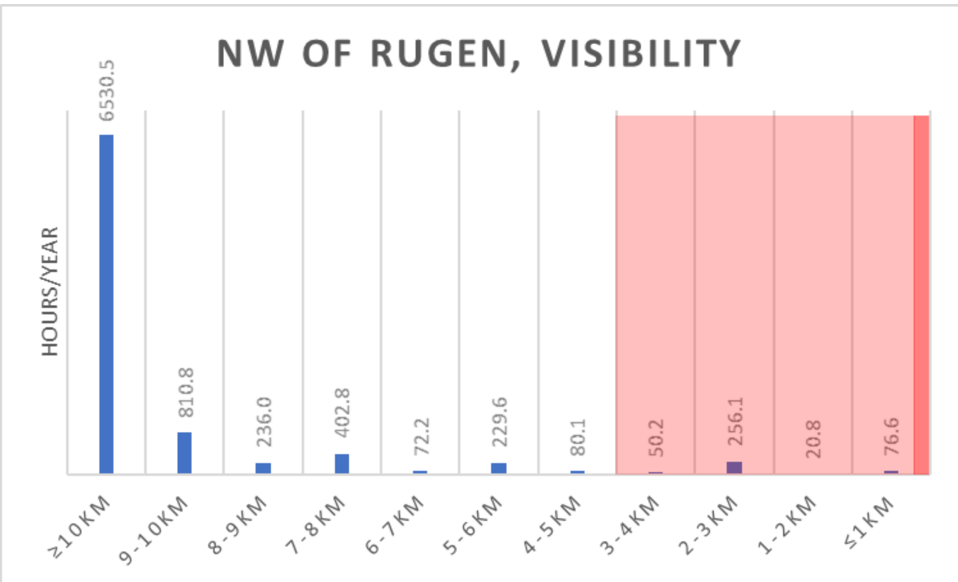


Figure 14: Visibility in hours/year, NW of Rugen area

From the analysis of the dataset, it is noted that the proportion of time when visibility exceeds 4km corresponds to 95.39%. In this interval, visibility has no impact on risk. The proportion of time when visibility can be classified as Mist/light fog (4000m-200m), for which the collision probability is 10·nominal, corresponds to 4.55%. Last, the proportion of time in which visibility is below 200m, and thus the collision probability is 300·nominal, corresponds to 0.01%.

The effects of visibility, therefore, can be externally applied to the results obtained by the model analysis for powered collisions and allisions, by multiplying the latter with the factor calculated below:

$$f_{.vis} = 95.39\% \cdot 1 + 4.55\% \cdot 10 + 0.01\% \cdot 300 = 1.45$$

An additional consideration related to the visibility is the obstruction caused by the physical presence of the OWF towers. In other words, from an Officer of Watch (OOW) perspective the presence of the windmill towers of an OWF development reduce his horizon generating blind sectors as it is difficult to carry out an appropriate look out of the stretch of the sea beyond the offshore development.

The watch of marine radars and the monitoring of AIS receivers (when not integrated with radar) might overcome the disability of not having the full horizon clear of obstructions. However, the interference that the same turbines could cause to radars, and the possibility to encounter units not fitted with AIS transducer are a hazard for safe navigation and some considerations need to be done in this regard.

As mentioned earlier and will be discussed in more detail later in this report, the marine radar is a very useful aid in the detection of targets with poor visibility and the Automatic Radar Plotting Aids (ARPA) tools allow the OOW to understand the target’s direction and speed in order to process a required action to avoid collision with the same target.

OWF obstruction would not allow the OOW to confirm the location and, most importantly, the target’s bow (and/or rules of the road[4] lights at night) of the echo spotted on the radar screen, in addition on some occasions, turbines can cause disturbance to the radar echoes shown. As a result, it might be the case that the OOW is required to obtain visual contact with the target before confirming its direction and taking a collision avoidance manoeuvre. Needless to say, the main function affecting such manoeuvre is the time and therefore the sea room at which the OOW can detect and confirm the intention of a potential colliding target. Shorter the distance, shorter the time and wider must be the avoidance manoeuvre

[4] Rules of the road is the term used to define the regulation contained in the Convention on the International Regulations for Preventing Collision at Sea, 1972 (COLREGs)

with the consequence that might be dragged to the traffic in the vicinity of the manoeuvring traffic.

Based on this, it is of paramount importance to give the OOW enough time to process his situational awareness and take appropriate actions whilst navigating in the vicinity of OWF. Several studies, not necessarily correlated between them, conclude that a reasonable distance at which the marine traffic should transit from an OWF installation is in the range of 2nm. It appears that the same distance could be assumed as a reasonable sea room for vessels navigating on collision courses.

Figure 15: Vessels approaching when navigating at 2nm from OWF. Figure 15 illustrates the distance at which two vessels on converging courses can visually spot each other when clear from the obstruction of the windmill towers of the OWF. They are navigating at a 2nm distance from the OWF restricted area (500m) and are in visual contact at an approximate distance of 5.5nm. The figure is self-explaining as if the vessels were navigating at less distance from the OWF they would have appeared on the same bearing (red line) but at less distance between each other, reducing the time at which an avoidance manoeuvre can be taken. In addition, 'Vessel A', according to COLREGs Rule 15, is the give-way vessel and should avoid crossing ahead of Target 1, therefore Vessel A should take an evasive manoeuvre altering her course to starboard and therefore approaching Arcadis Ost 1 OWF limits closer.

On a boundary of 1nm, the vessels would have obtained visual contact at a distance of approximately 3.3nm giving Vessel B only 1.1nm of sea room from Arcadis Ost 1 on her starboard to complete an avoidance manoeuvre (Figure 15).

In terms of timing, Vessel A has 22 minutes before reaching the Closest Point of Approach (CPA) which in our example is equal to 0.0nm, whilst Vessel B has only 12 minutes to her CPA and hence limited time and limited room to assess, process and take an action to avoid the collision with Target 2 and the allision with Arcadis Ost 1.

In summary, we consider a 2nm range off OWF installations a reasonable distance at which vessels can safely navigate with enough margin to take an evasive manoeuvre if required.

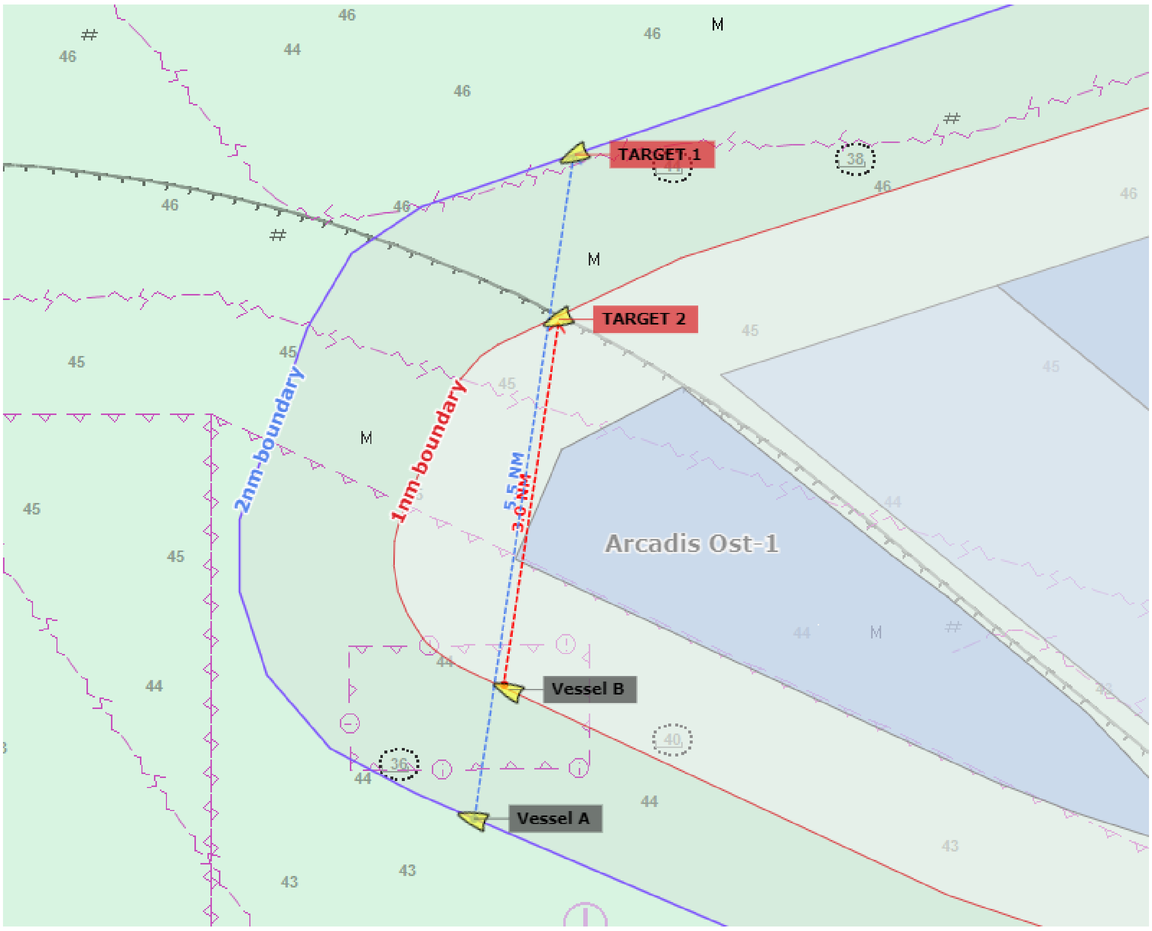


Figure 15: Vessels approaching when navigating at 2nm from OWF.

2.6.6 OWF interaction with marine radars

With respect to the risk associated with radar interference induced by OWF developments, a review of available literature on the issue has been carried out, to identify points of relevance to the current study.

Whilst there is a significant amount of literature on OWF effects on radars and vessel navigation, qualitatively discussing the effects that they can cause such as interference and radar clutter, there is a lack of information directly relating, or able to be used in a quantitative assessment.

It is expected that in the future there will be more information to work with, as with the expansion of offshore wind, and its significance in achieving net zero emissions, significant efforts are being put in by various groups to investigate and mitigate the effects of radar interference. Particularly so from a military/air defence standpoint, with significant funding for example being awarded in the UK to such projects as part of the 'Windfarm Mitigation for UK Air Defence' competition. In the US, a similar initiative has been established, the 'Wind Turbine-Radar Interference Mitigation Working Group'.

Much of the research currently available, proposes mitigation measures which are thought to reduce the risk to an acceptable level that does not significantly compromise marine navigation or safety. The risk itself is mainly seen in the potential for accidents involving small vessels, on which AIS is not compulsory/available. For larger vessels, AIS can be used to verify vessel positions, and avert collisions between them.

The UK Marine and Coastguard Agency (MCA) in the early 2000s, run a programme intended to investigate the effect of OWFs on marine positioning and communications systems in operational scenarios. As part of the trials for this programme, all practical communications systems used at sea and with links to shore stations, shipborne and shore-based, radar, position fixing systems, and the Automatic Identification System (AIS) were assessed.

The results of this in-field assessment found the effects on the majority of systems tested not to be significant enough to affect navigational efficiency or safety. The exception to that was the effect of OWFs on shipborne and shore-based radar systems. It was found that interference could be reduced by reducing receiver amplification (gain) which, however, would also reduce the amplitude of other received signals such as the ones emitted by small vessels, buoys, etc. within or close to the OWF, to the extent they may not be detectable. It was also noted that the performance of a vessel's automatic radar plotting aid (ARPA), could be affected when tracking targets in or near an OWF.

At around the same time, QinetiQ performed further trials, on various navigational aids, amongst which the radar shadowing effect was investigated. The radar shadowing trials resulted in very little evidence that shadowing of targets would present any significant problems, and the field effect proved less than what the theoretical study that preceded the testing had predicted. Whilst clutter was observed both in the form of ring-around and false plots, it was observed that problems could be suppressed by successfully adjusting the gain. The latter mitigation, however, corroborated the findings of the MCA, in that some smaller targets could not always be detected.

The AIS systems function was found undisturbed in both trials. Further information on this work may be found in the original proprietary publication [15]. This work fed into the development of the MCA guideline MGN 371 (M+F) [16], which considers the risk of navigation to a distance smaller than 0.45nm from the boundary of an OWF as intolerable, as a result of radar effects, whilst distances between 0.45nm and 1nm entail tolerable medium to high risk, subject to adherence to COLREGS and respecting vessel domains. Distances in excess of that are considered low risk.

Another study performed in the UK [18], notes that not all vessels showed effects from the wind farm on their radar. However, some pilots were concerned that ‘spurious echoes’ from wind farms could cause actual targets to be missed. Many of the radar effects seen were also caused due to the positioning of radar scanners on vessels, causing more reflections and other effects. This was also reflected in the navigational risk assessment carried out for Hornsea 3 OWF, and these effects and reflections can also be seen if passing vessels provide reflective surfaces. This is, therefore, more likely in areas with more vessels and heavy traffic, such as where many vessels are re-routed onto the same routes. It is stated in this risk assessment that the main issues are caused when there is also reduced visibility as mariners cannot confirm visually the presence of other nearby vessels.

Steamship Mutual, a Protection & Indemnity insurer, as part of their loss prevention risk bulletins to members, provide guidance on ‘Navigation in the vicinity of offshore renewable energy installations’ [17], highlighting that radar returns from wind farms are quite strong, however at close range (from approximately 1.5nm), they can produce multiple echoes which could hide real radar targets. The note proceeds to recommend that ‘it would be prudent for vessels when engaged in passage planning to lay off courses at least 2 nautical miles clear of windfarms.

This interference might also cause disturbance to VTS radars, which are similar to marine radars fitted on ships when the false echo phenomena generate a blind sector and targets on the same bearing cannot be detected and visualised on the plan positioning indicator (radar screen). However, an experienced radar observer, like a certified radar operator, is able to spot the false echo present on the radar screen and he will therefore apply extra cautions in the interpretation of the echoes shown in the vicinity. When the hypothetical echo moves, or due to its relative motion misaligns with the bearing at which the false targets are generated, it will reappear on the radar screen as a single echo and the observer will be able to confirm its actual presence in the sea.

However, keeping a distance of approximately 2nm from the windfarm turbines would allow the observer enough time to take counter measures, in case such phenomena had taken place.

In the area of the study, there are a number of areas where navigational traffic is directed in the proximity of OWFs. Vessels on the current ferry route from Swinoujscie to Ystad, navigate at distances down to 1nm from the boundaries of the Arkona and Wikinger OWFs. Looking at navigation that crosses the EnBW Baltic 2, a distance of as close as 0,7nm, whilst at the EnBW Baltic 1 OWF, vessel traffic appears to navigate as close as 0.4nm on either side (north/south). Considering these levels of proximity, especially in the case of the latter two, it is bound that some radar scatter will be experienced by vessels transiting the relevant routes, especially in the case of EnBW Baltic 1, where two routes are found converging to the west of it. The HELCOM accidents database currently does not record any incidents in the vicinity of these windfarms, which are the longest in operation within the model.

2.6.7 Traffic growth projection

For a projection of maritime traffic in the Baltic Sea between now and 2040, a literature review was undertaken on existing studies on traffic in the Baltic Sea.

The European Maritime Transport Environmental Report of 2021 [11], in the section discussing future trends in maritime transport and trade, forecasts a recovery of trade to the pre-pandemic levels within 2022, and onward growth of approximately 25% over the pre-pandemic levels by 2040, in terms of gross tonne-miles. This growth is expected to cover all sectors of shipping, with the exception of that of crude-oil tankers, which are expected to not follow this growth pattern and remain at present levels, as the continent moves away from fossils. The growth is not envisaged to be uniform, with rapid growth by 2025, and then a stabilisation until 2030, when a second period of strong growth is forecasted up to 2040. Then the report forecasts a plateau through 2040 and up to 2050, which is the upper bound for the prediction. It is forecasted that the largest part of this growth will be in short-sea shipping, and predominantly container and Ro-Ro cargo traffic. This report covers the shipping activity across the EU, however, there is explicit mention that the short-shipping growth will mainly occur in the Baltic.

HELCOM published a maritime assessment report of the activities in the Baltic Sea, in 2018 [12]. This report is mostly capturing existing traffic trends but contains a section discussing future trends in maritime traffic. The report uses references from studies conducted early in the past decade, with projections up to 2030, including work by the WWF, the Sustainable Shipping and Environment of the Baltic Sea region (SHEBA) Project, Lloyds Register, and DNV. However, in summary, the projection is that the Baltic will face oil-tanker-driven growth in excess of 65% between 2010 and 2030. Based on our current knowledge of the region moving away from fossils and into renewable and low carbon fuels, an insight that was not available at the time these studies were carried out, this does not appear to be a realistic scenario.

Perhaps the most useful of the references considered was the 2018 Baltic Lines report exploring the future of shipping in the Baltic Sea [13]. The report considers three different development scenarios. The “sustainable growth” scenario is based on a projection of the current growth rates at the time of performing the relevant study (between 2015 and 2018). The “limited growth scenario” corresponds to a scenario where economic growth is mainly driven by the central and eastern European countries and to a small extent by Russia, and assumes slow technological advancements in shipping, small take-up of modern greener technologies, and slow growth of the renewables sector. The “fast growth” scenario covers the case where growth is driven by all countries in the region, fast technological advancement, take-up of new technologies by the shipping sector, and sustained growth of the renewables sector due to high oil prices.

The three scenarios, from the limited to the sustainable and the fast growth, the respective rises in sea trade of the order of 4%, 8%, and 12% respectively between 2015 and 2030, with subsequent stabilisation and very small growth between 2030 and 2050. The report foresees a reduction of current traffic figures in the future, based on the size of the vessels tripling between 2015 and 2030. Considering the maximum draught of 17m for entering the Baltic Sea (Route – T), and the existing infrastructure, we consider this a very unlikely scenario to materialise for 2030, or in fact in the timeframe covered by the study.

ABL considers that the most reasonable projection is to anticipate a traffic increase in the order of 20% maximum between the present time and 2040. This is in consideration of the fact that the exit and bounce-back from the effects of the pandemic appear to be delayed in comparison to the first projections. Also, whilst the EU member states are moving away from fossils to cover their energy demand, we expect that the pace of development in offshore renewables will be tempered by infrastructure availability, capability, and capacity. At the same time, in many industries, it is expected that fossils will be largely replaced by alternative liquid fuels, and hence the reduction in tanker traffic in the next two decades will not be as high as currently envisaged by many publications. Whilst there will be high interest in the development of offshore wind in the Baltic Sea, our expectation is that infrastructure availability will stagger developments and hence the increased traffic from construction will not exceed the 20% increase compared to the current at any point. It is noted that once a development is operational, the crew transfer vessels running regular routes to/from the developments are not included in the risk models due to their small size, well below the criterion set in [01], [02].

Vessels are expected to keep increasing in size, however not to the rate of increase we witnessed in the last two decades, especially considering the draught restrictions mentioned earlier for the Baltic Sea, and also considering the maximum limits of the vessels’ size that existing port infrastructures can accommodate. Our estimate is that in the next two decades, the increase in the vessels’ external dimensions will not exceed 5% (which corresponds to a capacity increase of approximately 10%). It is estimated that a further 5%-10% capacity will be obtained by optimising the designs of new cargo vessels and adopting new propulsion technologies, without increasing the vessel size.

On this basis, the projected 20% increase in GT·nm forecasted for 2040, will constitute a traffic volume change of:

$$\frac{1.20}{1.10 \times 1.05} = 1.04$$

I.e., the increased demand in the Baltic Sea will be predominantly covered by the increase in the vessel sizes, whilst the traffic volumes will remain fairly constant. This assumption appears to be in line with what was noted by looking at the time-series data for the past decade in the traffic study for work package 1.

In the future case scenario, therefore, the risk models were run with traffic volumes increased by 4% compared to the base scenario, and, and vessel external dimensions increased by 5%.

3 TRAFFIC STUDY – BROADER AREA

The aim of this first work package is to report the traffic patterns, identify the traffic corridors and their distribution, and provide an understanding of the current use of maritime space.

3.1 General (Baltic Sea)

The traffic density plot reflecting the existing patterns in the South Baltic Sea based on 2019 and 2020 AIS data is presented in Figure 16 below:

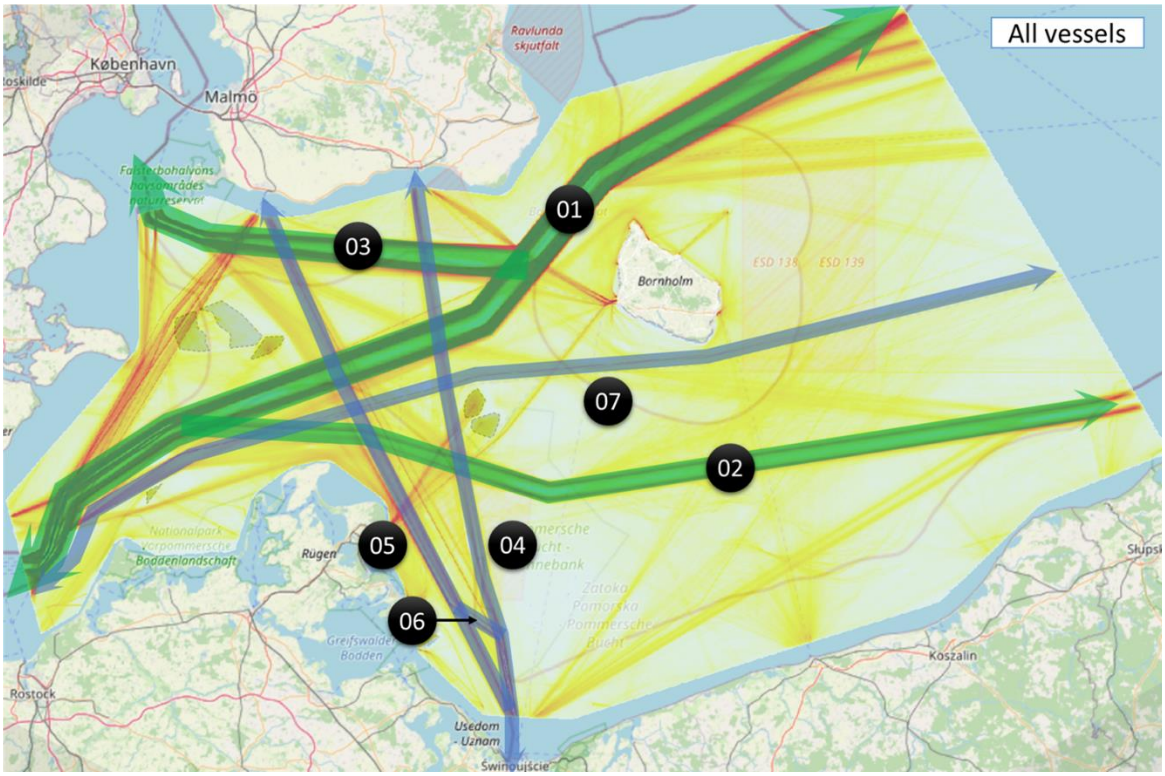


Figure 16: South Baltic Sea Traffic, all vessel types – Density Plot 200m x 200m.

The main traffic corridor in the Baltic is the SW-NE corridor that carries traffic from the Bay of Mecklenburg to the NE part of the Baltic (Note 01). Two other main corridors connect to the former. The first is the spur route to/from the SE Baltic, towards the ports of Poland and Kaliningrad (Note 02) and the second which spurs off to/from Kattegat and into The Sound (Note 03).

There are also two main N-S cargo and passenger routes running to the East of Rugen. The first is the route that connects Swinoujscie to Ystad (Note 04), and the second is between Swinoujscie and Trelleborg (Note 05). The former includes the deep-water channel approach of Swinoujscie used by traffic heading both from/towards Ystad and Trelleborg. This route is the actual continuation of the recommended route starting from the eastern end of the Kadet Rinne deep water route passing north and east of Rugen Island up to the Swinoujscie pilot boarding ground for vessels between 11 and 13.5 metres of draught (Note

06). Vessels requiring lower depths (< 11m) either head to the recommended route or use the area between the two main N-S bound corridors to head north (junction to the route marked with note 05).

A secondary corridor detaches from the main SW-NE traffic corridor (Note 01) just after the end of the South of Gedser Traffic Separation Scheme (TSS), heading south of Bornholm Island towards Klaipeda and the oriental section of the Baltic Sea (Note 07). This route is used primarily by Ro-Ro/Pax and General Cargo vessels.

3.2 Merchant traffic

Merchant vessel traffic typically uses the primary routes described in the general section, however, there are also secondary corridors that are of significance to this traffic. These are presented in Figure 17.

The route annotated as 08 on the figure, presents how shipping traffic uses the deep-water channel out of Swinoujscie before heading west to the deep-water route, following the recommended route marked with safe water buoys, along the coastline of Rugen to sail towards Kattegat or to adjoin the South of Gedser TSS.

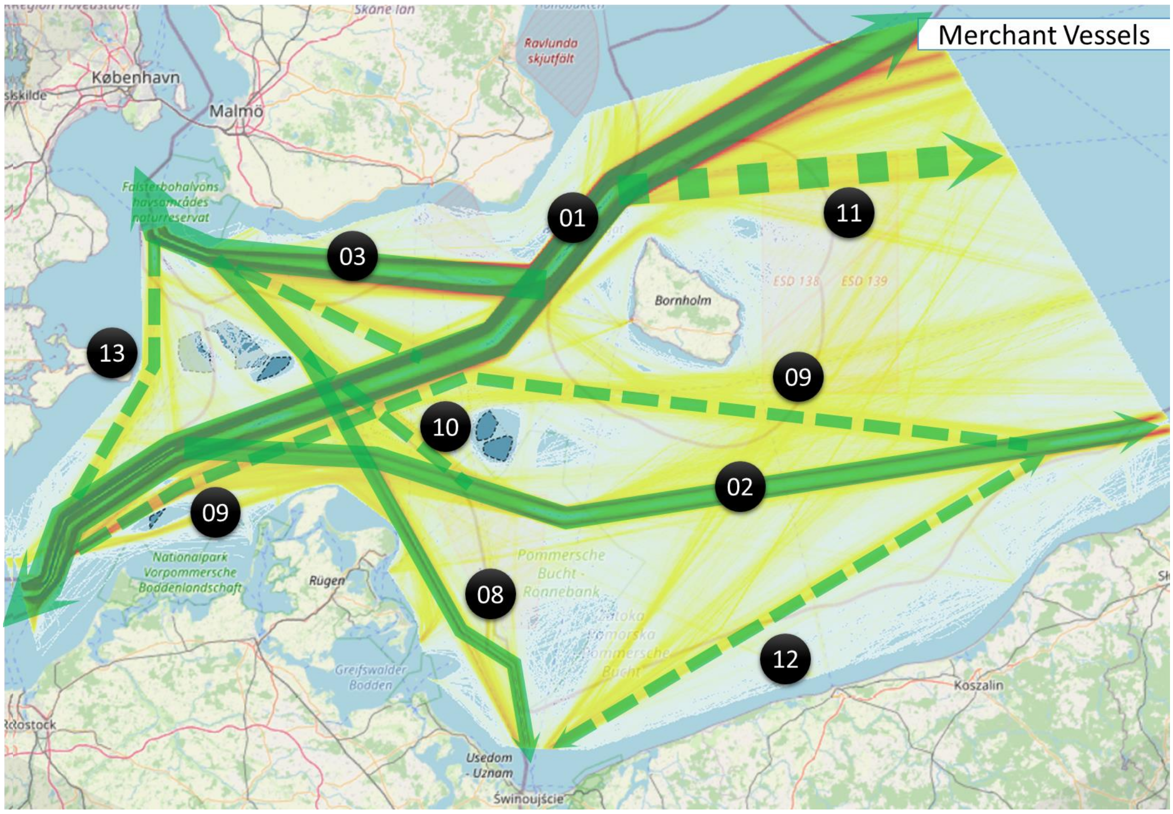


Figure 17: German Baltic Traffic, merchant vessels – Density Plot 200m x 200m.

Notes 09 displays the way cargo traffic that uses the secondary route to the east described earlier under note 07, with the difference that a significant portion of this traffic re-joins the main corridor towards the Polish ports. Most likely, this traffic tends to avoid the transit within the boundary of the TSS lanes.

Traffic between Kattegat and the eastern Baltic follows the route denoted as 03 up to the point where it meets the main SW-NE corridor (Note 01) and then spurs to the east to join the main traffic to the ports of Poland and Kaliningrad. A corridor carrying traffic to and from Klaipeda also spurs off from the main SW-NE corridor, North of Bornholm Island (Note 11).

Note 12 denotes the corridor along the Pomeranian coast used by cargo traffic between Swinoujscie and the ports in the Gulf of Gdansk.

A corridor taking traffic from the main SW-NE route towards Kattegat between South of Gedser and Off Falsterbro along the Danish coastline is marked by Note 13. Whilst predominantly used by Ro-Ro/Pax services, general cargo traffic is the secondary user of this passage.

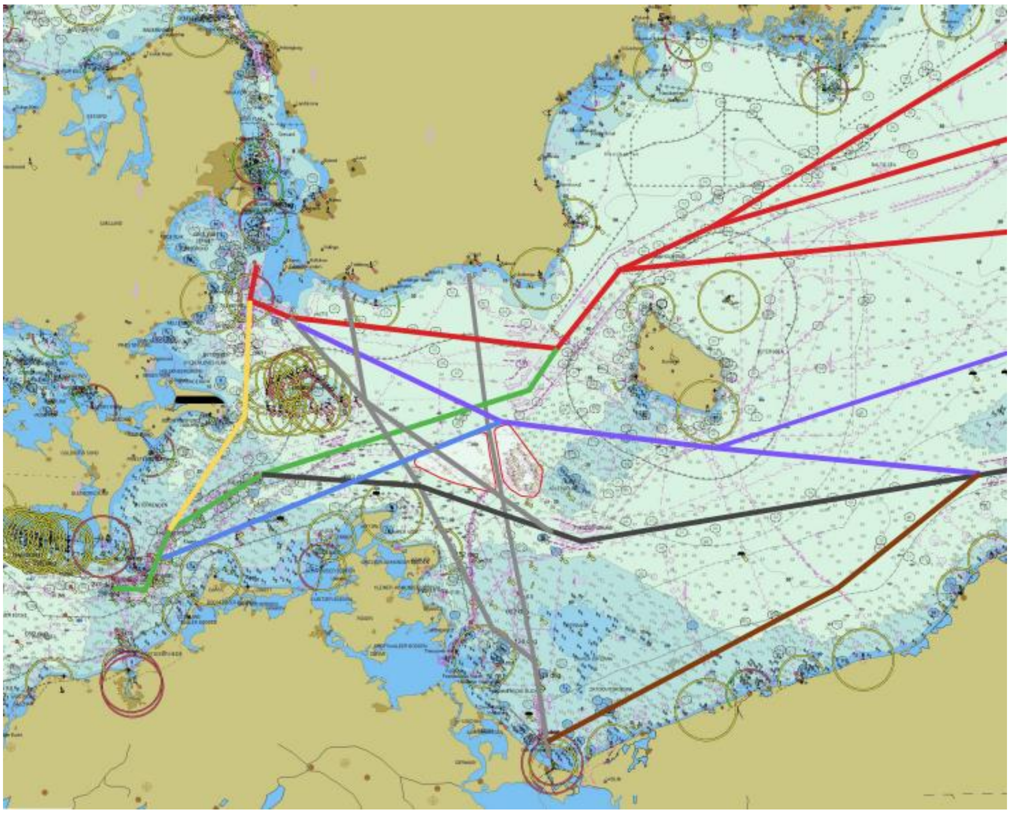


Figure 18: Overall representation of the main traffic corridors in the South Baltic Sea.

3.3 Passenger traffic

Passenger vessels constitute the second most important contributor to vessel traffic in the area of the study. This includes ferry (Ro-Ro/Pax) traffic as well as cruise ships, and other smaller passenger-carrying craft.

The two most important routes in the model, as they both run in the area of interest for Germany’s MSP and thus the present study, are the Swinoujscie to Ystad (Note 04) and Swinoujscie to Trelleborg (Note 05).

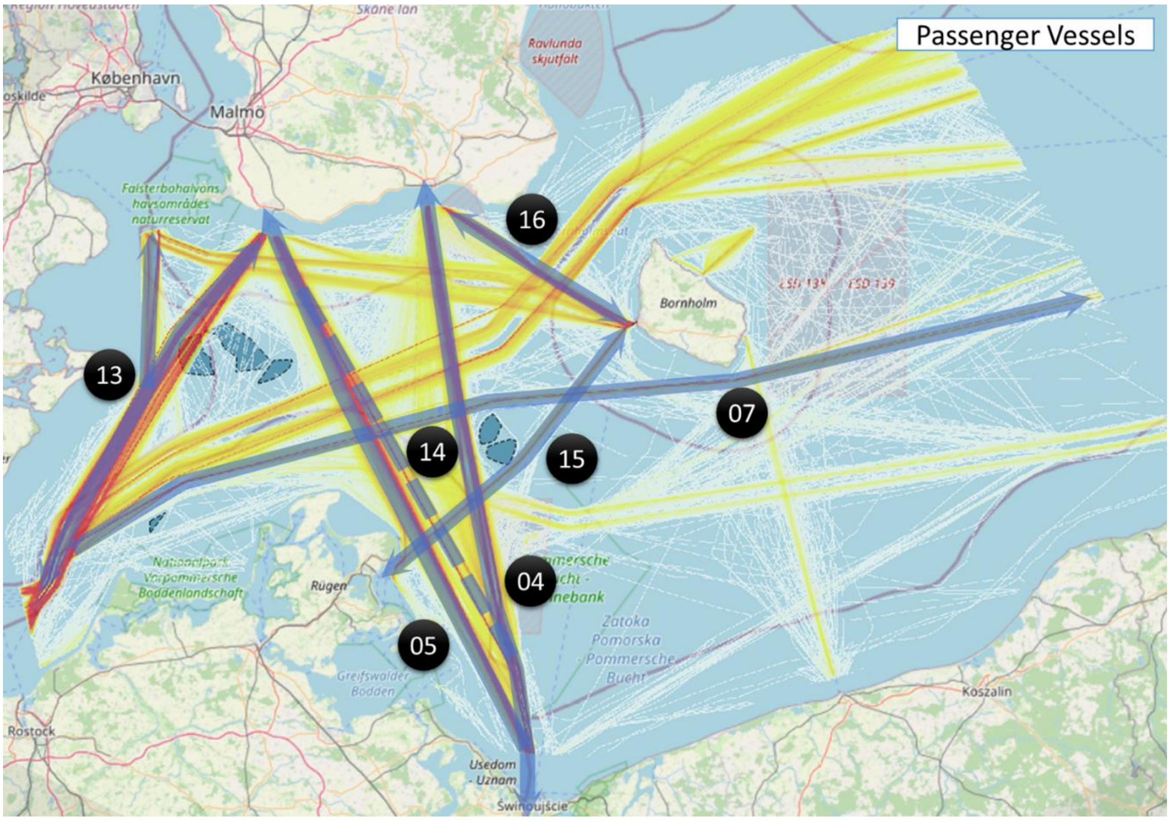


Figure 19: German Baltic Traffic, passenger vessels – Density Plot 200m x 200m.

Of significance is also the ferry traffic that leaves the Swinoujscie to Ystad corridor at the end of the deep-water route that leads to Swinoujscie and uses the intermediate space until it joins the Swinoujscie to Trelleborg route just south of the main SSE-NNW route (Note 14). Another route of high passenger vessel traffic is the Sassnitz to Bornholm line, which crosses to the immediate south of the area of interest (Note 15). Ferry services to Klaipeda, despite the lower volume, interest the area of the study Notable passenger vessel traffic is also noted between Bornholm and Ystad, but this route is of lower significance to the area. It is noted that Ro-Ro/Pax vessels are generally more manoeuvrable than cargo vessels if compared to a laden bulk carrier and tankers for example, and the crew is more acquainted with navigating through high traffic areas, as such, their effect on navigational risk would not have the same impact of other traffic.

It is worth pointing out how traffic adjusts its course in practice with the introduction of an OWF, as can be seen from the area where the Kriegers Flak OWF. The latter has been constructed within the period covered in the AIS dataset for the study (Note 13).

3.4 OWF support vessel traffic

Existing offshore windfarms have introduced additional regular traffic to the area, as they are frequently visited for maintenance activities. This can be on a daily basis or more frequently when the weather permits. This traffic, however, as Crew Transfer Vessels are generally small in size and extremely manoeuvrable vessels, is of very low risk, as it has the capability to easily avoid other traffic.

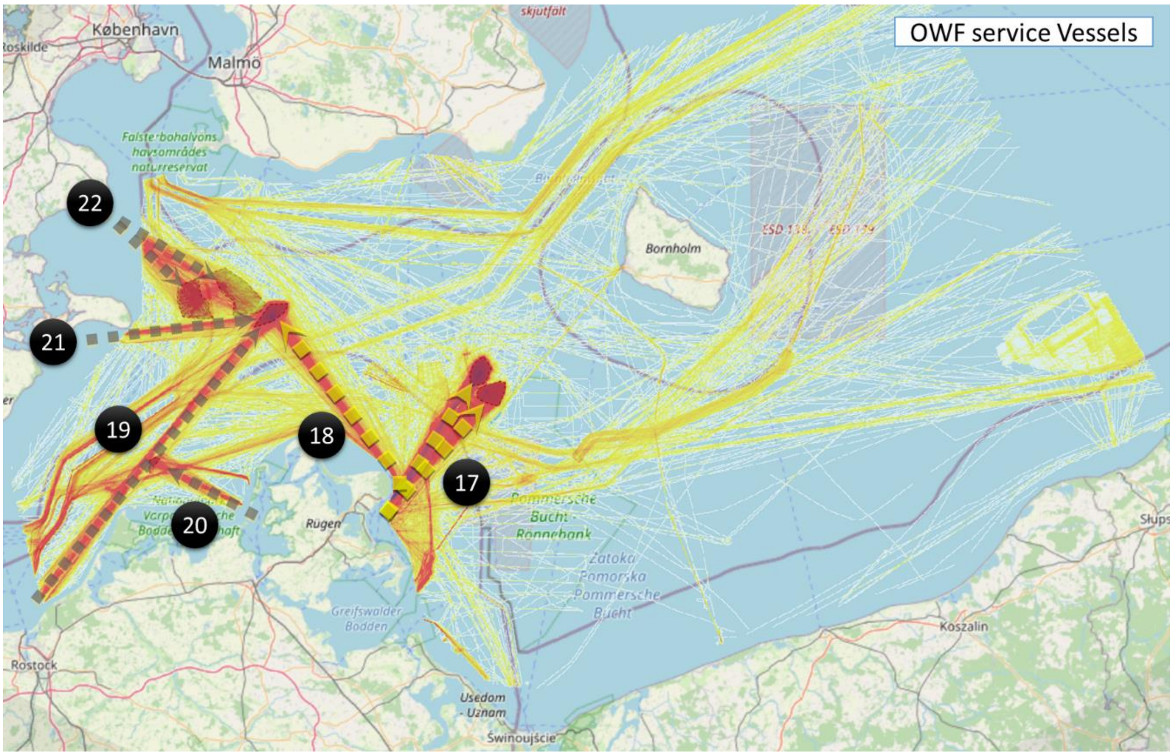


Figure 20: German Baltic Traffic, OWF support vessels – Density Plot 200m x 200m.

The main corridors used by CTV vessels that influence the study area is out of Sassnitz, and to the existing Wikinger and Arkona offshore windfarms (Note 17). Of smaller significance is the route of vessels out of Sassnitz to the EnBW Baltic 2 OWF, as it uses the West side of corridor noted 05 and discussed earlier (Note 18). EnBW Baltic 2 is also serviced out of two more corridors. It receives vessels from Rostock, using the space to the East of the main traffic, and crossing the main SW-NE corridor just to the West of the North of Rugen TSS (Note 19), and from Klintholm in Denmark (Note 21). EnBW Baltic 1 OWF, receives traffic from Stralsund (Note 20).

3.5 Fishing vessel traffic

The assessment of fishing fleets is always a challenging task since AIS data available cannot include the entirety of the fishing vessels, being these commercial or recreational and not mandatorily compliant with AIS.

The coastal states of the study (Germany, Denmark, Sweden, and Poland) report an overall commercial fishing fleet of approximately 410 units with a length overall (loa) > 10-12m and about 1,850 fishing boats of smaller loa[5].LOA. The model assessed included a total of 559 vessels reported as 'fishing' in one year period, however, this number also accounts for the potential fisheries activities conducted by units of other coastal states therefore registered in other countries located on the eastern side of the Baltic Sea

Based on the vessel categorized as fishing that appears in the dataset the plots of these units were observed and noticed to generally transit outside the main traffic corridors, with the exception of the main SW-NE corridor NE from the Bornholmsgat TSS, inclusive, and the corridor from the latter to/from Kattegat (Figure 21).

There appears to be an area between the main traffic corridors, where Arcadis Ost 1 and the Baltic Eagle OWFs are to be constructed, that is currently of interest in terms of fishing activities (Note 23). Fishing vessels use the space to the west of the main N-S corridor, around the coastline of Jasmund to transit to the West or the South (Note 24). Fishing vessels appear to also use the area to the east of the Swinoujscie deep-water recommended route (Note 25).

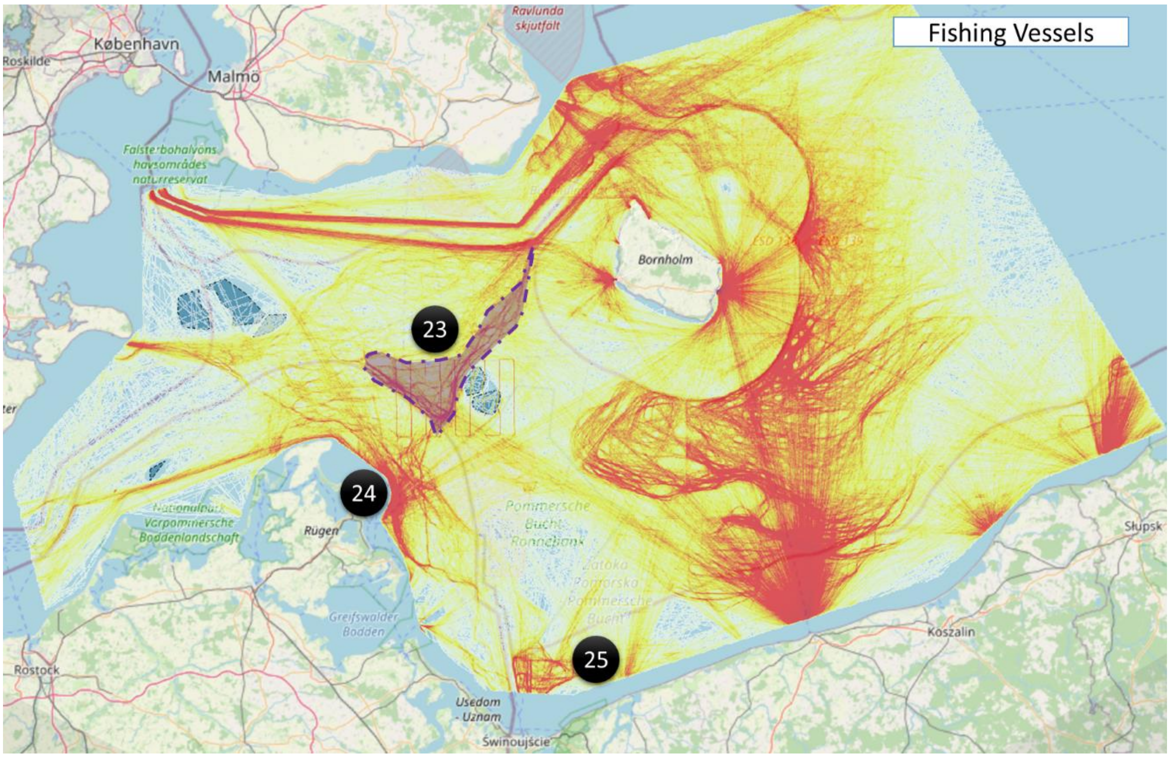


Figure 21: German Baltic Traffic, Fishing vessels – Density Plot 200m x 200m.

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To relate fishing traffic to fishing activity, ABL performed a speed analysis and plotted the density diagram for fishing vessel traffic at a speed of ≤ 5 kts. The result of this assessment is presented in Figure 22. It can be seen that the area to the East and South of Bornholm Island, and down to the Polish coast is an area of high fishing activity. The area of interest to the study is an area of moderate fishing activity, most of which takes place outside the German territorial waters and EEZ, between the Arcadis Ost site and the existing windfarms, with the EO2-West being the area of heaviest fishing activity.

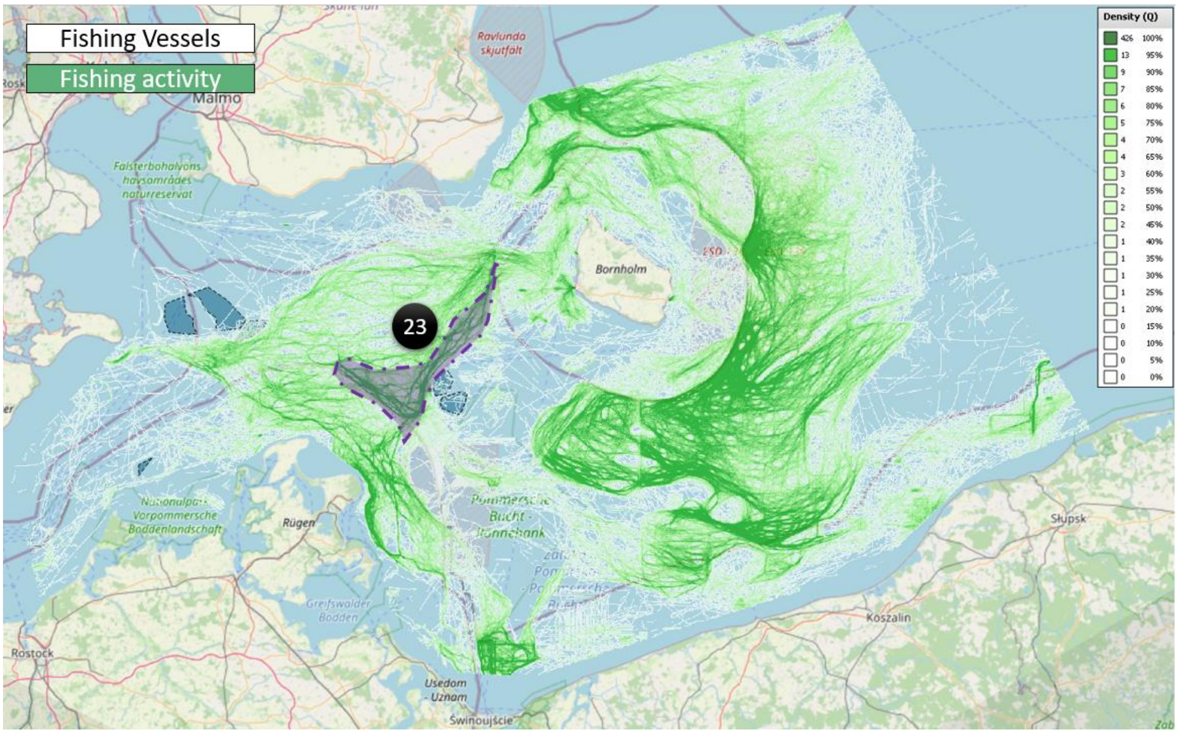


Figure 22: German Baltic Fishing Activity, Density Plot 200m x 200m.

4 NAVIGATIONAL RISK ASSESSMENT

4.1 Benchmark risk – Existing renewable developments under current traffic

The fundamental step in assessing risk is to identify the current risk in the system before any spatial and navigational changes are implemented. This allows the study to understand what the current situation is, and what is the level of risk associated with existing operations under the existing conditions.

The model used to analyse the existing risk is presented in Figure 23 below.

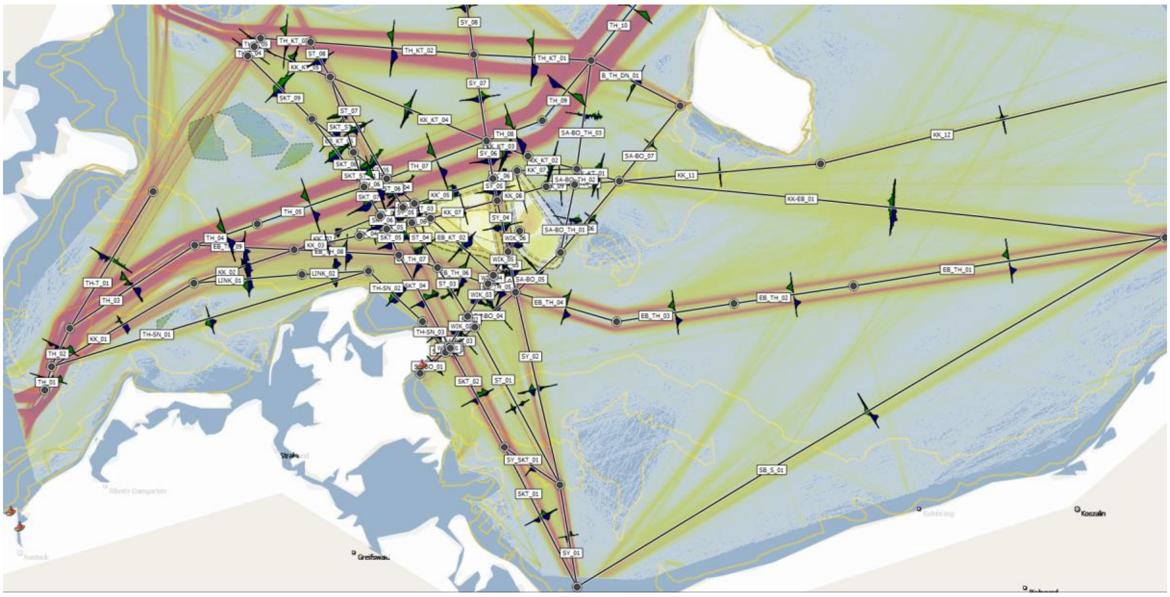


Figure 23: Risk analysis model, current case (2019-2020)

A close-up of the area of interest around the German development areas is presented in Figure 24 overleaf.

The area contains the existing OWFs Wikinger and Arkona, that occupy the centre of plan area EO1, and also in broken lines, the OWFs Baltic Eagle immediately to the west of the existing ones, on the other side of the traffic corridor connecting Swinoujscie to Ystad, within development area EO2, and Arcadis Ost 1 further to the west, in German territorial waters, outside development area EO2. The Baltic Eagle and Arcadis Ost 1 OWFs are in the pre-construction phase and are expected to be operational in the near future.

Between Arcadis Ost 1 and the boundaries of development area EO2, there is a secondary traffic corridor that acts as a spur that diverts traffic from The Sound to the eastern corridor through Adlergrund TSS. This corridor is predominantly used by General Cargo Ships and investigating the potential of this traffic being diverted to the west of the Arcadis Ost 1 OWF for the space to be used for Offshore Wind developments is the main scenario considered in the present study.

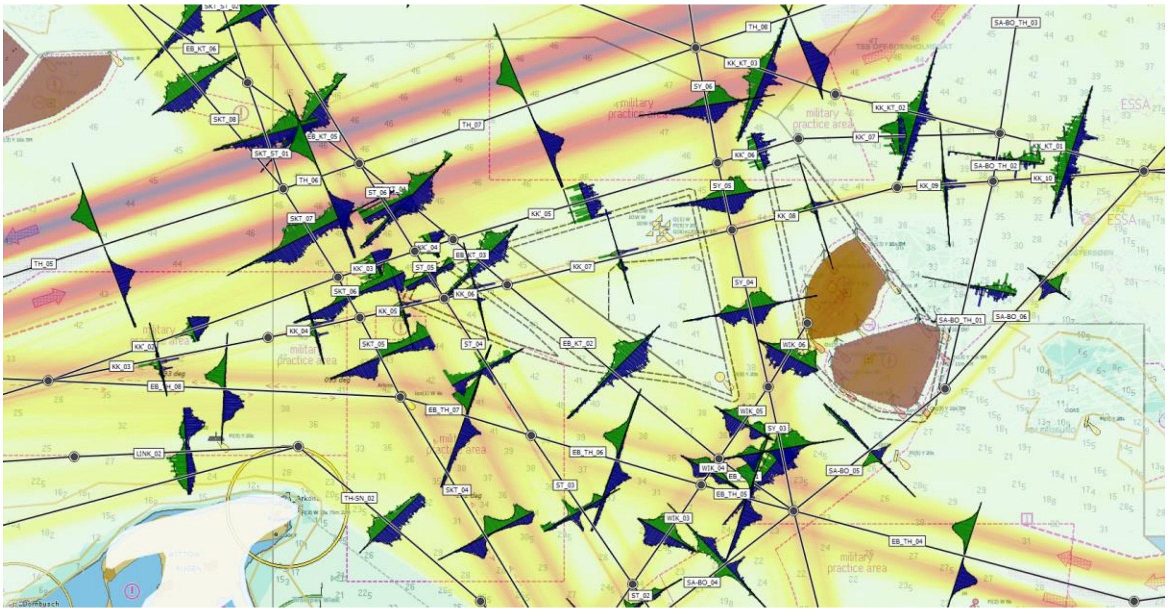


Figure 24: Area of interest in the risk analysis model, current case (2019-2020)

Based on the quantitative risk assessment considerations of section 2.6, the current risk profile in the area is presented in Figure 25.

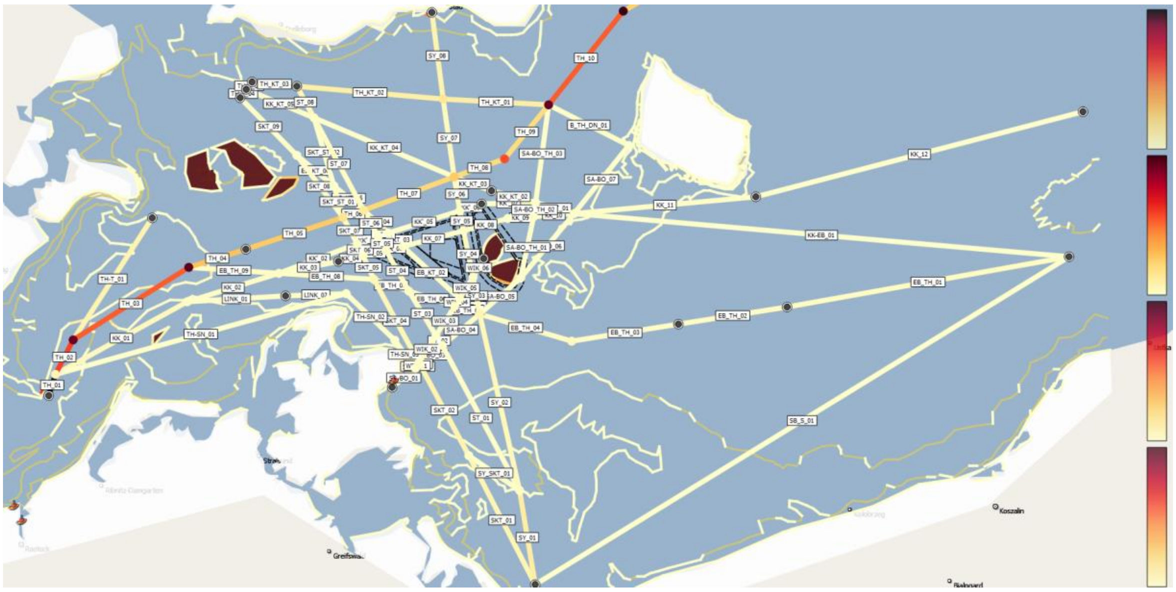


Figure 25: Risk profile of modelled area (percentage basis)

As expected, the higher risk for collisions is concentrated on the main SW-NE traffic corridor carrying the traffic from The Belt to the NE Baltic Sea (Kadetrenden-Bornholmsgat), where the traffic density is exceedingly large compared to all other routes in the model. The risk model calculates a collision probability between vessels of 1.121 incidents per year (i.e., one every 10-11 months). The HELCOM accidents database covering the years 1989-2018 records 23 collisions relevant to the area covered by the model noted in the same time period are circled in Figure 26. It is noted that collisions that took place in Ports or in sparsely trafficked areas outside the main traffic corridors are not picked up by the model. This suggests that the actual collision frequency in the model area is 0.77 collisions per year (i.e., one collision every 1.3 years) over the course of 30 years, approximately 30% lower than the calculated by the model. It is worth noting however, that vessel traffic volumes and sizes have been increasing during the same period.

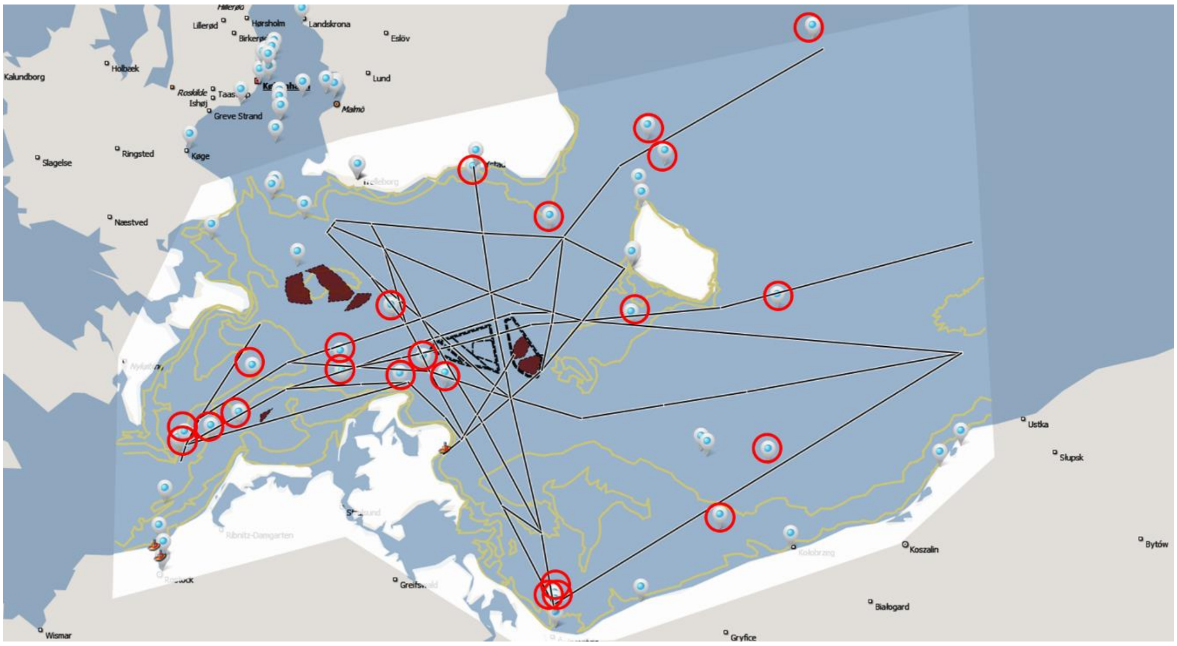


Figure 26: Collisions 1989-2018 (HECLOM Accidents database)

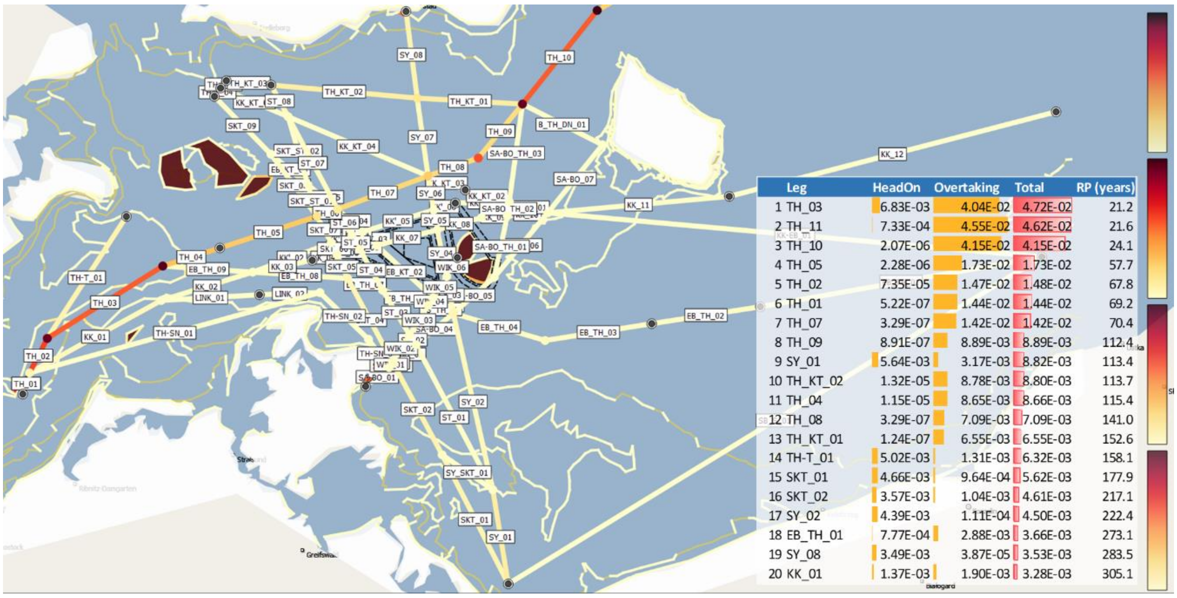
The model also reports a 0.3617 annual groundings probability (i.e., 1 grounding in 2.76 years) and a 0.06731 annual allision probability to an OWF (i.e., 1 allision in 14.86 years). The model comprises the EnBW Baltic 1 and 2 OWFs, the Wikinger and Arkona OWFs, and the two Kriegers Flak OWFs, however, allision risk for the latter will not be looked at in detail, as the traffic corridor to their west directing traffic from Kadet Rinne to The Sound has been interrupted in the model. This decision was made, as the western part of the development was constructed in the duration of the dataset, and thus the dataset included both traffic transiting through the area in 2019 as well as diverting around it in 2020, skewing results.

The overall traffic risks noted in the model are summarised in Table 10.

Table 10: Current incident annual probability summary

Collisions		Allisions		Grounding	
Merging	0.09779	Powered	0.03403	Powered	0.30580
Crossing	0.23680	Drifting	0.03327	Drifting	0.05593
Bend	0.47960				
Head-on	0.05296				
Overtaking	0.25370				
	1.12100		**0.06731**		**0.36170**

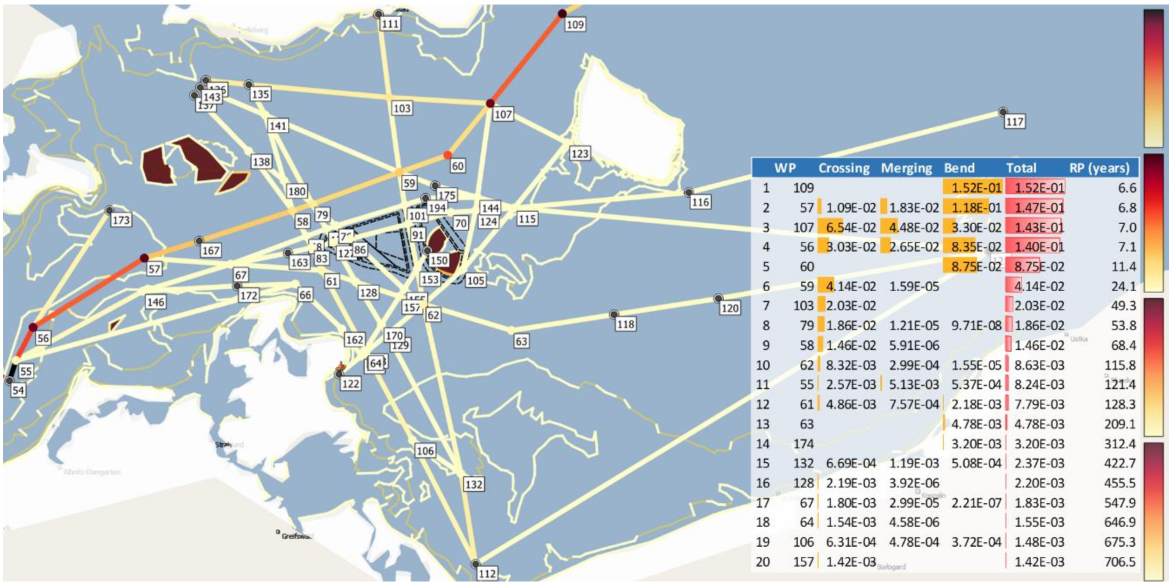
The leg risk in the model as reported earlier is concentrated on the main SW-NE traffic corridor. Other high-risk contributors are the deep-water corridor out of Swinoujscie (however, the navigation along this leg is performed with a pilot on board), as well as the legs on the Swinoujscie to Ystad route at the port approaches, and also the corridor TH_KT that connects The Sound with TSS Bornholmsgat. The top 20 risk-contributing legs are presented in Figure 27.



	Leg	HeadOn	Overtaking	Total	RP (years)
1	TH_03	6.83E-03	4.04E-02	4.72E-02	21.2
2	TH_11	7.33E-04	4.55E-02	4.62E-02	21.6
3	TH_10	2.07E-06	4.15E-02	4.15E-02	24.1
4	TH_05	2.28E-06	1.73E-02	1.73E-02	57.7
5	TH_02	7.35E-05	1.47E-02	1.48E-02	67.8
6	TH_01	5.22E-07	1.44E-02	1.44E-02	69.2
7	TH_07	3.29E-07	1.42E-02	1.42E-02	70.4
8	TH_09	8.91E-07	8.89E-03	8.89E-03	112.4
9	SY_01	5.64E-03	3.17E-03	8.82E-03	113.4
10	TH_KT_02	1.32E-05	8.78E-03	8.80E-03	113.7
11	TH_04	1.15E-05	8.65E-03	8.66E-03	115.4
12	TH_08	3.29E-07	7.09E-03	7.09E-03	141.0
13	TH_KT_01	1.24E-07	6.55E-03	6.55E-03	152.6
14	TH-T_01	5.02E-03	1.31E-03	6.32E-03	158.1
15	SKT_01	4.66E-03	9.64E-04	5.62E-03	177.9
16	SKT_02	3.57E-03	1.04E-03	4.61E-03	217.1
17	SY_02	4.39E-03	1.11E-04	4.50E-03	222.4
18	EB_TH_01	7.77E-04	2.88E-03	3.66E-03	273.1
19	SY_08	3.49E-03	3.87E-05	3.53E-03	283.5
20	KK_01	1.37E-03	1.90E-03	3.28E-03	305.1

Figure 27: Current collision risk at legs – highest 20

In terms of waypoints in the model, the highest risk is recorded as bend risk (vessels changing heading on the route) on the main SW-NE route. Secondary points of risk concentration at much lower risk are the junctions between the Swinoujscie to Trelleborg route, the main NW-SE corridor, the eastern corridor to Adlergrund TSS, and the bends on the latter. The top 20 risk-contributing waypoints are presented in Figure 28Figure 28.



	WP	Crossing	Merging	Bend	Total	RP (years)
1	109			1.52E-01	1.52E-01	6.6
2	57	1.09E-02	1.83E-02	1.18E-01	1.47E-01	6.8
3	107	6.54E-02	4.48E-02	3.30E-02	1.43E-01	7.0
4	56	3.03E-02	2.65E-02	8.35E-02	1.40E-01	7.1
5	60			8.75E-02	8.75E-02	11.4
6	59	4.14E-02	1.59E-05		4.14E-02	24.1
7	103	2.03E-02			2.03E-02	49.3
8	79	1.86E-02	1.21E-05	9.71E-08	1.86E-02	53.8
9	58	1.46E-02	5.91E-06		1.46E-02	68.4
10	62	8.32E-03	2.99E-04	1.55E-05	8.63E-03	115.8
11	55	2.57E-03	5.13E-03	5.37E-04	8.24E-03	121.4
12	61	4.86E-03	7.57E-04	2.18E-03	7.79E-03	128.3
13	63			4.78E-03	4.78E-03	209.1
14	174			3.20E-03	3.20E-03	312.4
15	132	6.69E-04	1.19E-03	5.08E-04	2.37E-03	422.7
16	128	2.19E-03	3.92E-06		2.20E-03	455.5
17	67	1.80E-03	2.99E-05	2.21E-07	1.83E-03	547.9
18	64	1.54E-03	4.58E-06		1.55E-03	646.9
19	106	6.31E-04	4.78E-04	3.72E-04	1.48E-03	675.3
20	157	1.42E-03			1.42E-03	706.5

Figure 28: Current collision risk at waypoints – highest 20

4.2 Near future – Consideration of permit holding, pre-construction developments

Having considered the existing risk in the model area, the next consideration is to modify the model to include the two OWFs that are at the pre-construction stage (Baltic Eagle and Arcadis Ost 1) and consider the changes they will cause to navigation in the area, and consequently, the profile of navigational risk.

The changes that the introduction of the two OWF developments will introduce, will be in the form of alignment changes in the current routes' parts of the vessel traffic use, and also of the lateral distribution of these vessels on the routes.

It is only normal to assume that navigation will look to clear additional infrastructure in the maritime space in the safest way, whilst following the shortest possible track along their route. To capture these changes, the study considered the most attractive navigation routes in the new spatial landscape as that will form after the construction of the aforementioned two OWFs, and to these routes applied the appropriate lateral traffic distributions in line with expert opinion and the recommendations of reports [01], [02].

4.2.1 Navigational changes to the model

The introduction of the Baltic Eagle will require an adjustment to the Swinoujscie – Ystad route, that will shift the axis of the route slightly to the east, to coincide with the centreline of the corridor that will be left between the Baltic Eagle, and the Wikinger and Arkona OWFs (Figure 29).

The expectation is that the route will maintain its current lateral distribution and alignment (for both northbound and southbound traffic) up to the point where it crosses the main eastern route that heads to TSS Adlergrund. Upon crossing the latter, the course will alter slightly to the east to align with the corridor between the three OWFs. The lateral distribution is conservatively assumed to be symmetrical about the axis of the route, with a standard deviation of 0.5nm (926m) for the gaussian lateral distribution (i.e., 95% of the traffic will be passing within 1nm on either side of the route axis) in both directions. As the traffic reaches the approximately 3.5nm wide corridor between the OWFs, the distribution is expected to condense to a standard deviation of 0.4nm (741m) for the gaussian lateral distribution (i.e., 95% of the traffic will be passing within 0.8nm on either side of the route axis) in both directions. Once this part of the route is cleared, the distribution is expected to widen to cross the main SW-NE route. The distribution for this part is also assumed symmetrical in both directions, with a standard deviation of 0.5nm (926m) for the gaussian lateral distribution (i.e., 95% of the traffic will be passing within 1nm on either side of the route axis). Onwards to Ystad, the current lateral distributions are maintained.

The introduction of the Arcadis Ost 1 OWF in the maritime space, will occupy a space that is currently predominantly used by part of the ferry traffic from Swinoujscie to Trelleborg.

This lane of traffic, represented by route ST in the model, is expected to shift to the west and merge with the N-S route (SKT in the model) as it approaches the latitude of the new OWF. When the main SW-NE route is crossed, the traffic to Trelleborg will detach from the latter, subsequently adjusting the heading to NNE to its destination (Figure 29).

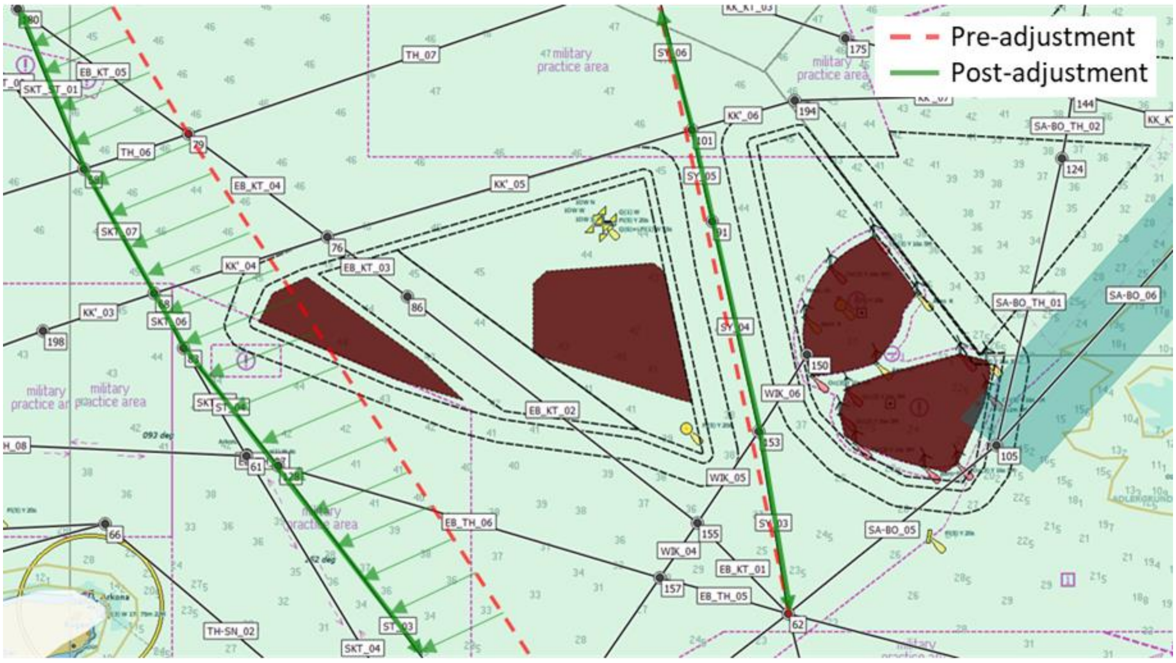


Figure 29: Changes in the model in the area of interest post-development of the 2 OWFs

This traffic corresponds to the vessels of a draught between 11 and 13.5m that opt to use the Swinoujscie and Szczecin roadstead under pilotage before they detach from it and sail to the west of that. The expectation is that their traffic pattern will be maintained as they sail the roadstead and will then spread out as they will select different tracks to re-merge into deeper waters. The current route does not show signs of directionality, so a symmetrical distribution has been assumed up to the point of intersection with the N-S route (SKT) near the Arcadis Ost 1 OWF. The standard deviation is considered as 0.5nm (926m) for the gaussian lateral distribution (i.e., 95% of the traffic will be passing within 1nm on either side of the route axis)[6]. Upon merging, the traffic is initially expected to maintain the latter distribution in both directions, before the northbound component expands to a wider distribution to cross the main SW-NE route. At that point, the standard deviation (SD) of the northbound distribution is expected to increase to the wider end of the spectrum for wide traffic corridors, at 1nm (1852m) for the gaussian lateral distribution, which means that 95%

[6] It is noteworthy to specify that the lateral distribution was assumed to widen or shrink based on the available room for manoeuvre an Officer of the Watch (OOW) might encounter during the transit, this of course, when it occurs in correspondence of the crossing of the main corridors such as the Kadet Rinne to Bornholmsgat TSS flow, it is expected to allow the OOW to increase the options for collision avoidance utilising a wider stretch of sea and therefore increasing the standard deviation in that area. Opposite consideration is made when the 'obliged' passage at a waypoint (i.e., west of Arcadis Ost 1) need to be achieved in order to proceed along the route to the final destination.

of the traffic is expected to cross within 2nm on either side of the route axis. Upon crossing the main SW-NE route, the traffic is expected to bifurcate, with traffic to Trelleborg veering to the NNE, and traffic to The Sound maintaining the course to the north. For both these routes, it is expected that near the main SW-NE route, the southbound traffic will maintain a wide distribution (SD of 1nm) whilst northbound traffic will condense to the narrower of the wide sea-lane permissible spectrum at a standard deviation of 0.5nm. Traffic to The Sound is expected to resume its current as-is distribution once it clears the EnBW Baltic 2 OWF, whilst traffic to Trelleborg is assumed to maintain the revised distribution up to the point it crosses the W-E route from The Sound to TSS Bornholmsgat, as a result of the change in its alignment.

The construction of the two OWFs will also require a slight adjustment to the centreline of the traffic navigating from The Sound to Adlergrund TSS that detach from the main route and use the space as a spur route to the SE (Figure 30). The traffic will tend to centre itself to navigate through the corridor. With approximately 1.5 transits per direction per day, the likelihood of crossing traffic is small.

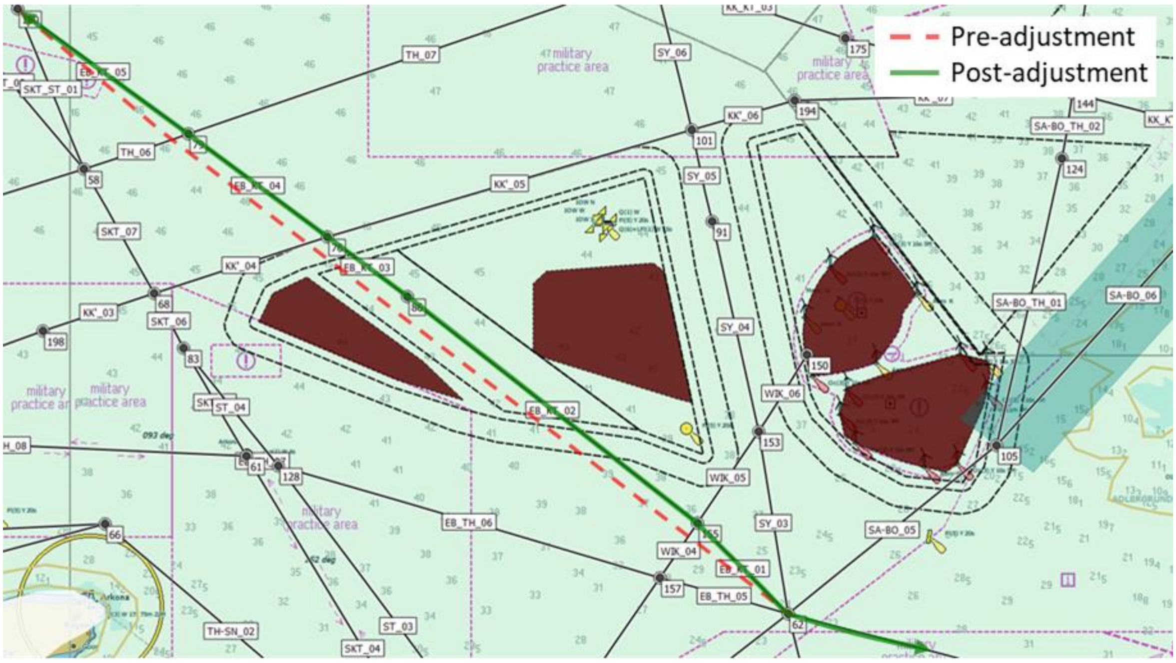


Figure 30: Adjustment to the centreline of the traffic navigating from The Sound to Adlergrund TSS

The lateral distribution assumed through the corridor is the same as the one used for the one between the Baltic Eagle, and Wikinger and Arkona OWFs. The standard deviation of 0.4nm (741m) for the gaussian lateral distribution (i.e., 95% of the traffic will be passing within 0.8nm on either side of the route axis) in both directions. To the south of the crossing, distribution is assumed to continue on its current as-is pattern. To the north of the corridor, the expectation is that the southbound traffic pattern will be condensed approaching the corridor, assuming a standard deviation of 0.4nm for the gaussian distribution, whilst the northbound traffic will be spreading to cross the main SW-NE route, thus developing a distribution with a standard deviation of 1nm. Further north, after crossing the main SW-NE route, traffic is expected to maintain its symmetrical characteristics, as well as the wide distribution (SD = 1nm) in both directions, up to the point of EnBW Baltic 2, where it will resume its current as-is distribution.

The fourth and final change that will be enforced as a result of the development of the OWFs will be the need for the traffic route to Klaipeda that currently crosses through the development area to be diverted. The obvious choice for this traffic is to shift to the north and use the space between the boundaries of the OWF development areas and the main SW-NE route up to the point it clears the development areas and then resume its course to the SW of Bornholm Island (Figure 31).

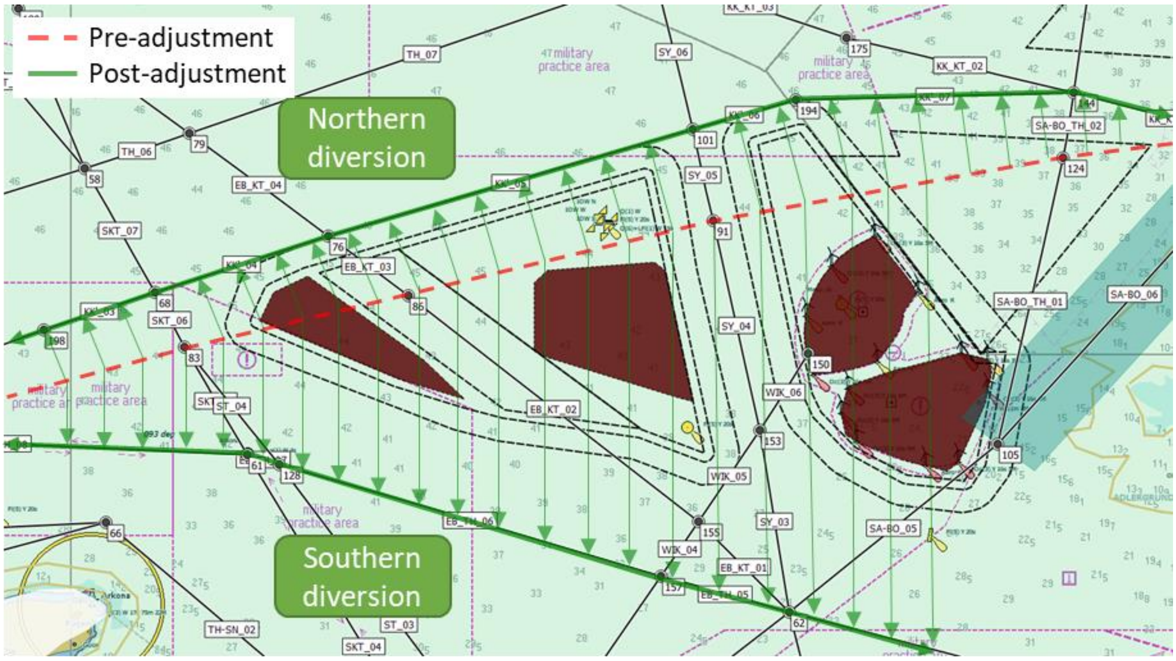


Figure 31: Klaipeda traffic, northern and southern diversion

This is consistent with the latest available information on the Danish MSP, which shows the relevant traffic corridors available for navigation despite the development of the area to the WSW of Bornholm Island for offshore wind. However, it should be noted that whilst this is the latest available information, it is not final or binding, as the Danish MSP for the area has not been finalised. Earlier versions considered a larger development plot in the area that would block this northern diversion within the Danish EEZ and would require the re-direction of the Klaipeda traffic to the south, through the main eastern route through Adlergrund TSS. For that matter, whilst all stakeholders agree that the most likely diversion route is the northern, GDWS, one of the stakeholders, requested that we consider a comparative risk analysis at this stage, between the northern and southern diversion routes (Figure 31).

4.2.1.1 Northern diversion

For the northern diversion, the traffic to Klaipeda is channelled between the main NW-SE corridor and the northern boundary of the offshore windfarms. This narrow space is currently used by a smaller number of vessels (mainly small cargo vessels) that choose to not follow the bend of the main route after they exit TSS South of Gedser, potentially as a shortcut. The minimum charted depth in correspondence of the Ronne Banke is an isolated 10.7m over an average between 13 and 14m, therefore it would not be an option considered by larger vessels with considerable draught. The northern diversion will commence at waypoint 67 (located approximately 2nm south of North of Rugen TSS) where this traffic crosses the recommended route of the main eastern route towards Adlergrund TSS. As the traffic will be intended to use a fairly narrow corridor, the lateral distribution will be quite dense, with a standard deviation for the gaussian part of 0.3nm (556m) in both directions (i.e., 95% of the traffic will be passing within 0.6nm on either side of the route axis). This distribution will be maintained in both directions up to the point it clears the NE corner of EO1 OWF areas. At that point, whilst the westbound traffic distribution will remain compact, the eastbound traffic will open up to a low-end wide sea lane distribution, with a standard deviation for the gaussian part of the distribution considered as 0.5nm (926nm – i.e., 95% of the traffic will be passing within 1nm on either side of the route axis). The lateral distribution of traffic will subsequently expand more to a wider open sea profile, as the corridor converges with traffic coming from The Sound. A standard deviation of 1nm is considered for both directions of this part of the route before it assumes its current track and distribution going further east.

4.2.1.2 Southern diversion

In the case of the southern diversion, the traffic to Klaipeda will be redirected along the main eastern EB_TH route, through Adlergrund TSS, and then detach to the ENE heading towards Klaipeda. The starting point for this diversion will also be waypoint 67.

The additional volume of traffic, as well as the fact that it comprises mainly Ro-Ro/Pax vessels that tend to move at faster speeds compared to cargo vessels, will alter the distribution of traffic, which currently is almost completely segregated in the two directions because of the recommended route and the approach to the Adlergrund TSS, however, at a tighter distribution. The expectation is that as faster traffic will be overtaking on the notional lanes of this route, the distribution will become wider, and to some extent seep into the opposite direction. Therefore, a lateral distribution matching the 0.5nm standard deviation of a TSS lane was considered in both directions, however, set at a distance between means that allows part of the tail of the distribution of each direction to be in the opposite traffic direction. At the point the diversion detaches from the main eastern route and heads NE to re-join its current alignment, the distribution of a wide sea lane is used, with a standard deviation of 1nm (1852m) for the gaussian lateral distribution (i.e., 95% of the traffic will be passing within 2nm on either side of the route axis), in both directions.

4.2.2 Risk assessment results

4.2.2.1 Northern diversion

The results of the quantitative risk assessment based on the routing and traffic distribution changes for the northern diversion, and in line with the parameters presented in section 2.6, delivered the risk profile presented in Figure 32.

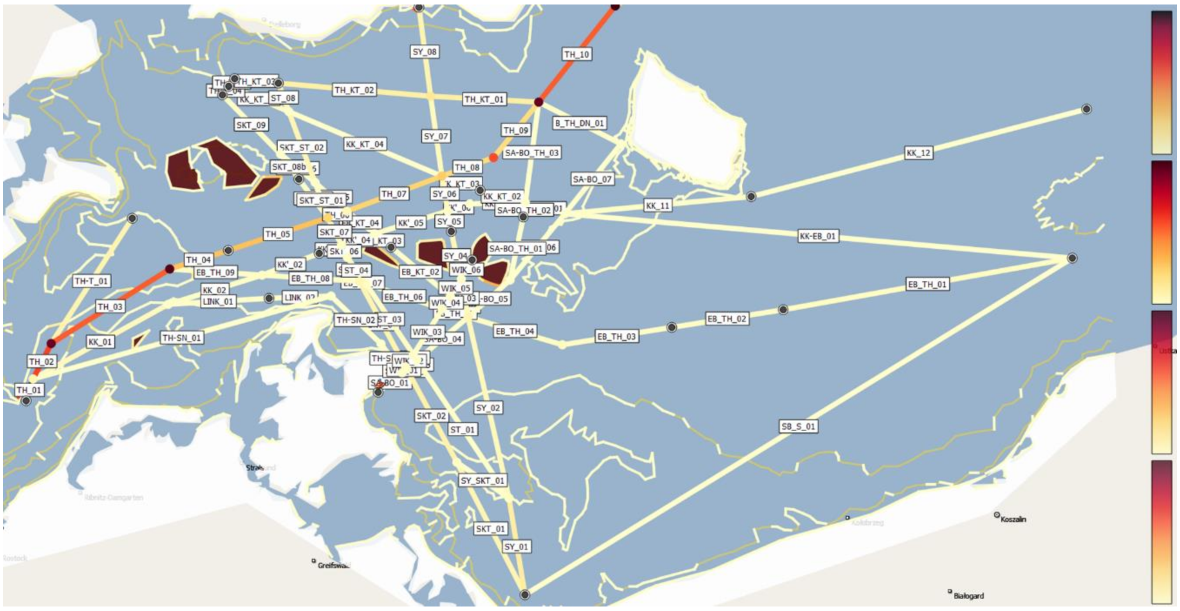


Figure 32: Near future risk profile of modelled area (percentage basis) for northern diversion of Klaipeda

The higher risk for collisions remains on the main SW-NE traffic corridor carrying the traffic from The Belt to the NE Baltic Sea, as a direct result of the traffic on that corridor substantially exceeding traffic elsewhere on the model. The risk model calculates a collision probability for vessel-to-vessel collisions of 1.11 incidents per year, slightly lower than the benchmark value before the construction of Arcadis Ost 1 and Baltic Eagle, but still in the one every 10-11 months range. This is most likely a result of the reduction in overtaking collisions.

The model also reports a probability for annual groundings of 0.3611 (i.e., 1 grounding in 2.76 years) which is almost identical (incrementally lower) to that of the conditions preceding the construction of the OWFs.

The annual allision probability, on the other hand, increases as more OWF areas were introduced to the maritime space, to a value of 0.1037 (i.e., 1 allision in 9.64 years). The additional OWFs in the model for this phase are Arcadis Ost 1 and Baltic Eagle. It is noted that as the analysis model extends substantially beyond the 15nm distance from each OWF specified in [01], [02], and beyond the 20nm maximum limit set by the latter. A substantially larger model is used in this instance, so as to capture the effect of changes to a broader area compared to that of an individual OWF study. As a result, however, the risk of drifting allision returned by this model is substantially higher than that of a model limited to the recommended 15nm range, for which the limits of acceptability of the GL guideline pertain. The reason for that is that based on the criterion that vessels may be drifting for up to 24h, there is a substantially higher number of drifting vessels in the model that may ultimately result in collisions with an OWF, although being highly unlikely in reality. For fairness, therefore, collision risks and return periods will not be reported for individual OWFs, however, where relevant, % increases in the noted risk will be reported.

The overall traffic risks noted in the model for the near-future scenario with the diversion of the Klaipeda line to the north of the development areas are summarised in Table 11.

Table 11: Near future incident annual probability summary – northern diversion

Collisions		Allisions		Grounding	
Merging	0.09793	Powered	0.03535	Powered	0.30580
Crossing	0.23780	Drifting	0.06838	Drifting	0.05527
Bend	0.48100				
Head-on	0.05721				
Overtaking	0.23630				
	1.11000		**0.10370**		**0.36110**

The leg risk in the model as reported earlier is concentrated on the main SW-NE traffic corridor. Other high-risk contributors are the corridor TH_KT that connects The Sound with TSS Bornholmsgat, the legs on the Swinoujscie to Ystad route at the port approaches, the deep-water route out of Swinoujscie to the north and the easternmost leg of the main eastern corridor through Adlergrund TSS towards the Polish ports of Gdynia and Gdansk. The top 20 risk-contributing legs are presented in Figure 33.

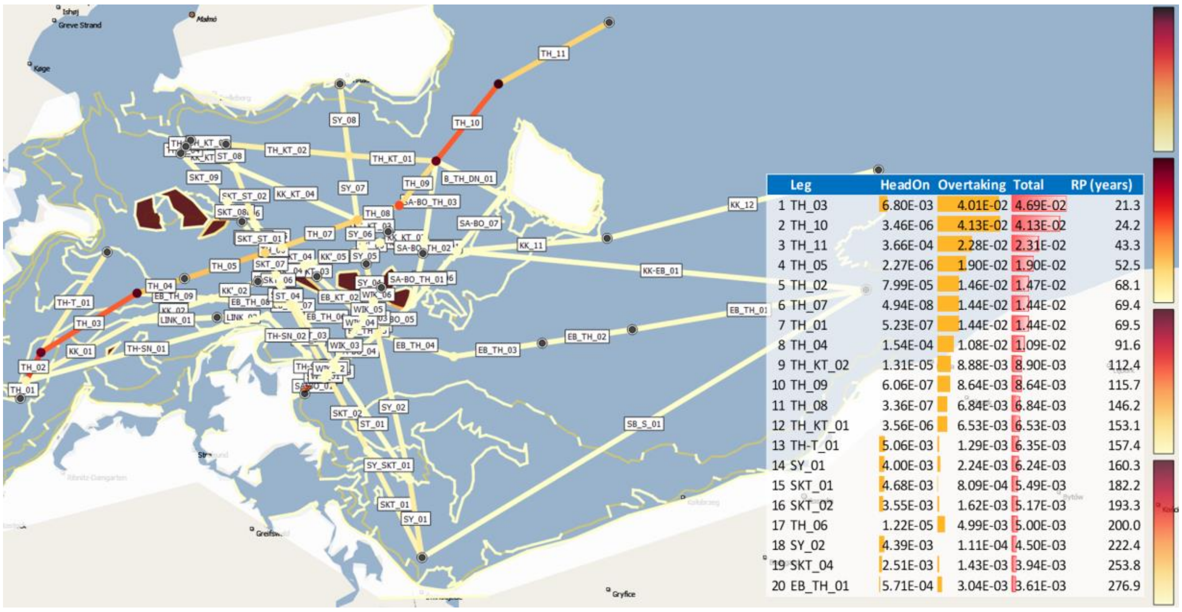
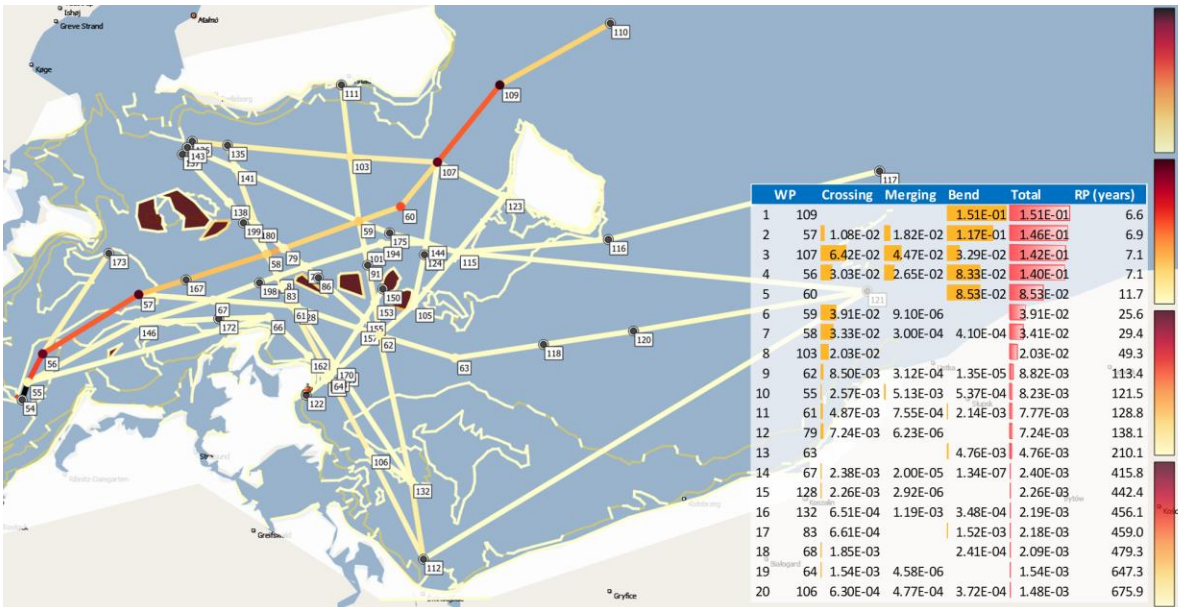


Figure 33: Near future leg collision risk for northern diversion of Klaipeda – top 20

The highest risk in waypoints of the model is recorded as bend risk, consistent with the benchmark model. It is still waypoint 109 on the main SW-NE route. Secondary points of risk concentration at much lower risk are the junctions between the Swinoujscie to Trelleborg route, the main NW-SE corridor, the eastern corridor to Adlergrund TSS, and the bends on the latter. The top 20 risk-contributing waypoints for the near-future model with the northern diversion of the Klaipeda route are presented in Figure 34.



	WP	Crossing	Merging	Bend	Total	RP (years)
1	109			1.51E-01	1.51E-01	6.6
2	57	1.08E-02	1.82E-02	1.17E-01	1.46E-01	6.9
3	107	6.42E-02	4.47E-02	3.29E-02	1.42E-01	7.1
4	56	3.03E-02	2.65E-02	8.33E-02	1.40E-01	7.1
5	60			8.53E-02	8.53E-02	11.7
6	59	3.91E-02	9.10E-06		3.91E-02	25.6
7	58	3.33E-02	3.00E-04	4.10E-04	3.41E-02	29.4
8	103	2.03E-02			2.03E-02	49.3
9	62	8.50E-03	3.12E-04	1.35E-05	8.82E-03	113.4
10	55	2.57E-03	5.13E-03	5.37E-04	8.23E-03	121.5
11	61	4.87E-03	7.55E-04	2.14E-03	7.77E-03	128.8
12	79	7.24E-03	6.23E-06		7.24E-03	138.1
13	63			4.76E-03	4.76E-03	210.1
14	67	2.38E-03	2.00E-05	1.34E-07	2.40E-03	415.8
15	128	2.26E-03	2.92E-06		2.26E-03	442.4
16	132	6.51E-04	1.19E-03	3.48E-04	2.19E-03	456.1
17	83	6.61E-04		1.52E-03	2.18E-03	459.0
18	68	1.85E-03		2.41E-04	2.09E-03	479.3
19	64	1.54E-03	4.58E-06		1.54E-03	647.3
20	106	6.30E-04	4.77E-04	3.72E-04	1.48E-03	675.9

Figure 34: Near future waypoint collision risk for northern diversion of Klaipeda – top 20

There appears to be a rise in the risk at waypoint 58, which is anticipated as the ferry route that was crossing the main NW-SE route (waypoint 126 – which was itself a top 20 risk point) merged into the main N-S route at point 58. All other waypoints appear to have slightly reduced risk compared to the current.

4.2.2.2 Southern diversion

The results of the quantitative risk assessment for the southern diversion, on the basis of the assumptions as used for the northern diversion, but with changes to the traffic distributions relevant to the circumstances formed under the southern diversion, are presented in Figure 35.

The general view of the risk profile looks identical to the one under the northern diversion, mainly because the higher risk for collisions remains on the main SW-NE traffic corridor carrying the traffic from The Belt to the north of Bornholm, and the level of risk on that route substantially exceeds what is recorded in the rest of the model. Secondarily, the risk appears on the deep draught route from Swinoujscie to The Sound and Trelleborg, and the main eastern corridor towards the ports of Gdynia and Gdansk.

The risk model for the southern diversion, calculates a collision probability for vessel-to-vessel collisions of 1.108 incidents per year, marginally lower than under the northern diversion (-0.2% - i.e., producing one less incident every 555 years), and slightly lower than the benchmark value before the construction of Arcadis Ost 1 and Baltic Eagle, but still in the one every 10-11 months range.

Figure 35: Near future risk profile of modelled area (percentage basis) for southern diversion of Klaipeda

The model also reports a probability for annual groundings of 0.3605 which is 0.15% lower than that of the northern diversion, with both being almost identical (incrementally lower) to that of the conditions preceding the construction of the Arcadis Ost 1 and Baltic Eagle OWFs.

The annual allision probability also appears reduced compared to that calculated for the northern diversion. The calculated annual probability of 0.09932 (i.e., 1 allision in 10.07 years) constitutes a 4.44% reduction in allision risk.

Looking at individual OWFs in the area, the southern diversion constitutes a reduction of risk of 0.25% for Arkona and a 0.62% reduction in risk for Wikinger. Looking at Arcadis Ost 1, the boundary of which is the closest to the northern diversion route, the calculated risk when the southern diversion is considered reduces by 18.86%, which is a substantial margin. For the Baltic Eagle, the risk reduction is in the order of 6.05%, which is also notable.

The overall traffic risks noted in the model for the near-future scenario with the diversion of the Klaipeda traffic through the southern route into the main eastbound route, are summarised in Table 12.

Table 12: Near future incident annual probability summary – southern diversion

Collisions		Allisions		Grounding	
Merging	0.09926	Powered	0.03507	Powered	0.30540
Crossing	0.23700	Drifting	0.06424	Drifting	0.05509
Bend	0.48460				
Head-on	0.05562				
Overtaking	0.23170				
	1.10800		**0.09932**		**0.36050**

The leg risk in the model as reported earlier is very similar to the one applicable for the northern diversion route. However, there are parts of the main SW-NE traffic corridor, that despite still appearing in the top 20 list when it comes to collision risk, they appear to slightly de-risk as the associated return periods increase. This is expected since traffic has been moved away from the space between the main route and the OWFs, which especially in the case of westbound traffic, helps reduce the risk in that part of the model. Other high-risk contributors remain to be the corridor TH_KT that connects The Sound with TSS Bornholmsgat, the legs on the Swinoujscie to Ystad route at the port approaches, however, are referred to as the section of the route under pilotage, the deep-water route out of Swinoujscie to the north and the easternmost leg of the main eastern corridor. The top 20 risk-contributing legs are presented in Figure 36.

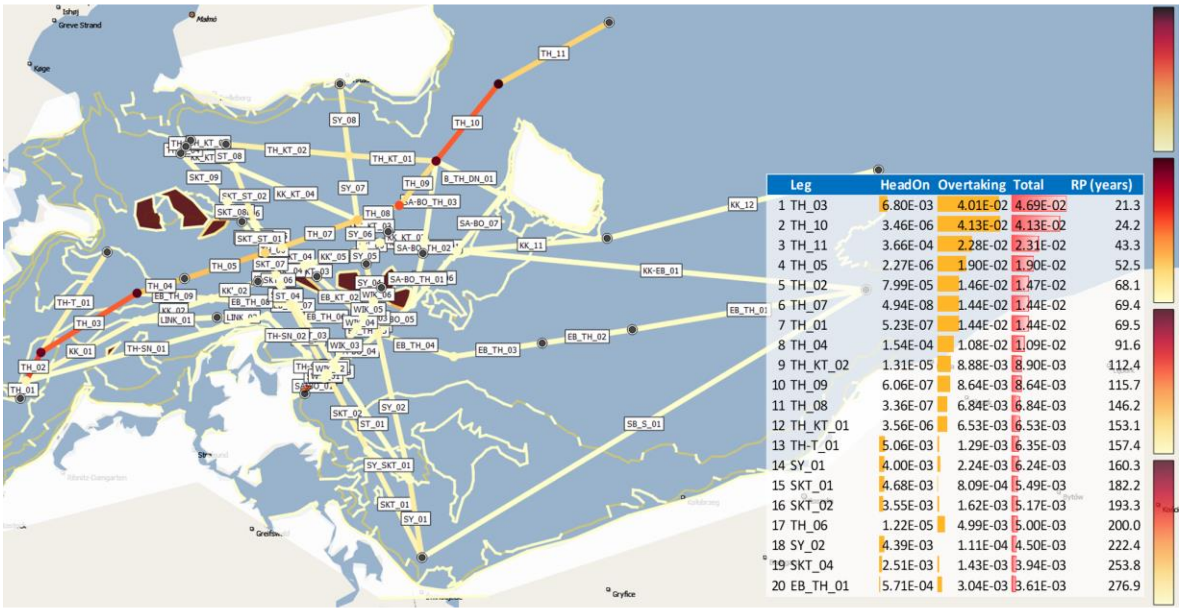
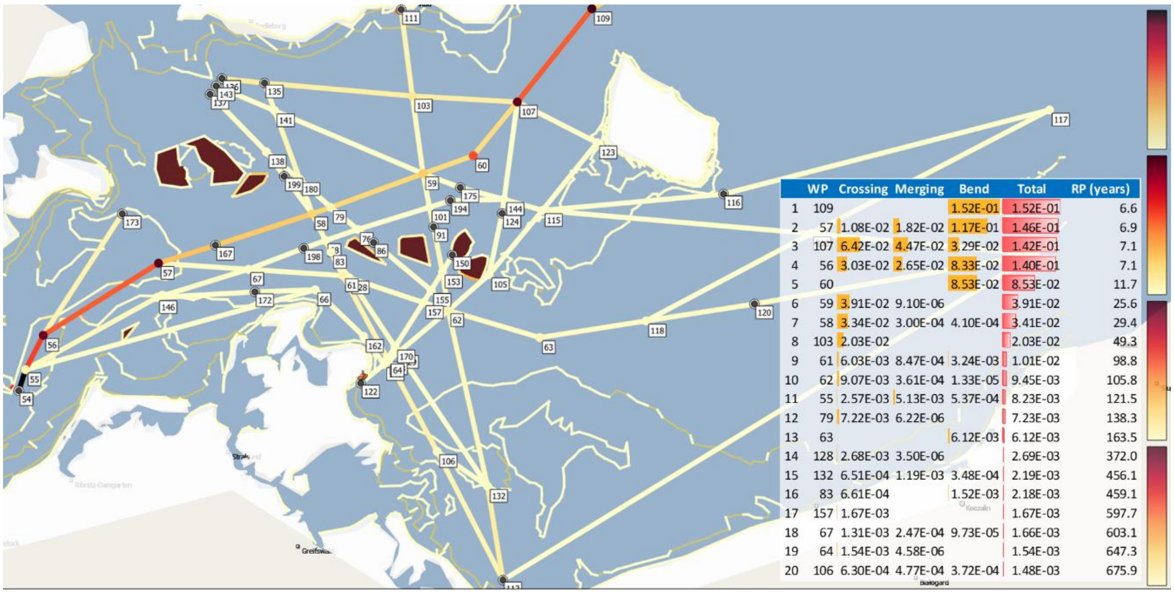


Figure 36: Near future leg collision risk for southern diversion of Klaipeda – top 20

The highest risk in waypoints of the model is recorded as bend risk at point 109 on the main SW-NE route, consistent with the benchmark model and the north diversion alternative. The top of the list both in terms of constituent waypoints and risk remain unchanged, as they are not affected by the changes in the immediate area of the developments. The top 20 risk-contributing waypoints for the near-future model with the northern diversion of the Klaipeda route are presented in Figure 37.

It is notable however that the risk has increased at waypoint 61, the junction between the N-S route from Swinoujscie to Trelleborg and The Belt, by a margin of 31%. The increased diverted traffic on the eastern route and the change in the lateral distribution of traffic about the axis of the route constitute the causation. This change in risk corresponds to one additional collision every 417 years. The same reasons led, to a lesser extent, to the increase of risk in subsequent waypoints on the same route, up to the point where the Klaipeda route traffic detaches from the eastern route.



	WP	Crossing	Merging	Bend	Total	RP (years)
1	109			1.52E-01	1.52E-01	6.6
2	57	1.08E-02	1.82E-02	1.17E-01	1.46E-01	6.9
3	107	6.42E-02	4.47E-02	3.29E-02	1.42E-01	7.1
4	56	3.03E-02	2.65E-02	8.33E-02	1.40E-01	7.1
5	60			8.53E-02	8.53E-02	11.7
6	59	3.91E-02	9.10E-06		3.91E-02	25.6
7	58	3.34E-02	3.00E-04	4.10E-04	3.41E-02	29.4
8	103	2.03E-02			2.03E-02	49.3
9	61	6.03E-03	8.47E-04	3.24E-03	1.01E-02	98.8
10	62	9.07E-03	3.61E-04	1.33E-05	9.45E-03	105.8
11	55	2.57E-03	5.13E-03	5.37E-04	8.23E-03	121.5
12	79	7.22E-03	6.22E-06		7.23E-03	138.3
13	63			6.12E-03	6.12E-03	163.5
14	128	2.68E-03	3.50E-06		2.69E-03	372.0
15	132	6.51E-04	1.19E-03	3.48E-04	2.19E-03	456.1
16	83	6.61E-04		1.52E-03	2.18E-03	459.1
17	157	1.67E-03			1.67E-03	597.7
18	67	1.31E-03	2.47E-04	9.73E-05	1.66E-03	603.1
19	64	1.54E-03	4.58E-06		1.54E-03	647.3
20	106	6.30E-04	4.77E-04	3.72E-04	1.48E-03	675.9

Figure 37: Near future waypoint collision risk for southern diversion of Klaipeda – top 20

4.2.2.3 Risk comparison

The outcome of the comparative exercise between the traffic of the Klaipeda route diverting to the north of the offshore windfarm development space or following the route towards Adlergrund TSS to the south and then detaching easterly after the TSS towards Klaipeda showed very little difference in the overall risk captured by the model.

In terms of the probability of vessel-to-vessel collisions, the frequencies returned by the two models are almost identical, with fractions of a percentage point risk-benefit in favour of the southern route. The same applies to the probability of groundings in the area covered by the model. Where there is a more notable benefit for the southern route is looking at allision risk, where the fact that the crossing between the main SW-NE route and the OWF developments is avoided, shows a notable reduction of risk for the Arcadis Ost 1 and the Baltic Eagle OWFs (18.86% and 6.05% respectively).

Said that, the overall change in the risk profile of the area does not appear to be of the extent that would benefit from regulating the route and forcing one diversion route over the other.

Calculated from waypoint 67 to Klaipeda, the southern diversion is 4nm longer than the northern. However, considering the transit at a larger distance from the OWFs, in deeper waters and with the inclusion of a TSS, this diversion would be an option for unexperienced Masters, larger vessels and/or simply more prudent mariners since the increase of the sea distance would be negligible also from a bunker consumption point of view and therefore voyage optimization. It is also considered that the majority of the traffic along this existing route comprises Ro-Ro/Pax vessels that might be more inclined to select the northern diversion, compared to trump general cargo vessels that might prefer a more precautionary approach. The marginal differences in the collision risk profile between applying the full Klaipeda traffic on either diversion, suggests that there is no risk escalation expected should portions of the traffic choose to use either corridor.

For the purpose of the study, however, the sensible option is to onwards proceed on the basis that most traffic will be using the northern diversion, and thus, this will become the main scenario for the study, despite the fact that we expect a 'dilution' of the traffic along both diversions.

4.3 Future – Consideration of traffic volume increase and vessel characteristics

For the future case, the impact of traffic volume increase on this baseline model is considered in order to estimate what the risk increment will be in the next two decades. For the future traffic projection, the information used is discussed in section 2.6.7 of the report.

Whilst the volume of traffic will just increase by 4%, the increase in the vessel dimensions, that will influence the space occupied by each sailing vessel is expected to notably increase the risk for powered allisions in proportion and influence the crossing and merging collisions probability.

The dimensions of the vessels (length and beam) in the sample static list were increased by 5% for the assessment, whilst draught was not adjusted. Additional risks were considered through a more conservative causation factor for powered grounding and allision incidents.

The re-run of the northern diversion risk model for the future demand scenario returned a collision probability between vessels of 1.228 incidents per year, which constitutes a risk increase of the order of 9.61%.

The risk of groundings appears to increase by 7.73%, which is mainly attributable to powered groundings, where the traffic volume increase supplements the larger vessel sizes.

Annual allision probabilities also increase, as expected, by 5.45%. This increase is also driven by a steeper increase of 8.40% in the powered allisions. The overall traffic risks noted in the model are summarised in Table 13.

Table 13: Incident annual probability summary – Future traffic, vessel sizes

Collisions		Allisions		Grounding	
Merging	0.10720	Powered	0.03859	Powered	0.33380
Crossing	0.26610	Drifting	0.07111	Drifting	0.05749
Bend	0.52780				
Head-on	0.06351				
Overtaking	0.26370				
	1.22800		**0.10970**		**0.39130**

The main qualitative characteristics of the risk profile in terms of where risk appears to be the highest are consistent with what was noted on the same model for the present, 2019-2020 traffic volume and vessel properties. The top 20 risk-contributing legs are presented in Figure 27.

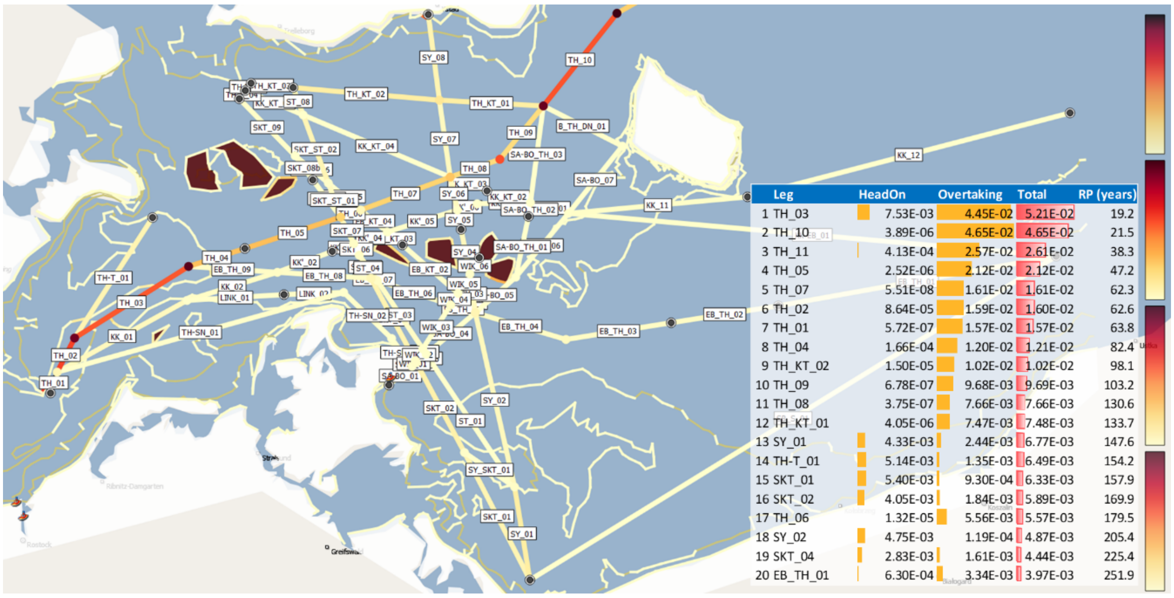
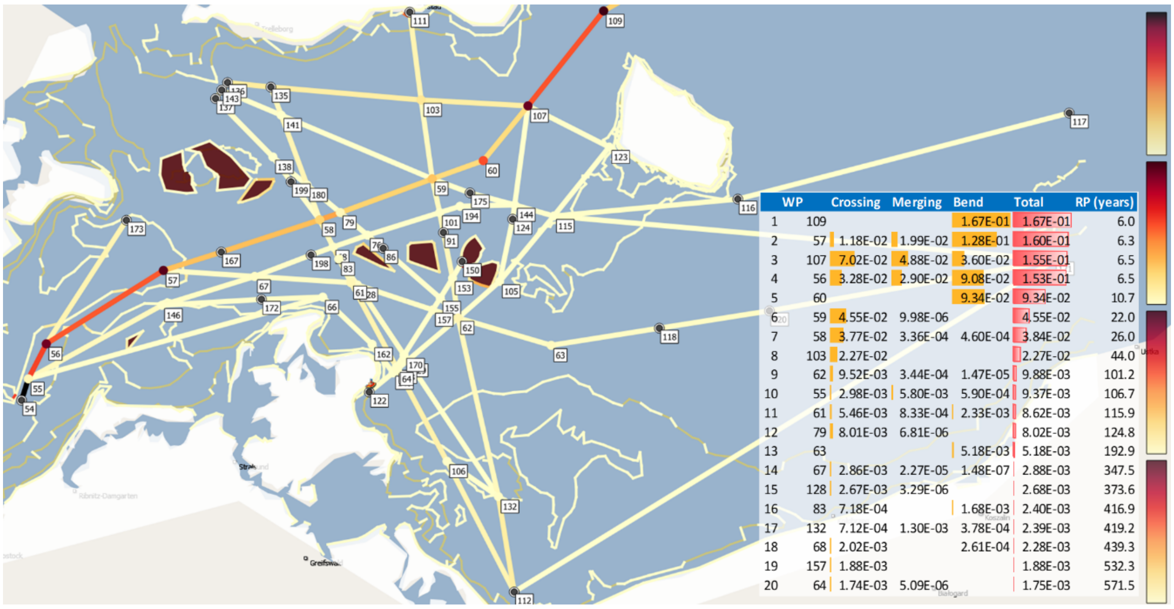


Figure 38: Future traffic and vessels – collision risk at legs – highest 20

In terms of waypoints, the results in terms of the risk distribution in the model appear consistent with the results of the current traffic scenario, as expected in such cases. The overall risk at waypoints has increased, however, its distribution in the model, as well as between incident types remains unchanged. The top 20 risk-contributing waypoints are presented in Figure 39.



	WP	Crossing	Merging	Bend	Total	RP (years)
1	109			1.67E-01	1.67E-01	6.0
2	57	1.18E-02	1.99E-02	1.28E-01	1.60E-01	6.3
3	107	7.02E-02	4.88E-02	3.60E-02	1.55E-01	6.5
4	56	3.28E-02	2.90E-02	9.08E-02	1.53E-01	6.5
5	60			9.34E-02	9.34E-02	10.7
6	59	4.55E-02	9.98E-06		4.55E-02	22.0
7	58	3.77E-02	3.36E-04	4.60E-04	3.84E-02	26.0
8	103	2.27E-02			2.27E-02	44.0
9	62	9.52E-03	3.44E-04	1.47E-05	9.88E-03	101.2
10	55	2.98E-03	5.80E-03	5.90E-04	9.37E-03	106.7
11	61	5.46E-03	8.33E-04	2.33E-03	8.62E-03	115.9
12	79	8.01E-03	6.81E-06		8.02E-03	124.8
13	63			5.18E-03	5.18E-03	192.9
14	67	2.86E-03	2.27E-05	1.48E-07	2.88E-03	347.5
15	128	2.67E-03	3.29E-06		2.68E-03	373.6
16	83	7.18E-04		1.68E-03	2.40E-03	416.9
17	132	7.12E-04	1.30E-03	3.78E-04	2.39E-03	419.2
18	68	2.02E-03		2.61E-04	2.28E-03	439.3
19	157	1.88E-03			1.88E-03	532.3
20	64	1.74E-03	5.09E-06		1.75E-03	571.5

Figure 39: Current collision risk at waypoints – highest 20

4.4 Future – Consideration of full development of plot EO2

In the future, and further to the development of the two OWFs that are at the pre-construction stage (Baltic Eagle and Arcadis Ost 1), the intention is to fully develop area EO2 for offshore wind. This covers the areas to the north, west, and south of the Baltic Eagle OWF.

The changes that the introduction of the subsequent OWF developments in plot EO2 is expected to induce, will not be in the form of further alignment changes in the navigational routes, and thus vessel-to-vessel collision risk is not expected to show notable variation. Allision risk, however, will inevitably increase, as the exposed perimeter of the developed area will incrementally augment with the introduction of each new development (Figure 40).

The most significant contributor to the risk increase is expected to be the risk from drifting vessels, as the target area for allision will increase. This is especially in relation to drifting vessels from the main traffic corridor TH on the north.

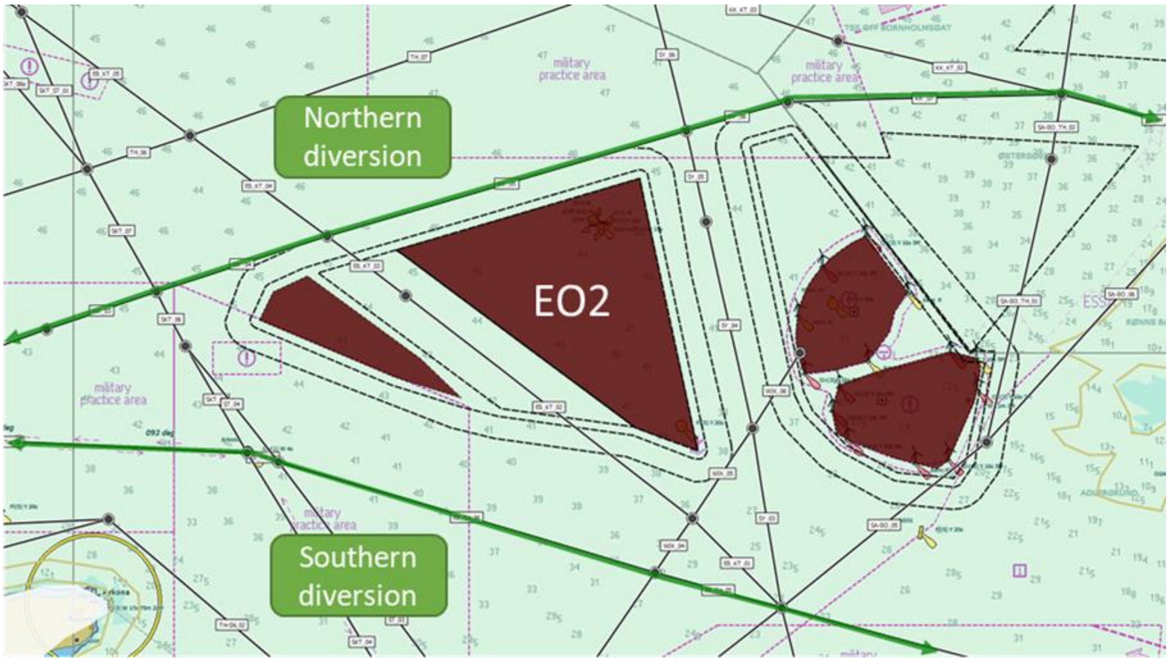


Figure 40: Full development of area EO2

4.4.1 Risk assessment

The results of the quantitative risk assessment based on the spatial changes described above, and in line with the parameters presented in section 2.6, have not induced any changes to the navigational risk profile as that was examined following the development of Arcadis Ost 1 and Baltic Eagle OWFs.

The vessel-to-vessel collision risk probability as expected has not changed, and the same applies to the annual probability for groundings. The annual probability of allision to the enlarged development area has increased by 25.5% compared to that calculated after the development of the Arcadis Ost 1 and Baltic Eagle OWFs.

This is a reasonable increase, as the exposed perimeter of the development area at the same point has increased from 15.3 nm (28,400 m – the approximate perimeter of the Baltic Eagle OWF) to 27.4 nm (50.700 km – the perimeter of area EO2). Most importantly, the part of the perimeter that is exposed to drifting vessels from the high traffic route TH has increased by a factor of 2.5 (+250%). The results of the analysis are summarised in Table 14.

Table 14: Incident annual probability summary – Full development of EO2, current traffic

Collisions		Allisions		Grounding	
Merging	0.09793	Powered	0.03611	Powered	0.30580
Crossing	0.23780	Drifting	0.09402	Drifting	0.05527
Bend	0.48100				
Head-on	0.05721				
Overtaking	0.23630				
	1.11000		**0.13010**		**0.36110**

4.5 Consideration of developing EO2-West

The final scenario considered in this part of the study is the effect of the development of the traffic corridor between OWFs Arcadis Ost 1 and Baltic Eagle for offshore wind. This will require the diversion of the spur traffic from The Sound towards Adlergrund TSS to the main N-S route, to the west of the development areas. The change will come in the form of an extension of area EO2 to the west, to approach the eastern boundary of Arcadis Ost 1, which coincides with the boundary of the German territorial waters. This area is referenced as EO2–West.

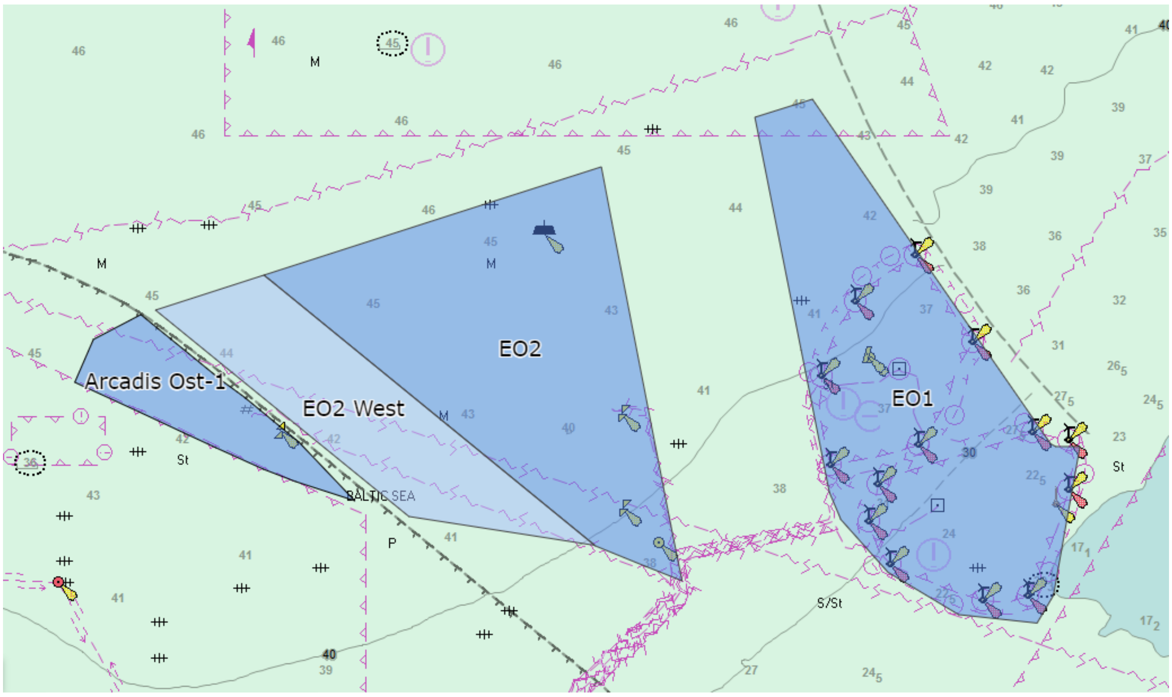


Figure 41: Depicting EO2-West

4.5.1 Navigational changes to the model

To redirect the traffic in the corridor that comprises EO2-West, the spur route EB_KT on the model needs to be redirected into the main N-S route from The Sound to Swinoujscie. The traffic volume is not vast, with traffic of approximately 1.5 vessels a day, mainly comprising General Cargo and small Tanker traffic.

The traffic will follow the SKT corridor on the model, on which it will cross the main SW-NE route (Figure 42). This is of interest as whilst risk is eliminated as crossings are removed to the east, initially with those of the Swinoujscie to Trelleborg traffic that used the area occupied by Arcadis Ost 1, and then with the elimination of the EB_KT route, these traffic increments are all transferred onto the SKT route. The latter has limited space to expand its lateral distribution on either side due to the presence of the Arcadis Ost 1 OWF to the east, and the presence of the EnBW Baltic 2 OWF to the north-west. The resulting projection of this corridor is of a width of approximately 3.0 nm (5,556 m).

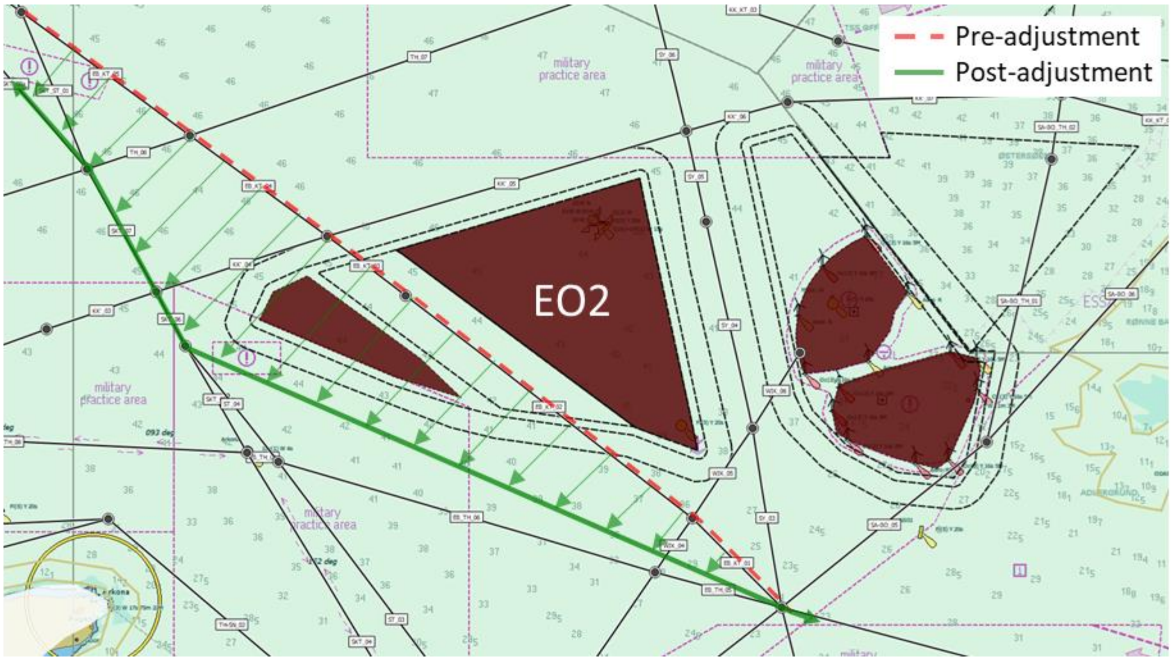


Figure 42: Diversion of the spur route EB_KT out of the area EO2-West

Traffic from the re-directed EB_KT route is expected to detach from the SKT route at waypoint 83 (located approximately 2nm off the westernmost corner of Arcadis Ost 1), just as it clears the western tip of the Arcadis Ost 1 OWF, and then create a new leg that runs parallel to the south-western boundary of the OWF then to merge with the traffic's original course to the south of the Baltic Eagle OWF (waypoint 62). This constitutes the shortest diversion, and it is expected to be used by north-bound and south-bound traffic

4.5.2 Risk assessment

The results of the quantitative risk assessment based on the routing and traffic distributions described above, and in line with the parameters presented in section 2.6, resulted in the risk profile presented in Figure 43.

Whilst the risk in the model increases, the risk pattern in the model does not change, which suggests that the operation is not introducing a risk hotspot in the model, but rather changing distributed increments to different parts of it. The higher risk for collisions remains on the main SW-NE route carrying the traffic from The Belt to the NE Baltic Sea.

Figure 43: Risk profile of modelled area (percentage basis) for development of EO2-West

The risk model calculates a collision probability for vessel-to-vessel collisions of 1.139 incidents per year. This value exceeds the risk calculated for the current as-is conditions by 1.57%, which corresponds to the introduction of one incident in 55.6 years. The risk is still in the one incident every 10-11 months range.

In terms of the annual probability for groundings, the model reports a value of 0.3611 (i.e., 1 grounding in 2.77 years) which is almost identical (incrementally lower) to that of the current situation as it stands, and identical to the one of the northern deviation scenario before diverting the traffic corridor and developing area EO2W.

The annual allision probability calculated in the model is 0.12370 (i.e., 1 allision in 8.08 years). This value constitutes a 25% reduction to the annual allision risk introduced by the full development of area EO2. This is a sensible outcome, as re-directing traffic away from the corridor between the two windfarms almost eliminates the allision risk in that area, and at the same time introduces a 4.5 km-long segment of the exposed perimeter to drifting vessels from the main corridor TH. The allision risk to the Arcadis Ost OWF reduces by a margin of 45% in the model, as a result of eliminating traffic in the space between its eastern boundary and the western boundary of EO2. The risk on the Arkona and Wikinger OWFs effectively remains the same, whilst a risk reduction benefit of the order of 4.0% is noted to the EnBW Baltic 2 OWF between the northern diversion scenario and the one currently presented.

The overall traffic risks noted in the model for the near-future scenario with the diversion of the Klaipeda line to the north of the development areas are summarised in Table 15 overleaf.

Table 15: Development of EO2-West, incident annual probability summary

Collisions		Allisions		Grounding	
Merging	0.09987	Powered	0.03476	Powered	0.30580
Crossing	0.24650	Drifting	0.08897	Drifting	0.05526
Bend	0.48820				
Head-on	0.05985				
Overtaking	0.24430				
	1.13900		**0.12370**		**0.36110**

The leg risk in the model follows the same pattern as discussed for previous scenarios, with the risk concentrated on the main SW-NE route. The top 20 risk-contributing legs are presented in Figure 44.

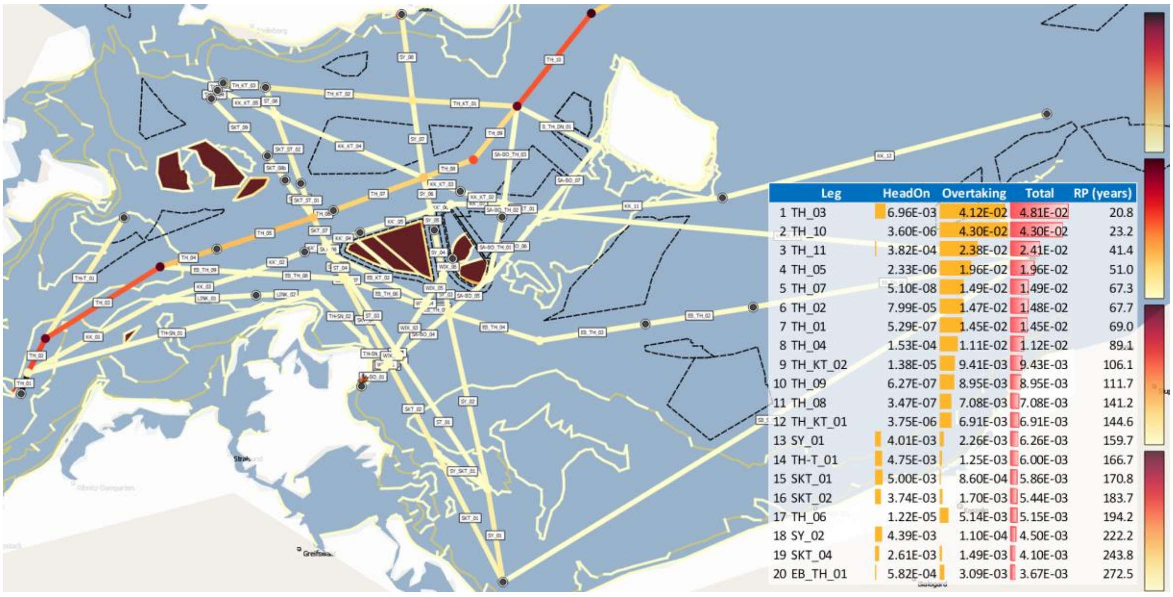
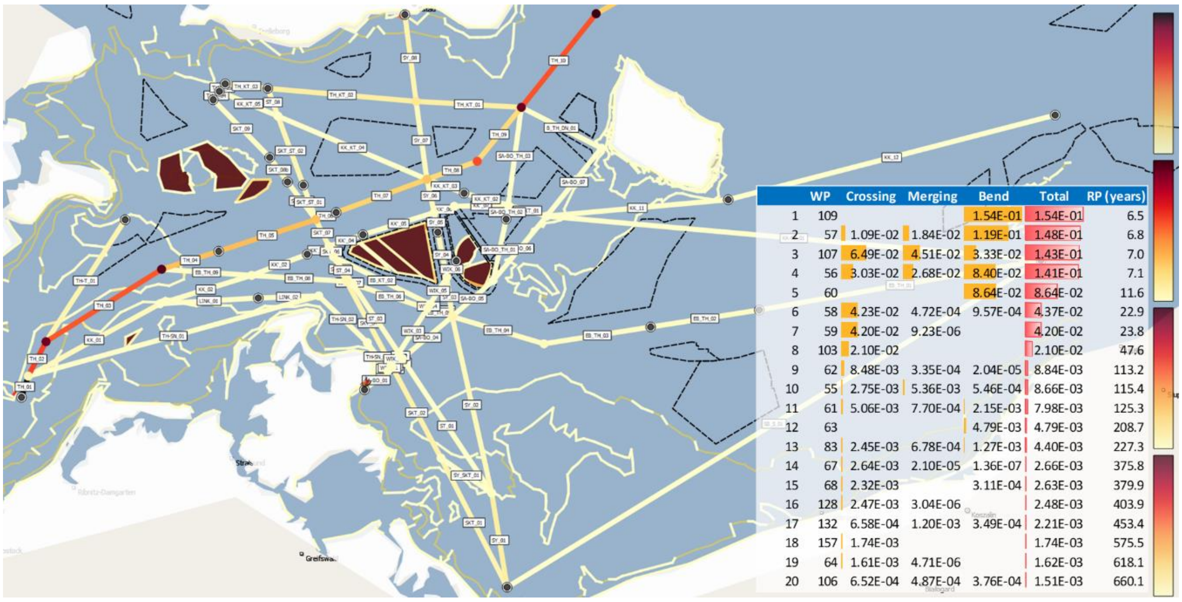


Figure 44: Development of EO2-West, collision risk at legs – highest 20

Whilst the risk has increased in the model, the study has not noted a substantial risk peak in the legs of the area to the west of Arcadis Ost 1, where the bulk of the intervention took place. This is of importance, as the risk in the legs of the SKT route in the area remains lower than that of legs of the same route further south, at the start of the route out of Swinoujscie and along the Rugen Island coastline.

Looking at risk in the model waypoints, the results in terms of the risk distribution in the model appear consistent with previous scenarios. It is normal that as crossing traffic is eliminated from waypoints along the main SW-NE route the risk is eliminated too and moved to waypoint 58 on the route (crossing of TH and SKT legs), where all the diverted traffic is concentrated.

The top 20 risk-contributing waypoints are presented in Figure 45. A key to the waypoints in the model is provided in Appendix B.



	WP	Crossing	Merging	Bend	Total	RP (years)
1	109			1.54E-01	1.54E-01	6.5
2	57	1.09E-02	1.84E-02	1.19E-01	1.48E-01	6.8
3	107	6.49E-02	4.51E-02	3.33E-02	1.43E-01	7.0
4	56	3.03E-02	2.68E-02	8.40E-02	1.41E-01	7.1
5	60			8.64E-02	8.64E-02	11.6
6	58	4.23E-02	4.72E-04	9.57E-04	4.37E-02	22.9
7	59	4.20E-02	9.23E-06		4.20E-02	23.8
8	103	2.10E-02			2.10E-02	47.6
9	62	8.48E-03	3.35E-04	2.04E-05	8.84E-03	113.2
10	55	2.75E-03	5.36E-03	5.46E-04	8.66E-03	115.4
11	61	5.06E-03	7.70E-04	2.15E-03	7.98E-03	125.3
12	63			4.79E-03	4.79E-03	208.7
13	83	2.45E-03	6.78E-04	1.27E-03	4.40E-03	227.3
14	67	2.64E-03	2.10E-05	1.36E-07	2.66E-03	375.8
15	68	2.32E-03		3.11E-04	2.63E-03	379.9
16	128	2.47E-03	3.04E-06		2.48E-03	403.9
17	132	6.58E-04	1.20E-03	3.49E-04	2.21E-03	453.4
18	157	1.74E-03			1.74E-03	575.5
19	64	1.61E-03	4.71E-06		1.62E-03	618.1
20	106	6.52E-04	4.87E-04	3.76E-04	1.51E-03	660.1

Figure 45: Development of EO2-West, collision risk at waypoints – highest 20

As part of the analysis, the effect of shifting the point where the ST route joins the SKT route was also investigated. The ST route was re-routed to converge with the SKT at waypoint 61, to the south of waypoint 83, at the main junction with the eastern route to Adlergrund TSS. The reason was to see if there would be a notable impact on the risk in the model if the traffic of the ST route opted to converge or diverge from SKT at the Arkona safe water pillar buoy.

The results of this additional analysis (Table 16) were overall identical to the base case when it comes to collisions and groundings. The results were slightly favourable when it comes to drifting allisions, an expected result as the axis of the traffic of the removed leg ST_04, which has now merged into SKT_05, was closer to the boundaries of Arcadis Ost 1 compared to that of SKT_05 that now carries all the relevant traffic.

Table 16: Development of EO2-West, incident annual probability summary – early merge of ST traffic

Collisions		Allisions		Grounding	
Merging	0.10080	Powered	0.03477	Powered	0.30580
Crossing	0.24500	Drifting	0.08725	Drifting	0.05524
Bend	0.48890				
Head-on	0.06023				
Overtaking	0.24430				
	1.13900		**0.12200**		**0.36100**

Further consideration of the legs and waypoints at the area of interest, to the west of the Arcadis Ost 1 OWF, where the diverted traffic is channelled, is provided in the discussion section that follows in the present report.

5 DISCUSSION AND PROPOSED MITIGATION

5.1 Discussion of risk analysis results in the area of interest

Having considered the overall impact of the changes that are arranged to take place or are currently considered for the area covered in the model, it is of value to present a closer look at how the area of focus, between Rugen Island and the Arcadis Ost 1 OWF where the diverted traffic is concentrated, is impacted by the changes.

Attention is focused on the legs and waypoints annotated in Figure 46, which constitute the parts of the model north-southbound traffic that had to be diverted away from the area marked in red in the same figure (Arcadis Ost 1 and EO2-West) has merged.

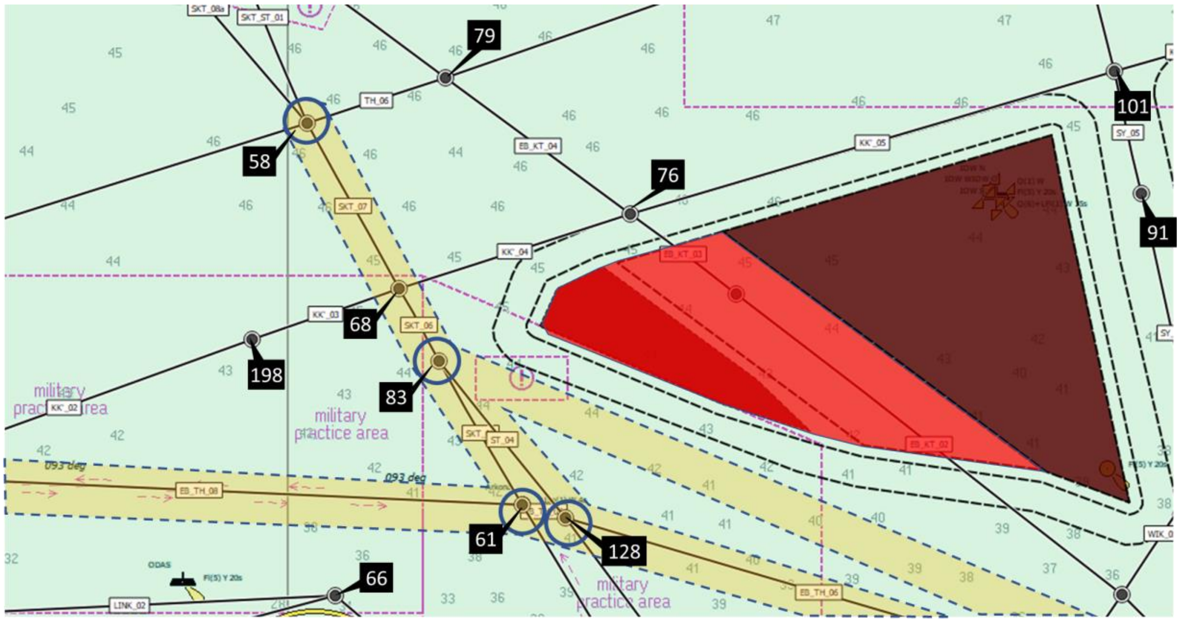


Figure 46: Components of the area of interest west of Arcadis Ost 1

At present, before any interventions to the area, and based on the analysis and modelling conducted with AIS data from 2019 and 2020, traffic navigating through the red area, crosses the main SW-NE route near waypoint 79. The remaining traffic to the west of that area, crosses the main route around waypoint 58, at the top of the figure.

For the near future scenario, the traffic that currently uses the space of Arcadis Ost 1, is diverted to the main N-S route, to the west. That traffic is mainly comprised of Ro-Ro/Pax vessels travelling the Swinoujscie to Trelleborg route. This traffic currently, partly uses the space of Arcadis Ost 1, and partly the main N-S route. Thus, this proportion of the crossing traffic shifts from waypoint 79 to waypoint 58. The traffic currently using the corridor between Arcadis Ost 1 and the Baltic Eagle OWFs (Area EO2-West), mainly comprising General Cargo and small Tanker vessels, at this stage remains able to use the corridor, and cross the main SW-NE route through waypoint 79.

The future scenario considers the impact of developing area EO2-West for offshore wind. The cargo traffic is also moved to the west, on the main N-S route (SKT on the model). This eliminates waypoint 79 completely, and, as a consequence, all the risk of the N-S traffic crossing the main SW-NE route subsequently does so at waypoint 58.

Waypoint 79 in the existing traffic case scenario, was attributed an annual probability of collision of 0.0186 (one incident in 53.8 years), and waypoint 58 a probability of 0.0146 (one in 68.4 years) totalling 0.0332 (one incident in 30.1 years). With the diversion of the ferry traffic to Trelleborg from 79 to 58, the corresponding probabilities changed to 0.00724 and 0.0341 respectively, increasing to a total value of 0.04134 (one incident in 24.2 years). With the traffic diverted away from area EO2-West, waypoint 79 was eliminated, and all risk has been transferred to waypoint 58. This risk is noted to be 0.0437 (one incident in 22.9 years). The impact of the diversion itself, therefore, added one incident every 95.2 years.

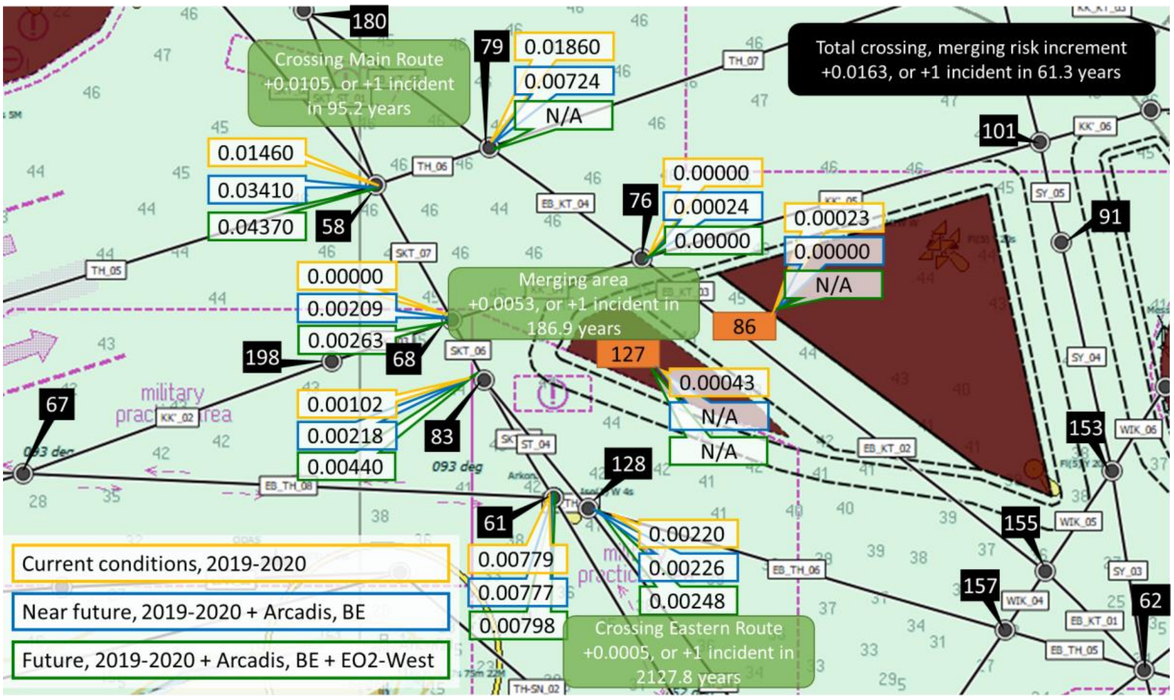


Figure 47: Crossing and merging risk increment in the focus area

The area at the centre of Figure 47 is also of interest, as it is the point where the latest point the two N-S routes (SKT and ST) can converge, and the closest to the OWF. The diverted corridor to the north of Waypoint 83, before the diversion of the Klaipeda route, carries almost no traffic at all and is thus not registering risk. As the Klaipeda traffic is diverted to the north, the risk profile changes, together with the point of its crossing with the N-S traffic. As the risk is gradually concentrated between Waypoints 68 and 83, they are both seeing much higher collision probabilities compared to their baseline values, nonetheless not prohibitive.

Waypoint 68, as a recipient of the risk of Waypoints 86 and 76, sees an additional annual collision probability of 0.0024 (i.e., 1 incident per 416.7 years). Waypoint 83, which is the recipient of risk from Waypoints 127 and 86, sees an additional risk increment of 0.0027 (i.e., 1 incident per 367.6 years).

Further south, between Waypoints 61 and 128, there is also risk escalation, mainly due to the changes from the extracted to the recommended lateral distributions for the traffic, though to a much smaller extent. Waypoint 61 sees an annual collision probability increase of 0.00019 (i.e., 1 incident in 5253.2 years) and Waypoint 128 a corresponding increase of 0.00028 (i.e., 1 incident in 3571.4 years). The combined effect of the two corresponds to 1 incident in 2127.8 years.

Looking at the waypoint risk in the focus area, covering vessel-to-vessel crossing and merging collisions, a cumulative collision probability of 0.0163 that corresponds to one incident in 61.3 years is added to the area as the combined effect of the changes. If we were to isolate the effect of diverting traffic away from area EO2-West, the risk increment would amount to 0.00531, or 1 crossing/merging collision incident in 188.3 years.

Similarly, by addressing the legs of the model and how they consolidate as N-S corridors are merged into others, it is worth reminding the sequence. In the current case, which corresponds to the traffic as captured by the 2019-2020 dataset, there are three routes through the focus area. The main N-S SKT route, the ferry traffic that crosses the area that will be occupied by Arcadis Ost 1 (ST – not necessarily a separate route, but modelled as such to facilitate the analysis), and route EB_KT, which is the route directing traffic from the area of The Sound through the area of interest EO2-West. The latter is orientated at 132-312 degrees, however, it will be considered with the other two, as it crosses the main SW-NE route. With the introduction of Arcadis Ost 1, route ST merges into route SKT. With the development of EO2-West, at the focal point, EB_KT also merges into SKT from the north before in order to circumnavigate Arcadis Ost 1.

The current annual collision probability in the aforementioned legs is 0.00138, or 1 incident in 724.6 years. The total increase of the annual collision probability to the legs of the focus area in the near future scenario (the development of the Arcadis Ost 1 and Baltic Eagle OWFs) and the subsequent merger of the two westernmost routes, is 0.00132, or 1 further incident in 757.6 years.

The introduction of the traffic from the EB_KT route, further raises the annual collision probability by 0.00103, introducing one further collision every 970.9 years.

The main eastern route EB_TH that crosses the traffic of the aforementioned legs on its way towards the Adlergrund TSS, sees a much smaller increase in the risk, mainly from the interaction with the diversion along the Arcadis Ost 1 boundary. The current annual collision probability on the three legs in the focus area is 0.00151, (i.e., 1 head-on or overtaking collision incident in 662.3 years). With the development of Arcadis Ost 1 and the Baltic Eagle, and the associated navigational changes, this risk remains almost constant at 0.00152. In the final scenario, where the traffic currently using the corridor of EO2-West is diverted to the west of Arcadis Ost 1, the collision probability rises to its final value of 0.00186 or one incident in 537.6 years.

Thus, the combined head-on and overtaking collision risk in the focus area following the changes, sums up to 0.00559 incidents per year, i.e., one incident in 178.9 years.

The combined effect of the changes in the legs and waypoints of the focus area compared to the present conditions based on the 2019-2020 data amount to a change in the annual probability of collision from 0.04776 (i.e., 1 in 20.9 years) to 0.06678 (i.e., 1 in 15.0 years). This corresponds to the introduction of one incident every 52.6 years.

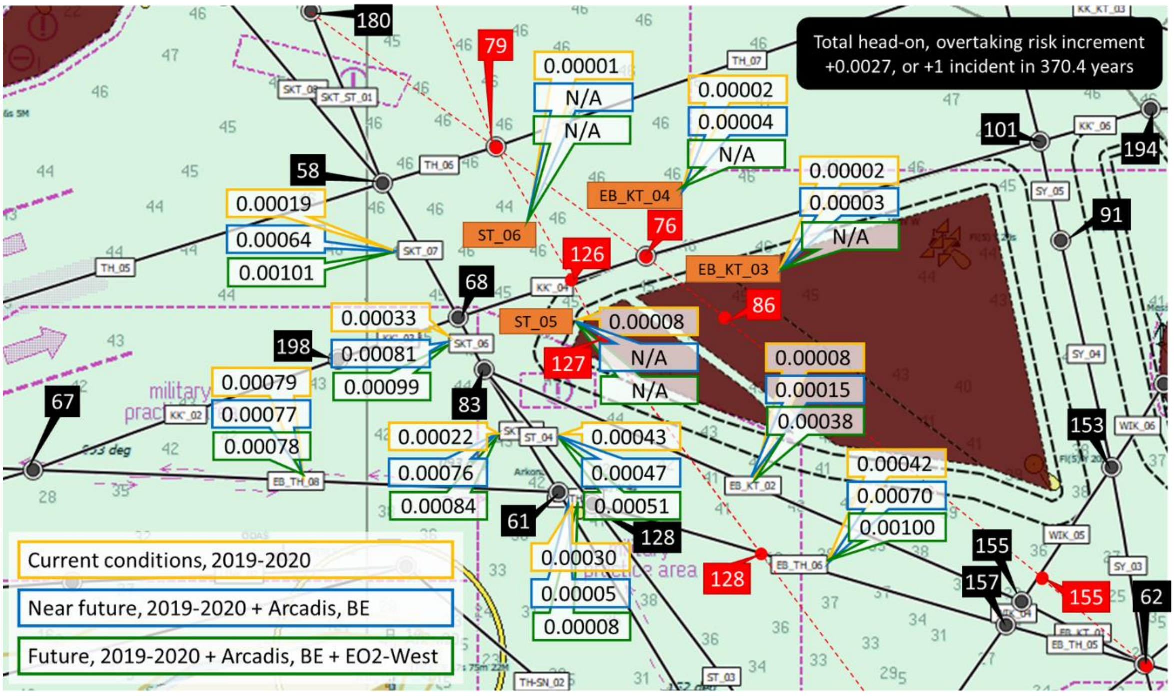


Figure 48: Head-on and overtaking risk increment in the focus area

The isolated impact of diverting traffic away from area EO2-West in the figure above is equal to a rise in the probability of collision of 0.00668 which corresponds to the introduction of 1 incident in 149.7 years.

5.2 Mitigation measures

5.2.1 Extension of the recommended route north of Kap Arkona

Whilst the risk increment obtained does not appear to be prohibitively high for the development of area EO2-west to proceed, it remains the case that the risk in the system has increased based on the analyses performed and discussed earlier in the report. The risk is expected to increase further as traffic volumes and the sizes of vessels navigating the Baltic Sea increase in the future. It is therefore of the essence, to propose where possible means and measures that mitigate risks and temper the impact of developments in the study area.

A measure that has the potential to be beneficial for navigational safety in the area, is the extension of the existing recommended route from the north of Cap Arkona maintaining the same orientation towards The Sound and past the main SW-NE traffic route, as presented in Figure 49.

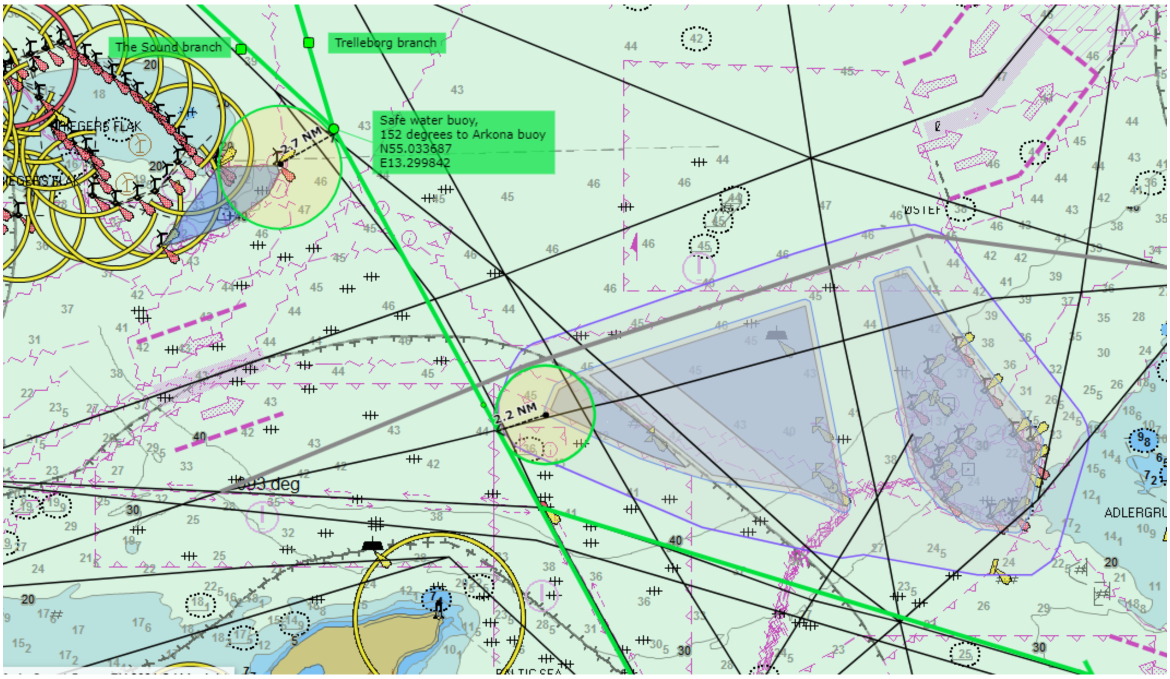


Figure 49: Mitigation proposal - Extension of the recommended route

Although a recommended route is not an obliged passage that needs to be strictly followed by mariners, we consider that it would be a beneficial ‘invite’ for the vessel’s Captains to opt to follow as they transit in that particular area, with the converging traffic originated to/from the Off Flaste TSS and Trelleborg at approximately 19nm NNW from Arkona safe water buoy with bearing 152˚. The following benefits are assumed:

i. Crossing the main artery of traffic between Kadet Rinne and Bornholmsgat at an angle close to 90˚ and therefore in line with rules of the road related to crossing traffic separations lanes (Rule 10c).

ii. Converge the traffic in an orderly manner obtaining a reduction in the diverging/converging headings within the traffic flow.

iii. Maintain the main axis of the traffic, and therefore the axis of the recommended route, at a minimum distance of 2.7nm and 2.2nm from EO3 and Arcadis Ost 1 respectively.

iv. Potential alignment of west-eastbound traffic with Adlergrund TSS whilst detaching/converging to Arkona buoy and thus maintaining a larger distance from the southern limits of Arcadis Ost 1 and eastern OWFs.

v. The possible introduction of a ship reporting point east of EO3 in order to monitor the traffic on the west corridor of Arcadis Ost 1 before the crossing of the main SW-NE traffic flow. This reporting system, which could be mandatory, would be introduced at the crossing of the German EEZ, whilst vessels enter the Sassnitz Traffic VTS area of competence. This option might also be implemented in cross-border cooperation between countries (i.e., Denmark and Germany) with reporting to consecutive VTS stations. Similarly, to what occurs in the Strait of Malacca (Straitrep) for example, where several countries (Malaysia and Singapore) share the waters in various sectors of competence and the vessel transiting a particular sector reports the exit from one VTS jurisdiction and entry to the next VTS jurisdiction.

It is noteworthy to highlight, at this point, that the model considers a risk reduction factor, based on the presence of VTS, as detailed in 2.6.2.3. However, it is difficult to actually quantify this factor when assuming additional implementation of measures within the same factor. The difficulty of this exercise is to quantify the increased reduction of the risk by the introduction of an improved traffic control area.

In short, the bridge team would take advantage of the additional lookout performed by the VTS operator, and it can be warned and advised of the potential hazards generated by the traffic in the vicinity. It should be noted that in busy traffic areas, the range at which the OOW and therefore the Captain of the vessel is able to process information, reduces with the increase of traffic. This is a result of the look-out being focused on vessels in the vicinity rather than those located at the margin of the radar plan positioning indicator. Consequently, vessels with higher speeds over the ground might be detected only when the time of the closest point of approach is sensibly small and requires a larger avoidance manoeuvre with all correlated risks of limited sea space and interaction with other traffic. In addition, the OOW needs to be aware of the intention of the surrounding traffic. This process requires the plotting of radar targets, identification of the AIS targets, look-out to identify the vessels' bow or navigational lights and, as the ultimate resource, radio contact with the vessel subject of the collision watch. This intention of awareness for the surrounding vessels is of paramount importance and can be readily collected and disseminated by the VTS (by means of ship reporting points). The latter being aware of the intentions of the overall traffic in the monitored area can advise/warn vessels in the vicinity appropriately.

The presence of an, as defined above, “additional look-out” gives the bridge team those “additional eyes” that can maintain the alert of the OOW over crossing situations that otherwise would have been considered safe. A very important factor, recently analysed in the maritime industry, is the so-called situational awareness where the perception and comprehension of the surroundings at all times is assumed to allow the OOW to predict how the environment will affect his own ship and what action can be taken if necessary. The information reported by a VTS to an OOW can effectively improve his situational awareness and reduce the risk of ending up in a hazardous situation caused by a wrong or late interpretation of the marine traffic environment.

To test mitigation overall, slight leg alignment changes were performed to the final scenario model, that tests the post – EO2-West development risk profile.

The first change was to shift the merging of the ferry traffic on leg ST out of Swinoujscie to merge into the SKT leg slightly earlier, integrating at the crossing with the main eastern traffic corridor EB_TH. On the field, this should happen naturally, as traffic on the secondary route will look to align and set the course early before the waterway narrows to the east.

Subsequently, the legs of the SKT route north of waypoint 61 (the crossing with the main eastern traffic corridor) which is marked by the buoy marking the existing end of the recommended route were adjusted to the west, to follow the alignment of the recommended route towards the north. The proposed alignment extends past the main SW-NE traffic corridor, to a point just clear of the EnBW Baltic 1 OWF (N: 55.033687, E: 13.299842).

The legs carrying the SKT traffic to/from The Sound and the ST traffic to/from Trelleborg were merged into that point, and the associated traffic in both directions onwards follows the new alignment of the SKT legs, on the extension of the existing recommended route.

In terms of the lateral distribution of traffic across the route, a standard deviation of 0.50nm (926m) was used for the gaussian part of the distribution in both directions. The peak (centre of the distribution) in each direction was placed 0.50nm from the axis of the route. This is relatively consistent with what is noted further south on the recommended route. The distribution used considers that approximately 50% of the traffic in both directions uses the central part of the route, however, further away from the axis of the route traffic becomes more one-directional.

The effects of implementing this change in navigation were tested in an additional run of the model, revised in line with the changes described above.

The results of this supplementary analysis (Table 17), show a reduction in crossing and head-on collisions, as well as a small reduction in allisions as a result of implementing this change. The remaining accident probabilities remain largely unchanged. The overall vessels to vessel collision probability with this intervention drops to a value that is below the current risk based on the 2019-2020 data and traffic distributions.

Table 17: Mitigation 1 – Extension of recommended route, incident annual probability summary

Collisions		Allisions		Grounding	
Merging	0.10040	Powered	0.03507	Powered	0.30580
Crossing	0.21570	Drifting	0.08733	Drifting	0.05526
Bend	0.48800				
Head-on	0.05746				
Overtaking	0.24460				
	1.10600		**0.12240**		**0.36100**

Looking into the focus area for the study, it can be seen that the intervention has a positive impact on navigational safety in the area. Figure 50 shows the risk change in the waypoints of the focus area.

The analysis shows a substantial benefit obtained in the reduction of 0.03141 (i.e., 1 less incident in 31.9 years) for the annual crossing collision probability of the N-S traffic as it crosses the main SW-NE route to the east of TSS North of Rugen. Smaller benefits are also noted in the central section, where diverted routes have merged as a result of the development scenarios considered, with a reduction in annual collision probability of 0.0028 (i.e., 1 less incident in 352.1 years). At the southern end of the area, the shift of the merging point of route ST into route SKT at the same point as the crossing of the main route to the east, has slightly increased the collision probability locally, introducing one incident in 347.2 years. It should be noted, however, that where the traffic will be merging in practice will most certainly be spread to the north and south, which is something that the modelling is not able to capture.

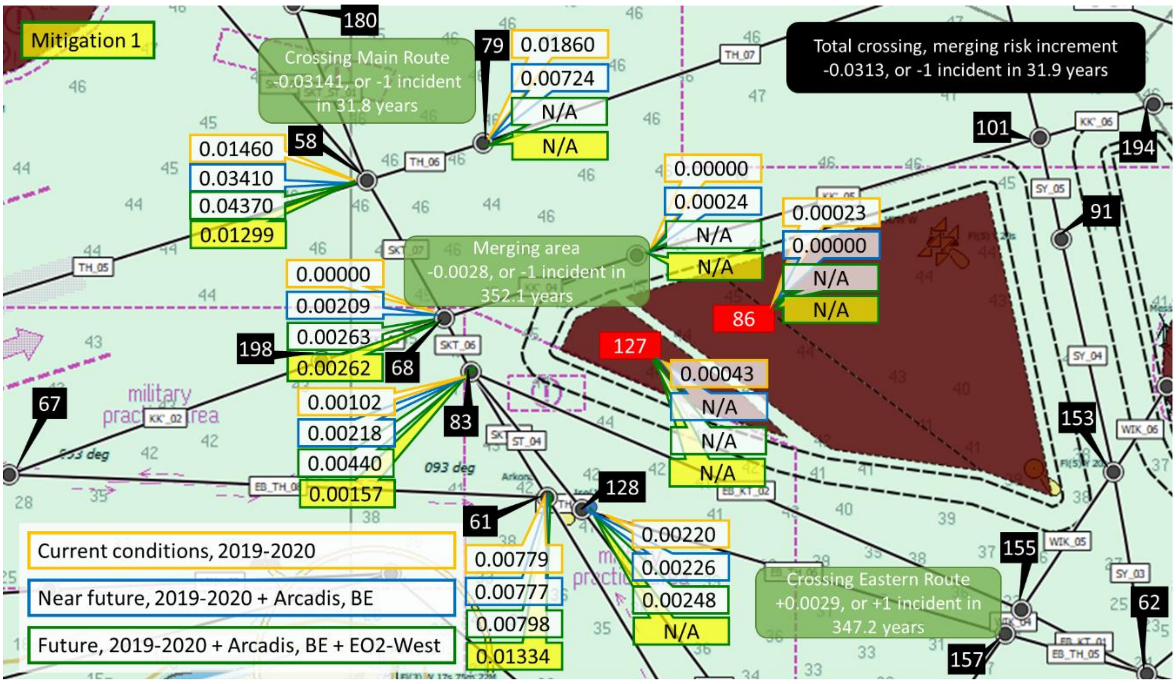


Figure 50: Crossing and merging risk increment in the focus area

Looking at the risk effect of the extension of the recommended route to the north on the traffic legs (Figure 51), showing the head-on and overtaking collision probability, the change results in a net benefit, although of a smaller proportion compared to crossing risks.

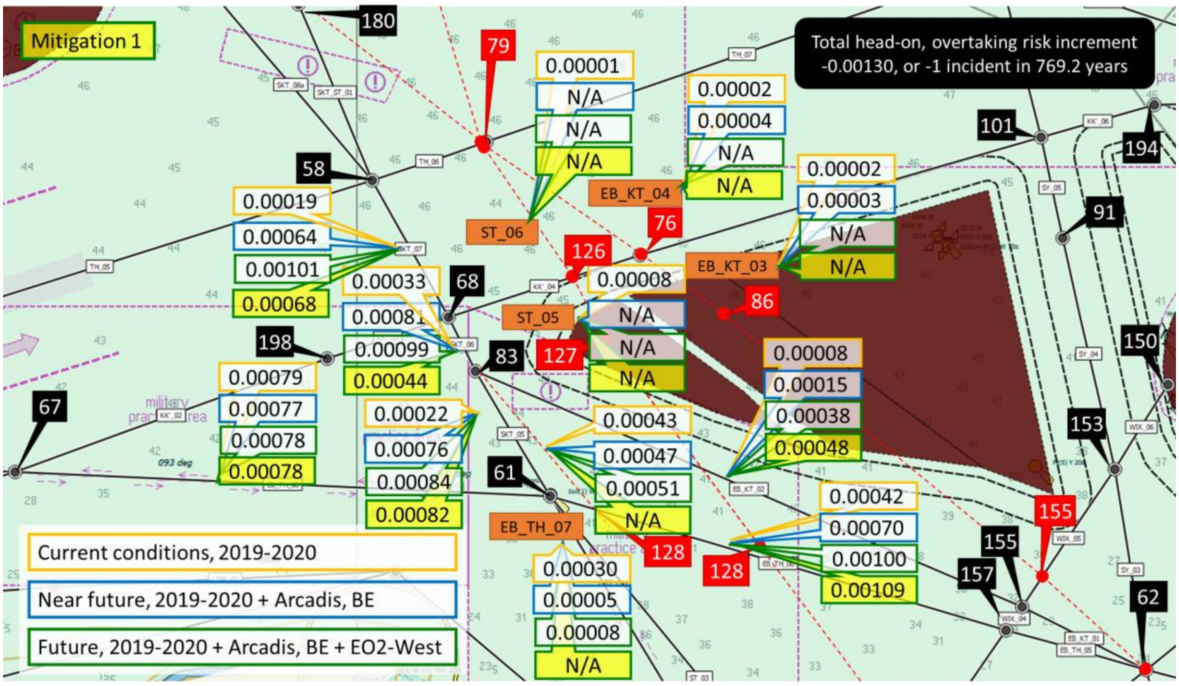


Figure 51: Head-on and overtaking risk increment in the focus area

The analysis showed an overall reduction in the annual collision probability of 0.0013, which is equal to one less collision per 769.2 years.

Looking at the combined effect of the mitigation to the crossing, overtaking, and head-on collision risk, there is a net benefit in reducing the annual collision probability by 0.0326, which corresponds to 1 less incident every 30.7 years.

In absolute terms, the collision probability in the focus area post mitigation is 0.03418, which corresponds to one incident every 29.3 years.

With respect to the allisions and grounding risk, the effect of the intervention is fairly small, with the only notable change, being the reduction in the collision risk on Arcadis Ost 1, in the order of 22.7%. This is attributed mainly to the realignment of the main N-S route, and the introduction of some directionality to the traffic flows.

5.3 Results summary

The evolution of the current annual probability for an incident in the area covered by the study, following each increment of development considered, is presented in Figure 52. The bar chart elements demonstrate the annual probability of an incident per type, for each development stage considered, whilst the red line, that corresponds to the secondary axis shows the percentage increase induced by each subsequent development/mitigation stage compared to the current system.

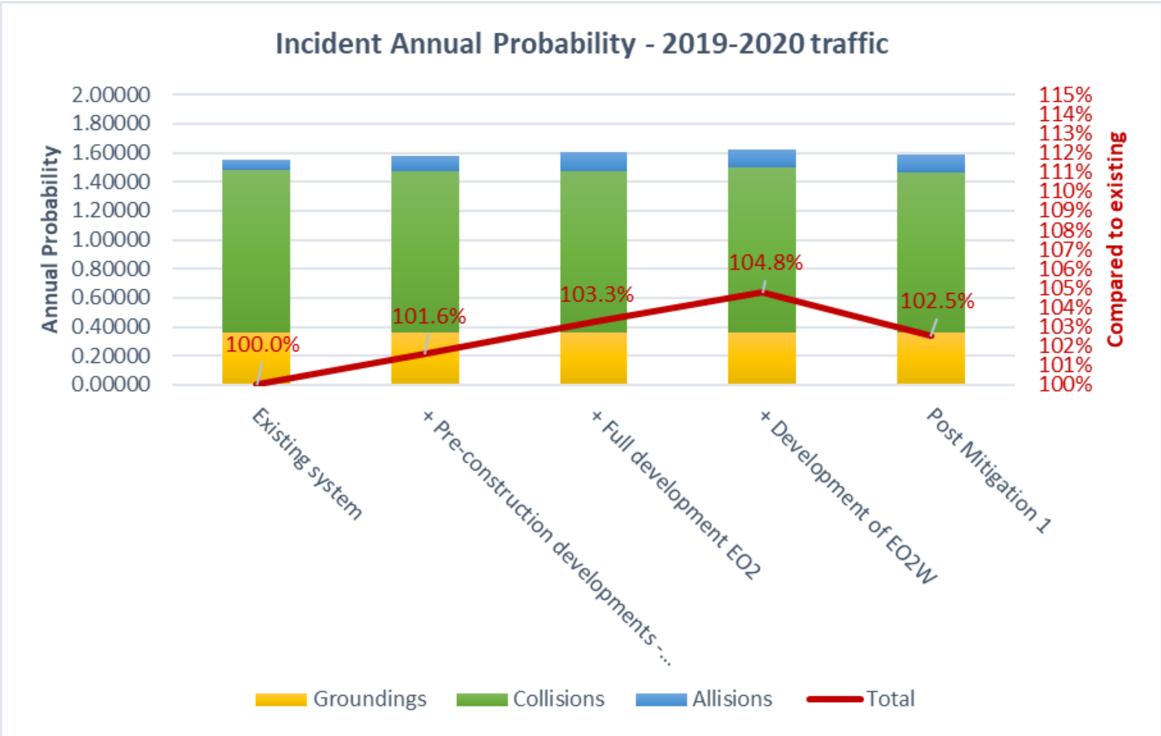


Figure 52: Evolution of risk as a result of OWF developments in the study area

The data used to plot the chart of Figure 52 are summarised in Table 18 overleaf. The trend shows that there is an increment of risk added to the system with every development step undertaken in the study area. The risk variation is mainly attributable to the additional allision risk induced by the introduction of developments occupying maritime space, as well as the concentration of maritime traffic to more restricted waters.

Table 18: Results summary – 2019-2020 traffic

	Existing system	+ Pre-construction developments - Northern Diversion	+ Full development EO2	+ Development of EO2W	Post-Mitigation 1
Annual Probability:					
Collisions	1.12100	1.11000	1.11000	1.13900	1.10600
Allisions	0.06731	0.10370	0.13010	0.12370	0.12240
Groundings	0.36170	0.36110	0.36110	0.36110	0.36100
Total	**1.55001**	**1.57480**	**1.60120**	**1.62380**	**1.58940**
Return Period:					
Collisions	0.89 y	0.90 y	0.90 y	0.88 y	0.90 y
Allisions	14.86 y	9.64 y	7.69 y	8.08 y	8.17 y
Groundings	2.76 y	2.77 y	2.77 y	2.77 y	2.77 y
Total	**0.65 y**	**0.64 y**	**0.62 y**	**0.62 y**	**0.63 y**

It is noted that the introduction of some development stages appears to have beneficial effects on the vessel-to-vessel collision risk, mainly due to inducing more ordered navigational patterns, however, as more traffic is directed into narrower sections this effect is being reversed.

Overall, an approximate risk increase of up to 5% appears to be expected at the end of the implementation of the German MSP, out of which 1.5% can be attributed to the direct effect of developing area EO2-west.

However, there is more to be considered, as the above figures correspond to a system operating based on the current (2019-2020) traffic volumes and qualitative characteristics. As discussed previously in the report (section 2.6.7), the expectation is that in the next two decades, both the traffic volume and the size of the vessels navigating the Baltic Sea are expected to increase.

This change is expected to also increase navigational risk, as vessels become larger, and traffic more frequent, whilst at the same time, the maritime space available for navigation reduces. This introduction of risk is independent of whether and which developments materialise and is thus expected to be introduced to the model irrespective of the former. It is noted that the rate of growth of traffic and vessel size have been assumed on the basis of what appears reasonable with the currently available information and may be subject to change.

To consider the impact of the above, the development stage scenarios of Figure 52 were run with traffic volumes increased by 4% compared to the base scenario, and vessel external dimensions increased by 5%. The results of this analysis are presented in Figure 53. The data used to plot Figure 53 are summarised in Table 19.

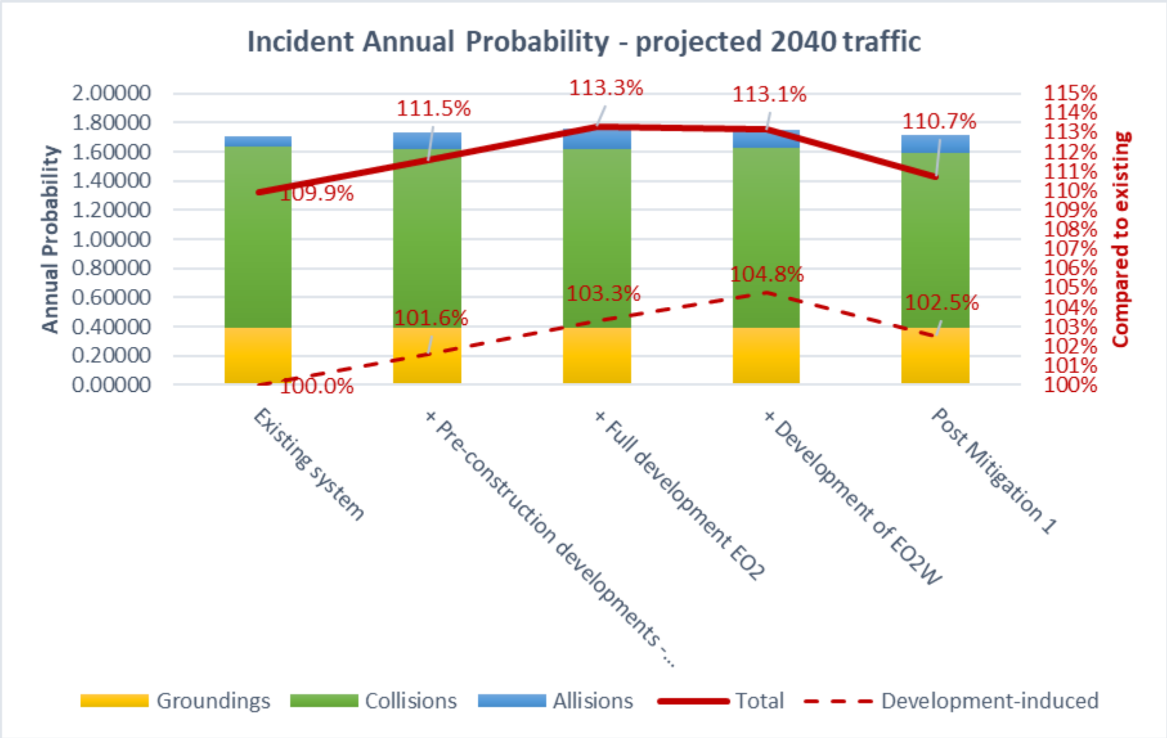


Figure 53: Evolution of risk as a result of OWF developments and projected future traffic

Table 19: Results summary – projected 2040 traffic and vessel sizes

	Existing system	+ Pre-construction developments - Northern Diversion	+ Full development EO2	+ Development of EO2W	Post-Mitigation 1
Annual Probability:					
Collisions	1.24000	1.22800	1.22800	1.23200	1.19600
Allisions	0.07176	0.10970	0.13720	0.13050	0.12910
Groundings	0.39200	0.39130	0.39130	0.39130	0.39130
Total	**1.70376**	**1.72900**	**1.75650**	**1.75380**	**1.71640**
Return Period:					
Collisions	0.81 y	0.81 y	0.81 y	0.81 y	0.84 y
Allisions	13.94 y	9.12 y	7.29 y	7.66 y	7.75 y
Groundings	2.55 y	2.56 y	2.56 y	2.56 y	2.56 y
Total	**0.59 y**	**0.58 y**	**0.57 y**	**0.57 y**	**0.58 y**

The results of the analysis show that in the present system, the impact of traffic and vessel size increases the risk by the order of 10% in the next 20 years. This exceeds the risk introduced by the implementation of all the developments examined in the present study by a factor of 2, showing that the former is a much more significant contributor to the anticipated risk increase.

The results of the analysis also demonstrate that the development of EO2-West appears to narrow the effect of traffic volume, as the risk reduction, mainly due to the elimination of allisions to Arcadis Ost 1 and the western boundary of EO2 outweigh the increase in collisions induced by re-routing the traffic between the two areas to the west of Arcadis Ost 1.

In both current and future cases, the results show that the mitigation measures proposed, have the potential to reverse half of the risk introduced into the study area as a result of the full implementation of the German MSP (under current traffic) and the benefit offered is maintained under future traffic volumes and vessel sizes.

5.4 Future development plans

The outcome and conclusions of the present study, represent the current best knowledge of the traffic and spatial parameters of the area. Whilst the study considers the latest available spatial plans from the four stakeholder countries in the greater study area, it is noted that these are not final, and changes may, and probably will take place as offshore wind energy in Europe develops.

As new developments have the potential not only to induce risk but also shift it to a different area, it is of utmost importance that coordination between the stakeholder nations is maintained and that changes are looked at holistically.

In reviewing the current traffic patterns, as well as considering the impact of changes from known upcoming developments, it is of value to point out and provide a short commentary on several areas that might be affected in the future development of the various MSPs.

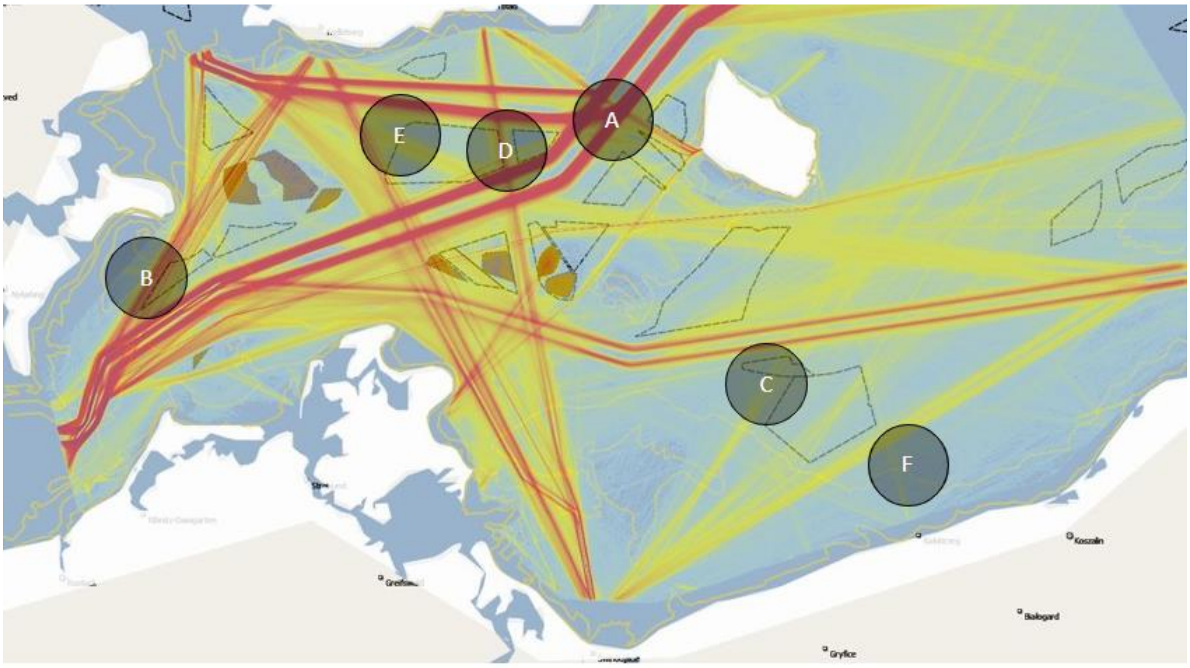


Figure 54: Areas proposed for offshore wind development in the Southern Baltic

Future developments are planned to take place on the western coast of Bornholm Islands (nota A in Figure 54), this area is interested, in our model, by the higher risk profile for head-on and bend collision, and despite the fact the developments are planned western to the main traffic corridor, it is possible that a potential reduction of the sea room in the surrounding area of TH leg in our model, might contribute to a further increase in such risk.

Danish MSP to date indicates also future interests in the zone marked on the figure with notes B and C. The plans for the area north of Kadet Rinne would shrink the lateral distribution that traffic currently takes whilst navigating the east coast of Falster Island between South of Gedser and Off Falsterboro TSS (TH_T leg) and towards the port of Trelleborg. Again, this leg and associated waypoints are part of the first 20 highest risk hotspots in the area of the study and therefore subject to a further increment of potential risk considering the reduction of sea room and consequent reduction of the lateral distribution for the legs concerned.

Note C represents future developments belonging to the Danish MSP, however, this area lies adjacent to the Polish development marked F in the figure and it has to be addressed together. Both areas (C and F) would occupy a considerable stretch of the sea north of the ports of Dzwirzyno and Kolobrzeg. The shipping traffic affected by these developments would be the traffic running between Swinoujscie and Szczecin ports and the ports in the northern Baltic Sea. This traffic would be obliged to follow the northern Polish coast, thence deviate towards north following the clearance of the F development or leaving the OWFs on the east after having reached deeper waters well clear from the Oderbank/Lawica Odrzana. However, this route would not be a feasible option for a vessel with a draught over 6m. In general terms, this should not result in a major raise of the risk in the consideration of the fact that the current traffic density is quite low.

An additional consideration, though, requires evaluating the behaviour of the fishing fleet operating in the area. As earlier treated in the report, that area was identified as one of the zones in the area of the study with the most density of fishing activities.

Following the construction of offshore installations and the most likely interdiction to fishery activities within the development area, the fishing fleet is expected to move, and this could cause disruption increasing the risk of collision with the traffic of merchant vessels navigating around the developments. The area in the Polish MSP is characterised by a plateau of about 30m depth and it appears that there are no similar areas with these dimensions and characteristics nearby where the fishing fleet might be diverted.

Also, the Swedish MSP includes two areas south of Ystad and one area offshore Abbekas that would affect the traffic as in the northern part of the model (notes E and D).

The inshore one appears to be deployed outside the main traffic of vessels between Bornholmsgat and Off Falsterboro, whilst the other two on the south, although designed to lay in an area with a scarce density of traffic, would interest particularly traffic to/from Ystad (SY) requiring the traffic to re-align with the corridor through the German developments and it results in being a third narrower than the latter.

The exercise of realignment should take place whilst crossing the main traffic corridor SW-NE leaving little room to manoeuvre vessels, particularly in the northbound direction. In addition, the current traffic transiting between Off Falsterboro and south of Bornholm Island would be required to divert towards south following the traffic heading to Swinoujscie to then alter the course eastward and crossing the main SW-NE traffic corridor at a not ideal angle, thence heading towards south of Bornholm once cleared EO1 area. This would most likely correspond to an increment of the risk in the TH_07 leg, which is already in the top 10 hotspots.

In summary, often an introduction of an offshore installation would increase the risk in the surrounding area, however, it would be beneficial to have a broader and wider approach and consider also the existing or future developments that potentially might affect the existing traffic. At times it might be the case that an installation being developed at the extreme south of a study area results in the diversion of traffic transiting at the extreme north. This is because the preparation of a passage plan on board vessels requires considering the passage in its entirety from berth to berth and tend to choose the safest and shortest route available in order to optimize time and consumption. Often the area claimed for energy or oil & gas purposes do not consider the aspect of a safe passage plan for vessels but, sometimes, is driven by interests that tend to push decisions toward pre-defined solutions. This is even amplified when it is considered within a single national MSP. The complexity of the Baltic Sea, where several stakeholders have to cohabit in narrow spaces, should be of example for other institutions in how an MSP beyond boundaries might be developed with the primary focus set on safety and the environment.

6 CONCLUSION AND RECOMMENDATIONS

The purpose of the study was to analyse from a navigational and risk perspective the Baltic Sea area around the German EEZ for possible areas for offshore wind development, with particular interest to examine the feasibility of the westward extension of area EO2 of the German MSP.

The study considered the existing offshore wind development in the area of relevance, between Kadet Rinne and Bornholmsgat, and between Swinoujscie and Trelleborg, as well as windfarms at the pre-construction stage, that have already obtained permits. Also, based on engagement with other stakeholder nations – Denmark, Poland, and Sweden – the study considered the best current knowledge on the area allocated for future offshore wind development in their respective territorial waters and EEZs.

The above considerations were used in deriving the traffic diversion scenarios in terms of navigational route axes, and the lateral distribution of traffic on them, which were used as the hypotheses to be tested in terms of navigational risk.

The findings of the study were reported on two levels. One which covers the full extent of the model that covers the broader area of the south Baltic Sea that is relevant to the potential developments within the German EEZ, and a more focused one, which covers just the area between the footprint of the Arcadis Ost 1 windfarm and the northwest coast of Rugen Island, where most of the navigational changes associated with the development hypotheses take place. This provided insight into how the risk in the area of focus changes and, at the same time, how risk is distributed to the rest of the area as a result.

The current risk in the broader model, based on the 2019-2020 navigation routes and traffic, was calculated based on the GL guidelines. The analysis produced an annual frequency of 1.1210 vessel-to-vessel collisions, an annual frequency of groundings of 0.3617 [7], and an annual frequency of allisions to OWFs of 0.0673 [8]. The calculated values exceed the actual figures extrapolated from the HELCOM accidents database, which for the study area would suggest an annual vessel-to-vessel collision probability of 0.77.

The risk in the modelled area is concentrated on the main SW-NE traffic corridor conveying the traffic from The Belt to the NE Baltic Sea (Kadet Rinne-Bornholmsgat), where the traffic density is exceedingly large compared to the rest of the routes. Other routes that report high risk are the W-E route from The Sound to Bornholmsgat TSS, the southern part of the routes from Swinoujscie to The Sound and to Ystad, and parts of the main eastern route, to the east of Adlergrund TSS. The highest crossing risk is noted in the western and easter ends

[7] It is noted that this is based on 5-m bathymetry contour intervals
[8] It is noted that the analysis model is larger than the 15nm recommended, as well as the 20nm-limit of the GL guideline, and thus collision risk from drifting vessels is overestimated, and thus is only looked qualitatively for individual windfarms.

of the model, namely the exit of the TSS South of Gedser, at Bornholmsgat TSS, and the route north of Bornholm Island.

Looking at the focussed area to the west of the Arcadis Ost 1, where the vast impact of the navigational changes is applied, the current vessel-to-vessel annual allision probability was calculated to be equal to 0.04776. This corresponds to a return period between incidents of approximately 21 years.

Further to the existing risk profile, two different near-future scenarios were considered, addressing the introduction of the Arcadis Ost 1, and the Baltic Eagle OWFs to the maritime space. Both developments have obtained permits and are at the pre-construction stage. Both scenarios consider the diversion of traffic that is currently using the footprint of the OWFs, with the difference between the two being the diversion options considered in each for the Klaipeda traffic. The “northern” scenario diverts the traffic to the space that will be formed between the OWF development areas and the main route (Kadet Rinne-Bornholmsgat) until the development areas are cleared when the traffic re-joins its original route west of Bornholm Island. The “southern” scenario diverts the same traffic to the south of the development areas, on the main eastern corridor through Adlergrund TSS, from which it detaches once it is clear of the OWF development area Ei1 in the Danish EEZ to head east-northeast towards Klaipeda.

The two scenarios produced very similar results for vessel-to-vessel collisions and for groundings, with deviations substantially lower than 1% between them. The “southern” diversion was found to offer a benefit of 4% in terms of the annual probability of allisions to OWFs compared to the “northern”. However, since the “northern” diversion offers a benefit in terms of route length, it will most likely be the preferred option for navigators.

The annual vessel-to-vessel collision probability was calculated to be 1.1100, approximately 1% lower than the current in the area. Groundings remained constant, with the annual probability calculated to be 0.3611. The annual allision probability increased substantially with the introduction of the two OWFs, to a value of 0.1037 in the prevailing scenario (northern diversion), which constitutes a 54% increase from the current. It is noted, however, that most of the rise is attributable to high strike probability from drifting vessels, which is irregularly augmented due to the large extent of the analysis model. Smaller models in line with the 15nm range around development would provide more modest results.

In the smaller domain, at the focussed area to the west of the Arcadis Ost 1, the calculated vessel-to-vessel annual collision probability increased to 0.06010 (+25.8%). This corresponds to a return period between incidents of approximately 17 years.

The third development stage considered the full development of the area EO2. This scenario does not come with changes to the navigational routes, as the relevant traffic is already condensed to navigate through the corridor between the Arcadis Ost 1 and Baltic Eagle OWFs. The full development of EO2, therefore, does not alter the expected vessel-to-vessel collision and grounding risk, but increases the allision risk in the EO2 area, as the exposed perimeter to aberrant and drifting vessels navigating the main traffic route between the North of Rugen TSS and the Off Bornholmsgat TSS substantially increases. The overall risk increase corresponds to one incident in 38 years.

The final development stage of the study considered the effect of nominating area EO2-West, which corresponds to the corridor between Arcadis Ost 1 and development area EO2, for development. To run this scenario, the traffic currently using this corridor was diverted to the main route connecting Swinoujscie to The Sound and Trelleborg. The traffic uses the aforementioned route from the north, and then once it clears the north-west corner of Arcadis Ost 1, detaches to the east, and follows the alignment of the south-western boundary of the OWF to the point it re-joins its original course before the diversion.

The analysis produced an annual frequency of 1.1390 vessel-to-vessel collisions, which constitutes a 2.5% increase from the previous scenario, i.e., a 1.5% increase from the current risk levels. The model also yielded an annual frequency of groundings of 0.3611 which is identical to that of the previous scenario and marginally (<1%) lower than the current. The annual frequency of allisions to OWFs was calculated to be 0.12370, a decrease of 5% from that of the previous scenario.

The impact of the diversion of traffic away from the area EO2-West, in the smaller domain, at the focussed area to the west of the Arcadis Ost 1, resulted in a vessel-to-vessel annual collision probability of 0.06678, a further increase of 11% (+40% from current). This corresponds to a return period between incidents of approximately 15 years.

Finally, a mitigation scenario was considered analytically, to calculate the impact of extending the recommended route on the Swinoujscie route to The Sound and Trelleborg, to a point past the main SW-NE route (Kadet Rinne-Bornholmsgat) and adjusting the traffic characteristics in line with this change.

The mitigation proposed, was calculated to have the potential to improve the vessel-to-vessel annual collision probability by almost 3% compared to the previous scenario, and to a value 1.3% lower than the current risk in the system. A further benefit is a marginal reduction in allisions compared to the previous scenario (diversion of EO2-West traffic).

In the smaller domain that is formed by the focus area of the study to the west of the Arcadis Ost 1, the analysis resulted in a vessel-to-vessel annual collision probability of 0.03481. This value constitutes a reduction of 48% compared to the previous scenario, and a reduction of 27% to the current risk in the area.

An additional analysis was undertaken to investigate the effect of increasing traffic and increasing vessel sizes on the risk in the model. The analysis was performed on the assumption of a 20% increase in transport demand projected for 2040, which is expected to convert to a 4% increase in traffic volume and a 5% increase in the dimensions of vessels.

The re-run of the northern diversion risk model for the future demand scenario returned a collision probability increase of the order of 10%. The probability of groundings was found to increase by almost 8%, whilst allisions probability was found to rise by 5%, driven by an increase in powered allisions in excess of 8%. The results of the model following the nomination of area EO2-West for offshore wind development returned a collision probability increase of the order of 7.5%. The increase in grounding and allision probability remains consistent with that for the previous scenario.

Overall, based on the analyses performed, the study has examined how risk increases and redistributes in the study area as different interventions are performed on the existing traffic. This provides a perception, as to the impact of changes to navigation on the overall collision, allision and grounding risk.

As expected, the introduction of offshore wind developments in the maritime space leads to an increase in the overall risk in the model and generates areas where the majority of the introduced risk accumulates. The study has considered the risk impact of upcoming and considered changes to maritime space.

Whilst the proposed changes constitute an increase in the collision probability in the affected area, this increase is not to an extent that converts the area into a risk hotspot, that is difficult to be managed. The risk increment of 1.5% from the use of EO2-west for offshore wind based on current traffic and vessel sizes is a small proportion of the overall, and a small proportion of the risk that is expected to be introduced into the system in the next 2 decades. In the future case scenarios (2040) the risk effect of the use of EO2-west for OWFs appears to have no impact on the overall risk, as the total risk is at the same level as the scenario in which it is still open to navigation with EO2 fully developed.

The cumulative risk in the area of interest which includes a crossing of the main SW-NE traffic route, remains lower than the risk attributed to any of the remaining crossings to the main route, thus being the safest point to cross from north to south.

Based on the above, the study sees no reason why the risk to navigation associated with the proposed changes cannot be managed, and therefore no reason for the changes not to be implemented.

It is however recommended, that the conditions associated with the management of risk in the area are periodically reviewed, and the evolution of risk is monitored as developments in navigation, traffic, and space allocation occur.

The report recommends the extension of the recommended route from the north of Kap Arkona to approximately 19nm NNW, which appears to be beneficial in terms of reducing vessel-to-vessel collision risk, and secondarily allision risk in the area of interest. This mitigation measure appears to have the potential to reverse the introduction of risk to the current environment if implemented at the same time as the changes, or in the future control the risk escalation as a result of increasing traffic and vessel sizes.

It is noted that the content of this report is advisory, and the final decisions rest with the German authorities and stakeholders.

7 ADDITIONAL TOPICS

7.1 Comments from Polish authorities

Further to the provision of the information requested for the purposes of this study, Poland pointed out a number of issues they see with the changes to the German Maritime Spatial Plan (MSP).

The first is the spatial conflict between the ferry line connecting the ports of Swinoujscie (Poland) and Trelleborg (Sweden) with planned OWF Arcadis Ost 1 (in German territorial waters). This is in regard to corridor ST that is discussed earlier in the report. The Polish authorities note that the operators of this line are Polish ferry company “Unity Line” and German ferry company “TT-Line”. Currently, ferries cross the area reserved for planned OWF Arcadis Ost 1 while after the building of this OWF they will be forced to transit on the west of the OWF area and enter the shipping corridor shown in MSP of Mecklenburg-Vorpommern (referenced as SKT in the present report).

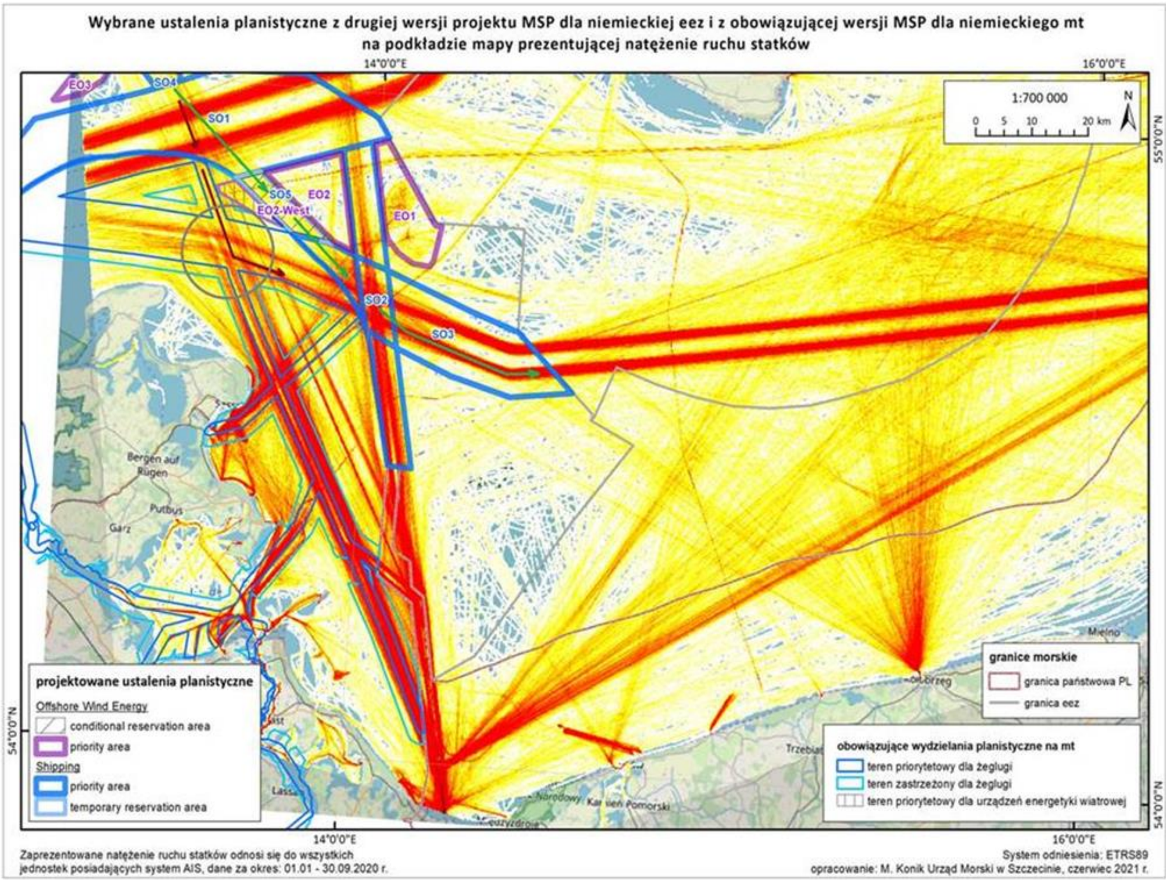


Figure 55: Figure provided by the Polish authorities

The second comment pertains to the shipping area marked as SO5 in Figure 55, laying between OWF Arcadis Ost 1 and OWF Baltic Eagle (area EO2 – in MSP for German EEZ, referred to as EO2-West in the present report) which will be used by vessels navigating from The Sound to Adlergrund TSS (traffic shown with green arrows on the map of Figure

55) which is a candidate area to be nominated for OWF development, marked as EO2-West. This way the joint areas of OWF Arcadis Ost 1, EO2-West and EO2 will be, in fact, the one area to be avoided by ships. In such a case, the Polish authorities assume that traffic from The Sound will move to the southwest to pass OWF Arcadis Ost on its west side (as shown with brown arrows on the map in Figure 55).

This raises the concern that these diversions may lead to a severe concentration of traffic from different directions in the area annotated by a grey circle: traffic on the route north of Rugen Island to Adlergrund TSS, traffic between Swinoujscie and the Danish strait, traffic from Swinoujscie to Trelleborg, and also described above traffic from The Sound strait to Adlergrund TSS. The Polish authorities, therefore, ask that this area is analysed, and countermeasures are proposed and taken if needed. Also, they would like low visibility conditions, impediments for using radar (radar shadow from OWF and Rugen Island), and rough weather conditions to be considered in the assessment.

The comments raised by Poland are fair and have already been discussed earlier in the report. In principle, the viability of merging the traffic into a single junction has been considered, and despite the introduction of risk to the area, this appears to be of manageable magnitude. Additional measures have been proposed, in the form of extending the recommended route to the north of Arkona. This shows the potential to mitigate the risk introduced by the diversions of traffic in the area and be of substantial value as the traffic volumes and vessel sizes increase.

7.2 Wartsila Modelling and Simulation

7.2.1 Overview

7.2.1.1 Objectives and setup

The objective was to set up and run a navigation simulation of the final arrangement of the German MSP implementation in the Southern Baltic Sea, inclusive of developments in areas EO2 and EO2W, in order to gain insights into the post-development environment. At the same time identify the minimum distance at which a Ro-Ro Pax ferry and a Tanker could safely transit Northbound west of Arcadis Ost 1 with minimal risk of allision with the installation even if caught in adverse environmental conditions.

The scenario considered is depicted in Figure 56, and is based on Rule 15 "Crossing situation" of the Convention on the International Regulations for Preventing Collisions at Sea. It reflects the situation where a vessel navigating alongside the boundary of the offshore wind development is confined by a combination of parallel and perpendicular courses of other vessels in its vicinity and is forced to perform an emergency avoidance manoeuvre to avoid a collision.

As depicted in Figure 56 presenting the scenario of the simulation, the green vessel is prevented by two ferries sailing southbound on her port side (FR_01 and FR_02) from crossing ahead of the other vessels coming from her starboard (vessel RR_01 and CT_01) and therefore is required to abruptly alter her course to starboard. The two small stationary fishing vessels (Fv_01 and Fv_02) are eliminating the option for the green vessel to pass astern of vessels RR_01 and CT_01, and the southbound passing ferries on the west deny the Officer of the Watch (OOW) of the green vessel the option to choose an alteration of course to the port side. In order to make the scenario more realistic, although an unlikely coincidence, in reality, it was simulated that Vessel 1 suffered from an engine failure whilst approaching the green vessel, requiring the latter to undertake a complete 180° avoidance manoeuvre to starboard and thus towards the wind turbine.

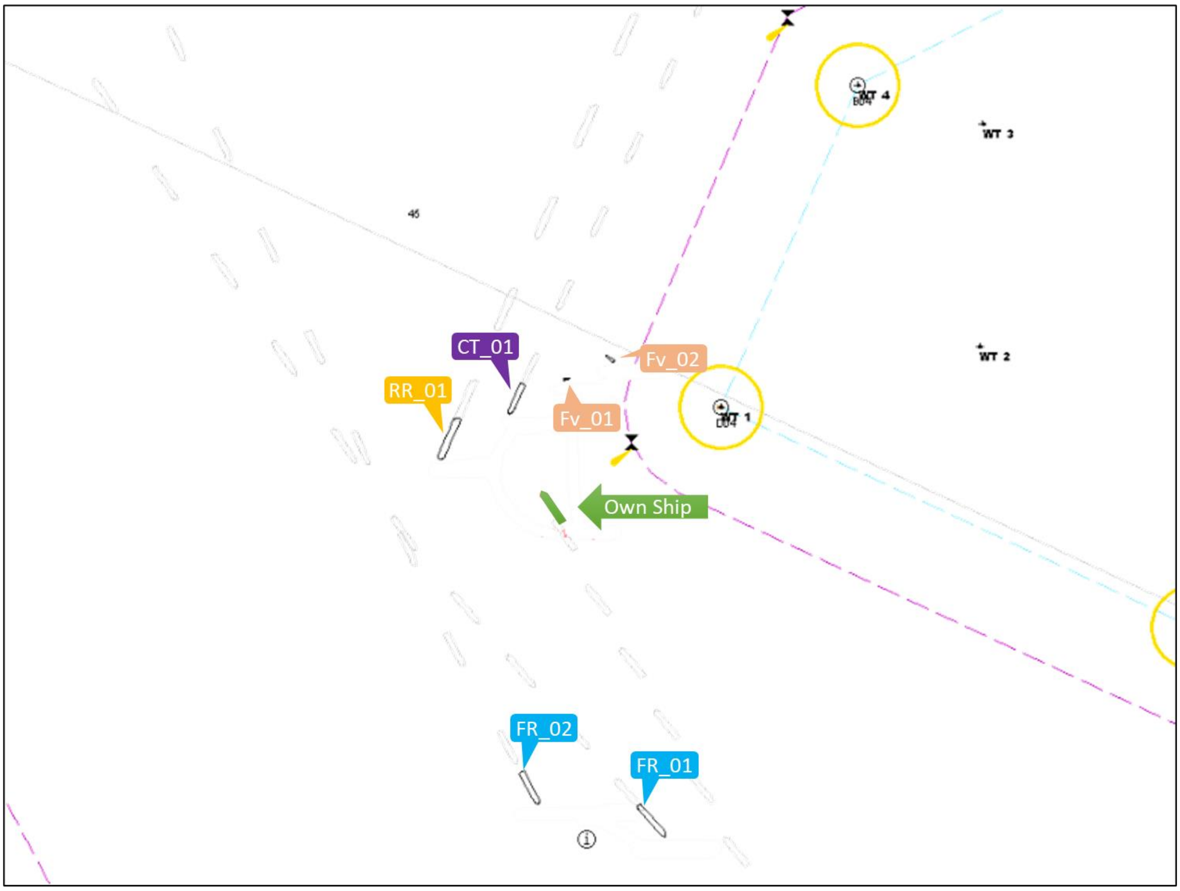


Figure 56: Depiction of the scenario used

In order to evaluate the minimum distance at which a vessel could transit off the western boundary of Arcadis Ost 1 whilst successfully performing the aforementioned avoidance manoeuvre, the following assumptions were made:

- The scenario was set up using the most representative vessels present in the area, based on a relevant analysis of the AIS dataset.
- The scenario required the green vessel to make an avoidance manoeuvre whilst heading Northbound and therefore altering her course to starboard, towards the installation.
- The environmental conditions were adapted to be unfavourable to such a manoeuvre, with winds and currents acting in the direction of Arcadis Ost 1.

Simulations were conducted whilst controlling a) a Ro-Ro Pax ferry, and b) a Tanker.

The simulation model was populated with third-party vessels based on the AIS dataset used in the traffic and risk analyses. ABL extracted the busiest period noted in the available 2-year dataset, which corresponds to the 3-hour window between 21:00-24:00 on 19 Sep 2019. A close-quarters encounter scenario was superimposed on the heaviest traffic noted and therefore the overall scenario represents a highly adverse circumstance during a busy period. Furthermore, adverse wind, wave, and current were added to the model all acting to cause the vessel being controlled (onwards referred to as the “Own Ship”) to be pushed easterly toward the western boundary of Arcadis Ost 1.

For the purposes of this section, this area is referred to herein as the simulation focus area.

Sections 7.2.2 to 7.2.6 below describe the Wartsila simulation model development, AIS data analysis used for the simulations (the AIS data scenario), the additional close quarters encounter scenario, and the metocean environmental conditions.

7.2.1.2 Simulation software

The simulator used for this study was a Wartsila NTPro5000 (previously called Transas NTPro5000) desktop version, which is a DNV-approved ship simulator. It simulates the integration of ship hydrodynamics and one of its functions is to be used as a tool to assist with vessel and scenario simulation.

The mathematical vessel models, including the physical forces and effects acting on them, have been based on results from research studies. Each vessel model has been designed to include the propulsion and manoeuvrability characteristics of the vessel based on six degrees of freedom (surge, heave, sway, pitch, yaw and roll) caused by the effects of wind, waves, currents, and water depths.

The simulator also has the capability of being able to model all forces, movements, closest point of approach to fixed structures or other vessels, vessel engine/rudder movements and numerous other parameters.

ABL use this software in-house, and it is understood that the BSH also operate the same Wartsila software in their simulation laboratory. The models prepared in this study will be passed onto the BSH for future use following the completion of this simulation study.

7.2.2 Wartsila simulation model development

A database file for local marine charts (up to date at the time of modelling) was provided by the BSH for use as the basis before any modifications. These charts were received in the form of a *.cab* filetype, recognisable by Wartsila Model Wizard software used to prepare the simulation models.

Modifications made to the charts database were focused on the simulation focus area – that is, the western boundary of Arcadis Ost 1. Specifically, these modifications are described below and demonstrated in Figure 57:

- The input of the locations of the windfarms for Arcadis Ost 1, EO-2, EO-2 West and EO-1. GPS coordinates were used to define all wind farm boundaries and for the turbine locations of Arcadis Ost 1 (turbine locations were also added to EO-1, EO-2 and EO-2 West, however, these are estimated positions and were not based on GPS coordinates for the specific turbine locations). Visual wind turbines were also added to the simulation graphics for the bridge view within the simulation software.

- 500m safety zone, restricted area marking around offset from the perimeter of the wind farm boundaries.

- Cardinal buoys are located at the corners of the 500m restricted area zone on Arcadis Ost 1 (note: cardinal buoys were not added to other windfarms as these were outside of the simulation focus area).

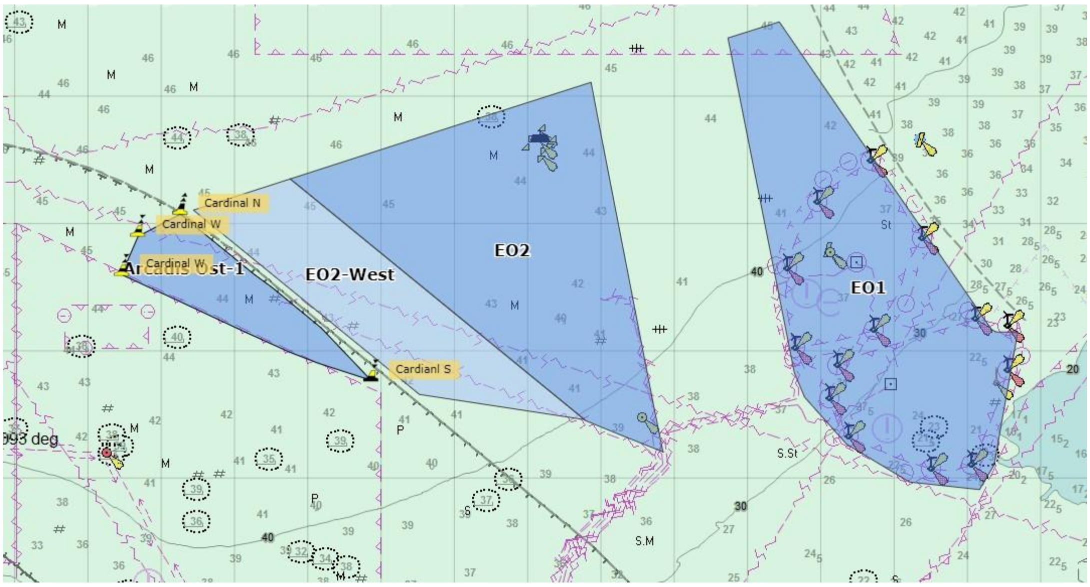


Figure 57: Modifications made to charts (note, image is representative and not of .cab file charts)

7.2.3 AIS data scenario

7.2.3.1 Vessels

Extracted from the AIS data used to populate the scenario, third-party ships were added to the model, called "Target" ships, generally fitting into one of the 8 categories as listed below, in order to reduce the number of separate vessel models used in the simulation:

- Ro-Ro Pax Ferries – represented by ~190m Ro-Pax Ferry model (also used as an "Own Ship")

- Tankers – represented by ~ m VLCC Tanker model (also used as an "Own Ship")

- Small Container vessels – represented by ~ 170m Feeder Container model
- Large Bulk Carriers – represented by ~235m Bulk Carrier model
- Small Bulk carriers – represented by ~75m Bulk Carrier model
- Cruise ships – represented by ~ 215m Cruise Ship model
- Ro-Ro vessels – represented by ~ 240m Car Carrier model
- Fishing vessels – represented by ~50m Trawler model or ~30m Conventional Tug model

7.2.3.2 Vessel tracks

Tracks from AIS data were simplified to only include major changes of course. Navigating in open waters, speeds were typically observed to be maintained as a constant speed with only minor variations for most of the vessels. The speed used in simulations for all vessels was therefore set at the average speed of the vessel over the 3-hour AIS data extract used.

Tracks were redirected when the actual AIS data showed crossing of the new windfarm areas. This was done in line with the assumptions of the risk study that preceded the simulation. Where practicable, these modified tracks were re-aligned to the new recommended routes. Tracks extending beyond the model extents were clipped at the boundary and therefore any vessel entering the boundary was set to “enter” the simulation at the time it crossed the boundary in real life. This was to maintain consistency with the situation recorded in the AIS data, but which did not affect the close-quarters scenario.

Refer to Appendix D for a visual representation of the third-party vessel tracks based on AIS data.

7.2.4 <u>Additional close quarters encounter scenario</u>

7.2.4.1 Vessels

Vessels were added to the scenario to create the fictional close-quarters encounter and evasive manoeuvre within proximity to the wind turbines. All vessels used in the close-quarters encounter were based on the vessels observed in the AIS dataset. Ships operated in the scenario, as the “Own Ship” were a Ro-Ro Pax Ferry and a Tanker. The details of the “Own Ship” vessels are presented in Figure 58 and Figure 59 respectively.

Figure 58: Ro-Ro Pax Object Information

Figure 59: Tanker Object Information

The selection of the representative vessels for the simulation was made by analysing the AIS database fleet with particular focus on the vessels regularly transiting West of Arcadis Ost 1 and particularly along the route Swinoujscie-Trelleborg/Ystad. The route is largely trafficked by Ro-Ro Pax vessels. It was noticed that the average size of this vessel type with the highest frequency of transits resulted in a ferry with a displacement of approximately 25,000 tonnes.

Similarly, AIS data was filtered to identify the recurring frequency of transits in the whole dataset for vessels with less manoeuvre capacity compared to what is expected from a Ro-Ro Pax vessel. This exercise was carried out to introduce a worst-case scenario factor given the largest room required by ‘less manoeuvrable’ vessels to evade the collision in the defined environmental conditions.

The vessel identified from the AIS dataset at the end of this process was a tanker with a displacement of approximately 60,000 tonnes. Conservatively, the tanker was considered to be sailing in ballast condition and therefore with a higher area exposed to external agents and thus requiring a larger area to perform the manoeuvre.

7.2.5 Vessel tracks

The Target ships followed a pre-defined track and speed designed to all arrive 25min after the simulation started in a position to contribute to the forced evasive manoeuvre.

Own Ships were also set to follow a pre-defined track dictated by the intended passing proximity to the 500m restriction zone (to the west of the cardinal buoy and speed as per other vessels in the AIS data set). The track and speed were followed using autopilot recreating the usual condition on the bridge of a vessel whilst sailing in open waters. When required, the operator then took manual control of the ship and navigated as required.

Refer to Appendix D for a visual representation of the vessel tracks used in this scenario.

7.2.6 Metocean environmental (metocean) conditions

Metocean conditions were chosen to simulate an adverse weather event based on data available to ABL from the relevant risk study. The scenario applied unfavourable wind, wave, and current acting simultaneously on the vessel to push the "Own Ship" towards the closest wind turbine. Since the manoeuvre would occur to the west of the installation, environmental conditions were set to act from 270° (pushing eastward). Details for each wind, wave and current are shown in Table 20 below.

Table 20: Simulation metocean conditions

Parameter	Magnitude	Direction
Wind	39 knots (steady)	From 270° (to 090°)
Wave	4.5m (significant height)	From 240° (to 060°)
Current	1.6 knots (steady)	From 270° (to 090°)

7.2.7 Scenario simulations

Both scenarios represent the transit of a vessel (a Ro-Ro Pax and a Tanker respectively) Northbound, passing West of Arcadis Ost 1 at a distance which resulted to be the minimum to avoid allision with the windfarm installations and to safely manoeuvre outside the 500 metres safety zone restricted area surrounding the installations. The scenario is diagrammatically presented in Figure 60 overleaf.

Albeit the track of these vessels does not follow any of the suggested recommendations previously described in the ABL report for the Baltic Sea (refer to section 5.2), they run parallel to the imaginary extension of the recommended route passing between the Arkona and Sassnitz safe water buoys. It is consequently noteworthy to point out that the extension of the recommended route that forms part of the recommendations of this report, lays at more than 4,000 metres from the Arcadis Ost 1 safety zone, whilst the simulations were conducted within 1,000 meters from the zone limits.

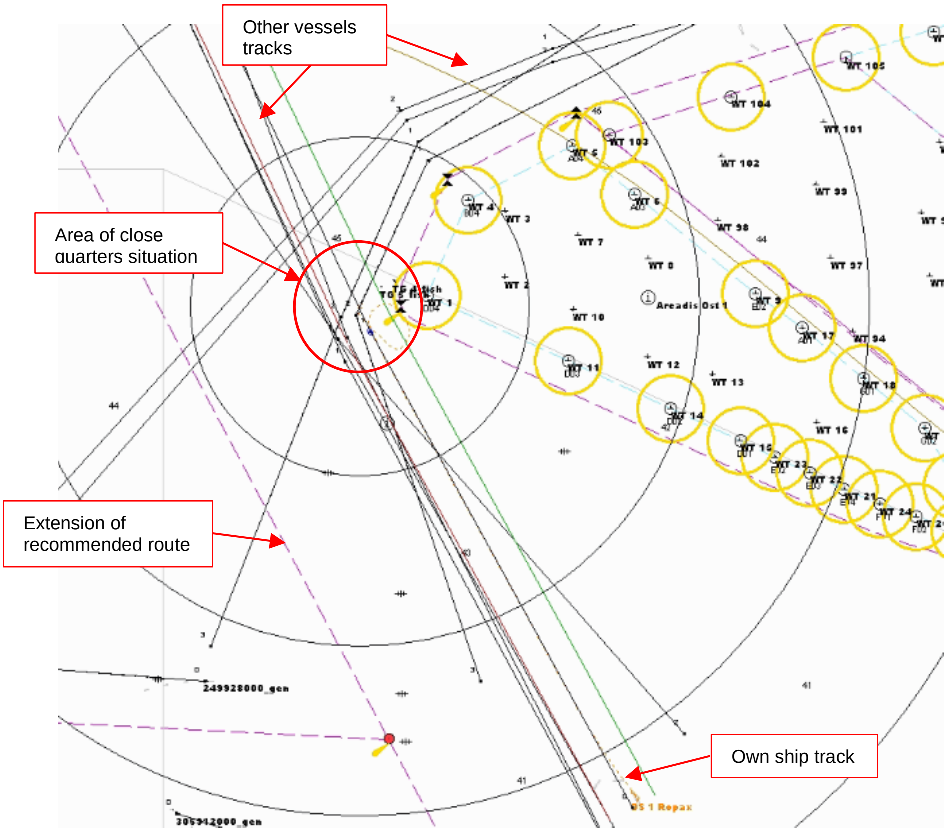


Figure 60: Scenario detailed

The “Own Ship” is modelled to navigate along a NNW’ly track with a speed over ground which was derived from the average speed recorded in the AIS dataset for the reference vessels and subjected by the simulator to the weather and marine current conditions being part of the setup of the scenario.

The “Own Ship” approaches the western end of the Arcadis Ost 1 development, heading towards Ystad/Trelleborg or the Sound, which is marked by a Cardinal Buoy West, with autopilot on a steady course, encountering two ferries Southbound on her port side (Figure 61). The latter impede the choice of the “Own Ship” to alter the course to port to avoid incoming traffic from the East.

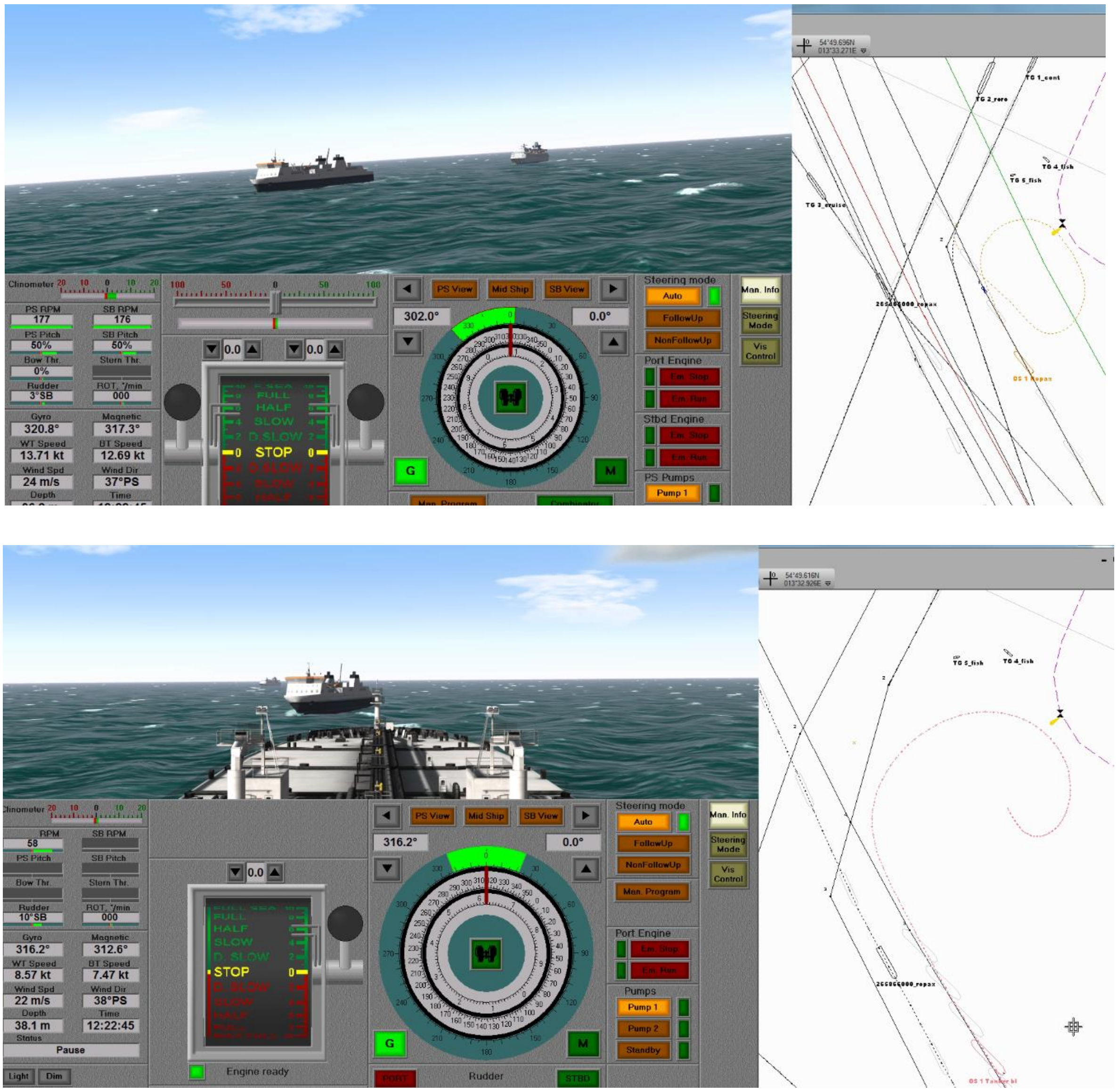


Figure 61: Ro-Ro Pax Port bow view (above)/Tanker bow view (below) approaching West of Arcadis Ost1

At the given time, at a distance of approximately 1,800 metres for the Ro-Ro Pax (3,400 m for the Tanker) on the starboard quarter, two ships (FR_01 and FR_02) are proceeding on SW'ly tracks, in addition to two fishing vessels (Fv_01 and Fv_02) that are modelled stationary near the boundary of the 500-metre restricted area at the outer boundary of the development (Figure 62).

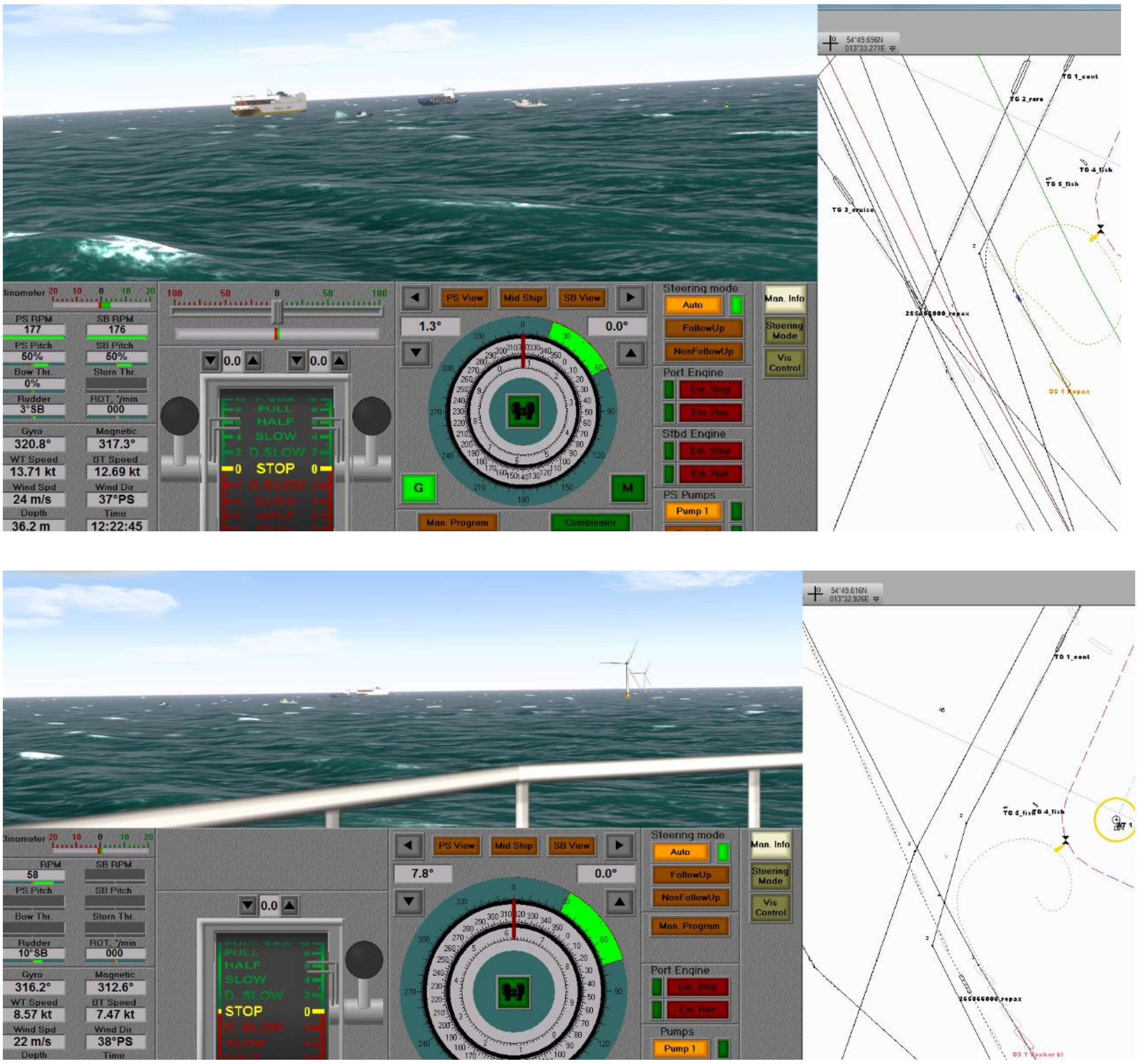


Figure 62: Ro-Ro Pax (above)/Tanker (below) starboard quarter view approaching West of Arcadis Ost1.

The present situation leaves the OOW with few options in hand to react since the regulation requires the “Own Ship” to manoeuvre with the only choice to alter the course to starboard (having other targets on the port side). In doing so and clearing vessels FR_01 and FR_02, the OOW has on the Own Ship’s bow the two fishing vessels (FV_01 and FV_02) obstructing the transit astern of the SW’ly ships (RR_01 and CT_01) on the starboard quarter.

Moreover, the presence of the windfarm on her starboard leaves the OOW only with the option to make a 180-degree turn to avoid the collision with the Southbound vessels, the stationary fishing vessels, and eventually the allision with the offshore windfarm installations.

The evasive manoeuvre was assumed as a “last minute manoeuvre” and started at approximately 100 seconds before the Closest Point of Approach (CPA) with the RR_01 for the Ro-Ro Pax (190 seconds for the Tanker) with the rudder set initially to 20 degrees to starboard (Figure 63) when the Ro-Ro Pax is at approximately 690 metres off the cardinal buoy (Tanker at 1,370 m of the same buoy). When the OOW realises that the present rate of turn with 20 degrees rudder is not enough, the rudder angle is set to 35 degrees (maximum angle).

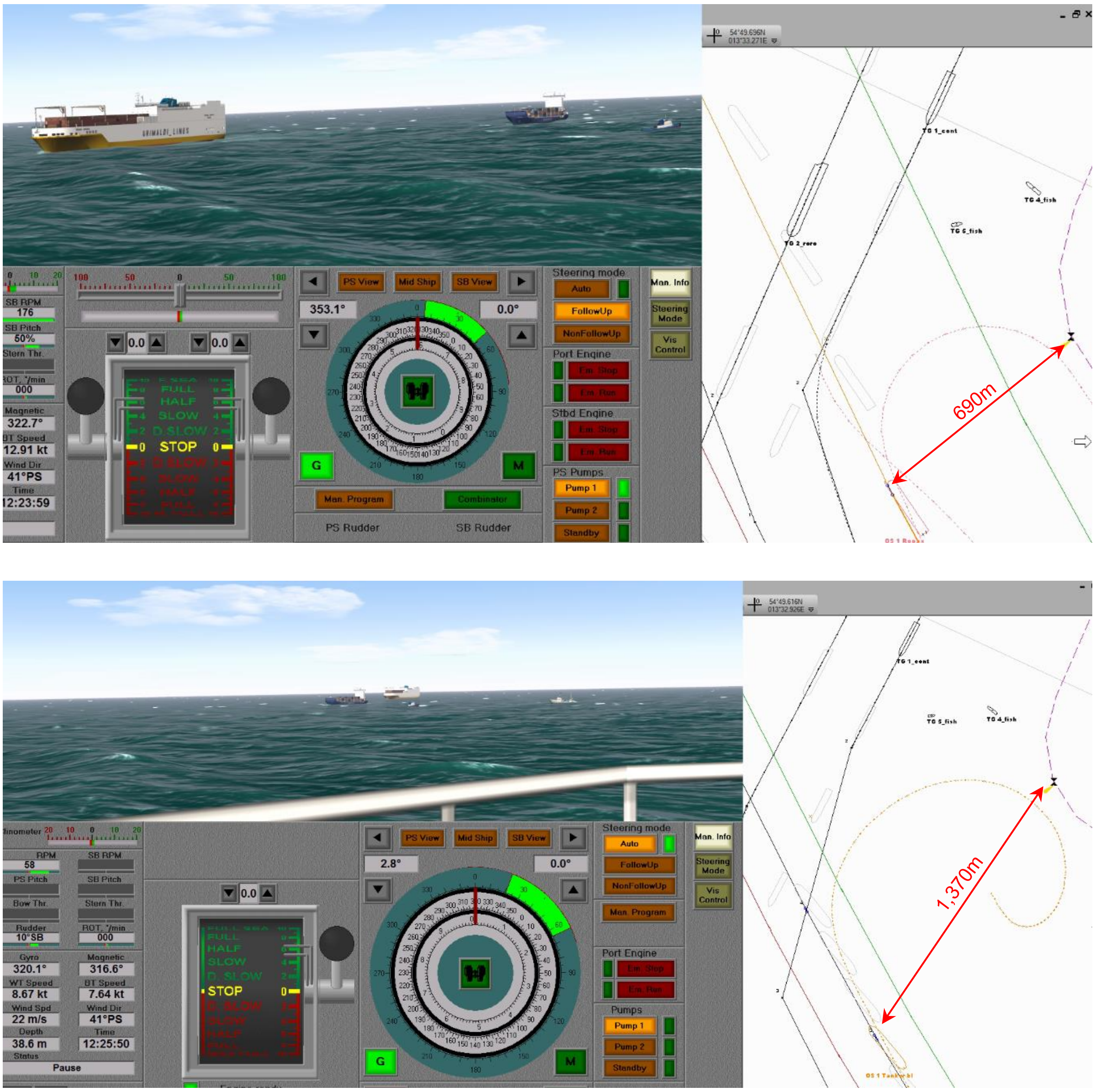


Figure 63: Ro-Ro Pax (above) Tanker (below) rudder set to 20 degrees to starboard.

Bow passage of the Cardinal Buoy West occurs at approximately 250 metres for the Ro-Ro Pax transit (410 m for the Tanker), as presented in Figure 64.

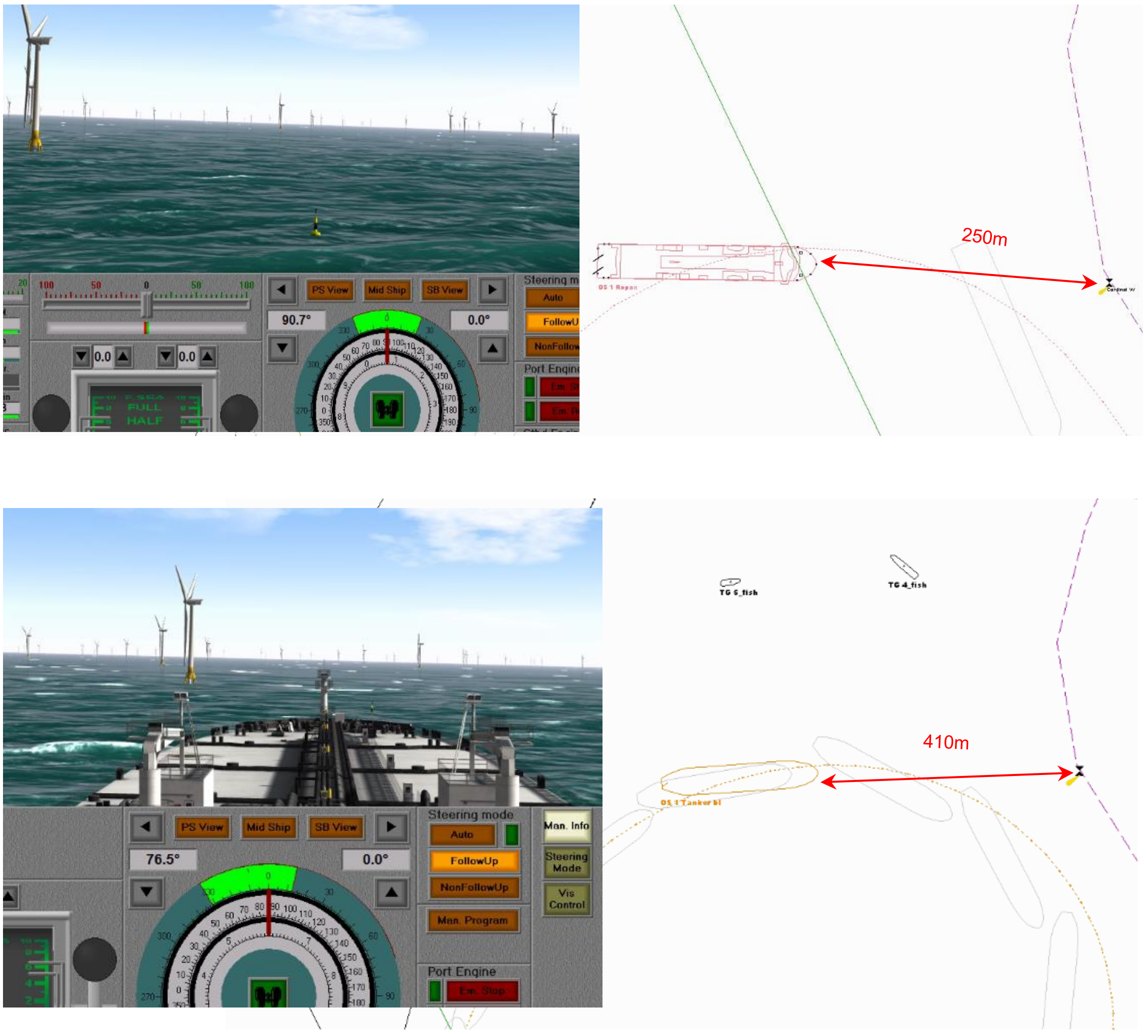


Figure 64: Bow passage of Cardinal Buoy West, Ro-Ro Pax (above)/Tanker (below).

In order to stop the swinging of the stern towards the Cardinal Buoy, the rudder of the Ro-Ro Pax was set to hard-to-port to counteract the drifting to the East. In the case of the Tanker, given her larger inertia and reduction of speed due to turning, this manoeuvre was not performed otherwise the further reduction of speed would have made the vessel's drift increase under the action of the wind and current. The closest distance between the vessel's stern and the buoy was measured to be 24 metres for the Ro-Ro Pax (42 m for the Tanker), as presented in Figure 65 overleaf.

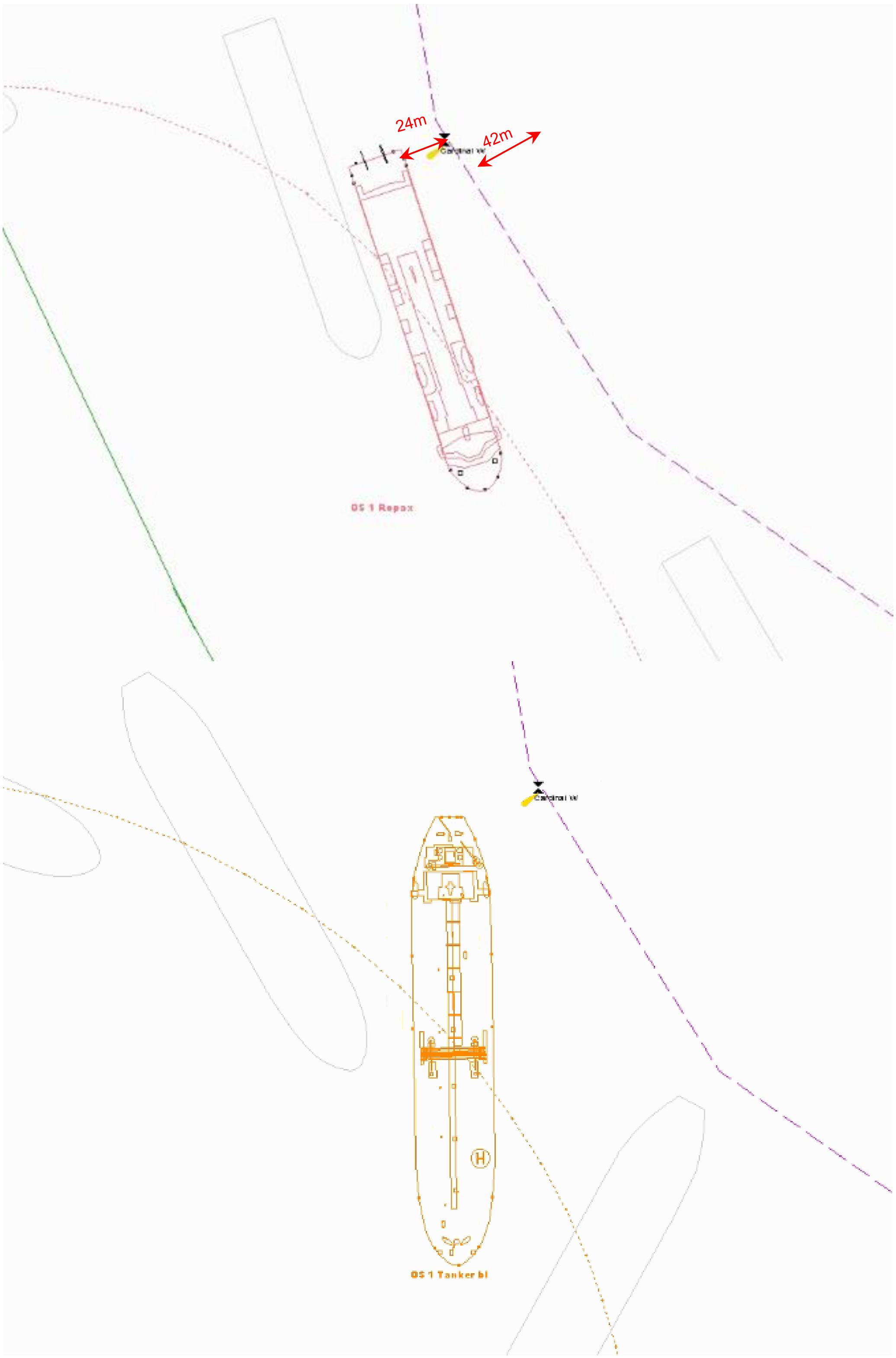


Figure 65: Closest distance to Cardinal Buoy West, Ro-Ro Pax (above)/Tanker (below).

Subsequently, the vessel resumed her turn to starboard until re-joining her original track.

7.2.8 Conclusions

Based on the setting up of the simulation scenario with a conservative approach (i.e. last-minute manoeuvre, and initial setting of rudder order to 20 degrees rather than hard over) under the effect of adverse weather and marine current conditions for vessels transiting West of Arcadis Ost 1, the reference ships used in the simulations are able to take an evasive manoeuvre with enough room to undertake a 180 degrees track path without allision with the hypothetical Cardinal Buoy West or without crossing the boundary of the Arcadis Ost 1 500 metres safety zone when their initial track lays at not less than 690 metres for the Ro-Ro Pax (Figure 66) and 1,370 metres for the Tanker (Figure 67).

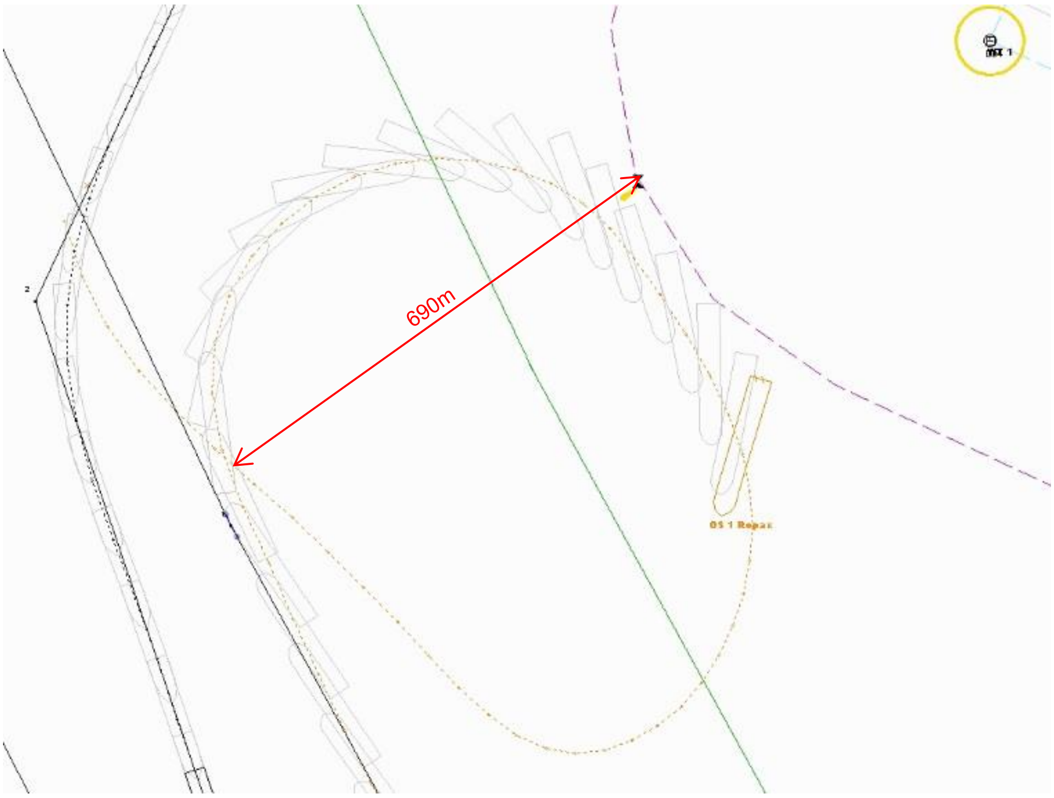


Figure 66: Ro-Ro Pax evasive manoeuvre path

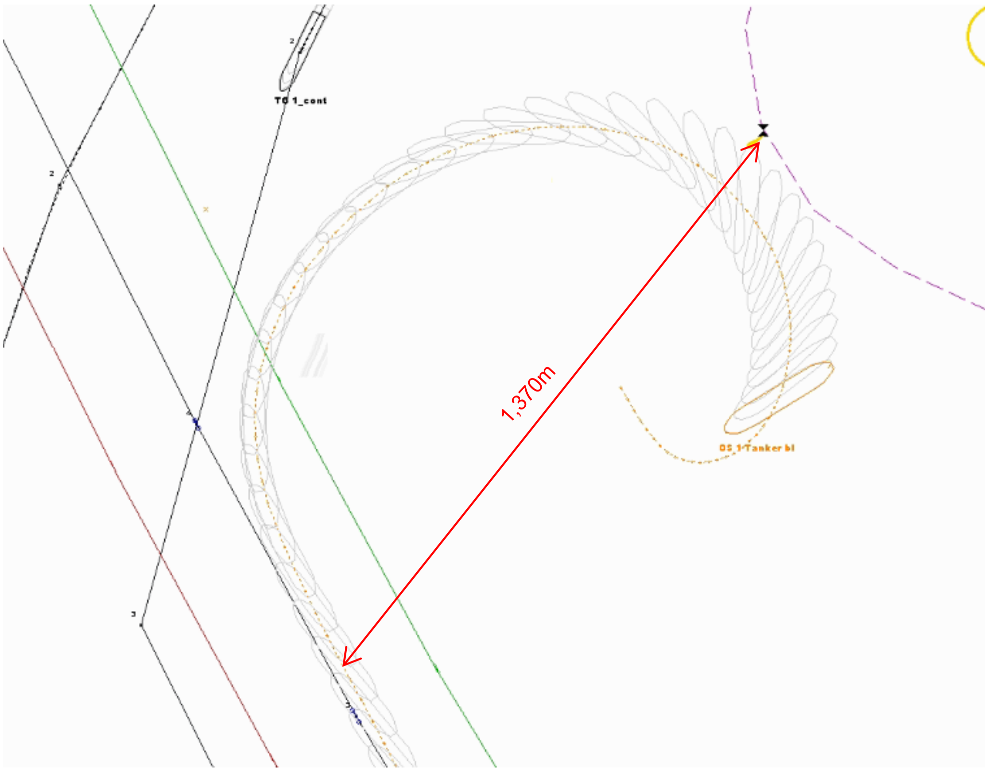


Figure 67: Tanker evasive manoeuvre path

Whilst the Ro-Ro Pax vessel is representative of the reference vessel for most of the traffic in terms of size and frequency noted transiting the Swinoujscie-Trelleborg/Ystad route, the Tanker in ballast condition, used in the simulation, is representative of a less manoeuvrable vessel based on the AIS dataset studied, resulting in what should be the largest room utilised by a vessel for a similar evasive manoeuvre within the fleet noted in the AIS dataset.

Although there are several aspects which should be considered whilst evaluating the actions of an OOW, it is almost impossible to include all the multiple variables that might affect the decision-making process of the OOW and, ultimately, the room utilised by the manoeuvring vessel in a “last minute action” scenario.

The overall distance at which a vessel should transit off the Cardinal Buoy West of the Arcadis Ost 1 offshore development should be considered not less than the distance resulted from the simulation of the Tanker in ballast condition and therefore (1,370 m), however, this should be considered a requirement for vessels with similar characteristics to the representative tanker only. It is acceptable for more manoeuvrable merchant vessels to transit in closer proximity if so required, but not below 700m.

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APPENDIX A
Metocean Data, South Baltic Sea

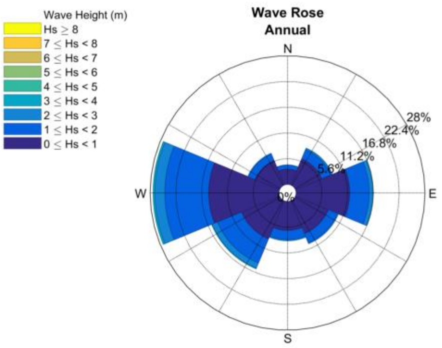
Metocean Data, South Baltic Sea

Dir (°N)	Current (m/s) - December											
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	>2.0	TOT.
0	4.71	0.65										5.35
30	6.15	1.69	0.10	0.01								7.95
60	10.27	3.14	0.16	0.03								13.60
90	11.81	3.28	0.10	0.01								15.20
120	7.34	1.05	0.01	0.02								8.42
150	4.89	0.39	0.02									5.30
180	3.92	0.25	0.02									4.19
210	5.01	0.59										5.60
240	7.45	1.80	0.10									9.35
270	9.89	1.85	0.15									11.89
300	6.63	0.73	0.01									7.37
330	5.15	0.63										5.78
TOT.	83.22	16.05	0.66	0.06								100.00

* Value lower than 0.01 %

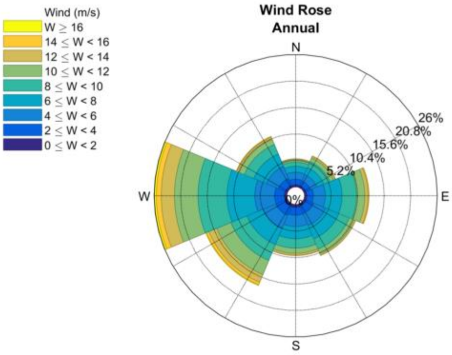
Dir (°N)	Hs (m) - December													
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	>6.0	TOT.
0	1.20	1.52	1.01	0.53	0.09	0.01	0.01							4.37
30	1.51	1.98	0.82	0.42	0.18	0.02								4.93
60	1.52	1.68	0.98	0.46	0.25	0.13	0.03							5.04
90	1.14	1.66	1.05	0.71	0.57	0.19	0.06	0.01						5.40
120	1.34	2.12	1.65	0.80	0.37	0.06	0.02	0.02						6.38
150	1.48	2.69	1.66	0.79	0.21	0.02								6.84
180	1.35	2.67	2.14	1.00	0.46	0.15	0.04	0.01						7.82
210	1.14	3.37	3.19	1.98	0.81	0.26	0.07	0.03	0.01					10.85
240	1.85	4.75	5.58	4.82	2.39	0.96	0.27	0.07	0.02	*	0.01	*	*	20.73
270	1.51	4.49	4.58	3.62	1.75	0.69	0.29	0.13	0.05	0.02	0.01	0.01	*	17.14
300	1.25	2.66	1.79	0.82	0.38	0.12	0.05	0.02	0.01	*				7.10
330	0.80	1.39	0.91	0.21	0.06	0.01	*							3.40
TOT.	16.09	30.99	25.36	16.17	7.53	2.62	0.84	0.27	0.08	0.03	0.02	0.01	0.01	100.00

* Value lower than 0.01 %

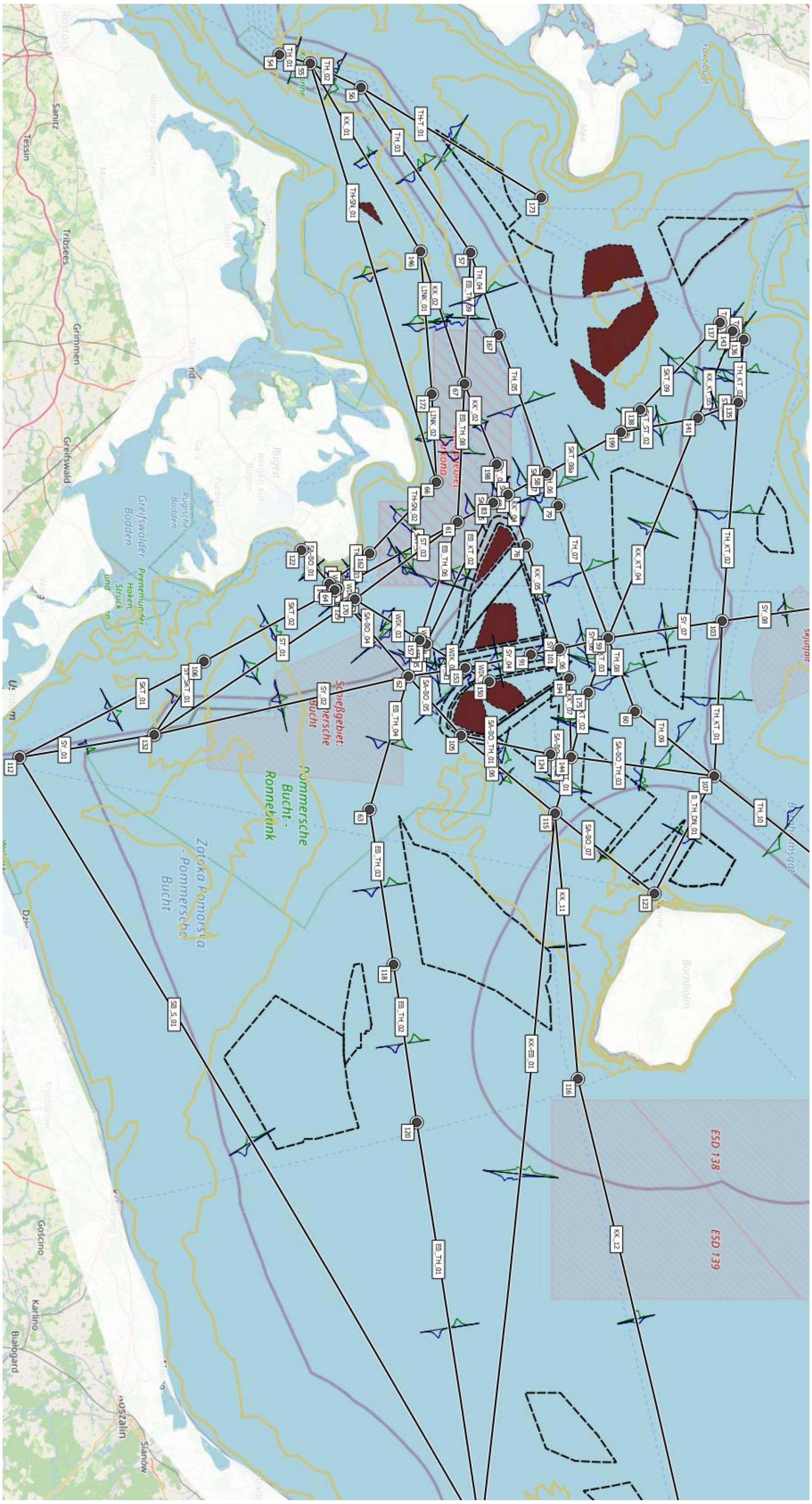


Dir (°N)	W (m/s) - December											
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	>20.0	TOT.
0	0.27	0.98	2.11	1.73	1.59	1.27	0.33	0.03	0.01			8.31
45	0.29	0.64	1.06	1.11	1.06	0.51	0.30	0.09				5.05
90	0.21	0.67	0.88	1.39	1.21	1.18	0.71	0.19	0.03			6.46
135	0.25	0.85	1.61	2.10	2.39	1.39	0.46	0.05	0.02			9.10
180	0.24	0.98	1.82	2.92	3.16	2.33	0.97	0.27	0.05			12.73
225	0.24	0.78	2.17	3.69	5.20	5.91	4.23	1.23	0.25	0.06	0.03	23.79
270	0.26	0.86	1.80	3.58	5.15	6.08	4.33	1.63	0.40	0.11	0.07	24.27
315	0.22	0.97	1.85	2.36	2.45	1.44	0.69	0.23	0.07	0.02	*	10.29
TOT.	1.97	6.73	13.29	18.88	22.21	20.11	12.01	3.71	0.82	0.19	0.10	100.00

* Value lower than 0.01 %



APPENDIX B
Map of model legs and waypoints



Map of model legs and waypoints

APPENDIX C
Wartsila Simulation – Own Ship Wheelhouse Posters

ROPAX FERRY

WHEELHOUSE POSTER

Ship's name Ro-Ro Ferry 2 (Dis.25598t) TRANSAS 2.31.9.0 , Call sign N/A ,
Gross tonnage N/A , Net tonnage N/A , Load Condition Full load , Displacement 25598 tons , Deadweight N/A tons

DRAFTS IN PRESENT CONDITION	
Forward	8 m
Forward extreme	8 m
After	8 m
After extreme	8 m

STEERING PARTICULARS	
Type of rudder	Becker's rudder
Maximum rudder angle	35 degrees
Hard-over to hard-over(1/2 pumps)	13 sec/13 sec
Neutral effect angle	0 degrees
Flanking Rudders	0

ANCHORS INFO	
Anchor(s) (No./types)	2 (PortBow / StbdBow)
No. of shackles	15 / 15
Max. rate of heaving, m/min	30 / 30
(1 shackle =25 m / 13.7 fathoms)	

PROPULSION PARTICULARS			
Type of Main Engine	Medium speed diesel	Number of propellers	2
No. of Main Engines	2	Propeller rotation	Outward
Max. power per shaft	2 x 25393.15 kW	Propeller type	CPP
Astern power	80 % ahead	Min. RPM	30
Time limit astern	N/A	Emergency FAH to FAS	47.2 seconds

Engine Telegraph Table (Shown regimes: Regime 0/Regime 1)

Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	24.1 / 24.1	48348 / 48348	175 / 175	1.64 / 1.64
"FAH"	19.6 / 20.9	35560 / 35560	175 / 170.7	1.23 / 1.4
"HAH"	16.4 / 17.7	22216 / 22216	175 / 159.7	0.9 / 1.21
"SAH"	13.8 / 12.6	8690 / 8690	175 / 137.5	0.6 / 0.86
"DSAH"	8.7 / 6.2	2719 / 2719	175 / 105	0.3 / 0.37
"DSAS"	-3 / -5	3915 / 3915	175 / 121.1	-0.05 / -0.26
"SAS"	-7.1 / -9.4	10221 / 10221	175 / 144.6	-0.25 / -0.61
"HAS"	-9.9 / -11.1	15329 / 15329	175 / 155.5	-0.47 / -0.73
"FAS"	-12 / -12.8	22608 / 22608	175 / 166.5	-0.68 / -0.84
"FSAS"	-14.3 / -14.3	31560 / 31560	175 / 175	-0.96 / -0.96

THRUSTER EFFECT

Thruster (s)	No. of units	Power (kW)	Time delay for full thrust(s)	Turning rate at zero speed(degrees/min)	Time delay to reverse full thrust(s)	Not effective above speed (knots)
Bow	2	3000	5.7	13.55	11.4	6
Stern	N/A					
Combined	N/A					

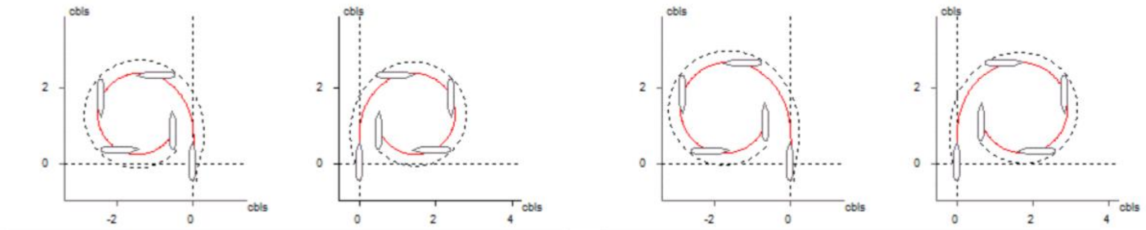
Auxiliary Steering Device(s): N/A

DRAFT INCREASE IN PRESENT CONDITION

Squat effect				Heel effect	
Under keel clearance	Ship's speed	Bow squat	Stern squat	Heel angle	Draft increase
3m	18.58 knots	-0.55 m	1.19 m	2 deg	0.41 m
	17.36 knots	-0.37 m	1.11 m	4 deg	0.8 m
	15.86 knots	0.05 m	0.8 m	8 deg	1.54 m
2 m	18.4 knots	-0.65 m	1.25 m	12 deg	2.21 m
	16.97 knots	-0.53 m	1.24 m	16 deg	2.81 m

TURNING CIRCLES

Deep Water — Shallow Water*



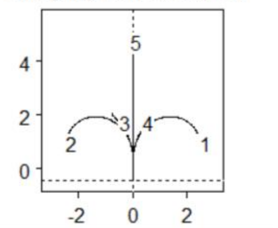
Deep Water:

Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.3 cbls	0.96 cbls	2.42 cbls	90 deg/min	10 knots	238 s
100	-35	2.3 cbls	-0.96 cbls	-2.42 cbls	-90 deg/min	10 knots	238 s

Shallow Water*:

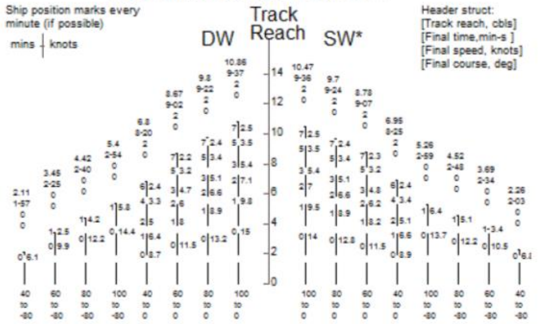
Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.61 cbls	1.26 cbls	2.84 cbls	87 deg/min	10 knots	256.6 s
100	-35	2.61 cbls	-1.26 cbls	-2.84 cbls	-87 deg/min	10 knots	256.6 s

Emergency Manoeuvers(DW)

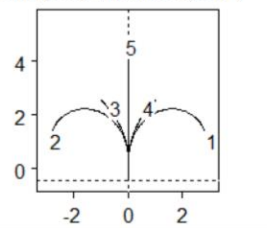


No.	Rudd.	Eng.	Full time	Head reach	Side reach
1	35	100	118.1 s	1.71 cbls	2.42 cbls
2	-35	100	118.1 s	1.71 cbls	-2.42 cbls
3	35	-80	99.4 s	2.52 cbls	-0.8 cbls
4	-35	-80	99.4 s	2.52 cbls	0.8 cbls
5	0	-80	154.4 s	5.04 cbls	0 cbls

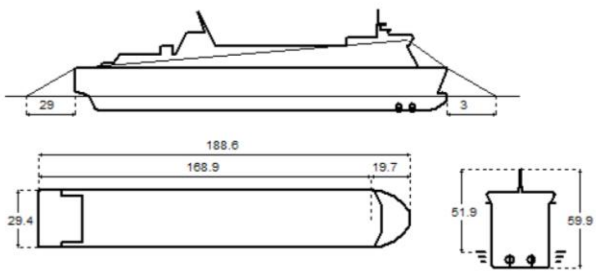
STOPPING CHARACTERISTICS



Emergency Manoeuvers(SW*)



No.	Rudd.	Eng.	Full time	Head reach	Side reach
1	35	100	131.3 s	1.81 cbls	2.84 cbls
2	-35	100	131.3 s	1.81 cbls	-2.84 cbls
3	35	-80	117 s	3.03 cbls	-1.01 cbls
4	-35	-80	117 s	3.03 cbls	1.01 cbls
5	0	-80	158.8 s	4.87 cbls	0 cbls



MAN OVERBOARD RESCUE MANOEUVRE

SEQUENCE OF ACTION TO BE TAKEN:

- TO CAST A BUOY
- TO GIVE THE HELM ORDER
- TO SOUND THE ALARM
- TO KEEP THE LOOK OUT

Approximate Maneuver Program

Time	Action
0 s	Set rudder 35 STBD. Wait till ship course altered to 51 degrees from initial.
32 s	Set rudder 35 PORT. Wait till course altered to -170 degrees from initial.
189 s	Turn AP on. The difference between AP course and initial course must be 180 degrees.

Bridge To Stern	168.9 m	Length of Midbody	69.4 m	Air Draft	51.9 m / 170 ft 8 in
Bridge To Bow	19.7 m	Length Overall	188.6 m	Forward Blind Zone	3 m
Breadth	29.4 m	Height	59.9 m	Backward Blind Zone	29 m

* Shallow Water: depth is equal 2 Draft ** Model: 2.214.1678.211; VSY02: 2.93.3721.0;

PERFORMANCE MAY DIFFER FROM THIS RECORD DUE TO ENVIRONMENT, HULL AND LOADING CONDITION

TANKER

WHEELHOUSE POSTER

Ship's name VLCC 6 (Dis.59356t) bl. TRANSAS 2.31.10.0 , Call sign N/A ,
Gross tonnage N/A , Net tonnage N/A , Load Condition Ballast , Displacement 59356 tons , Deadweight 40715.4 tons

DRAFTS IN PRESENT CONDITION	
Forward	5.8 m
Forward extreme	5.8 m
After	8.7 m
After extreme	8.7 m

STEERING PARTICULARS	
Type of rudder	Semisuspended
Maximum rudder angle	35 degrees
Hard-over to hard-over(1/2 pumps)	26 sec/26 sec
Neutral effect angle	0.02 degrees
Flanking Rudders	0

ANCHORS INFO	
Anchor(s) (No./types)	2 (PortBow / StbdBow)
No. of shackles	16 / 16
Max. rate of heaving, m/min	18 / 18
(1 shackle =25 m / 13.7 fathoms)	

PROPULSION PARTICULARS			
Type of Main Engine	Low speed diesel	Number of propellers	1
No. of Main Engines	1	Propeller rotation	Right
Max. power per shaft	1 x 21100 kW	Propeller type	FPP
Astern power	60 % ahead	Min. RPM	10
Time limit astern	N/A	Emergency FAH to FAS	2.1 seconds

Engine Telegraph Table

Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	16.3	18065	87.9	0.74
"FAH"	12.8	8000	67	0.74
"HAH"	11.6	5746	60	0.74
"SAH"	7.4	1241	36	0.74
"DSAH"	6.3	718	30	0.74
"DSAS"	-2.6	719	-30	0.74
"SAS"	-3.1	1243	-36	0.74
"HAS"	-5.2	5756	-60	0.74
"FAS"	-5.8	8015	-67	0.74

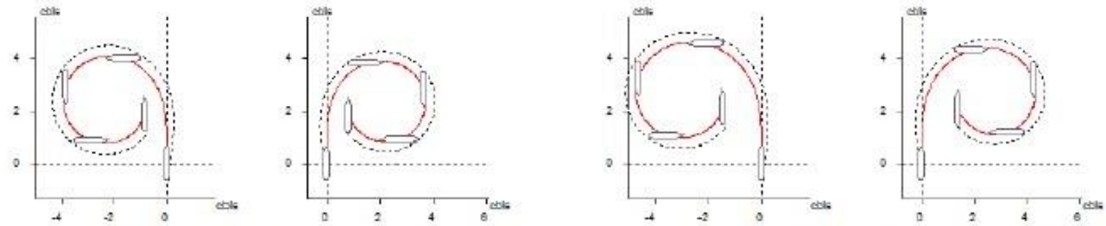
THRUSTER EFFECT						
Thruster (s)	No. of units	Power (kW)	Time delay for full thrust(s)	Turning rate at zero speed(degrees/min)	Time delay to reverse full thrust(s)	Not effective above speed (knots)
Bow	N/A					
Stern	N/A					
Combined	N/A					

Auxiliary Steering Device(s): N/A

DRAFT INCREASE IN PRESENT CONDITION					
Squat effect				Heel effect	
Under keel clearance	Ship's speed	Bow squat	Stern squat	Heel angle	Draft increase
3m	16.14 knots	0.08 m	1.48 m	2 deg	0.58 m
	12.75 knots	0.29 m	0.65 m	4 deg	1.13 m
	11.57 knots	0.22 m	0.53 m	8 deg	2.17 m
2 m	16.05 knots	-0.14 m	1.76 m	12 deg	3.12 m
	12.73 knots	0.38 m	0.8 m	16 deg	3.97 m

TURNING CIRCLES

Deep Water — Shallow Water*



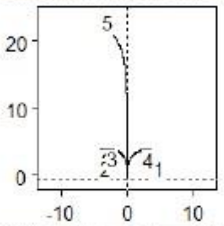
Deep Water:

Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	3.84 cbls	1.53 cbls	3.6 cbls	42 deg/min	6 knots	505.6 s
100	-35	4.02 cbls	-1.65 cbls	-3.86 cbls	-40 deg/min	7 knots	528.6 s

Shallow Water*:

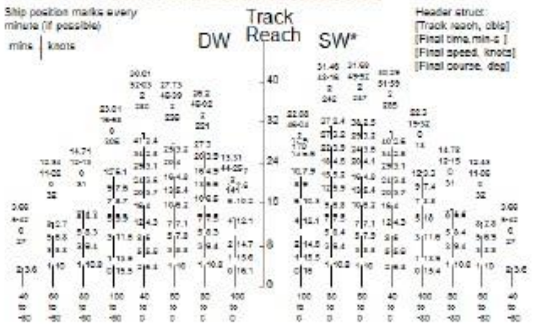
Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	4.34 cbls	1.91 cbls	4.25 cbls	41 deg/min	6 knots	540.6 s
100	-35	4.55 cbls	-2.08 cbls	-4.64 cbls	-39 deg/min	7 knots	571.6 s

Emergency Manoeuvers(DW)

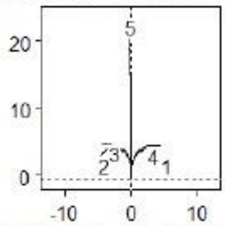


No.	Rudd.	Eng.	Full time	Head reach	Side reach
1	35	100	247.9 s	2.84 cbls	3.6 cbls
2	-35	100	260.6 s	2.91 cbls	-3.86 cbls
3	35	-80	431.6 s	4.4 cbls	-4.39 cbls
4	-35	-80	401.6 s	4.2 cbls	4.17 cbls
5	0	-80	1019.6 s	22.99 cbls	-3.46 cbls

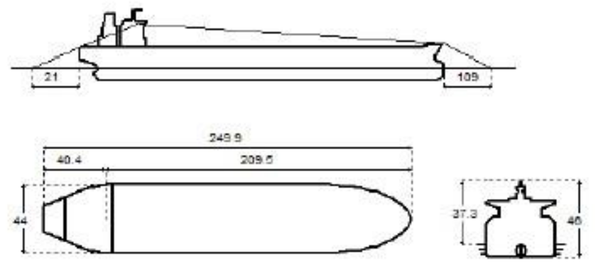
STOPPING CHARACTERISTICS



Emergency Manoeuvers(SW*)



No.	Rudd.	Eng.	Full time	Head reach	Side reach
1	35	100	278.6 s	3.2 cbls	4.25 cbls
2	-35	100	296.6 s	3.24 cbls	-4.64 cbls
3	35	-80	455.6 s	5.09 cbls	-4.66 cbls
4	-35	-80	426.6 s	4.87 cbls	4.47 cbls
5	0	-80	933.6 s	22.28 cbls	-0.52 cbls



MAN OVERBOARD RESCUE MANOEUVRE

SEQUENCE OF ACTION TO BE TAKEN:
- TO CAST A BUOY
- TO GIVE THE HELM ORDER
- TO SOUND THE ALARM
- TO KEEP THE LOOK OUT

Approximate Maneuver Program

Time	Action
0 s	Set rudder 35 STBD. Wait till ship course altered to 31 degrees from initial
56 s	Set rudder 35 PORT. Wait till course altered to -170 degrees from initial
429 s	Turn AP on. The difference between AP course and initial course must be 180 degrees

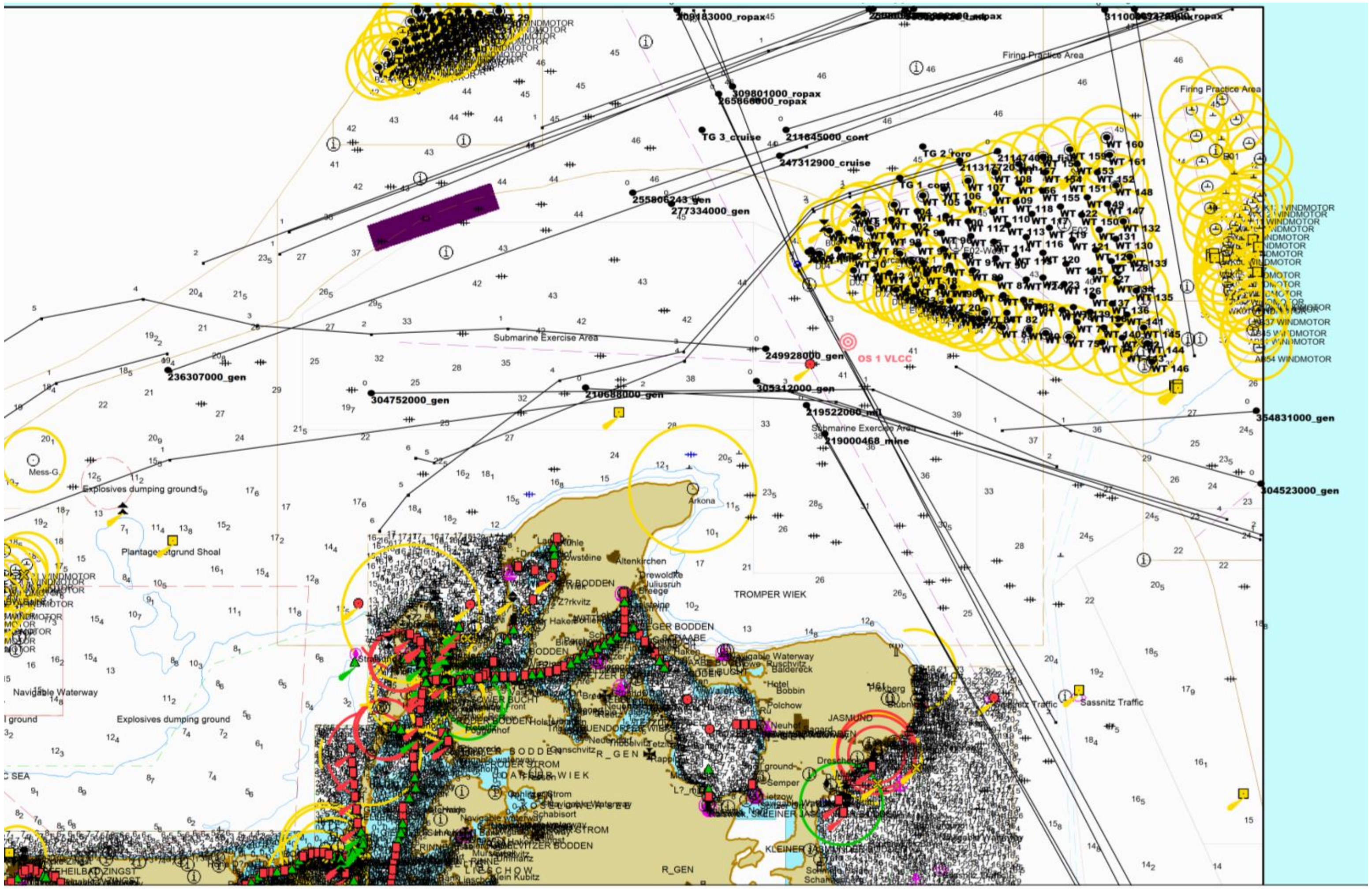
Bridge To Stern	40.4 m	Length of Midbody	159.9 m	Air Draft	37.31 m / 122 ft 8 in
Bridge To Bow	209.5 m	Length Overall	249.9 m	Forward Blind Zone	109 m
Breadth	44 m	Height	46.01 m	Backward Blind Zone	21 m

* Shallow Water: depth is equal 2 Draft ** Model: 2.214.1678.211; VSY02 2.93.3721.0;

PERFORMANCE MAY DIFFER FROM THIS RECORD DUE TO ENVIRONMENT, HULL AND LOADING CONDITION

APPENDIX D
Wartsila Simulation – Vessel Tracks

AIS Data – Third-party vessel tracks used (close quarters encounter hidden)



Close Quarters Encounter Scenario – Vessel tracks used (third-party AIS data vessel tracks hidden)