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# ENERGY ISLANDS BORNHOLM

## TECHNICAL REPORT – MARITIME

## TRAFFIC AND NAVIGATIONAL SAFETY

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# ENERGY ISLANDS BORNHOLM
# TECHNICAL REPORT – MARITIME TRAFFIC AND NAVIGATIONAL SAFETY

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## CONTENTS

# APPENDICES

**Appendix 1**
IWRAP modeLling details

**Appendix 2**
Detailed information about the ship traffic

# ABBREVIATIONS

| | |
|---|---|
| IMO | The International Maritime Organization |
| FSA | Formal Safety Assessment |
| SEA | Strategic Environmental Assessment |
| HAZID | Hazard Identification |
| AIS | Automatic Identification System |
| HVDC | High-voltage direct current |
| EEZ | Exclusive Economic Zone |
| TSS | Traffic Separation Scheme |
| HVAC | High Voltage Alternative Current |
| VMS | Vessel Monitoring System |
| HELCOM | The Baltic Marine Environment Protection Commission |
| MAS | Maritime Assistance Service (Søværnet) |
| NtM | Notices to Mariners |
| ECDIS | Electronic Chart Display and Information System |

# 1. SUMMARY

In this report, navigational safety is assessed in connection with the construction, operation, and decommissioning of offshore wind turbines and cables within the proposed plan for Energy Island Bornholm. Ship traffic in the area has been analysed based on historical knowledge of a year's ship movements in the area, and it has been assessed how ship traffic will have to adapt after the establishment of offshore wind turbines within the planning areas.

The area is already heavily trafficked, and the traffic generally proceeds in well-planned and unidirectional traffic flows. However, meeting situations between ships and the risk of blackout / machine failure also give rise to incidents in the area before the establishment of Energy Island Bornholm; including ship collisions, groundings and dragged anchors which have resulted in cable breaks.

Offshore wind turbines in the area will constitute obstacles that ships could collide with, while some sailing routes must be expected to be rerouted. The rescheduling of ship traffic is estimated to result in the densification of traffic on certain already existing routes, as well as the establishment of a new navigation corridor between two of the planning areas.

The denser traffic could lead to a small increased risk of ship collisions, just as blackout / machine failure would cause a risk of collisions between ships and offshore wind turbines. However, several risk reducing measures during both construction, operation, and decommissioning are considered to contribute to ensuring that navigational safety in the area can be maintained at an acceptable level.

For more detailed conclusions and recommendations, see section 6.

# 2. INTRODUCTION

The energy islands mark the beginning of a new era for the generation of energy from offshore wind, aimed at creating a renewable energy supply for Danish and foreign electricity grids. Operating as renewable power plants at sea, the islands are expected to play a major role in the phasing-out of fossil fuel energy sources in Denmark and Europe. One energy island is planned in the North Sea and one in the Baltic Sea.

After political agreement on the energy islands has been reached, the Danish Energy Agency plays a key role in leading the project that will transform the two energy islands from a vision to reality. The energy island projects are pioneer projects that will necessitate the deployment of existing knowledge into an entirely new context.

The Plan for Programme Energy Island Bornholm (”The plan”) sets the framework for the construction of Energy Island Bornholm - one of the first energy islands in the world and a pioneering offshore wind energy hub in the Baltic Sea (see Figure 2-1).

The plan includes offshore planning areas for an offshore wind farm ("OWF") 15 km from Bornholm, and for subsea cables in Danish waters between Bornholm and Zealand as well as between Bornholm and German waters.

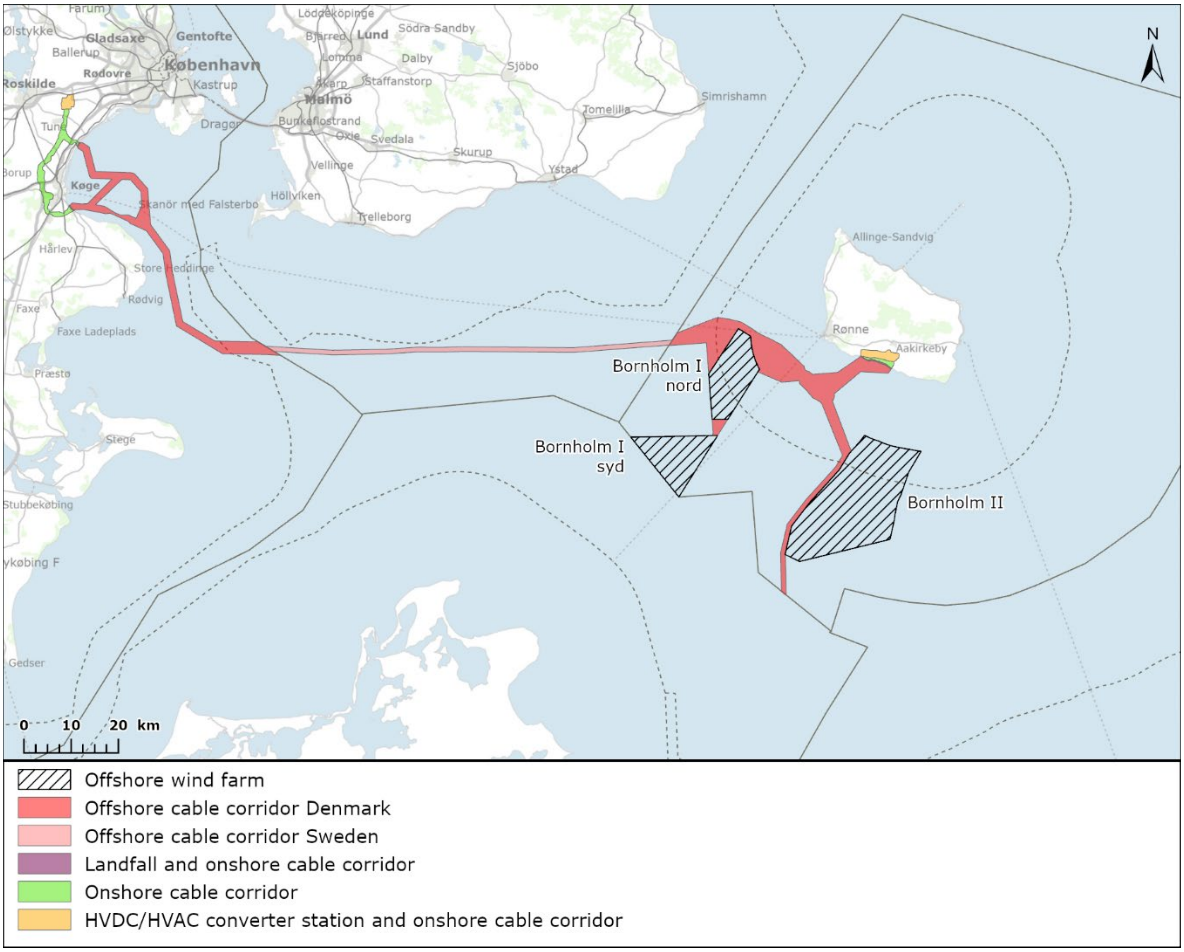


**Figure 2-1 Planning areas in the Plan for Programme Energy Island Bornholm.**

The before mentioned planning area is divided in to three OWF areas: Bornholm I Syd (118 km2), Bornholm I North (123 km$^2$) and Bornholm II (410 km$^2$). The planning areas, as mentioned above, will contain wind turbines with a maximum height of 330 m, maximum 7 transformer platforms, and subsea cables. These three OWF areas will have an installed production capacity of up to 3,8 GW including overplanting. Additional information regarding the planning area can be found in the draft of the Strategical Environmental Assessment for this project.

## 2.1 Purpose of the report

The report describes the maritime traffic in the area and provides an assessment of the maritime traffic and navigational safety based on an analysis of the area around the offshore wind farms, as well as a consultation with relevant users of the waters. The assessment is done in relation to the strategy plan for Energy Island Bornholm and, as a background for a future environmental impact assessment for a specific project.

## 2.2 General method for assessing navigational safety

The assessment of navigational safety has been carried out based on the standard method from the International Maritime Organization (IMO). The IMO created a guideline for formal safety assessment (FSA), which is used as a framework for risk assessment. A schematic illustration of the FSA process is shown in Figure 2-2. The FSA principles are followed for the early phase of the project; the hazard identification and initial risk assessment, including the effect of risk reducing measures, are developed as part of the background for the strategic environmental assessment (SEA) in relation to navigational safety, as well as background information for a future environmental impact assessment for a specific project.

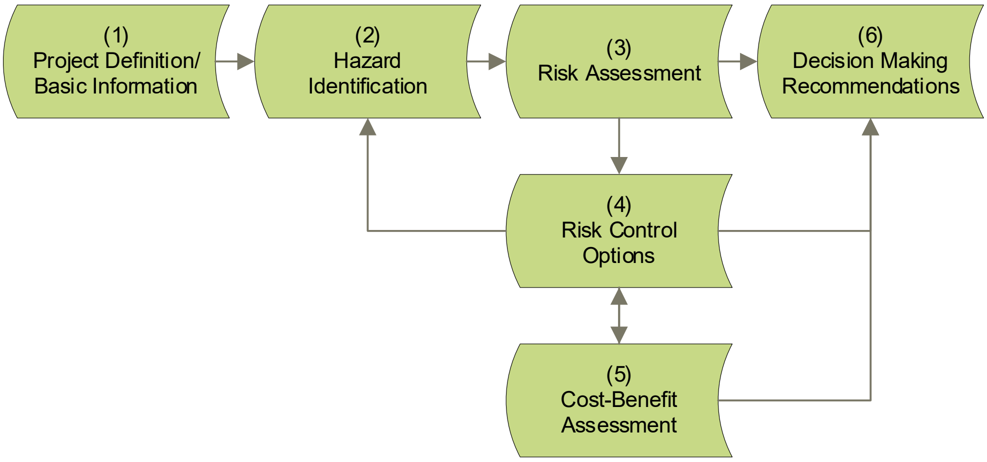


**Figure 2-2 Schematic illustration of steps leading up to a risk assessment and decisions taken based on the risk assessment.**

### 2.2.1 HAZID-workshop

A workshop was held on 15 December 2021 as a background for the assessment of the consequences for ship traffic and input to the SEA for the establishment of Energy Island Bornholm, the offshore wind farms in the Baltic Sea southwest of Bornholm. The purpose of the workshop was to consult the maritime users on the identification of possible hazards (HAZID) to address the effect on navigational safety in relation to Energy Island Bornholm.

The purpose of carrying out the hazard identification process was to identify hazards related to navigational safety during construction and operation of Energy Island Bornholm. Future decommissioning activities were not specifically addressed but are expected to be comparable to construction activities to some extent. The input given at the workshop forms the basis for the strategic environmental assessment and the maritime risk assessment as well as a technical background for future project phases. The detailed input given at the workshop can be seen in the HAZID report in ref. /1/.

At the HAZID workshop, the areas Bornholm I nord and Bornholm I syd (see Figure 2-1) were presented as a continuous area without the possibility of passing between the current two sub-areas. As the updated areas are reduced compared to the areas presented at the HAZID workshop as a result of a military exercise area and the navigation corridor south of Bornholm across the planning area for Bornholm I, a new hazard identification has not been carried out. Some of the identified hazards related to the possibility of passing between the two sub-areas are addressed in the updated planning areas. This is considered in the present risk analysis.

A total of three specific hazards related to the construction phase and 16 hazards related to the operational phase were identified.

### 2.2.2 Data and risk analysis

The navigational safety is assessed, among other things based on Automatic Identification System (AIS) data. AIS data is used as a basis for quantifying ship movements within the analyzed area. Together with input from the HAZID workshop, it is the most important data source for the risk calculations. AIS is a maritime radio system for automatic identification of ships and other units related to shipping. The system works by ships being equipped with an AIS transmitter, which frequently sends a digital radio message in the reserved VHF band. The message contains, among other things, information about the ship's name, geographical location, course, speed, draft, and is available from other AIS receivers that are within range. AIS equipment is a requirement for all ships over 300 gross tons, all passenger ships, and all fishing vessels over 15 meters in length (EU regulations), as mentioned in ref. /3/.

For military vessels there is no requirement to use AIS. The same is the case for smaller vessels, including pleasure boats. However, some of these small vessel owners have chosen to install an AIS transmitter on board to be more visible at sea and will therefore also be found in the data. The large number of voluntary AIS users, in addition to the required ones, makes AIS data a valuable data set for risk assessments, enabling the creation of representative traffic patterns and routes for recreational activities.

As not all ships indicate their ship type in AIS data, these will be presented as "other ships". These are mainly military vessels, pleasure boats, or other smaller ships that have not filled in their ship information.

AIS data for the whole of 2019 obtained from the Danish Maritime Authority, ref. /2/, is chosen as the basis for the analysis. In addition, AIS data for the year 2021 has been examined for any changes in ship traffic patterns, routes, offshore wind farms or other effects that are included in the analysis and risk assessment. Data from 2020 is largely affected by the COVID-19 pandemic, which broke out in the spring of 2020. Data for 2020 is therefore not used in the analysis. It is noted that the AIS data used is comprehensive within the Danish exclusive economic zone (EEZ), as well as to a certain extent in the areas outside. However, the coverage is more sporadic outside the Danish EEZ.

The modelling of the ship traffic is done in the IALA-recommended software IWRAP, ref. /4/, /5/. Input from the HAZID workshop has been considered in the modelling process. Modelling in IWRAP is used to estimate the frequency of collisions between ships, or between ships and offshore wind turbines, as well as foundations. Modelling principles and collision models for ship traffic are described in appendix 1.

The risk assessment is carried out as a comparative analysis, where the risk is modelled in a base scenario with the current conditions, as well as in future scenarios with Energy Island Bornholm in operation. Here, some sailing routes and traffic intensities will be changed, just as the location of offshore wind turbines in the area could pose a risk to ship traffic. When modelling risk, account is taken of existing, nearby offshore wind farms. For the future conditions, the risk is modelled for two different indicative installation patterns for wind turbines, see section 3.2.

The consequences of a collision are not estimated in detail in relation to personal injury, damage to equipment and environmental damage. In contrast, the extent of the consequences of a collision is qualitatively assessed and related to the framework indicated by the Danish Maritime Authority in the document "Assessment of safety of navigation in connection with marine construction works”. The classification of the size of the consequence is done here on a scale from 0 to 4 in relation to approximate costs from limited to catastrophic damage, see Figure 2-3.

| **Incident**<br>**(What could go wrong?**<br>**”brainstorm”)** | **Consequence figure**<br>(total amount for environmental cleaning, loss of values, loss of lives/injuries per year):<br>0 in the amount of DKK 20,000 (limited)<br>1 in the amount of DKK 200,000 (minor)<br>2 in the amount of DKK 2,000,000 (considerable)<br>3 in the amount of DKK 20,000,000 (serious)<br>4 in the amount of DKK 200,000,000 and above (catastrophic) | **Probability**<br>7=10 accidents/year (often) – about once a month<br>6=1 accidents/year (relatively often) – once a year<br>5=0.1 accident/year (probable) – once every 10. year<br>4=0.01 accident/year (possible) – once every 100. year<br>3=0.001 accident/year (seldom) – once every 1000. year<br>2=0.0001 accident/year (very seldom) – once every 10,000. year<br>1=0.00001 accident/year (extremely seldom) – once every 100,000. year<br>0=0.000001 accident/year (improbably seldom) – once every 1,000,000. year | **M** | **R**<br>**(C+P)**<br><5> |
|---|---|---|---|---|
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**Figure 2-3 The Danish Maritime Authority's assessment form for assessing the safety of navigation for works at sea, ref. /13/.**

The assessment form is not primarily based on an operational phase but is used to give an indication of the level of risk.

The frequency of accidents of various kinds is determined based on analysis of ship traffic, basic estimation of collision frequencies carried out in IWRAP, and subsequent assessments.

Pleasure boats and fishermen will not necessarily follow simple routes through the area and will not necessarily be fully covered by AIS data. Separate, qualitative assessments have therefore been made for these.

The risk assessment has been carried out for a proposed planning of cable routes and possible wind turbine installations within the planning areas. The purpose of this report is to show that it is possible to establish the plan (the offshore wind turbines and submarine cables) while navigational safety is maintained at an acceptable level and as such can be used as a background for future project phases. However, the risk assessment should be revisited and updated in relation to the implementation of a specific project within the planning areas.

# 3. PROJECT DESCRIPTION

This section describes the project and the area, where Energy Island Bornholm is planned to be established. It includes technical specifications for the offshore wind turbines, installation patterns, and cable routing, as well as nearby ship traffic routes and wind and weather conditions.

## 3.1 Location of Energy Island Bornholm

The offshore wind turbines for Energy Island Bornholm are planned to be located south and southwest of Bornholm. Figure 3-1 shows the plan areas for setting up wind turbines, areas for cable routing from the wind turbines to Bornholm, as well as a trace for high-voltage direct current cables between Bornholm and Zealand. The project is planned with three planning areas for setting up offshore wind turbines located in Danish waters; respectively Bornholm I nord and Bornholm I syd located southwest of Bornholm and Bornholm II located south of Bornholm.

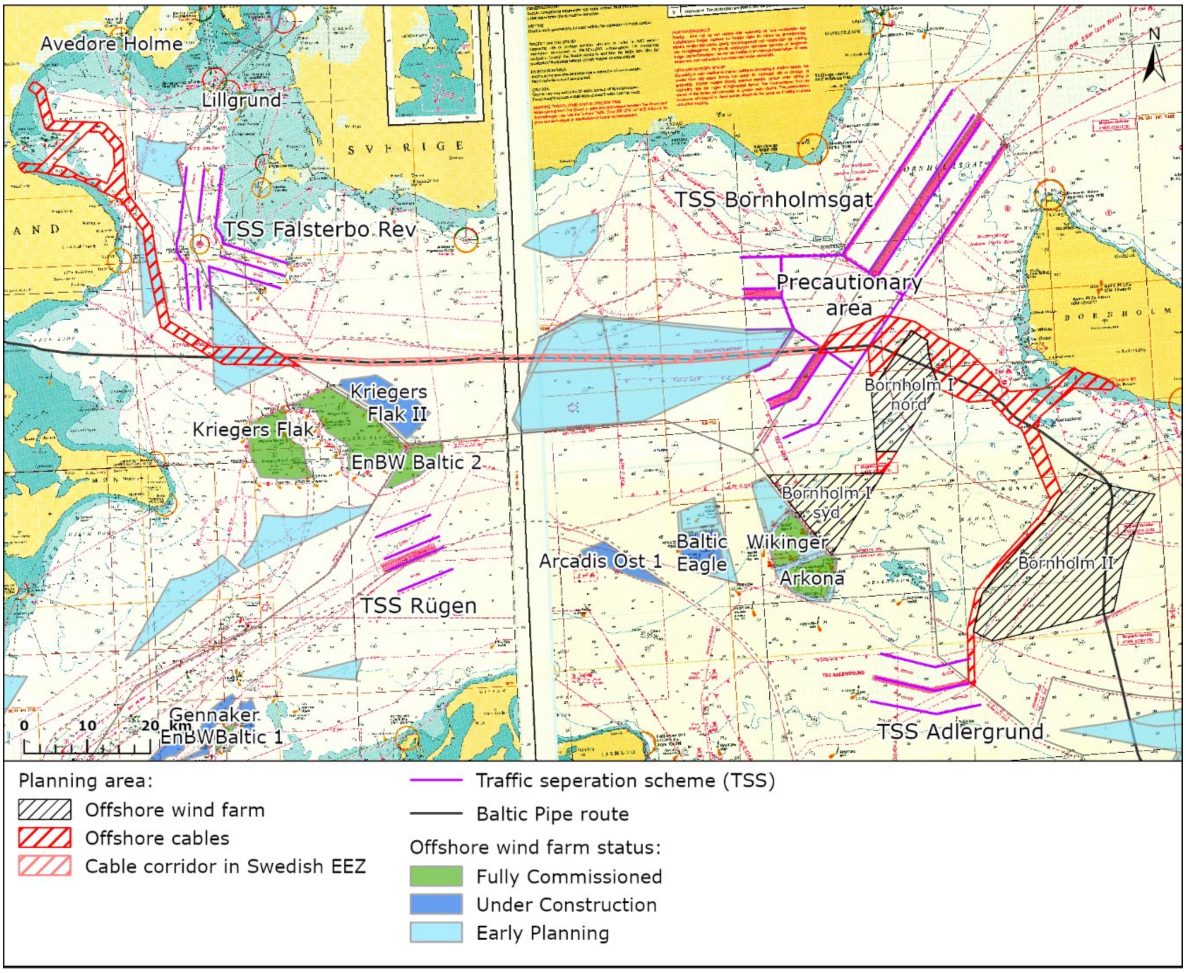



**Figure 3-1 Location of cables, survey area and the offshore wind farms for Energy Island Bornholm.**

There is intense ship traffic in the area, and part of the traffic is controlled by traffic separation systems (TSSs), where ship traffic is unidirectional and special rules apply to, for example, crossing traffic. TSS Bornholmsgat and TSS Adlergrund lie immediately north and south of the planning areas, and in particular TSS Bornholmsgat is heavily trafficked, as this area forms the main route in and out of the Baltic Sea. The intense ship traffic in the waters appears in the Danish Maritime Authority's statistics, which annually calculate the number of passengers of AIS-equipped ships that cross the border between two sections of water. Here you can see, among other things, that approximately 50,000 ships pass annually through TSS Bornholmsgat between Sweden and Bornholm and in addition approx. 17,000 south of Bornholm, ref. /2/. TSS Falsterbo Rev and TSS Rügen lead the traffic from Øresund and Fehmarn Belt further towards TSS Bornholmsgat.

The shipping traffic that sails on the routes to and from the TSSs sails along Bornholm I nord at TSS Bornholmsgat through the precautionary area. In addition, daily ferries sail to and from Rønne, e.g., from Køge and Ystad, just as some shipping traffic passes between the planning areas Bornholm I nord and syd. Ship traffic in the area is described in further detail in section 4.1, where AIS data is processed, analysed, and presented.

Within the planning areas Bornholm I nord, Bornholm I syd and Bornholm II, an internal cable network will be established. In addition, cables with high voltage alternating current will be laid in an area towards Bornholm's south coast. Furthermore, up to two cable systems with high-voltage direct current will be established between Bornholm and Zealand via a cable corridor, which runs partly through the Swedish EEZ.

The export cable between Bornholm and Zealand will cross the TSS Bornholmsgat, the precautionary area west of Bornholm, and pass southwest of TSS Falsterbo on Zealand's east coast. The cable is planned to follow the Baltic Pipe pipeline on the east-west section between Bornholm and Zealand. The export cable has two possible landing points in Køge Bay at Vallø and Karlstrup Strand, see Figure 3-1.

In the area between Bornholm and Zealand, four wind farms are already in operation. EnBW Baltic 2 is in the German EEZ between Bornholm and Zealand south of Trelleborg. In the Danish EEZ is the Kriegers Flak wind farm, which is divided into an eastern and western wind turbine area, located close to the planned corridor of the HVDC export cables. In addition, the Wikinger and Arkona wind farms are located south-west at the end of Bornholm I syd. In addition to the wind farms that are already in operation, the planned wind farms Arcadis East 1 and Baltic Eagle are under construction and located west of Bornholm I syd. Close to EnBW Baltic 2 in German waters and Kriegers Flak in Danish waters is the approved location for the Kriegers Flak II wind farm in Swedish waters. In addition, several wind farms are planned in the Swedish EEZ. The specific locations of these wind farms are shown in Figure 3-1. Realization of any of these potential offshore wind farms could lead to closer ship traffic on the routes; see section 4.1 for an analysis of ship traffic in the area. The shipping traffic from Trelleborg and Ystad on the way to the south will or could have to pass through future offshore wind farms. Similar conditions for ship traffic can be expected when passing between Bornholm I nord and Bornholm I syd.

A pilot boarding station is located north of Bornholm, see Figure 3-2. Ships that need to have a pilot use the area between TSS Bornholmsgat and Bornholm to sail between the precautionary area and the pilot boarding station. Ships will therefore travel in and out of TSS Bornholmsgat north of Bornholm I nord to receive pilot, which increases the traffic density outside the TSS between TSS Bornholmsgat and Bornholm.

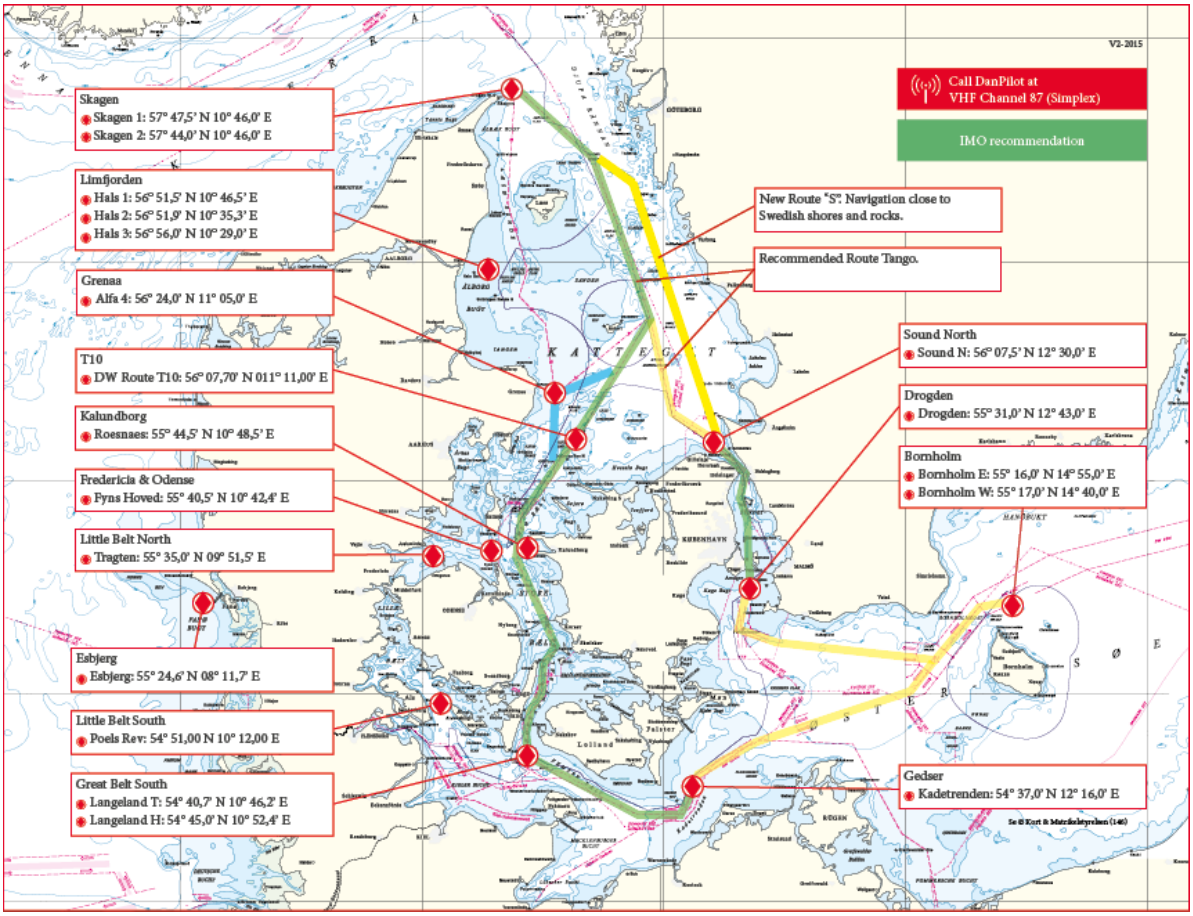



**Figure 3-2 DanPilot stations in Danish waters, source: https://danpilot.dk/pilotage/transit-pilotage/.**

The area around Energy Island Bornholm is also limited by a military training area, which is the reason why Bornholm I nord is reduced in size on the western side. The impact of possible military exercises in the area is not included in the present report, which focuses on the safety of navigation.

## 3.2 Wind turbines and installation patterns

The size and number of wind turbines have not been determined and the final details are left to a future project. A range of wind turbine sizes from 15 MW to 27 MW have been chosen for use in the SEA. An installed power of up to 3.8 GW is assessed, of which 0.6 GW is installed as "overplanting". The purpose of overplanting may, for example, be to be able to deliver the maximum capacity even if some wind turbines are out of operation or to deliver the maximum permitted power in hours of weaker wind or to Power-to-X (PtX) through direct lines. When replanting, more wind turbines are established. Similar to the scenarios for assessing the visual impact of Energiø Bornholm, see ref. /18/, two scenarios are used here with an installed effect of 3.2 GW and 3.8 GW.

Different terms are described in Figure 3-3 and specifications for the smallest and largest wind turbines on 15 MW and 27 MW can be seen in Table 3-1. The number of wind turbines depends on the total capacity and therefore varies for scenarios with and without replanting.

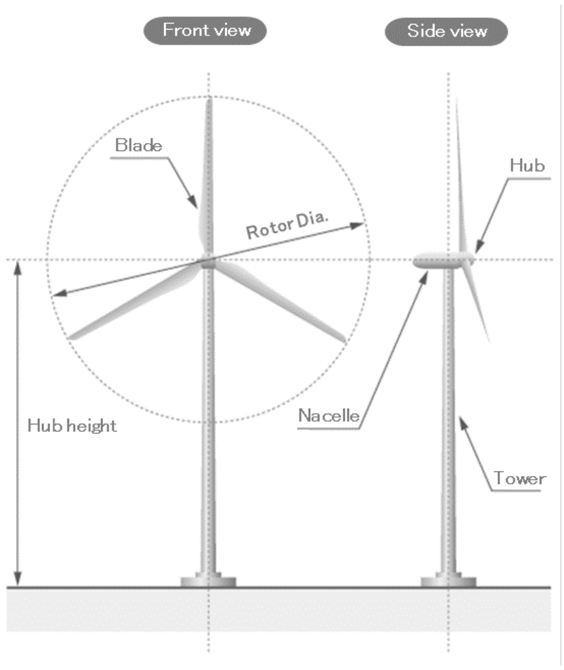



**Figure 3-3 Illustration of the technical terms used for wind turbines.**

The number of wind turbines has an influence on the impact on ship traffic. If several wind turbines are built, each of these could cause disturbances. More wind turbines in an area decreases the distance between them, possibly blocking visibility and leading to an increased risk of ship collisions. In the risk analysis, the largest number of wind turbines is conservatively assumed and the scenarios with 15 MW wind turbines are with and without overplanting.

**Table 3-1 Technical specifications for the various wind turbines that are planned to be installed at Energy Island Bornholm.**

| Offshore wind turbine | 15 MW turbines | 27 MW turbines |
|---|---|---|
| Number of wind turbines | 214 – 3.2 GW<br>254 – 3.8 GW (overplanting) | 119 – 3.2 GW<br>141 – 3.8 GW (overplanting) |
| Hub height | 146.5 m | 180 m |
| Rotor diameter | 233 m | 300 m |
| Maximum wingtip height | 263 m | 330 m |
| Distance from mean sea level to lower wing tip | 30 m | 30 m |

Possible installation patterns for 15 MW offshore wind turbines are shown in Figure 3-4 for a total capacity of 3.2 GW and 3.8 GW. The number of wind turbines is lower if larger wind turbines are installed.

The nearest wind turbine will be approximately 15 km from Bornholm's coast. The shortest distance to the Swedish coast is about 30 km from Bornholm I nord, and the shortest distance to the German coast is approximately 40 km from Bornholm I syd. For Bornholm II, the shortest distances are approximately 65 km to the German and Polish coasts.

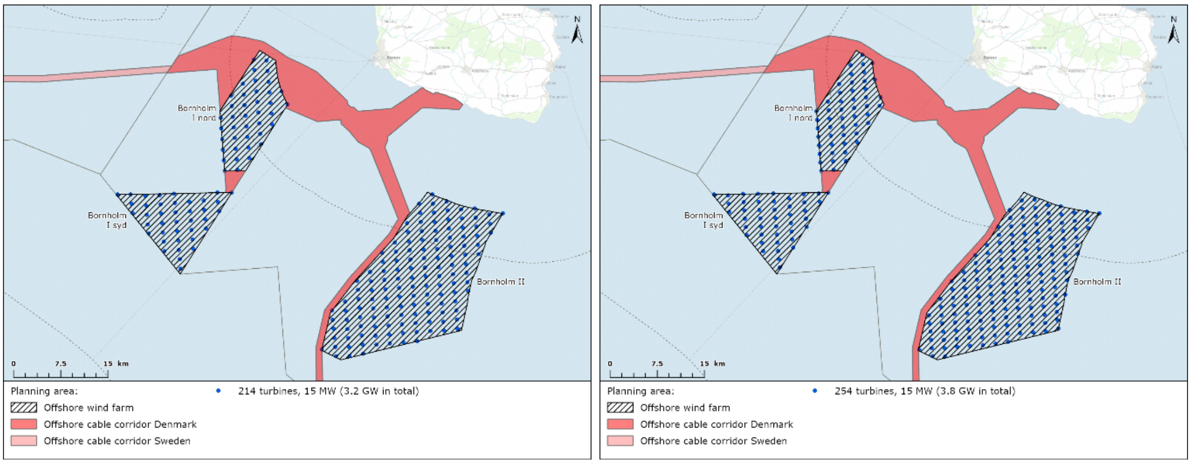



**Figure 3-4 Indicative installation patterns for offshore wind turbines; respectively 3.2 GW (left) and 3.8 GW (right) using 15 MW offshore wind turbines.**

In addition to the offshore wind turbines, up to seven transformer stations will also be erected within the planning areas. A transformer station will be wider but lower than a wind turbine. The location of the transformer stations has not been specified in connection with the analyses, but they will probably be located inside the areas between the wind turbines to optimize the overall cable routing. However, the transformer stations can also be located along the edge of the planning areas.

### 3.3 Navigation corridors

Overall, a marine plan has been drawn up in Denmark, which describes the use of the sea territory. The areas covering the planning areas Bornholm I nord, Bornholm I syd, and Bornholm II have been defined as development zones for renewable energy and energy islands. Relevant for the analysis of navigation safety is also that zones have been defined for navigation corridors, as shown in Figure 3-5.

Two primary navigation corridors are defined for the main traffic, one through Bornholmsgat northwest of the planning areas, and one south of Bornholm II. In addition, a navigation corridor is described between the precautionary area and Rønne harbour north of Bornholm I nord, as well as a corridor between the planning areas Bornholm I nord and Bornholm I syd.

As described earlier, the area for the development of renewable energy has been reduced because of a military training area, leading to an area reduction on the western side of Bornholm I nord. On the other hand, it has been extended slightly to the south by the shipping corridor. The sailing corridor is therefore planned to be narrowed in the area between Bornholm I nord and Bornholm I syd. This is further described in section 5.1.

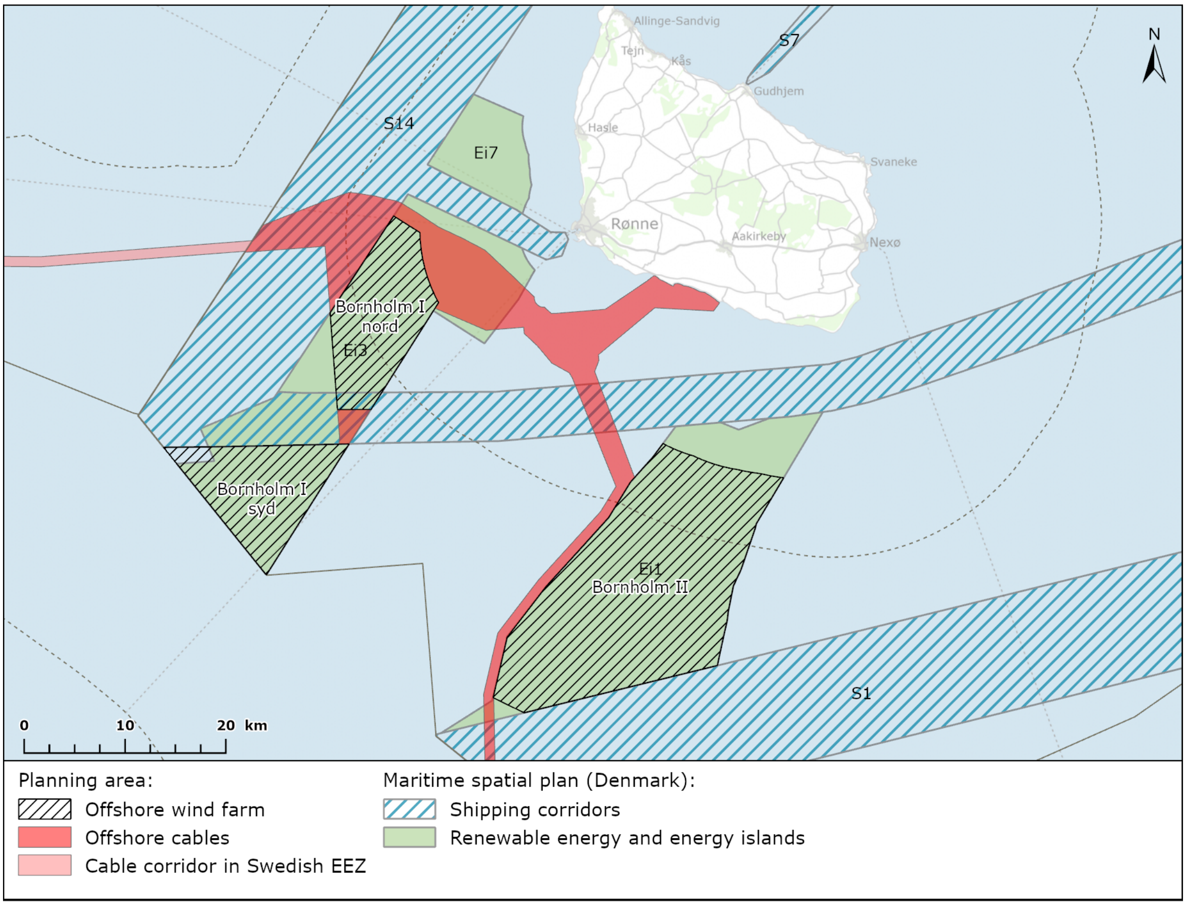



**Figure 3-5 Navigation corridors at Bornholm according to Denmark's Maritime Spatial Plan.**

## 3.4 Weather conditions and bathymetry

Southwest of Bornholm, in the middle of the areas for the offshore wind farms that make up Energy Island Bornholm, the water depth is more limited than in the surrounding waters. The water depth between the offshore wind farms varies between 10 m and 20 m at mean sea level (MSL). The area between the offshore wind farms is also known as "Rønne Banke", with more shallow waters. At the offshore wind farm areas, the water depth is approx. 25-45 m MSL. Similar water depths are found west and east of the areas. A detailed map of the water depth around Rønne Banke is shown in Figure 3-6, of which contour lines for the water depth are indicated every 5m and coloured accordingly.

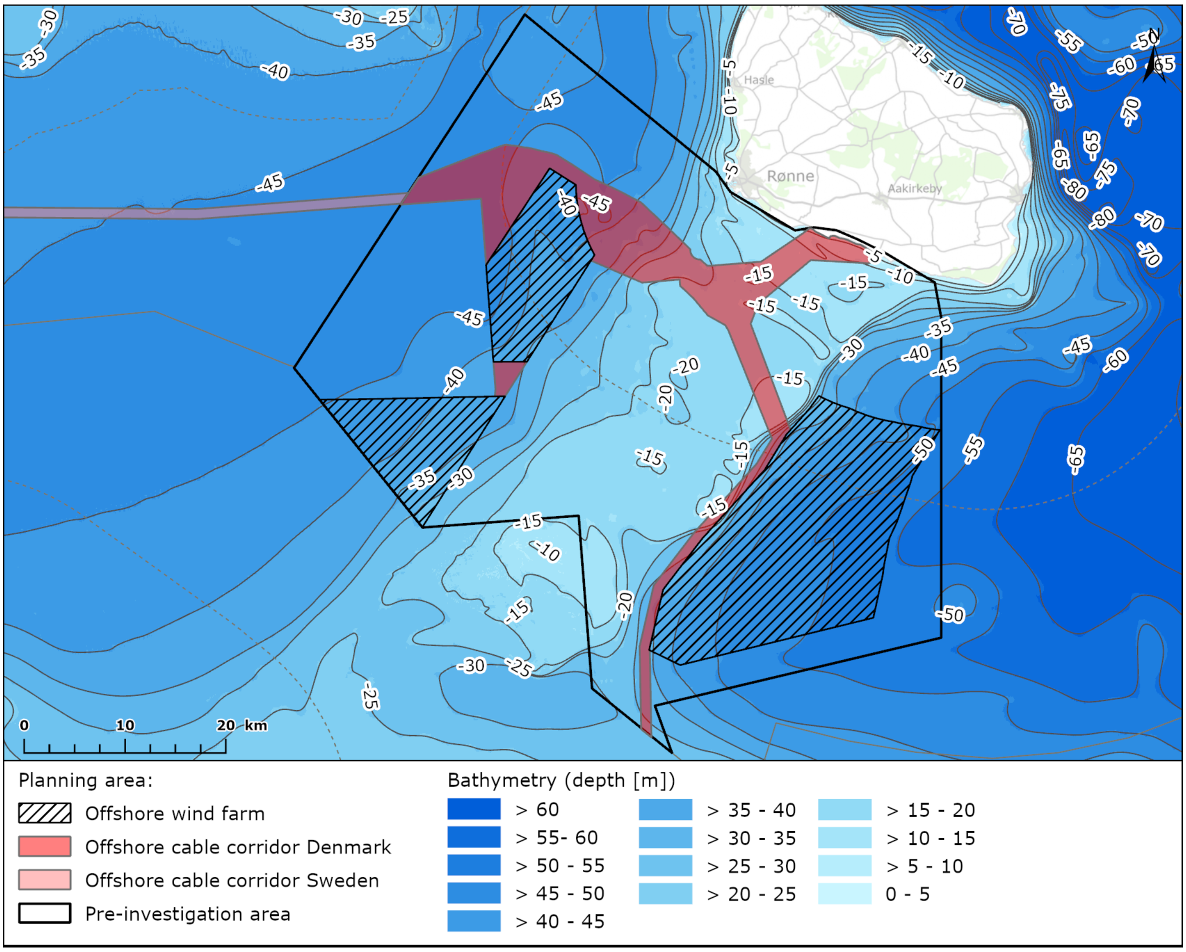
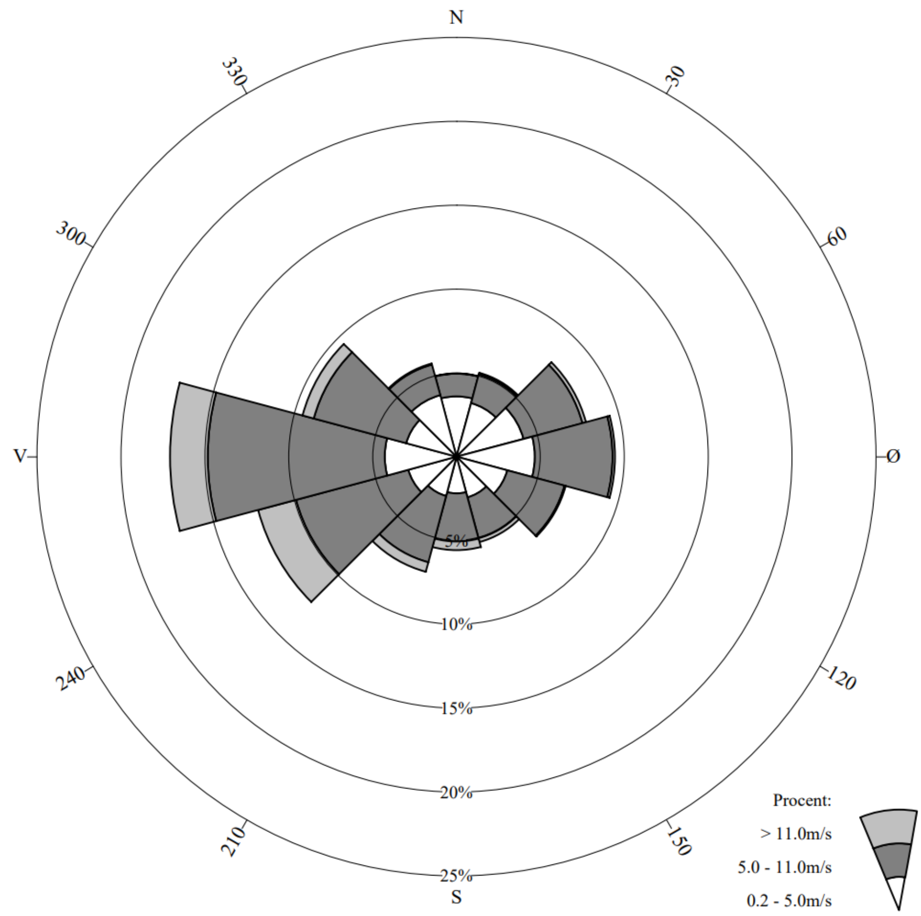



**Figure 3-6 Overview of the water depth at Rønne Banke southwest of Bornholm with contour lines every 5m.**

The planning areas are in open water, which means that the wind is relatively stable in direction and strength.

Figure 3-7 shows a wind rose that, with wedges towards the centre of a compass circle, shows the wind conditions at Bornholm's airport over a 30-year period from 1961-1990. The wind rose indicates the direction and frequency of the wind based on the wind measurements at the given location. In Figure 3-7 is shown graphically the distribution of which wind direction has the most measurements for weak, medium, and strong wind strength, and in Figure 3-7 is also shown the percentage distributions of the wind measurements for the different wind strengths.




| | N | 30 | 60 | Ø | 120 | 150 | S | 210 | 240 | V | 300 | 330 | Ialt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | 5.0 | 5.2 | 8.0 | 9.4 | 6.7 | 5.3 | 5.6 | 7.1 | 12.3 | 17.1 | 9.5 | 5.8 | 96.9 |
| % 0.2-5.0m/s | 3.6 | 3.3 | 4.1 | 4.7 | 3.1 | 2.5 | 2.2 | 2.4 | 3.0 | 4.3 | 3.1 | 3.8 | 40.2 |
| % 5.0-11.0m/s | 1.4 | 1.8 | 3.6 | 4.6 | 3.5 | 2.5 | 2.9 | 4.1 | 6.9 | 10.6 | 5.7 | 1.9 | 49.5 |
| % > 11.0m/s | 0.0 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.5 | 0.6 | 2.3 | 2.2 | 0.7 | 0.1 | 7.2 |
| Middel hastighed | 3.9 | 4.5 | 5.2 | 5.3 | 5.3 | 5.6 | 6.3 | 6.6 | 7.8 | 7.3 | 6.5 | 4.4 | 6.1 |
| Største hastighed | 11.3 | 15.0 | 18.0 | 15.9 | 13.9 | 16.5 | 17.5 | 19.5 | 21.6 | 26.8 | 22.2 | 16.5 | 26.8 |

Totalt antal observationer = 29013 Kilde: DMI
Vindstille defineret som hastighed <= 0.2m/s
Antal observationer med vindstille/varierende vind: 895 = 3.1%

**Figure 3-7 Wind rose for the period 1961-1990 measured at Bornholm Airport, ref. /7/.**

Overall, the wind measurements show that there is primarily wind from the west and south-west. Strong winds also occur most frequently from the west. Winds from the north and south are rare, while easterly winds are more frequent.

Strong winds from western directions will contribute to waves building up over a long distance from the coast of Zealand towards Energy Island Bornholm. In case of strong winds from the northeast and east, Bornholm will to some extent protect the offshore wind farms and shipping traffic in this area against larger waves.

# 4. BASELINE

In this section, the current sailing safety situation in the area around Energy Island Bornholm is presented as a basis for a comparative assessment. Frequencies of collisions between ships and between ships and current wind turbines in the area are estimated together with the frequency of grounding.

## 4.1 Ship traffic in the area

Ship traffic in the area has been analysed based on historical ship registrations for the area. The traffic intensity is shown in Figure 4-1 and is based on AIS data covering the time from 1 January to 31 December 2019. The requirement to use an AIS transponder applies to all ships over 300 gross tons, all passenger ships, and all fishing vessels over 15 meters in length (EU rules), as mentioned in ref. /2/. Some considerations about the future shipping traffic are given in section 4.1.3.

For military vessels there is no requirement to use AIS. The same is the case for smaller vessels, including mainly yachts. As not all ships indicate their ship type in their AIS data, these will be presented as "other ships". These are often military vessels, yachts or other smaller ships that have not filled in their ship information. In addition, it is expected that there will be military ships that do not use AIS in connection with exercises in the area.

The intensity map for ship traffic in Figure 4-1 shows the area around Energy Island Bornholm and includes all types of ships, for example commercial ships, military vessels, passenger ships, and pleasure boats, as recorded in AIS data. A black colour indicates a high intensity, a red or orange colour indicates a medium intensity, whereas a yellow colour is a low intensity of ship traffic.

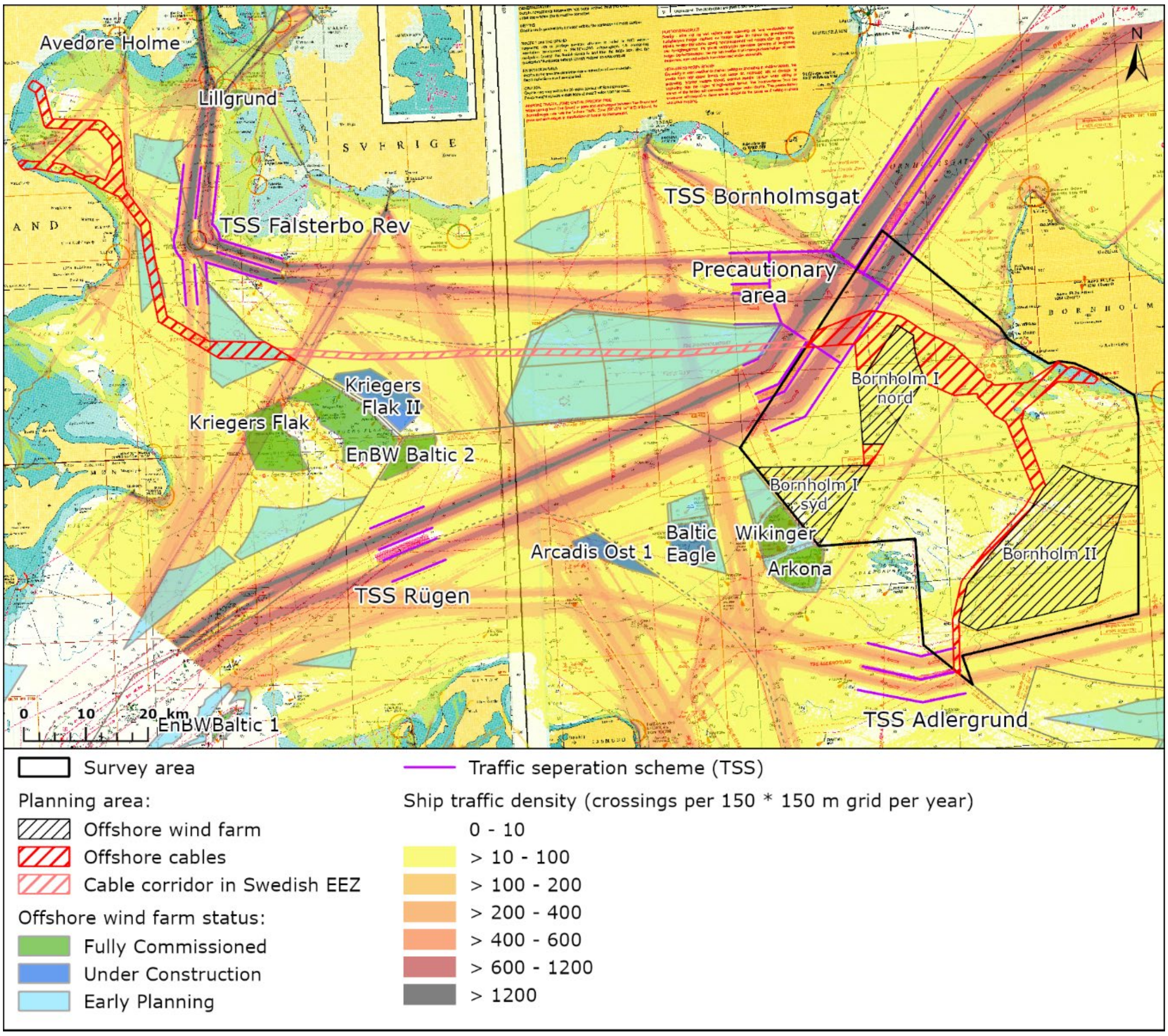



**Figure 4-1 The intensity of ship traffic in the Baltic Sea south of Sweden for the whole year 2019. The intensity map highlights patterns in ship traffic and where ship traffic is most common together with the area of Energy Island Bornholm, relevant cities, and navigation channels.**

Figure 4-1 generally shows that ship traffic follows the TSSs. In addition, there are other routes with moderate intensity that cross the Baltic Sea in north and south directions.

The routes with ship traffic in and around the planning areas for Energy Island Bornholm are numbered and coloured in Figure 4-2 for easier reference. A total of 19 routes have been identified. The identified routes are presented with arrows for each route, where the colour describes the characteristics of the route. A green route passes outside the planning areas for Energy Island Bornholm, whereas the red routes cross the planning areas, and the blue routes run from and to Rønne harbour on Bornholm.

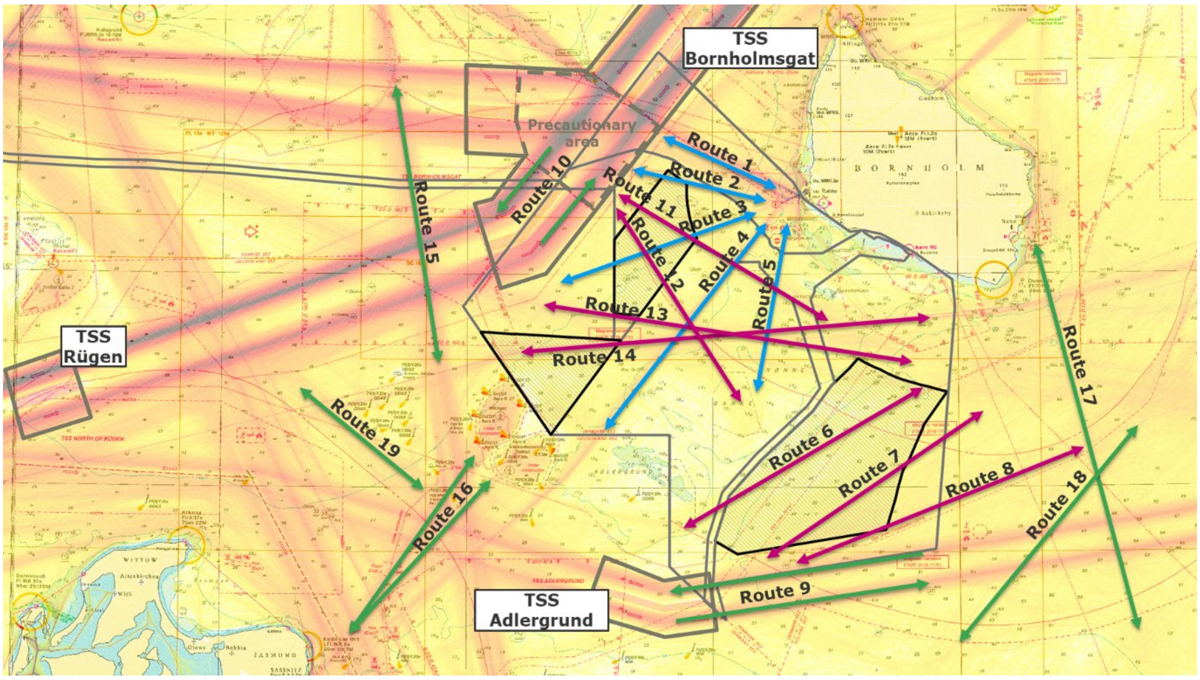



**Figure 4-2 The intensity of ship traffic and the identification and numbering of routes at Energy Island Bornholm's offshore wind farms for the entire year 2019.**

The ship traffic routes in Figure 4-2 are further detailed and described in Table 4-1, and the annual number of ships registered on each of the routes in each direction and in total is shown in Table 4-2. A detailed overview of the ship traffic in terms of ship lengths and ship types can be seen in appendix 2.

**Table 4-1 Description of ship traffic routes at Energy Island Bornholm.**

| Route | Description | |
|---|---|---|
| 1 | Mainly the fast ferry between Rønne and Ystad, but also ships that sail out of Rønne and into the precautionary area and further west to TSS Falsterbo | Routes to / from Rønne |
| 2 | Traffic from TSS Falsterbo, TSS Rügen, and the precautionary area towards Rønne harbour | |
| 3 | The traffic between TSS Rügen and Rønne sailing south of the precautionary area | |
| 4 | Mainly passenger ferries sailing between Rønne and Sassnitz along Bornholm I and the nearby German wind farm, Arkona | |
| 5 | Ship traffic between a natural resource extraction area and Rønne | |
| 6 | Shipping traffic before and after TSS Adlergrund, depending on the sailing direction, merges/splits with route 9 | Routes through Bornholm II |
| 7 | | |
| 8 | | |
| 9 | Ship traffic passing through TSS Adlergrund | TSSer |
| 10 | Ship traffic passing through TSS Bornholmsgat and the precautionary area | |
| 11 | Ship traffic passing south of Bornholm between the precautionary area and southeast of Bornholm | Routes through |
| 12 | Ship traffic between a recovery area and the precautionary area | |

| Route | Description | |
|---|---|---|
| 13 | Ship traffic between TSS Falsterbo with course directly south of Bornholm and south of TSS Bornholmsgat | |
| 14 | Traffic sailing between TSS Rügen and southeast of Bornholm | |
| 15 | Passenger ferries between Ystad and Sassnitz/Swinoujscie | Routes around Energy Island Bornholm |
| 16 | Work and maintenance traffic to and from the German wind farms, Wikinger and Arkona located in southwest Bornholm I syd | |
| 17 | Sailing between Nexø and Poland (Kotobrzeg) in north/south directions | |
| 18 | Passing ship traffic with direction between the Baltic Sea southeast of Bornholm and to and from Swinoujscie | |
| 19 | Ship traffic between TSS Falsterbo heading directly towards TSS Adlergrund south of the German wind farms in operation southwest of Bornholm I syd | |

**Table 4-2 Counts of ship traffic on the identified routes based on AIS data covering 2019.**

| | North/West | South/East | Total |
|---|---|---|---|
| Route 1 | 1,495 | 1,487 | 2,982 |
| Route 2 | 166 | 571 | 737 |
| Route 3 | 138 | 203 | 341 |
| Route 4 | 362 | 360 | 722 |
| Route 5 | 116 | 131 | 247 |
| Route 6 | 101 | 92 | 193 |
| Route 7 | 355 | 214 | 569 |
| Route 8 | 351 | 286 | 637 |
| Route 9 | 3,242 | 3,079 | 6,321 |
| Route 10 | 11,308 | 13,639 | 24,947 |
| Route 11 | 226 | 198 | 424 |
| Route 12 | 129 | 123 | 252 |
| Route 13 | 412 | 519 | 931 |
| Route 14 | 591 | 534 | 1,125 |
| Route 15 | 1,747 | 1,786 | 3,533 |
| Route 16 | 1,235 | 1,199 | 2,434 |
| Route 17 | 208 | 241 | 449 |
| Route 18 | 232 | 178 | 410 |
| Route 19 | 323 | 538 | 861 |

It can be seen from the intensity map, but also from Table 4-2, that route 9 and route 10 are the busiest, after which the ferry traffic from Ystad on route 1 and route 15 is also heavily trafficked. Route 16 also has medium intensity with its ship traffic to and from the German wind farms. In addition, more than 1,000 annual movements have been registered on route 14, which passes south of Bornholm within the planning area for Bornholm I syd. Part of this traffic is made up of DFDS ferries between Kiel and Klaipeda. The remaining routes have lower intensities.

In the IWRAP tool, a distinction is made by default between eight different ship types as listed in Table 4-3. For each ship type, the ships are divided into several length categories in 25 m intervals, 0-25, 25-50, etc., ending with 400 and above. Given AIS data, IWRAP divides ship traffic based on ship type and length, which is subsequently processed to be able to visualize this graphically. The analyses in this report are based on vessel types and lengths as provided in the AIS data set and processed in the IWRAP.

**Table 4-3 Classification of ship types in IWRAP, ref. /4/.**

| Ship types in IWRAP (standard) | | | |
|---|---|---|---|
| Oil products tanker | Passenger ship | Support ship | Pleasure boat |
| General cargo ship | Fast ferry | Fishing ship | Other ship |

In Figure 4-3 and Figure 4-4, the ship traffic counts for each of the routes are presented to show the distribution of the ships' lengths and types.

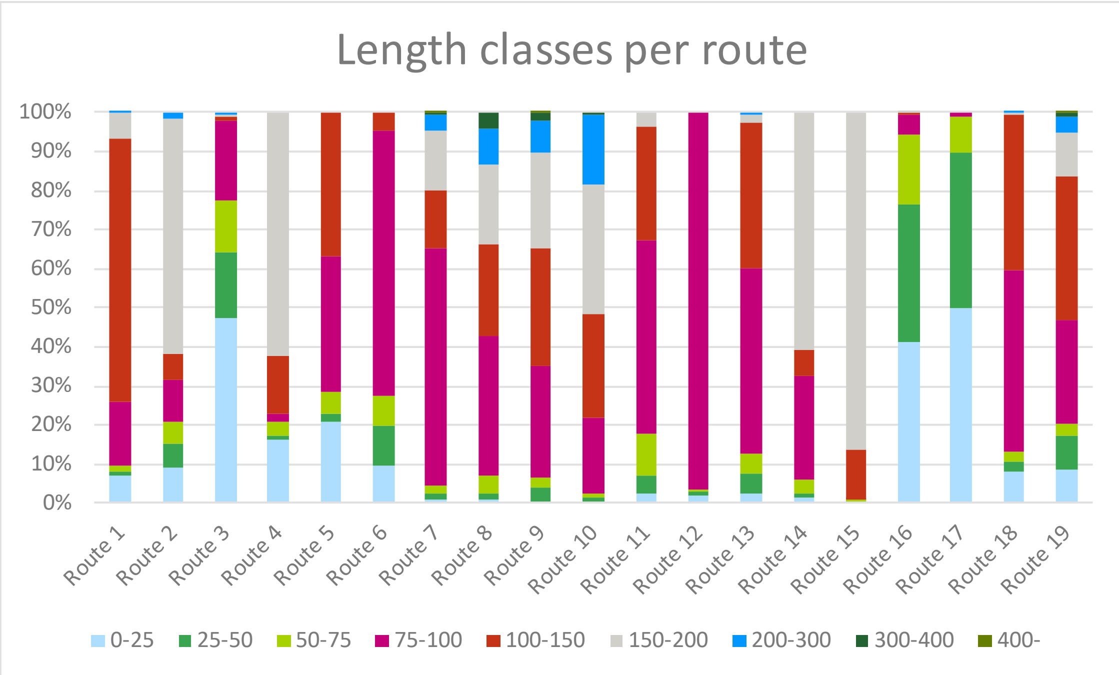



**Figure 4-3 Distribution of ship traffic on the identified routes in relation to ship lengths.**

Since sailing in open waters is most often represented by larger commercial ship traffic, smaller ships and yachtsmen are only expected to a limited extent in these areas. On coastal routes or between ports, however, it is expected that the routes will include smaller boats.

Figure 4-3 shows that most routes are only sailed to a very limited extent by smaller ships. Exceptions are particularly route 3, which runs through the planning area Bornholm I nord, and routes 16 and 17, which run outside the planning areas. The largest ships with lengths greater than 300 m sail on or near the main ship traffic routes at the TSSs on routes 7-10 and 19. Although these routes have the longest ships, they are also represented by shorter ships down to 75 meters, but only very few smaller ships.

On the routes from Rønne or south of Bornholm, routes 2, 4, 14, and 15, more than half of the ships have a length of over 150 meters, which is due to the ferry traffic that sails on these routes (see Figure 4-4). Ferry traffic is also represented on route 1, but here the fast ferry between Rønne and Ystad is shorter than the ferries on the other ferry routes.

Figure 4-4 shows that the ships on route 5 and route 12 largely only consist of support ships that sail to and from the natural resource extraction area south of Rønne harbour.

It is noted that routes 16 and 17 mainly count ships of less than 100 meters in length. Figure 4-4 shows that route 16 consists of other ships and fast ferries, which is work and maintenance traffic to and from the German wind farms. Route 17 between Nexø and Poland is a contrast to many of the other routes, as this has a large proportion of fishing vessels and yachts and a smaller proportion of passenger ships.

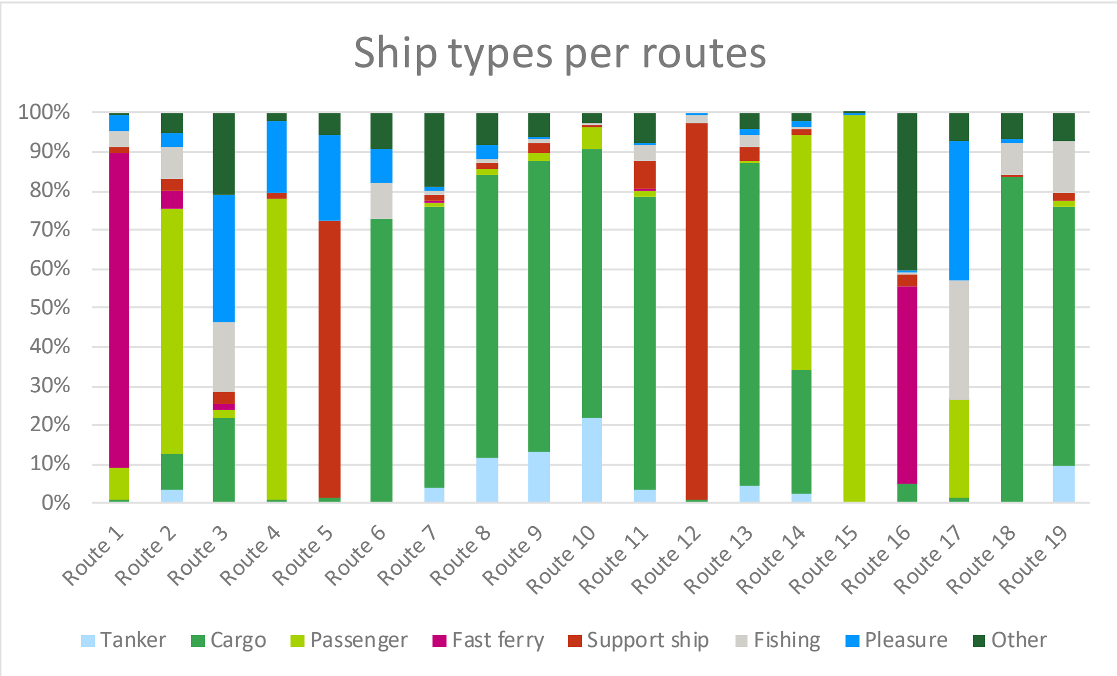



**Figure 4-4 Distribution of ship traffic on the identified routes in relation to the ship types.**

### 4.1.1 Fisheries

According to EU legislation, all fishing vessels over 15 m must use AIS and are thus included in the general ship traffic analysis. However, fishermen do not necessarily use the regular sailing routes, and especially in connection with fishing activities, the fishermen's movements will take place outside the routes and in different patterns depending on fishing activities. Smaller fishing vessels will not necessarily use AIS, and these will therefore not be fully represented in the data set used.

The Vessel Monitoring System (VMS) is a system for the automatic detection of fishing vessels. A specific analysis of the fisheries has been carried out in a separate technical report and includes analysis of VMS data for the period 2010 to 2020 for the commercial fisheries in Denmark, Sweden, Poland, and Germany. In connection with the analysis of the fisheries, interviews were also conducted with local Danish fishermen on Bornholm. The analysis of fishing is divided by type of fishing, e.g., illustrated by the intensity of activities with bottom trawling for Danish fishermen Figure 4-5.

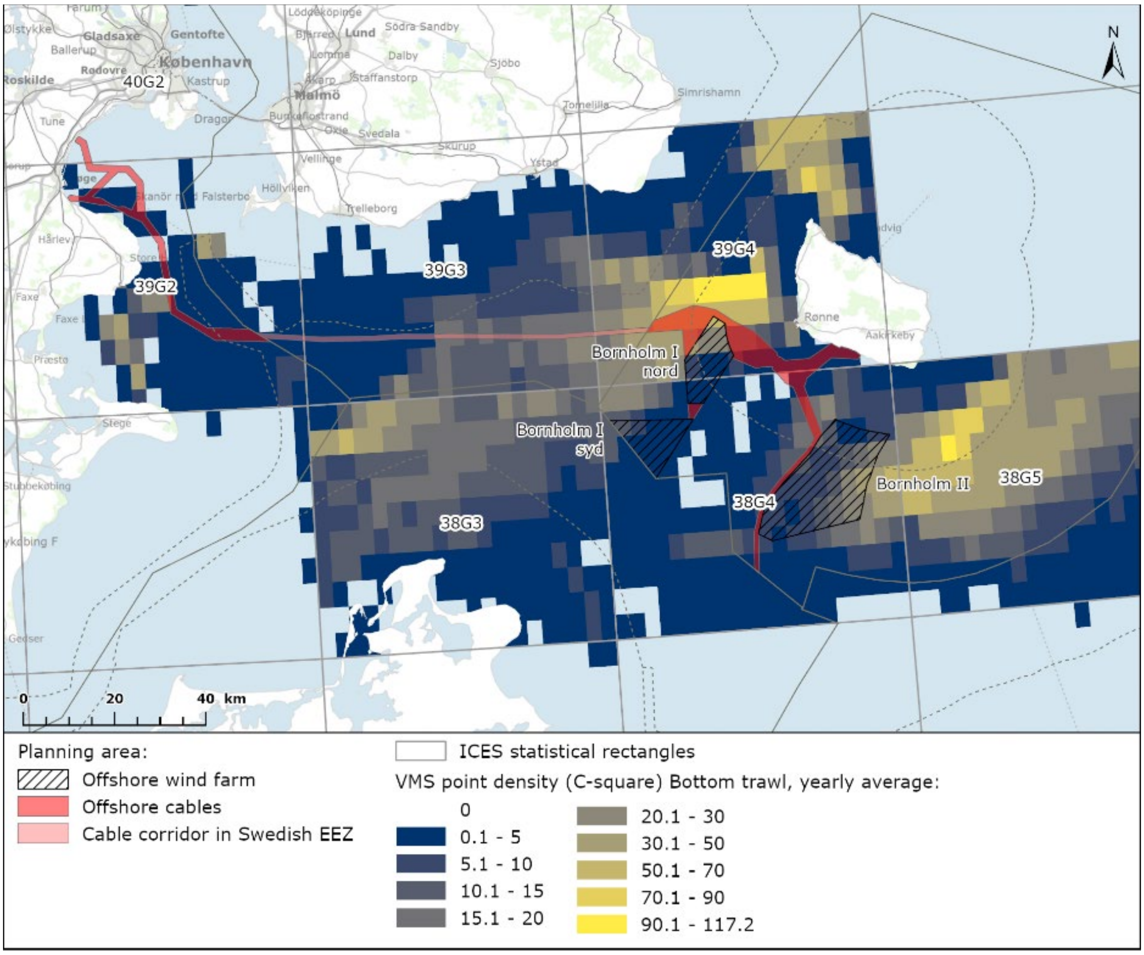



**Figure 4-5 Illustration of detailed fishing analysis for Danish fishermen's use of bottom trawls in the area of Energy Island Bornholm.**

Fishing activities can move around from year to year depending on fish stocks and the location of good fishing spots and detailed impacts on fishing are not included in the analysis of navigational safety conditions. General images of fishing vessel movements are presented in Figure 4-6 and Figure 4-7, based on AIS data. It is noted that the AIS data used do not cover areas far outside the Danish EEZ, which is why the density of fishermen seems low or non-existent near Germany. In Figure 4-7, the density map is limited to only include fishing vessels sailing at a speed between 2 and 4 knots. The speed at which different fishing methods are used can vary and the figure is used only to illustrate the difference between clear transport routes, as seen in Figure 4-6, and areas with more distinct fishing, which is generally done at lower speeds.

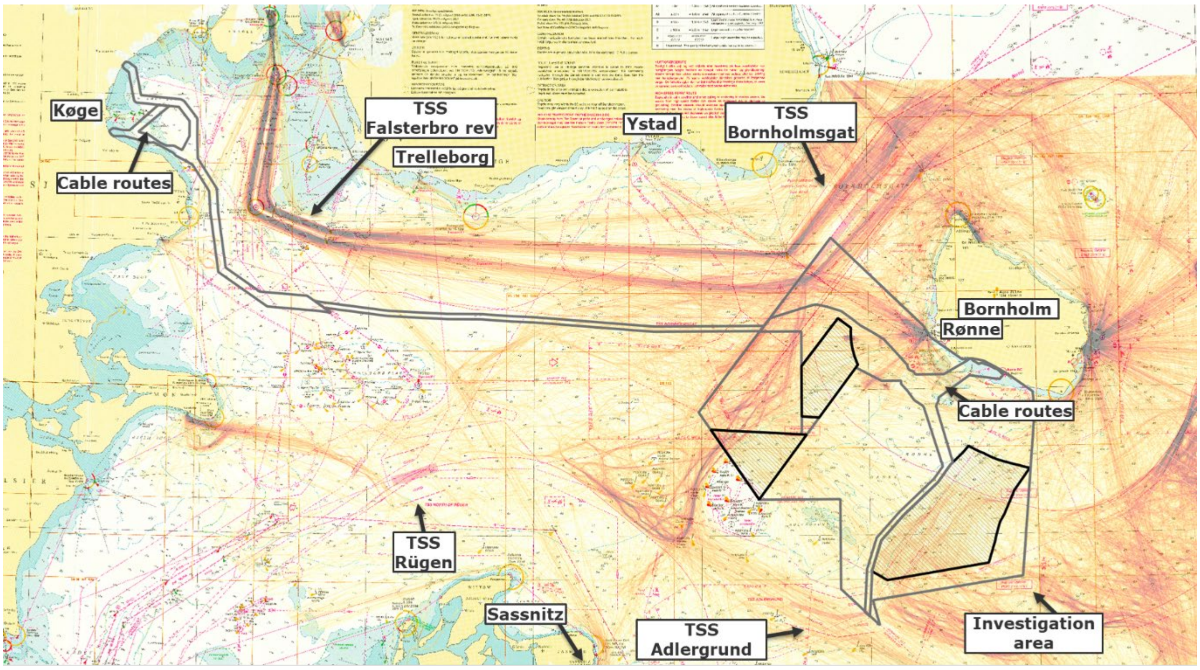



**Figure 4-6 The density of fishing vessel movements in the Baltic Sea south of Sweden for the whole year 2019.**

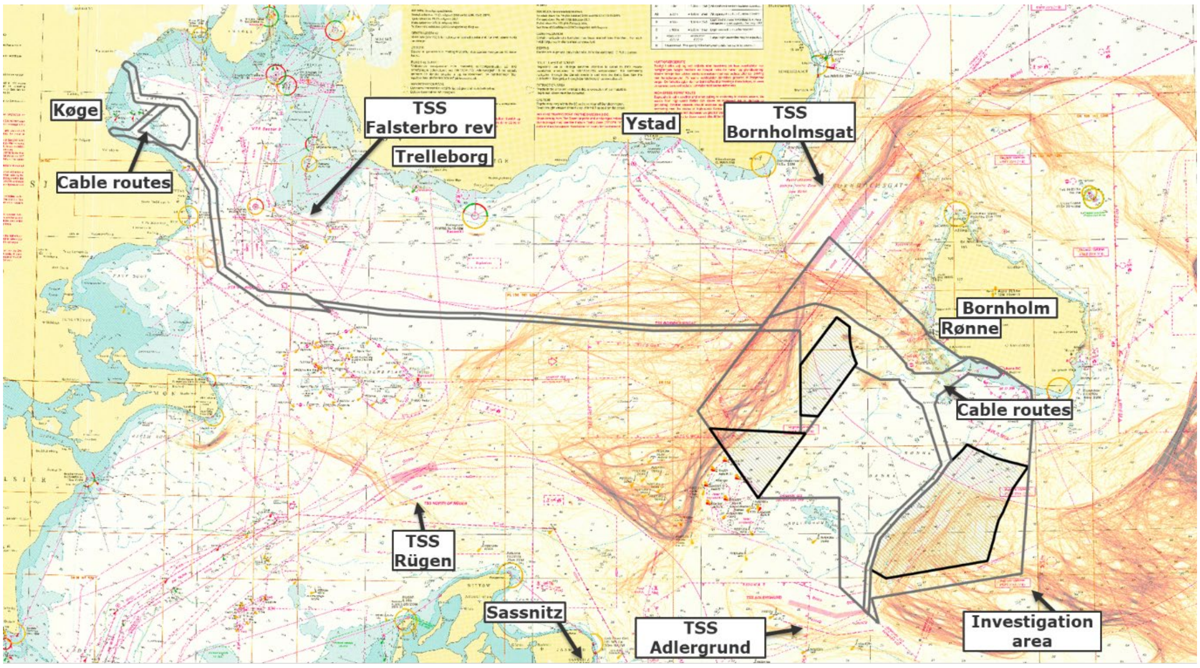



**Figure 4-7 The density of fishing vessels sailing with 2-4 knots in the Baltic Sea south of Sweden for the whole year 2019.**

It is seen that fishing vessels largely use the route between TSS Falsterbo Rev and TSS Bornholmsgat, but that movements northwest of Bornholm I and within the area covered by Bornholm II are largely made up of fishing activities at lower speeds.

### 4.1.2 Pleasure sailing

For pleasure boats there is no requirement to use AIS equipment, and especially smaller pleasure boats will therefore only be represented in AIS data to a limited extent based on experience. There are no exact figures of the proportion of pleasure boats equipped with AIS, but depending on the area, it could be as little as 1%. In a study carried out by Rambøll in the Port of Copenhagen in connection with the environmental impact assessment for Lynetteholmen, it was found that approximately 10% of the pleasure boats were equipped with AIS, see ref. /14/. A density map of the pleasure boats included in AIS data is shown in Figure 4-8.

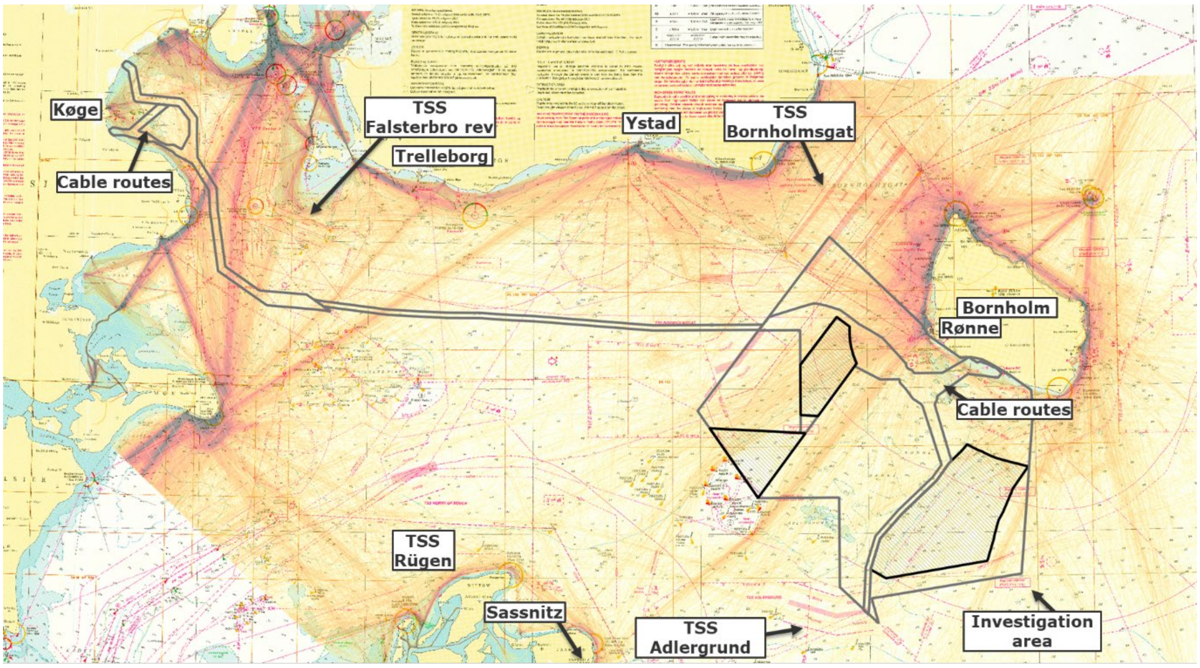



**Figure 4-8 The intensity of yachting traffic in the Baltic Sea south of Sweden based on AIS data for the whole year 2019.**

It can be seen in Figure 4-8 that there is intense yachting traffic along Bornholm's coasts, just as intense traffic is seen along Sweden's south coast, and Zealand. Further from the coasts, the yachtsmen move to a greater extent between ports in straight lines when crossing over greater distances. However, there is some yachting traffic in the area west of Bornholm, as well as south of Bornholm and out into the area near the Bornholm I wind turbine area. It is assumed that yachtsmen that move further from the coasts are to a greater extent larger boats.

### 4.1.3 Ship traffic of the future

The above ship traffic analysis is based on AIS data from 2019. However, there may be changes in the traffic patterns that may be relevant to include in the risk assessment, which is examined in this section.

The historical development of shipping traffic in the Baltic Sea is indicated by HELCOM in ref. /11/, Figure 3 which is inserted below in Figure 4-9. A significant effect of the economic crisis is seen to have reduced the number of ships passing north of Bornholm in the years after 2007. Since then, the number of ship passages has been relatively stable in this area with only a small increase for cargo ships from a low point in 2010. In addition, cargo ships, tankers, and other ships show a small decrease in the number of ship passengers from 2017 to 2018. In the future, there may be an increase in the number of ship traffic, but the development of ship traffic has over the past many years had a different tendency towards larger ships, which can counteract the increase in ship traffic.

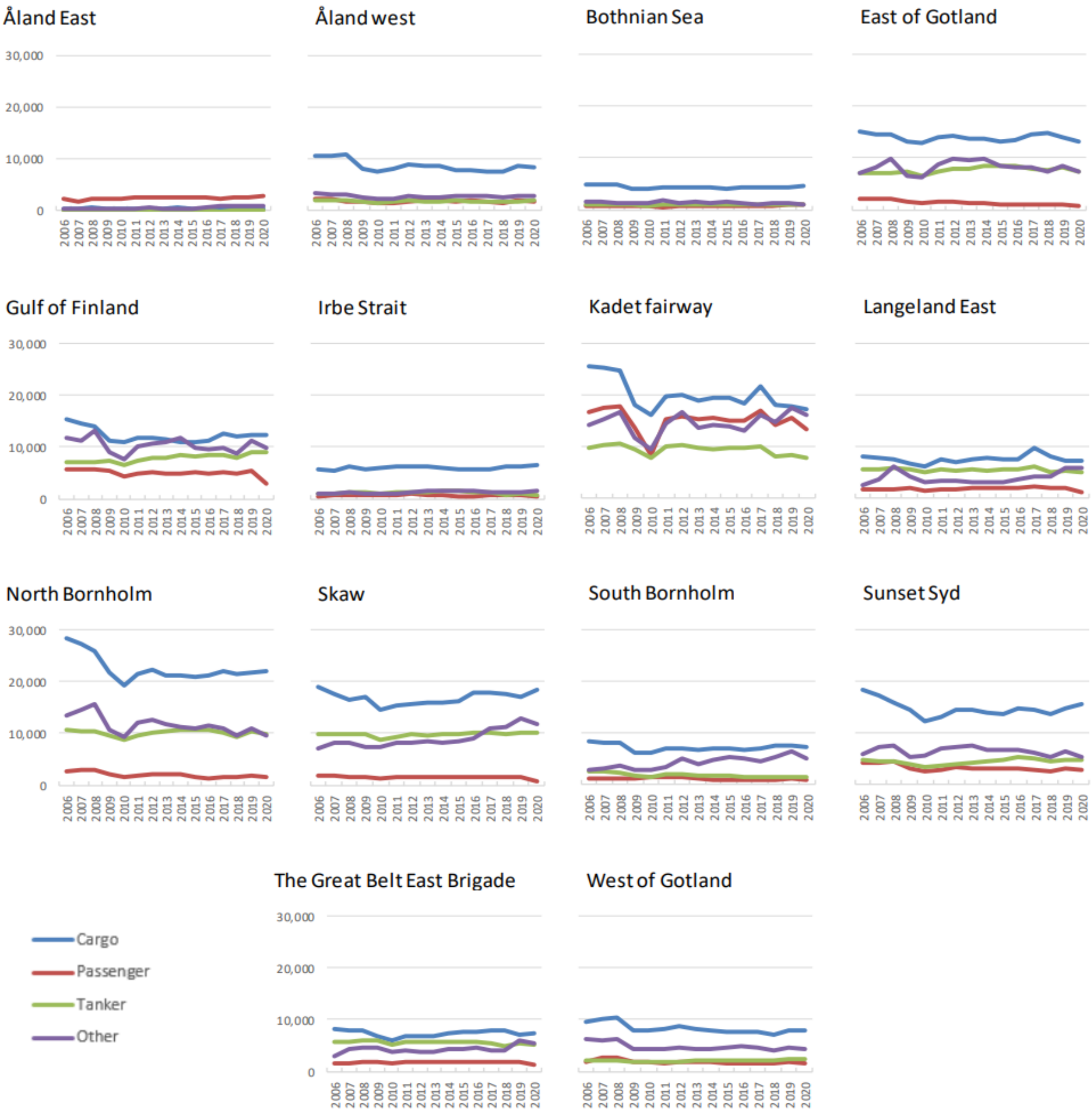



**Figure 4-9 Historical development of shipping traffic in the Baltic region. Adopted from HELCOM, ref. /11/, figure 3.**

In general, passenger traffic across the Baltic Sea, as shown in Figure 4-9, is seen to be stable and in some areas – including the area north of Bornholm – to show a slight decline. However, there may be local changes to ferry routes and sailing schedules for ferry routes. For instance, in the autumn of 2020, the ferry company FRS started a ferry service between Ystad and Sassnitz, ref. /10/. This traffic is therefore not included in the traffic analysis shown above. Instead, the traffic intensity including all passenger ships is shown for the whole year 2021 in Figure 4-10. The FRS ferry route is seen to sail with a course more north/south than the passenger ferries between Ystad and Swinoujscie, i.e., on a more direct course between Ystad and Sassnitz.

In addition, the offshore wind farms at Kriegers Flak have been constructed and put into operation in 2021, which has increased work traffic there and changed the ferry route from Trelleborg towards Kadetrenden in the western part of the area as shown in Figure 4-10 to a more westerly route outside of Kriegers Flak. In the area of Energy Island Bornholm, no significant change of routes is observed from the analysis based on AIS data from 2019.

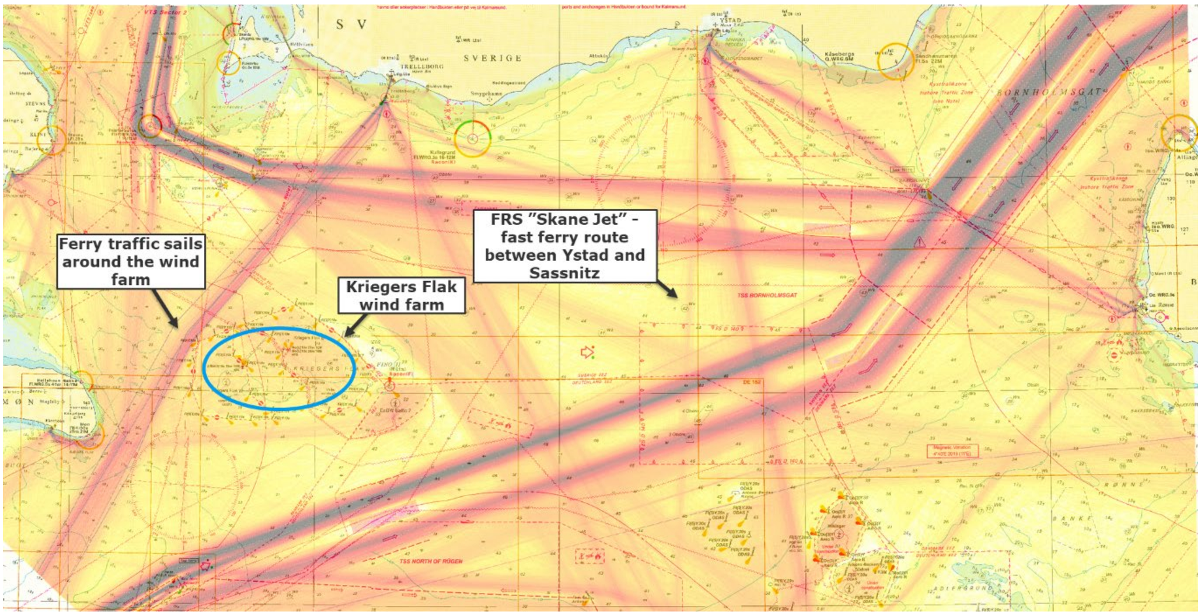



Figure 4-10 The intensity of ship traffic in the Baltic Sea south of Sweden for the entire year 2021.

For the purpose of this report, the future development of commercial shipping traffic in the area is assumed to follow the trend observed over the past years, without showing any significant increase in the number of shipping traffic.

### 4.1.4 Known incidents in the area

Shipping accidents in the Baltic Sea are reported annually by the Baltic Marine Environment Protection Commission (Helsinki Commission, HELCOM). Below are parts of the accident report from 2020, ref. /11/, summarized.

A total of two pollution accidents were recorded in the Baltic Sea however, both accidents were in ports. The only ship accidents near the planned planning areas for Energy Island Bornholm are three situations categorized as "Other" in TSS Bornholmsgat. In the accident report, it is noted that these incidents concerned respectively one cargo and two passenger ships. The location of all incidents in the Baltic Sea in 2020 is shown in Figure 4-11.


Figure 4-11 Collision and contact accidents in the Baltic Sea in 2020 from the report, ref. /11/.

The result from the HELCOM report only covers incidents within the year 2020. In order to compare with other years and gain greater insight into where ship accidents most often occur, data from the Danish Maritime Authority's accident statistics are shown in Figure 4-12 for the waters around Bornholm. Here are the past 12 years of events recorded in the Baltic Sea south of Sweden.

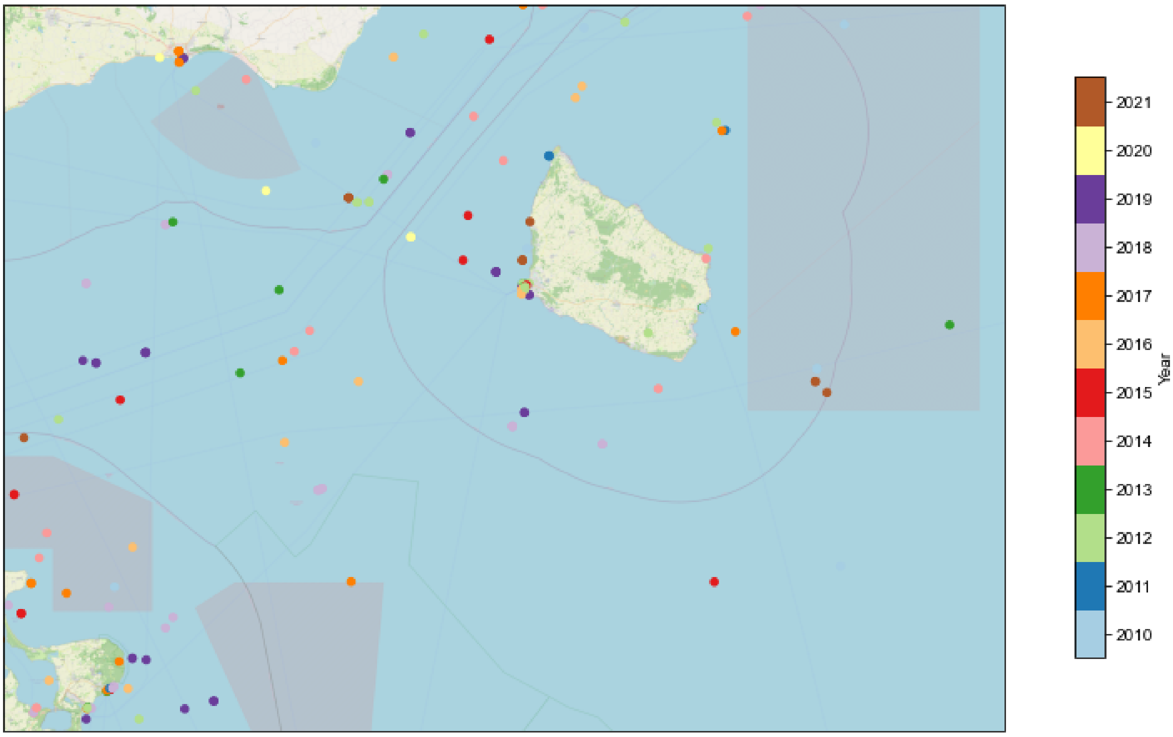



**Figure 4-12 Shipping accidents in the past 12 years in the Baltic Sea around Bornholm. Source: The Danish Maritime Authority.**

Incidents around Bornholm occur most frequently in connection with the busy shipping routes and at the precautionary area and TSS Bornholmsgat west of Bornholm, where traffic merges from several directions. Only a few incidents have been reported in the planning areas for Energy Island Bornholm; a single incident in the year 2016 at Bornholm I syd (light orange marking), and a few incidents (pink and small markings) in the year 2018-2019 at Bornholm II. It should be noted that the incidents here cover all registrations and thus also a large number of incidents that have not resulted in collisions or grounding. It can, for example, be engine failure which is rectified before grounding, or a fire incident on board a ship.

Overall, incidents and accidents outside the planning areas for Energy Island Bornholm generally appear to occur quite frequently in the heavily trafficked shipping corridors and less frequently outside the heavily trafficked shipping corridors.

It is worth noting that the potential environmental impacts from collisions within the wind turbine areas may spread to German or Swedish waters and thus contribute to an effect across national borders.

## 4.2 Modelling of ship traffic and collision scenarios

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

Three different accident scenarios are modelled: respectively

- Foundation supports
- Collisions between ships and fixed obstacles – here turbines and platforms
- Mutual collisions between ships

The location of facilities in the maritime territory will generally be able to influence the way the ships in the area sail, e.g. change sailing patterns, more ships follow the same main routes, etc. The location of Energy Islands Bornholm will thus be able to influence how many ships, in different situations, are heading towards shallow areas, how closely the ships sail on surrounding routes, etc. Energy Islands Bornholm could cause both collisions with the turbines themselves, as well as a change in the frequency of grounding and ship-ship collisions.

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

Ship-ship collisions can occur within a single route in connection with the passage of oncoming traffic (head-on), as well as when overtaking other ships. In addition, collisions can occur in connection with crossing traffic, route breaks, and merging traffic. Modelling scenarios as implemented in IWRAP are shown in Figure 4-13.

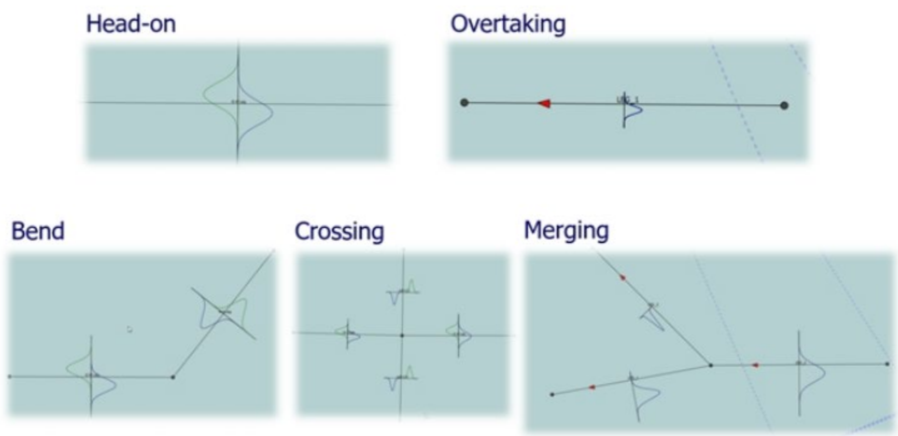



**Figure 4-13 The different event types for ship-ship collisions modelled in IWRAP.**

Figure 4-14 shows an example of the possibility of a frontal ship collision (head-on). Two statistical distributions describe the possible locations of ships moving in different directions along a route. Based on the ships' width and possible location across the route, the probability that two ships are on a collision course is calculated. If an evasive manoeuvre is not carried out in such a situation, a collision will occur. The IWRAP includes causation factors to describe the likelihood that evasive manoeuvres will not be performed correctly. Further details of the calculations performed in IWRAP are described in the tool's manual in ref. /4/.

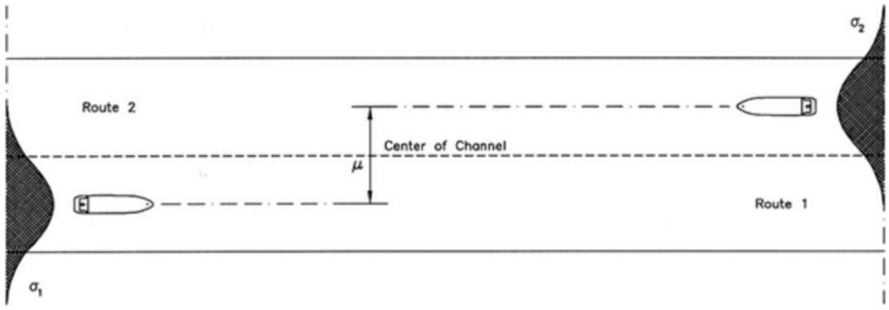



Figure 4-14 Example of the risk of head-on collision.

Head-on ship collisions occur most frequently on routes where the distribution of ship traffic overlaps in both directions, which applies to narrow corridors, as these routes do not have a large dispersion of their traffic in opposite directions. On the other hand, overtaking is more frequent on larger shipping routes, where ships of different sizes sail at different speeds, which gives rise to overtaking and an increased risk of a ship collision. The change in the frequency of head-on ship collisions can, among other things, be affected by the construction of new wind farms. The establishment of new wind farms can contribute to the rerouting of traffic and some routes will experience an increase in traffic. This will naturally contribute to more collisions, especially on routes that pass past or between several wind turbine areas, where the ships sail closely in both directions. Shipping traffic on routes that are narrowed will experience a reduced ability to make evasive manoeuvres or the ability to stop a drifting collision with a wind turbine.

Routes that change direction and bend can give rise to collisions regardless of the type of shipping traffic. Crossing routes, merging, and splitting routes correspondingly increase the risk of ship collisions and are also modelled and included in the calculations in IWRAP.

## 4.3 Modelling the base scenario

In the base scenario, the current sailing conditions in the Baltic Sea around Bornholm are modelled. Included here are the nearest wind farms that are already in operation, Arkona and Wikinger, in German waters southwest of Bornholm. In the base scenario, this will contribute to collision frequencies against wind turbines, so that the modelling of the future conditions can be compared with the current one.

Ship traffic is modelled given a large number of line segments (route legs) with a given width, where ship traffic is counted. The route legs collectively describe the traffic on the routes presented in section 4.1. The route legs are defined in relation to the observed sailing directions, and the traffic distribution across each individual route leg is estimated by IWRAP based on the traffic intensity in AIS data. All modelled route legs can be seen in Figure 4-15.

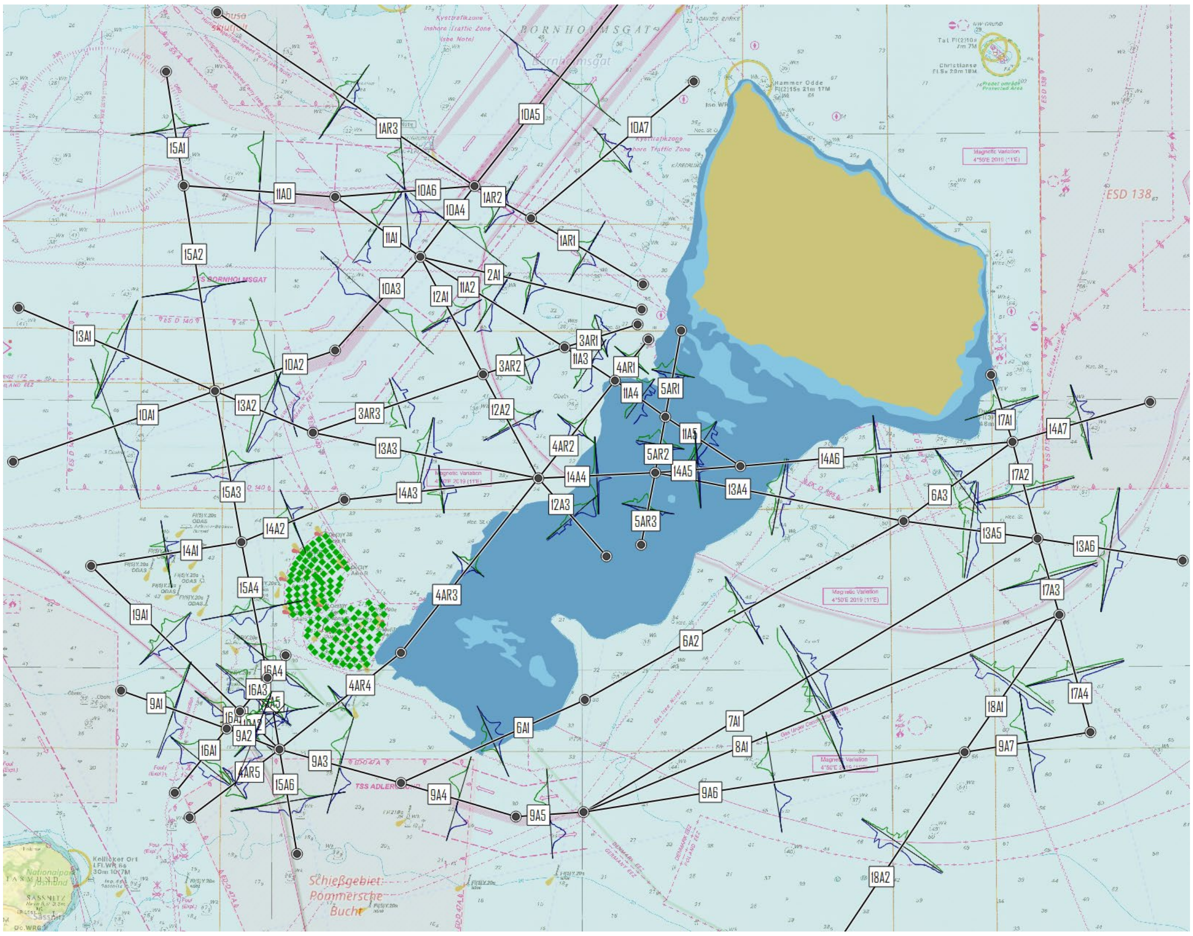



**Figure 4-15 The modeling of the current conditions for ship traffic based on the ship traffic intensity map in Figure 4-2, with green markings of wind turbines in the German EEZ, Bathymetry for Rønne Banke and Bornholm.**

All crossing routes and route bends result in so-called waypoints in IWRAP. These waypoints are marked with black circles in Figure 4-15, and for each waypoint it is defined how the traffic from one route leg continues onto one or more other route legs. Thus, traffic flows through the area are described by the traffic on the individual route legs and interactions in waypoints.

The traffic distribution across each individual route leg is illustrated in Figure 4-15, and these distributions of traffic contribute to the estimation of collision frequencies. In addition to sailing along the route legs, ships will – due to human errors – be able to continue an unchanged course after a route bend and thus risk grounding or colliding with obstacles in the area, just as ships on all routes may experience engine failure. For the maintenance traffic between Germany and the German wind farms Wikinger and Arkona, however, these ships naturally sail directly towards and between the wind turbines. In order not to overestimate the collision frequency against the wind turbines, the scenario where the maintenance traffic collides directly with the current wind turbines is not included.

## 4.4 Collision frequencies

In the base scenario, the collision frequencies will cover ground collisions, as well as ship-ship collisions and collisions against the wind turbines that are already in operation. The German wind farms, Wikinger and Arkona, are included in the modelling. The wind turbines will be exposed to drifting ship collisions from several of the routes, as well as collisions from ship traffic where a human error occurs, and the ship collides with a wind turbine at a higher speed.

When estimating collision frequencies in IWRAP, basic navigational measures have been considered, including the possibility of correcting machine faults and the use of emergency anchorage to prevent grounding or collision with the turbines in some cases. On the other hand, no account has been taken of specific mitigation measures in connection with the establishment of the offshore wind farm.

As mentioned at the HAZID workshop, see ref. /1/, the eastbound ship traffic on the main traffic route in the direction towards Bornholmsgat will be able to ground at Bornholm. In the current situation, there is an alert zone in the area west of Bornholm in relation to reacting to ships that may go off course from the main route and towards grounding on Bornholm. The Maritime Assistance Service (MAS) guard responds to an automatic alarm here, which has an impact on the number of groundings that take place on Bornholm. In the estimate of grounding frequencies, conservatively, the effect of the alert zone has not been taken into account.

In Table 4-4, the estimated collision frequencies are shown for each grounding, ship-wind turbine collisions and ship-ship collisions. The results are also shown as the annual return period, i.e., the number of years expected on average between incidents.

**Table 4-4 Summarized annual collision return periods for the baseline scenario.**

| | Baseline scenario | |
|---|---|---|
| **Collision scenario** | **Frequency [years]** | **Return period [years]** |
| Powered grounding | 3.48E-03 | 287 |
| Drifting grounding | 3.05E-02 | 33 |
| **Total number of groundings** | **3.39E-02** | **29** |
| Powered wind turbine collision | 1.07E-04 | 9,378 |
| Drifting wind turbine collision | 2.26E-03 | 443 |
| **Total number of wind turbine collisions** | **2.36E-03** | **423** |
| Overtaking collision | 3.15E-02 | 32 |
| Head-on collision | 4.23E-04 | 2,364 |
| Crossing collision | 4.56E-02 | 22 |
| Merging collision | 1.94E-02 | 51 |
| Bend collision | 4.89E-02 | 20 |
| **Total number of ship collisions** | **1.46E-01** | **7** |
| **Total number of collisions and groundings** | **1.82E-01** | **5.49** |

The risk of groundings in the base scenario is modelled against the shallow area at Rønne Banke and Bornholm. Overall, a ground impact is estimated to occur approximately every 29 years, and a collision with one of the existing wind turbines in the two German wind farms is expected approximately every 425 years. Most groundings and wind turbine collisions are estimated to be due to drifting ships and will thus occur at lower speeds.

For different types of ship-ship collisions, return periods of between approximately 20 and 50 years are estimated, excluding collisions related to oncoming traffic, which are very rare. This is because the traffic in the area is largely divided into unidirectional traffic flows. Overall, the return period for a ship-ship collision in the area is estimated to be approximately 7 years, which is due to the dense surrounding traffic from the main routes where overtaking and merging etc. takes place and contribute to the risk.

When both ship-ship collisions and groundings are considered, a collision or grounding is estimated to occur approximately every five and a half years within the modelled area. When compared with the list of incidents in section 4.1.4, it should be noted that the listed incidents also include incidents that did not result in collision or grounding. In addition to the estimated collisions and groundings, incidents may occur and are dealt with before they develop into actual collisions or groundings.

## 4.5 Risk assessment

As a result of the intense ship traffic in the area, there is a significant probability of collisions and groundings, which can also be seen from the number of recorded incidents in section 4.1.4 and the estimation of collision frequencies in Table 4-4. However, the consequences of a collision can vary from head-on collisions at high speed to more superficial collisions at lower speed. Both collisions and groundings can cause material damage and personal injury as well as damage to the environment. Collisions against wind turbines and other fixed installations can also cause damage to both ships and installations.

The severity of collisions depends on collision speed, ship type and ship size, and thus on whether the incident involves drifting ships or ships sailing at full speed. The ratio between personal injury and material damage can also vary depending on the size of the ship, just as the risk of damage to the environment can depend on the type of ship involved in a collision. In particular, collisions involving tankers will be able to contribute to greater environmental damage.

Overall, the shipping traffic in the area consists of all possible ship types, from tankers and cargo ships to passenger ferries, pleasure boats, and fishing vessels. The consequences of collision and ground impact scenarios can thus vary from minor to catastrophic. As a result of the large volume of traffic with commercial traffic on the main routes in and around the planning areas, many collisions may involve larger, commercial ships.

When using the assessment scales in the Danish Maritime Authority's scheme, see Figure 2-3, the collision frequencies in Table 4-4 are seen to give rise to a probability index of approx. 4-5 depending on the event – corresponding to events every 10 to 100 years. The consequences of grounding could be significant, but less so than ship-ship collisions at full speed, which in the worst case could be catastrophic, e.g., in connection with a major collision with a tanker. Collisions between ships and wind turbines can also be serious for both ships and wind turbines, although the more frequent drifting collisions will probably give rise to smaller consequences. Qualitatively assessed risk indices for the various incidents are presented in Table 4-5.

**Table 4-5 Assessment of risk index for the base scenario before establishment of Energy Island Bornholm.**

| Incident | Frequency index | Consequence index | Risk index |
|---|---|---|---|
| Ship-ship collision | 5 | 2-4 | 7-9 |
| Grounding, drifting | 4-5 | 1 | 5-6 |
| Grounding, powered | 3-4 | 1-2 | 4-6 |
| Ship-wind turbine collision, drifting | 3-4 | 2 | 5-6 |
| Ship-wind turbine collision, powered | 2 | 2-3 | 4-5 |

In relation to construction projects, it is generally planned that a risk after the establishment of preventive measures is acceptable at a risk index of five or less. The risk related to both grounding and collisions is therefore seen as a starting point before the establishment of Energy Island Bornholm to be high in the area around Bornholm. The highest risk is assessed to be related to ship-ship collisions.

However, it is noted that this risk is known and accepted and is largely linked to the intense commercial traffic that invariably passes through the area.

# 5. IMPACT ASSESSMENT

In this section, the changes to the navigational conditions resulting from the establishment of Energy Island Bornholm are assessed. In addition, the impact on navigational safety is assessed.

## 5.1 Rerouting of ship traffic

Establishment of Energy Island Bornholm will give rise to changes to the ship traffic in the area, as larger ships will no longer be able to pass the planned areas with wind turbines. It is therefore assumed that some of the ship traffic will be rerouted to avoid passing through the planning areas for Energy Island Bornholm. The routes used to model the shipping traffic in the risk analysis are therefore adapted based on the assumed future behaviour of this traffic.

At the HAZID workshop, ref. /1/, the Bornholm I area was assessed to pose a greater risk, as ship traffic passes through the area, and as there is intense traffic immediately north of the area. As a starting point for the HAZID workshop, there was no planned navigation corridor between the areas Bornholm I nord and Bornholm I syd. With the division into Bornholm I nord and Bornholm I syd, passage through the area is made possible, which has been taken into account in the modelled rerouting of the traffic.

The route that will be most directly affected by the establishment of the wind farms of Energy Island Bornholm is the DFDS route that sails between Kiel in Germany and Klaipeda in Lithuania. Based on discussions before and during the HAZID workshop, ref. /1/, it is expected that the navigation corridor between Bornholm I nord and Bornholm I syd is the most likely future route for the DFDS ferries and other commercial traffic on this stretch.

In connection with the project, two scenarios for installed wind turbines are processed as described in section 3.2; a scenario with a total capacity of 3.2 GW, and a scenario with a total capacity of 3.8 GW. In addition to the offshore wind turbines, up to seven transformer stations will also be installed in each scenario. In the scenario with 3.8 GW, additional wind turbines will be erected within the planning areas. However, the planning areas are unchanged, and the rerouting of ship traffic is therefore modelled in the same way, independently of the layout patterns. With reference to the current routes defined in section 4.1, changes are assumed as described in Table 5-1.

**Table 5-1 Adjustment of routes after construction of Energy Island Bornholm.**

| Route | Description | Impact after establishment of Energy Island Bornholm |
|---|---|---|
| 1 | Rønne towards Bornholmsgat (direction Ystad) | Unchanged |
| 2 | Towards Rønne from Øresund | Rerouting to the north through the precautionary area to merge with route 1 |
| 3 | From Rønne to the southwest through Bornholm I nord | Rerouted to pass west of Bornholm I nord via route 4 and then through the corridor between Bornholm I nord and Bornholm I syd |
| 4 | Southwest from Rønne along Bornholm I and Bornholm II | Unchanged |

| Route | Description | Impact after establishment of Energy Island Bornholm |
|---|---|---|
| 5 | Between Rønne and the natural resource extraction area at Rønne Banke | Unchanged |
| 6 | From TSS Adlergrund and over Bornholm II | Rerouted through TSS Adlergrund and to a new route east of Bornholm II |
| 7 | From TSS Adlergrund and over Bornholm II | Rerouted through TSS Adlergrund and to a new route east of Bornholm II |
| 8 | From TSS Adlergrund and over Bornholm II | Rerouted through TSS Adlergrund and to a new route east of Bornholm II |
| 9 | Main traffic through TSS Adlergrund | Unchanged |
| 10 | Main traffic through TSS Bornholmsgat | Unchanged |
| 11 | From TSS Bornholmsgat and south of Bornholm through Bornholm I nord | Rerouted to a route north of Bornholm I nord, partly together with route 1 |
| 12 | From TSS Bornholmsgat and towards the natural resource extraction area on Rønne Banke above Bornholm I nord | Rerouted to a route north of Bornholm I nord, partly together with route 1 |
| 13 | From TSS Falsterbo Reef and south of Bornholm | Rerouted to use the corridor between Bornholm I nord and Bornholm I syd |
| 14 | From TSS Rügen and south of Bornholm | Rerouted to use the corridor between Bornholm I nord and Bornholm I syd |
| 15 | Ystad – Sassnitz/Swinoujscie | Unchanged |
| 16 | Maintenance traffic to Wikinger and Arkona | Unchanged |
| 17 | Nexø - Kotobrzeg | Unchanged |
| 18 | Southeast of Bornholm and to and from Swinoujscie | Unchanged |
| 19 | Southeast of Bornholm and to and from Swinoujscie | Unchanged |

The rerouting of the ship traffic as described in Table 5-1 entails a reassessment of the distribution of traffic on the individual routes, just as some routes will be limited by the location of the wind turbines. The changed routes, modelled in IWRAP, are shown in Figure 5-1, and special conditions in connection with changing the routes after the establishment of the wind farms for Energy Island Bornholm are described below.

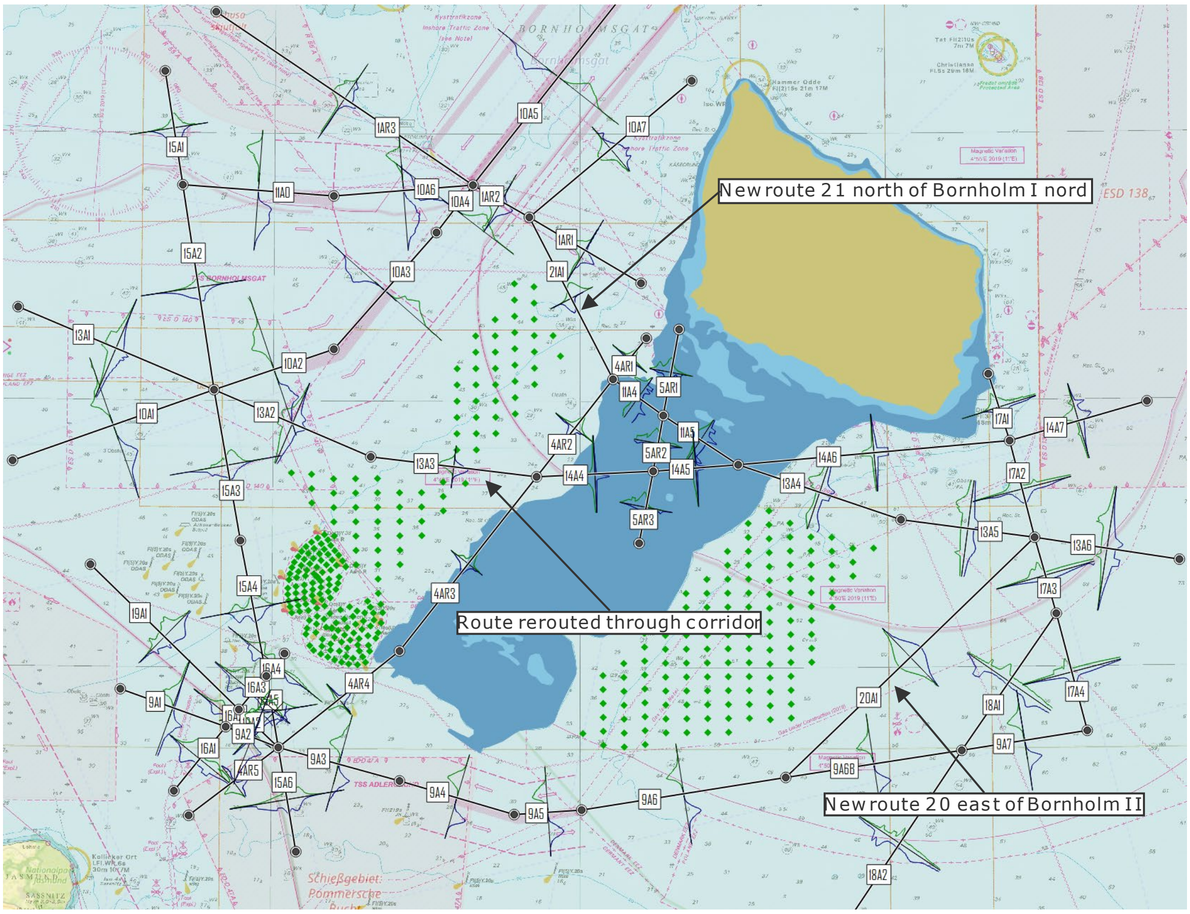



**Figure 5-1 The modeling of the future conditions for ship traffic based on the changes the planning areas for Energy Island Bornholm give to ship traffic compared to the base scenario, with green markings of wind turbines, Bathymetry for Rønne Banke and Bornholm.**

*Ship traffic west and south of the planning areas, as well as south of Nexø*

The traffic west and south of the planning areas and between Nexø and Poland is only affected to a minor extent by the establishment of wind turbines within the planning areas, but is included in the model, as ships in the immediate area will be able to drift towards the wind turbines in the event of an engine failure.

*Rerouting of traffic through Bornholm I*

Before the establishment of Energy Island Bornholm, the traffic between Rønne and TSS Bornholmsgat can spread over a larger area. Thus, traffic to/from TSS Falsterbo Rev crosses diagonally through the precautionary area, whereas the fast ferries between Ystad and Rønne pass north through the precautionary area on a direct course between the two ports. After the establishment of Bornholm I in the north, the traffic between Rønne and TSS Falsterbo Rev is assumed to pass further north through the precautionary area to avoid the northernmost offshore wind turbines. The traffic that previously left TSS Bornholmsgat in the southern part of the precautionary area to follow a course south of Bornholm or towards Rønne Banke, is assumed in the same way to take a more northerly course through the precautionary area and then sail north of Bornholm I nord and subsequently south of Bornholm. A new route has thus been modelled north of Bornholm I nord north of the traffic that previously passed through the area. The width of the route is limited by the northernmost wind turbine, and the rerouting means that the traffic between Rønne and the precautionary area is intensified.

The current traffic from Rønne and through the planning area for Bornholm I nord (route 3) will also be rerouted in the future situation. As the route is primarily used by smaller ships, it is assumed that this route is rerouted over Rønne Banke and through the corridor between Bornholm I nord and Bornholm I syd.

*Rerouting of traffic through Bornholm II*
The traffic that currently passes through the area designated for Bornholm II is assumed to use TSS Adlergrund in the future and only change to a north-easterly course east of Bornholm II. All traffic that previously sailed through the area designated for Bornholm II is thus assumed to proceed via a new route east of Bornholm II. The traffic on the current routes spread over a larger area, and there is plenty of space in the area east of Bornholm II. The ships are thus assumed to sail over a wide distribution on the new route (route 20). The traffic is modelled in IWRAP, and the distribution of the traffic across the route is here normally distributed with a standard deviation of 1,500 m for both directions.

*The corridor between Bornholm I nord and Bornholm I syd*
The existing traffic from TSS Falsterbo Rev (route 13) is assumed to follow the same course in the future, although limited by the corridor between Bornholm I nord and Bornholm I syd. The traffic from TSS Rügen (route 14), on the other hand, is assumed to take a more northerly course to sail north of Bornholm I syd and merge with the traffic from TSS Falsterbo Rev, so that the total traffic from the two routes continues through the established corridor. In addition, it is assumed that part of the traffic that previously sailed through the planning area Bornholm I nord (route 3) will also use the corridor. In 2019, there were a total of 341 ships on route 3, 931 ships on route 13, and 1,125 ships on route 14. Overall, around 2,400 ships are therefore assumed to pass through the corridor per year.

The width of navigation corridors should be sufficient for ships to pass through safely; also, in case of need for evasive manoeuvres. The Danish Maritime Authority generally refers to principles for assessing sufficient width as described in a Dutch white paper, ref. /15/ and corresponding principles described in a PIANC guide "Interaction Between Offshore Wind Farms And Maritime Navigation", ref. /8/.

The assessment of the necessary width of navigation corridors is based on the number of ships that use the corridor, a necessary space for overtaking, as well as the possibility to give room and give way within the width of the route.

Since the rerouting of traffic shows that there will be around 2,400 ships per year in the corridor in the east/west direction between Bornholm I nord and Bornholm I syd, a width corresponding to four times the length of a standard ship is recommended. A larger width is only required for more than 4,400 ship passages per year. A standard ship is defined so that 98.5% of the ships that use the route in question are not larger than the standard ship. A standard ship in the corridor between Bornholm I nord and Bornholm I syd is estimated to be approximately 200 m, see also Figure 4-3, where all ships on route 14 are under 200 m, and only very few of the current ships on routes 3 and 13 are longer.

In addition to space for the normal traffic flow, there is a need for an extra safety margin or buffer zone from the outer edge of the traffic flow to the wind turbines along the corridor. This is an area where a ship will be able to make evasive manoeuvres. An evasive manoeuvre consists of a course change to starboard of 0.3 nautical miles followed by a 360-degree turn. A turn of 360 degrees is normally estimated to take up six times the length of the ship. The corridor will have traffic in both directions, and the above will therefore basically apply in both directions.

Based on the standard ship's length (L) and the traffic intensity, the indicative width of the corridor can be calculated by the following formula:

$$(4L + (0.3nm + 6L)) \times 2$$

The calculation gives a width of approx. 5.1 km (2.8 nautical miles), which corresponds to the width of the corridor indicated in the Maritime Spatial Plan, see Figure 3-5.

The shortest distance between the planning areas Bornholm I nord and Bornholm I syd is approximately 3.4 km (1.85 nautical miles) and thus less than the width of the corridor proposed in the Maritime Spatial Plan. However, the corridor will be quite short and will only include the passage of a few wind turbines on each side, see Figure 5-2. The figure illustrates a possible pattern for a park layout based on the highest total capacity and the smallest possible, and thus the most, offshore wind turbines. Both east and west of the passage between Bornholm I nord and Bornholm I syd, there is more room to avoid potential collisions. The shipping corridor can therefore roughly be considered as a passage between two bridge piers, although the eastbound traffic up towards the passage will sail along the northern side of Bornholm I syd, where a safety distance will be needed from the row of wind turbines. Compared to the passage under the Great Belt Bridge, where the volume of traffic is significantly greater, here there are only approx. 1.6 km. between the pylons. A clear width of approx. 3.4 km in the passage between Bornholm I nord and Bornholm I syd is therefore assessed as sufficient to be able to handle traffic safely.

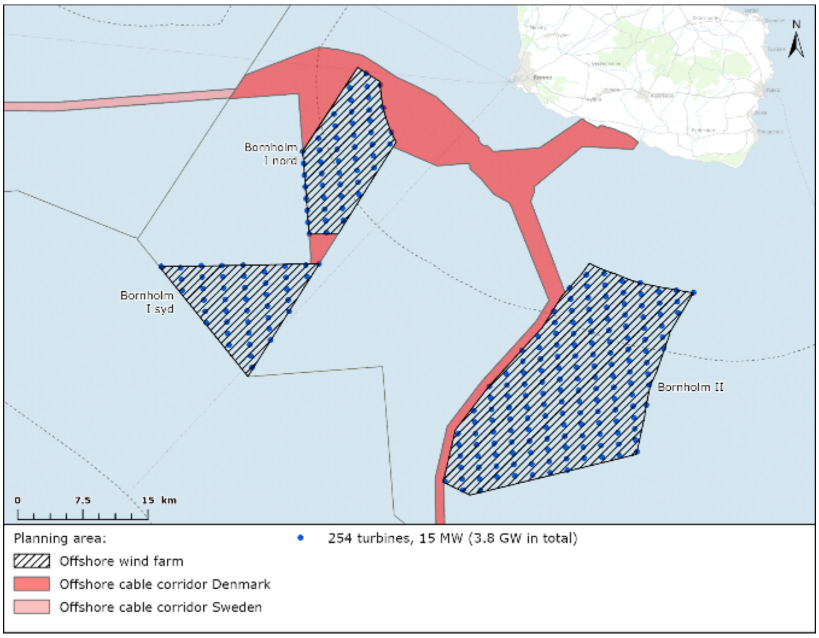



**Figure 5-2 Indicative installation pattern for offshore wind turbines 3.8 GW using 15 MW offshore wind turbines.**

Energinet is aware that there is an overlap between the planning area for Bornholm I nord and the sailing corridor, and informs that the sailing corridor will be narrowed, ref. /16/.

The expected ship traffic distribution for ship traffic on route 14, carrying among others the DFDS ferries between Kiel and Klaipeda, and the traffic from Øresund and south of Bornholm on route 13 between the planned wind turbine areas in Bornholm I nord and syd, is assumed to be narrower when the traffic is rerouted and adapted to the sailing corridor. The justification for assuming a narrower distribution is linked to the fact that the shipping corridor limits the space for sailing alternative routes. The wind turbines will limit the ship's navigation and safety distances between itself and other objects, thus narrowing the ship traffic. It is therefore assumed that ships sailing through the wind farm are forced to sail in a narrower lane, which leads to the distribution of ship traffic on route 13 and route 14 can be assumed to be narrower after the construction of Energy Island Bornholm's wind farms.

To quantify the effect, the effect of the implementation of the TSS Bornholmsgat is described below, which forces ships into a narrower lane shown in Figure 5-3. In this figure, the ship traffic intensity before and after the implementation of the TSS Bornholmsgat is visualized. This clearly indicates the effect of TSS Bornholmsgat. The shipping corridor through Energy Island Bornholm's wind farms is therefore assumed to have a similar effect.

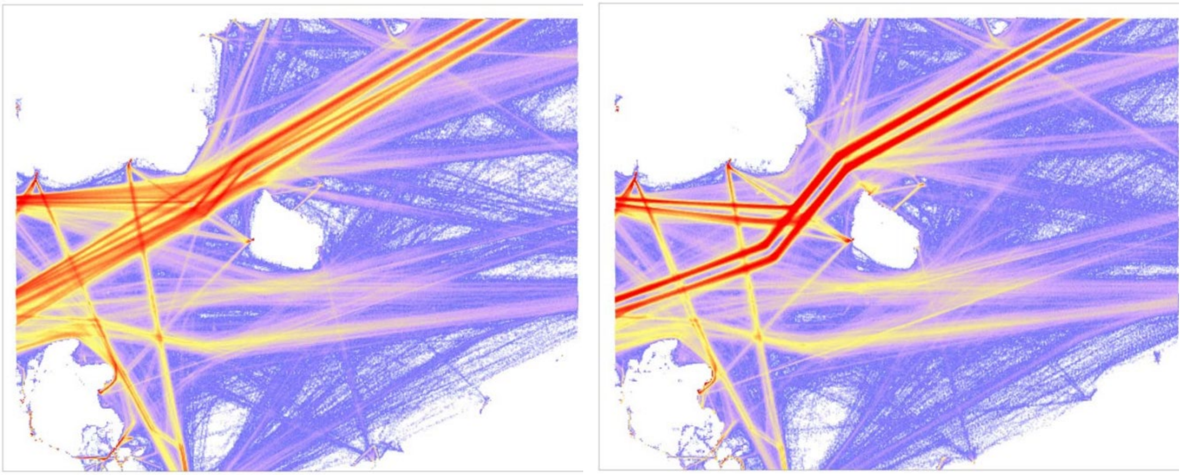


**Figure 5-3 Ship traffic in the Baltic Sea south of Sweden before and after the establishment of TSS Bornholmsgat. Left: Data from July-December 2005, right: Data July-December 2006, from ref. /9/.**

In similar projects for estimating ship traffic collision frequencies with bridge piers, it is assumed that the ships will follow a narrower distribution to stay within the routes between the obstacles. It is assumed in this connection that 5% of the shipping traffic is distributed uniformly within the width of the corridor, and the remaining 95% is distributed normally with a standard deviation of 9% of the width of the route. With a standard deviation of 9% of the width of the route (3.4 km), this is set to 306 m. This forces the shipping traffic to sail on a narrower route, as the ships are expected to avoid collisions with the wind turbines under normal circumstances. The effect of this may be an increase in head-on and overtaking collisions for ship traffic, which is reflected in the frequency results, just as rare head-on collisions against the wind turbines and the risk of machine failure when passing through the corridor are included in the modelling.

The ship traffic, which is rerouted north of Bornholm I nord on route 21 shown in Figure 5-1, is similarly modelled in IWRAP with a normal distribution of the traffic that resembles the routes it connects. Here, a narrower distribution is used for the eastbound traffic with a standard deviation of 350 m, as this traffic is pushed up towards the wind farm to make room for the oncoming ship traffic, which merges with the westbound traffic from Rønne. The westbound traffic on the route is also normally distributed, but with a significantly wider standard deviation of 600 m to take into account the merging with the Ystad-Rønne route into the precautionary area and TSS Bornholmsgat. It is also assumed that the opposite traffic is partially separated, and thus that the eastbound traffic navigates closer to Bornholm I nord, whereas the westbound traffic navigates closer to Bornholm.

## 5.2 Collision frequencies

After rerouting the ship traffic and installing wind turbines, the collision frequencies are again estimated in IWRAP.

The results of the accident frequencies for the two scenarios with a total capacity of 3.2 GW or 3.8 GW, corresponding to placement of 214 or 254 wind turbines within the planning areas, is presented in Table 5-2. Here, the collision frequencies and corresponding return periods for each scenario are shown.

**Table 5-2 Summarized annual return periods for collisions after establishment of Energy Island Bornholm.**

| Collision scenario | 3.2 GW capacity | | 3.8 GW capacity | |
|---|---|---|---|---|
| | Frequency [years] | Return period [years] | Frequency [years] | Return period [years] |
| Powered grounding | 3.43E-03 | 292 | 3.43E-03 | 292 |
| Drifting grounding | 3.02E-02 | 33 | 3.01E-02 | 33 |
| **Total number of groundings** | **3.36E-02** | **30** | **3.36E-02** | **30** |
| Powered wind turbine collision | 2.22E-03 | 451 | 2.50E-03 | 401 |
| Drifting wind turbine collision | 5.78E-03 | 173 | 6.55E-03 | 153 |
| **Total number of wind turbine collisions** | **7.99E-03** | **125** | **9.04E-03** | **111** |
| Overtaking collision | 3.23E-02 | 31 | 3.23E-02 | 31 |
| Head-on collision | 6.38E-04 | 1,567 | 6.38E-04 | 1,567 |
| Crossing collision | 4.84E-02 | 21 | 4.84E-02 | 21 |
| Merging collision | 1.94E-02 | 51 | 1.94E-02 | 51 |
| Bend collision | 4.91E-02 | 20 | 4.91E-02 | 20 |
| **Total number of ship collisions** | **1.50E-01** | **7** | **1.50E-01** | **7** |
| **Total number of collisions and groundings** | **1.91E-01** | **5.22** | **1.92E-01** | **5.20** |

The total collision frequencies at the bottom of Table 5-2 containing both groundings, ship collisions with wind turbines and ship-ship collisions do not differ significantly between the two scenarios. The difference is seen in the collision frequencies for wind turbine collisions, where collisions are more often expected in the scenario with most wind turbines.

The percentage of wind turbine collisions that relate to Energy Island Bornholm's offshore wind turbines is summarized in Table 5-3. The percentages show that approximately 75% of all wind turbine collisions are related to Energy Island Bornholm's offshore wind turbines. The remaining approximately 25% are thus related to the nearby German wind farms. It can be seen that the percentages for powered collisions are approximately 95%, which means that only 5% of the powered collisions against wind turbines are related to the German wind turbines, and the proportion of the powered collisions against Energy Island Bornholm's wind turbines is therefore not significantly different from the previously shown results in Table 5-2. The drifting collisions against Energy Island Bornholm's offshore wind turbines are significantly fewer than summarized in Table 5-2, as only 66% of these are estimated to collide with Energy Island Bornholm's wind turbines.

As part of the estimated wind turbine collisions relate to collisions against the existing German wind farms, the frequency of collisions against Energy Island Bornholm's offshore wind turbines is lower than indicated in Table 5-2. The total return period for collisions against Energy Island

Bornholm's offshore wind turbines is thus estimated to be every 174 years and 148 years, respectively, depending on the number of offshore wind turbines.

**Table 5-3 Proportion of collision frequencies against Energy Island Bornholm wind turbines.**

| | 3.2 GW capacity | 3.8 GW capacity |
|---|---|---|
| Powered wind turbine collision | 95% | 96% |
| Drifting wind turbine collision | 63% | 67% |
| **Total number of wind turbine collisions** | **72%** | **75%** |
| **Total return period for Energy Island Bornholm's wind turbine collisions** | **174 years** | **148 years** |

Specifically for collisions against Energy Island Bornholm's offshore wind turbines, collisions for different ship types in both scenarios are distributed as follows: approximately 72% cargo ships, 11% tankers and 2-3% divided between each of the other ship types. As the main route (route 10) to TSS Bornholmsgat passes close by Bornholm I with almost 25,000 ships per year, which is the busiest route in the area, for instance with approximately 70% cargo ships on this route (see Figure 4-4), it is expected that the majority of collisions against the wind turbines are related to approaching and drifting cargo ships. Tankers are also represented on the same route, which explains 11% of collisions. In addition, route 9 through TSS Adlergrund is also a busy route south of the wind farms.

Specifically for the length of the ship that collide with Energy Island Bornholm's wind turbines, collisions in both scenarios are distributed such that 12% of the ships are under 50 m, 72% are under 100 m, 95% are shorter than 175 m and 99% are shorter than 250 m. Most of the ships that collide with Energy Island Bornholm's offshore wind turbines are thus expected to be less than 175 m long.

In addition to collisions against the offshore wind turbines, collisions against the transformer stations within the planning areas will also be possible. The location of the transformer stations within the planning areas has not been specified, and concrete collision frequencies have not been estimated. If the transformer stations are placed centrally in the planning areas, however, they are not considered to give rise to significantly more collisions, as they will to some extent be protected by the outer rows of offshore wind turbines. If they are placed on the edge of the planning areas, they will constitute more significant obstacles. When comparing the two calculated scenarios, however, a relatively small difference is seen between placing 214 and 254 offshore wind turbines. As the transformer stations are larger than the offshore wind turbines, it is estimated that up to seven transformer stations can contribute to additional collisions in the same order of magnitude as the 40 additional offshore wind turbines.

## 5.3 Risk assessment

The risk assessment is carried out as a comparison between existing conditions in the base scenario and the two scenarios with wind turbines located within the planning areas Bornholm I nord, Bornholm I syd, and Bornholm II.

The comparison of the accident frequencies for ship collisions is summarized in Table 5-4, where the results from the base scenario (Table 4-4) and the future conditions (Table 5-2) are presented together with the percentage difference.

**Table 5-4 Comparison of annual collision return periods for the scenarios studied.**

| Collision scenario | Baseline<br>Return period [years] | 3.2 GW capacity<br>Return period [years] | 3.2 GW capacity<br>Difference to baseline (%) | 3.8 GW capacity<br>Return period [years] | 3.8 GW capacity<br>Difference to baseline (%) |
|---|---|---|---|---|---|
| Powered grounding | 287 | 292 | -1.57% | 292 | -1.57% |
| Drifting grounding | 33 | 33 | -0.96% | 33 | -1.02% |
| **Total number of groundings** | **29** | **30** | **-1.03%** | **30** | **-1.08%** |
| Powered wind turbine collision | 9,378 | 451 | 1,977.79% | 401 | 2,240.22% |
| Drifting wind turbine collision | 443 | 173 | 156.20% | 153 | 190.40% |
| **Total number of wind turbine collisions** | **423** | **125** | **238.44%** | **111** | **282.95%** |
| Overtaking collision | 32 | 31 | 2.41% | 31 | 2.41% |
| Head-on collision | 2,364 | 1,567 | 50.86% | 1,567 | 50.86% |
| Crossing collision | 22 | 21 | 6.25% | 21 | 6.25% |
| Merging collision | 51 | 51 | -0.10% | 51 | -0.10% |
| Bend collision | 20 | 20 | 0.47% | 20 | 0.47% |
| **Total number of ship collisions** | **7** | **7** | **2.76%** | **7** | **2.76%** |
| **Total number of collisions and groundings** | **5.49** | **5.22** | **5.11%** | **5.20** | **5.68%** |

When comparing the base scenario grounding with the two future conditions where the wind turbines in the planning areas for Energy Island Bornholm are in operation, only a minor change is seen, where grounding is less likely to occur. When the wind turbines are in operation, each wind turbine will protect Rønne Banke and Bornholm for some of the shipping routes, which will lead to some groundings in the base scenario instead turning into wind turbine collisions.

The risk of ship-wind turbine collisions in the base scenario only includes the two German wind farms Wikinger and Arkona southwest of Bornholm I syd, which are currently in operation. In the base scenario, the total return period for ship-wind turbine collisions against the German wind turbines is estimated to be every 423 years. After the establishment of Energy Island Bornholm, the return period for both sailing and drifting collisions is reduced. When setting up a capacity of up to 3.2 GW with up to 214 wind turbines, a return period for collision is estimated every 451 years, a collision from a drifting ship every 173 years, and overall, a ship-wind turbine collision every 125 years. For the scenario with overplanting and 254 offshore wind turbines with a total capacity of 3.8GW, the return periods are further reduced to a total return period for a ship-wind turbine collision every 111 years.

Table 5-4 shows that the frequency of direct collisions with wind turbines has changed the most, but that it is still the drifting ship collisions against the wind turbines that constitute the largest contribution to the total return period in both future scenarios with wind turbines in operation within the planning areas. Drifting ships due to engine failure may occur for all ships in the area. With a high traffic intensity both north and south of the planning areas, there will naturally be a risk for drifting ships.

If collisions against transformer stations are included, the return period for collisions will be slightly reduced, and it is estimated that the total return period for collisions against both offshore wind turbines and transformer stations will be approximately 100 years in the scenario of overplanting. If the transformer stations are placed inside the wind turbines, the transformer stations will contribute less to the risk.

The risk of ship-ship collisions changes as a result of the rerouting of the ship traffic routes. The rerouting gives rise to more traffic around the areas with offshore wind turbines, which increases the risk of ship-ship collisions, where the biggest change is related to oncoming ship collisions where the return period decreases from every 2,364 years to every 1,567 years. However, it is the other collision scenarios that contribute to the most frequent incidents with return periods from approx. 20 to 50 years. After the establishment of Energy Island Bornholm, ship-ship collisions due to merging routes are estimated to occur less frequently, which is linked to the fact that the current routes across the area are expected to converge into fewer routes around the planning areas. Overall, Table 5-4 shows that ship-ship collisions are events that are estimated to occur every seven years for all scenarios, and only a minor increase is seen after the establishment of Energy Island Bornholm.

As the rerouting of traffic through Bornholm I moves some shipping routes north of the planning area Bornholm I nord, the traffic intensity will increase in this area, which was also mentioned at the HAZID workshop, ref. /1/. Ship traffic, which previously sailed across the precautionary area, is now forced into the busiest area in TSS Bornholmsgat, after which it sails towards Rønne and then south of Bornholm and correspondingly in the opposite direction. This increase in traffic makes a greater contribution to ship-ship collisions in the area marked in red in Figure 5-4.

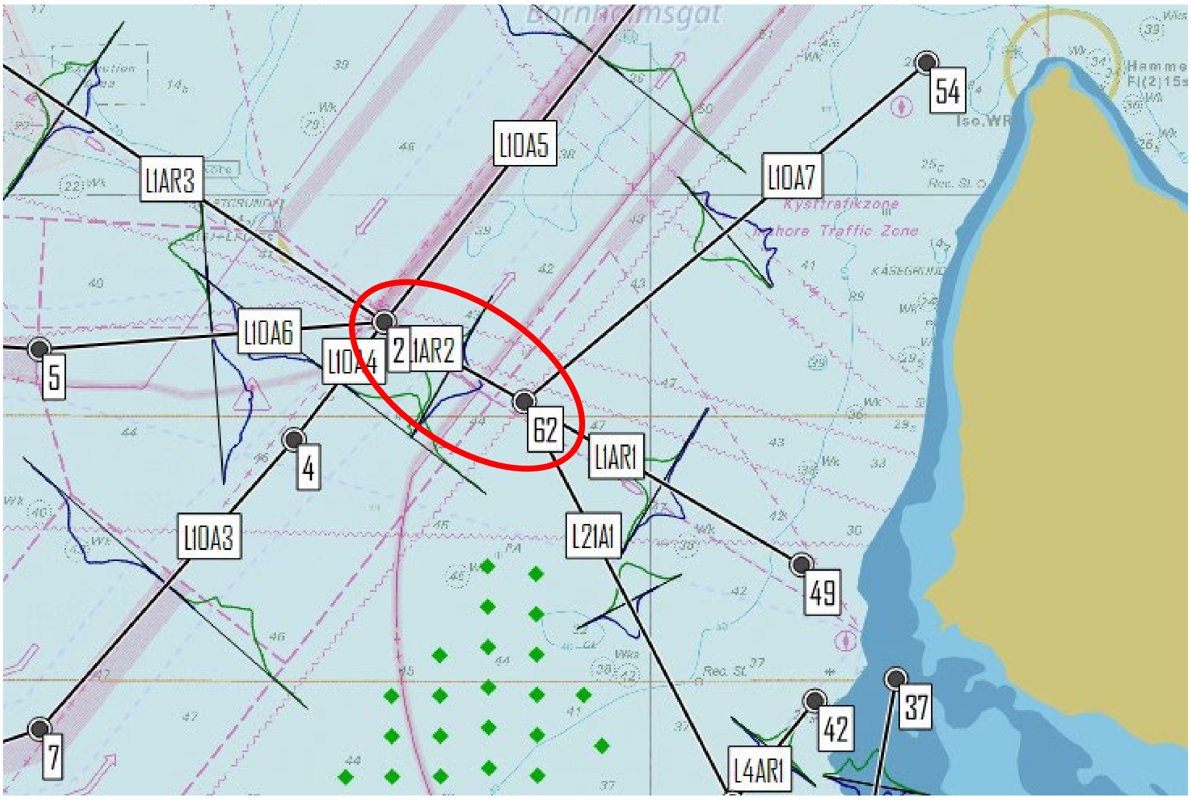



**Figure 5-4 Section of the northern area at TSS Bornholmsgat and the Ystad-Rønne ferry route modeled in IWRAP. The passing traffic merges north of the planning area Bornholm I nord, which is marked in red.**

Ship traffic merges in the two waypoints (2 and 62) after which the traffic sails along route 1 (L1AR2). Table 5-5 summarizes the annual collision frequencies in the two waypoints and the route leg in between for the base scenarios and the future scenarios where Energy Island Bornholm's wind farms are in operation.

**Table 5-5 Annual frequencies of collisions in the northern area for the scenarios studied.**

| | Baseline | 3.2 GW capacity | 3.8 GW capacity |
|---|---|---|---|
| LEG_1AR2 | 7.63E-06 | 5.10E-05 | 5.10E-05 |
| WAYPOINT_2 | 6.19E-02 | 6.74E-02 | 6.74E-02 |
| WAYPOINT_62 | 8.89E-06 | 1.01E-04 | 1.01E-04 |
| **Total** | **6.19E-02** | **6.76E-02** | **6.76E-02** |

Table 5-5 shows that the collision frequencies in the specific waypoints and on the modelled route leg increase after the rerouting of ship traffic. The total ship collision frequency increases by 0.57E-02 after the establishment of Energy Island Bornholm's wind farms. The return period for this area given the two waypoints' individual route legs corresponds to every 16 years, which after the rerouting leads to every 15 years. The rerouting of ship traffic results in a small increase in ship collisions in the area but is estimated to be at the same level as before.

For the total collision frequency covering grounding, collisions against offshore wind turbines, and ship-ship collisions, an increase of approx. 5-6% compared to the base scenario is estimated. In all cases, the annual return period for a grounding or collision is around 5 years.
Risk of collision with maintenance vessels will relate to transit routes between the maintenance port and the planning areas, movements within the planning areas, and between the planning areas. To and from the areas, maintenance vessels are expected to follow normal ship traffic and normal rules for safe navigation, which leads to a small risk for transit navigation. Depending on the choice of maintenance port, different main traffic routes may have to be crossed, e.g., the traffic at TSS Adlergrund when choosing a maintenance port in Germany. Crossings of main traffic must take place in accordance with general rules of the sea, and for example as perpendicular as possible if the crossing takes place within or near a TSS.

Maintenance vessels operating within the planning areas can also contribute to an increased risk of ship collisions. Within the planning areas, ship movements will only relate to very few ships sailing in the area, as it is assumed that commercial ships will use and sail on the main routes outside the planning areas. Since sailing within Danish wind farms is permitted and larger commercial ships sail outside wind farms on main routes, it is assumed that the ship traffic that can be observed within the planning areas consists of pleasure boats, trolling fishermen (see HAZID Appendix, ref. /1/), and other smaller boats. In addition, it was also mentioned at the workshop that pleasure boats would most likely also sail outside the plan areas rather than inside. Ship traffic sailing between the installed wind turbines will generally be very few but the number will increase during high times for trolling fishing. The risk of having a maintenance vessel sailing between the wind turbines as well as stationary at the wind turbines within the planning area must be considered a small risk as smaller vessels are not limited by their draft or manoeuvrability and could give way to a maintenance vessel and vice versa.

When passing from one planning area to another, maintenance vessels are expected to follow normal ship traffic and normal rules for safe navigation, which leads to a small risk of transit navigation. But for maintenance vessels sailing between the planning areas Bornholm I nord and syd, an overview must be ensured before passing across the sailing corridor. The passage crosses the future route between the planning areas where it is expected that up to approximately 2,500 commercial ships use this path on an annual basis, which corresponds to an average of 7 ships per day. Maintenance vessels that must pass the 3.4 km corridor will need approximately 10 minutes on its passage given it sails at 10 knots. Maintenance vessels will only be in the corridor for a short time. In addition, it is assumed that the vessel uses AIS, VHF radio, radar reflector, etc. to ensure visibility at sea for larger ships. It is assessed that maintenance vessels that pass from one planning area to another across the sailing corridor only pose a minor risk to shipping traffic.

If the assessment scales in the Danish Maritime Authority's scheme are used again, see Figure 2-3, a qualitatively assessed risk index is obtained for the various incidents, as presented in Table 5-6. The risk related to grounding and ship-ship collisions is assessed to be at the same level as before, and the risk related to ship-wind turbine collisions has increased marginally. However, the risk of ship-ship collisions in the area is still greatest due to the intense commercial traffic and the potentially large consequences.

**Table 5-6 Assessment of risk index after establishment of Energy Island Bornholm.**

| Incident | Frequency index | Consequence index | Risk index |
|---|---|---|---|
| Ship-ship collision | 5 | 2-4 | 7-9 |
| Grounding, drifting | 4-5 | 1 | 5-6 |
| Grounding, powered | 3-4 | 1-2 | 4-6 |
| Ship-wind turbine collision *), drifting | 4 | 2 | 6 |
| Ship-wind turbine collision *), powered | 3-4 | 2-3 | 5-7 |

*) Incl. transformer stations

With the determined distance between the wind turbines and the main traffic routes, as well as the establishment of a passage option between Bornholm I nord and Bornholm I syd, it is therefore considered possible to establish wind turbines within the planning areas. However, especially the area north of Bornholm I nord is estimated to experience an increase in the risk of collisions as a result of a densification of traffic.

The wind turbines are located outside the major traffic arteries, and most collisions are estimated to occur in connection with drifting ships and thus at lower speeds. Overall, the establishment of Energy Island Bornholm – regardless of whether 3.2 GW or 3.8 GW are installed – is estimated to cause a limited increase in the overall risk for shipping traffic. However, the area north of Bornholm I is estimated to experience an increased concentration of ship traffic in an area that is already heavily trafficked. This could lead to an increased risk locally. Marking the wind turbines in this area is therefore considered particularly important.

### 5.3.1 Risk in the construction and decommissioning phases

During the construction phase, work vessels will operate in the area, most of which are expected to be support vessels as well as larger vessels for the installation of foundations and turbines.

To reduce risks during the construction phase and the decommissioning phase, it is expected that sufficient safety zones will be used and that all work areas will be marked with Aids to Navigation (AtoN). AtoN are all types of navigation aids that can be helpful for ship traffic to mark work areas, e.g., lighthouses, buoys, signals, or other guidance for ship traffic that helps ship traffic to navigate afterwards. It is also important to have a communication plan in accordance with the

Danish Maritime Authority and daily updates in communication with the authority to inform all ships sailing in this busy area of the Baltic Sea.

Collision frequencies have not been quantitatively estimated for the construction phase. Sailing patterns of work vessels are assumed to interact with normal ship traffic according to COLREGS (normal IMO rules for interaction between ships) when not working within defined work areas. Collisions between third-party ship traffic and construction activities are assessed to be of a similar nature to ship-ship collisions and wind turbine collisions in the operational phase, where all wind turbines will be permanently present in the area.

The decommissioning phase of the wind farm is assumed to be similar to the construction phase, where work areas are set up with safety zones, and traffic to and from the area follows the normal routes. The risk is therefore assumed to be comparable, and the decommissioning phase is not dealt with further.

## 5.4 Other conditions

The collision analysis and risk assessment above largely relate to commercial ship traffic. Various other relevant matters related to navigational safety are commented on and assessed qualitatively below.

### 5.4.1 Cables from Energy Island Bornholm

The areas planned for cables can be seen in Figure 4-1 together with the ship traffic intensity for 2019.

In connection with the construction phase, there will be cable-laying activities within the marked areas; between the wind turbine areas and Bornholm's south coast (HVAC cables), and between Bornholm and Zealand (HVDC cables), respectively. This construction activity could affect the ship traffic, especially in areas with crossing ship traffic. The construction vessels used in connection with the cable lay will have limited manoeuvrability and be exposed to collisions from crossing ship traffic. However, cable-laying activities are generally well-known activities, and several risk-reducing measures are expected to be implemented, including information about the activities announced in Notices to Mariners (NtM), use of a safety zone around the construction vessels, relevant navigation markings and lights on the construction vessels, as well as possible use of a deflector vessel. The final planning of the construction activities for the specific cable route should be assessed in accordance with the Danish Maritime Authority's guidance for construction work at sea and final risk-reducing measures should be determined in dialogue with the Danish Maritime Authority.

During the operating period, the cables will lie buried in the seabed or otherwise protected. In addition, the cables will be marked on charts, and there will by default be a zone of 200 m from the cables where anchoring and fishing with bottom trawls will be prohibited. However, there will still be a risk of cable breakage as a result of:

- Dropped anchors or other objects
- Sinking or grounding ships
- Fishing activities
- Anchors dragged along the seabed

In the area within the wind farms and between the parks and Bornholm, ship traffic is limited and mostly consists of fishermen and pleasure boats. There is, however, a limited amount of commercial traffic that passes south of Bornholm and north of the wind farms, just as there is commercial traffic in the corridor between Bornholm I nord and Bornholm I syd. As traffic in the area is limited, the cables will only be exposed to the risk of dragged anchors to a lesser extent.

In the area immediately west of Bornholm I nord, the cable route for the export cable between Bornholm and Zealand crosses the heavily trafficked area at TSS Bornholmsgat. In this area, the export cable is expected to follow the cable route of the Baltic Pipe gas pipeline. The large number of commercial vessels in this area increases the risk of damage to the cable due to dragged anchors. Incidents of dragged anchors are observed regularly in the area between Bornholm and Sweden. It is therefore very relevant to protect the cables in this area.

In the area towards Køge Bay, ship traffic is more limited, although the route will cross several less busy sailing routes. The degree of special cable protection in these areas must be assessed in connection with concrete planning of the cable.

The risk in connection with a cable break is primarily related to the actual operation of the cable, and the break itself is not considered to pose a major risk to the passing ship traffic or the environment. Repairing a cable damage will, however, require the presence of a vessel with limited manoeuvrability, which will give rise to an increased risk of collision during the period of repair. Since cable breaks as a result of dragged anchors are most often expected to occur in areas with a lot of ship traffic, the remedial activities will therefore also take place in these areas.

On the HAZID workshop, see ref. /1/, Rønne harbour mentioned a need for anchorage in an area off Rønne harbour in connection with the handling of larger cruise ships, as well as in connection with bunkering activities. The Port of Rønne therefore wanted to exempt an area of 5 nautical miles radius around Rønne from all obstacles incl. submarine cables to accommodate anchoring activities. Such an area is indicated on Figure 5-5. There are about 4 nautical miles between the indicated areas for cables and Rønne harbour, and dialog with Rønne harbour should therefore be considered when planning the cable routes at Bornholm in detail.

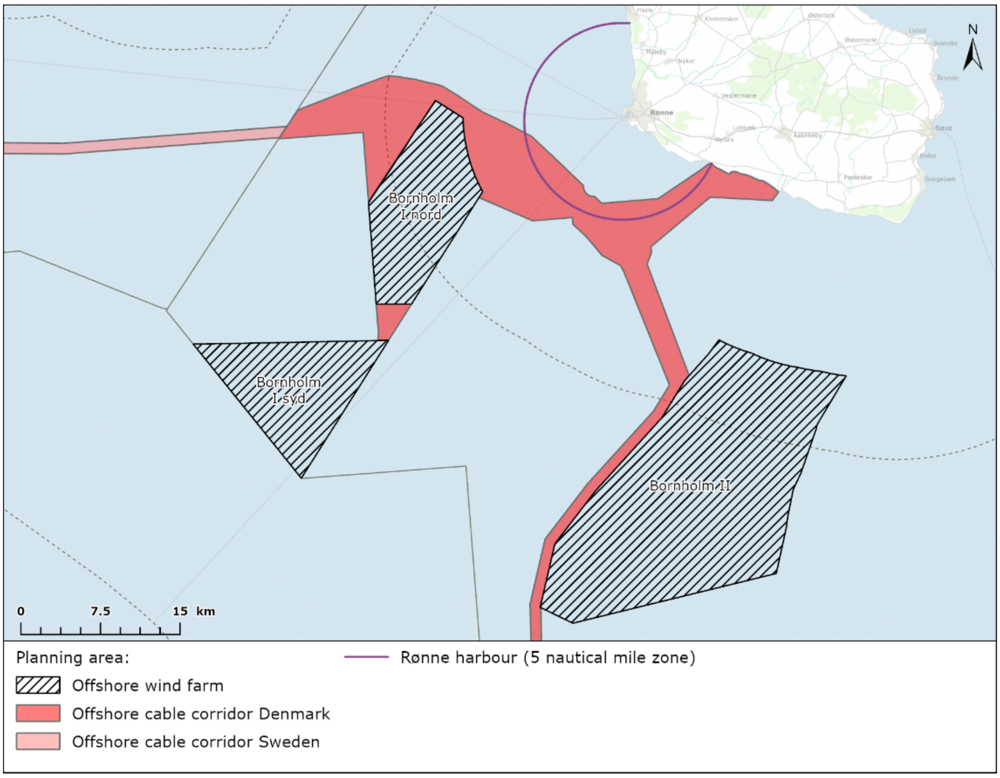



Figure 5-5 Indication of the area around Rønne with a radius of 5 nautical miles.

#### 5.4.1.1 Compass disturbances

HVDC cables can give rise to static magnetic fields which can affect the compass display on passing ships. However, most larger and commercial ships will use electronic equipment and electronic charts (ECDIS), which are not disturbed by the static magnetic fields. Compass disturbances will thus primarily be able to disturb smaller ships and pleasure boats when passing the HVDC cables.

The magnitude of the possible compass misalignment depends on various conditions such as the current in the cable, the distance from the cable to the water surface, and the distance between conductor and return conductor. There are various conditions that can limit the resulting magnetic field. In particular, bundled cables, where conductor and return conductor are close to each other, will result in the influence of the total magnetic field being minimized. The final design will thus be able to reduce any impact, just as the cable will be marked on charts and its presence thus known to passing ships.

Possible compass disturbances are not considered to be an obstacle to the project, although any risk-reducing measures in connection with the detailed cable design must be assessed.

### 5.4.2 Fisheries

The fishery will be affected by Energy Island Bornholm, and the commercial impact is assessed in a separate technical report on the fishery.

In connection with construction and decommissioning activities, exclusion zones will prevent fishermen from sailing in areas with construction activities. In terms of navigational safety, prohibited areas must be marked and communicated in Notices for Mariners and will thus constitute known obstacles.

Within 200 m of submarine cables, after establishment of the wind farms, there will be a ban on fishing with tools that affect the seabed, such as bottom trawls. Within the offshore wind farms, there are basically no restrictions, and fishermen are therefore free to move around in the areas. Activities with bottom trawling gear may, however, be limited as a result of cables internally in the offshore wind turbine areas, just as activities with longer trawls may in practice be hindered within the areas with offshore wind turbines.

In connection with the HAZID workshop, consultation responses were received from Bornholm's Trolling Club, see ref. /1/. Since it will not be prohibited to sail within the offshore wind farms, local fishermen look positively on the opportunities for fishing at the many wind turbine foundations, which will form fertile ground for new fauna and life in the area.

It is therefore to be expected that some larger commercial fishermen will in the future refrain from fishing in the areas with offshore wind turbines, while at the same time that angling activities will continue between the offshore wind turbines. In terms of navigational safety, fishermen in the area will not move along fixed routes, but to a greater extent sail crisscrossing between the wind turbines.

The collision risk for the fishermen's general movements along routes by and through the wind turbine areas is included under section 5.2. The more local movements within the areas can also give rise to collisions with the wind turbines as a result of deliberately sailing close to the wind turbines. However, this is a general and accepted risk when sailing within areas with wind turbines.

### 5.4.3 Pleasure boats

In connection with construction and decommissioning activities, prohibited areas will be established where unauthorized persons - including pleasure boats - will not have access. Marking and information must be coordinated, but the activities are also assessed not to pose a greater risk for pleasure boats, which will be able to avoid these areas.

During the operational phase, there will be access to sailing within the offshore wind farms. There is a greater activity of pleasure boats between Rønne and the area at Sassnitz above Rønne Banke, see section 4.1.2. This traffic will be able to continue unimpeded after the establishment of the wind farm, as it runs west of Bornholm I. In addition, the sailing patterns of pleasure boats are more sporadic in the area, and collisions could occur when sailing between the wind turbines. The wind turbines will be actual excursion destinations, and it is to be expected that pleasure boats will sail the area to a certain extent.

In connection with sailing close to the wind turbines, collisions with the wind turbine foundations may occur. In addition, there will be a risk of masts on sailboats colliding with the wind turbine blades. It is therefore essential to ensure a certain clearance from sea level to the lower wing tip. In this connection, the Danish Maritime Authority requires a clearance of at least 20 m from sea level highest astronomical tide (HAT) to the lower wing tip. In addition, the Danish Maritime Authority requires that foundations must be constructed as collision-friendly, so that the least possible damage occurs in the event of a collision. For the currently proposed wind turbines, there will be a clearance from mean water level (MSL) to the lower tip of the blade of 30 m, which complies with the Danish Maritime Authority's minimum requirements.

The wind farm's impact on the activities of pleasure boats in the area is therefore assessed as small.

#### 5.4.4 Radar disturbances

General impact of radars and radio chains is assessed in a separate technical report. Specifically for ship traffic, however, interference with radars could affect navigational safety, and the situation was commented on at the HAZID workshop as a risk of reduced overview, see ref. /1/. The risk was particularly commented on in connection with sailing in a sailing corridor through Bornholm I, in relation to an overview of any crossing maintenance traffic.

Experiences with false echoes at Sprogø in the Great Belt were mentioned at the HAZID workshop, but beyond that no examples of major, known radar disturbances were mentioned. With the establishment of more and more wind farms, more challenges with radar shadows and false echoes may appear.

Based on input from the HAZID workshop, the greatest risk of reduced overview due to radar shadows is assessed to occur around the corners of the offshore wind farms, where ship traffic meets from different sides. A focus area with a large volume of traffic will be the northern part of Bornholm I nord, where passage to and from the precautionary area should be carried out with caution in advance. The navigation corridor defined in the Maritime Spatial Plan for Bornholmsgat, see Figure 3-5, however, includes a safety margin, so that there is an area between the planning area and the main traffic, so that westbound traffic north of Bornholm I nord will be able to orient themselves before sailing into the precautionary area.

### 5.5 SAR operations – rescue operations

There will initially be no restrictions in relation to sailing between the wind turbines, and with more than 1,000 m between the offshore wind turbines, it is estimated that search and rescue operations can still take place in the area after the construction of the offshore wind turbines for Energy Island Bornholm.

### 5.6 Cumulative projects

The ongoing expansion of wind power means that several wind farms are planned in the area between Sweden, Germany, and Bornholm as described in section 3.1.

The shipping corridor between the wind farms Bornholm I nord and syd is planned to take into account the location and development of wind turbines in German waters, and the routes through the area of Energy Island Bornholm are not expected to be further affected by other wind farms. Skåne Havsvindpark is for instance located on the other side of TSS Bornholmsgat and as such does not affect traffic in the area of Energy Island Bornholm.

Since several wind farms are planned to be constructed in the Baltic Sea, it is expected that this will further condense some of the traffic that currently sails outside the main routes, in the same way that the traffic in connection with the construction of Energy Island Bornholm is expected to be moved outside the planning areas. Straightening and densifying the traffic could give rise to more collisions within the individual routes, but at the same time could also reduce the risk of collisions at route crossings. The risk of collisions with wind turbines will naturally increase with the establishment of more wind farms; especially the risk of drifting collisions, as blackouts / machine failures will occasionally occur. The establishment of Energy Island Bornholm will thus, as well as other wind farms in the area, contribute to the overall risk increasing. An overall coordination of ship traffic (HELCOM) could be advantageous in relation to the continued expansion. Not just around Energy Island Bornholm, but for the Baltic Sea as a whole. Locally, for Energy Island Bornholm, neighbouring projects are not considered to have a major influence.

# 6. CONCLUSION AND RECOMMENDATIONS

It is generally concluded that the establishment of offshore wind turbines within the framework of the strategic environmental assessment, as well as the laying of cables to Bornholm and between Bornholm and Zealand, will be possible while maintaining navigational safety in the area at an acceptable level.

Based on the analysis of ship traffic, as well as potential hazards and possible risk-reducing measures, the most significant impacts on navigational safety related to the construction, operation, and decommissioning of Energy Island Bornholm are listed below.

Significant impacts during construction and decommissioning of the offshore wind farms:

- Construction traffic to and from the area will interact with other traffic in the area. The concrete routes for construction traffic will depend on the choice of working port and some routes will be able to cross main traffic corridors.
- Within the planning areas, the presence of construction vessels and vessels with limited manoeuvrability will constitute a local risk.
- In connection with cable laying, work vessels will have to operate within the planning areas, between the planning areas and Bornholm, and between Bornholm and Zealand. In this connection, several densely trafficked corridors will have to be crossed by construction traffic, some of which vessels will have limited manoeuvrability.

Risk-reducing measures during construction and decommissioning of the offshore wind farms:

- Construction traffic to and from the planning areas, as well as work traffic related to cable laying, will follow general maritime rules. Special attention should be paid to any crossing of main traffic corridors.
- All construction activities must be carefully planned, and the final planning must be assessed in accordance with the Danish Maritime Authority's guidance for construction works at sea. Risk-reducing measures should be determined in dialogue with the Danish Maritime Authority.
- Construction activities should, in agreement with the Danish Maritime Authority, be notified in Notices to Mariners (NtM). Additional communication to pleasure boats and fishermen should be considered.
- For vessels with limited manoeuvrability, several risk-reducing measures should be considered, including the use of a safety zone around the construction vessels, relevant navigation markings and lights on the construction vessels, as well as the possible use of a deflector vessel. The final risk-reducing measures should be determined for the specific project in agreement with the Danish Maritime Authority.

Significant conclusions after establishment of the offshore wind farms are:

- The main traffic corridors through TSS Bornholmsgat and TSS Adlergrund respectively, north and south of the planning areas will not be affected by Energy Island Bornholm.
- Sailing will be permitted between the wind turbines. Pleasure boats and anglers are expected to a certain extent to sail in the areas with offshore wind turbines, which could constitute recreational excursion destinations.

Significant impacts after establishment of the offshore wind farms are:

- The wind turbines will constitute visible obstacles in the area, just as they will be visible on radars.
- Sailing will be permitted between the wind turbines, but commercial ships and most fishermen are assessed to be limited in practice in their ability to navigate the area. This means that most of the ship traffic must now follow the routes around the planning areas.
- The main traffic routes around the planning areas are heavily trafficked, and it cannot be avoided that ships will experience blackouts / machine failures at intervals. Depending on the wind conditions, this will give rise to the risk of drifting ships colliding with the offshore wind turbines.
- Ships using corridors in and around the planning areas will have to deal with the offshore wind turbines, and the space for evasive manoeuvres in connection with potential ship-ship collisions will be affected by the presence of the offshore wind turbines.
- Especially the area between Rønne and TSS Bornholmsgat at the precautionary area – north of the planning area Bornholm I nord – is heavily trafficked, and ship traffic in this area is expected to be further concentrated after the establishment of offshore wind turbines in the planning area Bornholm I nord. The total ship collision frequency after the establishment of Energy Island Bornholm's offshore wind farms and the rerouting of ship traffic results in a small increase in ship collisions precisely in the precautionary area. Collisions in other areas, where ship traffic is displaced by the offshore wind turbines, will of course become less frequent. Future changes in traffic patterns as a result of cumulative projects in the area will also further affect the traffic density, e.g., in the precautionary area.
- The consequences in the event of ship-ship collisions or ship-wind turbine collisions can be great given the type of vessels sailing in the area. Both collisions between ships and collisions between ships and offshore wind turbines can result in material damage, personal injury, and damage to the environment in the event of an oil spill from the ships. However, collision scenarios vary from glancing to head-on collisions. It is also estimated that the most frequent collisions between ships and offshore wind turbines will occur in connection with blackout / machine failure and thus at a lower drifting speed.
- Potentially greater environmental consequences from both ship-ship collisions and ship-wind turbine collisions will be able to spread across borders to German and Swedish waters. However, this is no different from the consequences of a possible ship-ship collision before the establishment of offshore wind turbines in connection with Energy Island Bornholm.
- In Danish waters, according to the cable order, ref. /17/, there is a prohibition of anchoring in a zone of 200 m from submarine cables. The cable routes within the planning areas, between the planning areas and Bornholm and between Bornholm and Zealand (within the Danish EEZ) will therefore give rise to a ban on anchoring and a ban on fishing with bottom trawling gear. This may affect the possibilities for anchoring in the area off Rønne harbour.

Risk-reducing measures in connection with the design and operation of the offshore wind turbines:

- When establishing Energy Island Bornholm's offshore wind turbines, general risk-reducing measures should be implemented. These include marking the offshore wind farms on charts, marking the offshore wind farms based on IALA standards for sea marking, and adding navigation lights on the wind turbines. In addition, the offshore wind turbines should be designed and constructed as collision-friendly, so that the consequences of a possible collision are minimized, just as emergency procedures must be drawn up for shutdown in the event that a ship is on a collision course.
- In connection with light marking, it should be considered whether this should be coordinated with nearby wind farms in German waters, so that the areas with wind farms appear uniform.
- The offshore wind turbines are planned with a minimum distance from the mean water level to the lower blade tip of approximately 30 m, which reduces the risk of collisions between wind turbine blades and yacht masts.
- The precise location of offshore wind turbines in the northernmost part of Bornholm I nord, as well as along the corridor between Bornholm I nord and Bornholm I syd, should be further assessed in future project phases, e.g., in connection with the risk of radar shadowing and securing an overview for ships that must pass the areas.
- The location of substations within the planning areas should be considered in connection with future project phases. If these are placed at the outer edge of the planning areas – and particularly near primary navigation corridors to the north and south – they will contribute to an increased risk of collision. If they are placed inside among the offshore wind turbines, they will only contribute to the risk in the area to a lesser extent, as the outer rows of offshore wind turbines will partially shield them from collisions.
- Planning of cable routes in the vicinity of Rønne should be coordinated with the Port of Rønne.
- In addition to the layout of the wind farm and mitigation measures to be implemented by the project, major initiatives such as the Sea Traffic Management initiative STM BALT SAFE[1] are also underway in the Baltic Sea region to generally increase navigational safety. Such initiatives should be followed by the project, and the project should potentially contribute to a cooperation to improve navigational safety in the area.

[1] https://www.seatrafficmanagement.info/projects/stm-balt-safe/

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# APPENDIX 1
# IWRAP MODELLING DETAILS

## A1.1 Modelling principles / collision models

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

The IWRAP model takes into account ship-ship collisions and collisions (ship-object collisions). IWRAP uses a geometric-statistical model in the sense that it considers ship traffic as moving along defined routes with statistical lateral distributions. IWRAP does not model the trajectory of the individual ships. The level of detail in the model input, e.g., bathymetry and the degree of detail in the interpretation of the results must reflect this. For details on how the IWRAP model works, please refer to the IWRAP User Manual /4/ and to the IALA wiki page on IWRAP /5/. In the following, the settings used in the models are described.

The value of the causation factor is of course essential to the model and shown in Table A1 1. IALA, together with a group expert, has defined a set of globally applicable causation factor values. The total number of collisions is the number of geometric candidates multiplied by the causation factor. So one part of IWRAP is geometry and statistics, and the other part is the human factor.

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

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

**Drifting ships**

In Figure A1 1, the operating parameters used are shown. In connection with an engine failure, it is possible that the error is rectified so that the ship can again be manoeuvrable before it drifts towards an obstacle. The repair time is modelled in IWRAP as a cumulative Weibull distribution. In addition, there will often be the possibility that a drifting ship will be able to drop anchor and thus prevent a collision or grounding. In the Baltic Sea between Germany and Sweden, the depth varies from 40 m to 45 m and lower closer to land. The probability of successful anchoring in case of engine failure is considered to be the default parameter for IWRAP of 70%. The anchoring parameters are also shown in Figure A1 1.

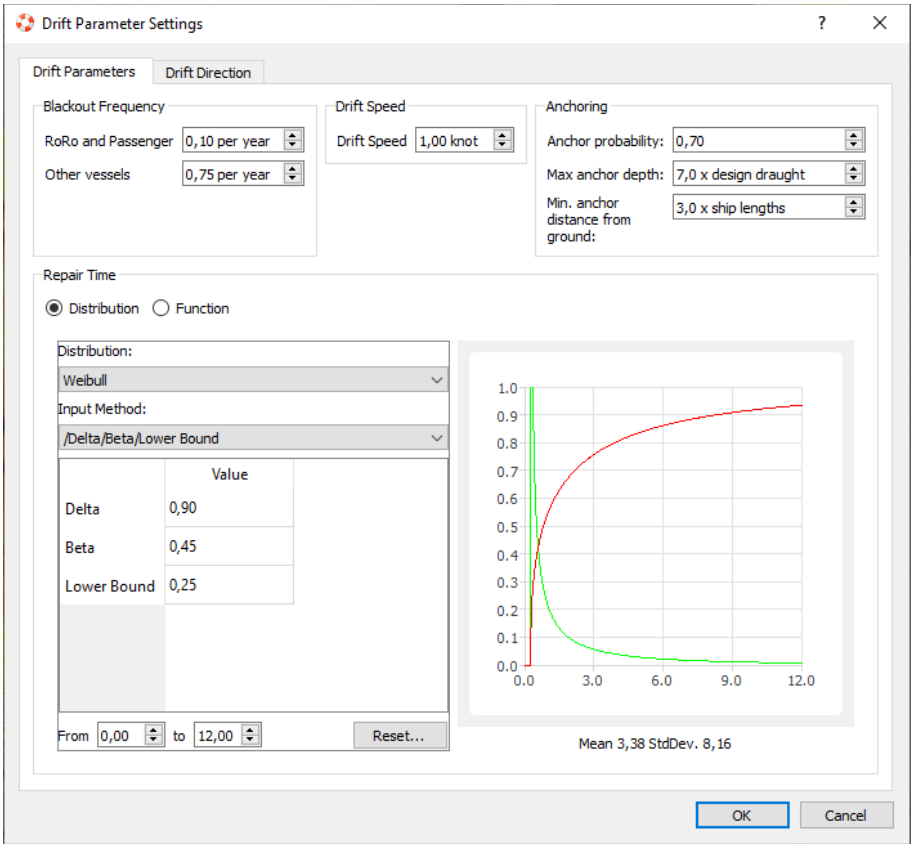


**Figure A1 1 Operating parameters and settings for drifting ships where speeds of 1 knot are used.**

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

The probability of drift in each direction is assumed to be given by the distribution of wind directions measured at Bornholm Airport cf. ref. /7/; see Figure A1 2. In 3.1% of the time there is no wind and thus no direction in which drift is modelled. This is not supported by IWRAP. Here a ship will always drift. This is considered conservative in the model results.

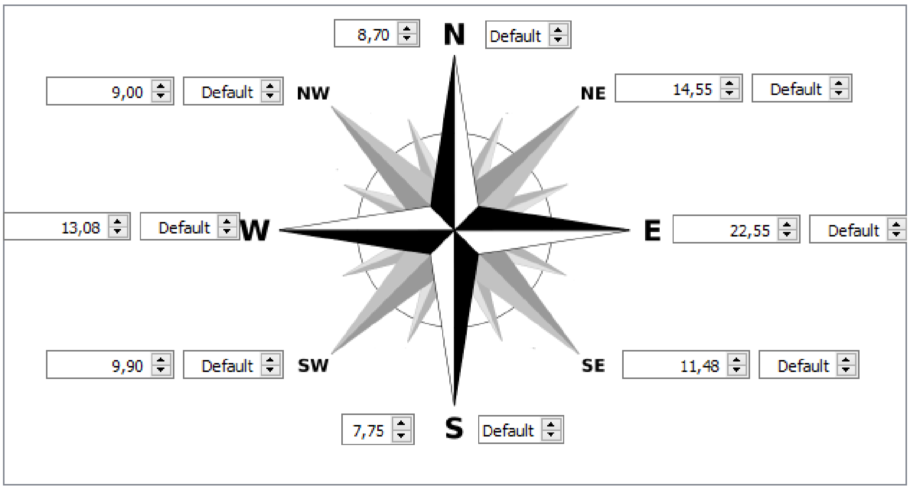


Figure A1 2 Probability of a ship drifting in a given direction, given as a percentage by the wind direction distribution from Bornholm Airport in ref. /7/.

### Routes and waypoints

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


Figure A1 3 Illustration of a route modelled in IWRAP, ref. /4/.

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

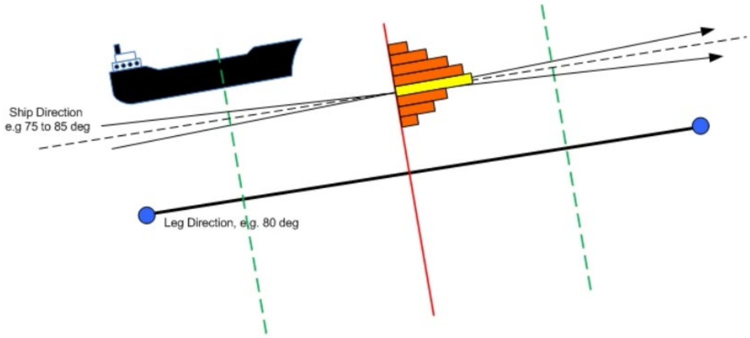


**Figure A1 4 Routes and counting of ship traffic as well as distribution on the route.**

## A1.2 Causation factors

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

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

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

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

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

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

# APPENDIX 2
# DETAILED INFORMATION ABOUT THE SHIP TRAFFIC

Detailed ship traffic counts for the 19 routes in terms of ship lengths and ship types are summarised in this section.

**Table A2 1 Counting of ship traffic on the identified routes in relation to ship lengths.**

| Length [m] | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 | Route 7 | Route 8 | Route 9 | Route 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-25 | 209 | 68 | 161 | 119 | 51 | 19 | 6 | 7 | 28 | 155 |
| 25-50 | 31 | 44 | 58 | 7 | 5 | 19 | 8 | 9 | 233 | 156 |
| 50-75 | 43 | 41 | 45 | 25 | 14 | 15 | 11 | 29 | 142 | 252 |
| 75-100 | 484 | 79 | 70 | 16 | 86 | 131 | 347 | 229 | 1825 | 4874 |
| 100-150 | 2020 | 50 | 3 | 105 | 91 | 9 | 85 | 148 | 1912 | 6591 |
| 150-200 | 194 | 443 | 2 | 450 | 0 | 0 | 87 | 131 | 1526 | 8312 |
| 200-300 | 1 | 12 | 2 | 0 | 0 | 0 | 21 | 59 | 524 | 4412 |
| 300-400 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 25 | 130 | 195 |
| 400- | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| **Total** | **2982** | **737** | **341** | **722** | **247** | **193** | **569** | **637** | **6321** | **24947** |

**Table A2 2 Counting of ship traffic on the identified routes in relation to ship lengths.**

| Length [m] | Route 11 | Route 12 | Route 13 | Route 14 | Route 15 | Route 16 | Route 17 | Route 18 | Route 19 |
|---|---|---|---|---|---|---|---|---|---|
| 0-25 | 10 | 5 | 23 | 18 | 19 | 1003 | 224 | 33 | 76 |
| 25-50 | 21 | 3 | 50 | 9 | 4 | 865 | 178 | 10 | 73 |
| 50-75 | 45 | 1 | 47 | 39 | 3 | 431 | 42 | 11 | 27 |
| 75-100 | 209 | 243 | 440 | 300 | 7 | 123 | 5 | 190 | 230 |
| 100-150 | 124 | 0 | 349 | 76 | 457 | 8 | 0 | 163 | 314 |
| 150-200 | 15 | 0 | 17 | 683 | 3043 | 4 | 0 | 2 | 97 |
| 200-300 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 1 | 33 |
| 300-400 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| 400- | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Total** | **424** | **252** | **931** | **1125** | **3533** | **2434** | **449** | **410** | **861** |

**Table A2 3 Counting of ship traffic on the identified Router in relation to the ship types.**

| | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 | Route 7 | Route 8 | Route 9 | Route 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Oil products tanker | 10 | 25 | 0 | 0 | 0 | 0 | 24 | 75 | 845 | 5478 |
| General cargo ship | 24 | 68 | 74 | 8 | 4 | 141 | 408 | 461 | 4707 | 17236 |
| Passenger ship | 243 | 465 | 8 | 556 | 0 | 0 | 7 | 11 | 131 | 1293 |
| Fast ferry | 2405 | 31 | 4 | 0 | 0 | 0 | 1 | 0 | 0 | 5 |
| Support ship | 37 | 24 | 12 | 10 | 175 | 0 | 10 | 10 | 154 | 149 |
| Fishing ship | 127 | 59 | 60 | 1 | 0 | 17 | 5 | 6 | 60 | 128 |
| Pleasure boat | 118 | 26 | 112 | 132 | 54 | 17 | 5 | 22 | 33 | 65 |
| Other ship | 18 | 39 | 71 | 15 | 14 | 18 | 109 | 52 | 391 | 593 |
| **Total** | **2982** | **737** | **341** | **722** | **247** | **193** | **569** | **637** | **6321** | **24947** |

**Table A2 4 Counting of ship traffic on the identified Router in relation to the ship types.**

| | Route 11 | Route 12 | Route 13 | Route 14 | Route 15 | Route 16 | Route 17 | Route 18 | Route 19 |
|---|---|---|---|---|---|---|---|---|---|
| Oil products tanker | 15 | 0 | 43 | 26 | 1 | 0 | 1 | 2 | 85 |
| General cargo ship | 319 | 3 | 770 | 357 | 7 | 124 | 5 | 340 | 568 |
| Passenger ship | 6 | 0 | 4 | 680 | 3500 | 4 | 113 | 0 | 13 |
| Fast ferry | 1 | 0 | 0 | 0 | 0 | 1228 | 0 | 0 | 0 |
| Support ship | 32 | 242 | 33 | 15 | 3 | 73 | 1 | 3 | 20 |
| Fishing ship | 17 | 6 | 29 | 7 | 8 | 13 | 136 | 34 | 113 |
| Pleasure boat | 1 | 1 | 15 | 15 | 10 | 12 | 161 | 4 | 1 |
| Other ship | 33 | 0 | 37 | 25 | 4 | 980 | 32 | 27 | 61 |
| **Total** | **424** | **252** | **931** | **1125** | **3533** | **2434** | **449** | **410** | **861** |