

Study on maritime safety and wind farms in the Gulf of Bothnia

Formal Safety Assessment

Ramboll

TRAFICOM/174207/02.03.00/2025



Date of publication
2025-04-29

Title of publication
Study on maritime safety and wind farms in the Gulf of Bothnia, Formal Safety Assessment

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Commissioned by, date
Finnish Transport and Communications Agency Traficom, 17.09.2024

Publication series and number
Traficom Research Reports 13/2025
ISSN (e-publication) 2669-8781
ISBN (e-publication) 978-952-311-974-1

Keywords
Ship traffic, wind farms, collision and allision, formal safety assessment, open-water conditions, maritime planning

Abstract
The present study investigates the open-water situation – the ice-free period – and the possible impact on the ship traffic from wind farm development in the Gulf of Bothnia. The main purpose of the study is to identify critical/key areas in the Gulf of Bothnia that need to be preserved for future shipping activities, ensuring the continued safety, sustainability, and efficiency of maritime transport. These findings will inform decision-making processes aimed at optimizing the use of the sea area between maritime transport and wind farm development while considering ethical values.

Contact-person
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Language
English

Confidence status
Public

Pages, total
204

Distributed by
Finnish Transport and Communications Agency Traficom

Published by
Finnish Transport and Communications Agency Traficom

Foreword

The Gulf of Bothnia plays a significant role in the foreign trade of both Finland and Sweden, and in promoting the green transition. The shipping routes and coastal ports in the Gulf of Bothnia form a key logistical network that supports the transport needs of the region's industry, economic growth and security of supply. Part of this sea area is also suitable for the construction of wind farms, and the clean energy they produce can support environmental goals in both Finland and Sweden in the near future. However, many potential wind farms are located in the vicinity of important shipping routes and ports, which poses challenges for the development of operations. Therefore, it is important to produce a comprehensive analysis that helps to minimize the risks to shipping traffic arising from the construction of wind farms and maximize their benefits in the production of clean energy.

The aim of this study is to assess the risks to shipping traffic arising from the construction of wind farms in the Gulf of Bothnia and to present ways to manage them. The results are expected to support the decision-making of the Finnish and Swedish authorities when seeking an optimal solution for coordinating shipping and wind power operations in this sea area. The report was commissioned by the Finnish Transport and Communications Agency, the other members of the steering group are the Finnish Transport Infrastructure Agency and the Swedish Maritime Administration, and the practical implementation of the work is being carried out by Ramboll. This work is also part of a broader study process, which will address the impacts of wind farms on winter shipping, as well as their benefits and costs for Finland and Sweden. Finally, thanks to all stakeholders who have participated in the preparation of this report.

Helsinki, 31 03 2025

Valtteri Laine

Chief Advisor

Finnish Transport and Communications Agency, Traficom

Alkusanat

Perämeren alueella on merkittävä rooli sekä Suomen ja Ruotsin ulkomaankaupan kuljetuksissa että vihreän siirtymän edistämisessä. Perämeren laivareitit ja rannikon satamat muodostavat keskeisen logistisen verkoston, joka palvelee alueen teollisuuden kuljetustarpeita, talouskasvua ja huoltovarmuutta. Osa tästä merialueesta soveltuu myös tuulivoimapuistojen rakentamiseen, ja niiden tuottama puhdas energia voi lähitulevaisuudessa tukea ympäristötavoitteita niin Suomessa kuin Ruotsissa. Kuitenkin monet potentiaaliset tuulivoima-alueet sijaitsevat tärkeiden laivareittien ja satamien läheisyydessä, mikä tuo haasteita toiminnan kehittämiseksi. Siksi on tärkeää tuottaa kattavaa analyysia, joka auttaa minimoimaan tuulivoimapuistojen rakentamisesta aiheutuvia riskejä laivaliikenteelle ja maksimoimaan niiden hyödyt puhtaan energian tuotannossa.

Tämän selvityksen tavoitteena on arvioida tuulivoimapuistojen rakentamisesta aiheutuvia riskejä Perämeren laivaliikenteelle ja esittää keinoja niiden hallitsemiseksi. Tulosten toivotaan tukevan Suomen ja Ruotsin viranomaisia päätöksenteossa, kun etsitään optimaalista ratkaisua laivaliikenteen ja tuulivoimatoiminnan yhteensovittamiseen tällä merialueella. Selvityksen tilaajana on Liikenne- ja viestintävirasto, ohjausryhmän muihin jäseniin kuuluvat Väylävirasto ja Ruotsin merenkululaitos, ja työn käytännön

toteutuksesta vastaa Ramboll. Tämä työ on myös osa laajempaa selvitysprosessia, jossa tullaan vielä käsittelemään tuulivoimapuistojen vaikutuksia talvimerenkulkuun sekä niiden hyötyjä ja kustannuksia Suomelle ja Ruotsille. Lopuksi kiitokset kaikille sidosryhmien edustajille, jotka ovat osallistuneet tämän selvityksen laadintaan.

Helsinki, 31 03 2025

Valtteri Laine

Johtava asiantuntija

Liikenne- ja viestintävirasto Traficom

Förord

Bottenvikens område spelar en betydande roll både i Finlands och Sveriges utrikeshandelstransporter samt i främjandet av den gröna omställningen. Bottenvikens sjörutter och kusthamnar utgör ett centralt logistiskt nätverk som betjänar regionens industriella transportbehov, ekonomisk tillväxt och försörjningsberedskap. En del av detta havsområde är också lämpligt för byggande av vindkraftsparker och den rena energi som produceras kan på kort sikt stödja miljömål både i Finland och Sverige. Emellertid ligger många potentiella vindkraftsområden nära viktiga sjörutter och hamnar, vilket innebär utmaningar för utvecklingen av verksamheten. Därför är det viktigt att ta fram en omfattande analys som hjälper till att minimera de risker som byggandet av vindkraftsparker innebär för sjöfarten och maximera deras fördelar för produktion av ren energi.

Syftet med denna utredning är att bedöma de risker som byggandet av vindkraftsparker innebär för Bottenvikens sjöfart och föreslå metoder för att hantera dessa. Förhoppningen är att resultaten ska stödja Finlands och Sveriges myndigheter i beslutsfattandet när man söker den optimala lösningen för att samordna sjöfart och vindkraftsverksamhet på detta havsområde. Beställaren av utredningen är Transport- och kommunikationsverket, till övriga medlemmar i styrgruppen hör Trafikledsverket och Sjöfartsverket i Sverige. Ramboll ansvarar för det praktiska genomförandet av arbetet. Detta arbete är en del av en större utredningsprocess där man senare kommer att behandla vindkraftsparkernas påverkan på vintersjöfarten samt deras fördelar och kostnader för Finland och Sverige. Slutligen tackar vi alla de representanter för intressenterna som har deltagit i utarbetandet av denna utredning.

Helsingfors, den 31 Mars 2025

Valtteri Laine

Ledande expert

Transport- och kommunikationsverket Traficom

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1 Introduction

Shipping routes in the Gulf of Bothnia between Finland and Sweden are vital for various industrial sectors of both countries, facilitating smooth maritime transportation and logistics operations. However, parts of the sea area are also relevant for potential construction of offshore wind farms (OWFs) contributing to the green energy transition. Wind farm developers have during several years performed initial surveys of relevant areas, and a lot of factors influence the selection of potential wind farm areas. These factors include ship traffic as one part, but more driving forces are factors such as water depths, soil conditions, access to shore-based power grids, and a plethora of environmental conditions. Currently, several potentially interesting areas from a wind farm development perspective intersect with existing shipping routes in the entire Gulf of Bothnia – from the southern Bothnian Sea to the northernmost part of the Bay of Bothnia.

On behalf of the Finnish Transport and Communications Agency (Traficom), Ramboll has therefore performed the study documented in the present report. The steering group for the project included Traficom, the Finnish Transport Infrastructure Agency (FTIA), and the Swedish Maritime Administration (SMA).

The main purpose of the study is to identify critical/key areas in the Gulf of Bothnia that need to be preserved for future shipping activities, ensuring the continued safety, sustainability, and efficiency of maritime transport. These findings will inform decision-making processes aimed at optimizing the use of the sea area from different perspectives while considering ethical values. The study focuses on open-water conditions and hence the results do not include the effect of ice and the impact on winter navigation.

The study adheres to the risk assessment guidelines outlined in the International Maritime Organization's (IMO) Formal Safety Assessment (FSA), Ref. /1/, adapted to addressing various scenarios and cumulative effects related to the implementation of OWF plans and the evolution of maritime traffic in the study area.

1.1 Terms and abbreviations

Abbreviation	Description
AIS	Automatic identification system
BSH	Bundesamt für Seeschifffahrt und Hydrographie
COLREG	Convention on the International Regulations for Preventing Collisions at Sea
DNV	Det Norske Veritas
EEZ	Exclusive economic zone
EMCIP	European Marine Casualty Information Platform
EMSA	European Maritime Safety Agency
FSA	Formal Safety Assessment
FTIA	Finnish Transport Infrastructure Agency (in Finnish Väylävirasto)
GIS	Geographic Information System
GOFREP	Gulf of Finland Reporting
HAZID	Hazard Identification
HELCOM	Baltic Marine Environment Protection Commission
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IMO	International Maritime Organisation
IOPC	International Oil Spill Conference
MARIN	The Dutch maritime research institute
NATO	The North Atlantic Treaty Organization
OWF	Offshore Wind Farm
PIANC	World Association for Waterborne Transport Infrastructure
RCM	Risk Control Measure
RCO	Risk Control Option
SAR	Search and rescue
SOLAS	International Convention for the Safety of Life at Sea
SMA	Swedish Maritime Administration (in Swedish Sjöfartsverket)
TRAFICOM	Finnish Transport and Communications Agency (in Finnish Liikenne- ja viestintävirasto)
TSS	Traffic separation scheme
VHF	Very high frequency
VTS	Vessel Traffic Service

1.1.1 Central definitions

Indicative, possible routing is a hypothetical ship traffic routing defined on basis of hazard identification and a worst-case layout of wind farm areas. The actual ship traffic routing in the future will most likely differ from this and the indicative, possible routing shall not be seen as a specific recommendation.

2 Executive summary

The main purpose of this study is to identify critical/key areas in the Gulf of Bothnia that need to be preserved for future shipping activities, ensuring the continued safety, sustainability, and efficiency of maritime transport.

The current Finnish and Swedish Maritime Spatial Plans, Ref. /2/ and /3/, indicate areas for various purposes including areas for shipping routes, areas for offshore energy production, fishing areas, areas with cultural values, etc. However, the markings in the plan are not intended to reserve areas for a particular purpose and should not be interpreted as such. Activities may also take place other than in the areas identified in the plan.

The current study has addressed the ship traffic in relation to potential wind farm development areas, some of which overlap with currently used ship traffic routes. The potential wind farm development areas therefore do not necessarily align with the Maritime Spatial Plans and current ship traffic routes. In a future planning process where wind farm development areas are selected or commissioned through public processes, it is important to consider also the interests of the ship traffic for the specific wind farm, and potential cumulative effects from nearby wind farms.

The present study addresses only an open-water condition, i.e., the approximately five months per year where the area is not affected by ice buildup and more challenging winter conditions. The study shows that for the open-water situation, wind farm development could possibly occur in all the currently proposed areas, once the areas have been adjusted for needed shipping corridors. With the relatively limited ship traffic density in the area – as compared to the North Sea or the southern part of the Baltic Sea – the overall collision and allision frequencies are generally assessed to be at an acceptable level during the open-water situation. However, the ship traffic needs to navigate around or through certain wind farm areas, and there must be a sufficient safety zone around the ship traffic routes. When defining the layout of the wind farms, considerations must therefore be done to include sufficient space for the ship traffic routes as well as a safety space between the routes and the wind farm areas. It is recommended that a safety space is considered as early in the planning process as possible, e.g., by commissioning out only areas where at least a minimum safety space has already been reserved for nearby ship traffic routes.

The results of the study are based on an idealized route layout indicatively adapted to accommodate the wind farm areas. However, it is emphasized that the idealized route layout studied as basis for the present risk assessment will most likely not be seen in practise. The final ship traffic routes will depend on the actual developed wind farm areas which may be a subset of the currently studied wind farm areas, or even include new areas. It

is also emphasized that winter conditions and ice buildup in the area may significantly change the situation, and that interactions between turbines and ice buildup is a field of another current study commissioned by Finnish Transport Infrastructure Agency (FTIA) and expected completed in 2027. This leads to several uncertainties for the interactions between ships traffic and wind farm development during the winter season.

The results of the present study do not point to exact locations where wind farms should or should not be established. However, some central points are concluded from the study:

- Already without turbines in the area, winter and severe weather conditions require ships to use alternative routes. It is therefore necessary to ensure redundancy in the route network with possibilities for sailing both centrally in the Bothnian Sea and the Bay of Bothnia as well as along the coastlines. With the most severe winter conditions in the northern part of the Bay of Bothnia, this area is also the area creating the most uncertainty for the ship traffic routing in winter conditions.
- Longer corridors with turbines on both sides of ship traffic routes create a risk for additional collisions and allisions as well as more difficult conditions for search-and-rescue operations and environmental cleanup. The layout of wind farm areas should therefore as far as possible avoid longer corridors.
- Due to prevailing wind directions from south/southwest, blackout will often lead to ships drifting towards north/northwest. A significant contribution to ship-turbine allisions is assessed to be drifting ship impacts. Hence, wind farm locations north/northwest of main ship traffic routes are generally assessed to be more exposed than other wind farm areas.

While the open-water study generally shows an acceptable risk level, the situation during winter will likely change this conclusion. Hence the above general recommendations – as well as more detailed results and indicative risk reducing measures presented in this report – should be taken into account when addressing the increased risk in winter conditions.

3 Procedure for the analysis

The overall procedure for the analysis follows the FSA approach illustrated in the central part of Figure 1. In addition, the study is based on an initial data collection and finally reported in the present report. Each of the elements of the procedure are described in the following and related to the chapters of the report.

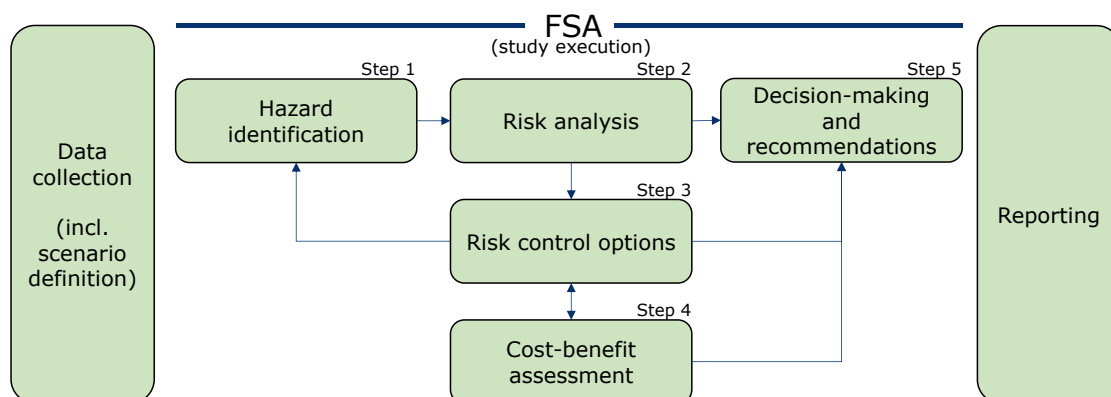


Figure 1. Overall methodology adhering to the IMO, FSA, Ref. /1/.

3.1 Scope and limitations

The main purpose of the study is to identify critical/key areas in the Gulf of Bothnia that need to be preserved for future shipping activities, ensuring the continued safety, sustainability, and efficiency of maritime transport. These findings will inform decision-making processes aimed at optimizing the use of the sea area between maritime transport and wind farm development while considering also the need for green energy and an overall sustainable development.

The study area is defined by the black line in Figure 2 including the Swedish EEZ and both the Finnish EEZ and the Finnish territorial waters. Some potential wind farm development areas, see Section 4.3, are located outside the study area, and while assessments concerning these areas are not detailed, the presence of ship traffic and potential wind farms outside the study area are addressed at the boundary of the study area.

The study is limited to the open water season, i.e., the situation without winter conditions and ice formation. However, ice build-up is often significant in the Gulf of Bothnia, and winter conditions therefore have a great impact on the ship traffic for a large part of the year. A separate study is underway via FTIA, where the ice formation, ice-turbine interactions and winter conditions affecting the ship traffic are investigated. While this study is expected to be completed in 2027, some aspects of winter navigation must be addressed in the present study.

data is described in Chapter 4, and the ship traffic is further analysed in Chapter 5.

The currently observed ship traffic and the potential wind farm development areas are studied in more detail to identify overlaps and propose indicative scenarios for co-existence of ship traffic and wind farms. These initial scenarios are defined in Section 5.2 as outset for a hazard identification and the risk assessment.

3.3 FSA – Study execution

The study involves a large area, important shipping routes, and potential wind farm development areas. The potential wind farm development areas will not all be developed in practice, and a final, cumulative situation for which to identify hazards and perform the risk assessment is unknown. Therefore, identifying specific hazards and risk control measures related to concrete areas cannot be done in detail as part of this study. The indicative scenarios defined as part of the data collection are therefore used to structure the study around relevant critical areas within the study area considering a generic, worst-case wind farm development.

3.3.1 Hazard identification

A hazard identification (HAZID) workshop was performed to involve and engage relevant stakeholders in a discussion on indicative ship traffic scenarios, and to identify relevant hazards, hazard causes, and critical areas/situations.

Accidents, hazard causes, and critical areas/situations were identified and discussed by the workshop participants in relation to shipping routes including information on potential future wind farm developments. Initial risk control measures related to establishment of shipping corridors and/or re-routing of ship traffic were included in form of the indicative scenarios, but the purpose of the HAZID was also to elaborate on these indicative routing options as basis for the following risk assessment, as well as identify especially critical areas/situations. Details on the hazard identification and the results, including idealized ship traffic routing scenarios, are found in Chapter 6.

3.3.2 Risk analysis

The risk analysis is based on the results of the HAZID workshop, and the idealized ship traffic routing developed on basis of the HAZID results.

It is emphasized that the idealized ship traffic routing shall not be seen as directly applicable in practice as it is not known which wind farm areas will be applied for and developed, and in which order. In fact, the worst-case

situation with full development of all proposed wind farms is highly unlikely to be realized in practice, and even in the unlikely situation where all potential areas are developed, they may not be fully exploited. The idealized ship traffic routing therefore only forms a basis for analysing the potential ship-ship collision and ship-turbine collision risk for the maximum windfarm developed area within the study area. In this way, the idealized ship traffic routing indicates specific ship traffic lanes to be considered for future ship traffic as well as critical areas throughout the study area.

The IALA recommended tool IWRAP, Ref. /4/, is used to estimate ship-ship collision and ship-turbine collision frequencies in a basis scenario as seen today, and in a situation with full exploitation of all currently proposed wind farm areas. Consequences of collision and collisions are not estimated in detail, but indicative consequences are estimated based on data on fatalities, property damage, and environmental damage resulting from historical ship casualties. In addition, the idealized ship traffic routing results in changes to the distances sailed, and an estimate of the additional travelling distances and corresponding CO₂ emissions are provided. Modelling principles for frequency modelling, consequence assessments, and evaluation of CO₂ emissions are all described in Chapter 7. An overall framework for assessment of the risk level is also described in Section 7.5 in relation to indicatively acceptable accident frequencies related to ship traffic and turbines.

Results from the IWRAP modelling and risk analysis are presented in Chapter 8.

3.3.3 Risk control options

The hazard identification and the initial risk assessment results showed possible hot spots for accidents and primarily for ship-turbine collisions. A number of possible risk reducing measures were identified in collaboration between Ramboll, Traficom, FTIA, and SMA. These risk control measures are described in Chapter 9.

The effectiveness of selected risk control measures is also evaluated in terms of carrying out specific model changes reflecting the implementation of a risk reducing measure. The overall, estimated capitalized effect of implementing each measure is estimated based on their effect on fatalities, property damage and environmental spill, i.e., their effect on the expected, annual risk level. It is emphasized that the effect is estimated as the annual effect considering only open-water conditions.

3.3.4 Cost-benefit assessment

The benefit of introducing specific measures will depend on the wind farm development areas, ship traffic routing, etc., as well as factors outside the scope of this study. Only indicative costs and benefits are therefore assessed for selected measures in relation to the idealized ship traffic routing,

and a qualitative assessment of the cost-benefit related to the presented risk control measures is given in Chapter 9.

3.3.5 Decision-making and recommendations

Finally, input to decision-making and recommendations is presented in Chapter 10 as conclusions of the FSA based on the HAZID process, the risk assessment and the evaluation of specific risk reducing measures. This involves elaboration on critical areas in the Gulf of Bothnia and central conditions that need to be preserved for future shipping activities to ensure the continued safety, sustainability, and efficiency of maritime transport.

4 Basic information and background data

The basis information underlying both the hazard identification and the risk assessment is described in the present chapter. Information has primarily been obtained through Traficom and available, public references.

4.1 General conditions in the Gulf of Bothnia

The Gulf of Bothnia is the northernmost part of the Baltic Sea and consists mainly of two parts; in the south is the Bothnian Sea (Selkämeri), and in the north is the Bay of Bothnia (Perämeri), see Figure 3. South of the Bothnian Sea lies the Sea of Åland (Ahvenanmeri) and the Archipelago Sea (Saaristomeri).

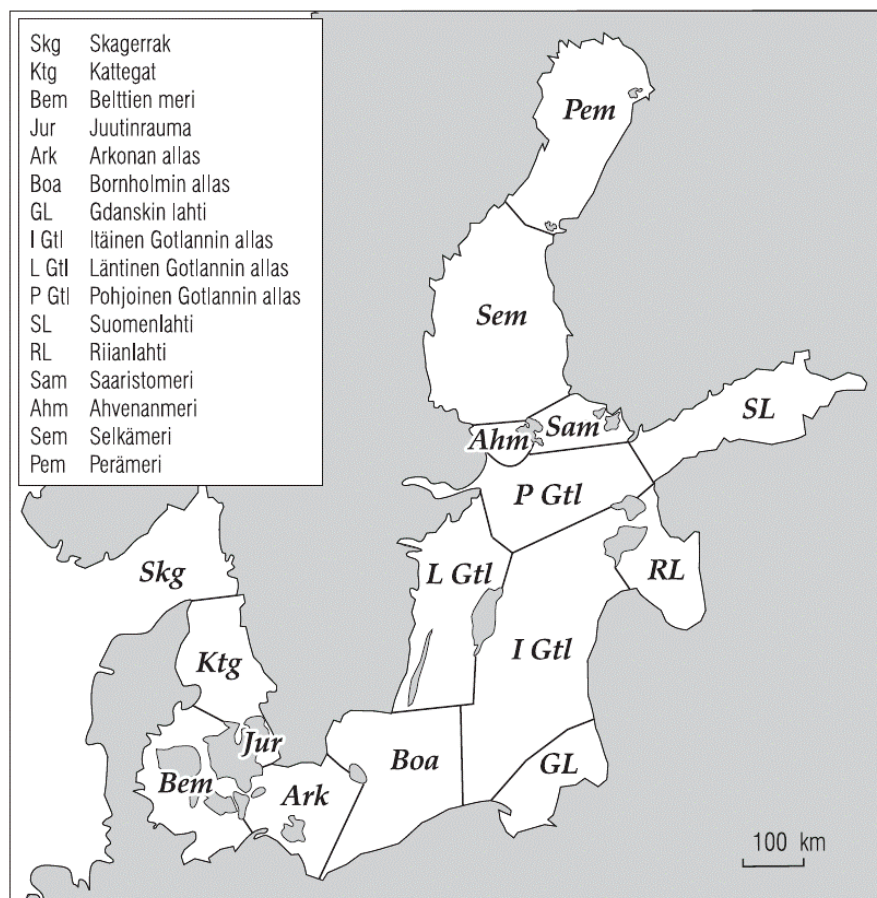


Figure 3. Areas of the Baltic Sea, Ref. /5/.

According to MarineFinland.fi, Ref. /5/, the average depth of the Bothnian Sea is 66m, and the largest depth is 293m, while the average and largest depth of the Bay of Bothnia is 41m and 146m respectively. The water depths are lower close to Finland, and the deepest points in the Bay of Bothnia and the Bothnian Sea are both located closer to Sweden.

The weather in the Gulf of Bothnia is related to its northern location and affected by strong autumn storms as well as ice buildup during autumn,

winter and spring. In general, ice can be found from October to May, especially in the Bay of Bothnia. The extent of ice varies from year to year as does the location of the ice which depends primarily on the weather. With westerly winds, the ice tends to move toward the Finnish coast whereas easterly winds push the ice towards the Swedish coast. The ice coverage and ice formations can have great variations even within the timespan of days to weeks.

In general, the dominant wind direction is from southwest as identified from Global Wind Atlas, ref. /6/, see Figure 4. It is also seen that wind from east is most rare, especially in the central part of the Bothnian Sea.

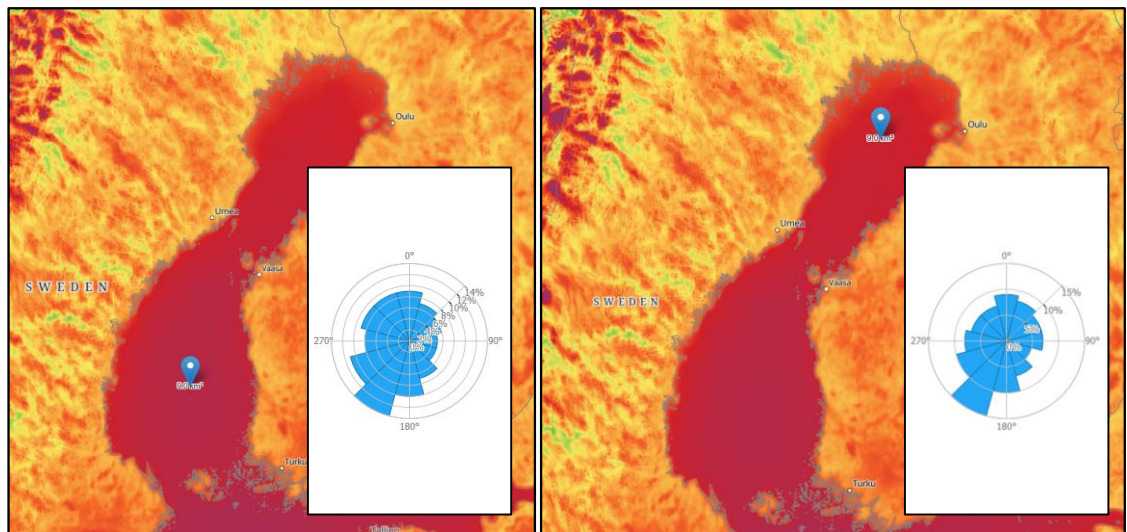


Figure 4. Distribution of wind directions in the Bothnian Sea and Bay of Bothnia. Source Global Wind Atlas, Ref. /6/.

Tide and tidal currents are generally insignificant in the area. The average water current speed is about 0.1-0.2 knots, but in narrow straits, it may rise to 1.0-2.0 knots, especially during severe weather conditions. The general surface current flow direction is seen in Figure 5. The current is generally characterised by a northbound flow along the Finnish coast in the Gulf of Bothnia and a southbound flow along the Swedish coast. Current loops are seen in the central parts of both the Bay of Bothnia and the Bothnian Sea. The stronger currents are generally associated with narrow straits, e.g., between the Bothnian Sea and the Bay of Bothnia (the Quark), and near Åland in the southern part of the Bothnian Sea.

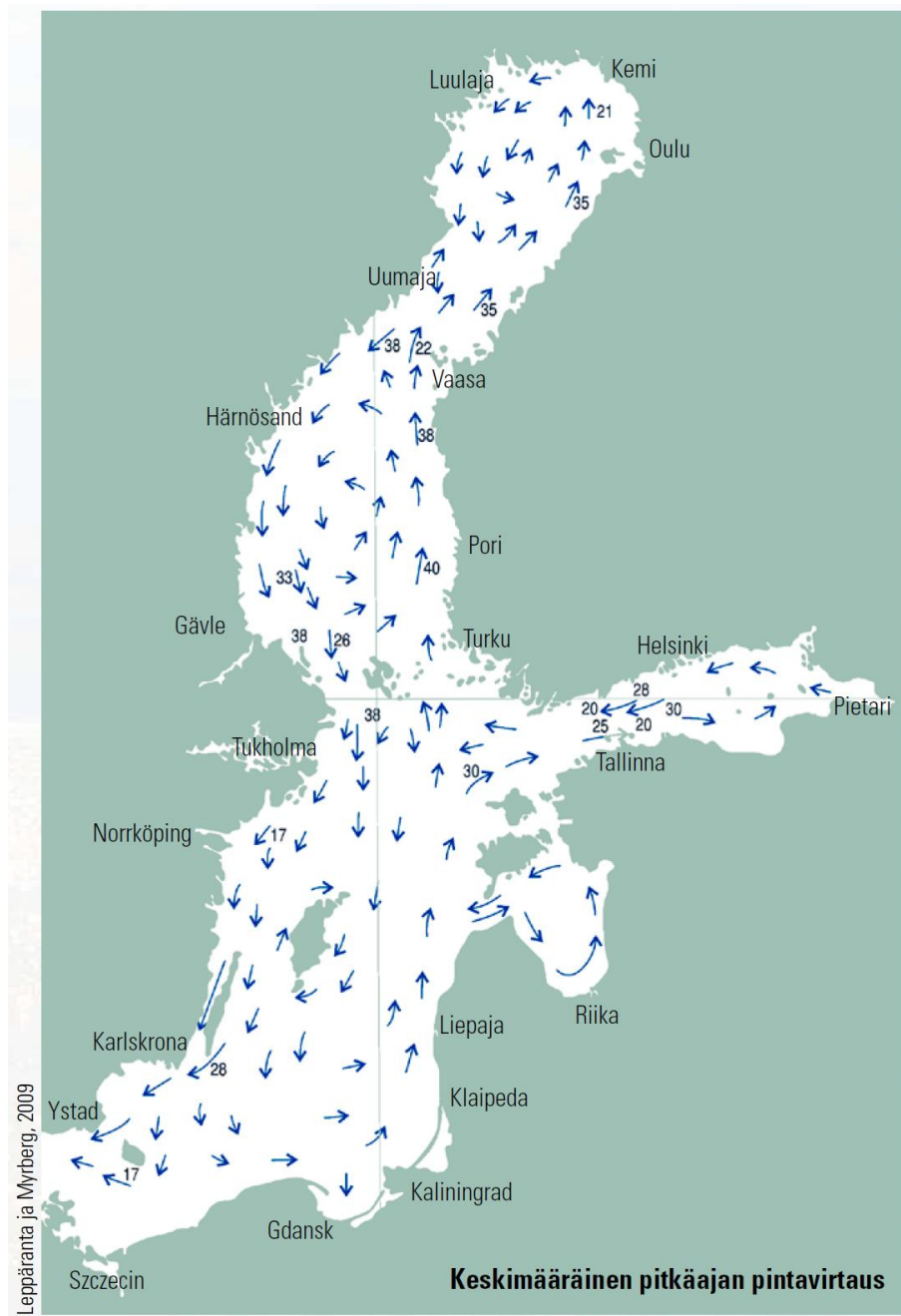


Figure 5. Main surface current movements in the Baltic Sea, Ref. /7/.

Another special feature of the Baltic Sea is the land rise with a rate of elevation of 0-9 mm per year, Ref. /7/. The fastest uplift is seen in the Bay of Bothnia with an uplift of 8-9 mm per year. On average, the effect of the uplift has been higher than the rise in sea-level. However, future climate changes may affect both water level and other features such as the ice cover during winter.

4.2 Ship traffic

Information on the historical ship traffic in the area is used for the assessment of the navigational safety. For this reason, data from the Automatic Identification System (AIS) is used as the basis to quantify ship

movements within the area of interest. Together with input from the HAZID-workshop, Section 3.3.1, this is the most important data source used in the risk assessment.

Ship traffic information is obtained from HELCOM through Traficom as a raw AIS data set including information on ship positions, ship type, length, speed, etc. The data is obtained for ice-free months from June to October, incl., for the years 2019, 2022, and 2023. Data covers all of the Bothnian Sea and the Bay of Bothnia and extends all the way south of the traffic separation scheme west of Åland where most of the traffic enters and leaves the Bothnian Sea.

The overall process for data validation is possible because of known Swedish and Finnish port arrival statistics in the Bay of Bothnia and the Bothnian Sea, Ref. /8/, /9/, as well as official registrations of the ship traffic across defined passage lines from HELCOM, Ref. /10/.

In the following is a general density plot of the ship traffic from the AIS data for the entire area. Figure 6 shows a density map of ship traffic in the Bothnian Sea and Bay of Bothnia, with traffic intensity represented by a color scale where yellow indicates low intensity, orange represents medium, red denotes high intensity, and dark red/black signifies maximum ship traffic density. The AIS data have been compared to the ship traffic numbers from HELCOM for verification to ensure that the quality of the data are at a reasonable level matching the amount of ships sailing in Gulf of Bothnia.

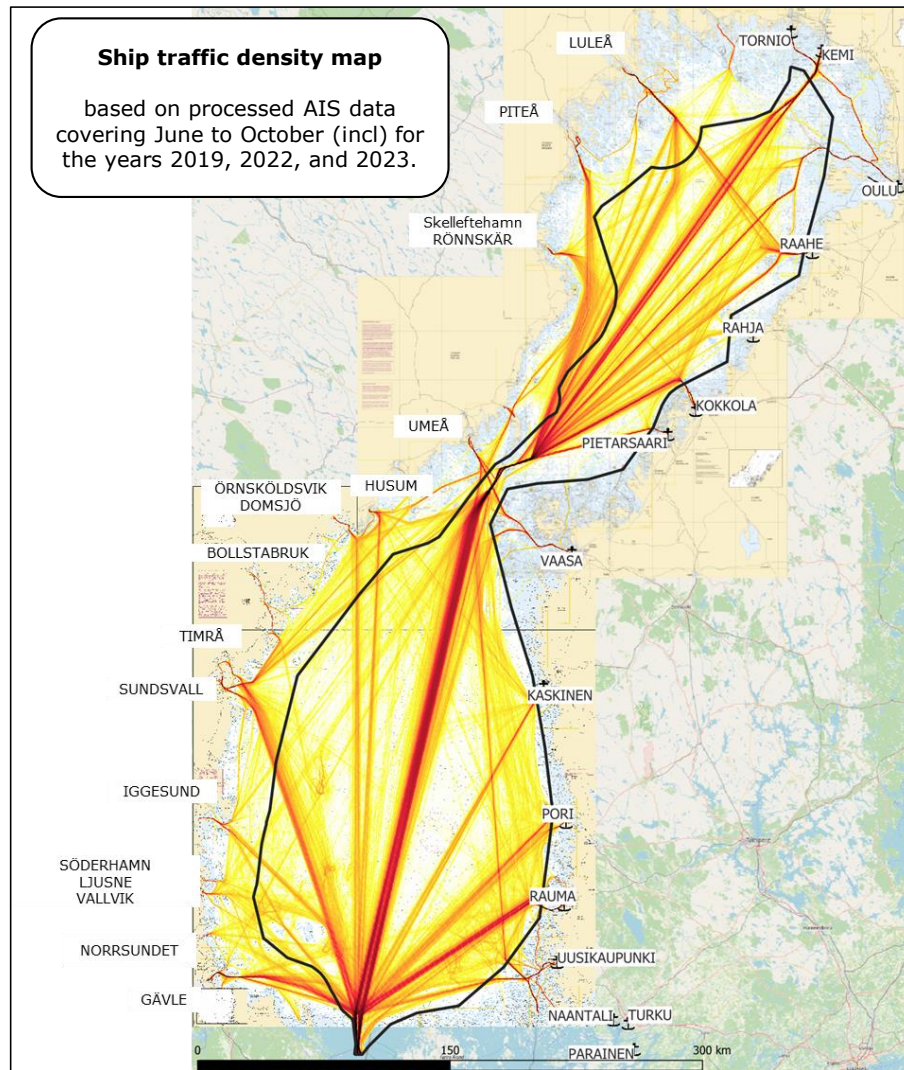


Figure 6. Density of the ship traffic in the Bothnian Sea and Bay of Bothnia.

Figure 6 shows the most intense traffic corridors appear along major shipping route coming from the Traffic Separation Scheme (TSS) Åland. The main central route in the middle of the Bothnian Sea is trafficked and most traffic uses this route between the southern area of the Bothnian Sea, from the TSS Åland to the northern area of the Bothnian Sea, the TSS Kvarken, which is the route to the Bay of Bothnia.

Also, the intense traffic from TSS Åland goes to Finland and Sweden, with high-density routes extending from the southern areas of the Bothnian Sea to ports such as Rauma and Pori in Finland, as well as Sundsvall and Gävle in Sweden.

The ship traffic converges at key points, notably around Umeå and Vaasa, indicating major crossing or convergence zones. Lesser-used routes, shown in yellow and orange, spread out from the main traffic lanes, reaching smaller ports and coastal areas. In the northern parts, such as near Tornio and Kemi, significant traffic density is visible. The visualization effectively highlights the primary navigational patterns and key areas of maritime activity in the region.

To verify the quality of the AIS data, HELCOM map service, see Ref. /10/, has been used to check that the amount of ship traffic is complete. Figure 7 shows the HELCOM passage line which is used to count the annual ship traffic. It should be noted that this line goes from coast to coast and therefore also cover the coastal traffic and the main ship traffic in the central part passing the TSS Åland located inbetween. HELCOM map service has traffic counts from 2006 and until 2020.

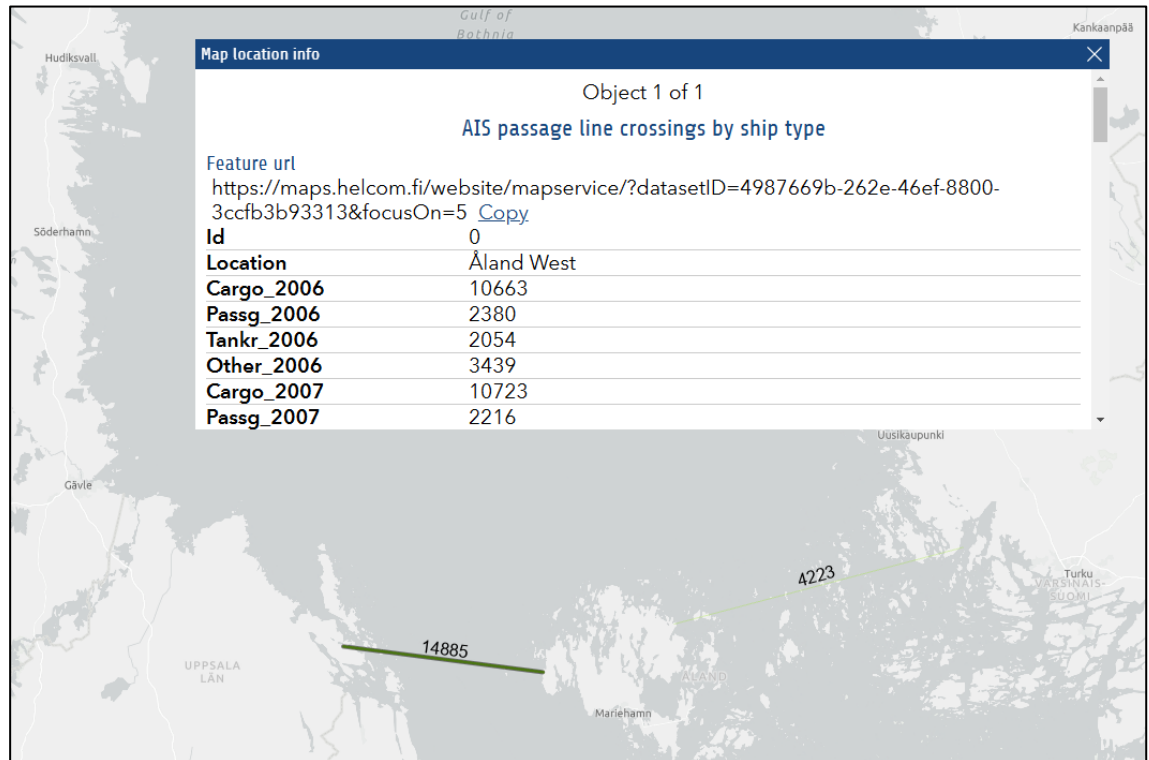


Figure 7. HELCOM AIS passage line showing annual crossings for groups of ship types at Åland West, Ref. /10/.

Figure 7 show that in the recent measured year (2020), that 14,885 ships crossed the line. The annual traffic across the passage line is summarised in Table 1, which gives a clear indication of the average number of ships in a year across the line for each group of ships, but also the total number. Further, Table 1 also gives an indication about the future traffic, whether the tendencies show an increase or decrease.

Table 1. HELCOM AIS passage line showing annual crossings for groups of ship types at Åland West, Ref. /10/.

Åland West					
Year	Cargo	Pas-sen-ger	Tanker	Other	Total
2006	10,663	2,380	2,054	3,439	18,536
2007	10,723	2,216	1,965	3,017	17,921
2008	10,849	1,784	2,082	3,049	17,764
2009	8,021	1,821	1,783	2,533	14,158
2010	7,674	1,478	1,465	2,172	12,789
2011	8,123	1,390	1,659	2,418	13,590
2012	9,005	1,875	1,958	2,879	15,717
2013	8,661	1,899	1,795	2,704	15,059
2014	8,643	1,937	1,795	2,694	15,069
2015	7,842	1,845	1,904	2,829	14,420
2016	7,956	1,944	1,733	2,891	14,524
2017	7,653	1,773	1,872	2,957	14,255
2018	7,671	1,597	1,640	2,646	13,554
2019	8,718	1,896	1,852	2,916	15,382
2020	8,416	1,737	1,957	2,775	14,885

Table 1 shows the traffic counts from 2006 and until 2020, where a decreasing trend is seen for most groups except tankers which has some smaller variations during the years. The decrease is most dominant between years of 2007 and 2009. However, the recent years have had quite stable traffic counts, and the decreasing trend is not seen or expected based on HELCOMs traffic counts for this area where ship traffic enters the Gulf of Bothnia.

Figure 8 shows a density map of the ship traffic for ice-free months from June to October, incl., for the years 2019, 2022, and 2023 at the TSS Åland incl. a passage line across. The AIS data software, IWRAP Mk2, Ref. /4/, has been used to analyse the data and extract traffic count across the passage line from the data, which are presented in Table 2 and Table 3.

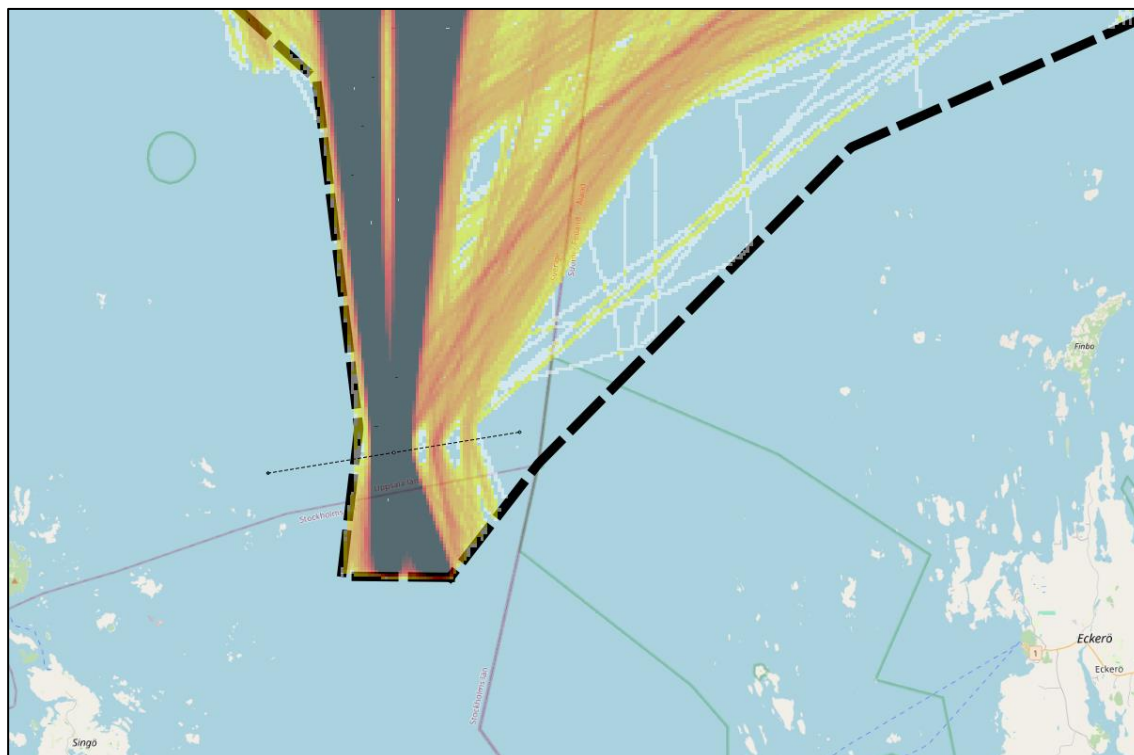


Figure 8. Density map of the AIS data at the TSS Åland incl. a passage line.

Table 2 shows the traffic counts for the AIS data at the TSS Åland. The traffic counts do not cover to coastal areas outside the dashed black line and outside the TSS Åland. Table 3 shows the average ship traffic over the years 2019, 2022, and 2023 distributed onto ship types and lengths.

Table 2. Annual ship traffic counts for ice-free months from June to October, incl., for the years 2019, 2022, and 2023 at the TSS Åland.

TSS Åland Ship length (m)	Number of ships, 2019, 2022, and 2023					Indica- tive an- nual traffic
	0-50	50-100	100-200	200-300	Total	
2019	45	1,885	3,515	135	5,580	13,400
2022	60	1,535	3,035	130	4,760	11,430
2023	25	1,495	2,885	110	4,515	10,840

Table 3. Average ship traffic counts for ice-free months from June to October, incl., for the years 2019, 2022, and 2023 at the TSS Åland.

TSS Åland Ship length (m)	Avg. number of ships, 2019, 2022, and 2023					Indica- tive an- nual traffic
	0-50	50-100	100-200	200-300	Total	
Fishing ship	15	5	0	0	20	50
General cargo ship	0	1,515	2,410	115	4,040	9,700
Oil products tanker	0	85	665	5	755	1,820
Passenger ship	0	0	15	5	20	50
Support ship	30	35	65	0	130	320
Total	45	1,640	3,155	125	4,965	11,920

Table 2 and Table 3 show that most ships are of length between 100-200 meters, and the most frequent ship type is general cargo ships. The ship traffic counts from the AIS data show similar counts as in the HELCOM traffic counts for cargo ships and tankers. It makes good sense that these types of ships are of a similar annual traffic count, since these ships use the TSS when entering the Bothnian Sea.

For support or other ships, which also consists of pleasure crafts, these are expected sailing closer to shore outside the TSS. These ships are therefore not seen in the AIS data for the passage line at the TSS Åland and therefore the counts differ between the tables for this grouping.

For the passenger ships is also noted a difference between the HELCOM data shown in Table 1 and the AIS data shown in Table 2 and Table 3. The difference is due to the HELCOM covering the ferry between Grisslehamn at the Swedish east coast and Eckero at Åland, which do not cross the TSS Åland passage line extracting AIS data.

Overall, the AIS data shows comparable ship traffic numbers that align well with HELCOM's traffic data from their website for the TSS Åland area.

4.2.1 Calls to ports and cargo volume

The number of international port calls have been analysed based on data received from SMA for Sweden and Traficom for Finland, Ref. /8/ and /9/. Selected ports and groups of ports are analysed in the study area.

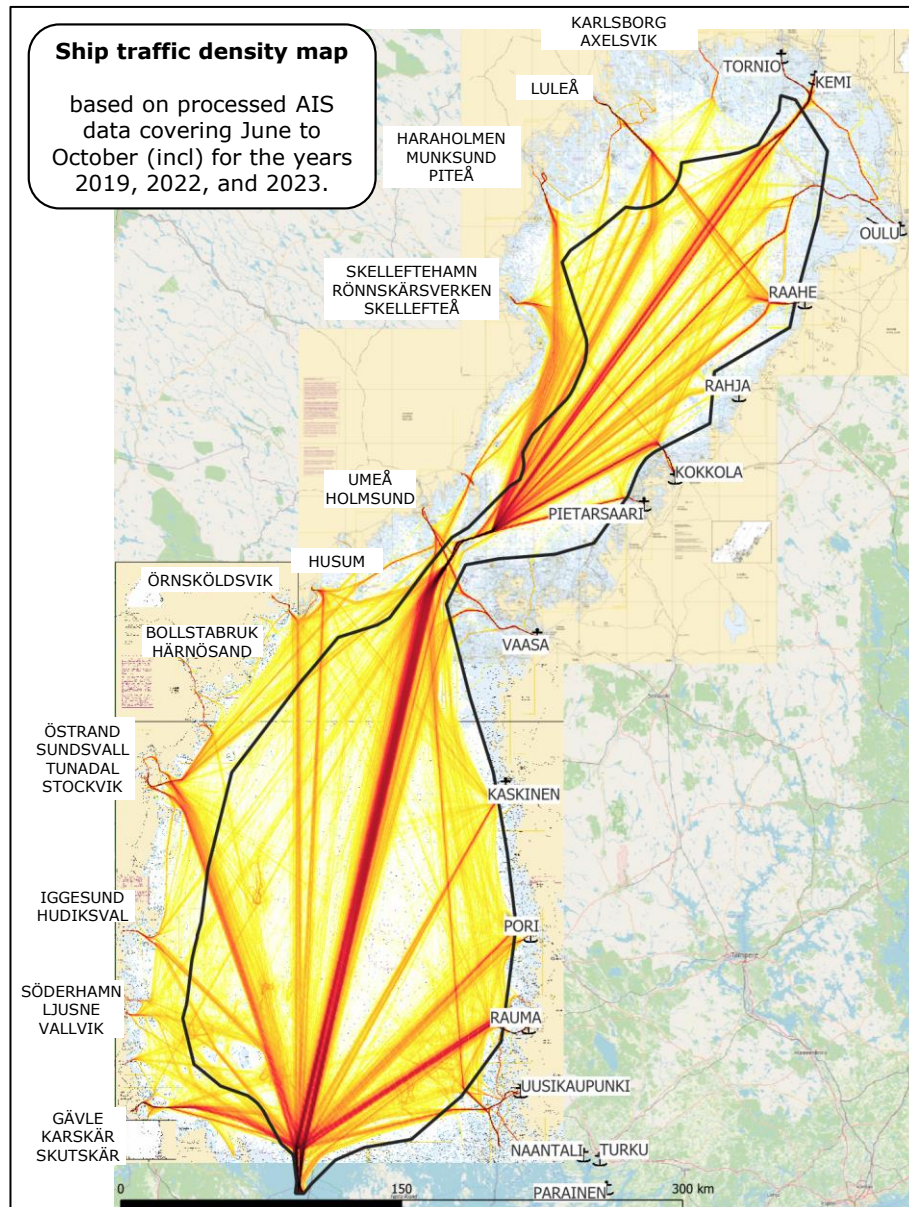


Figure 9. Overview of selected, main ports in Sweden and Finland in the Gulf of Bothnia.

Figure 10 presents an overview of several Finnish ports in the Bothnian Sea and Bay of Bothnia. The illustration encompasses data on port calls and the types of vessels that visited each port, which include cargo ships, tankers, passenger ships, and other types of vessels from the years 2019 to 2023.

Overall, the Finnish ports demonstrate a relatively stable trend in the total number of port calls over the analysed period, with slight fluctuations. Ports like Kemi and Oulu exhibit a gradual decrease in port calls, especially in recent years, possibly reflecting a downturn in maritime traffic in these areas, as well as increasing ship sizes. On the other hand, ports such as Vaasa show a more stable or slightly increasing trend.

The breakdown by ship type reveals that cargo ships consistently account for the largest portion of port calls in most Finnish ports. Tankers and

passenger vessels represent a smaller share, with passenger vessels being notably significant in Vaasa. The "Other" category, although present, mostly at Raahе but remains a minor component of the total traffic in most ports. The general trend for Finnish ports suggests a potential stabilization or slight decline in shipping activity.

Figure 11 provides a similar analysis for Swedish ports, including major ports like Luleå, Umeå, and Gävle. Swedish ports exhibit a trend of either stability or a slight increase in port calls over the five-year period, with certain ports such as Umeå and Luleå showing consistent or falling trends. Conversely, some ports, like Gävle, Karskär, Skutskär and Östrand, Sundsvall, Tunadal, and Stockvik, display minor variations with a slight decrease in certain years.

In general, cargo ships dominate the traffic in most Swedish ports, similar to the Finnish ports. Tankers and passenger vessels play a secondary role, although there is a notable presence of passenger traffic for the ferry between Holmsund and Vaasa. The "Other" category, while present, contributes less significantly to the overall traffic but remains a part of the maritime landscape in several ports.

Number of port calls to selected Finnish ports

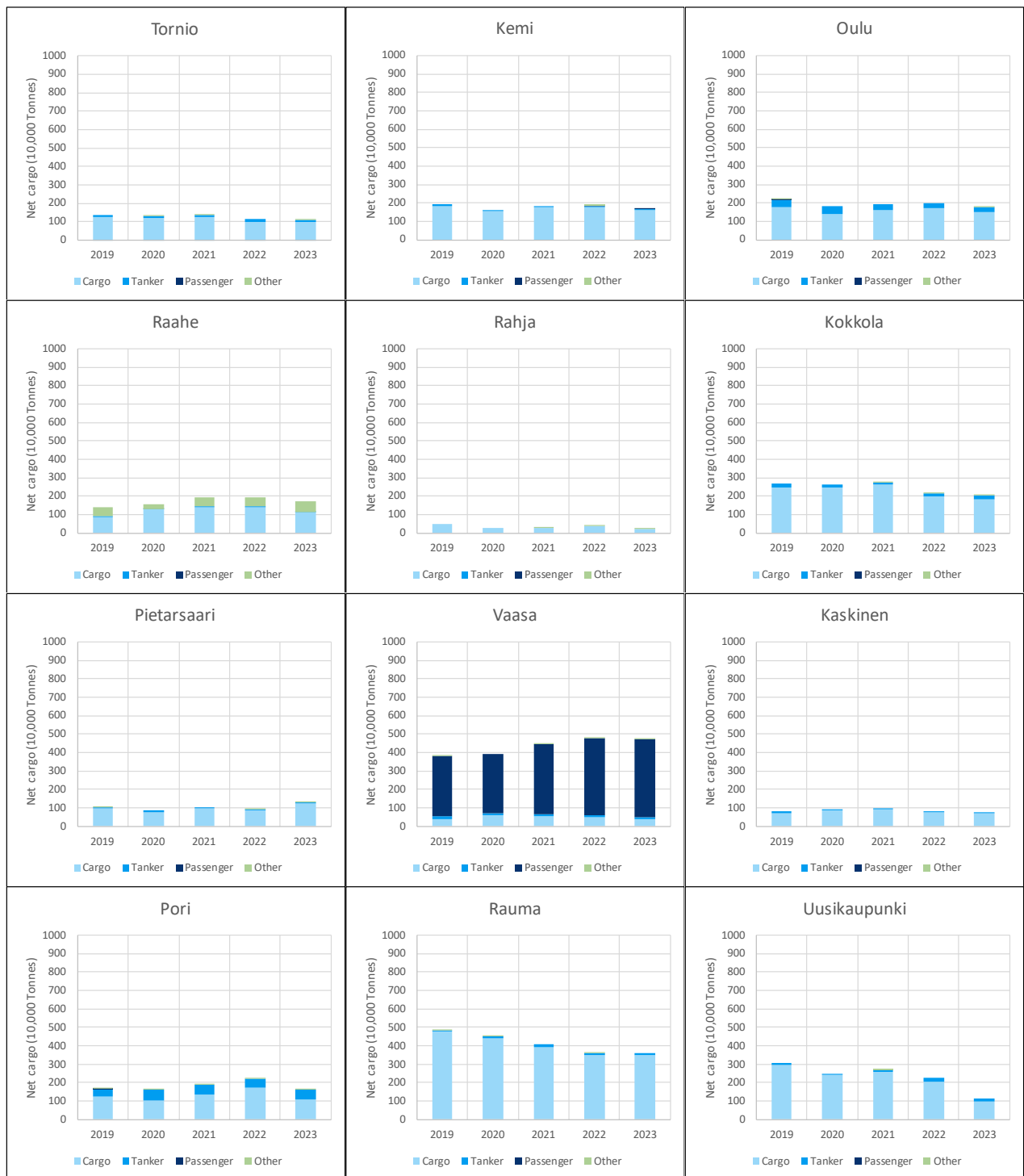


Figure 10. Development in port calls to Finnish ports.

Number of port calls to selected (groups of) Swedish ports

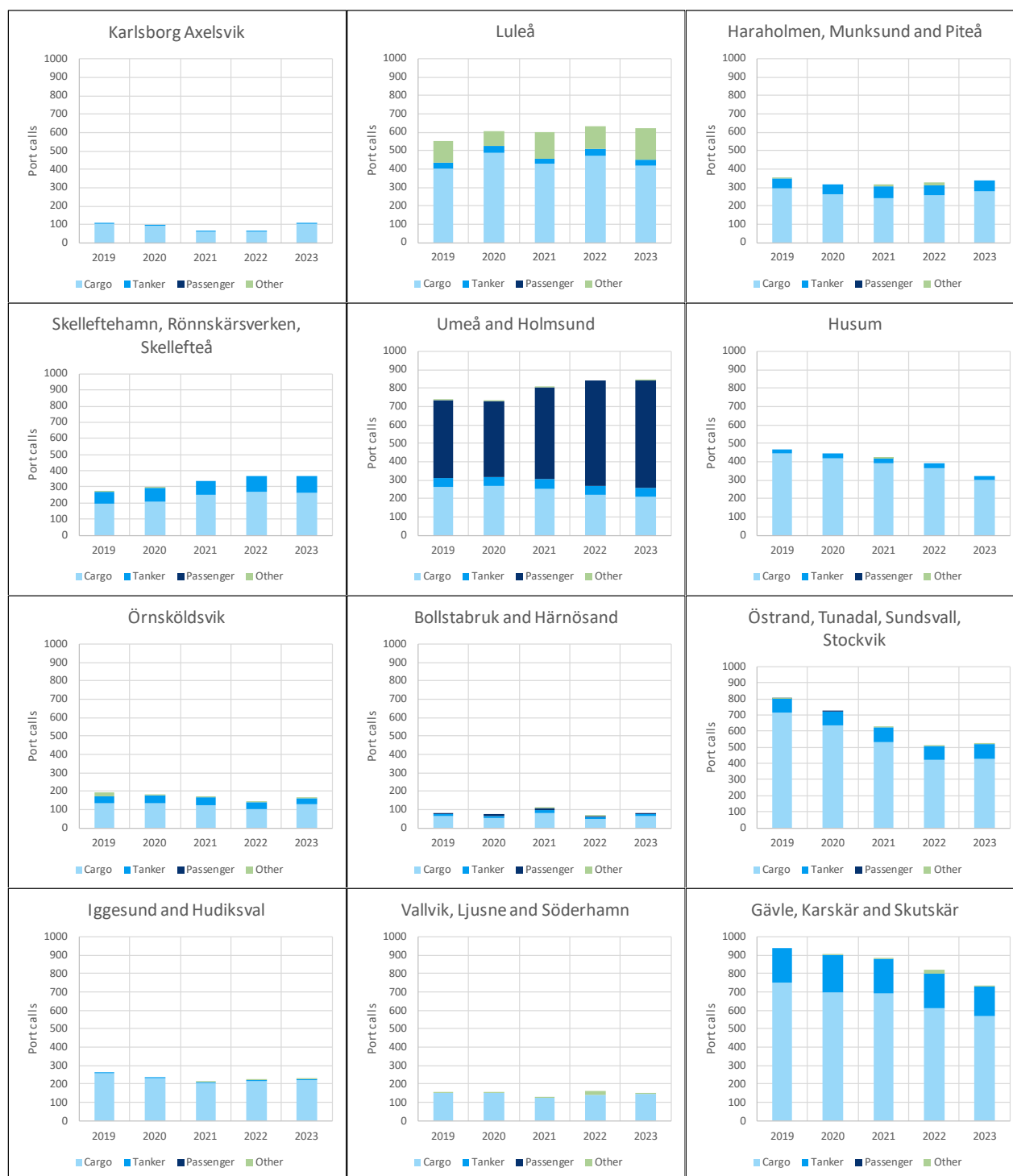


Figure 11. Development in port calls to Swedish ports.

Comparing Finnish and Swedish ports reveals that Swedish ports, on average, tend to have either stable or decreasing port calls, and Finnish ports display a more mixed pattern, with some stability and slight declines.

The Swedish port of Gävle stands out as having the most port calls among all the analysed ports, indicating its importance as a maritime hub. In contrast, the Finnish port with the highest number of port calls is Rauma, dominated by cargo traffic. Ports often have hinterland facilities such as railway

lines and businesses that support their operations, making it difficult to shift cargo traffic from one port to another. Therefore, cargo routes to all ports are vital for local businesses and shipping routes cannot be diverted to other ports.

When examining specific categories:

- Cargo ships: Rauma (Finland) and Gävle (Sweden) lead in cargo ship traffic.
- Passenger ships: Vaasa (Finland) and Umeå (Sweden) are notable for their passenger ship traffic.
- Tankers: Both Finnish and Swedish ports show relatively lower activity in this category, with slight variations among specific ports.
- Other: Raahе (Finland) and Luleå (Sweden) are notable for their "Other" ship traffic, which consists of tugs pushing barges.

In summary, Swedish ports generally display a more stable and some decreasing trend in port calls similar to the relatively stable or declining pattern in Finnish ports. A few ports have a slight increase, these are: Vaasa (Finland), Umeå (Sweden) and Skelleftehamn (Sweden). Also, the pandemic in start 2020, could have an influence in that year and the following. However, most port calls are cargo ships, and those had less impact than passenger ships due to the potential spread.

In the following is shown similar figures for the net cargo volume for selected Finnish and Swedish ports for each year.

Figure 12 presents the annual net cargo volume data for ports in Finland and Sweden within the Bay of Bothnia and Bothnian Sea regions from 2019 to 2023. The figure offers insight into the trends in cargo movement across different types of vessels, including cargo ships, tankers, passenger ships, and other categories.

The northern Finnish ports (Tornio, Kemi, and Oulu) demonstrate relatively stable cargo volumes, with slight fluctuations observed over the five-year period. The same stable trend is also seen for Raahе, Pietarsaari, Kaskinen and Pori where most of the net cargo volume is from cargo ships.

Raahе's net cargo volume has increased in the first year and stabilised in the recent years. Raahе is also the primary port with net cargo volume from "Other" ships. Raahе is also one of the more prominent Finnish ports, showcasing higher cargo volumes together with Kokkola, Rauma, Uusikaupunki and Vaasa.

Kokkola, Rauma and Uusikaupunki are all with a slight decreasing tendency in net cargo volume compared to the previous years.

Vaasa have moderate cargo volumes with minimal changes over the years. Vaasa's volume has remained relatively stable, with a slight increase in 2022 with most coming from passenger ships.

Rauma: Pori's cargo volume shows a minor decrease over time, while Rauma displays a consistent trend with some annual fluctuations.

Overall, Finnish ports exhibit relatively stable trends in net cargo volumes with minor annual variations.

Figure 13 shows selected Swedish ports and their net cargo volume in thousand tons from 2019 to 2023. The Swedish ports demonstrate relatively stable cargo volumes, with slight fluctuations observed over the five-year period. The ports with the most net cargo volume are Gävle and Luleå. Luleå has also cargo volumes from "Other" ships as the only port. Östrand is the only port with a slight decreasing tendency in net cargo volume.

Swedish ports generally display stable trends in net cargo volumes, with Luleå, and Gävle emerging as prominent ports due to their higher volumes.

International net cargo volume for selected Finnish ports

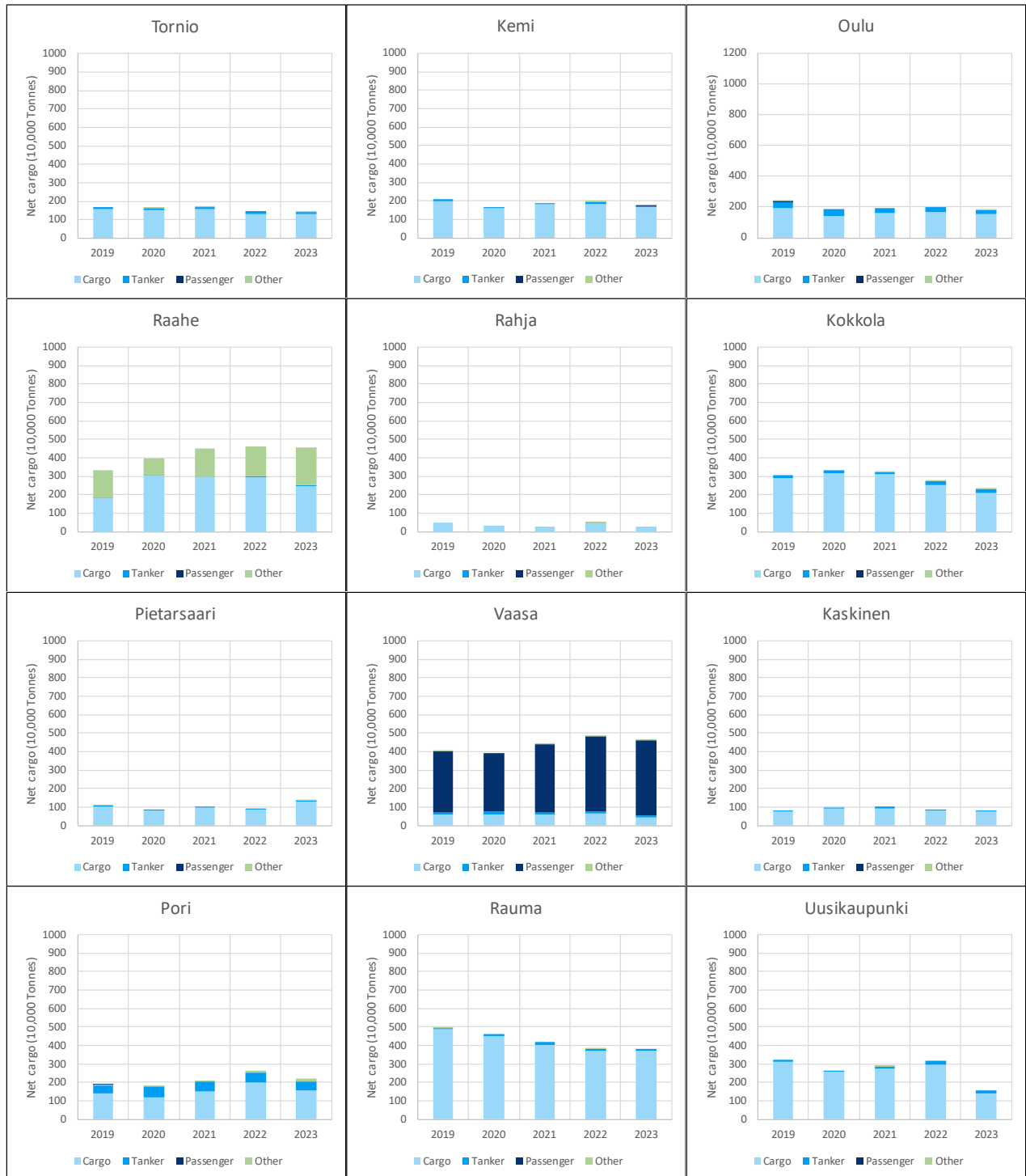


Figure 12. Development in net cargo volume for selected Finnish ports.

Net cargo volume for selected Swedish ports



Figure 13. Development in net cargo volume in selected Swedish ports.

Both countries' ports show overall stability in cargo volumes with minor fluctuations. In Finland, Kokkola, Raahе, Rauma, Uusikaupunki and Vaasa are leading in terms of cargo volume, whereas, in Sweden, Luleå and Gävle dominate.

This analysis underscores the stability in cargo volumes at key ports in both Finland and Sweden, highlighting their roles in regional and international maritime trade.

Overall comparing port calls and net cargo volumes, no direct result shows that the decreasing number of port calls leads to larger ship carrying more cargo volumes.

In the following is an analysis of the international port calls and the AIS data for selected Finnish and Swedish ports. The comparison of international port calls and AIS data for selected Finnish ports from 2019, 2022, and 2023 provides additional insights into the maritime traffic trends but also how well the AIS data match the port calls. The AIS data, which represents ship arrivals over five months of each year, has been scaled to estimate annual figures, allowing for a more direct comparison with the yearly port calls data. This scaling assumes a uniform distribution of ship traffic throughout the year, which may not fully account for seasonal variations such as reduced traffic during winter months. The comparison is shown in Figure 14.

In Finnish ports, e.g. Kaskinen shows that the scaled AIS data generally aligns with the port calls data, suggesting consistent monitoring and reporting of ship arrivals. However, the scaling method might slightly overestimate the annual traffic due to the lower activity expected in colder months. This alignment with a slight overestimation is seen across all Finnish ports. This comparison highlights the reliability of AIS data in capturing ship movements and its potential to complement traditional port call records in maritime traffic analysis.

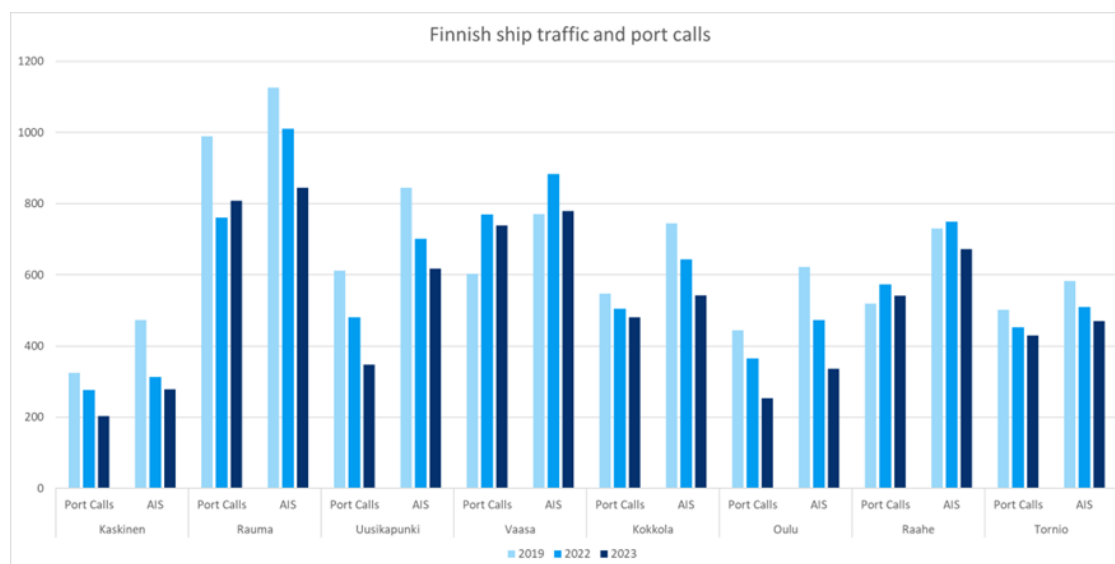


Figure 14. Port Calls and AIS Data Analysis for Finnish Ports.

Similarly, the analysis of port calls and AIS data for selected Swedish ports from 2019, 2022, and 2023 follows the same approach. The AIS data, representing five months of ship arrivals each year, has been scaled to annual estimates to facilitate comparison with the port calls data. This method provides a useful approximation but like in the Finnish case, may not perfectly reflect the actual annual distribution due to seasonal traffic variations.

In general, Swedish ports are also showing a reasonable correlation between the scaled AIS data and the port calls data, indicating that AIS data serves as a robust supplementary tool for maritime traffic analysis. Few of them shows a larger difference, e.g. Luleå, where the scaling of AIS data is too high relative to the actual port calls for all three years. The potential discrepancy introduced by scaling is an important consideration, especially in ports with significant seasonal variations, which could affect the accuracy of the annual traffic estimates.

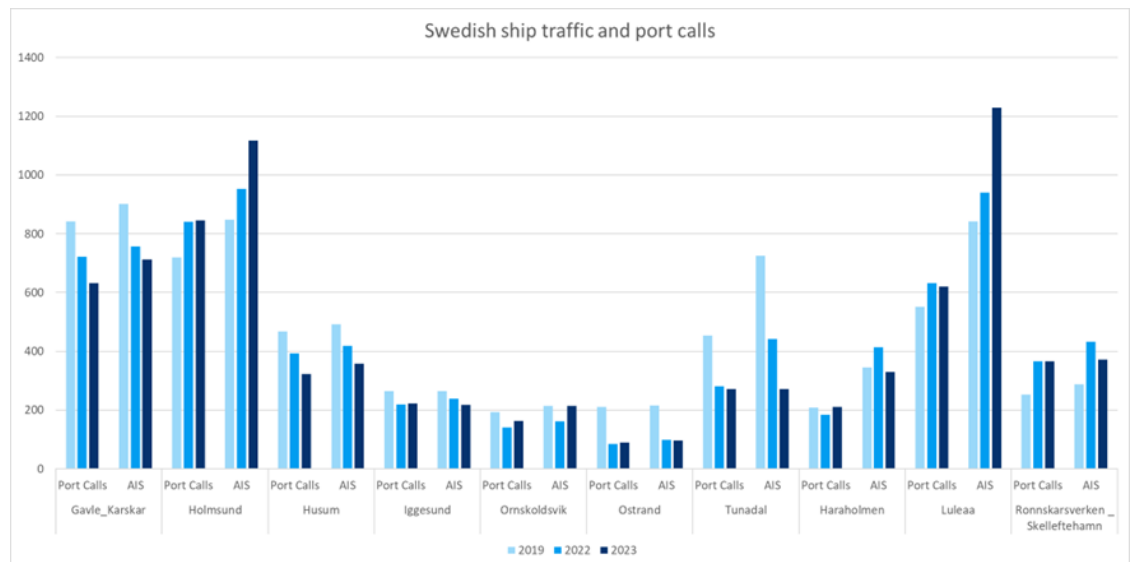


Figure 15. Port Calls and AIS Data Analysis for Swedish Ports.

Overall, the comparison of AIS data with port call records shows a clear similarity between both types of data. The AIS data are therefore giving a representative ship traffic reporting without showing any lack of data, for both analyses in Finland and Sweden.

4.2.2 Historical marine casualties

Maritime accidents in the Bothnian Sea and Bay of Bothnia have been documented over the past decades, highlighting the challenges posed by ice conditions and other special circumstances. Ice formation significantly affects navigation, increasing the risk of groundings, collisions, and other hazardous incidents. The data from HELCOM, Ref. /10/, provides valuable insights into accident trends and contributing factors in the region.

The dataset provides detailed information on each accident, including date, location, type, cause, vessel characteristics, human factors, ice conditions, pollution, and response actions. This comprehensive record spanning 35 years offers valuable insights into accident trends and risk factors in the Baltic Sea.

The dataset contains ship accidents in the Baltic Sea from 1989 to the end of 2023. It is compiled from annual data collected by HELCOM Contracting Parties and, since 2019, supplemented by data extracted from the EMSA EMCIP Database for EU member states. The HELCOM Secretariat and EMSA have collaborated to compile and maintain the dataset.

The reported accidents cover a range of incidents, including groundings, collisions, contacts with fixed structures, machinery failures, fires, and explosions, regardless of whether pollution occurred. Most accidents in the dataset are related to ice conditions and other special circumstances, significantly impacting maritime safety. Ice formation reduces vessel manoeuvrability, increases collision risks, and creates hazardous conditions for navigation. Additionally, human factors, structural failures, and environmental conditions contribute to accident occurrence.

Figure 16 shows a screenshot of the shipping accidents in the Baltic 1989-2023 from the HELCOM website.

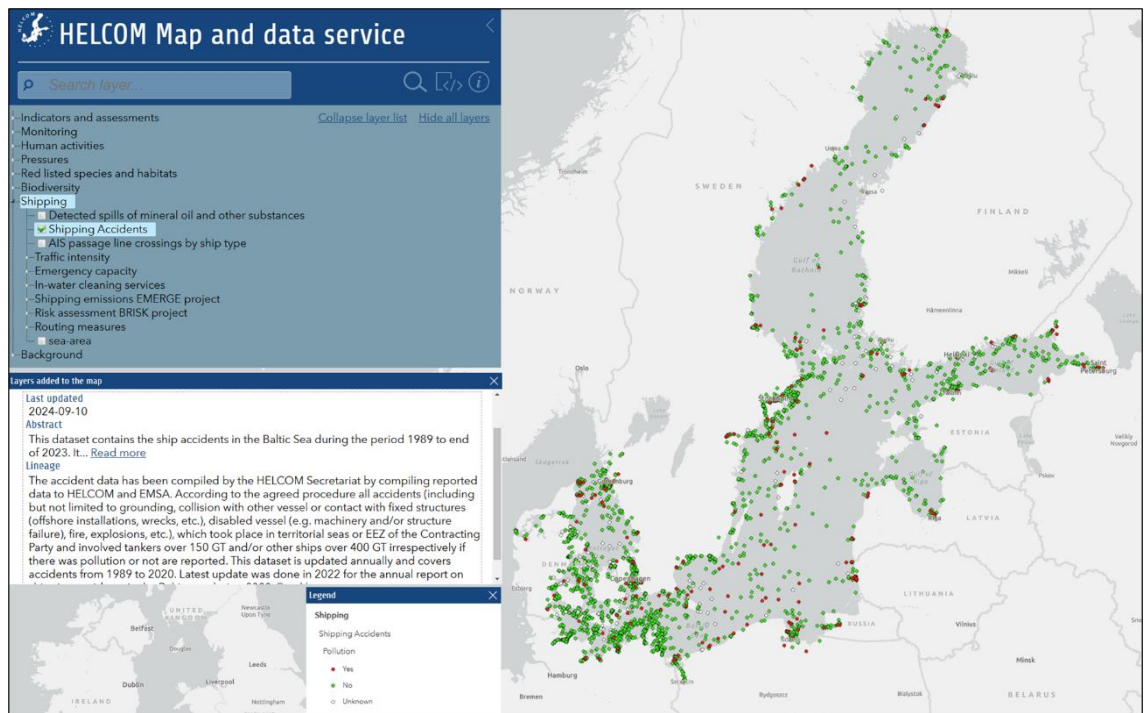


Figure 16. Shipping accidents in the Baltic 1989-2023, Ref. /10/.

The dataset contains several points also located in the Bothnian Sea and Bay of Bothnia. Figure 17 gives an overview of accident locations and their possible contributing factors. The underlying geographic area includes the territorial waters of Sweden and Finland, with key coastal cities labeled together with the different accident types, categorized by color-coded points.

- Blue dots represent all recorded shipping accidents.
- Orange dots indicate ship collisions at open sea involving other vessels.
- Red dots signify ship collisions at open sea occurring without the presence of an icebreaker and during the summer period.

In the northern part of the Bay of Bothnia, a cluster of accidents is noted, primarily related to ice conditions. Another grouping of accidents is observed near TSS Kvarken, where incidents involve ship-object collisions or accidents occurring in winter conditions with the presence of an icebreaker. In the southern part of the mapped area, a cluster of accidents involves fire incidents, a ship heeling 20 degrees, or grounding events. A specific accident related to ice maneuvering is highlighted with an orange marker.

Finally, a red arrow indicates a particular accident classified as "relevant", which occurred during summer months. This accident is a ship accident at open sea together with another vessel. However, this is the only event in the available dataset which corresponds to a ship-ship collision event.

According to the data, ship collision at open sea during summer month are not very common.

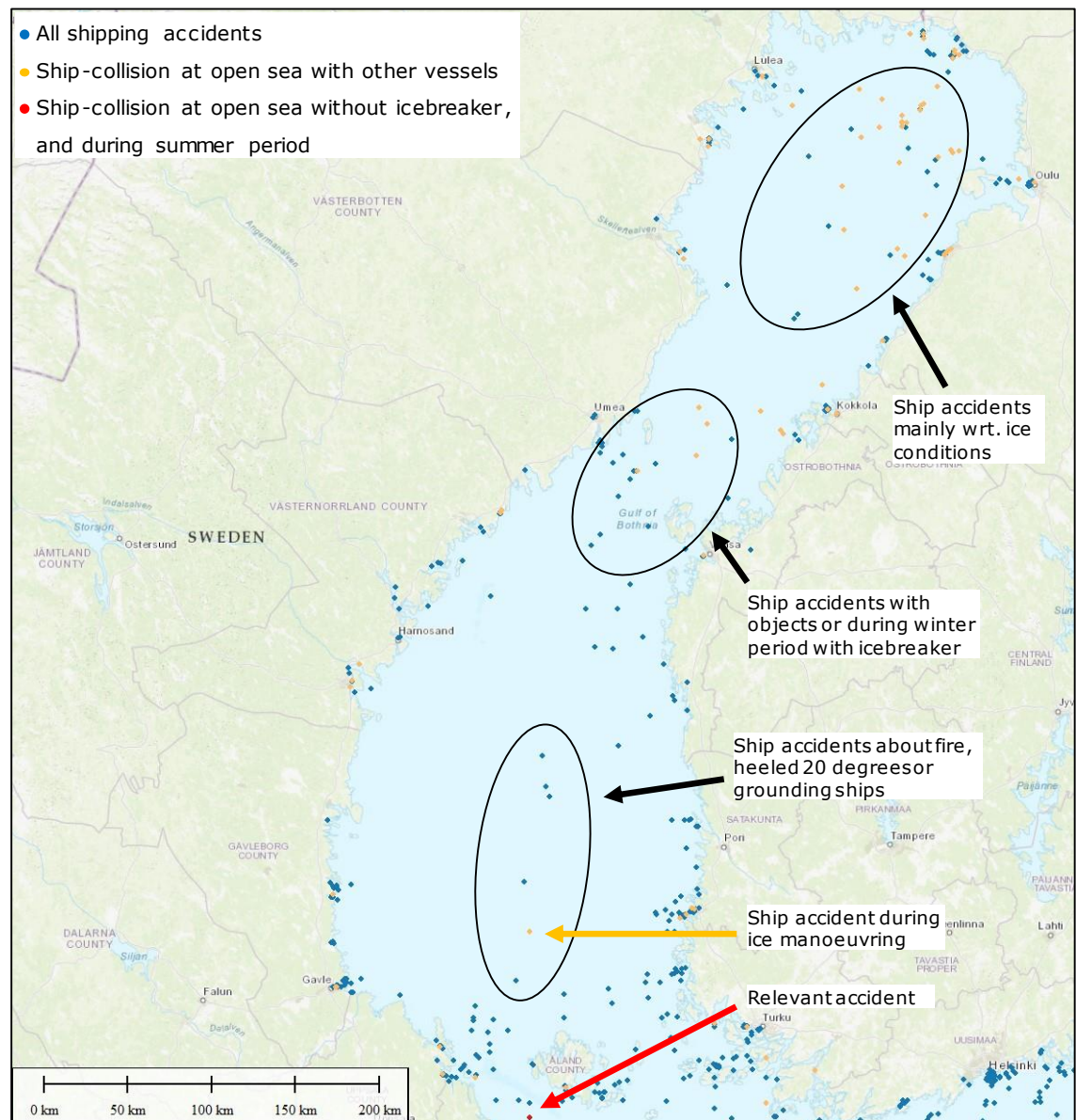


Figure 17. Shipping accidents in the Bothnian Sea and Bay of Bothnia 1989-2023, Ref. /10/.

4.2.3 Nautical charts and formal ship traffic routing systems

In the realm of maritime navigation, the Bothnian Sea and Bay of Bothnia constitute an important junction for shipping routes between Sweden and Finland. This area includes key TSS'es that streamline maritime traffic and enhance navigational safety.

Two significant TSS'es in this region are the TSS North Åland Sea and TSS Norra Kvarken. These TSS'es are integral for organizing the maritime traffic, ensuring that vessels follow designated lanes to minimize the risk of collisions and navigational errors.

The TSS Norra Kvarken is essential for vessels navigating the narrow straits between Sweden and Finland. It includes markers and routes as depicted in Figure 18. The TSS delineates clear channels for northbound and southbound maritime traffic, aided by navigational tools such as racon buoys and depth markers, but may be put out of service during winter due to ice buildup in the area. Even if outside the scope of the current study, it should be mentioned that the TSS Norra Kvarken is sometime taken out of service during winter in case of ice buildup in the area. In such a situation, ship traffic navigates where possible, and if needed by use of icebreakers.

In the remaining part of the Bothnian Sea and Bay of Bothnia, no formal ship traffic routes are defined, except for the dredged navigational channels to ports.

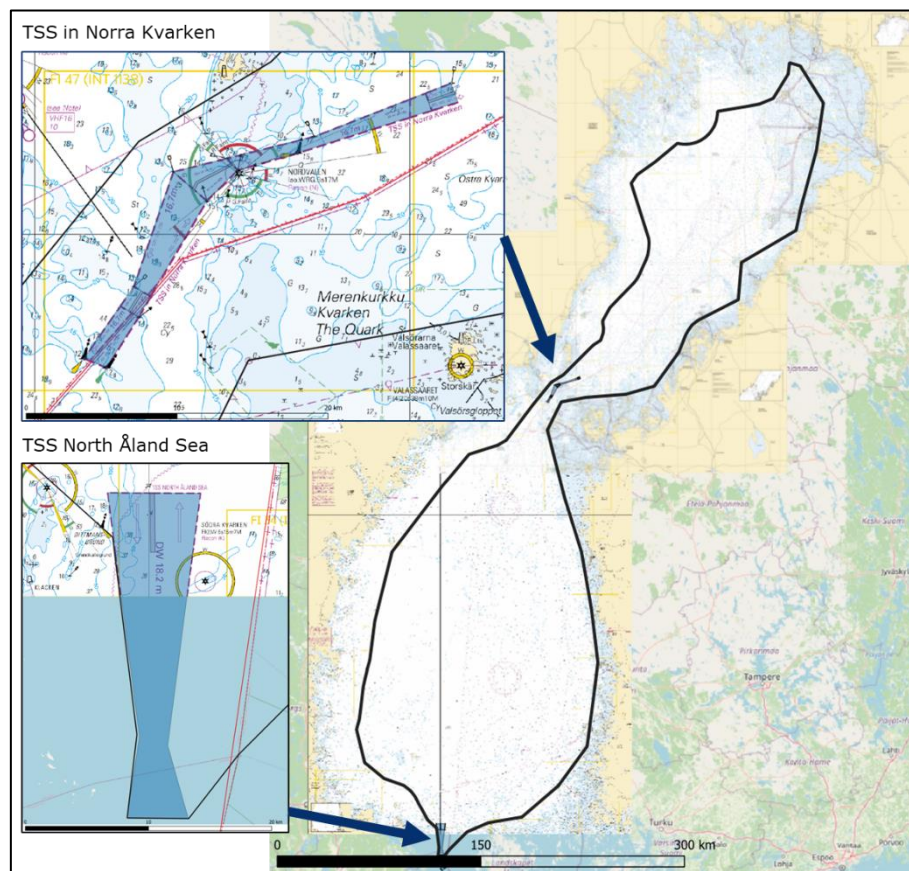


Figure 18. Swedish and Finnish formal ship traffic routing systems for the Bothnian Sea and Bay of Bothnia.

4.3 Offshore wind farm areas

Offshore wind energy is vital for the renewable transition. In Sweden and Finland, numerous OWF projects are in various stages of planning and construction. These areas are mapped using Geographic Information System (GIS) tools, such as QGIS, to assess spatial distribution, project status, and potential future developments.

Figure 19 and Figure 20 show overviews of OWF development areas in Swedish and Finnish waters, categorized by their development status. The areas shown are to be seen as a “temporary overview” based on areas where wind developers have shown interest, and not a fixed list of possible wind farm development sites. The legend in the figures distinguishes different stages of OWF projects using specific colour codes, indicating whether a Swedish area is planned, have submitted application, or have an application approved. For Finnish areas, different colour codes are used to indicate to what degree the areas are fixed, i.e., whether an area can be modified. This visualization provides insight into the extent and progression of off-shore wind energy in the region.

The visual representation of OWF areas facilitates an understanding of the current and future landscape of renewable energy in the Gulf of Bothnia.

It should be mentioned that these areas are larger geographical areas. Actual final wind farms may be proposed in only parts of the areas. They are included in the study as worst-case areas that may be used for wind farms.

Figure 19 shows the Bothnian Sea, and that the coastal Finnish OWFs are coloured in blue and red and therefore with a minor or no possibility to apply modifications. Areas in open water are coloured in green, where many overlapping areas are seen.

For the Swedish water, it is seen that many of the areas are orange, yellow or white-blue striped when considering OWFs within the project area (the black outline). The situation is that the OWF developers are working on achieving feasible areas but still not getting the approvement or finalised the material for submission. However, several areas are of interest also in Swedish waters in the Bothnian Sea, but mostly in the southern part.

Figure 20 shows the development in the Bay of Bothnia, where both the Finnish and Swedish developers are seeking potential in areas in the north and the south, but currently no interest in the central part of the Bay.

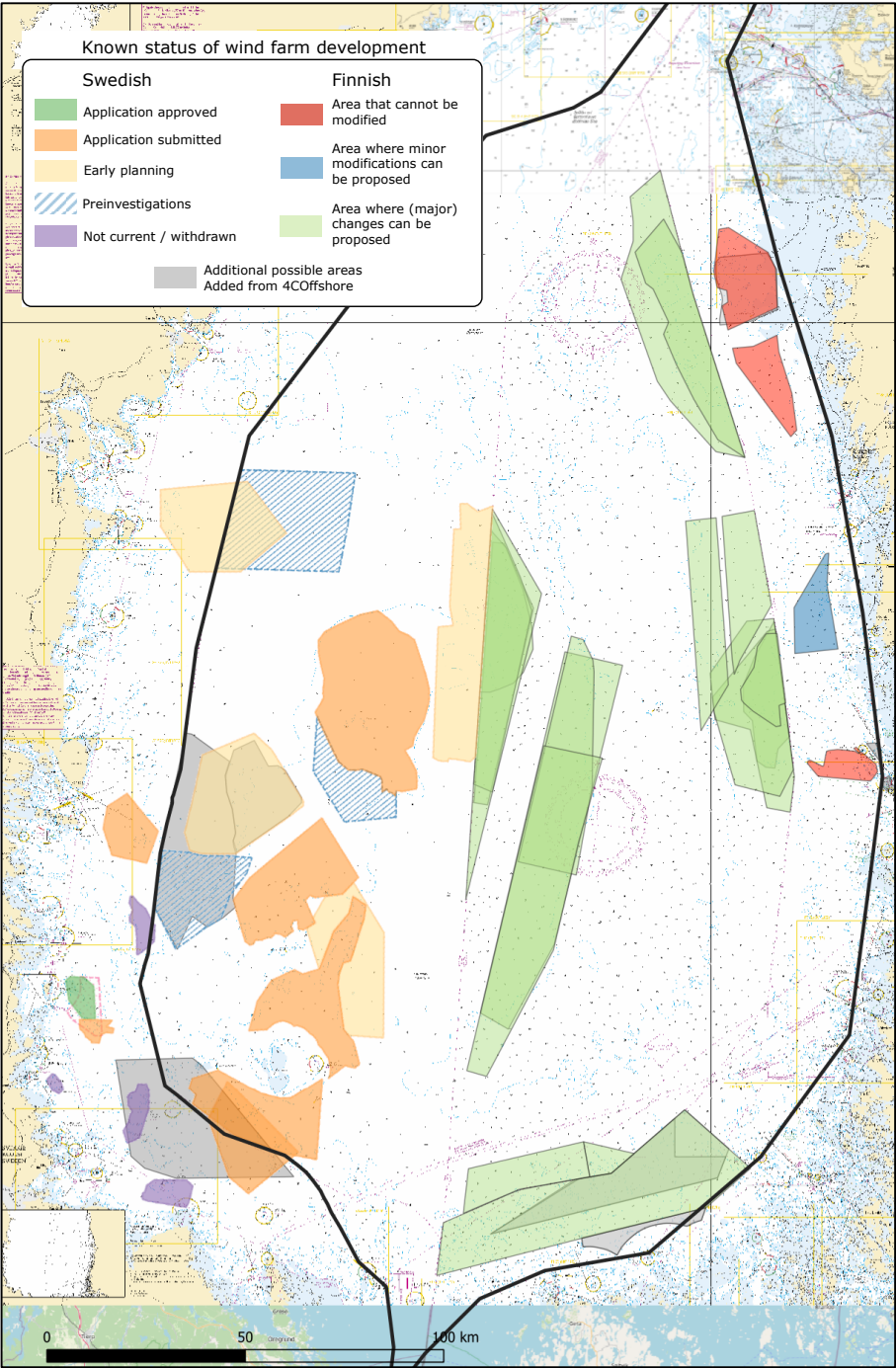


Figure 19. The current development OWFs in the Bothnian Sea.

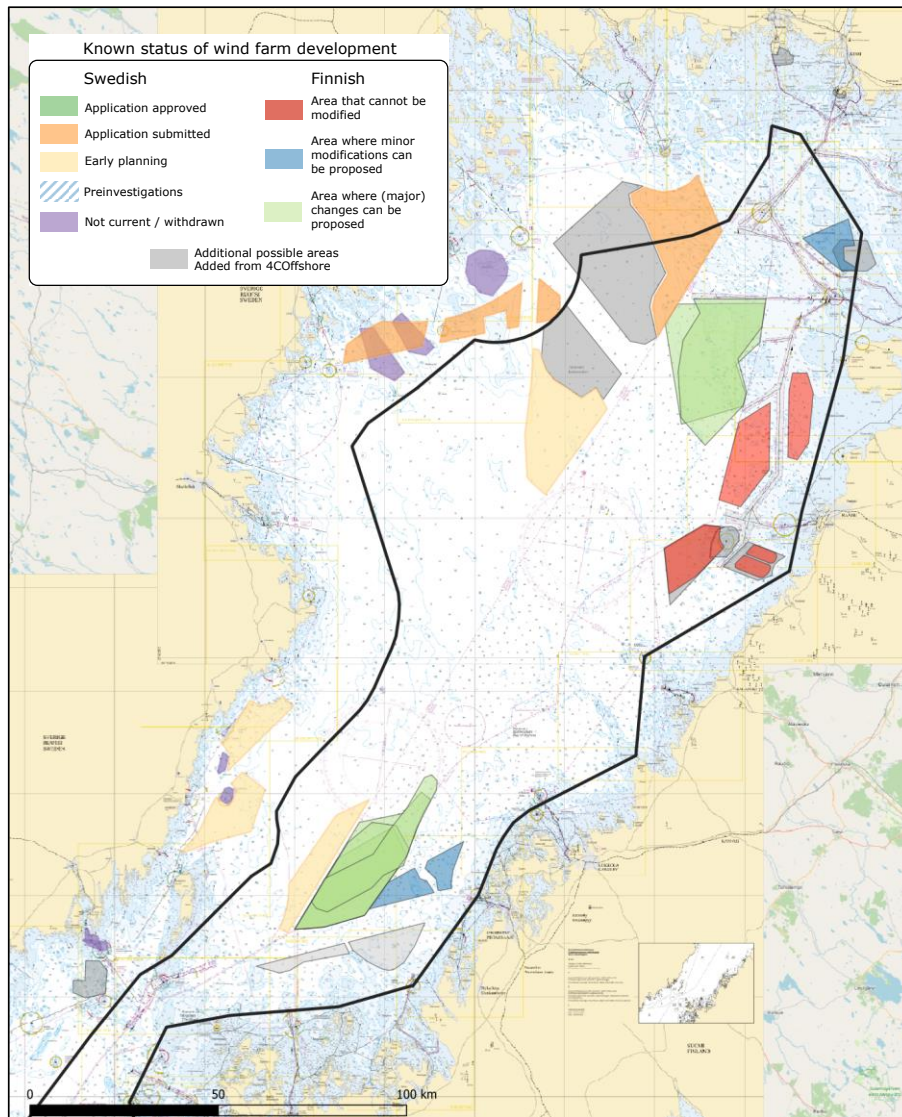


Figure 20. The current development OWFs in the Bay of Bothnia.

For improved clarity and reference throughout this report, the Bothnian Sea and Bay of Bothnia OWF areas are displayed and listed in Figure 21, irrespective of their development status or any spatial overlap.

The currently planned and ongoing OWF development projects are presented. Subsequently, overlapping areas have been consolidated, and distinct names have been assigned to each resulting area. This process involved refining the spatial extent of the wind farm areas to ensure that they remain within the designated project boundary, as delineated by the black line in the figures. Any OWF areas located outside this boundary have been excluded from the analysis.

This approach ensures a structured and coherent representation of wind farm areas while aligning with the constraints of the current study and navigational safety requirements.

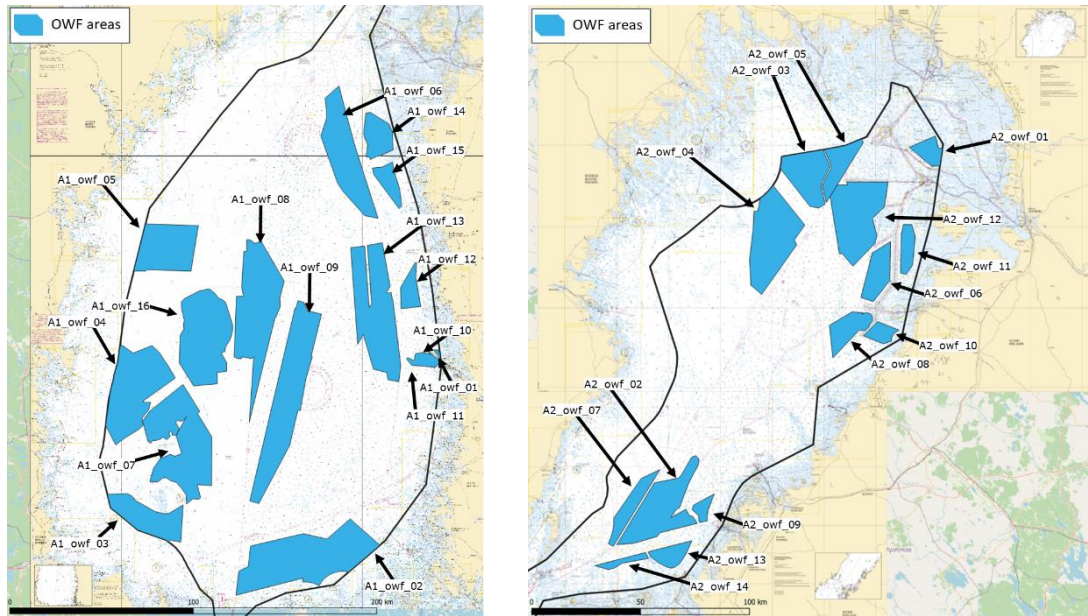


Figure 21. Combined gross OWF areas labelled for easier reference.

4.4 Maritime Spatial Plans

A maritime spatial plan is a strategic framework for managing sea areas, balancing different uses such as shipping, energy production, defence, and fishing. It aims to promote sustainable development, environmental protection, and efficient resource use while considering economic and social factors. These plans are based on multiple data sources, including AIS ship traffic information, and are updated periodically to reflect changing needs and regulations. The plan indicates significant and potential areas or connections. The markings in the plan are not area reservations and should not be interpreted as such. Activities may also take place in areas other than those identified in the plan.

Figure 22 and Figure 23 shows Finland's maritime spatial plan, which divides territorial waters and the exclusive economic zone into three areas, managed by eight coastal regions. Åland prepares its own plan separately. These strategic plans, following the Land Use and Building Act, include an impact assessment and are published digitally with thematic maps. The Finnish Maritime Spatial Plan 2030 highlights merchant shipping fairways, offshore wind areas, defence zones, and commercial fishing areas. However, the map service covers only Finland's waters in the Gulf of Bothnia, excluding Åland. Åland's first maritime spatial plan took effect in 2021 and is updated every six years. Planning is based on HELCOM's 2016 AIS data.

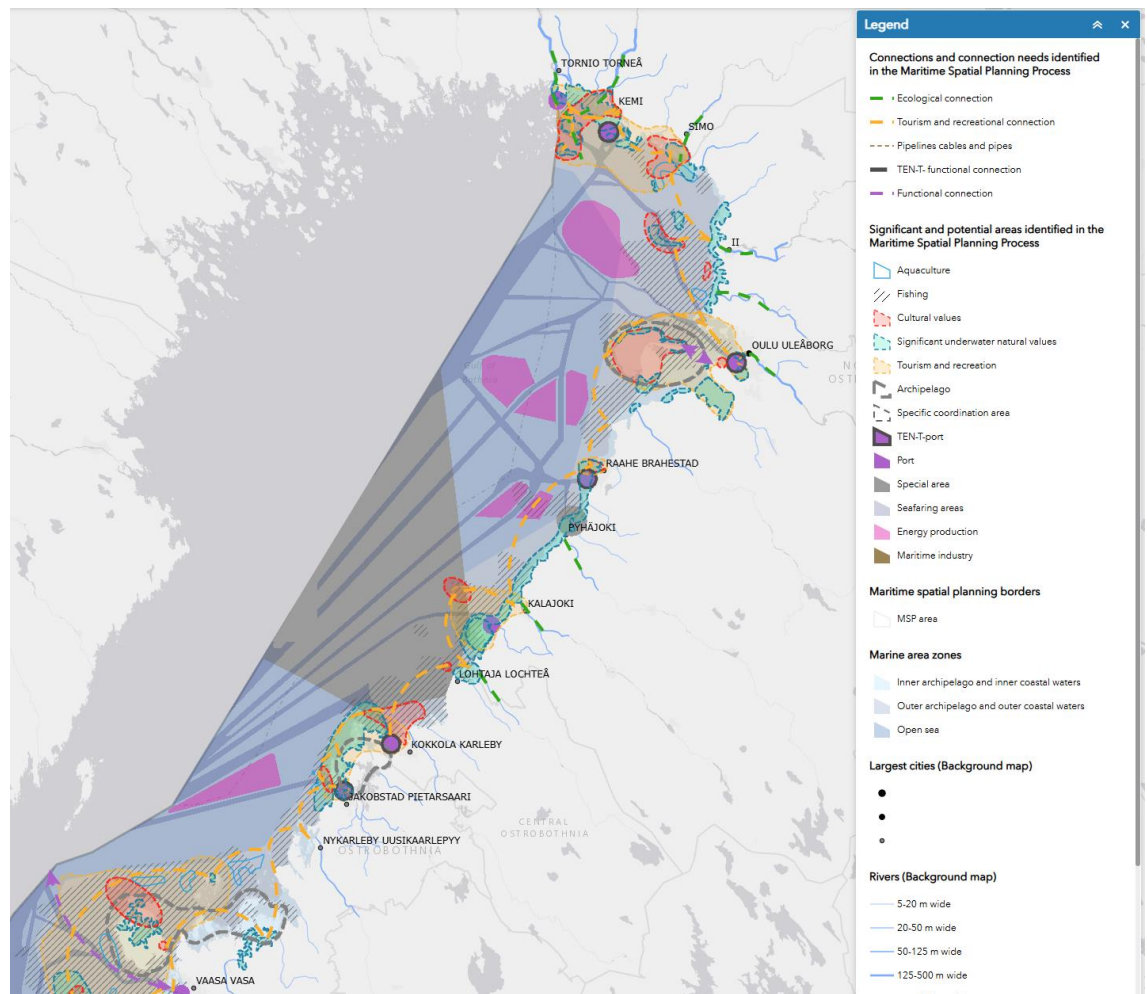


Figure 22. Open interfaces of Finland's Maritime Spatial Plan 2030 for the Bay of Bothnia. Energy production is shown in pink, Ref. /2/.

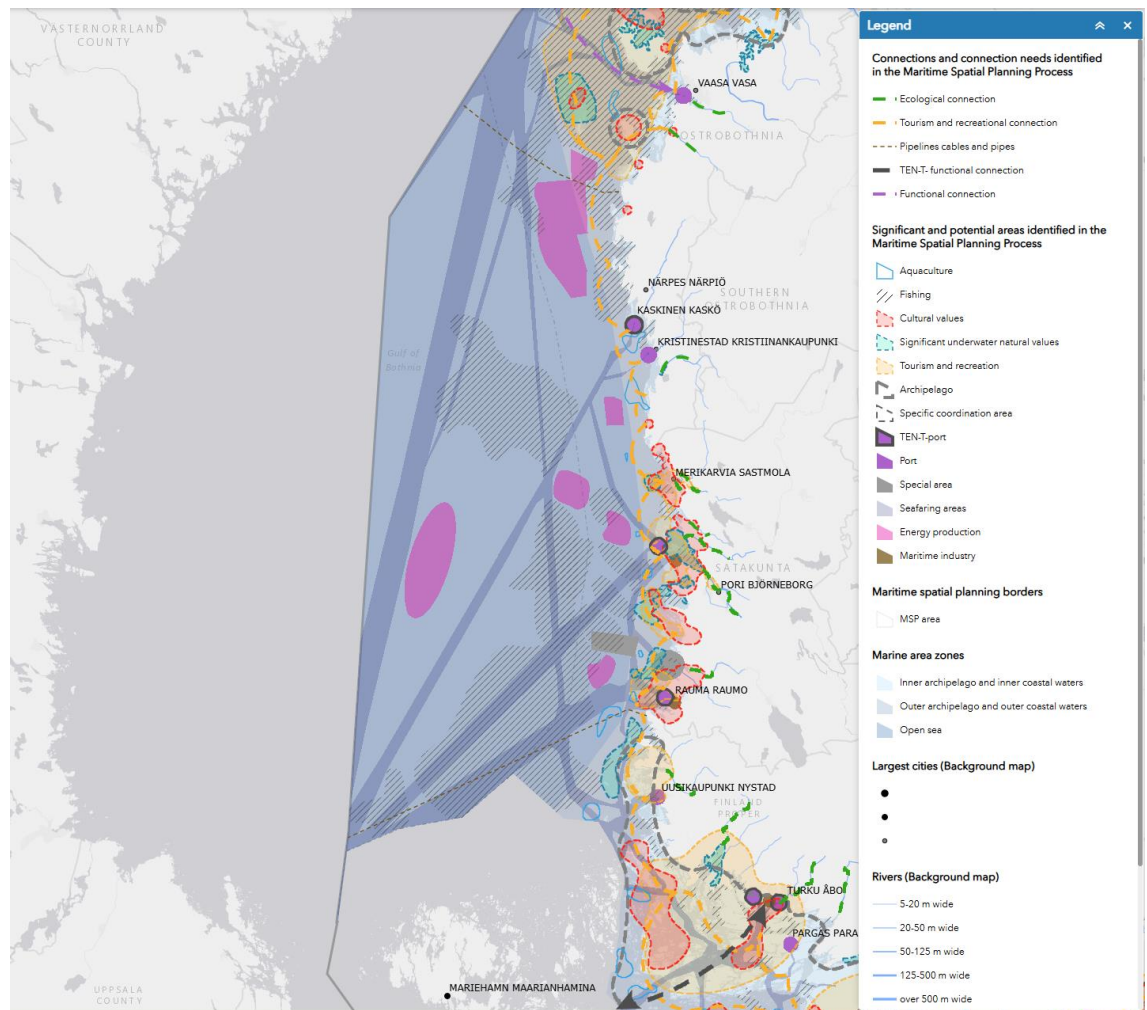


Figure 23. Open interfaces of Finland's Maritime Spatial Plan 2030 for the Bothnian Sea. Energy production is shown in pink, Ref. /2/.

Sweden has a Maritime Spatial Plan like Finland, Ref. /3/. The current plan is from 2022, and it is currently under revision with proposals submitted to the Swedish government by December 31, 2024. An overall map of the current plan from 2022 is seen in Figure 24.

The maritime spatial planning framework is also a basis for defining key navigation routes – national interest routes - to ensure efficient and safe maritime transport in both Sweden and Finland.

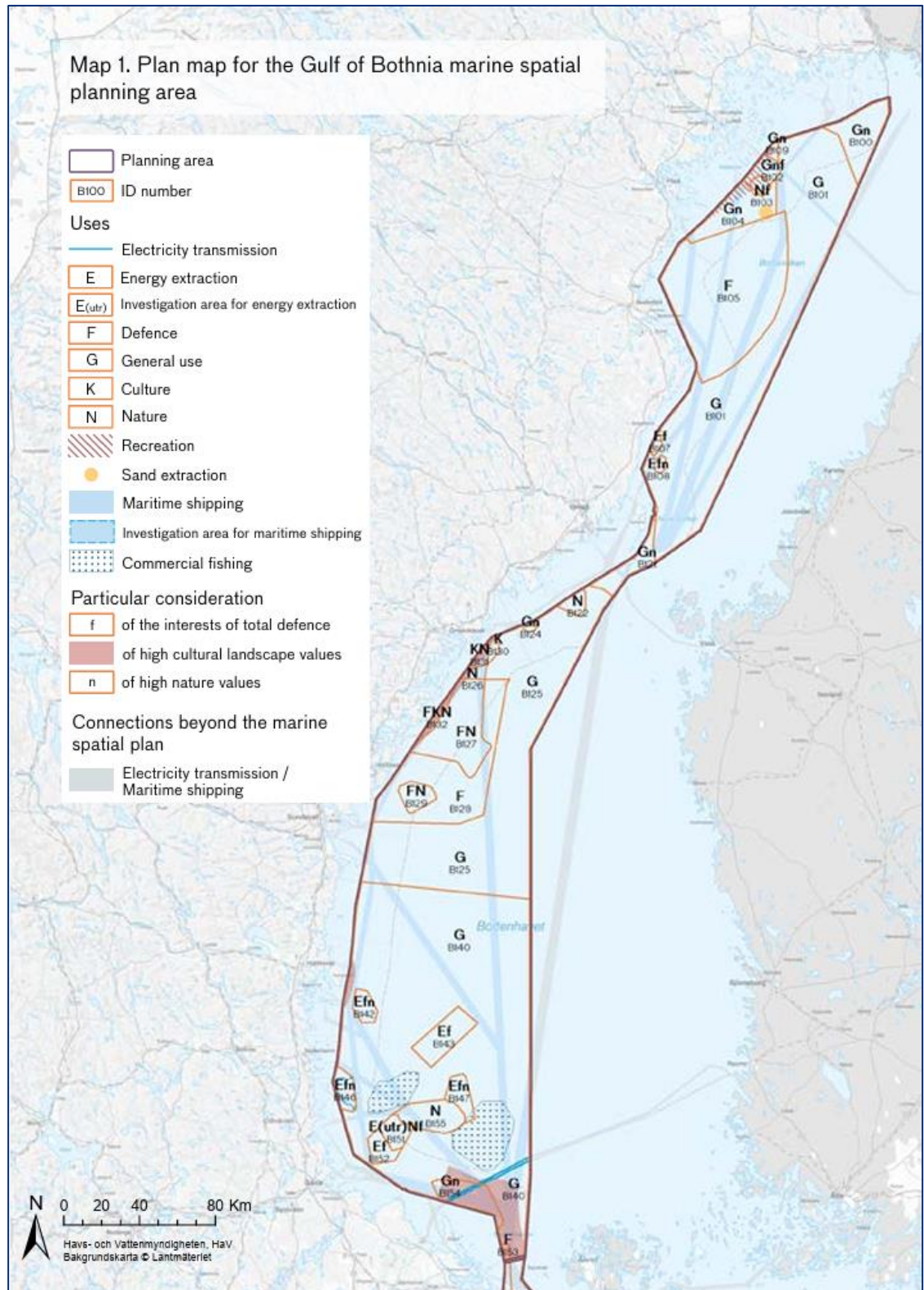


Figure 24. Swedish Maritime Spatial Plan, 2022, Ref. /3/.

4.4.1 VTS areas

In general, the Vessel Traffic Services (VTS) play a crucial role in ensuring the safety and efficiency of maritime navigation. The VTS service also plays a role in the Bothnian Sea and Bay of Bothnia in Swedish and Finnish waters. Figure 25 shows the Swedish and Finnish VTS coverage for the

Bothnian Sea and Bay of Bothnia together with the remaining other areas outside the Gulf of Bothnia, where it is clear that each country has different VTS coverage in the area.

The Finnish has the Archipelago VTS and West Coast VTS covering all the Finnish territorial waters in the Bothnian Sea, whereas Sweden has VTS Luleå and VTS Stockholm covering smaller areas near Luleå and Hargshamn in the Bothnian Sea. For the Bay of Bothnia, Bothnia VTS covers the territorial waters of Finland in the entire area.

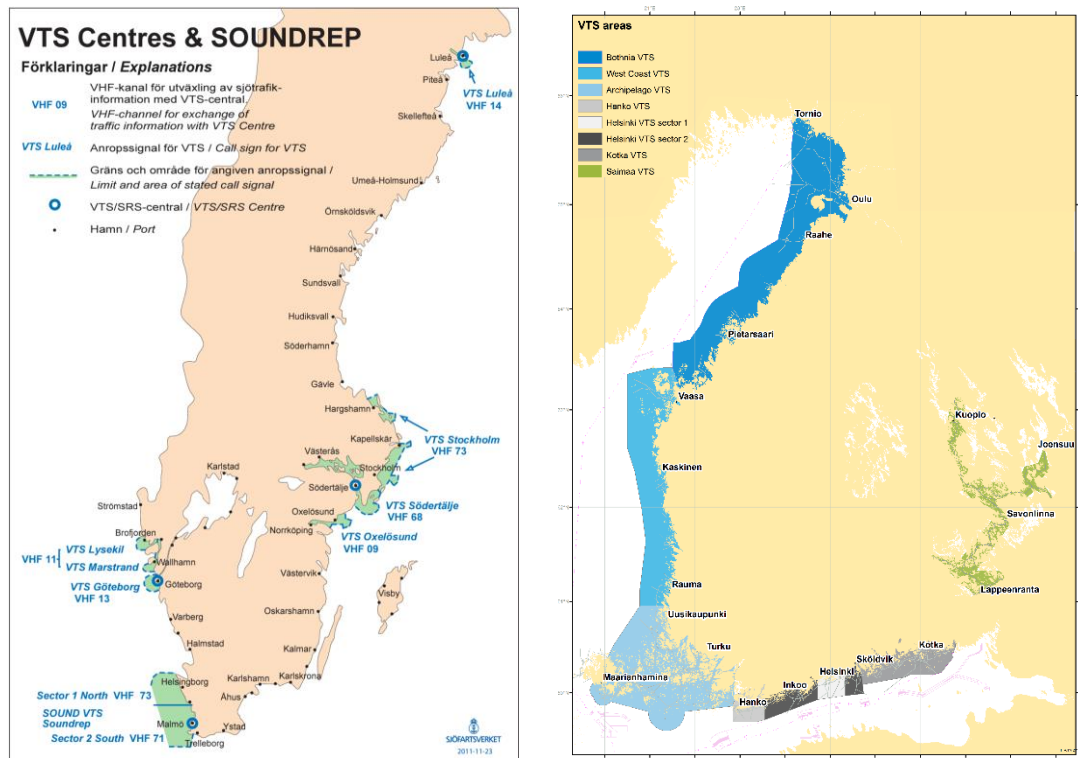


Figure 25. Swedish and Finnish VTS areas in the Bothnian Sea and Bay of Bothnia, Ref. /11/and /12/.

VTS radars are located along the Finnish coast as well as on islands and the mainland. The effectiveness of VTS radars depends on coverage. In areas with only one radar, shadow areas form more easily compared to areas with overlapping radar coverage. While multiple radars improve operational efficiency, expanding the radar network in the Gulf of Bothnia remains a financial challenge.

OWFs pose additional challenges for VTS radar operations. They can create blind spots and interference, with wind turbine blades occasionally causing radar echoes that resemble vessels. The impact of OWFs on radar functionality is primarily related to interference rather than blind spots. To mitigate these issues, OWF operators may be required to install compensation radars.

4.4.2 Pilot boarding points

Navigation close to the coast may involve use of pilots, e.g., to navigate to and from ports through dredged channels. The Finnish pilot boarding points follow a structured path along the Finnish coast, indicating predefined entry points for vessels at each navigational channel to each Finnish port. Figure 26 shows the Finnish pilot boarding points for the Bothnian Sea (left) and the Bay of Bothnia (right). These locations are marked with black pilot symbols, indicating designated points where pilots board vessels to assist with navigation through Finnish waters. Additionally, temporary pilot locations are highlighted in orange and specifically marked in the Bay of Bothnia, potentially reflecting changes in operational needs. The same goes for the Swedish pilot boarding points, which also are located along the coast next to larger ports.

The pilot boarding points are relatively evenly spaced, situated offshore at key access points leading toward major harbours. The pilot boarding locations extend along the coastal region, ensuring coverage for vessels approaching from the open sea.

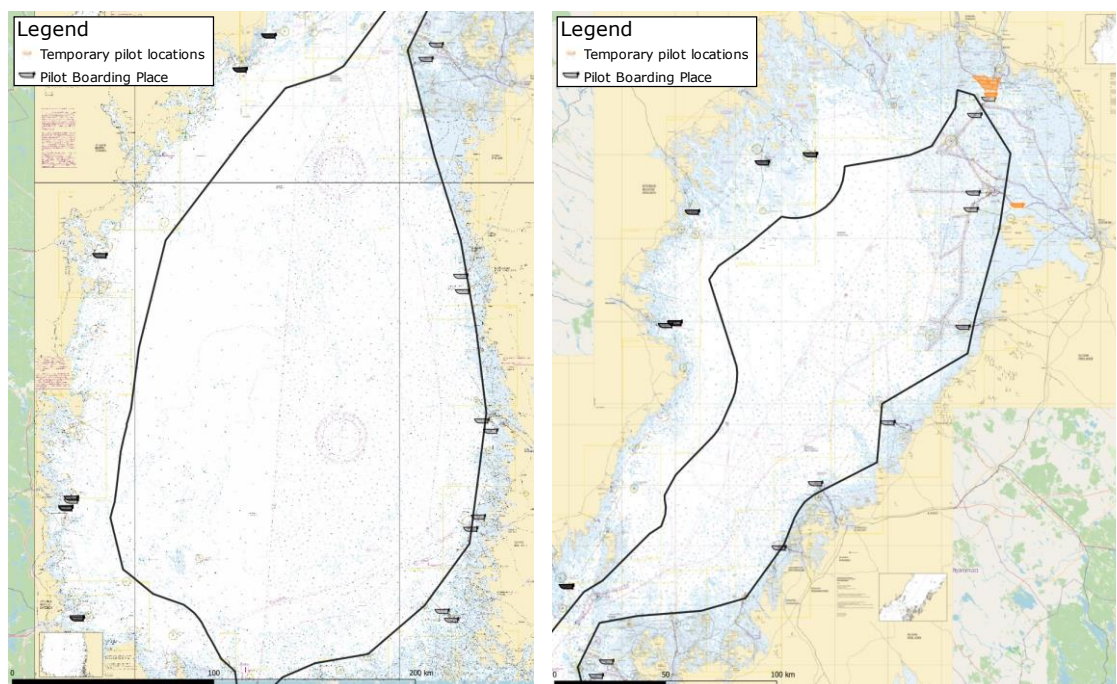


Figure 26. Finnish and Swedish pilot boarding points in the Bothnian Sea (left) and Bay of Bothnia (right).

5 Ship traffic analysis and scenarios

The AIS data presented in Section 4.2 is analysed further by identifying the main ship traffic routes. For each identified route, the composition of ship traffic on ship types and general size category is analysed. The analysis is based on the average ship traffic seen during June to October in the data covering years 2019, 2022, and 2023. Assuming an equal amount of commercial ship traffic throughout the year, an indication of the annual ship traffic is also estimated from the five months of data analysed.

5.1 Ship traffic routes based on AIS data

The entire area is split into two main areas covering the Bothnian Sea (area 1) and the Bay of Bothnia (area 2), see Figure 27, and the main ship traffic routes are identified and described in the following for the two areas, respectively.

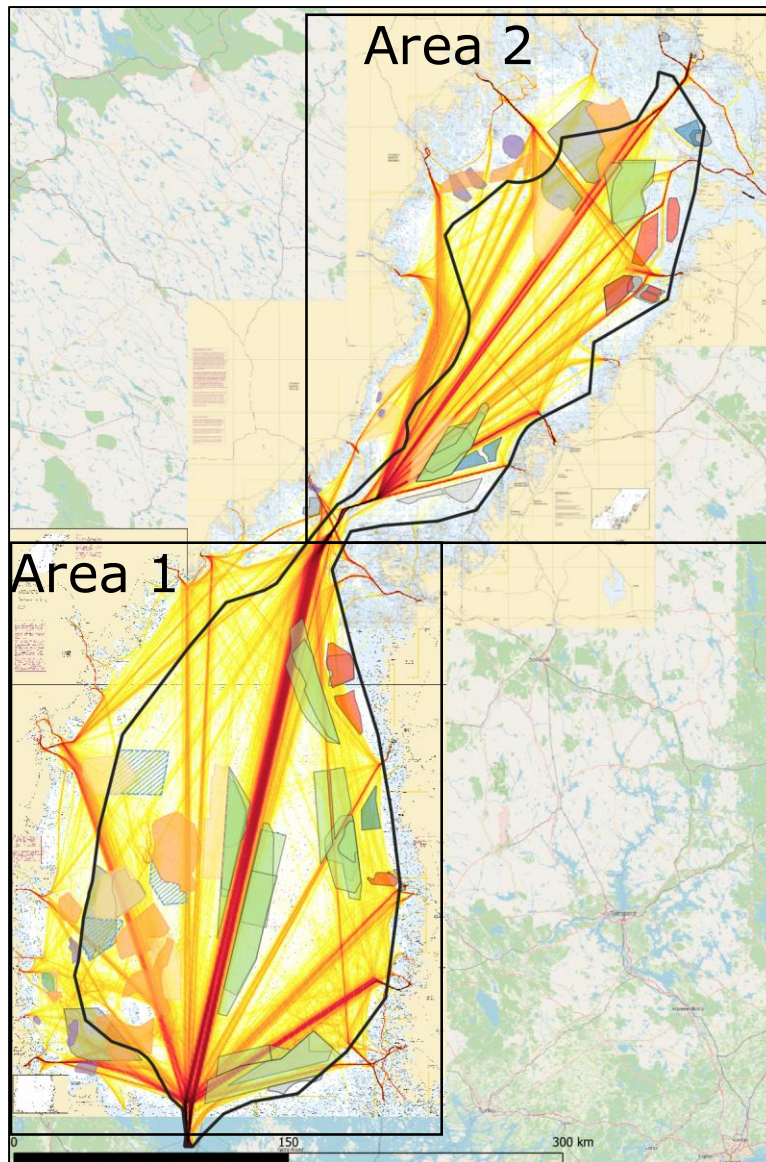


Figure 27. Study area split into two main areas.

The main routes are identified based on the AIS data within each of the two areas. Furthermore, some of the routes are grouped with other routes that are assessed to be related in terms of being potentially affected by wind farm developments. This leads to seven routes or groups of routes in area 1 and eight routes or groups of routes in area 2. Each of the groups are defined as subareas as basis for the hazard identification and risk assessment.

5.1.1 Area 1 – The Bothnian Sea

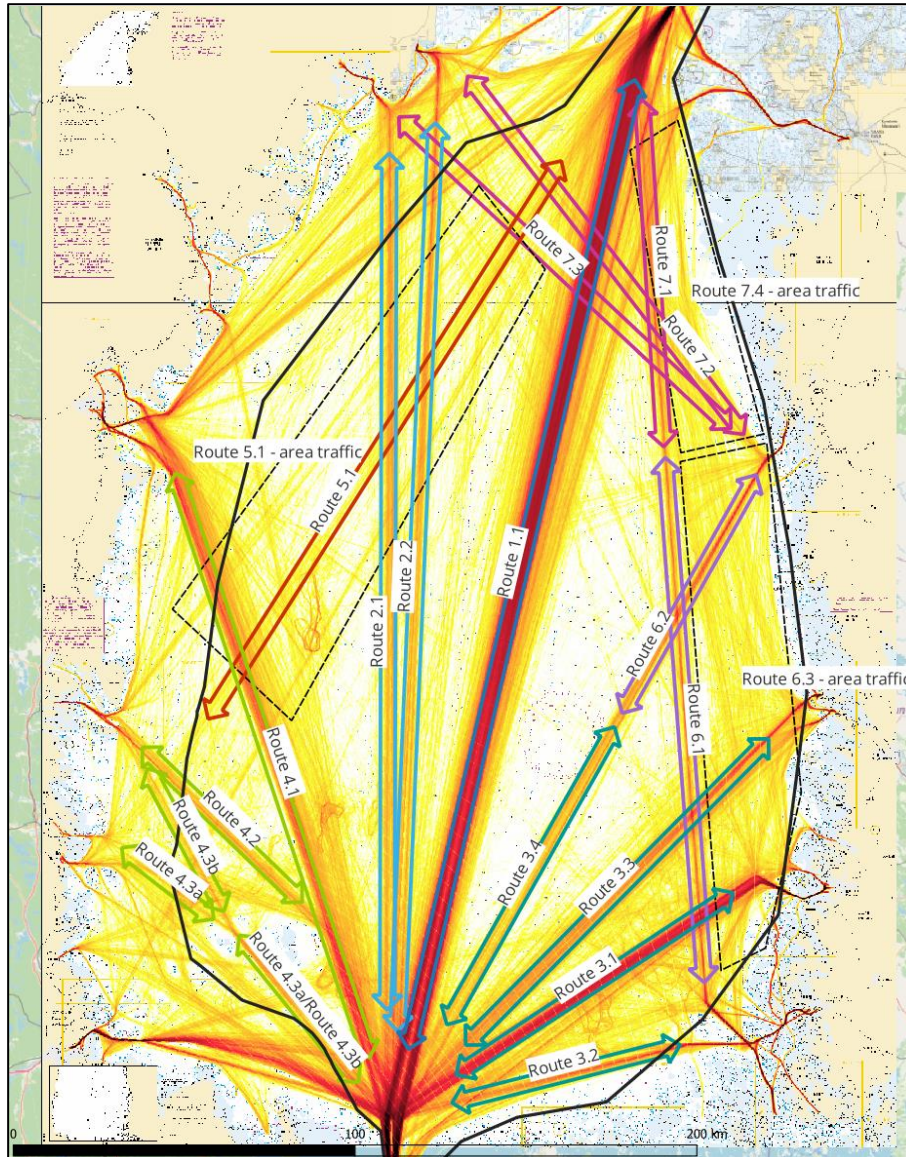


Figure 28. Main ship traffic routes identified in the Bothnian Sea (area 1).

Figure 28 gives an overview of identified ship traffic routes in the Bothnian Sea. The figure visually represents the density of the ship traffic, highlighting the most frequently used routes. The routes have been grouped and colored based on which part of the Bothnian Sea they are located in or where the routes start and end.

The Bothnian Sea serves as a crucial maritime corridor with well-defined shipping routes facilitating regional and international trade. The identified routes provide a structured framework for analyzing maritime traffic patterns.

Table 4 presents an analysis of the ship traffic counts of the ship traffic along these identified routes. The counts are rounded to nearest 5, and the table categorizes ship movements based on length groupings, offering a quantitative assessment of vessel distribution across different size classes. The routes have been analysed based on ship traffic counts from AIS data for the ice-free month during 2019, 2022, and 2023.

Table 4. Ship traffic counts for routes identified in the Bothnian Sea (area 1) split into groups of ship lengths.

Routes Ship length (m)	Avg. number of ships, 2019, 2022, and 2023 (June to October)					Indicative annual traffic
	0- 50	50- 100	100- 200	200- 300	Total	
A1_Route 1.1	15	385	885	55	1,340	3,240
A1_Route 2.1	15	35	115	5	170	430
A1_Route 2.2	10	60	105	10	185	470
A1_Route 3.1	40	150	440	35	665	1,610
A1_Route 3.2	5	125	60	5	195	490
A1_Route 3.3	25	70	185	10	290	710
A1_Route 3.4	10	75	75	10	170	430
A1_Route 4.1	25	165	265	5	460	1,120
A1_Route 4.2	15	20	75	0	110	290
A1_Route 4.3a	10	20	20	0	50	150
A1_Route 4.3b	15	45	15	0	75	200
A1_Route 5.1	15	55	60	0	130	320
A1_Route 6.1	10	80	25	5	120	320
A1_Route 6.2	10	80	55	5	150	390
A1_Route 6.3	70	100	100	10	280	700
A1_Route 7.1	5	85	35	0	125	320
A1_Route 7.2	5	15	25	0	45	120
A1_Route 7.3	5	10	15	0	30	90
A1_Route 7.4	45	80	105	5	235	590

Table 4 shows the analysed ship traffic counts along different routes, with Route 1.1 having the highest recorded number of vessels. The annual traffic estimates provide further insight to scale the five month of ice-free data into a full year of traffic assuming similar activity between summer and winter months.

Table 5 also shows the analysed ship traffic counts along different routes but split into groups for each ship type instead of ship lengths. This shows that most ships along the identified routes are cargo ships and in general fewer of all other ship types.

This overview of ship counts wrt. ship types and lengths serve as a foundation for further analysis regarding navigational safety and maritime risk assessment in the Bothnian Sea. Detailed ship traffic route counts can be found in Appendix 2.

Table 5. Ship traffic counts for routes identified in the Bothnian Sea (area 1) split into groups of ship types.

Routes Ship types	Avg. number of ships, 2019, 2022, and 2023 (June to October)						Indicative annual traffic
	<i>Fishing ship</i>	<i>Cargo ship</i>	<i>Oil tanker</i>	<i>Passenger ship</i>	<i>Support ship</i>	<i>Total</i>	
A1_Route 1.1	5	1,065	225	10	35	1,340	3,240
A1_Route 2.1	10	115	25	10	10	170	430
A1_Route 2.2	5	135	30	0	15	185	470
A1_Route 3.1	35	580	25	0	25	665	1,610
A1_Route 3.2	5	155	25	0	10	195	490
A1_Route 3.3	25	155	90	0	20	290	710
A1_Route 3.4	5	125	20	5	15	170	430
A1_Route 4.1	20	350	60	10	20	460	1,120
A1_Route 4.2	10	85	5	0	10	110	290
A1_Route 4.3a	5	30	10	0	5	50	150
A1_Route 4.3b	10	45	5	0	15	75	200
A1_Route 5.1	0	85	25	0	20	130	320
A1_Route 6.1	5	85	15	5	10	120	320
A1_Route 6.2	5	115	15	5	10	150	390
A1_Route 6.3	5	165	30	15	65	280	700
A1_Route 7.1	0	95	15	5	10	125	320
A1_Route 7.2	0	20	10	0	15	45	120
A1_Route 7.3	0	20	5	0	5	30	90
A1_Route 7.4	5	165	15	5	45	235	590

5.1.2 Area 2 – The Bay of Bothnia

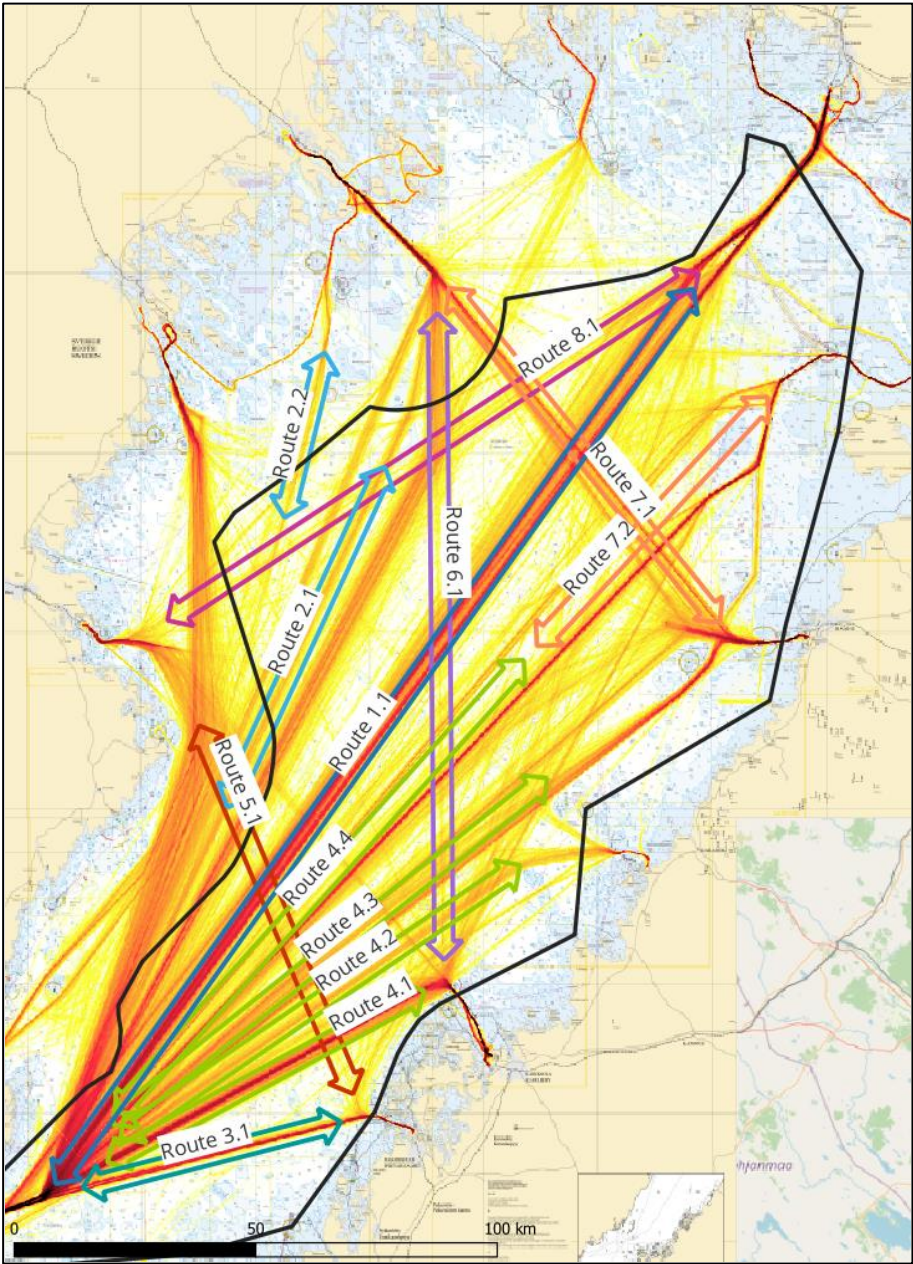


Figure 29. Main ship traffic routes identified in the Bay of Bothnia (area 2).

Figure 29 illustrates the main ship traffic routes identified in the Bay of Bothnia. As for the Bothnian Sea, this map is generated using AIS data to visualize the density of ship traffic. The routes are defined based on frequent vessel movements, with primary corridors clearly visible due to high traffic intensity. The colour gradient represents the density of ship movements, with red indicating the most used pathways and yellow showing lower intensity traffic.

Table 6 summarizes the ship traffic numbers for the identified routes in the Bay of Bothnia, classified according to ship length. The table presents the average number of ships recorded over the years 2019, 2022, and 2023

from June to October, along with an indicative estimate of annual traffic volumes assuming similar activity between summer and winter months.

Figure 29 shows that most routes go from the TSS Norra Kvarken in the bottom left corner and directly to the port in a straight line, and only few routes are going across. These routes are all with numbers above 4, e.g. Route 5.1. The traffic in the area can, as in the Bothnian Sea, be seen and regarded as a broad spectrum which splits and merge at the south in the TSS Norra Kvarken.

Table 6. Ship traffic counts for routes identified in the Bay of Bothnia (area 2) split into groups of ship lengths.

Routes	Avg. number of ships, 2019, 2022, and 2023 (June to October)					Indica- tive annual traffic
Ship length (m)	0- 50	50- 100	100- 200	200- 300	Total	
A2_Route 1.1	5	125	385	10	525	1,270
A2_Route 2.1	5	120	195	30	350	860
A2_Route 2.2	5	20	30	5	60	160
A2_Route 3.1	15	55	145	10	225	550
A2_Route 4.1	15	135	200	20	370	900
A2_Route 4.2	10	45	55	10	120	300
A2_Route 4.3	5	105	95	0	205	510
A2_Route 4.4	5	80	200	10	295	720
A2_Route 5.1	5	10	10	5	30	90
A2_Route 6.1	5	15	20	5	45	130
A2_Route 7.1	5	25	155	10	195	490
A2_Route 7.2	10	80	205	10	305	750
A2_Route 8.1	5	15	30	10	60	160

Table 6 shows the analysed ship traffic counts along different routes for the Bay of Bothnia. It follows a similar pattern to the Bothnian Sea, with high-density routes such as Route 1.1 and Route 4.1 serving as major transit corridors.

Table 7 also shows the analysed ship traffic counts along different routes but split into groups for each ship type instead of ship lengths. This shows that most ships along the identified routes are cargo ships and in general fewer of all other ship types.

This overview of ship counts wrt. ship types and lengths serve as a foundation for further analysis regarding navigation safety and maritime risk assessment in the Bay of Bothnia. Detailed ship traffic route counts can be found in Appendix 2.

Table 7. Ship traffic counts for routes identified in the Bothnian Sea (area 1) split into groups of ship types.

Routes Ship types	Avg. number of ships, 2019, 2022, and 2023 (June to October)						Indicative annual traffic
	<i>Fishing ship</i>	<i>Cargo ship</i>	<i>Oil tanker</i>	<i>Passenger ship</i>	<i>Support ship</i>	<i>Total</i>	
A2_Route 1.1	0	425	75	5	20	525	1,270
A2_Route 2.1	0	290	35	10	15	350	860
A2_Route 2.2	0	40	5	0	15	60	160
A2_Route 3.1	0	185	20	0	20	225	550
A2_Route 4.1	0	280	65	0	25	370	900
A2_Route 4.2	0	90	15	0	15	120	300
A2_Route 4.3	0	175	10	5	15	205	510
A2_Route 4.4	0	175	90	15	15	295	720
A2_Route 5.1	0	20	5	0	5	30	90
A2_Route 6.1	0	30	10	0	5	45	130
A2_Route 7.1	0	170	5	5	15	195	490
A2_Route 7.2	0	185	85	15	20	305	750
A2_Route 8.1	0	40	10	0	10	60	160

5.2 Ship traffic scenarios

In a future situation with wind farm developments in the area, the ship traffic and the wind farms will have to co-exist. It is not possible to define any preferred ship traffic routing and estimate specific risk levels and risk controls for such a scenario as it is uncertain which areas will be developed for wind farms. Instead, several scenarios are defined as basis for the hazard identification and the following risk assessment based on a worst-case establishment of wind turbines in all proposed areas.

The groups of routes defined in Section 5.1, Figure 28 and Figure 29, are used as basis for defining a number of scenarios for the hazard identification. Groups of routes are also identified as "subareas", and scenarios defined prior to conducting the HAZID workshop are seen in Table 8.

Table 8. Groups of routes and scenarios used for hazard identification.

Subareas: routes	Scenarios
Bothnian Sea (Area 1)	
A1-1: Route 1.1	3 scenarios: A1-1A to A1-1C
A1-2: Routes 2.1, 2.2	2 scenarios: A1-2A to A1-2B
A1-3: Routes 3.1, 3.2, 3.3, 3.4	6 scenarios: A1-3A to A1-3F
A1-4: Routes 4.1, 4.2, 4.3a, 4.3b	4 scenarios: A1-4A to A1-4D
A1-5: Routes 5.1	2 scenarios: A1-5A to A1-5B
A1-6: Routes 6.1, 6.1, 6.3	4 scenarios: A1-6A to A1-6D
A1-7: Routes 7.1, 7.2, 7.3, 7.4	4 scenarios: A1-7A to A1-7D
Bay of Bothnia (Area 2)	
A2-1: Route 1.1	2 scenarios: A2-1A to A2-1B
A2-2: Route 2.1, 2.2	3 scenarios: A2-2A to A2-2C
A2-3: Route 3.1	1 scenario: A2-3A
A2-4: Route 4.1, 4.2, 4.3, 4.4	3 scenarios: A2-4A to A2-4C
A2-5: Route 5.1	2 scenarios: A2-5A to A2-5B
A2-6: Route 6.1	2 scenarios: A2-6A to A2-6B
A2-7: Route 7.1, 7.2	2 scenarios: A2-7A to A2-7B
A2-8: Route 8.1	2 scenarios: A2-8A to A2-8B

An example of three scenarios is seen in Figure 30 for subarea A1-1 in the Bothnian Sea. The first scenario maintains the ship traffic on Route 1-1 in a direct line from south to northeast through a corridor between wind farm development areas in the central part of the Bothnian Sea and cutting off a part of a wind farm area in the northern part of the Bothnian Sea. In the second scenario, the wind farm development area in the northeastern part of the Bothnian Sea is avoided by letting the ship traffic pass around while still passing through a long corridor centrally in the area. Finally, a third scenario proposes to move the ship traffic centrally in the area to pass the wind farm areas through a shorter corridor along the EEZ boundary between Finland and Sweden – potentially making room for additional wind farm development.

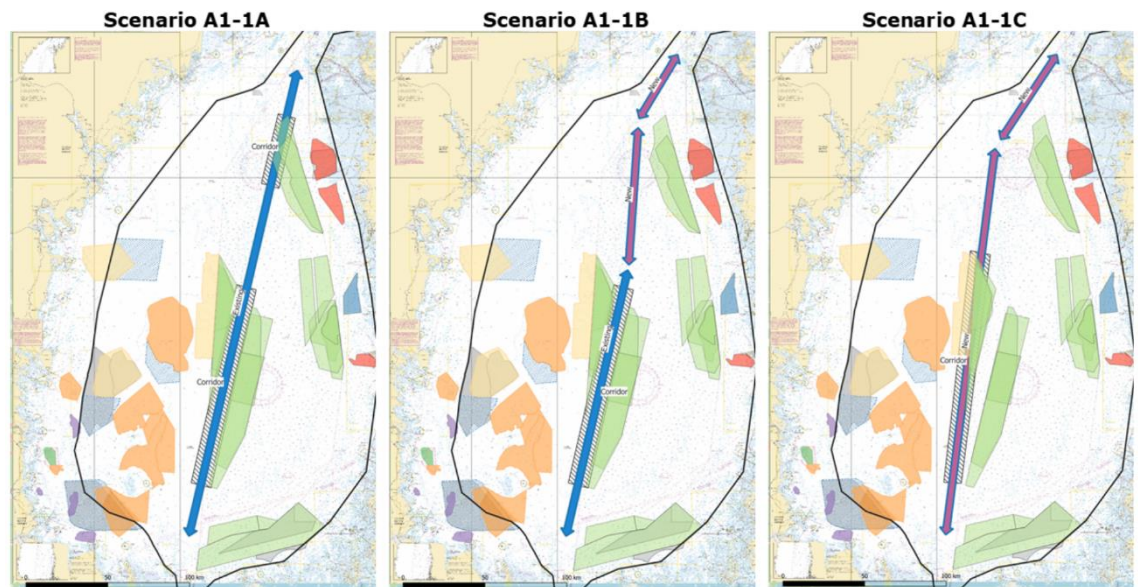


Figure 30. Example scenarios for A1_Route 1-1 in the Bothnian Sea.

All scenarios defined as basis for the analysis are presented in Appendix 1. The scenarios are used as basis for identifying and discussing hazards and hazard causes, and for discussing pros and cons on the scenarios as described in Section 6.1.

6 Hazard identification (FSA step 1 / partly step 3)

The basis for the hazard identification is the entire Gulf of Bothnia and all the currently proposed areas for wind farm development. It is well-known that not all the proposed wind farm areas will be developed and that the different areas will not be fully exploited. Hence, concrete plans in the future may change and therefore have an uncertain impact on the future conditions.

Performing a specific hazard identification leading to specific risk control measures and recommendations is therefore not directly applicable as such recommendations would change with the concrete plans for wind farm development. The methodology for hazard identification is therefore based on a larger set of predefined scenarios addressing potential ship traffic routing. The scenarios are defined in relation to a worst-case situation with an assumption that all currently known areas of interest for wind farm development could potentially be developed and fully exploited. The hazard identification is therefore performed as a combination of a scenario analysis and an identification and discussion of hazards related to the predefined scenarios.

The hazard identification and preliminary assessment of scenarios was performed in two steps.

- A two-day HAZID workshop was planned and conducted on November 25 and 26, 2024 in Espoo, Finland.
- A follow-up survey was issued in the weeks following the workshop detailing a ranking of indicative routing scenarios and specific hazards.

The workshop, follow-up survey and the results are presented in the following. Moreover, a resulting idealized, possible ship traffic routing for a future situation with wind farm development is described in Section 6.4 as basis for the following risk assessment.

6.1 Hazard identification workshop and methodology

Relevant stakeholders for the workshop were identified between Ramboll and Traficom and include representatives from authorities, and organisations representing shipping, harbours, and wind energy developers. The list of stakeholders who attended the workshop is summarized in Table 9. The stakeholders listed in Table 10 were also invited for the workshop, but did not participate.

Table 9. Stakeholders present at the workshop.

Stakeholder	
Finland	
Finnpilot	Finnish Pilot Service
Fintraffic	Marine traffic services VTS
Raja	Finnish border guard
Traficom	Finnish Transport and Communication Agency
FTIA	Finnish Transport Infrastructure Agency
Suomen Varustamot	Finnish Shipowner's Association
Wind farm developers	
Suomen Uusiutuvat	Renewables Finland
Svensk Vindenergi	Swedish Wind Energy
Åland	
Ålands Landskapsregering	Government of Åland
Sweden	
SMA	Swedish Maritime Administration
Area experience	
Viking Supply Ships	Icebreakers and navigating in the Gulf of Bothnia

Table 10. Stakeholders invited but not present at the workshop.

Stakeholder	
Finland	
YM	Finnish Ministry of Environment
LVM	Finnish Ministry of Transport and Communication
Wega	Energy analyst, projects and project development
Perämeren satamat RY	Bay of Bothnia Port Association
Suomen Satamaliitto	Finnish Port Association
Sweden	
Trafikverket	Swedish Transport Administration
Transportstyrelsen	Swedish Transport Agency
Svensk Sjöfart	Swedish Shipowner's Association

The workshop was conducted as a physical two-day workshop on November 25 and 26, 2024, and a total of 18 people participated during the entire duration of the workshop. The representative from Åland participated half of the first day where the area close to Åland was on the agenda.

The workshop was facilitated by Louise Bjerrum Paillet and Toke Koldborg Jensen from Ramboll and attended also by a Master Mariner and Lead Consultant Matti Utriainen from Ramboll as given in Table 11.

Table 11. Workshop facilitators.

Workshop facilitation	
Ramboll	
Toke Koldborg Jensen	Senior Risk Analyst
Louise Bjerrum Paillet	Senior Risk Analyst
Matti Utriainen	Master Mariner and lead consultant

The workshop was conducted in the meeting facilities of Ramboll's office in Espoo, Finland with the outline agenda for the two days as given in Figure 31. The workshop was built up around discussions and hazard identification for the subareas defined in Table 8. In practise, the hazard identification was speeded up for later subareas, and the workshop was concluded mid-afternoon of day 2. Also, a short presentation of typical radar challenges was given by Matti Utriainen during the workshop.

Day 1

10:00 Welcome and introductions
 10:30 Purpose of workshop
 10:40 Methodology
 10:55 Safety distances and challenges
 11:00 Presentation of Area 1
 11:15 Hazard identification for subarea A1-1
 11:45 Lunch
 12:25 Hazard identification for subareas A1-2 to A1-3
 14:15 Coffee break
 14:30 Hazard identification for subareas A1-4 to A1-5
 16:00 Workshop closing. See you tomorrow.

Day 2

08:30 Coffee and recap from Day 1 – comments
 08:45 Hazard identification Area A1-6 and A1-7
 10:15 Short coffee break
 10:25 Presentation of Area 2
 10:40 Hazard identification for subarea A2-1 to A2-2
 11:45 Lunch
 12:25 Hazard identification for subareas A2-3 to A2-5
 14:00 Coffee break
 14:15 Hazard identification for subareas A2-6 to A2-8
 15:30 Summary of hazard causes and scenarios
 15:40 Final remarks, comments
 15:50 Workshop evaluation
 16:00 Workshop closing

Figure 31. Outline agenda for the two-day HAZID workshop.

All hazard identification was performed in a plenum session through discussions of the scenarios in each subarea.

Input to hazards and additional comments were collected during the workshop through interactive sessions by means of Mentimeter¹. This is an online tool allowing participants to vote and comment using laptop or cell phone interactively during the workshop. Based on the hazard identification and discussions, each ship traffic scenario was evaluated on three different parameters:

- Maritime safety
- Sustainability
- Efficiency of shipping

Maritime safety was evaluated using a risk matrix combining assessed consequence level and probability for any perceived hazard related to the given scenario. Sustainability and efficiency of shipping were evaluated only as the assessed negative impact on the possibility for wind farm development, and on additional travelling distance for the ship traffic. The consequence scales applied in the hazard workshop are summarized in Table 12. Moreover, the risk matrix for maritime safety, and the corresponding scoring schemes for sustainability and efficiency of shipping are seen in Figure 32.

Table 12. Description of consequences as applied in hazard workshop.

Description of consequences	None	Minor	Moderate	Significant	Severe / catastrophic
Maritime safety		Man-overboard, minor glancing with local equipment damage and no environmental damage. Single or minor injuries.	Ship collision or turbine allision with minor damage and no or very limited environmental damage. Non-severe ship damage, multiple or severe injuries.	Major ship collision or allision causing severe property damage, single fatality or multiple severe injuries, and environmental damage.	Largescale collision or allision with extensive material damage, total loss, multiple fatalities and/or large environmental damage.
Sustainability	No negative impact on possibilities for offshore wind	Potential, smaller impacts on offshore energy production. Potential impact on total energy production is insignificant.	Moderate impact on possibilities for offshore wind energy production not significantly affecting the total energy output.	Significant reductions of the potential wind farm area, but still potentially relevant for offshore energy production.	Severe impact on potential for developing offshore energy in the area. Major restrictions or reductions of area.
Efficiency of shipping	No negative effect on efficiency of shipping	Smaller additional travel distances that can generally be accepted by the shipping industry.	Additional travel distances, but moderate and acceptable - yet unwanted - for the shipping industry. Moderate additional CO2 emissions.	Significant additional costs and CO2 emissions for the ship traffic resulting in possible minor effects on future growth.	Additional travel distances add severe additional costs and CO2 emissions for the ship traffic. Likely impact on consumer prices, future growth, etc.

¹ <https://www.mentimeter.com/>

			Maritime Safety				
			Minor	Moderate	Significant	Severe	
			Mentimeter Index value	1	2	3	4
Probability / return period	Likely to occur once every year or more within the area	4	5	6	7	8	
	Likely to occur once every 10 years within the area	3	4	5	6	7	
	Likely to occur once every 100 years within the area	2	3	4	5	6	
	Likely to occur once every 1,000 years or less within the area	1	2	3	4	5	

		Sustainability				
		None	Minor	Moderate	Significant	Severe
Mentimeter - index value		0	1	2	3	4
Assessment of expected "certain" impact on sustainability		0	2	4	6	8

		Efficiency of shipping				
		None	Minor	Moderate	Significant	Severe
Mentimeter - index value		0	1	2	3	4
Assessment of expected "certain" impact on efficiency of shipping		0	2	4	6	8

Figure 32. Scheme for scoring scenarios at the hazard workshop.

6.2 Workshop results

The workshop results are summarized in the following. Within the study area, general hazards are all related to ship-ship collisions and ship-turbine collisions. Grounding will primarily occur closer to shore and are therefore omitted in the discussion of hazards and hazard causes.

Discussions on hazards and hazard causes were recorded during the workshop and noted down in a preliminary hazard register. These are summarized in 6.2.1 including additional comments recorded during the workshop. Comments on ice conditions are reported separately in Section 6.2.2, and an initial evaluation of the scenarios according to the scoring scheme in Figure 32 is presented in Section 6.2.3.

6.2.1 Hazards and hazard causes

A processed list of hazards causes as outcome of the workshop is presented in Table 13.

Table 13. List of hazard causes.

ID	Hazard cause	Comment
H1	Loss of power / blackout.	General ship-turbine allision hazard.
H2	Navigation through corridors between rows of wind turbines.	General allision hazard for all corridors. More critical for longer corridors.
H3	Extra traffic caused by wind farm development for an extended period.	Additional ship traffic related to wind farm construction activities causing increase in ship-ship collision frequency.
H4	Service / maintenance traffic related to the wind farms during operation.	Additional ship traffic related to operating the wind farms causing increase in ship-ship collision frequency.
H5	Dragged anchor in corridors between wind turbines.	Damage to wind farm related cables in corridors between turbines.
H6	Difficult access for SAR vessels to area in corridors between wind turbines.	SAR operations challenged in corridors between turbines. Visibility in wind farm area, false radar images, available space for manoeuvring.
H7	Difficult access for environmental clean-up operations in corridors and between wind turbines.	Environmental cleanup challenged in corridors and between turbines with limited space to handle containment of the spill.
H8	Ice storms.	Navigation in winter conditions such as ice storms increase the risk of collisions and allisions.
H9	Radar shadows and disturbed radar images.	Wind turbines create false echoes on radar images and may result in increased confusion and therefore in additional collision and allision risk.
H10	Uncertainties of authority responsibilities on EEZ boundary.	SAR operations and environmental cleanup close to the EEZ between Sweden and Finland may be challenged by unclear responsibilities between authorities.
H11	Congestion of ship traffic due to rerouting.	Joining of currently separate ship traffic routes will create more ship traffic on some routes. This may be a cause of a hazard, especially in corridors between wind turbines.
H12	Corridors and "gaps" between wind farm developments attracting ship traffic.	Space between wind farms – planned corridors or space left open between development areas – may attract ship traffic resulting in a higher collision/allision frequency compared to going around the wind farm.
H13	Navigation around wind farm corners.	Corners of wind farms may cause disturbances and challenge the ship traffic. Challenges include limited visibility and radar coverage around wind farm corners, merging and crossing ship traffic, etc.
H14	Complicated ship traffic patterns.	Several routes splitting and merging in certain areas may be challenging.
H15	Lack of possibilities for monitoring ship traffic in corridors.	By pushing traffic to certain areas such as corridors without monitoring and having a possibility to intervene might create more hazards.
H16	Larger vessels in the northern part of the Bay of Bothnia.	Larger vessels (240m) arrive to harbours in the far north, including Tornio in Finland. Navigation, especially during winter conditions, can be challenging and require additional space.

ID	Hazard cause	Comment
H17	Ships approaching and using pilots at pilot boarding points.	Some ships deviate from the main routes to take up a pilot at specific pilot boarding points. While navigating to/from pilot boarding points, ships may come close to proposed wind farm development areas, especially in the northern part of the Bay of Bothnia.
H18	Increased ship traffic in the future.	Additional ship traffic to the Bothnian Sea and Bay of Bothnia may create more congestion. At a larger scale, if part of the transport to the ports in the Gulf of Finland cannot be carried out due to the geopolitical situation, the traffic in the Bothnian Sea may see significant increases. A factor of 10 was mentioned at the workshop.

6.2.2 Additional input from workshop participants and winter conditions

Much of the discussions on the HAZID workshop did not relate to specific hazard causes or hazards, but the conditions in the area as such. Main discussion points are elaborated below.

- Both the Bothnian Sea and the Bay of Bothnia can experience harsh weather also in periods without ice, which already in the current situation forces the ship traffic to choose more coastal routes rather than the shortest direct route. For a specific trip, the shortest route is therefore not necessarily chosen. Strong head wind may also cost more than choosing a slightly longer route.
- More coastal parts of the Bay of Bothnia are also used for smaller vessels including tugboats that need to reposition between ports, e.g., between Luleå and Piteå. Obstructing an area with wind farm developments will make tug operations more challenged – both in normal operation, and especially in winter conditions.
- Corridors through wind farms must be wide enough to carry the ship traffic. Especially in hard weather, it may not be possible to maintain a steady course through a corridor. A British guideline, Ref. /14/, was mentioned at the workshop suggesting that a 20° deviation or more from the ship traffic route should be considered when determining the corridor widths.
- Re-thinking the entire layout may suggest avoiding corridors by placing larger wind farm “islands” in central parts of the Bothnian Sea and the Bay of Bothnia and re-routing the ship traffic around. However, this may not coincide with relevant areas for wind farm development.
- In general, a complex routing system may challenge SAR operations.

- Many harbours in the area are specialized and have back-country connections (pipelines, railways, etc.). The ship traffic must therefore be allowed access to all ports and cannot just be diverted to other ports due to favourable conditions for wind farm developments in certain areas.
- Several harbours in the north rely on more than one fairway for ship access, to have redundancy in case one is closed due to weather conditions.

The following general aspects were rated most critical by the workshop participants:

- Coordination across authorities both within Finland and Sweden, and on the boundary between the two countries.
- Winter conditions in Bay of Bothnia. There may be a need for additional icebreakers.
- Risk for congestion of ship traffic and increased risk in corridors. In general, longer corridors between rows of turbines were considered problematic.
- Uncertain cumulative effect – it is currently unknown which parks will be developed and to which degree they will be exploited, and therefore how this will or will not affect the suggestions for traffic lanes.

Although the current study focuses on the open water situation, ice conditions during winter were mentioned repeatedly during the workshop. An ongoing research study addressing ice conditions and the interaction between wind turbines and different types of ice coverage is ongoing and is first expected to be completed in 2027. However, even if ice conditions are not included in the scope of the current report, it is evident that a future reservation of areas for the ship traffic in the Bothnian Sea and Bay of Bothnia must consider the challenging situations introduced by the harsh winter conditions in the area.

As ice coverage can change from week to week it is necessary to allow for redundancy in the area reserved for ship traffic, such that it is possible to have several routing alternatives. When wind come from the west the ice coverage is generally pushed to the east and vice versa. Given the unknown on how the presence of wind farms will affect ice build-up, and if a row of wind turbines will act as a wall with respect to the ice, it is necessary to not only allow for a reserved shipping area centrally in each of the areas, but also along each coast, where ships often go in periods with harsh weather.

For the northernmost part of Bay of Bothnia, currents will sometimes keep an area along the coast clear of ice. This was referred to as “the half moon valley” during the workshop, see illustration in Figure 33.

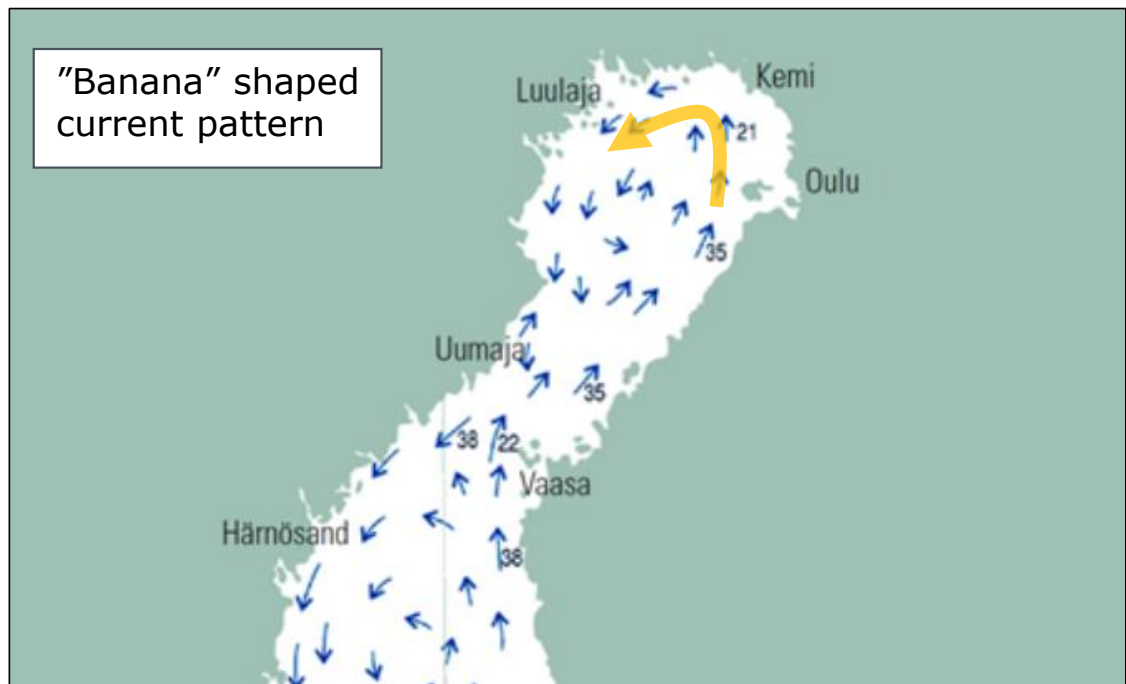


Figure 33. Illustration of “the half moon valley” in northern part of Bay of Bothnia. Background figure from Ref. /7/.

It is sometimes possible and necessary to use “the banana” shaped area to navigate the northern part of the Bay of Bothnia by sailing near the coast in situations where the more direct routes are blocked. The general winter conditions and the possible routing along the coast was at the workshop addressed to be a challenge in relation to any wind farm development in this area.

6.2.3 Initial evaluation of scenarios

Initial scenarios were setup prior to the workshop as a structured basis for the discussions as described in Section 5.2 and shown in Appendix 1. Some workshop evaluation comments reflected that the scenarios were fixed and unrealistic, and that a workshop could be more effective after having final plans, or through a more general analysis of hazards. However, other workshop evaluations found it very valuable with a fixed structure, the identification of risks and difficult areas, open and relaxed discussions, and wide range of experience present. The evaluation of the scenarios – and the following analyses – shall therefore be seen in the light that final plans will differ, and that the scenarios are idealised.

All scenarios were initially evaluated by the workshop participants according to the scoring scheme presented in Table 12 and Figure 32. The average scoring of each scenario addressed at the HAZID workshop is seen

Table 14 and Table 15 for Area 1, the Bothnian Sea, and Area 2, the Bay of Bothnia, respectively.

Table 14. Initial evaluation of scenarios for Area 1, the Bothnian Sea, at the HAZID workshop.

Scenario	Maritime Safety	Sustainability	Efficiency of shipping	Total risk value
Scenario A1-1A	6	2	2	10
Scenario A1-1B	5	2	2	9
Scenario A1-1C	4	2	4	10
Scenario A1-2A	4	2	2	8
Scenario A1-2B	5	2	4	11
Scenario A1-3A	6	4	4	14
Scenario A1-3B	4	2	4	10
Scenario A1-3C	4	4	2	10
Scenario A1-3D	4	2	2	8
Scenario 1A-3E	5	4	4	13
Scenario 1A-3F	6	4	4	14
Scenario 1A-4A	6	4	2	12
Scenario 1A-4B	5	2	2	9
Scenario 1A-4C	4	2	4	10
Scenario 1A-4D	4	4	4	12
Scenario 1A-5A	4	2	2	8
Scenario 1A-5B	4	2	4	10
Scenario 1A-6A	6	4	2	12
Scenario 1A-6B	4	2	4	10
Scenario 1A-6C	4	4	2	10
Scenario 1A-6D	6	4	2	12
Scenario 1A-7A	6	4	2	12
Scenario 1A-7B	4	2	2	8
Scenario 1A-7C	5	4	2	11
Scenario 1A-7D	6	4	2	12

Table 15. Initial evaluation of scenarios for Area 2, the Bay of Bothnia, at the HAZID workshop.

Scenario	Maritime Safety	Sustainability	Efficiency of shipping	Total risk
Scenario A2-1A	4	2	2	8
Scenario A2-1B	5	2	2	9
Scenario A2-2A	4	4	2	10
Scenario A2-2B	4	2	2	8
Scenario A2-2C	6	2	4	12
Scenario A2-3A	4	0	2	6
Scenario A2-4A	6	4	2	12
Scenario A2-4B	5	4	2	11
Scenario A2-4C	4	2	4	10
Scenario A2-5A	4	2	2	8
Scenario A2-5B	4	2	2	8
Scenario A2-6A	4	2	2	8
Scenario A2-6B	4	2	2	8
Scenario A2-7A	5	4	2	11
Scenario A2-7B	4	2	2	8
Scenario A2-8A	6	4	2	12
Scenario A2-8B	4	2	4	10

The initial scoring indicates that some scenarios are perceived leading to higher additional risk than others. Moreover, rerouting and taking up space that could otherwise be used for wind farms could have a minor to moderate effect on the sustainability and efficiency of shipping parameters.

The scoring performed at the workshop was not aligned between the scenarios, and hence only provides an indication of different risk levels. However, it is clear from the evaluations that scenarios scoring in the orange range mainly are related to traffic situations with extensive use of corridors leading through wind farm areas. This is in line with the identified hazard causes in Table 13 where several are related explicitly to ship traffic in corridors.

6.3 Follow-up survey

Following the workshop, an additional Mentimeter survey was sent out to the workshop participants for online submission. The purpose of this survey was primarily to let the workshop participants perform a relative ranking of the scenarios for each subarea. A few additional scenarios were added to the initial list based on the input received during the workshop. All the

scenarios are listed in Table 16 and shown in Appendix 1. Scenarios added following the workshop are marked by red bold text.

Table 16. List of scenarios. Scenarios marked in red bold text were added for the follow-up survey.

Subareas: routes		Scenarios
Area 1 - Bothnian Sea		
A1-1: Route 1.1	5 scenarios: A1-1A - A1-1C + A1-1D - A1-1E	
A1-2: Routes 2.1, 2.2	2 scenarios: A1-2A - A1-2B	
A1-3: Routes 3.1, 3.2, 3.3, 3.4	6 scenarios: A1-3A - A1-3F	
A1-4: Routes 4.1, 4.2, 4.3a, 4.3b	4 scenarios: A1-4A - A1-4D + A1-4E	
A1-5: Routes 5.1	2 scenarios: A1-5A - A1-5B + A1-5C	
A1-6: Routes 6.1, 6.1, 6.3	4 scenarios: A1-6A - A1-6D	
A1-7: Routes 7.1, 7.2, 7.3, 7.4	4 scenarios: A1-7A - A1-7D	
Area 2 - Bay of Bothnia		
A2-1: Route 1.1	2 scenarios: A2-1A - A2-1B	
A2-2: Route 2.1, 2.2	3 scenarios: A2-2A - A2-2C	
A2-3: Route 3.1	1 scenario: A2-3A	
A2-4: Route 4.1, 4.2, 4.3, 4.4	3 scenarios: A2-4A - A3-4C	
A2-5: Route 5.1	2 scenarios: A2-5A - A2-5B	
A2-6: Route 6.1	2 scenarios: A2-6A - A2-6B	
A2-7: Route 7.1, 7.2	2 scenarios: A2-7A - A2-7B + A2-7C	
A2-8: Route 8.1	2 scenarios: A2-8A - A2-8B	

In a reply to the follow-up survey, Ref. /15/, SMA in Sweden informed that the general scenarios used here do not fully agree with ongoing work in Sweden. Hence, SMA were not able to participate in the survey in order not to indicate any recommended routing. Replies from SMA are therefore omitted from the following.

The remaining replies are grouped into four groups covering representatives for wind farm developers, Finnish authorities (Traficom and FTIA

), ship traffic and surveillance (Viking Ship Supply, VTS, and piloting), and the Shipowner's organisation. The top ranked scenario within each group and the overall preferred scenarios are shown in Table 17.

Table 17. Highest ranked scenarios according to the follow-up survey.

Group/Area	Wind farm developers	Finnish authorities	Ship traffic and surveillance	Ship owner's organization	Overall
Area A1 – Bothnian Sea					
Area A1-1	1C	1B	1E	1B	1B/1D ^{1*}
Area A1-2	2A	2A	2B	2A	2A
Area A1-3	3D/ 3B	3B	3D	3D	3D/3B ^{2*}
Area A1-4	4D/ 4C	4E	4D	4C	4C ^{3*}
Area A1-5	5B	5C	5C	5C	5C
Area A1-6	6C	6B	6B	6B	6B
Area A1-7	7D/ 7B	7B	7B	7B	7B
Area A2 – Bay of Bothnia					
Area A2-1	1A/ 1B	1B	1B	1B	1B
Area A2-2	2C	2B	2B/ 2C	2B	2B
Area A2-4	4C	4C	4C	4C	4C
Area A2-5	5B	5B	5B	5B	5B
Area A2-6	6A/ 6B	6B	6B	6B	6B
Area A2-7	7B/ 7C	7C	7C	7C	7C
Area A2-8	8B	8B	8B	8B	8B

In most cases, the overall highest ranked scenario corresponds to the scenario preferred by most of the respondents. However, in a few cases, detailed analysis of the results has led to different conclusions, as described below.

1*: The overall preferred scenario is a combination of scenarios A1-1B and A1-1D. Scenario A1-1B consists of a long corridor through the central part of the Bothnian Sea, while scenario A1-1D consists of a north-south corridor between the Swedish wind farm development areas. Scenario A1-1D is not the highest ranked scenario by any group of respondents but is consistently ranked second-highest. The chosen combination adds redundancy to the ship traffic.

2*: The overall preferred scenario is a combination of A1-3D and A1-3B. This is due to the corridor close to land in scenario A1-3D, where large ships may encounter depth issues, forcing them to take the longer route north of the wind farms like in scenario 3B.

3*: For the large area off the coast of Gävle in Sweden, there is a strong preference to reduce the number of corridors, but still maintain at least one passage through the wind farm development area – either as in scenario A1-4C or A1-4D. Scenario A1-4C is chosen as the more direct route.

The results of the ranking in the follow-up survey are used to build an idealized ship traffic routing for a situation with a worst-case full wind farm development, hence all proposed areas are developed and fully exploited, see Section 6.4.

In addition to the ranking, also hazards related to specific locations were scored as part of the Mentimeter survey. The scoring was performed according to a risk matrix aligned with the FSA guideline and related to human safety, property damage, and environmental spill. The risk matrix is shown in Figure 34.

				Severity - Human safety, property damage or environmental spill			
				Minor	Significant	Severe	Catastrophic
				1	2	3	4
Probability / return period	Frequency / definition	Frequency (per ship year)	Mentimeter Index value				
	Frequent Likely to occur once per month on one ship	10	4	8	9	10	11
	Reasonably probable Likely to occur once per year in a fleet of 10 ships, i.e., likely to occur a few times during the ship's life	10^{-1}	3	6	7	8	9
	Remote Likely to occur once per year in a fleet of 1,000 ships, i.e., likely to occur in the total life of several similar ships	10^{-3}	2	4	5	6	7
	Extremely remote Likely to occur once in the lifetime (20 years) of a world fleet of 5,000 ships	10^{-5}	1	2	3	4	5

Figure 34. Risk matrix used for scoring of hazards in the follow-up survey.

The hazards were defined based on the input received during the HAZID workshop and classified as representative hazards related to navigation through corridors, allisions when navigating around wind farm corners and in tight areas, and ship-ship collisions at selected route interactions.

A total of 22 hazard locations were defined, and the risk assessed by the respondents is recorded in the Mentimeter survey. All the selected hazard locations are shown in Figure 35, Figure 36, and Figure 37, and scorings according to Figure 34 and processed from the survey replies are presented in Table 18.

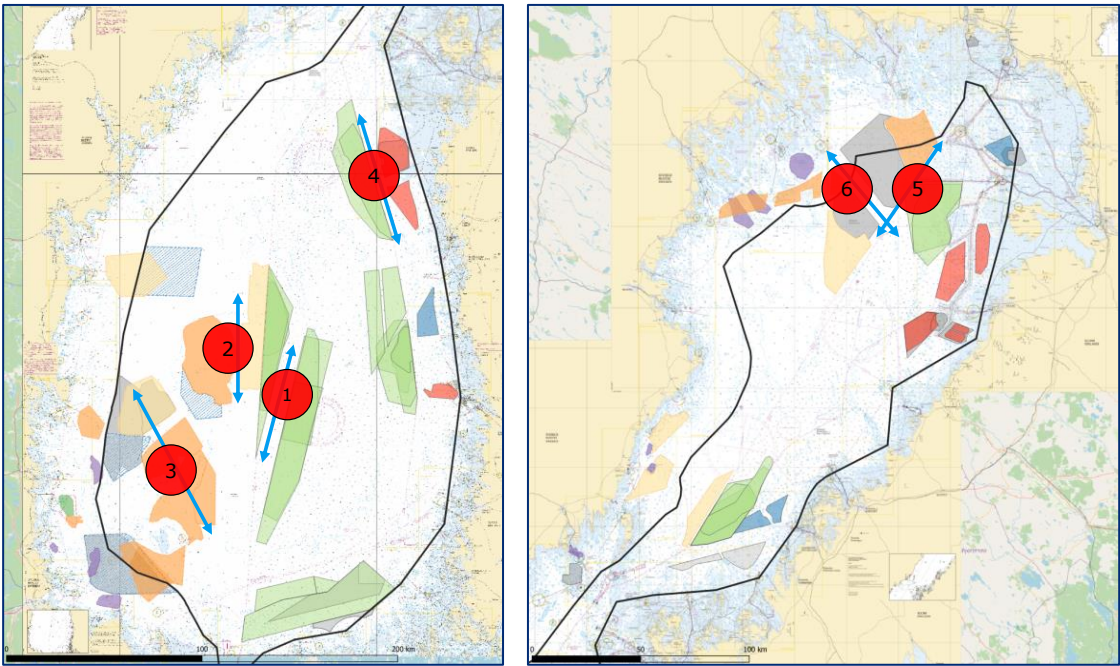


Figure 35. Hazard locations in corridors for the follow-up Mentimeter survey.

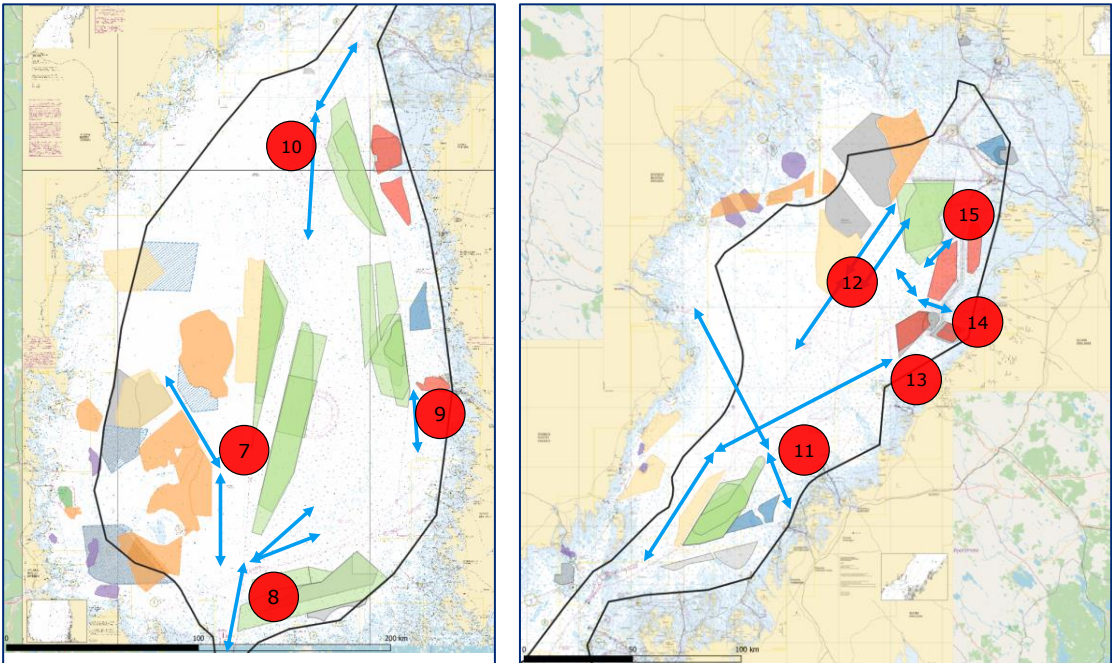


Figure 36. Hazard locations for turbine allisions at wind farm corners and tight spaces (short corridors).

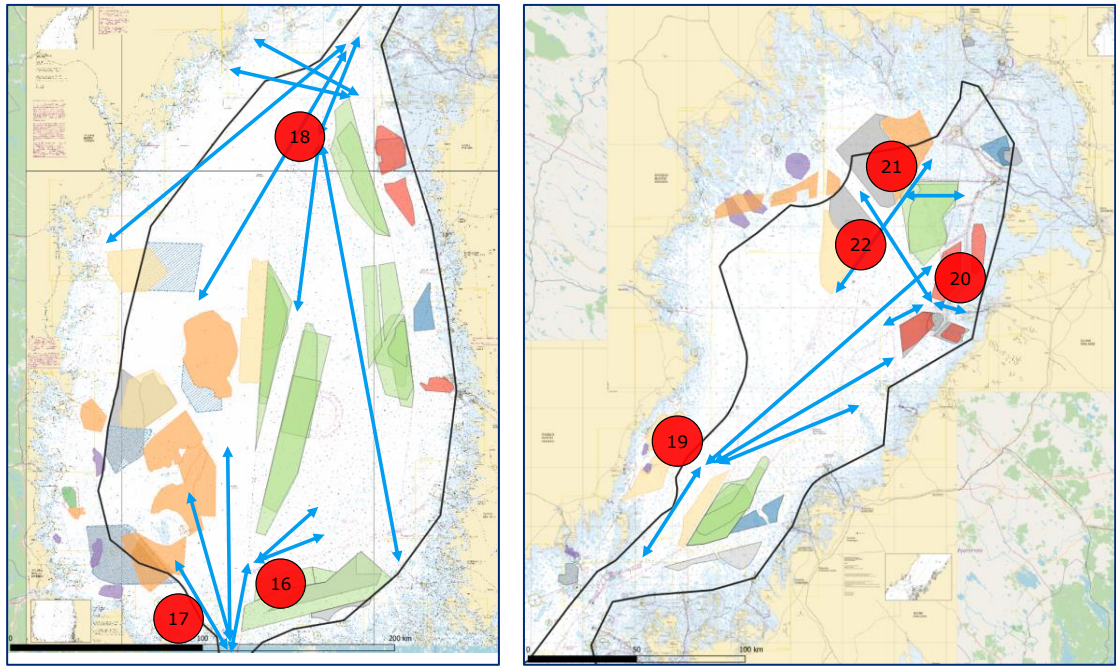


Figure 37. Hazard locations for ship-ship collisions at selected route interactions.

Table 18. Processed scorings of location specific hazards from follow-up survey.

ID	Ship-ship collision			Ship-turbine allision		
	Human safety	Property damage	Environ.	Human safety	Property damage	Environ.
1	6	9	9	6	9	6
2	6	8	8	6	8	6
3	8	8	9	6	9	8
4	6	8	8	6	8	6
5	6	9	8	6	8	6
6	6	8	9	6	8	6
7				6	6	6
8				6	6	6
9				6	6	6
10				3	6	4
11				6	6	6
12				3	6	4
13				3	6	4
14				5	6	6
15				6	6	6
16	6	8	6			
17	6	6	6			
18	6	6	6			
19	6	6	6			
20	6	6	6			
21	6	8	6			
22	6	6	6			

The results show a concern related to hazards 1, 3, 5, and 6 which are all related to long corridors in the Bothnian Sea, and corridors in the northern part of the Bay of Bothnia. The concern is mainly related to ship-ship collisions, and turbine allisions in the longest corridors represented by hazard 1 and 3.

Hazards representing ship-turbine allisions in more open waters – hazard 10, 12, and 13 – are generally assessed lower on human safety and environmental damage. This is in line with the initial hazard discussions at the workshop where SAR operations and environmental cleanup were addressed as more challenged in more confined spaces such as corridors.

The insights from the initial hazard identification and the follow-up survey are used in the following.

6.4 Resulting idealized, possible ship traffic routing

Based on the results from the follow-up Mentimeter survey, the ranking of scenarios has been used to determine an idealized, possible routing network for the ship traffic.

It is important to keep in mind, that the future use of the areas for wind farms is not yet decided, and not all the indicated wind farm areas will be exploited. Moreover, wind farms may be proposed in yet other areas, and the rate of development may differ across the areas. The future ship traffic routing therefore depends intricately on the extent and rate of development of wind farm area, and the cumulative effects need to be considered in an ongoing process along with the development.

In a reply to the follow-up survey, Ref. /15/, SMA made it clear that any indicative ship traffic routing based on potential interactions with all the proposed areas would be unrealistic. Hence, the idealized, possible ship traffic routing is not to be seen as a recommendation, but merely as a basis for how the ship traffic could be conducted in different parts of the area while also considering coherence between the shipping industry and the wind farm development. In reality, some wind farm areas may be reduced in size, some may not be developed, and new areas may emerge, and the cumulative effect on the interaction between wind farms and ship traffic will likely result in a different ship traffic routing than the one presented here.

However, the idealized ship traffic routing is valuable for the risk analysis assessing the current traffic flows and the potential risk increase in different areas.

6.4.1 Interpretation of Mentimeter results

The data from the Mentimeter post-workshop survey has been analysed as a total ranking, but it has also been investigated if certain groups of respondents have a pattern in their ranking, i.e., if the captains have ranked the scenarios in a similar way, weight has in the evaluation been put on their votes rather than the wind farms developers when considering the preferred routes, when designing a possible shipping route network with focus on the navigational safety.

6.4.2 Idealized routes for the Bothnian Sea – Area A1

For the Bothnian Sea the workshop participants were in the post-workshop Mentimeter survey asked to consider seven different areas with one to five proposed scenarios for the ship traffic.

6.4.2.1 Traffic along Route 1.1

Route 1.1 carries the main traffic from TSS North Åland to TSS Norre Kvarken. This traffic is distributed onto three different potential routes, all with equal amount of traffic, see Figure 38 (left).

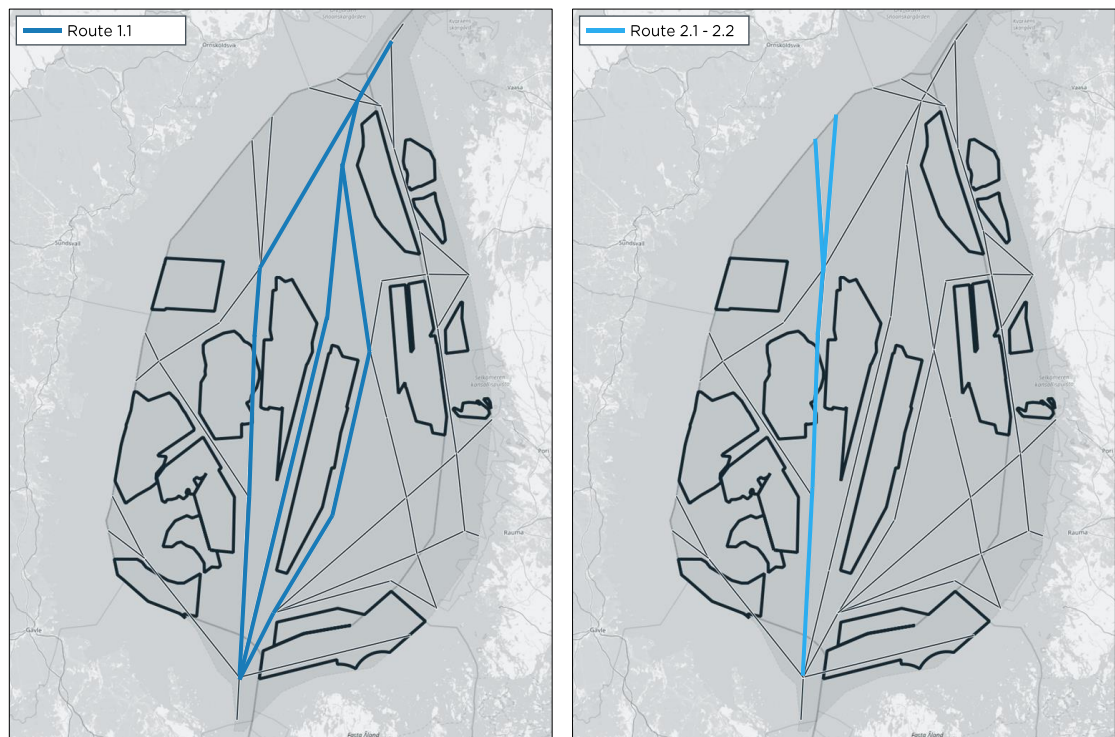


Figure 38. Idealized routes for accommodation of the traffic along Route 1.1 from TSS North Åland to TSS Norra Kvarken (left) and along Route 2.1 and 2.2 from TSS North Åland to Örnsköldsvik/Domsjö (route 2.1) and Husum (route 2.2) (right).

The results from the Mentimeter survey yields that a solution with traffic along the main route, as today, together with two alternative routes west and east of the main route is to be preferred. This is a combination of

scenario A1-1B and A1-1D. This combination also allows for redundancy as described necessary during the workshop. Furthermore, it allows for the ship traffic to avoid the long corridor in the central Bothnian Sea.

6.4.2.2 Traffic along Routes 2.1 and 2.2

Route 2.1 and 2.1 carries the ship traffic from TSS North Åland to Örnköldsvik/Domsjö (route 2.1) and Husum (route 2.2). The traffic is collected to one route from TSS North Åland and until north of the wind farm areas, from where the traffic splits out with directions towards the destinations, see Figure 38 (right).

6.4.2.3 Traffic along Routes 3.1 to 3.4

Routes 3.1 to 3.4 carry traffic from the TSS North Åland to the Finnish coast. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 39 (left).

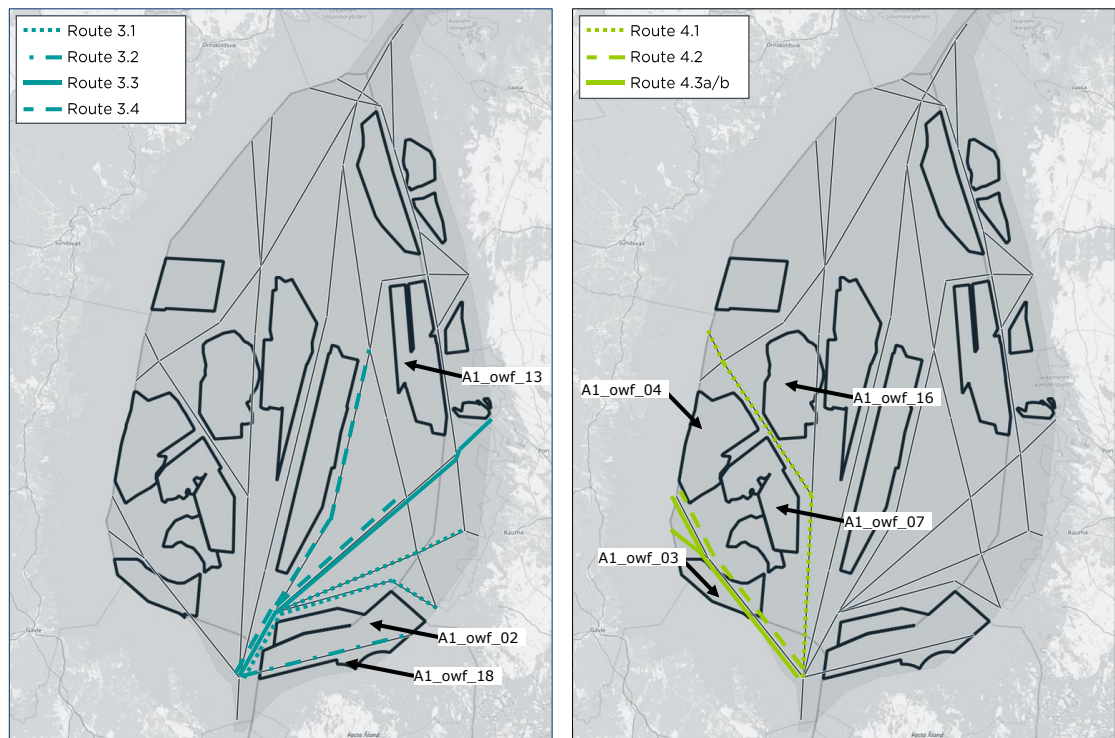


Figure 39. Idealized routes for accommodation of the traffic along Route 3.1 to 3.4 from TSS North Åland to the Finnish coast (left) and idealized routes for accommodation of the traffic along Route 4.1-4.3 from TSS North Åland to the Swedish coast (right).

All traffic towards the west coast of Finland, except for Route 3.2, is collected to a common route after the TSS North Åland until north of wind farm area A1_OWF_02, from where the traffic spreads out on routes as a fan. In the basis scenario, the traffic splits already when exiting the TSS North Åland.

To accommodate traffic going around the wind farm area A1_OWF_02 and towards Turku, 10% of the traffic on Route 3.1 towards Rauma has been moved to the route towards Turku. Route 3.2 is unchanged and is placed between the wind farms A1_OWF_02 and A1_OWF_18. All traffic on Route 3.3 towards Pori is kept as in the basis scenario.

The traffic on Route 3.4, which extends into Route 6.2 towards Kaskinen cuts through the wind farm A1_OWF_13. The traffic has been divided around the wind farm area, with the traffic distributed evenly on the two alternatives around the wind farm.

6.4.2.4 Traffic along Routes 4.1 to 4.3

Routes 4.1 to 4.3 carry traffic from the TSS North Åland to the Swedish coast. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 39 (right).

The traffic splits into two directions north of the TSS North Åland. Route 4.1 towards Sundsvall and Timrå follows the southernmost part of Routes 2.1 and 2.2, before the traffic is directed towards the east coast of Sweden north of the wind farm A1_OWF_07. The traffic is accommodated in the space between the wind farms A1_OWF_07 and A1_OWF_16.

The traffic on Route 4.2, is moved to Route 4.3b, to avoid the wind farm areas A1_OWF_04 and A1_OWF_07. The traffic diverts to a more northerly direction after exiting the corridor in wind farm A1_OWF_03. All the traffic on Route 4.3b is kept, such that the traffic along here is the combined traffic from Route 4.2 and 4.3b.

The traffic on Route 4.3 is accommodated through the corridor in wind farm A1_OWF_03, and the route is unchanged from the basis scenario.

6.4.2.5 Traffic along Route 5.1

Route 5.1 carries traffic from the east coast of Sweden towards TSS Norra Kvarken. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 40 (left).

All the traffic along Route 5.1 is moved to have a bend, to avoid the wind farm area A1_OWF_05. All traffic on Route 5.1 follows the new path.



Figure 40. Idealized routes for accommodation of the traffic along Route 5.1 from the east coast of Sweden towards TSS Norra Kvarken (left). The idealized routes for accommodation of the traffic along Route 6.1 to 6.3 from southwest Finland (Turku and Rauma) towards north and the continuation of Route 3.4 from TSS North Åland to Kaskinen in Finland (right).

6.4.2.6 Traffic along Routes 6.1 to 6.3

Route 6.1 to Route 6.3 carry traffic from the southwest coast of Finland (Turku and Rauma) towards TSS Norra Kvarken (Routes 6.1 and 6.3). Furthermore, the continuation of the traffic from TSS Norra Kvarken towards Kaskinen (Route 3.4) is accommodated along route 6.2. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 40 (left).

The traffic on Route 6.1 is moved towards west, to avoid the wind farm A1_OWF_13. All traffic on Route 6.1 in the basis scenario is placed on this route. The traffic defined as *area traffic* along route 6.3 in the basis scenario, is placed on a route along the coast, between the wind farm areas A1_OWF_13 to the west and A1_OWF_11 and A1_OWF_12 to the east.

The traffic on Route 6.2, which extends into Route 3.4 between TSS North Åland towards Kaskinen cuts through the wind farm A1_OWF_13. The traffic has been divided around the wind farm area, with the traffic distributed evenly on the two alternatives around the wind farm.

6.4.2.7 Traffic along Routes 7.1 to 7.4

Routes 7.1 and 7.4 carry traffic from the west coast of Finland towards TSS Norra Kvarken, while Routes 7.2 and 7.3 carry traffic from Husum/Örn Sköldsvik on the Swedish coast to Kaskinen on the Finnish coast. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 41.

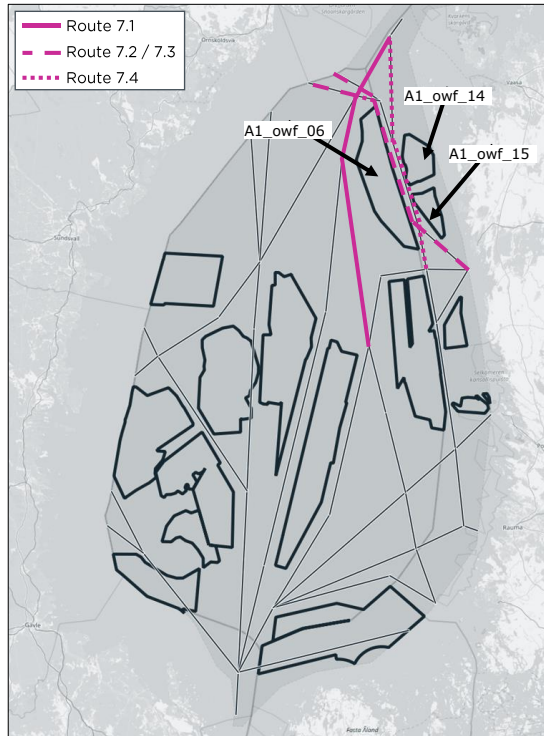


Figure 41. Idealized routes for accommodation of the traffic along Route 7.1 to 7.3 crossing the northern part of the Bothnian Sea and accommodating traffic towards TSS Norra Kvarken.

The traffic on Route 7.1 is moved towards west to avoid the wind farm A1_OWf_06. This route is a continuation of Route 6.1, and the traffic from the basis scenario is placed on this route. The traffic defined as *area traffic* along Route 7.4 in the basis scenario, is placed on a route along the coast, between the wind farm areas A1_OWf_06 to the west and A1_OWf_14 and A1_OWf_15 to the east. North of A1_OWf_14 the route changes course towards TSS Norra Kvarken.

The traffic on Routes 7.2 and 7.3 from Kaskinen to Husum and Örn Sköldsvik / Domsjö on the Swedish coast is collected into one route, following the same route as Route 7.4 between the wind farm areas A1_OWf_06 to the west and A1_OWf_14 and A1_OWf_15 to the east. North of wind farm area A1_OWf_06 the traffic splits into two routes and diverts towards the destinations on the Swedish coast.

6.4.2.8 Idealized ship traffic routing in the Bothnian Sea – Area 1

The idealized routes in the Bothnian Sea taking wind farms into consideration as they are currently proposed are shown in Figure 42.

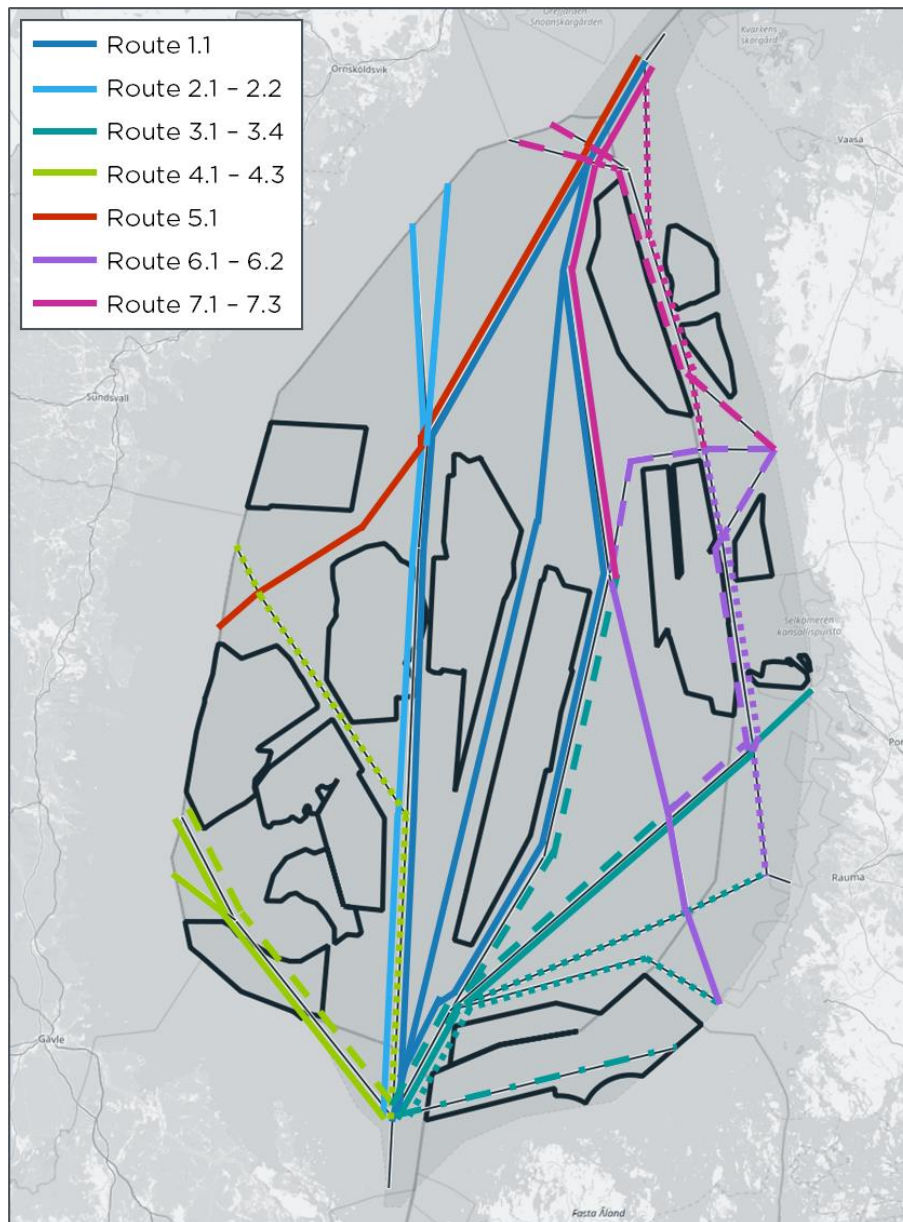


Figure 42. Ship traffic routes used in the modelling of the navigational safety for the Bothnian Sea. The details for each route and the legend for the different types of dashes are described in Figure 38 to Figure 41. The wind farms are marked as outlines and not adjusted to the route network.

The traffic on each section of the routing network shown in Figure 42 is summarized in Table 19.

Table 19. Summary of the idealized route network for accommodating the ship traffic in the Bothnian Sea in a future situation with wind farms.

Route marking	Description	Traffic	Number of ships
	Former Route 1.1	A third of the traffic from Route 1.1	1140
	Former Route 1.1, Route 2.1 and 2.2 and 4.1 merged to one route	- A third of the traffic from Route 1.1 - All traffic from Route 2.1 - All traffic from Route 2.2 - All traffic from Route 4.1	2940
	Former Route 2.1 and 2.2 merged to one route	- A third of the traffic from Route 1.1 - All traffic from Route 2.1 - All traffic from Route 2.2	1880
	New route	- A third of the traffic from Route 1.1 - Half of the traffic from Route 3.4	1310
	New route	- A third of the traffic from Route 1.1 - All traffic from route 7.1 - In the northernmost part, the route contains two thirds of the traffic from Route 1.1	1380
	Former Route 5.1	- A third of the traffic from Route 1.1 - All traffic from route 5.1	1440
	Former Route 1.1	- All traffic from Route 1.1 - All traffic from Route 7.1 - All traffic from Route 5.1	4280
	Former Routes 2.1 and 2.2	Traffic from Route 2.1 and 2.2, respectively	820
	Former Routes 3.1, 3.3, and 3.4 merged to one route	- Traffic from Route 3.1 - Traffic from Route 3.3 - Traffic from Route 3.4	3740
	Former Route 3.2	Traffic from Route 3.2	470
	Former Routes 3.3 and 3.4	- Traffic from Route 3.3 - Half of the traffic from Route 3.4	900
	Former Routes 3.3 and 6.4	- Traffic from Route 3.3 - Half of the traffic from Route 6.4	900
	Former Route 3.3	Traffic from Route 3.3	700
	Former Route 4.1	Traffic from Route 4.1	1110
	Former Routes 4.2 and 4.3	- Traffic from Route 4.2 - Traffic from Route 4.3	460

Route marking	Description	Traffic	Number of ships
	Former Route 4.3a	Traffic from Route 4.3a	120
	Former Route 5.1, area traffic, gathered into one route	Traffic from Route 5.1	320
	Former Route 6.1	Traffic from Route 6.1	290
	Former Route 6.2	Traffic from Route 6.2 split into two routes	360
	Former Route 6.3, area traffic, gathered into one route	Traffic from Route 6.3	680
	Former Route 6.2 and route 6.3, area traffic, gathered into one route	- Half of the traffic from Route 6.2 - Traffic from Route 6.3	480
	Former Route 7.1	Traffic from Route 7.1	300
	Former Routes 7.2 and 7.3	Traffic from Route 7.2 and 7.3, respectively	160
	Former Route 7.4, area traffic, gathered into one route	Traffic from Route 7.4	570
	Former Routes 7.2, 7.3, and 7.4, area traffic, gathered into one route	- Traffic from Route 7.2 - Traffic from Route 7.3 - Traffic from Route 7.4	680

6.4.3 Idealized routes for the Bay of Bothnia – Area 2

For the Bay of Bothnia the workshop participants were in the post-workshop Mentimeter survey asked to consider seven different areas with one to three proposed scenarios for the ship traffic.

6.4.3.1 Traffic along Route 1.1

Route 1.1 carries the main traffic from TSS Norra Kvarken to Tornio/Kemi in the north. This traffic is kept on a central route through the area, see Figure 43 (left).

The route has a small bend to around the wind farm area A2_OWF_04, while the wind farm areas A2_OWF_03, A2_OWF_04, A2_OWF_05, and A2_OWF_12 are reduced in size to accommodate safety distances.



Figure 43. Idealized routes for accommodation of the traffic along Route 1.1 from TSS Norra Kvarken to Tornio/Kemi (left) and along Routes 2.1 and 2.2 from TSS Norra Kvarken to Luleå (route 2.1) and Piteå (route 2.2) (right).

6.4.3.2 Traffic along Routes 2.1 and 2.2

Route 2.1 and 2.2 carry the ship traffic from TSS Norra Kvarken to Luleå (route 2.1) and Piteå (route 2.2). The traffic is collected to one route from TSS Norra Kvarken and until north of the wind farm area A2_OWF_07, from where the traffic splits out with directions towards the destinations, see Figure 43 (right).

6.4.3.3 Traffic along Route 3.1

Route 3.1 carries traffic from the TSS Norra Kvarken to Pietarsaari. The route is not changed in the idealized scenario, as the traffic can be accommodated in the corridor between wind farm areas A2_OWF_02, A2_OWF_07 to the north and A2_OWF_13 and A2_OWF_14 to the south as shown in Figure 44 (left).

6.4.3.4 Traffic along Routes 4.1 to 4.4

Routes 4.1 to 4.4 carry traffic from the TSS Norra Kvarken to the Finnish coast. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 44 (right).

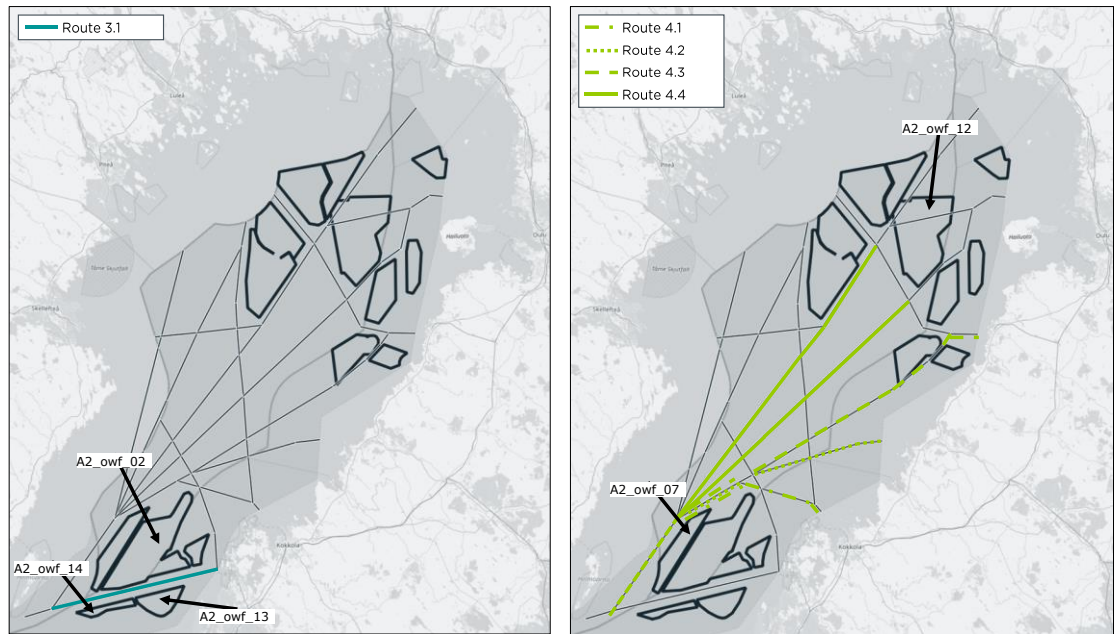


Figure 44. Idealized routes for accommodation of the traffic along Route 3.1 from TSS Norra Kvarken to Pietarsaari (left) and potential routes for accommodation of the traffic along Route 4.1 to 4.4 from TSS Norra Kvarken to the Finnish coast (right).

All traffic towards the west coast of Finland is collected to a common route after the TSS Norra Kvarken until north of wind farm area A2_OWF_07, from where the traffic is spread out on routes as a fan. In the basis scenario, the traffic splits already when exiting the TSS Norra Kvarken.

The traffic on Route 4.1 to Kokkola is diverted north and around all the wind farm areas in the south of the Bay of Bothnia. Routes 4.2 and 4.3 are directed towards Rahja and Raahe, respectively. The traffic on the three routes is kept as in the basis scenario.

The traffic on Route 4.4, which extends into Route 7.2 towards Oulu, cuts through wind farm area A2_OWF_12. The traffic has been divided around the wind farm area, with the traffic distributed evenly on the two alternatives around the wind farm.

6.4.3.5 Traffic along Route 5.1

Route 5.1 carries traffic from Rönnskär in Sweden to Pietarsaari in Finland. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 45 (left).

All the traffic along Route 5.1 is moved to have a slight bend, to avoid wind farm area A2_OWF_02 and A2_OWF_09. All traffic on Route 5.1 follows the new path.

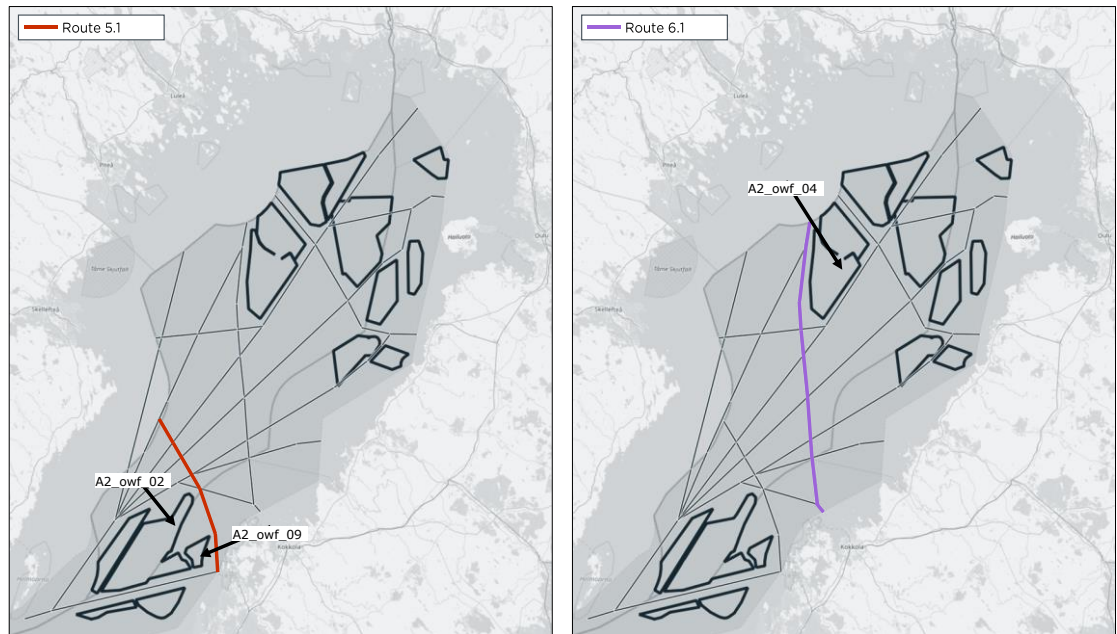


Figure 45. Idealized routes for accommodation of the traffic along Route 5.1 from Rönnskär to Pietasrsaari (left) and along Route 6.1 from Kokkola to Luleå (right).

6.4.3.6 Traffic along Route 6.1

Route 6.1 carries traffic from Kokkola in Finland to Luleå in Sweden. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 45 (right).

All the traffic along Route 6.1 is moved to have a bend, to avoid wind farm area A2_OWF_04. All traffic on Route 6.1 follows the new path.

6.4.3.7 Traffic along Routes 7.1 and 7.2

Route 7.1 carries the traffic from Raahe to Luleå, while Route 7.2 is a continuation of Route 4.4 and carries the traffic from TSS Norra Kvarken to Oulu. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 46 (left).

The traffic out of Oulu is bend to accommodate the traffic south of wind farm A2_OWF_06, and the traffic will be accommodated by the corridor between A2_OWF_03 and A2_OWF_04 in the west.

The traffic on Route 7.2 is the continuation of the traffic on Route 4.4 towards Oulu, which cuts through wind farm area A2_OWF_12. The traffic has been divided onto two routes. One east of wind farm area A2_OWF_12, and one through the northern part of A2_OWF_12 where a pilot boarding point is located and should be accessible.

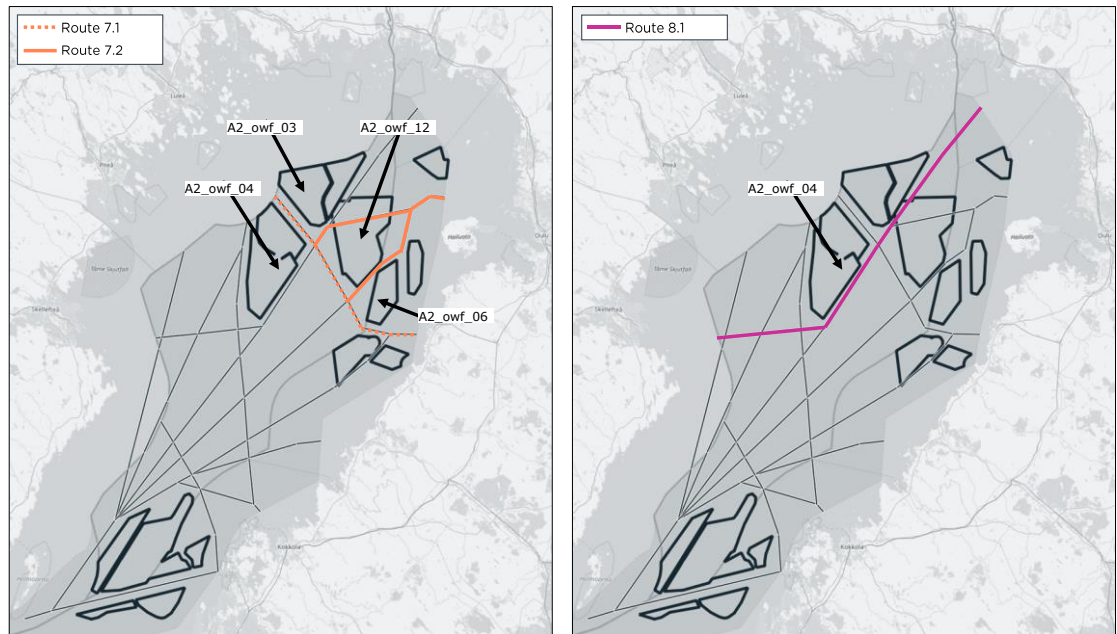


Figure 46. Idealized routes for accommodation of the traffic along Routes 7.1 and 7.2 from Raahe to Luleå (Route 7.1) and continuation of Route 4.4 from TSS Norra Kvarken to Oulu (Route 7.2) (left) and Route 8.1 from Skelleftehamn/Rönnskär to Kemi/Tornio (right).

6.4.3.8 Traffic along Route 8.1

Route 8.1 carries the traffic from Kemi/Tornio in Finland to Skelleftehamn/Rönnskär in Sweden. In the idealized scenario the traffic is suggested to be accommodated as shown in Figure 46 (right).

All the traffic along Route 8.1 is moved to have a bend, to avoid wind farm area A2_OWF_04. All traffic on Route 8.1 follows the new path.

6.4.3.9 Idealized ship traffic routing in the Bay of Bothnia – Area 2

The idealized routes in the Bothnian Sea taking wind farms into consideration as they are currently proposed are shown in Figure 47.

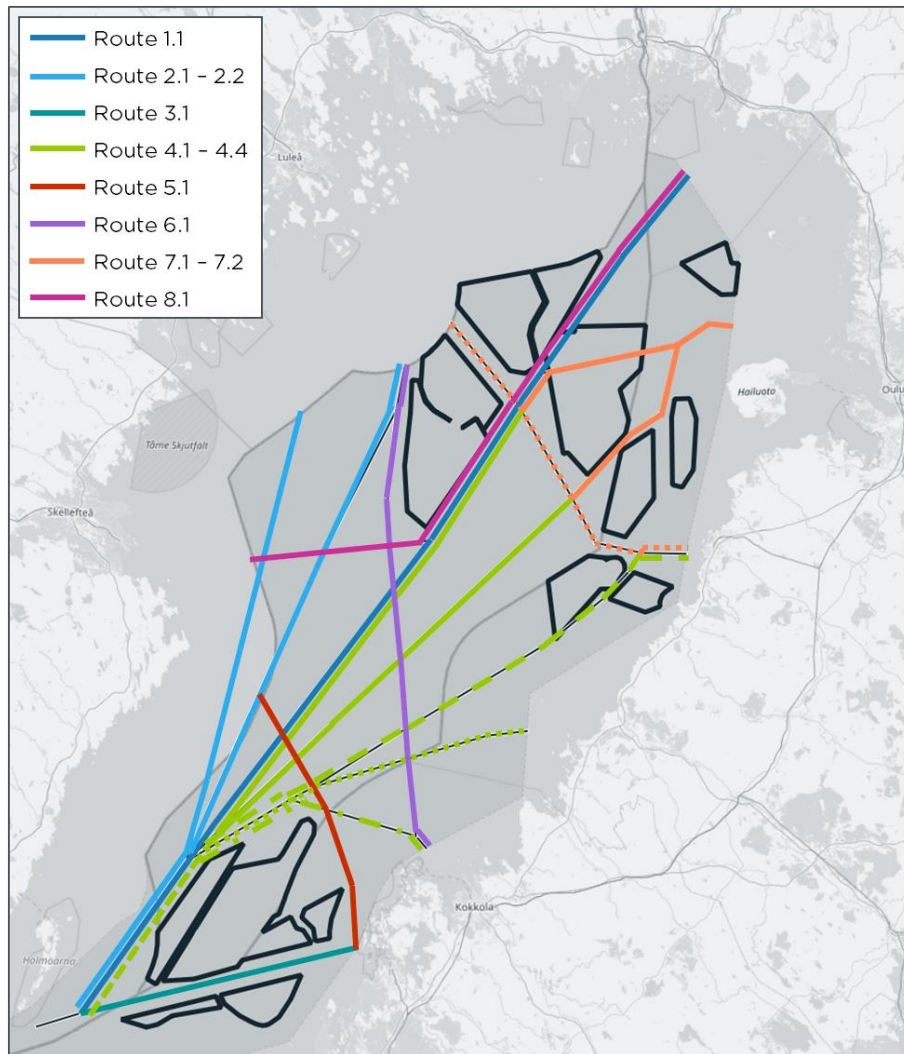


Figure 47. Ship traffic routes used in the modelling of the navigational safety for the Bay of Bothnian. The details for each route and the legend for the different types of dashes are described in Figure 43 to Figure 46. The wind farms are marked as outlines and not adjusted to the route network.

The traffic on each section of the routing network shown in Figure 47 is summarized in Table 20.

Table 20. Summary of the idealized route network for accommodating the ship traffic in the Bothnian Sea in a future situation with wind farms.

Route marking	Description	Traffic	Number of ships
	Former Route 1.1, Routes 2.1-2.2 and Routes 4.1-4.4 gathered into one route.	- All traffic from Route 1.1 - All traffic from Route 2.1 - All traffic from Route 2.2 - All traffic from Route 4.1-4.4	4320
	Former Route 1.1, and Route 4.4 merged into one route	- All traffic from Route 1.1 - Half of the traffic from Route 4.4	1640
	Former Route 1.1, Route 4.4, and Route 8.1	- All traffic from Route 1.1 - Half of the traffic from Route 4.4 - All traffic from Route 8.1	1710
	Former Route 1.1, Route 7.2, and Route 8.1	- All traffic from Route 1.1 - Half of the traffic from Route 7.2 - All traffic from Route 8.1	1710
	Former Route 1.1 and Route 8.1	- All traffic from Route 1.1 - All traffic from Route 8.1	1360
	Former Routes 2.1-2.2	Traffic from Route 2.1 and 2.2, respectively	940
	Former Route 2.1 and Route 6.1	- All traffic from Route 2.1 - All traffic from Route 6.1	930
	Former Route 3.1	All traffic from Route 3.1	540
	Former Routes 4.1-4.3	- All traffic from Route 4.1 - All traffic from Route 4.2 - All traffic from Route 4.3	1580
	Former Route 4.1	All traffic from Route 4.1	890
	Former Route 4.2	All traffic from Route 4.2	290
	Former Route 4.3	All traffic from Route 4.3	500
	Former Route 4.4	All, traffic from Route 4.4 split into two routes	410
	Former Route 4.3 and Route 7.1	- All, traffic from Route 4.3 - All traffic from Route 7.1	930
	Former Route 5.1	All traffic from Route 5.1	80
	Former Route 6.1	All traffic from Route 6.1	110
	Former Route 7.1	All traffic from Route 7.1	470
	Former Route 7.2	Half of the traffic from Route 7.2	410
	Former Route 8.1	All traffic from Route 8.1	150

7 Modelling principles

This chapter describes the method for determining the frequencies for collisions (ship-ship), allisions (ship-obstacle), and groundings, as well as how the consequences in case of collision, allisions and grounding are determined. For the modelling of frequencies, the IALA recommended tool IWRAP is applied.

7.1 Frequency modelling (IWRAP)

The IWRAP tool is used for modelling ship-ship collisions and allisions between ships and obstacles. The method is purely probabilistic, that is, based on statistics. IWRAP has been part of the IALA risk toolbox, as mentioned in IMO SN Circular 296, Ref. /16/. IWRAP is also recommended by the SMA and the Swedish Transport Agency in their recommendations in planning and establishment of offshore wind power, Ref. /17/.

7.1.1 The modelling tool IWRAP

The IWRAP model considers ship-ship collisions, allisions (ship-object collisions) as well as groundings. 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 paths of the individual ships. The level of detail in model input, for example, bathymetry, and the degree of detail in the interpretation of the results should reflect this. For details on how the IWRAP model works, refer to the IWRAP user manual Ref. /4/ and to IALA's wiki page on IWRAP Ref. /18/. The settings used in the models are described in the following.

In IWRAP, a series of "causation factors" are used to describe the frequency of errors and collisions in different scenarios. The value of the causation factors is of course essential for the modelling of collisions and is described in Section 7.1.6. IALA, along with a group of experts, 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. Hence, one part of IWRAP is geometry and statistics, and the other part is the human factor.

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

Technical failures are failures 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 functioning, and a steering failure will cause the ship to sail in circles. Generic frequencies of engine failure and steering failure are based on general statistical data for commercial vessels. The IWRAP tool includes modelling of engine failure/drift- ing ships but does not implement the steering error.

7.1.2 Modelling of ship traffic and collision scenarios

Two different accident scenarios are modelled:

- Allisions (collisions between ships and fixed obstacles)
- Collisions between ships

The placement of offshore structures generally influences the way the ships in the area navigate, e.g., causing ships to change sailing patterns, enforcing more ships to follow the same main routes, etc. The presence of turbines can thus influence the navigational situation in an area and require that the traffic adapts to the new surroundings. These changes may cause allisions with the turbines themselves, as well as change the frequency of ship-ship collisions on routes around the wind farm, as well as the frequency of groundings in an area.

Collisions with fixed obstacles, known as allisions, can be caused by human error where a ship continues at an unchanged speed until the allision occurs. In the event of engine failure or a blackout, 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 collide with a turbine. The possibility of anchoring and restarting the engine before grounding or collision is considered in the IWRAP modelling, just as the wind rose (Section 4.1) is considered when estimating the drift direction.

Ship-ship collisions can occur within a single route in connection with the passage of oncoming traffic (head-on), or when overtaking other ships. Additionally, collisions can occur in connection with crossing traffic, with route bends, and with merging traffic. Modelling scenarios as implemented in IWRAP are shown in Figure 48.

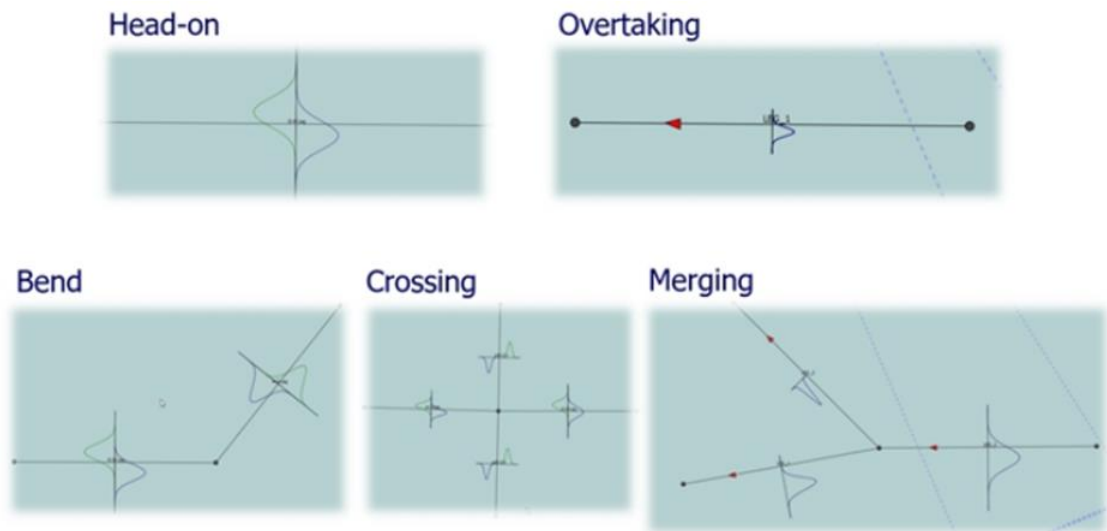


Figure 48. The different event types for ship-ship collisions modelled in IWRAP, Ref. /4/.

Figure 49 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. 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 software manual in Ref. /4/.

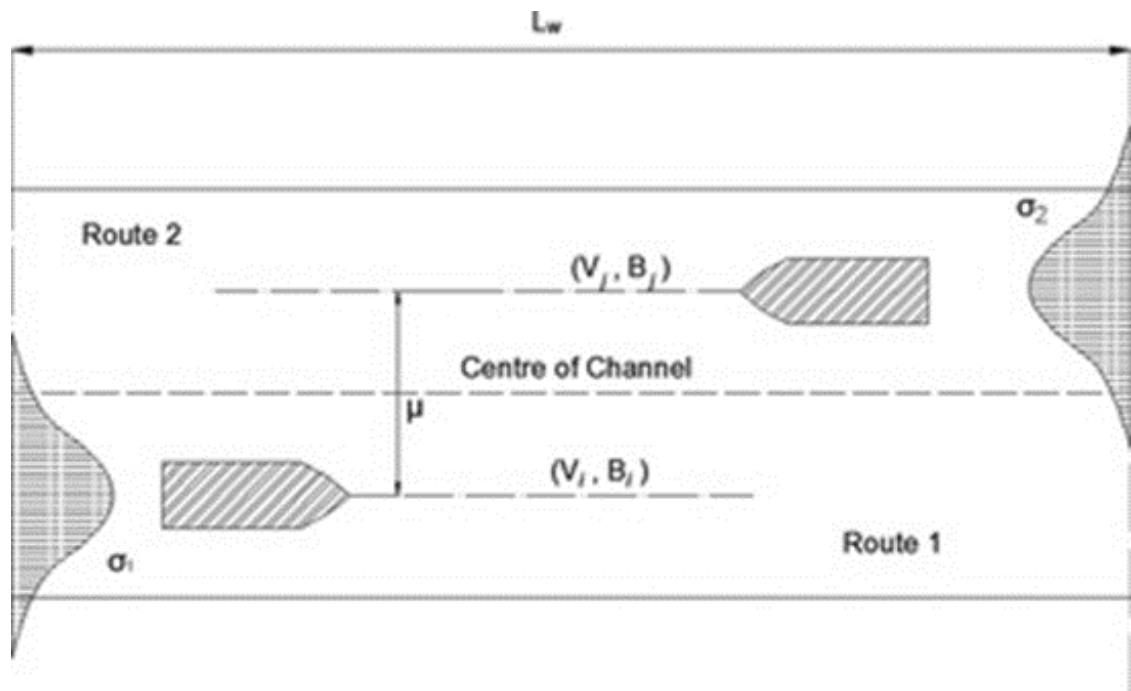


Figure 49. Example of the risk of head-on collision between two ships in opposite direction, Ref. /4/.

Head-on ship collisions occur most frequently on routes where the distribution of ship traffic overlaps in both directions, e.g., in narrow corridors. On the other hand, overtaking is more frequent on larger shipping routes, where ships of different sizes sail at different speeds, which gives rise to overtaking and hence an increased risk of a ship-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 need of adjustment of traffic, why some routes will experience an increase in the traffic density. This may contribute to more collisions, especially on routes that pass or sail between several wind turbine areas, where the ships sail closely in both directions. Ship traffic on routes that are narrowed will also experience a reduced ability to make evasive manoeuvres, or reduced ability to stop a drifting collision with a wind turbine. Routes that change direction or split up can give rise to collisions regardless of the type of ship traffic. Crossing routes, merging and splitting of routes correspondingly increase the risk of ship collisions and are also modelled and included in the calculations in IWRAP.

For shipping routes identified it is in IWRAP possible to set the lateral distribution of ships across the route, i.e. define how ships position themselves across the route. For this purpose, lateral distributions of routes are generally defined in two parts; most of the ship traffic (98%) navigating according to a Gaussian distribution across the defined route, and a small part (2%) of the traffic navigating uniformly across the route. In general, the ship traffic along a route will navigate along the shortest path, and most ships will navigate centrally within a traffic lane, hence justifying the Gaussian distribution. The uniform distribution is added to conservatively model ship traffic diverging significantly from the given course. A similar modelling has been applied in previous studies, and similarly, German guidelines for modelling of ship traffic routes also mention a 2% uniform distribution on top of a Gaussian distribution, see Ref. /19/. The standard deviation of the Gaussian distribution as well as the total width of the uniform distribution are defined specifically for the individual route, partly based on the German guidelines, partly on general experience from previous projects. German guidelines have been applied in lack of Swedish and Finnish guidelines herein. The distributions are in the model defined as idealized distributions for all routes, both in the basis scenario and the future scenario where the wind farms are introduced.

The frequencies of collisions calculated by IWRAP include all situations where contact between the ship and wind turbines is estimated. Thus, many of the collisions will be minor collisions, where the ship at the last moment has time to avert the collision, reduce speed, etc.

7.1.3 Area traffic modelling

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

7.1.4 Drifting ships

In the event of a vessel losing the ability to propel itself it will begin to drift. The direction and speed of the drifting is dictated by a drifting rose. The drifting rose is ideally a mix of currents and winds in the area.

In Figure 50, the used drift parameters are shown. The default IWRAP drifting speed of 1 knot is applied and used by IWRAP to estimate how far a ship moves on average while drifting. In practice and depending on the weather conditions, ships may sometimes drift slower and sometimes faster. In connection with engine failure, it is possible that the fault is remedied, so the ship can be manoeuvrable again before it drifts towards an obstacle. The repair time is modelled in IWRAP as a cumulative Weibull distribution. Furthermore, there will sometimes be an opportunity for a drifting ship to be able to drop anchor and thus avert a collision or grounding. The probability of successful anchoring in case of engine failure is defined from the standard parameter for IWRAP at 70%, in case the water depth allows for anchoring. The parameters for anchoring are also shown in Figure 50.

Drift Parameter Settings

Drift Parameters | **Drift Direction**

Blackout Frequency

RoRo and Passenger: 0,10 per year

Other vessels: 0,75 per year

Drift Speed

Drift Speed: 1,00 knot

Anchoring

Anchor probability: 0,70

Max anchor depth: 7,0 x design draught

Min. anchor distance from ground: 3,0 x ship lengths

Repair Time

☒ Distribution ☐ Function

Distribution: Weibull

Input Method: /Delta/Beta/Lower Bound

	Value
Delta	0,90
Beta	0,45
Lower Bound	0,25

From 0,00 to 12,00 Reset...

Mean 3,38 StdDev. 8,16

OK Cancel

Figure 50. Setting of drift parameters for drifting ships, including parameters used for anchoring.

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 modelled blackout frequencies are per ship per year and scaled by IWRAP to account for their actual presence at the routes in the area near the wind farm.

The probability of drift in each direction is assumed to be given by the distribution of drift rose, as described in Section 4.1. A drifting ship is assumed to move with a drift speed of 1 knot.

7.1.5 Routes and waypoints

The sailing routes are modelled in IWRAP with routes and waypoints at intersections where ship traffic crosses. A route is given by a distance and a width within which the ship traffic is evaluated based on the AIS data. In IWRAP the ship traffic is modelled with a Maximum Extension, which is used to control powered collisions, i.e. powered collisions will only occur within the indicated boundaries. This is shown in Figure 51.

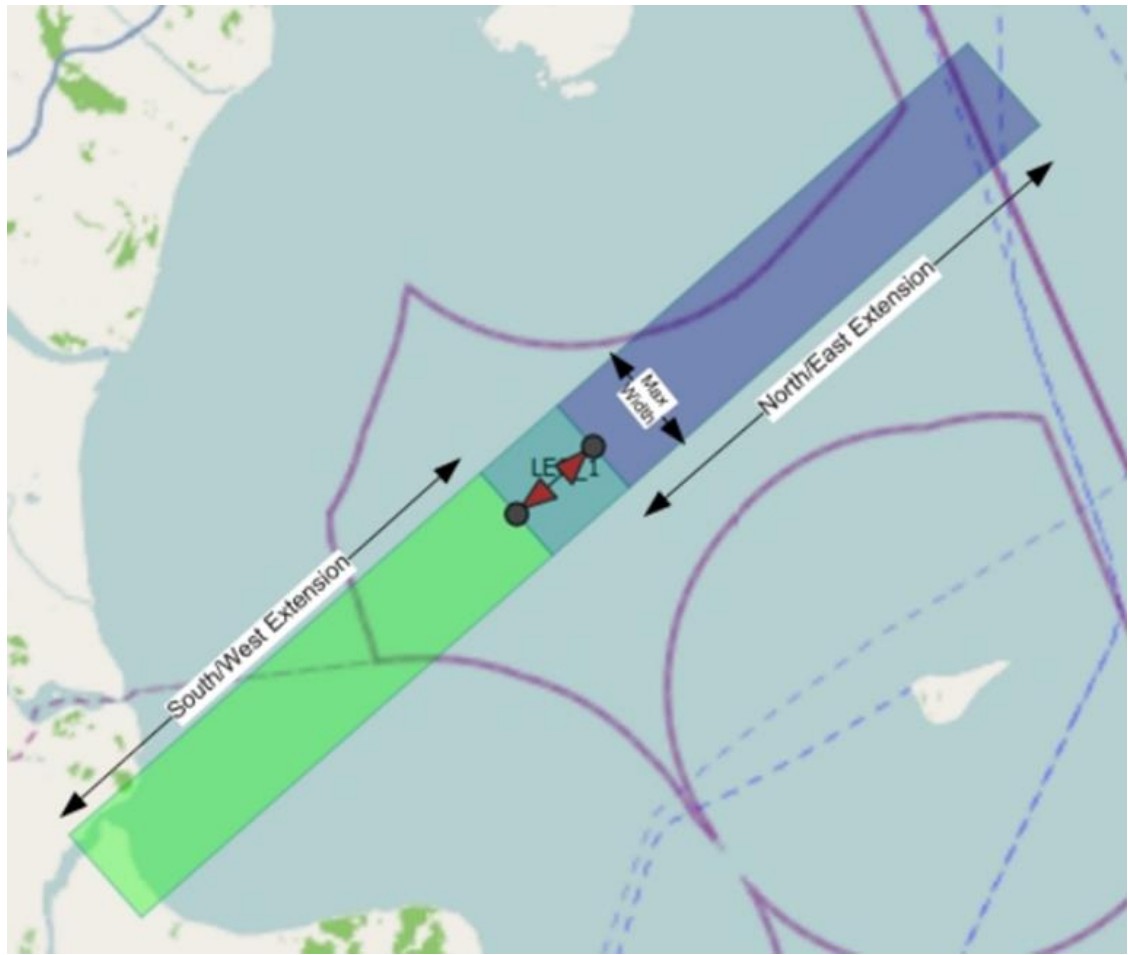


Figure 51. Illustration of a route modelled in IWRAP, Ref. /4/.

7.1.6 Causation factors

The causation factors indicate the probability that the officer on watch does 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 for the results, as they serve as reduction factors on the calculated number of blind navigation collisions. The standard values that have been selected in IWRAP are shown in Table 21 below. These settings for the causation factors are primarily based on observations of Fujii and Mizuki (1998), Ref. /20/.

Table 21. IWRAP's standard causation parameters for modelling ship collisions.

Merging routes	Crossing routes and bends	Opposite routes	Takeovers on routes	Groundings	Collision with obstacle
$1.3 \cdot 10^{-4}$	$1.3 \cdot 10^{-4}$	$0.5 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$	$1.6 \cdot 10^{-4}$	$1.6 \cdot 10^{-4}$

7.1.7 Sensitivity scenarios used in the frequency modelling

The frequency modelling in is based on the observed traffic for the five summer months of the years 2019, 2022 and 2023. Due to uncertainties in the data used as the basis for the frequency modelling, and uncertainties in the future shipping situation in the Bothnian Sea and the Bay of Bothnia two sensitivity scenarios have been defined for this study:

- 1) 10% increase in traffic
- 2) 10 times more traffic

Scenario 1) is defined as a situation with a general increase in the traffic across the entire area in both south and north. In this scenario, the traffic on all routes has been increased by 10%.

Scenario 2) represent a political situation where the traffic in the Gulf of Finland is closed for traffic in and out of Finnish harbours. In such a situation, all the traffic in and out of Finland must be accommodated through the Bothnian Sea and the Bay of Bothnia. Also, it is assumed, that there is an extra need for transportation between Sweden and Finland in such a situation. In this scenario, the traffic on all routes has been increased by a factor 10 on all routes, see also hazard H18 in Section 6.2.1.

7.2 IWRAP modelling input

The accuracy of the risk assessment depends on well-defined input parameters that reflect the traffic conditions, navigational constraints, and potential future developments.

The following sections describe key aspects of the IWRAP modelling input, including safety distances and necessary route widths, which define spatial constraints for safe navigation. They also cover the approach to route modelling in IWRAP and how traffic is represented within the modelling. Finally, the influence of wind turbines in a future scenario is discussed, examining their potential impact on vessel routing and navigational risk.

7.2.1 Safety distances and necessary route width

Most of the indicative routes come close to possible wind farm development areas, and there is a need to ensure sufficient space to allow ships to pass along the ship traffic lanes. Both Swedish and Finnish guidelines exist for determining safety distances along ship traffic routes, see Ref. /17/ and /21/.

An important aspect of the navigational safety is the safety distance between shipping routes and wind turbines in case a ship needs to perform an evasive manoeuvre to avoid collision. In case of machine failure and

blackout, a navigator will often try to perform evasive manoeuvres away from the main ship traffic to avoid collision with other ships. The safety distance allows for a zone for vessels with emergencies in a similar way as emergency lanes on highways. The Swedish and Finnish guidelines are based on similar guidelines found in the World Association for Waterborne Transport Infrastructure (PIANC) guideline on "Interaction Between Off-shore Wind Farms And Maritime Navigation", Ref. /22/, and addressed in the following. The PIANC guideline also touches upon Search and Rescue (SAR) operations which may also be challenged by the presence of wind turbines.

Relevant for the safe navigation is also sufficient width of the fairway/route itself for ordinary manoeuvres such as overtaking, passing, merging of traffic, etc. Guidelines for the width of ship traffic fairways are often referred to a Dutch Whitepaper, Ref. /23/. The Dutch Whitepaper is also related to the above PIANC guideline.

The PIANC guideline describes a safety distance for vessels passing wind turbines at the starboard side to account for evasive manoeuvres as seen in Figure 52. The guideline is related to Convention on the International Regulations for Preventing Collisions at Sea (COLREG) clause 8 – Action to Avoid Collision. The elements in the safety distance include the following:

0.3 nm covering first deviation from course before starting the round turn.

Six ship lengths to cover for the round turn itself. This includes an extra ship length to compensate for the fact that the Officer on Duty is not fully prepared for the manoeuvre.

500 m covering a default safety zone around offshore obstacles.

A slightly reduced safety distance can be applied to the port side of a shipping lane omitting the first 0.3 nm.

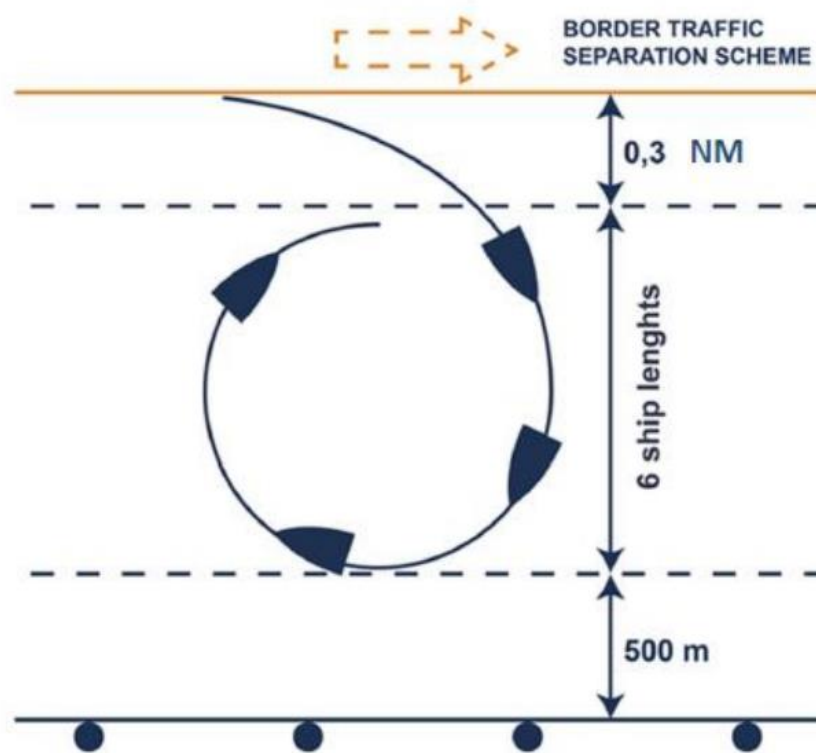


Figure 52. Concept of safety distance, PIANC, Ref. /22/, Section 4.2.1.

The necessary fairway width and the safety distance is based on the length of the ships using a shipping lane. For selection of a relevant ship length, Swedish guideline, Ref. /17/, suggests defining shipping corridors according to a "standard ship" such that 98% of the ships in the corridor are smaller than the standard ship.

The "standard ship" varies between routes from ships with lengths of 125m for smaller routes to 250m for some of the main routes. This affects the theoretically estimated minimum free width needed between possible wind turbines including fairway and safety space from 3 and 4 nm. Considering also to some extent winter conditions and bad weather, the Finnish authorities suggest an additional safety distance for the main route north/south through both the Bothnian Sea and the Bay of Bothnia, such that this route has a width of 6 nm including fairway and safety distances. The default width of the indicative routes including fairways and safety spaces are defined based on the above as shown in Figure 53.

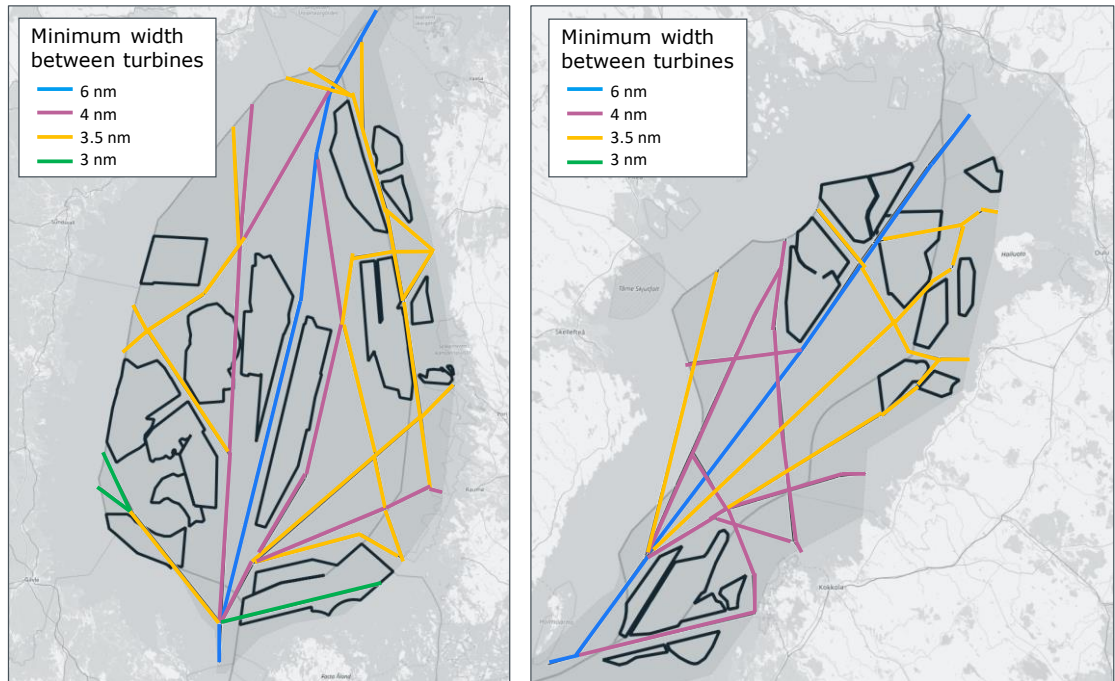


Figure 53. Minimum distance between turbines around ship traffic routes.

7.2.2 Route modelling in IWRAP

This section describes the input to route modelling in IWRAP, focusing on how vessel movements are represented within the analysis. The lateral ship traffic distribution along a ship traffic lane depends on the available space, navigational conditions, etc. In AIS data, IWRAP can estimate the currently seen ship traffic distributions across ship traffic lanes on the identified routes. However, the lateral distribution of ship traffic will change for the idealized scenario due to presence of wind farms, corridors, re-routing of ship traffic, etc. We therefore apply a standardized approach for modelling the lateral ship traffic distribution both in the basis scenario and for the idealized route network, ensuring a reliable foundation for assessing collision and allision risks. In lack of local guidelines, we refer to German guidelines, Ref. /19/, describing distributions for ship traffic in different situations.

The German guidelines for modelling of ship traffic routes mention a 2% uniform distribution on top of a Gaussian distribution, see Ref. /19/. It defines categories of navigational areas for where to apply specific standard deviations for the Gaussian distribution, which is shown in Table 22.

Table 22. The German guidelines for suggested specific standard deviations for the gaussian distribution, Ref. /19/.

Route categories	Standard deviation [nautical miles]
Port approach	0.2 to 0.3
Approach points, e.g. navigation marks, buoys	0.3 to 0.4
Traffic separation areas	0.5
Waypoints in wide shipping lanes	0.5 to 1.0
Waypoints on the open sea	2.0

In the following is shown examples of ship traffic distributions for routes with ship traffic traveling in both directions including both types of distributions. Figure 54 shows how wide a Gaussian distribution with a standard deviation of 0.2nm, 0.4nm and 0.6nm look like, where a shift to split the ship traffic lanes in each direction has been incorporated. Since the uniform distribution accounts for only 2%, it is not highly visible. Therefore, it has been explicitly marked in the figures to indicate its start and end points together with the centerline of the lanes on the routes.

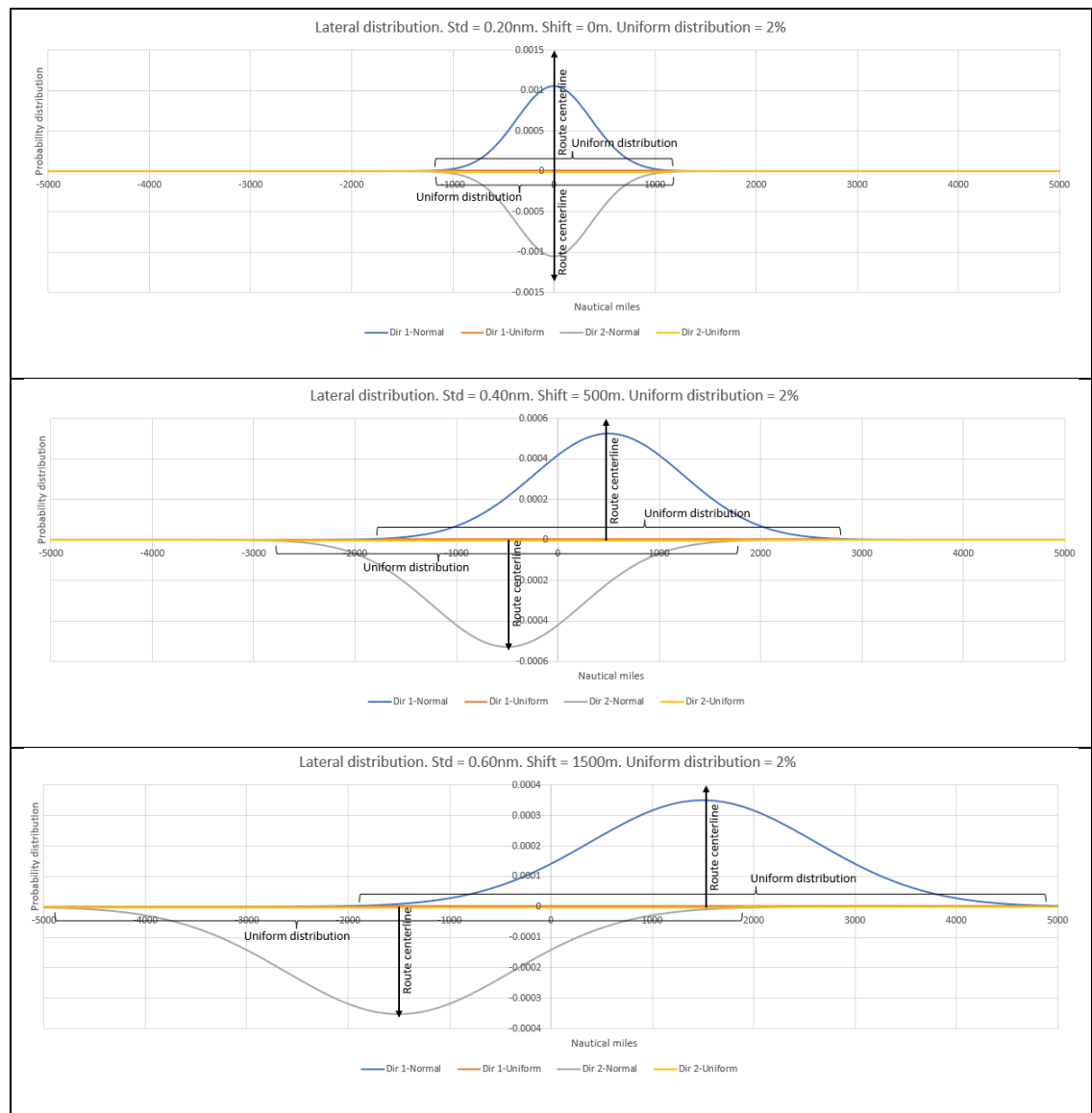


Figure 54. Examples of different traffic distributions.

Figure 54 illustrates that the Gaussian distribution with a standard deviation of 0.2nm has a width of about 1000m to each side, where a 0.4nm is about 2000m and a 0.6nm is approximately 3000m wide to each side. In the modelling, specific routes are given a shift, given the assumption that these in the basis and future scenario will follow the same shift as seen in the historical AIS data. Routes with a shift in the modelling refer to identified AIS-based routes where historical AIS data shows lanes of ship traffic in opposite directions that are offset from the route centerline. This shift has been incorporated into the modelling to accurately reflect the AIS data.

Figure 55 show the traffic routes used in the modelling coloured to match route legs with traffic distributions. In general, the legs have in the open water more wide traffic distributions than those legs closer to the Swedish or Finnish coast, which match with the traffic density map presented in Section 5.1. Figure 55 shows that the north/south route second closest to the Finnish shore is purple, which is because the ship traffic in AIS data, see Figure 28, is seen to navigate in a very narrow route, and it is

therefore assumed that this will stay unchanged in the basis and future scenarios.

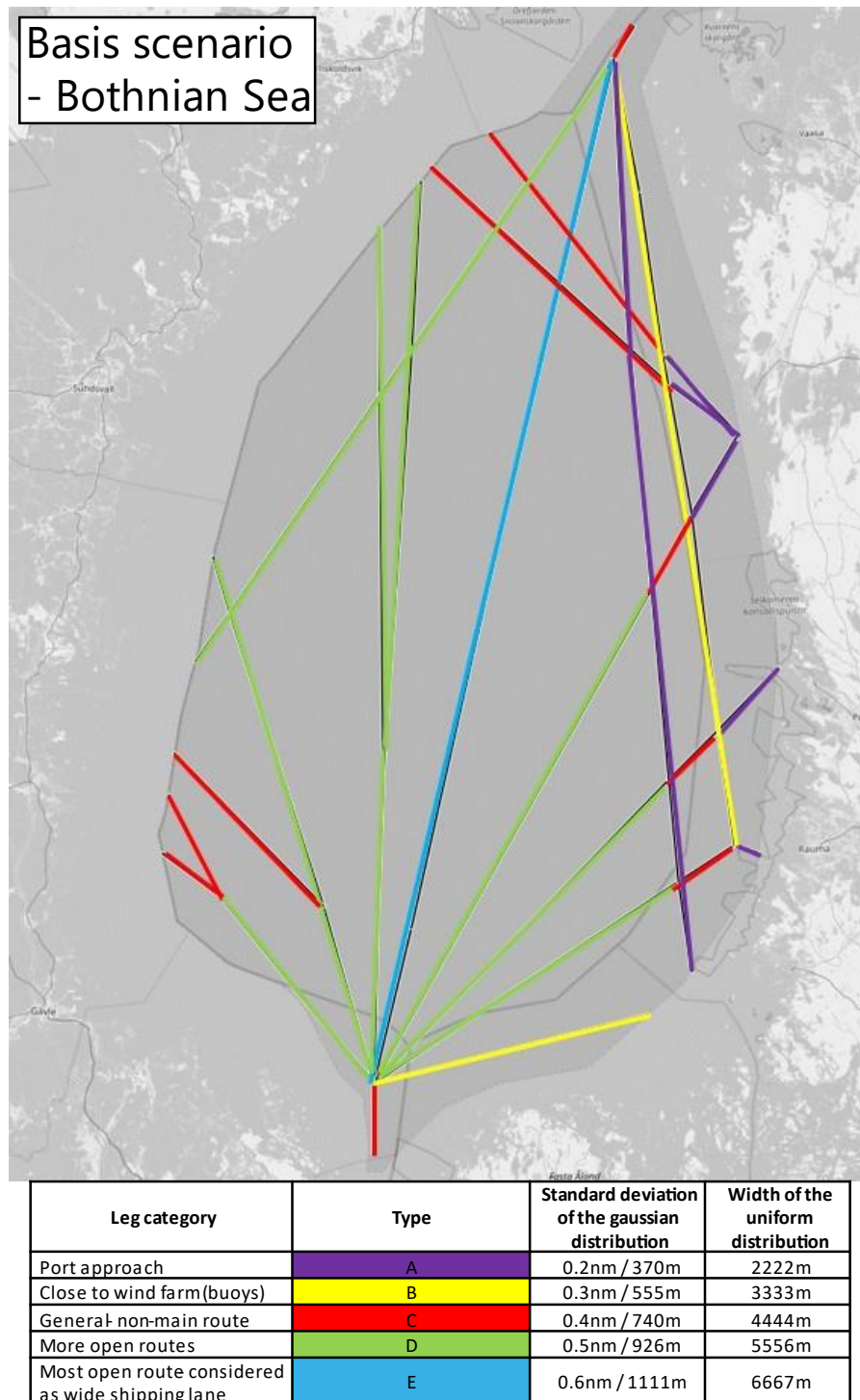


Figure 55. The modelled traffic distribution along each route leg in the basis scenario for the Bothnian Sea.

Figure 56 shows the IWRAP future model with the idealised route network around all the known OWF areas mentioned in Section 4.3. The IWRAP future model similarly shows the different traffic distributions applied in the modelling, where more routes have been changed from green to yellow,

leading to a narrower route distribution to ensure traffic passing through corridors or passing by the OWF areas.

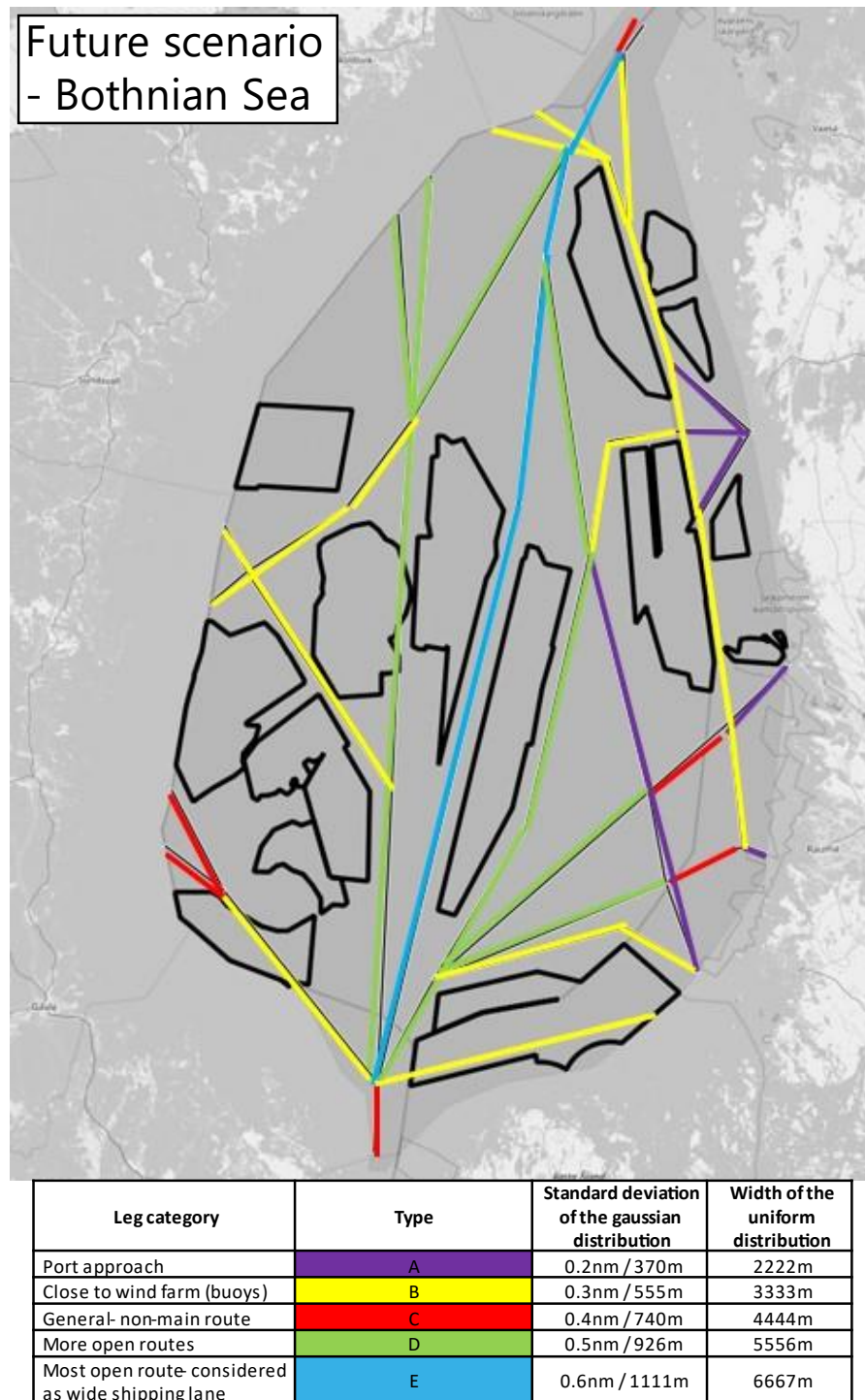


Figure 56. The modelled traffic distribution along each route leg in the future scenario for the Bothnian Sea.

Similar illustrations of the applied traffic distributions along the route legs are shown for the Bay of Bothnia. Figure 57 shows the basis scenario and Figure 58 shows the future scenario with OWF areas inserted, where it is assumed that ship traffic will follow a narrower distribution along the routes when passing nearby OWF areas.

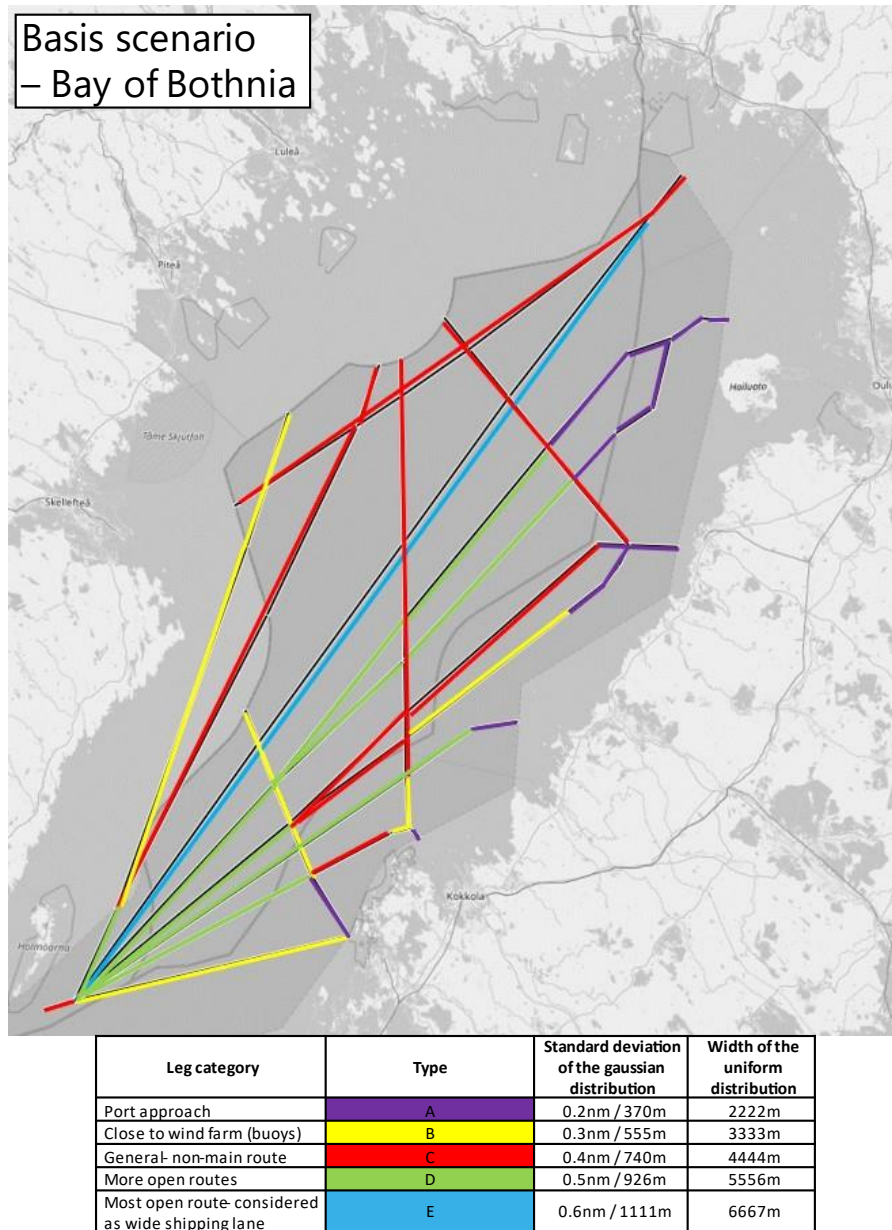


Figure 57. The modelled traffic distribution along each route leg in the basis scenario for the Bay of Bothnia.

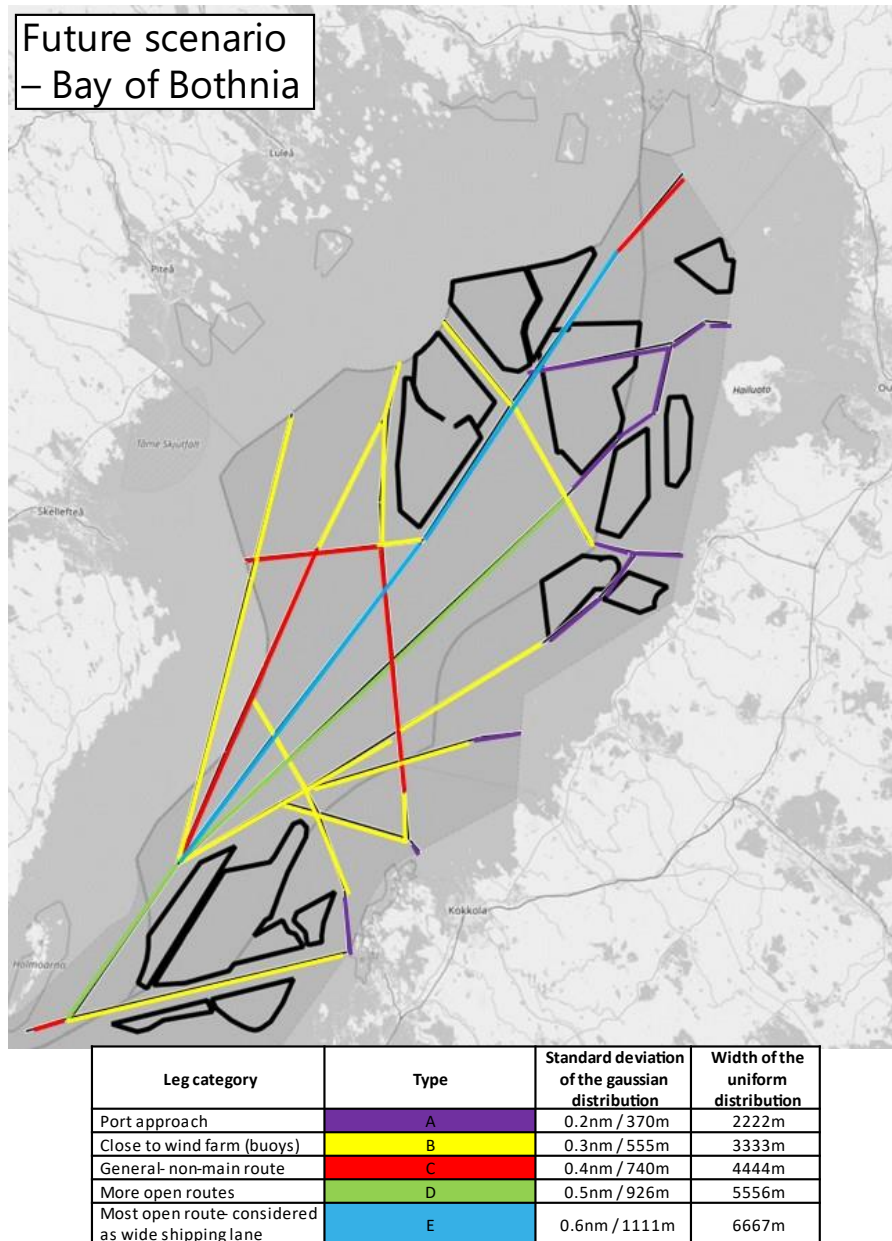


Figure 58. The modelled traffic distribution along each route leg in the future scenario for the Bay of Bothnia.

7.2.3 Wind turbines in future scenario

The presence of wind turbines in a future scenario introduces spatial constraints that may influence vessel routing and navigational risk. As OWFs expand, it becomes necessary to assess their impact on shipping lanes, particularly in relation to safety distances and route availability.

This section examines how areas within the gross wind farm footprint are cut out to establish safe passage corridors, considering the placement and size of individual turbines. Additionally, maps illustrating the turbine layout are presented to provide a spatial overview of their distribution and potential implications for vessel navigation.

Section 4.3 showed the OWF areas in the Bothnian Sea and Bay of Bothnia. The OWF areas have been reduced such that only areas or the area that are within the specified study area is kept, followed by merging overlapping areas to make all areas no matter their development status be part of the modelling input. This gives the gross OWF areas which is shown in Figure 59 together with the areas defining the route width from Figure 53.

It is seen that there are overlaps between the route width and the combined OWF areas. In the Bothnian Sea shown on the left in Figure 53, the overlap is seen in the southern part where OWF are placed on top of existing routes. This is also seen on other routes. Also, other overlaps are seen where routes need slightly more width and therefore reduced the edge of some of the OWF areas.

The gross OWF areas have therefore been reduced given the need for safe navigation and guidelines for the route widths, which gives a smaller area for the OWF areas in both the Bothnian Sea and Bay of Bothnia.

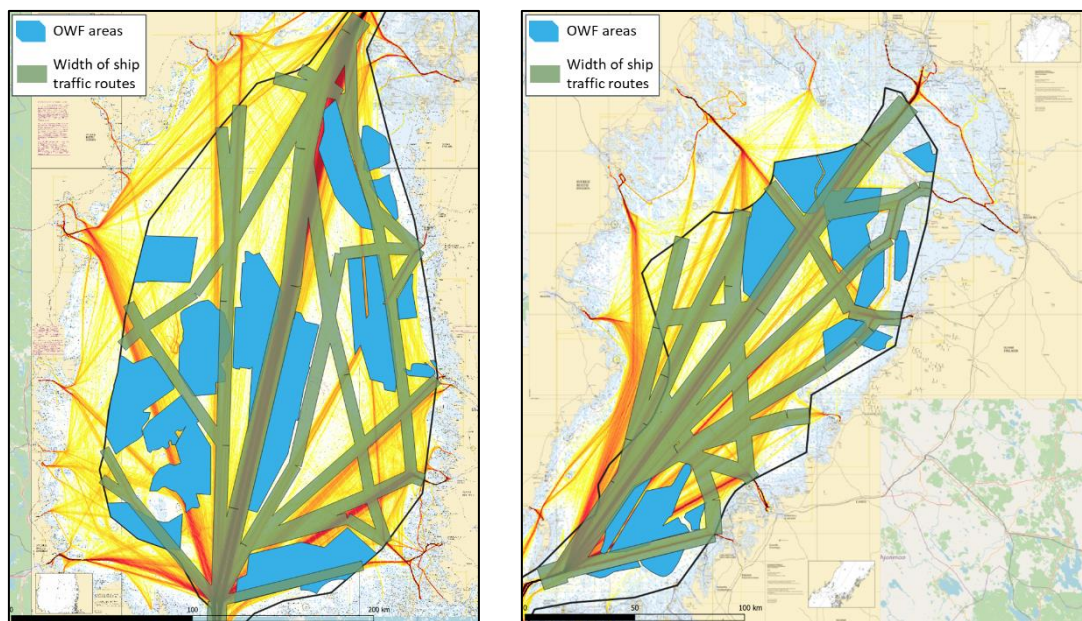


Figure 59. The blue gross OWF areas together with the necessary route widths coloured in green.

Figure 60 shows both the gross OWF areas and the reduced OWF areas after cutting off areas overlapping with the width of the routes used in the modelling. The figure also shows the OWF labels for the reduced areas.

A larger area has been removed in the northern part of the Bay of Bothnia. This is due to a pilot boarding point located in connection with one of the access channels towards Oulu. At the HAZID workshop, it was deemed necessary to avoid wind farm development in this area to allow access to the channel and the pilot boarding point. Figure 60 also shows that the OWF areas in the southern part of the Bothnian Sea, the OWF areas A1_owf_02

and A1_owf_03 are split by a corridor to form two new areas: A1_owf_17 and A1_owf_18.

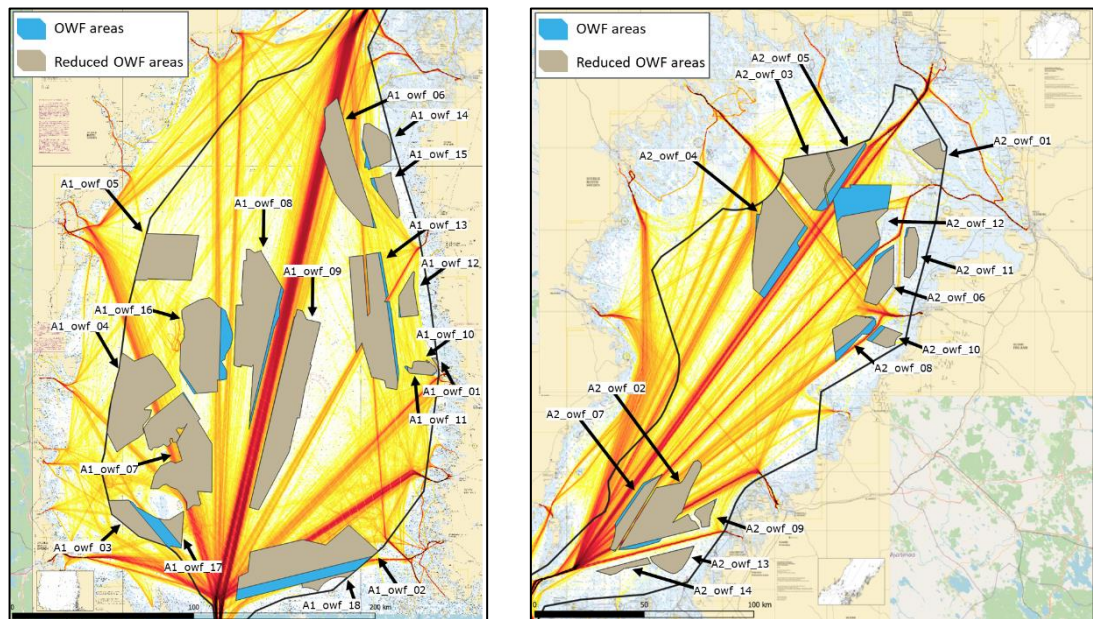


Figure 60. The grey reduced OWF areas together with the blue gross OWF areas behind.

For the modelling, the grey reduced OWF areas have been used, where wind turbines have been placed in a grid with a spacing of one nautical mile between each turbine. The size of the turbines at the sea surface has been set to 25m x 25m, which has been deemed a reasonable size for the modelling. This dimension aligns with sizes observed in other projects where "jackets" have been used instead of modelling monopiles or floating foundations. In general, it is expected that monopiles have a smaller footprint, and floating foundations may have larger footprints. Monopiles and floating foundations are used for either shallow or deeper water which would not be the ideal use for all OWF areas in this project.

Figure 61 shows the placement of the turbine grid in the OWF areas and Figure 62 shows a zoom to see the grid more detailed in the southern area of the Bothnian Sea.

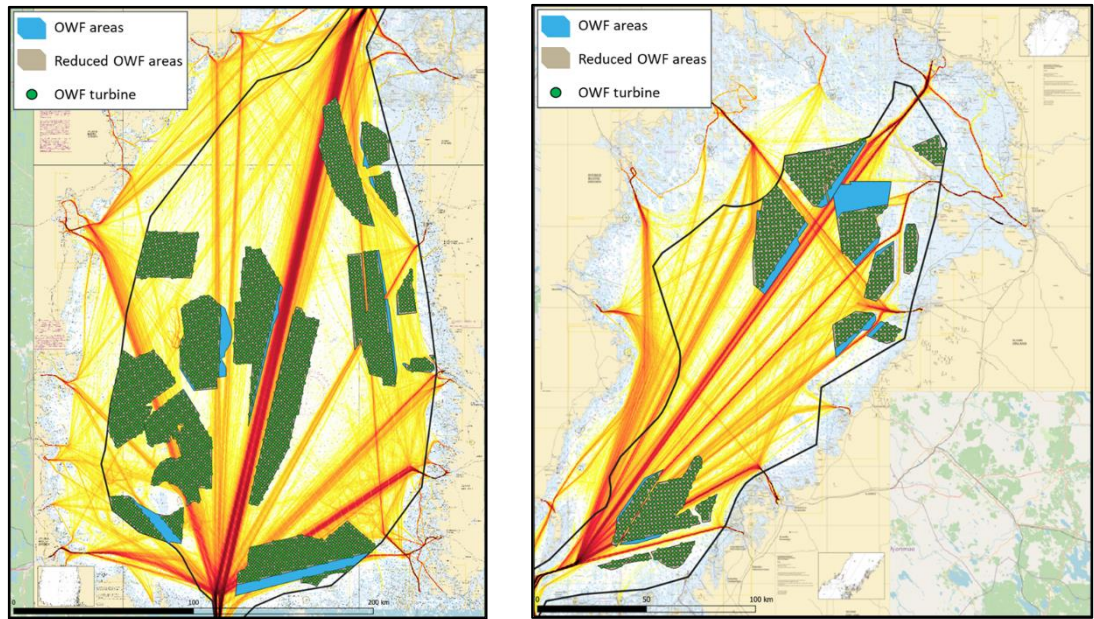


Figure 61. The inserted OWF turbine grid within the grey reduced OWF areas together with the blue gross OWF areas behind.

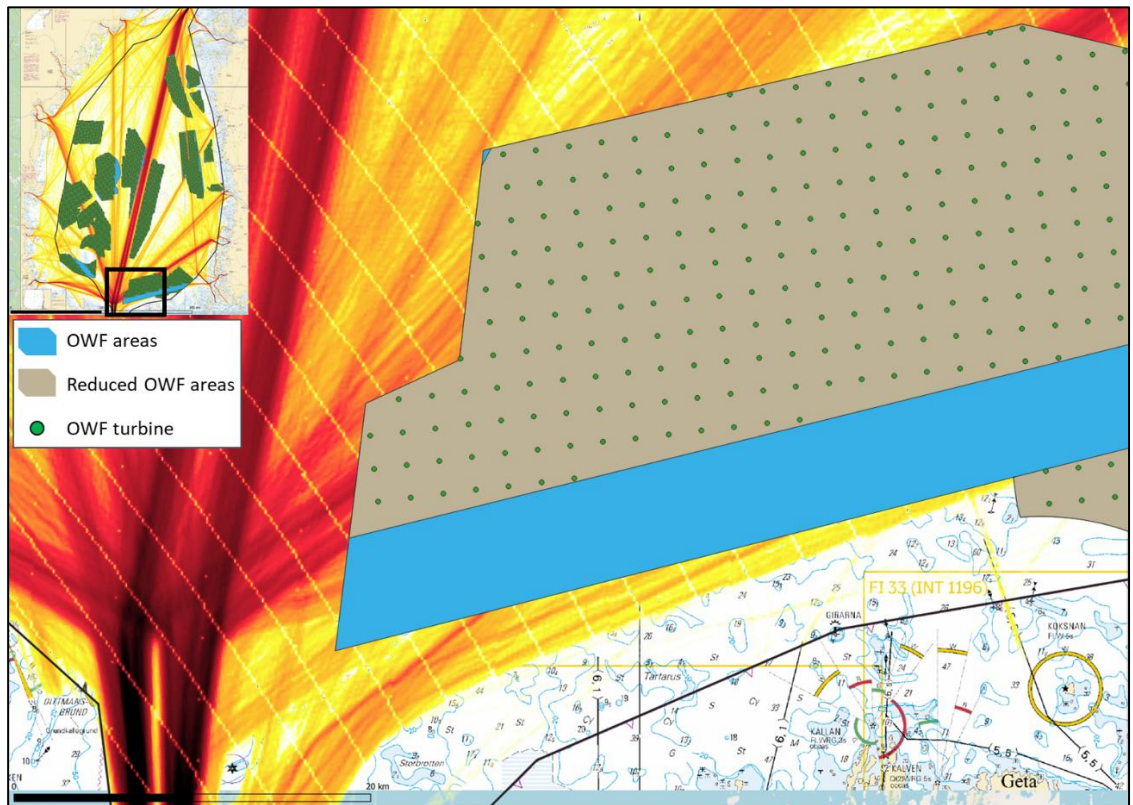


Figure 62. Zoom of the inserted OWF turbine grid within the grey reduced OWF areas together with the blue gross OWF areas behind.

7.3 Consequence modelling

Collisions and allisions may result in consequences such as fatalities, property damage, and damage to the environment in case of oil spill. No detailed consequence modelling is performed as part of this overall FSA study, and indeed the variability in possible consequences is large considering the uncertainties in possible route layout, unknown wind farm development, turbine types and sizes, etc. However, an indicative assessment of the economic consequences is provided in the following based on overall statistics concerning marine casualties.

The total costs related to a hazard, and in turn to all collisions and allisions related to a ship traffic route, can be summarized across consequence types as illustrated in Figure 63. The total cost is used in an indicative cost-benefit analysis in Section 9.3 following a discussion on risk control measures in Chapter 9.

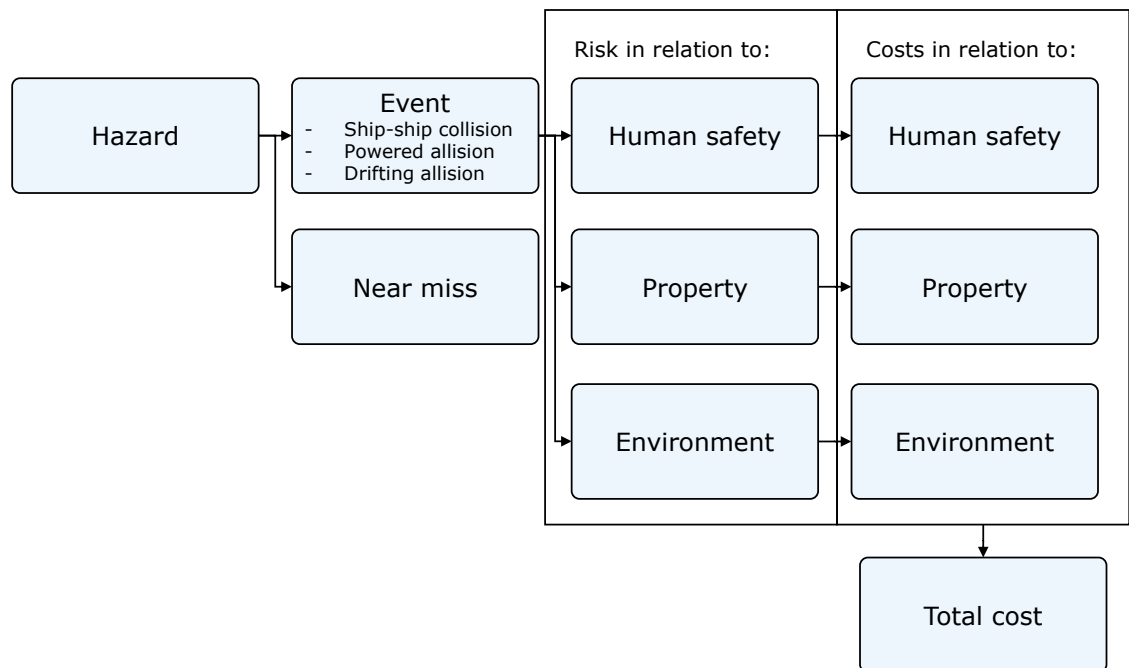


Figure 63. Principle in calculating the risk cost related to hazards.

The European Maritime Safety Agency publishes an annual overview of marine casualties and incidents, Ref. /24/. This overview provides general statistics on marine casualties related to various ship types, and also data on number of fatalities and marine casualties leading to pollution with either bunker oil or cargo. Marine casualties and incidents are in Ref. /24/ defined as given Figure 64.

5. Marine casualty: means an event, or a sequence of events, that has resulted in any of the following which has occurred directly in connection with the operations of a ship: .1 the death of, or serious injury to, a person; .2 the loss of a person from a ship; .3 the loss, presumed loss or abandonment of a ship; .4 material damage to a ship; .5 the stranding or disabling of a ship, or the involvement of a ship in a collision; .6 material damage to marine infrastructure external to a ship, that could seriously endanger the safety of the ship, another ship or an individual; or .7 severe damage to the environment, or the potential for severe damage to the environment, brought about by the damage of a ship or ships. However, a marine casualty does not include a deliberate act or omission, with the intention to cause harm to the safety of a ship, an individual or the environment.
6. Marine incident: means an event, or sequence of events, other than a marine casualty, which has occurred directly in connection with the operations of a ship that endangered, or, if not corrected, would endanger the safety of the ship, its occupants or any other person or the environment. However, a marine incident does not include a deliberate act or omission, with the intention to cause harm to the safety of a ship, an individual or the environment.

Figure 64. Definition of marine casualty and marine incident from Ref. /24/.

A total of 26,595 marine casualties are reported from 2014 to 2023. Moreover, 7,622 of the marine casualties and incidents are reported with at least one occurrence with persons (slipping, body movement, etc.), and 19,023 are reported with at least one occurrence with ships (loss of control, collision, contact, grounding, etc.).

The overall development in marine casualties and incidents from 2014 to 2023 are shown in Figure 65, and the overall numbers are summarized in Table 23 organizing marine casualties by severity and ship type. The total number of marine casualties is 27,891 and thereby higher than 26,595 as some marine casualties involve more than one ship type.

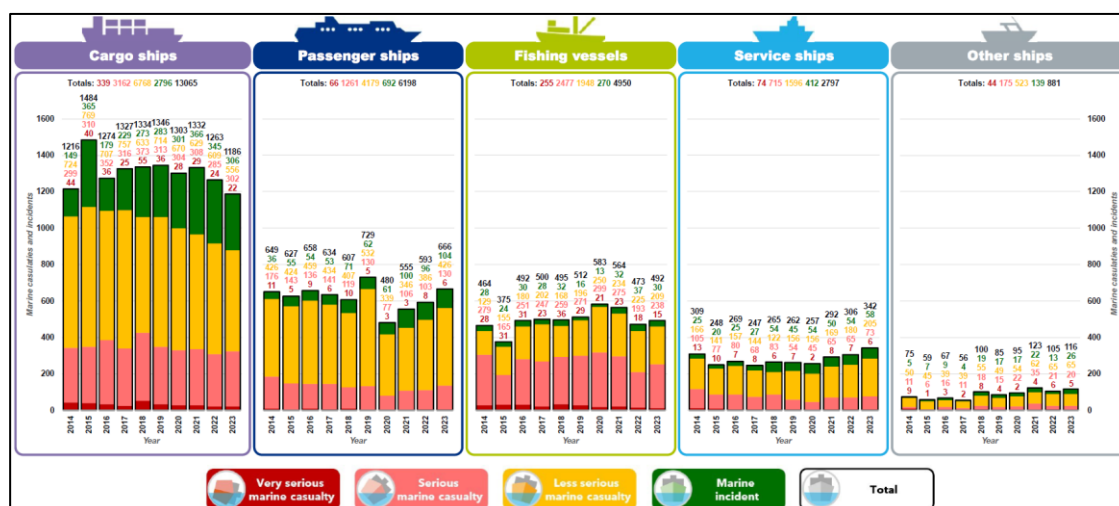


Figure 65. Evolution of number of marine casualties and incidents in the period 2014-2023, from Ref. /24/, Figure 2.1-2.

Table 23. Evolution of number of marine casualties and incidents, organized by severity and ship type, Ref. /24/ Figure 2.1-2.

Severeness	Cargo	Passen-ger	Fishing	Service	Other	Total
Very serious marine casu-alty	339	66	255	74	44	778
Serious marine casualty	3162	1,261	2,477	715	175	7,790
Less serious marine casu-alty	6768	4,179	1,948	1,596	523	15,014
Marine incident	2,796	692	270	412	139	4,309
Total	13,065	6,198	4,950	2,797	881	27,891

7.3.1 Fatalities

The development in number of fatalities through the years 2014 to 2023 for various ship types is given in Ref. /24/ as seen in Figure 66 and summarized in Table 24.

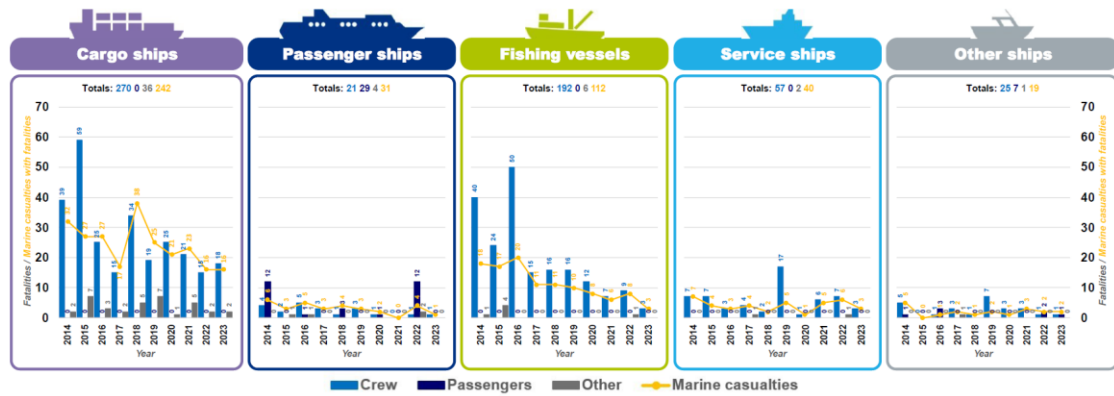


Figure 66. Fatalities and marine casualties with fatalities from Ref. /24/.

Table 24. Summary of the number of fatalities in the period 2014-2023, based on Ref. /24/, Figure 2.5-3.

Number of fatalities	Cargo	Passenger	Fishing	Service	Other	Total
Crew	270	21	192	57	25	565
Passenger	0	29	0	0	7	36
Other	36	4	6	2	1	49
Total	306	54	198	59	33	650

Data from Figure 2.6-7 in Ref. /24/ is tabulated in Table 25. The data shows that there are 22,343 marine casualties with occurrences with ships, and that about 21.4% of these are related to collisions. Moreover, Figure 2.5-5 in Ref. /24/ is tabulated in Table 26 showing that about 596 of the 650 fatalities are related to occurrences with ships, and that about 34.6% of those are related to collisions.

Table 25. Occurrences with ships organized by casualty event type.

Event type	Count	Share	Event type	Count	Share
Loss of control - Loss of propulsion power	4,784	21.4%	Loss of control - loss of containment	561	2.5%
Collision	4,759	21.3%	Flooding / foundering	548	2.5%
Contact	3,262	14.6%	Loss of control - loss of electrical power	472	2.1%
Damage / loss of equipment	3,070	13.7%	Capsizing / listing	145	0.6%
Grounding / stranding - Power	1,938	8.7%	Hull failure	88	0.4%
Fire / explosion	1,214	5.4%	Loss of control - other	25	0.1%
Loss of control - loss of directional control	900	4.0%	Other / unspecified	3	0.0%
Grounding / stranding - other	574	2.6%	Total	22,343	100.0%

Table 26. Fatalities in occurrences with ships organized by casualty event type.

Event type	Count	Share	Event type	Count	Share
Collision	206	34.6%	Loss of control - containment	6	1.0%
Flooding/Foundering	128	21.5%	Grounding/stranding - other	4	0.7%
Capsizing/Listing	105	17.6%	Contact	3	0.5%
Fire/explosion	62	10.4%	Other/unspecified	3	0.5%
Damage/loss of equipment	32	5.4%	Loss of control - directional control	2	0.3%
Loss of control - propulsion	23	3.9%	Hull failure	0	0.0%
Loss of control - electrical power	11	1.8%	Loss of control - other	0	0.0%
Grounding/stranding - power	11	1.8%	Total	596	100.0%

Based on the marine casualties organized by ship type and severity in Table 23, we assume that occurrences with ships, the number of collisions, and the fraction of fatalities related to collisions are equally distributed across ship types. This results in an indicative number of fatalities per collision as given in Table 27.

Table 27. Indicative number of fatalities per collision.

	Cargo	Passenger	Fishing	Service	Other	Total
Marine casualties and incidents with occurrences related to ships	10,466	4,965	3,965	2,241	706	22,343
Marine casualties and incidents related to collisions	2,229	1,058	845	477	150	4,759
Fatalities related to collisions	97	17	63	19	10	206
Fatalities per collision	0.04	0.02	0.07	0.04	0.07	0.04

The indicative number of fatalities is based on ship-ship collisions. Detailed data on ship-turbine collision is not available, but it is assumed that consequences in case of a falling turbine can be comparable to a full-blown ship-ship collision. Hence, we assume a similar number of average fatalities when considering powered ship-turbine collisions. Finally, an collision at drifting speed may still result in very serious casualty, but due to the lower speed, we assume only half as many fatalities in average.

The economic consequences of fatalities are based a general assessment of the value of a statistical life. This value varies between countries and use cases, but typical values in the range of 1-10 m EUR are used. In Denmark, the value of a statistical life is in transport economic evaluations, Ref. /25/, set to about 41 m DKK corresponding to about 5.5 m EUR. Applying this value as an indicative figure, the resulting, indicative fatality cost per collision and allision is estimated as shown in Table 28.

Table 28. Assumed fatality costs related to accidents.

Ship type	Indicative fatality cost per accident in EUR		
	Collisions	Allisions (powered)	Allision (drifting)
Fishing ship	408,625	408,625	204,312
General cargo	239,264	239,264	119,632
Oil products tanker	239,264	239,264	119,632
Passenger ship	89,004	89,004	44,502
Support ship	255,529	255,529	127,765

7.3.2 Property damage

The economic value of damage to ships as a result of a marine casualty will vary significantly from minor damage to loss of ship. In a more detailed consequence assessment, the value of ships will also vary from simpler cargo vessels to luxury cruise ships. However, as an indicative property damage value, the Nordic Association of Marine Insurers publish information on claim costs related to marine casualties, Ref. /26/. There is a large variability in claim size, and historically about 10-20% of claims exceed 10 m USD, and the highest claims are typically related to fires and explosions. As seen from Figure 67, the average claim cost related to collisions, contacts and groundings is about 1 m USD.

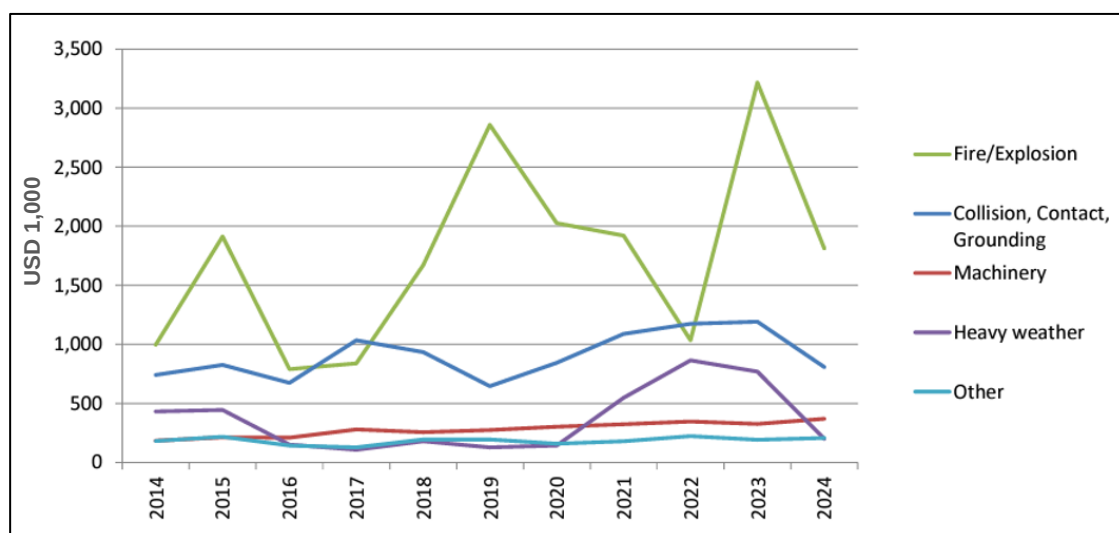


Figure 67. Average insurance claim costs for different types of marine casualties, from Ref. /26/.

For the population of ships seen in the Bothnian Sea and in the Bay of Bothnia, we assume an average cost of collision of 1 m USD, or conservatively about 1 m EUR for a collision. The property damage cost is scaled for larger and smaller ship sizes proportionally to the population of ships in the area.

In case of allisions, the turbine may also suffer damage. The extent of damage is not elaborated in detail, but may range from minor damage to full collapse of the turbine. However, replacing offshore turbines in case of a total loss is expensive. In one case, a claim size of EUR 11 million is reported following a fire in an 8 MW offshore wind turbine, Ref. /27/. Also potential loss of energy production may be costly if a turbine is not reinstalled after collapse, e.g., the annual revenue as generated by a 4MW turbine is reported at about \$700,000 in 2019 prices at 100% production, Ref. /28/. The loss of a 15MW turbine over a part of its intended lifetime may therefore result in a significant revenue loss if not reinstalled. Smaller damage may only require smaller surveys and repair works, but nevertheless involving costs in accessing the turbine. For the present work, we assume a cost distribution as given in Table 29 which results in turbine related costs per allision comparable to ship collision costs for smaller ships, and significantly higher for larger ships with a higher probability for turbine collapse.

Table 29. Assumed turbine damage cost per allision.

	EUR	Ship size (any ship)			
		0-50 m	50-100 m	100-200 m	200-300 m
Smaller damage	200,000	95%	90%	50%	1%
Moderate damage	2,000,000	5%	9%	40%	49%
Loss of turbine	20,000,000	0%	1%	10%	50%
Weighted cost [EUR]		290,000	560,000	2,900,000	10,982,000

Allisions at drifting speed may still result in significant damage or even collapse of a turbine. However, in general, property damage is assumed half as expensive for drifting speed allisions. In summary, indicative, average property costs per accident are given in Table 30.

Table 30. Assumed property costs related to accidents.

Ship length (any ship type)	Indicative property cost per accident in EUR			
	0-50 m	50-100 m	100-200 m	200-300 m
Collision	200,000	500,000	1,250,000	3,125,000
Powered allision	490,000	1,060,000	4,150,000	14,107,000
Drifting allision	245,000	530,000	2,075,000	7,053,500

7.3.3 Environmental damage

The cleanup costs after environmental spills vary significantly with a lot of factors such as type of spill and the environment in which the spill occurs. A review given in an abstract to the 2024 International Oil Spill Conference (IOPC), Ref. /29/, indicates a relationship between tanker size and cleanup costs. The relationship is seen in Figure 68 where a black line is added for the present study to indicate the trend.

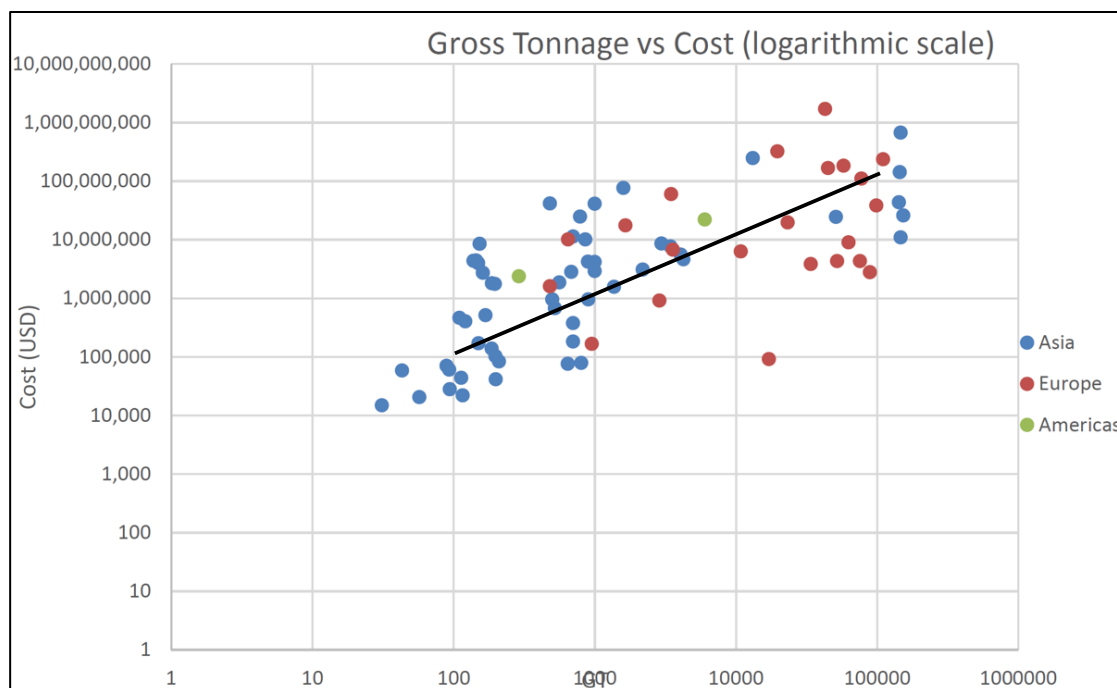


Figure 68. Relationship between tanker size and cleanup costs for IOPC Fund incidents only, from Ref. /29/, with additional, indicative trendline added (black line). Notice the scales are logarithmic.

Even if small spill volumes may result in high clean-up costs depending on the environmental conditions, there is a tendency that larger spills result in higher cleanup costs, especially for European spills. The relationship between spill size and cost is shown in Figure 69.

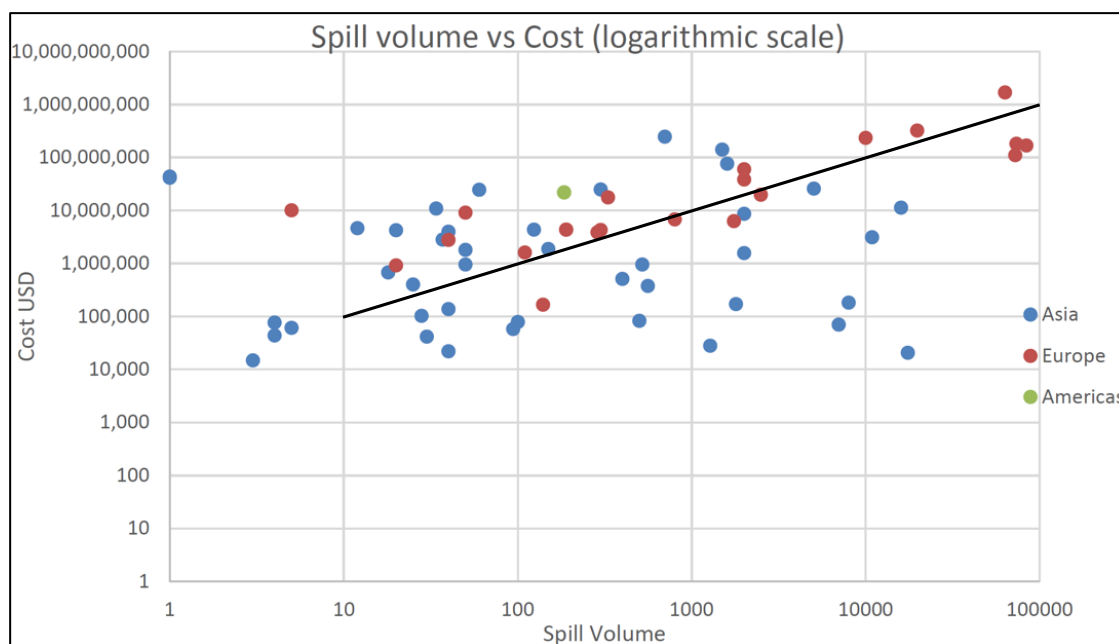


Figure 69. Relationship between spill size and cleanup costs for IOPC Fund incidents only, from Ref. /29/, with additional, indicative trendline added (black line). Notice the scales are logarithmic.

We assume spill costs related to the figures given in Ref. /29/ ranging from 100,000 EUR for smaller bunker spills up to 1,000 m EUR for large tanker cargo spills. The spill costs are assumed in the higher end of the scale based on the input from the HAZID workshop on the environmental conditions in the area where hard weather and potential future placement of wind turbines could make cleanup more difficult.

Table 31. Assumed clean-up costs per environmental spill.

Ship length	Indicative clean-up cost per spill in EUR			
	0-50 m	50-100 m	100-200 m	200-300 m
Bunker spill	100,000	1,000,000	10,000,000	100,000,000
Cargo spill				
- Non-tanker	100,000	1,000,000	10,000,000	100,000,000
- Tanker	1,000,000	10,000,000	100,000,000	1,000,000,000

The annual review of marine casualties, Ref. /24/, summarizes the number of marine casualties involving environmental damage distributed on main ship types. For instance, the data shows that 191 cargo ships casualties have resulted in bunker spill, and 81 cargo ship casualties have resulted in cargo spill.

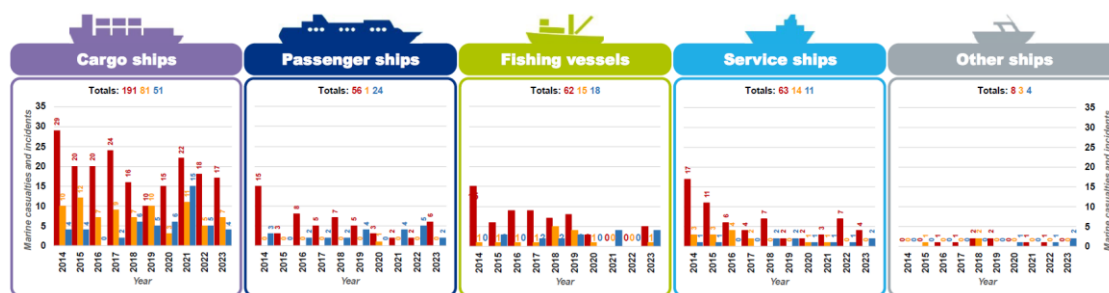


Figure 70. Marine casualties resulting in bunker pollution (red), cargo pollution (orange), and air pollution (blue), from Ref. /24/, Figure 2.5-19.

Oil pollution responses are categorized according to casualty event in Ref. /24/, Figure 2.5-21, and tabulated in Table 32. Most oil pollution responses are related to loss of control – loss of containment, damage / loss of equipment, and flooding/foundering. Only about 9% of the oil pollution responses are reported in relation to collisions. As basis for estimating the probability for oil spill in case of a collision, we here conservatively assume that also loss of containment may result from collisions. We therefore estimate the number of ship occurrences related to collisions and loss of containment, and the fraction of oil spill related to these events. The resulting estimates are summarized in Table 33.

Table 32. Pollution responses categorized according to casualty event, Ref. /24/.

Event type	Count	Share	Event type	Count	Share
Loss of control - loss of containment	75	35.7%	Fire / explosion	7	3.3%
Damage / loss of equipment	38	18.1%	Capsizing / listing	6	2.9%
Flooding / foundering	26	12.4%	Loss of control - loss of propulsion power	6	2.9%
Collision	18	8.6%	Loss of control - loss of directional control	2	1.0%
Contact	11	5.2%	Loss of control - loss of electrical power	2	1.0%
Grounding / stranding - other	10	4.8%	Hull failure	1	0.5%
Grounding /stranding - Power	8	3.8%	Loss of control - other	0	0.0%
			Total	210	100.0%

Table 33. Assumed probability of environmental spill per casualty.

	Cargo	Passenger	Fishing	Service	Other	Total
Marine casualties and incidents with occurrences related to ships	10,466	4,965	3,965	2,241	706	22,343
Related to collisions and loss of containment						
Marine casualties and incidents	2,492	1,182	944	534	168	5,320
Bunker pollution events	85	25	27	28	4	168
Cargo pollution events	36	0	7	6	1	50
Bunker pollution per collision or loss of containment	3.39%	2.10%	2.91%	5.23%	2.11%	3.16%
Cargo pollution per collision or loss of containment	1.44%	0.04%	0.70%	1.16%	0.79%	0.95%

For collisions and powered allisions, we assume full environmental damage in case the marine casualty results in a spill. For drifting allisions, we assume only bunker oil spill will occur in case of damage. Indicative, average clean-up costs per accident are summarized in Table 34.

Table 34. Assumed average clean-up costs per accident.

Ship lengths	Indicative, average clean-up cost per accident in EUR			
	0-50 m	50-100 m	100-200 m	200-300 m
Collisions and powered allisions				
Fishing ship	3,612	36,116	361,162	3,611,617
General cargo	4,834	48,337	483,365	4,833,654
Oil products tanker	17,789	177,886	1,778,856	17,788,559
Passenger ship	2,135	21,352	213,520	2,135,204
Support ship	5,555	55,550	555,504	5,555,038
Drifting allisions				
Fishing ship	2,908	29,081	290,805	2,908,055
General	3,394	33,942	339,422	3,394,221
Oil products tanker	3,394	33,942	339,422	3,394,221
Passenger ship	2,098	20,977	209,774	2,097,744
Support ship	4,482	44,819	448,191	4,481,906

7.4 CO₂ emissions from ships

In addition to consequences related to collisions and allisions, the amount of exhaust gases from ships will also be affected if shipping routes are changed. Several factors such as ship and engine type, sailing speed, weather conditions, etc. affect the needed engine power and the fuel consumption. As an additional input for further considerations, we estimate in general terms the CO₂ emissions from ships travelling on the currently seen routes as well as on the idealized route network with wind turbines in the area. We emphasize that the estimate is performed assuming open water conditions for a full year of ship traffic. Hence the estimate gives an indication on the overall, annual CO₂ emissions not considering winter navigation which will affect both the current situation and a situation with wind turbines in the area.

Ship-Desmo, Ref. /30/, developed by HOK Consult in collaboration with the Technical University of Denmark is used to estimate the CO₂ emissions from ships in the area. The model consists of several Excel sheets where empirical and semi-empirical methods are applied to predict powering requirements and emissions from ships based only on their type and bulk parameters including length, breadth, draft and block coefficient. Ship-Desmo models for tankers, bulk carriers, and RoRo passenger ships are used as basis for estimating average CO₂ emissions for ships within the study area. The Ship-Desmo models are generally built for larger ships, and the results are extrapolated to the smallest ships shorter than 50m. Similarly, no specific Ship-Desmo model exists for support ships and fishing vessels, and these are therefore assumed comparable to smaller cargo vessels. The average sailing speeds between 9 knots for fishing vessels and smaller support ships to 13 knots for tankers are applied in the calculations. The Ship-Desmo model for RoRo passenger ships assume a higher speed for larger vessels covering also cruise ships moving at above 20 knots. This is also considered in the calculations, and resulting, estimated CO₂ emissions per nautical mile are seen in Table 35.

Table 35. Estimated CO₂ emissions in kg per nautical mile for ship types and lengths observed within the study area.

Ship lengths	Indicative CO ₂ emission [kg per nautical mile]			
	0-50 m	50-100 m	100-200 m	200-300 m
Collisions and powered allisions				
Fishing ship	68	88	-	-
General cargo	104	134	247	470
Oil products tanker	-	135	261	-
Passenger ship	-	155	300	808
Support ship	68	88	197	-

The CO₂ emissions from fishing ships and support ships are generally lower than for cargo ships and tankers as they in general move at a lower speed. Similarly, larger passenger ships are estimated to have a higher CO₂ emission due to higher speeds.

7.5 Risk assessment

The risk level is the combination of the frequency of events occurring and their severeness. Insignificant events with small consequences may be accepted to occur at a higher frequency than major and catastrophic events.

Neither Swedish nor Finnish guidelines define what an acceptable risk is for navigational safety. However, the Swedish guidelines state that the risk for navigational safety shall not be larger than what can be seen as generally accepted, Ref. /17/. In Germany, the Bundesamt für Seeschifffahrt und Hydrographie (BSH), define a framework for frequency and consequence assessment as part of the standard design and minimum requirements concerning the constructive design of offshore structures within the EEZ, Ref. /31/.

Assuming a life expectancy of a wind farm of 40-50 years, a qualitative classification of probabilities of occurrence related to accidents involving or influenced by a wind farm is suggested in Table 36. This classification is inspired by a similar classification in the framework from BSH, Ref. /31/.

Table 36. Classification of probability of occurrence of accidents.

Description	Probability of occurrence (return period)
Frequent – expected to happen several times during the life of the wind farm	Up to 10 years
Occasional – may happen once or a few times during the life of the wind farm	10 to 100 years
Rare – not expected to happen during the life of the wind farm, but could occur	100 to 1,000 years
Very rare – not expected to happen during the life of the wind farm	More than 1,000 years

The BSH framework also defines consequence levels as background for a detailed consequence analysis, e.g., estimated using suitable simulation programmes such as finite element modelling, etc. This is outside the scope for the present assessment, but the qualitative description of consequence categories and a risk matrix combining the frequencies and consequences are shown in Table 37 and Figure 71.

Table 37. Qualitative consequence classes from BSH framework, Ref. /31/.

Qualitative	Offshore Wind Turbine	Ship/environment	Safety
Insignificant	Offshore wind turbine can continue to be operated	No or minor damage, no leakage of pollutants	No injuries
Significant	Offshore wind turbine defect, repair possible	Outer hull penetrated, operating materials from side tank/double floor flow into the water	Few injuries
Serious	Offshore wind turbine destroyed	Inner hull penetrated, loading tanks are leaking	Serious injuries, small number of fatalities
Catastrophic	-	Ship breaks apart, sinks	Large number of fatalities

Catastrophic	4	5	6	7
Serious	3	4	5	6
Significant	2	3	4	5
Insignificant	1	2	3	4
	Extremely rare	Rare	Occasional	Frequent

Figure 71. Risk matrix with risk levels from BSH framework, Ref. /31/.

The BSH framework requires representative reference ships to be used in a detailed collision analysis for the specific wind farm. With reference to the risk matrix in Figure 71 the risk for each individual scenario shall not exceed risk level 4 for offshore wind turbines and risk level 3 for ships. In addition, German guidelines suggest that not more than one collision cumulated within 100 years are acceptable, and hence events occurring occasionally or frequently are not admissible.

The ship traffic in the study area consists of routes carrying larger ships including cargo ships, tankers, and cruise ships. Consequences of ship-ship collisions at full speed may therefore result in both fatalities, property damage, and environmental spill as described in Section 7.3. The type of scenarios and consequences are, however, already relevant today before establishment of wind farms. Ship-turbine collisions are new risk scenarios, and consequences will differ with the type of ship and speed of impact. While consequence scenarios are not developed in detail, indicative consequences are also included for ship-turbine collisions in Section 7.2.1.

Based on the BSH framework, Ref. /31/, an initial risk evaluation is performed such that any impact scenario assessed to occur frequently or occasionally, i.e., once or several times during the life of a wind farm, is considered a high or very high risk and unacceptable. Rare drifting collisions are on average assessed as a medium risk (index 3 in the risk matrix in Figure 71), whereas rare, powered collisions are on average assessed as high risk

(index 4). Only very rare, powered allisions are on average assessed as a medium risk (index 3). A more detailed consequence assessment may be performed for a final design of a specific wind farm based the specific wind turbine design.

The above leads to an initial assessment that drifting allisions are acceptable with a return period of about 100 years or more whereas powered allisions are only acceptable with a return period of about 1,000 years or more.

The extension of the area considered as basis for the risk assessment according to the above-mentioned guidelines is relevant as more accidents will occur in a larger area. The cumulative risk is therefore often considered covering the wind farm under assessment and cumulatively any other wind farm within a radius of 20 nm, e.g., as presented in a preliminary investigation of wind farms in the German North Sea and Baltic Sea, Ref. /32/.

Figure 72 illustrates areas with a radius of about 20 nm within the study area. This indicates that the Bothnian Sea has about six local areas where the cumulative effect of wind farms should be considered when assessing specifically the risk for a given wind farm under study. In the Bay of Bothnia, the wind farm areas within the study area are grouped approximately within two local areas. The indicative acceptable return period of about 100 years for the cumulative situation around a given wind farm therefore translates to an acceptable return period of about 17 years in the Bothnian Sea and a return period of about 50 years in the Bay of Bothnia given six and two cumulative areas, respectively. Concentrated risks in some areas shall of course be avoided, and these return periods indicate a lower bound in case most allisions are drifting allisions. Powered allisions with larger consequences must occur with higher return periods.

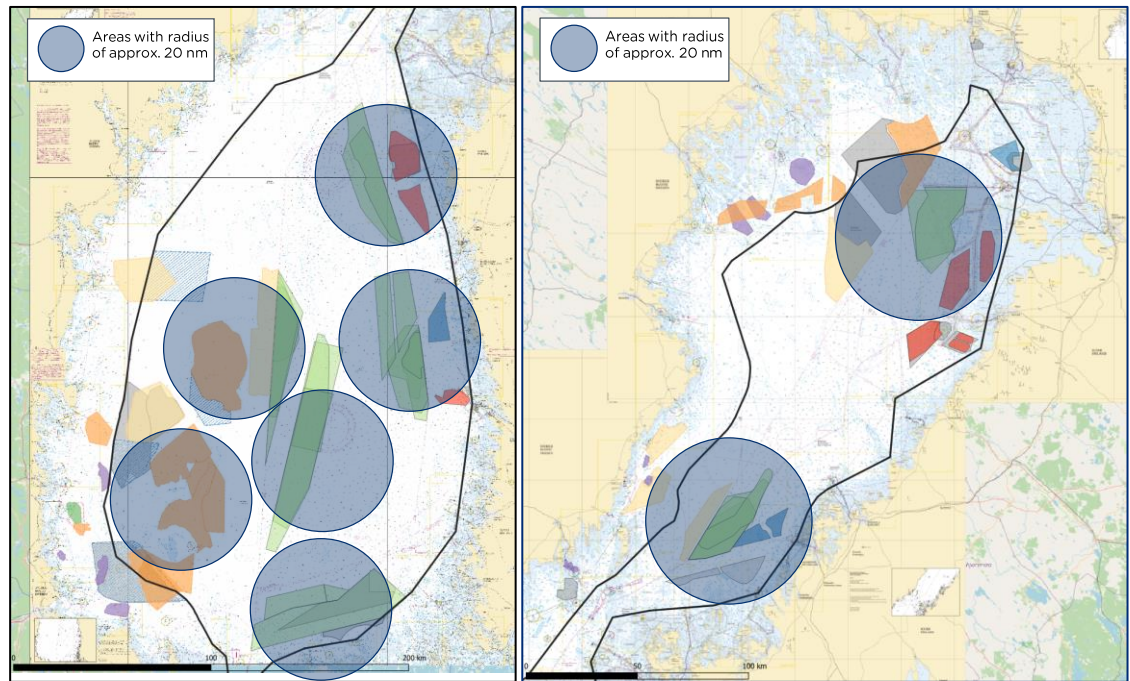


Figure 72. Areas with a radius of approximately 20 nm.

8 Risk analysis (FSA step 2)

In general, the purpose of the risk analysis in step 2 for the FSA process is a detailed investigation of the causes and initiating events and consequences of the more important accident scenarios identified in step 1. This can be achieved by the use of suitable techniques that model the risk. This allows attention to be focused upon high-risk areas and to identify and evaluate the factors which influence the level of risk.

Due to uncertainties in wind farm developments, the hazard identification has for the present study led to an idealized ship traffic pattern based on a worst-case wind farm development as described in Section 6.4. The risk analysis is therefore in the following based on an assessment of the differences between ship-ship collisions and ship-turbine collisions in the current situation and in a potential future situation. Collision and collision frequencies are estimated for the entire study area to gain an overview over potentially critical areas.

The routing is based on the results of the HAZID workshop, and hence cover the general ship traffic situation. However, some hazard causes are not addressed specifically in the model, and Table 38 shows how identified hazard causes are addressed.

Table 38. Modelling of hazard causes.

ID	Hazard cause	Comment
H1	Loss of power / blackout.	Included in the model
H2	Navigation through corridors between rows of wind turbines.	Included in the model
H3	Extra traffic caused by wind farm development for an extended period.	The construction ship traffic is expected to follow the ordinary routes for transport of materials, and manoeuvre in areas away from the main ship traffic routes during construction activities. An assessment of the collision frequencies with a general increase of ship traffic is included in a sensitivity analysis in Section 8.3.
H4	Service / maintenance traffic related to the wind farms during operation.	Service and maintenance traffic is expected to follow ordinary routes when in transit, and an assessment of the collision frequencies with a general increase of ship traffic is included in a sensitivity analysis in Section 8.3. Service and maintenance traffic within the wind farm areas are not included in the assessment.
H5	Dragged anchor in corridors between wind turbines.	This is mainly a risk for the wind farm operators and not elaborated further here.
H6	Difficult access for SAR vessels to area in corridors between wind turbines.	Difficult conditions for search-and-rescue may result in a higher fatality rate and hence higher fatality costs. Results with a 50% increased fatality rate in marine casualties is indicated in a sensitivity analysis in Section 8.3.

ID	Hazard cause	Comment
H7	Difficult access for environmental clean-up operations in corridors and between wind turbines.	Difficult conditions for environmental cleanup in higher environmental costs. Results with a 50% increased cost for marine casualties leading to environmental damage are indicated in a sensitivity analysis in Section 8.3.
H8	Ice storms.	Winter conditions are not covered within the scope of the study.
H9	Radar shadows and disturbed radar images.	The possible effect of radar shadows and disturbed radars is not explicitly considered in the modelling. However, route widths in the idealized scenario ensure safety distances, and specific, local conditions must be assessed for the individual wind farm development.
H10	Uncertainties of authority responsibilities on EEZ boundary.	The idealized, possible scenario is kept away from the EEZ boundary, and the possible effect of this hazard cause is therefore mitigated already in the idealized route layout.
H11	Congestion of ship traffic due to rerouting.	Included in the modelling.
H12	Corridors and "gaps" between wind farm developments attracting ship traffic.	Included in the setup of the idealized route layout and the modelling.
H13	Navigation around wind farm corners.	Included in the setup of the idealized route layout and the modelling.
H14	Complicated ship traffic patterns.	Included in the setup of the idealized route layout and the modelling.
H15	Lack of possibilities for monitoring ship traffic in corridors.	The model assumes no monitoring of ship traffic. The indicated effect of VTS and ship traffic monitoring is addressed as a risk control measure in Section 9.
H16	Larger vessels in the northern part of the Bay of Bothnia.	Included in the setup of the idealized route layout and the modelling. However, special challenges in winter conditions are outside the scope of the study.
H17	Ships approaching and using pilots at pilot boarding points.	Ordinary ship traffic patterns are modelled, and diverging from the routes to take on pilot is also occurring before construction of wind farms. Specific, local conditions must be assessed for the individual wind farm and are not addressed further in this study.
H18	Increased ship traffic in the future.	An assessment of the collision frequencies with a general increase of ship traffic is included in the sensitivity analysis in Section 8.3.

8.1 Collision and allision frequencies

In this section, the modelling of collision frequencies in the Bothnian Sea and the Bay of Bothnia with and without wind farms is described. This includes descriptions of the basis scenario with no wind turbines, and the introduction of wind turbines, and traffic re-routing due to the placement of wind turbines.

The frequency modelling was done with IWRAP Mk2 extended 64bit version 6.7.7 and with IALA defined causation factors, see Section 7.1 for specific values or the IWRAP manual for details about how IWRAP models incident frequencies, Ref. /4/.

8.1.1 Basis scenario

First, the current navigational safety situation in the Bothnian Sea and the Bay of Bothnia is presented. This serves as a basis for a comparative evaluation. Hence, collision frequencies are calculated for a situation similar to the current where no turbines are placed in either of the areas and allisions will for this reason not occur.

Based on the density map of the ship traffic, the two areas were defined into a route network that captures all the major ship traffic is modelled using IWRAP. The two route networks are shown in Figure 28 and Figure 29.

The overall results of the frequency modelling for the basis scenarios are shown per route in Table 39 and Table 40 as return periods, the total sailing distances and estimated CO₂ emissions.

Where the collision frequencies are calculated in IWRAP, the total sailing distance is found by multiplying the length of each route, with the number of ships on each route. Likewise, the estimated CO₂ emission for each route is calculated based on the CO₂ release per ship type, see Section 7.4, and then multiplied with the number of ships per ship type for each route.

Table 39. Overall collision return periods, total sailing distance, and estimated CO₂ emissions per route for the basis scenario without wind farms for Area 1, the Bothnian Sea.

Routes	Ship collisions	Allisions		Total sailing distance [nm]	CO ₂ -emission [ton]
		Powered	Drifting		
		Return period [years]			
A1_R1.1	320			617,259	138,191
A1_R2.1	4,455			62,613	14,080
A1_R2.2	3,995			72,312	15,113
A1_R3.1	800			139,147	30,685
A1_R3.2	5,205			27,291	4,720
A1_R3.3	2,380			75,048	15,852
A1_R3.4	5,395			43,113	8,917
A1_R4.1	1,380			113,581	22,966
A1_R4.2	7,015			20,814	4,077

Routes	Ship collisions	Allisions		Total sailing distance [nm]	CO ₂ -emission [ton]
		Powered	Drifting		
		Return period [years]			
A1_R4.3a	20,500			7,591	1,270
A1_R4.3b	13,575			12,620	1,725
A1_R5.1	8,410			40,852	7,119
A1_R6.1	18,465			30,041	4,951
A1_R6.2	31,135			10,537	2,030
A1_R6.3	3,660			55,247	10,016
A1_R7.1	15,010			16,285	2,652
A1_R7.2	159,930			7,110	1,259
A1_R7.3	319,780			5,383	880
A1_R7.4	5,580			34,661	6,353
Total	135			1,391,507	292,856

For Area 1, the Bothnian Sea, the overall return period for collisions is found to be 135 years. For the main route going from TSS North of Åland to TSS Kvarken (A1_Route 1.1) the return period is found to 320 years. This is the route where the most collisions are modelled, which is correlating with also being the route with the most traffic. The route with the second lowest return period between collisions is route A1_Route 3.1, which is the route between TSS North of Åland and Rauma in Finland. The modelling results for most of the routes in Area 1 yield very high return periods.

Table 40. Overall return periods, total sailing distance, and estimated CO₂ emissions per route for Area 2, the Bay of Bothnia.

Routes	Ship collisions	Allisions		Total sailing distance [nm]	CO ₂ -emission [ton]
		Powered	Drifting		
		Return period [years]			
A2_R1.1	1,320			187,362	42,366
A2_R2.1	2,315			86,999	20,009
A2_R2.2	27,420			13,851	2,739
A2_R3.1	7,380			23,788	5,156
A2_R4.1	2,395			52,752	11,113
A2_R4.2	12,880			22,795	4,693
A2_R4.3	4,290			56,531	10,221
A2_R4.4	4,250			52,101	11,947
A2_R5.1	244,295			2,802	546

Routes	Ship collisions	Allisions		Total sailing distance [nm]	CO ₂ -emission [ton]
		Powered	Drifting		
		Return period [years]			
A2_R6.1	57,850			7,452	1,578
A2_R7.1	6,085			22,519	5,509
A2_R7.2	4,500			48,836	10,982
A2_R8.1	60,025			11,780	2,690
Total	365			589,569	129,550

For Area 2, the Bay of Bothnia, the overall return period for collisions is found to be 365 years. The return periods between collisions for routes in Area 2 is larger than what was found in Area 1. This is due to the lower amount of traffic in this area as well as the area being smaller.

Figure 73 show a graphical representation of the collision frequencies for the current situation for the Bothnian Sea and the Bay of Bothnia, respectively.

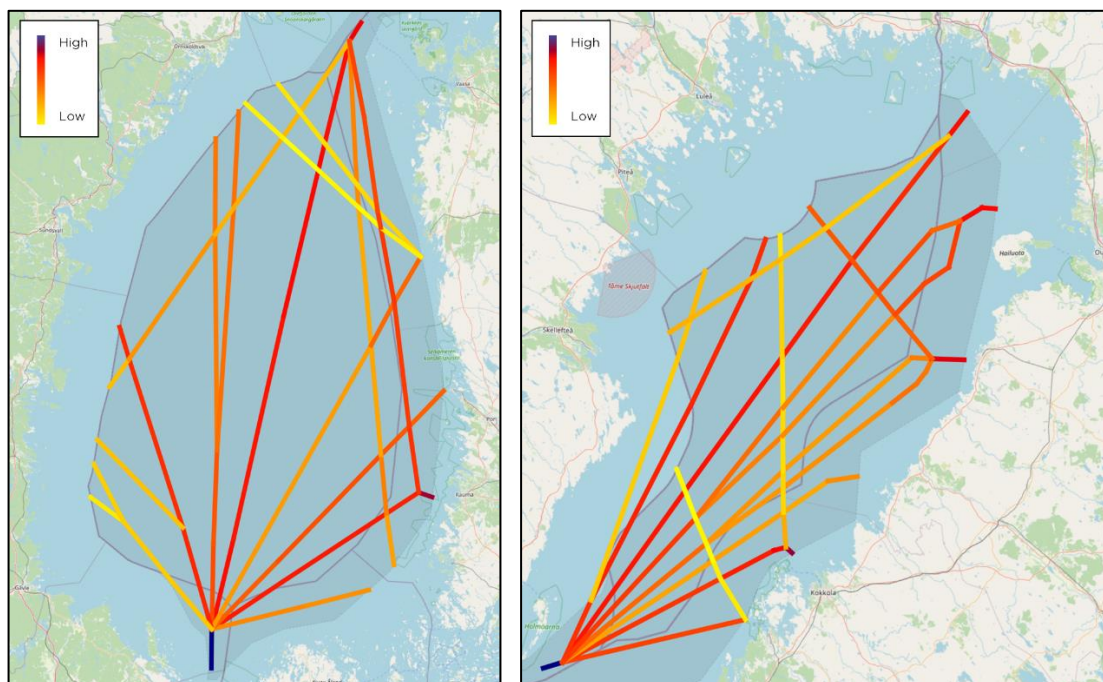


Figure 73. Routes modelled for Area 1, the Bothnian Sea (left) and the Bay of Bothnia (right), where the colours denote the collision frequencies.

Comparing the calculated return periods from the IWRAP modelling to incidences reported from HELCOM in the period 1989-2023 (see Section 4.2.1) yields much lower return periods for incidents in the area. However, as stated in Section 4.2.1 most of the reported incidents are linked to winter and ice conditions. The modelling in IWRAP considers only open water conditions, and for which there is only one relevant reported event in the period 1989-2023. Moreover, the reported accident occurred outside the

study area. In ice conditions, the number of collisions – even without presence of wind farms – must therefore be expected to be much higher than what is modelled in IWRAP. This again indicates that the modelling of open water season shows a quite positive picture, and that ice conditions will change the navigational safety significantly.

Overall, return periods of above 100 years for normal collisions along the main routes of each of the two areas is considered to be a high return period. To clarify, high return period means that there is estimated a relatively low and acceptable number of collisions in open water conditions

8.1.2 Future – idealized – scenario with wind farms

In this section the results for the modelling of a situation where the wind farms have been installed is presented. The modelling considers the route network described in Section 6.4, and is shown in Figure 42 and Figure 47 for Area 1 and Area 2, respectively.

In the modelling the wind farms are filled with regular patterns of wind turbines equally spaced with one nm and with an assumption of the foundation sizes to be 25 x 25 m. With wind turbines introduced into the model, collisions will be included in the modelling results.

The overall results of the frequency modelling for the future idealized scenario with wind farms in Area 1, the Bothnian Sea, are shown per route in Table 41 as return periods, the total sailing distances, and estimated CO₂ emissions.

Where the collision and allision frequencies are calculated in IWRAP, the total sailing distance is found by multiplying the length of each route, with the number of ships on each route. Likewise, the estimated CO₂ emission for each route is calculated based on the CO₂ release per ship type, see Section 7.4, and then multiplied with the number of ships per ship type for each route.

Table 41. Overall collision and allision return periods, total sailing distance, and estimated CO₂ emissions per route for an idealized future scenario with wind farm for Area 1, the Bothnian Sea.

Routes	Ship collisions	Allisions		Total sailing distance [nm]	CO2-emission [ton]
		Powered	Drifting		
		Return period [years]			
A1_R1.1	250	44,215	45	627,260	140,430
A1_R2.1	2,580	133,045	440	63,205	14,213
A1_R2.2	2,335	121,220	400	72,228	15,096
A1_R3.1	765	>1,000,000	305	141,783	31,266
A1_R3.2	5,265	279,365	725	27,208	4,706

Routes	Ship colli- sions	Allisions		Total sailing distance [nm]	CO2- emission [ton]
		Powered	Drifting		
		Return period [years]			
A1_R3.3	1,890	>1,000,000	715	75,730	15,996
A1_R3.4	3,150	>1,000,000	855	37,604	7,778
A1_R4.1	1,185	>1,000,000	180	122,966	24,864
A1_R4.2	7,755	>1,000,000	1,975	18,942	3,710
A1_R4.3a	18,040	>1,000,000	5,645	7,644	1,278
A1_R4.3b	11,635	>1,000,000	2,960	12,628	1,727
A1_R5.1	5,575	>1,000,000	1,190	38,545	6,716
A1_R6.1	22,135	>1,000,000	2,425	20,553	3,387
A1_R6.2	22,970	287,340	1,500	19,822	3,818
A1_R6.3	6,665	>1,000,000	910	49,537	8,981
A1_R7.1	6,185	>1,000,000	1,580	27,354	4,455
A1_R7.2	91,690	>1,000,000	4,545	5,991	1,060
A1_R7.3	64,380	>1,000,000	5,685	5,763	942
A1_R7.4	8,505	>1,000,000	730	45,851	8,404
Total	110	20,450	20	1,420,613	298,828

For Area 1, the Bothnian Sea, the overall return period for collisions is found to be slightly lower than for the basis scenario, namely 110 years. As for the basis scenario, the lowest return period is for the main route going from TSS North of Åland to TSS Kvarken (A1_Route 1.1), which is found to 250 years – hence a 70 year reduction in return period. This is the route where the most collisions are modelled, which is correlating with also being the route with the most traffic. Parts of the traffic in the idealized scenario is also pushed to be more overlapping for the opposite directions when using the long corridor between the wind farms on either side. As for the basis scenario, the route with the second lowest return period between collisions is route A1_Route 3.1, which is the route between TSS North of Åland and Rauma in Finland, where the return period is found to be 765 years. The modelling results for most of the routes in Area 1 yield very high return periods, and overall, return periods of above 100 years for normal collisions along the main routes of the area is considered to be a high return period, and hence corresponding to a relatively low number of collisions.

The allisions are calculated as both powered and drifting allisions. The powered allisions are found to have a total return period of 20,450 years, which is very large and therefore acceptable. Figure 74 shows a graphical representation of the collision frequencies on the routes and powered allisions for the future idealized scenario with wind farms for the Bothnian Sea. It is mainly allisions along the corridors, or wind turbines in the direction from routes with a bend, in case the ship does not turn as planned, which are

modelled to experience powered collisions. It should be emphasized that the colours in the figure are scaled such that the highest frequencies are blue and dark red - even if these collision frequencies are indeed very low.

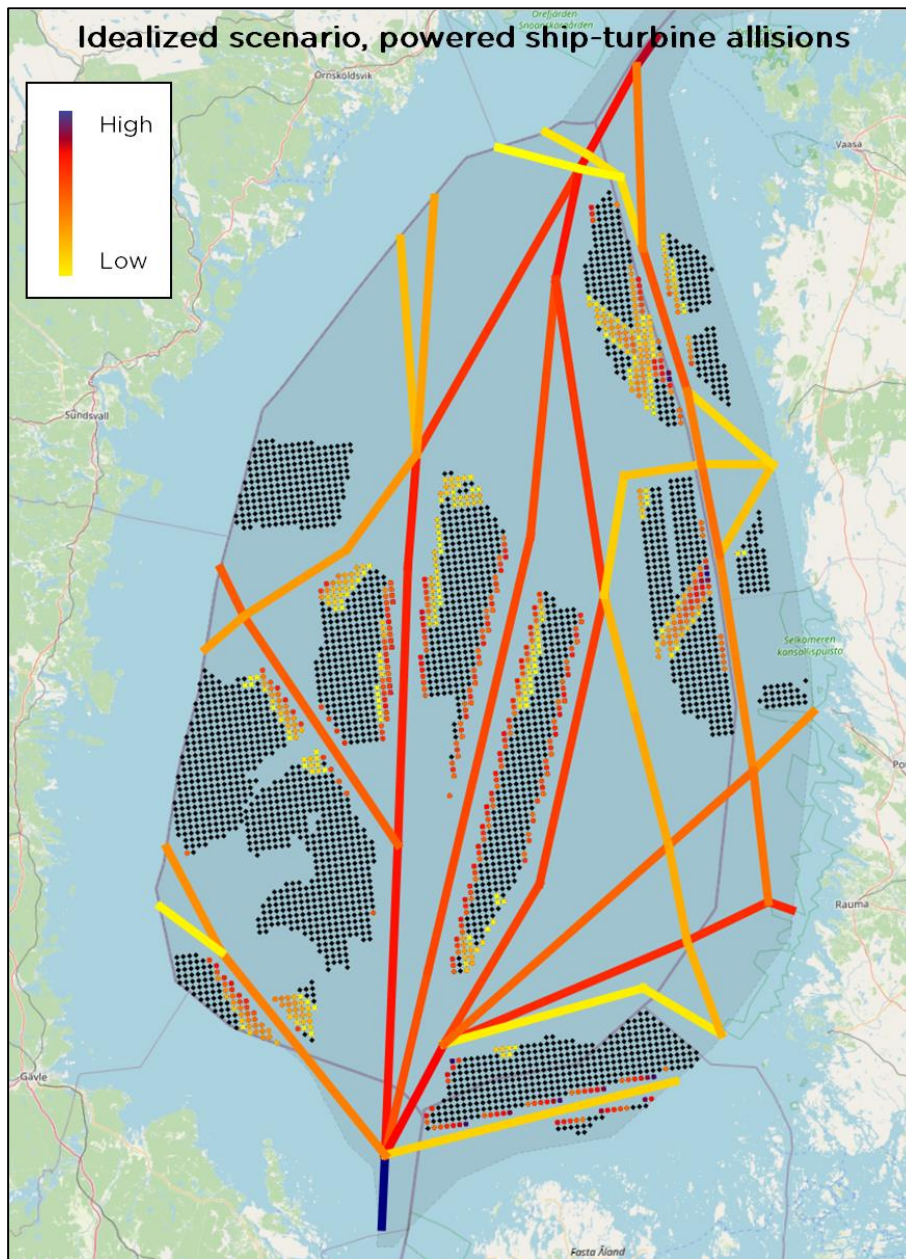


Figure 74. Collision on routes and powered allisions with wind turbines modelled for the future idealized scenario with wind farms for Area 1, the Bothnian Sea.

When considering the drifting allisions, the overall return period is found to be 20 years. The lowest return period is found for the main route going from TSS North of Åland to TSS Kvarken (A1_Route 1.1), which is found to 45 years. This is the only route with a return period for drifting allisions of less than 100 years. In total, return periods between 100 and 500 years are found for three routes, namely A1_Route 2.1, A1_Route 2.2, and A1_Route 3.1. Figure 75 shows a graphical representation of the collision

frequencies on the routes and drifting allisions for the future idealized scenario with wind farms for the Bothnian Sea.

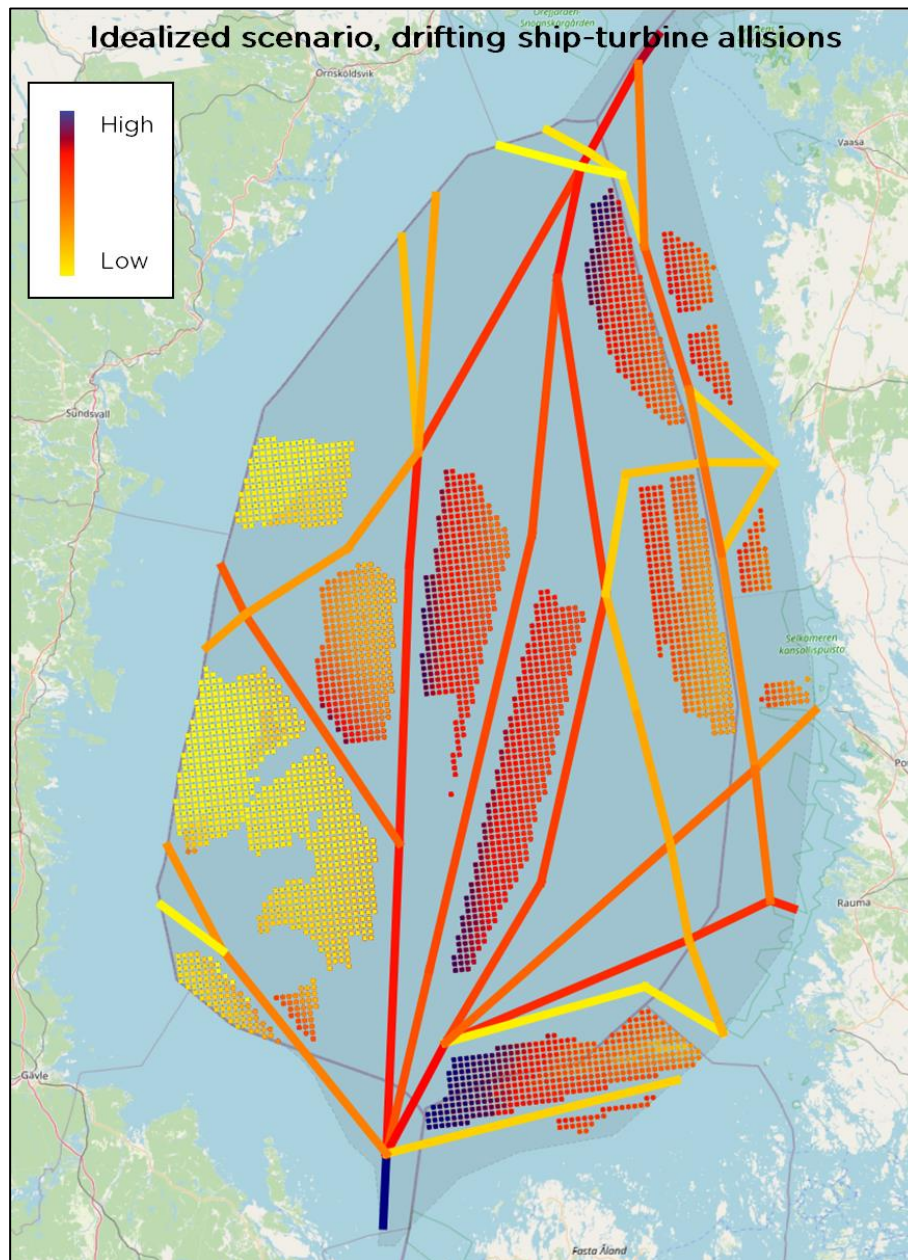


Figure 75. Collision on routes and drifting allisions with wind turbines modelled for the future idealized scenario with wind farms for Area 1, the Bothnian Sea.

From Figure 75 it is evident that the majority of the drifting allisions are towards the western edge of wind farms, which is due to the dominant winds in the area, blowing towards east and northeast. Moreover, the central routes with the highest ship traffic volumes passing west of wind farm areas are seen to give rise to the highest drifting ship-turbine allision frequencies. This also means, that most drifting allisions will be within the Finnish EEZ.

The return period of 110 years for ship-ship collisions and 20 years for drifting allisions found for Area 1, the Bothnian Sea, is considered within an acceptable return period, as described in Section 7.5.

Table 42 summarizes the overall results of the frequency modelling for the future idealized scenario with wind farms in Area 2, the Bay of Bothnia. The results are shown per route in Table 41 as return periods, the total sailing distances and estimated CO₂ emissions.

Table 42. Overall return periods, total sailing distance, and estimated CO₂ emissions per route for Area 2, the Bay of Bothnia.

Routes	Ship collisions	Allisions		Total sailing distance [nm]	CO2-emission [ton]
		Powered	Drifting		
		Return period [years]			
A2_R1.1	875	> 1,000,000	385	190,084	42,982
A2_R2.1	1,475	> 1,000,000	610	90,616	20,841
A2_R2.2	11,915	> 1,000,000	7,605	14,478	2,863
A2_R3.1	5,920	> 1,000,000	850	24,880	5,392
A2_R4.1	1,460	> 1,000,000	920	62,036	13,069
A2_R4.2	4,740	> 1,000,000	2,935	24,314	5,006
A2_R4.3	2,210	> 1,000,000	1,025	57,881	10,465
A2_R4.4	2,175	> 1,000,000	1,605	57,584	13,205
A2_R5.1	169,720	> 1,000,000	37,110	3,026	590
A2_R6.1	49,735	> 1,000,000	6,965	7,475	1,583
A2_R7.1	7,530	52,705	925	23,329	5,707
A2_R7.2	4,620	125,185	985	46,045	10,355
A2_R8.1	26,535	> 1,000,000	4,850	13,054	2,981
Total	235	36,005	90	614,803	135,038

For Area 2, the Bay of Bothnia, the overall return period for collisions is found to be lower than for the basis scenario, namely 235 years. As for the basis scenario, the lowest return period is for the main route going from TSS Kvarken to Kemi/Tornio (A2_Route 1.1), which is found to 875 years. This is the route where the most collisions are modelled, which is correlating with also being the route with the most traffic. All other routes are found to have return periods of more than 1,000 years, which is very large return periods.

The allisions are calculated as both powered and drifting allisions. The powered allisions are found to have a total return period of about 36,000 years, which is very large and therefore acceptable. Figure 76 shows a graphical representation of the collision frequencies on the routes and powered allisions for the future idealized scenario with wind farms for the Bay of

Bothnia. It is mainly allisions with wind turbines placed along the main routes, or wind turbines in the direction from routes with a bend, in case the ship does not turn as planned, which are modelled to experience powered collisions.

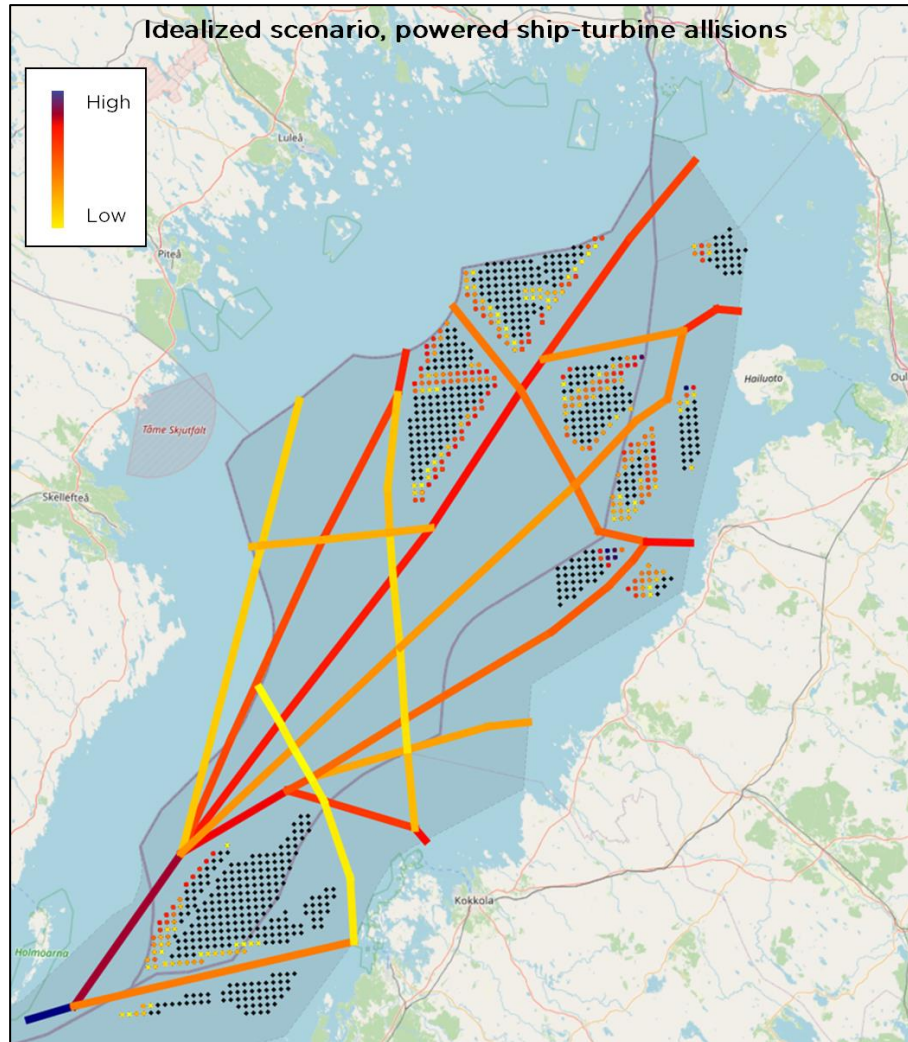


Figure 76. Collision on routes and powered allisions with wind turbines modelled for the future idealized scenario with wind farms for Area 2, the Bay of Bothnia.

When considering the drifting allisions, the overall return period is found to be 90 years. The lowest return period is found for the main route going from TSS Kvarken to Kemi/Tornio (A2_Route 1.1), which is found to 385 years. This is the only route with a return period for drifting allisions of less than 500 years. Generally, the return periods per route are found to be large.

Figure 77 shows a graphical representation of the collision frequencies on the routes and drifting allisions for the future idealized scenario with wind farms for the Bay of Bothnia.

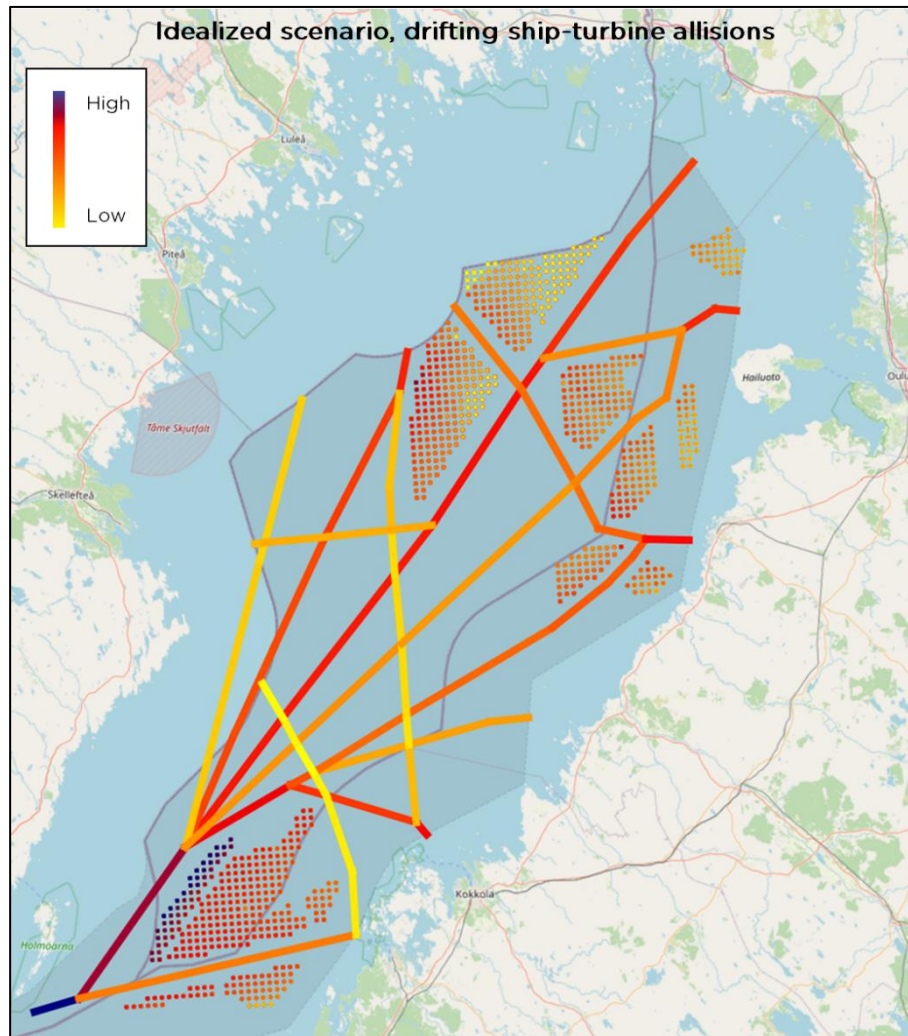


Figure 77. Collision on routes and drifting allisions with wind turbines modelled for the future idealized scenario with wind farms for Area 2, the Bay of Bothnia.

From Figure 77 it is evident that the majority of the drifting allisions are along the main route from TSS Kvarken before the routes fan out. This is a combination of almost all the traffic sailing in the vicinity of the wind farm in combination with the dominating western and southwestern winds, pushing the ships into the wind turbines in this area.

The return period of 235 years for ship-ship collisions and 90 years for drifting allisions found for Area 2, the Bay of Bothnia, is within acceptable return period, as described in Section 7.5.

Considering the amount of wind turbines which are introduced in the future, idealized, scenario with wind farms, the modelled return periods are considered reasonable. As mentioned in Section 8.1.1, return periods of above 100 years along the main routes of each of the two areas is a high return period. Furthermore, the found return periods for both Area 1, the Bothnian Sea and Area 2, the Bay of Bothnia are within the acceptable return periods estimated in Section 7.5.

8.2 Risk analysis results

The annual risk is calculated as the product of the frequency and consequence for each risk measure, fatalities, property damage, and damage to the environment. The risk is presented in economic value in EUR.

The risk results are presented for Area 1, the Bothnian Sea and Area 2, the Bay of Bothnia with and without wind farms in the following. Finally a comparison between the two scenarios is made.

8.2.1 Basis scenario

The risk results for the basis scenario for Area 1 and Area 2 are summarized in Table 43 and Table 44, respectively. For Area 1, the Bothnian Sea, the overall risk summarizes to approximately 14,000 EUR per year, reflecting the annual risk based on the open water season collision and allision scenarios. This is distributed between fatalities (approximately 1,800 EUR), property damage (approximately 7,500 EUR), and environmental damage (approximately 4,500 EUR).

Table 43. Calculated annual risk for the basis scenario without wind farms for Area 1, the Bothnian Sea.

Route	Indicative annual risk [EUR per year]			
	Fatalities	Property damage	Environmental damage	Total
A1_R1.1	745	3,423	2,247	6,414
A1_R2.1	54	238	124	415
A1_R2.2	61	263	183	508
A1_R3.1	312	1,399	774	2,484
A1_R3.2	47	152	73	272
A1_R3.3	107	439	358	904
A1_R3.4	45	179	104	328
A1_R4.1	177	683	343	1,202
A1_R4.2	37	138	57	232
A1_R4.3a	13	36	17	66
A1_R4.3b	20	43	10	73
A1_R5.1	29	96	53	179
A1_R6.1	13	40	24	77
A1_R6.2	8	27	12	47
A1_R6.3	65	215	98	378
A1_R7.1	16	47	18	81

Route	Indicative annual risk [EUR per year]			
	Fatalities	Property damage	Environmental damage	Total
A1_R7.2	2	6	3	10
A1_R7.3	1	3	1	5
A1_R7.4	44	149	61	254
Total	1,792	7,576	4,561	13,929

Given that return periods for both collisions and allisions were lowest for the main route from TSS North of Åland to TSS Kvarken (A1_Route 1.1) this is also the route where the largest risk is found.

For Area 2, the Bay of Bothnia, the overall risk summarizes to approximately 5,500 EUR per year. This is distributed between fatalities (approximately 650 EUR), property damage (approximately 3,000 EUR), and environmental damage (approximately 2,000 EUR).

Table 44. Calculated annual risk for the basis scenario without wind farms for Area 2, the Bay of Bothnia.

Route	Indicative annual risk [EUR per year]			
	Fatalities	Property damage	Environmental damage	Total
A2_R1.1	180	830	460	1,471
A2_R2.1	102	492	334	928
A2_R2.2	9	39	28	76
A2_R3.1	33	146	85	264
A2_R4.1	100	433	315	848
A2_R4.2	19	81	63	162
A2_R4.3	55	196	65	316
A2_R4.4	55	257	191	503
A2_R5.1	1	5	4	10
A2_R6.1	4	19	16	39
A2_R7.1	39	201	99	339
A2_R7.2	52	240	171	463
A2_R8.1	4	21	20	45
Total	653	2,960	1,852	5,464

Given that return periods for both collisions and allisions were lowest for the main route from TSS Norra Kvarken to Kemi/Tornio (A2_Route 1.1) this is also the route where the largest risk is found.

The consequences are on average composed as 13% related to fatalities, 54% related to property damage, and 33% related to environmental damage. These figures align well with the main ship traffic composition on the main routes. However, variations are seen. For instance, for A1 Route 4.3a and 4.3b, 19% and 27% of the consequence cost is related to fatalities, respectively, and a correspondingly lower consequence for environmental damage. This could be related to the ship traffic composition with relatively more fishing vessels and support vessels compared to the main routes, as well as more smaller cargo ships with lower property damage and environmental damage, but still at risk of fatalities. In general, the property damage and environmental damage is therefore assessed to be relatively higher for routes with a majority of larger ships whereas the risk is to a higher degree related to fatalities for routes with smaller vessels.

8.2.2 Future – idealized – scenario with wind farms

The risk results for the future, idealized, scenario with wind farms for Area 1 and Area 2 are summarized in Table 45 and Table 46, respectively. For Area 1, the Bothnian Sea, the overall risk for the future idealized scenario with wind farms summarizes to approximately 113,000 EUR per year. This is distributed between fatalities (approximately 8,000 EUR), property damage (approximately 85,000 EUR), and environmental damage (approximately 20,000 EUR).

Table 45. Calculated annual risk for the future, idealized, scenario with wind farms without wind farms for Area 1, the Bothnian Sea.

Route	Indicative annual risk [EUR per year]			
	Fatalities	Property damage	Environmental damage	Total
A1_R1.1	3,516	43,134	10,795	57,444
A1_R2.1	371	4,408	897	5,676
A1_R2.2	414	4,851	1,299	6,564
A1_R3.1	735	7,652	2,168	10,555
A1_R3.2	216	1,767	373	2,356
A1_R3.3	313	2,945	933	4,191
A1_R3.4	218	2,155	564	2,938
A1_R4.1	887	9,030	1,686	11,602
A1_R4.2	98	908	172	1,178
A1_R4.3a	37	234	46	318
A1_R4.3b	68	315	45	427
A1_R5.1	145	1,161	225	1,530
A1_R6.1	61	487	117	665
A1_R6.2	92	910	159	1,162
A1_R6.3	166	1,482	281	1,929

Route	Indicative annual risk [EUR per year]			
	Fatalities	Property damage	Environmental damage	Total
A1_R7.1	112	715	120	947
A1_R7.2	30	310	52	393
A1_R7.3	25	235	40	300
A1_R7.4	195	1,891	330	2,417
Total	7,698	84,593	20,302	112,593

Given that return periods for both collisions and allisions were lowest for the main route from TSS North of Åland to TSS Kvarken (A1_Route 1.1) this is also the route where the largest risk is found.

For Area 2, the Bay of Bothnia, the overall risk for the future idealized scenario with wind farms summarizes to approximately 34,000 EUR per year, reflecting the annual risk based on the open water season collision and allision scenarios. This is distributed between fatalities (approximately 2,500 EUR), property damage (approximately 25,000 EUR), and environmental damage (approximately 7,000 EUR).

Table 46. Calculated annual risk for the future, idealized, scenario with wind farms without wind farms for Area 2, the Bay of Bothnia.

Route	Indicative annual risk [EUR per year]			
	Fatalities	Property damage	Environmental damage	Total
A2_R1.1	583	5,898	1,506	7,987
A2_R2.1	353	3,962	1,299	5,614
A2_R2.2	36	329	127	493
A2_R3.1	182	2,292	554	3,027
A2_R4.1	295	2,563	933	3,791
A2_R4.2	92	818	326	1,236
A2_R4.3	223	1,592	297	2,111
A2_R4.4	179	1,619	580	2,378
A2_R5.1	5	63	25	92
A2_R6.1	22	296	96	414
A2_R7.1	164	2,495	544	3,202
A2_R7.2	171	2,064	505	2,740
A2_R8.1	34	537	200	771
Total	2,339	24,527	6,991	33,858

Given that return periods for both collisions and allisions were lowest for the main route from TSS Norra Kvarken to Kemi/Tornio (A2_Route 1.1) this is also the route where the largest risk is found.

The consequences in the idealized scenario are on average composed as 7% related to fatalities, 73% related to property damage, and 20% related to environmental damage. These figures align well with the introduction of wind turbines in the model, and therefore allisions, which will have economic consequences both to the ships and the wind turbines, as well as lost revenue to the wind farm developers. As for the basis scenario, variations between the different routes are seen. For instance, for A1 Route 4.3a, 4.3b and 7.1, 12%, 16% and 12% of the consequences are related to fatalities, respectively. For A1 Route 7.2, 7.3 and 7.4, almost 80% of the costs are related to the property damage. These are the routes in the northern Bothnian Sea, which are located with wind farms on both sides, and with a corridor width of only 3.5 nm. For A1 Route 2.2, 3.1 and 3.3, more than 20% of the costs are related to environmental damage. Where A1 Route 2.2 has a corridor, the two other routes are more in the open sea. For the Bay of Bothnia, A2 Route 4.3 has the largest relative consequence for fatalities, namely 11%. For A2 Route 3.1 and 7.1, 76% and 88%, respectively, of the consequences are related to property damage. These are also the routes in the Bay of Bothnia with the longest corridor through wind farm areas. Finally, A1 Route 2.2, 4.3, 5.1, and 8.1 all have more than 26% of the consequences related to environmental damage.

8.2.3 Sailing distance, CO₂ emissions and sustainability

The difference in sailing distance and CO₂ emission per route and in total for Area 1, the Bothnian Sea and Area 2, the Bay of Bothnia are summarized in Table 47 and Table 48. Increases in sailing distance and CO₂ emissions are marked in red, bold text, where decreases are marked with green, bold text.

For Area 1 the overall increase in sailing distance, when considering all ships on all routes, is about 2%, corresponding to an extra sailing distance of approximately 29,000 nm per year. Similarly, the increase in CO₂ emissions is about 2%, corresponding to an increase of around 6,000 tons CO₂ per year. These changes are considered quite small considering the potential green energy production from the wind farms across the entire area. Furthermore, it was mentioned during the HAZID workshop that ships sometimes choose to take a longer route, not only due to ice conditions, but also in open-water season, due to harsh weather conditions. If a ship on the main route through the Bothnian Sea must sail along the Swedish coast, the extra sailing length corresponds to approximately 30 nm per ship, depending on how close to the coast the ship sails. Say 1000 ships from the main route chooses this detour each year – mainly during winter, this corresponds to an extra sailing distance of 30,000 nm. Hence, the

impact of smaller rerouting in the open-water season is assessed to be small compared to the potential other routes used during winter conditions.

Table 47. Comparison of sailing distances and CO₂ emission from the basis scenario to the future idealized scenario with wind farms for Area 1, the Bothnian Sea.

Routes	Total Sailing distance		CO ₂ emission	
	Δ nm	%-change	Δ tons	%-change
A1_R1.1	10,002	2%	2,239	2%
A1_R2.1	592	1%	133	1%
A1_R2.2	-84	0%	-18	0%
A1_R3.1	2,636	2%	581	2%
A1_R3.2	-83	0%	-14	0%
A1_R3.3	682	1%	144	1%
A1_R3.4	-5,508	-13%	-1,139	-13%
A1_R4.1	9,385	8%	1,898	8%
A1_R4.2	-1,872	-9%	-367	-9%
A1_R4.3a	53	1%	9	1%
A1_R4.3b	8	0%	1	0%
A1_R5.1	-2,307	-6%	-402	-6%
A1_R6.1	-9,489	-32%	-1,564	-32%
A1_R6.2	9,285	88%	1,789	88%
A1_R6.3	-5,711	-10%	-1,035	-10%
A1_R7.1	11,069	68%	1,803	68%
A1_R7.2	-1,119	-16%	-198	-16%
A1_R7.3	380	7%	62	7%
A1_R7.4	11,190	32%	2,051	32%
Total	29,106	2%	5,972	2%

For Area 2 the overall increase in sailing distance, when considering all ships on all routes is about 4%, corresponding to an extra sailing distance of approximately 25,000 nm per year. Similarly, the increase in CO₂ emissions is about 4%, corresponding to an increase of around 5,500 tons CO₂ per year.

Some routes are in Table 47 marked as becoming shorter. However, the routes must be seen as a combined picture, as some of the ship traffic is cut into several routes in the model setup. E.g., A1 Route 3.4 must be considered in combination with A1 Route 6.2 as these two routes together compose the traffic from TSS North of Åland to Kaskinen in Finland. In total the extra sailing length for these two routes is found to be 3.777 nm, as

the traffic must be diverted north of the wind farms south-west of Kaskinen. For A1 Route 4.2, it is assumed that the traffic currently on R4.2 can use the shorter route R4.3. Part of the shorter distance is related to the route being shorter, but maybe more challenging going close to more shallow waters. However, a reason for the shorter distance can also be that a slightly longer distance is needed outside the study area after the rerouting. So the route may be shorter within the study area, but slightly longer outside, which even out the change in distance listed in Table 47. A1 Route 6.1 is continued into A1 Route 7.1, composing the ship traffic from Turku to TSS Norra Kvarken, hence in total the extra sailing distance for these two routes is found to be about 1,580 nm as the traffic must be diverted west around the wind farms in the north of the Bothnian Sea.

The shortening of sailing distances for A1 Routes 2.2, 3.2, 5.1 and 7.2 are due be modelling artifacts. For A1 Route 2.2 and 3.2 the shorter sailing distance is negligible (80 nm per year), whereas the shorter sailing distance for A1 Route 5.1 due to the change of the routes character catching a wider area traffic in the basis scenario, and having another end point in the south than what is modelled in the future idealized scenario. The route is composed of all diagonal ship traffic in the area, it is difficult to say how much of the ship traffic is actually affected by a route change. For A1 Route 7.2 the route ends are located at slightly different place on the project boundary due to the rerouting, and hence the distance outside the project boundary becomes slightly longer in return for the shorter route here. All in all, smaller modelling artifacts may give rise to route changes of up to maybe 5-6%, in the larger picture, such changes will be quite insignificant compared to how ships actually move, change course due to bad weather, etc.

Table 48. Comparison of sailing distances and CO2 emission from the basis scenario to the future idealized scenario with wind farms for Area 2, the Bay of Bothnia.

Routes	Total Sailing distance		CO2 emission	
	Δ nm	%-change	Δ tons	%-change
A2_R11	2,722	1%	615	1%
A2_R21	3,617	4%	832	4%
A2_R22	627	5%	124	5%
A2_R31	1,092	5%	237	5%
A2_R41	9,285	18%	1,956	18%
A2_R42	1,519	7%	313	7%
A2_R43	1,350	2%	244	2%
A2_R44	5,483	11%	1,257	11%
A2_R51	223	8%	44	8%

Routes	Total Sailing distance		CO2 emission	
	Δ nm	%-change	Δ tons	%-change
A2_R61	23	0%	5	0%
A2_R71	810	4%	198	4%
A2_R72	-2,791	-6%	-628	-6%
A2_R81	1,274	11%	291	11%
Total	25,234	4%	5,488	4%

The changes in total sailing distance and CO₂ emission are considered quite small in consideration of the potential green energy production from the wind farms across the entire area.

As for the Bothnian Sea, A2 Route 7.2 is in Table 48 found as becoming shorter. However, this route must be seen in combination with A2 Route 4.4 as these two routes together compose the traffic from TSS Norra Kvarken to Raahen in Finland. In total the extra sailing length for these two routes is found to be 2,692 nm, as the traffic must be diverted north of the wind farms in the south of the Bay of Bothnia, and around the wind farms in the north.

A measure for the impact on sustainability was at the HAZID workshop presented as the impact on the future use of the area for wind energy production. This is here calculated as the reduction in the gross wind farm area needed to make room for the ship traffic. The reduction is needed to ensure a minimum width of ship traffic routes in the idealized route network. The total wind farm area was presented in Section 4.3, and the needed reduction is summarized in Table 8-12.

Table 49. Reduction in sustainability expressed as reduction in wind farm area and number of wind turbines.

	Area [km ²]	% reduction	Number of turbines	% reduction
Area 1 – Bothnian Sea				
Gross wind farm	12,709		3,698	
Future scenario	11,638		3,398	
Reduction	1,071	8%	300	8%
Area 2 – Bay of Bothnia				
Gross wind farm	3,896		1,114	
Future scenario	3,185		910	
Reduction	711	18%	204	18%

	Area [km ²]	% reduction	Number of turbines	% reduction
Total Area				
Gross wind farm	16,605		4,812	
Future scenario	14,823		4,308	
Reduction	1,782	11%	504	10%

As summarized in Table 49, the overall wind farm area is reduced with 11% corresponding to approximately 1,800 km² to have sufficient safety distances around the idealized routes.

The largest reduction in wind farm area is made in Area 2, the Bay of Bothnia, where 18% of the original wind farm is removed to make sufficient room for the ship traffic. This is especially in the very north of the Bay of Bothnia, where large areas have been cut to ensure sufficient space for the traffic going to Kemi/Tornio and Oulu. This includes keeping the "banana", see Section 6.2.2, free from wind turbines, to ensure space for the ship traffic and taking advantage of the area often being free from ice in the winter due to the strong currents in the area. Furthermore, there are several proposed windfarms proposed near the coast, outside the study area, some of these may also need to be cut to allow for coastal ship traffic in a winter situation. However, for the current study, only wind turbines within the study area are modelled, and it is only a reduction in windfarm area within the study area which is considered in the sustainability consideration.

The reduction in wind farm area in Area 1, the Bothnian Sea is estimated to 8%. This reduction is made widespread across the entire area, especially when defining needed corridor widths, as described in Paragraph 7.2.1.

It is unlikely that all wind farm areas will be developed, and only considering the open-water situation, it is possible to develop a significant amount of wind farm areas. Hence, the impact on the "green transition, future development of wind farms", is not large. There is room for wind farms, but it must be ensured that the ship traffic has sufficient routes, and the situation can be very different for the winter season also considering the ice conditions.

8.2.4 Comparison and summary of risk results

The increase in risk between the basis scenario and the future, idealized scenario with wind farms is presented in Table 50 and Table 51. For both areas the increase in risk is controlled by the drifting allisions, which has the lowest return periods, and which are introduced to the model when turbines are included.

For Area 1, the Bothnian Sea, the average risk increase for the open water situation is found to be just under 100,000 EUR per year, while it for Area 2, the Bay of Bothnia is found to be just under 30,000 EUR per year. The total risk increase is distributed between the economic value of fatalities, property damage and environmental damage. For both areas it is the risk increase in property damage which is the controlling factor. This is due to the introduction of allisions in the future scenarios. In the estimation of the property damage, damage to the ships, wind turbines and loss of power production – in case of collapse of wind turbine – is considered.

Table 50. Risk increases between the basis scenario to the future idealized scenario with wind farms for Area 1, the Bothnian Sea.

Route	Risk increase [EUR]			
	Fatalities	Property damage	Environmental damage	Total
A1_R11	2,771	39,711	8,548	51,030
A1_R21	316	4,171	773	5,260
A1_R22	353	4,588	1,116	6,056
A1_R31	423	6,254	1,394	8,070
A1_R32	169	1,615	299	2,084
A1_R33	206	2,507	575	3,287
A1_R34	173	1,976	460	2,610
A1_R41	710	8,347	1,344	10,400
A1_R42	61	770	115	947
A1_R43a	25	198	29	252
A1_R43b	48	272	34	354
A1_R51	116	1,064	171	1,352
A1_R61	48	447	93	588
A1_R62	84	883	148	1,115
A1_R63	101	1,267	183	1,551
A1_R71	97	668	101	866
A1_R72	28	305	50	383
A1_R73	24	233	38	295
A1_R74	152	1,742	269	2,163
Total	5,906	77,017	15,741	98,664

Table 51. Risk increases between the basis scenario to the future idealized scenario with wind farms for Area 2, the Bay of Bothnia.

Route	Risk increase [EUR] and %			
	Fatalities	Property damage	Environmental damage	Total
A2_R11	403	5,068	1,046	6,517
A2_R21	251	3,470	965	4,687
A2_R22	28	290	99	417
A2_R31	149	2,146	468	2,763
A2_R41	195	2,130	618	2,943
A2_R42	73	737	263	1,074
A2_R43	168	1,396	232	1,795
A2_R44	125	1,362	389	1,875
A2_R51	4	58	20	82
A2_R61	18	277	80	375
A2_R71	125	2,294	444	2,863
A2_R72	119	1,824	334	2,277
A2_R81	30	515	180	725
Total	1,687	21,567	5,139	28,393

Generally, the risk increases are considered rather low, especially considering the potential gain in fossil free energy production, which potentially also will have a positive effect on the public health. Furthermore, development of the wind energy is also ensuring more stability in the fossil free energy production, as wind can be use, when energy production of e.g. water is low.

All the risk results are, as mentioned in Section 3.1, calculated for the summer period, and considering the majority of the observed accidents are registered for the winter period, see Section 4.2.1, the picture is expected to change when also considering the risk during winter conditions, as is being studied in a separate study via Traficom, where the ice formation, ice-turbine interactions and winter conditions affecting the ship traffic are investigated. This study is first expected completed in 2027.

8.3 Sensitivity analyses

Several factors may change, and a primary driver for the collision frequencies is the amount of ship traffic. Also, the local conditions in the area as well as accidents occurring in corridors between rows of turbines may cause an increase in consequences when SAR operations and environmental cleanup are challenged. A few sensitivity analyses are therefore performed

to further address some of the identified hazards and uncertainties in the modelling.

8.3.1 Collision and allision frequencies – 10% increase in ship traffic

The analysis of AIS data indicates a relatively stable amount of ship traffic in the past years, and data on international port calls and cargo volume show a generally stable situation, see Section 4.2.1. However, ports may develop further in the future, and both export and import forecasts show increasing trends of 9% and 19%, respectively, until 2060, Ref. /33/. While some of the increase in cargo volume may come with more ship traffic, part of the increase may also come with larger ships. As an indicative sensitivity scenario, collision and allision frequencies are estimated by assuming a general 10% increase on all ship traffic routes within the study area. Part of an increase may also be due to ship traffic related to the construction or operation of the wind farms. The resulting return periods for collision and allision are seen in Table 52 and Table 53.

The first columns show the default results for the future, idealized scenario, and the last columns show the same results for a situation with 10% increase in ship traffic.

Table 52. Bothnian Sea, collision results for sensitivity analysis +10%.

Default traffic, Section 8.1.2				+10%		
Routes	Ship col- lisions	Allisions		Ship collisions	Allisions	
		Powered	Drifting		Powered	Drifting
	Return period [years]				Return period [years]	
A1_R1.1	250	44,215	45	205	40,195	45
A1_R2.1	2,580	133,045	440	2,135	120,950	400
A1_R2.2	2,335	121,220	400	1,930	110,200	365
A1_R3.1	765	>1,000,000	305	635	> 1,000,000	275
A1_R3.2	5,265	279,365	725	4,350	253,965	660
A1_R3.3	1,890	>1,000,000	715	1,560	> 1,000,000	650
A1_R3.4	3,150	>1,000,000	855	2,605	> 1,000,000	775
A1_R4.1	1,185	>1,000,000	180	980	> 1,000,000	165
A1_R4.2	7,755	>1,000,000	1,975	6,410	> 1,000,000	1,795
A1_R4.3a	18,040	>1,000,000	5,645	14,910	> 1,000,000	5,130
A1_R4.3b	11,635	>1,000,000	2,960	9,615	> 1,000,000	2,690
A1_R5.1	5,575	>1,000,000	1,190	4,605	> 1,000,000	1,085
A1_R6.1	22,135	>1,000,000	2,425	18,290	> 1,000,000	2,205
A1_R6.2	22,970	287,340	1,500	18,985	261,220	1,360
A1_R6.3	6,665	>1,000,000	910	5,510	> 1,000,000	830

Routes	Default traffic, Section 8.1.2			+10%		
	Ship col- lisions	Allisions		Ship collisions	Allisions	
		Powered	Drifting		Powered	Drifting
		Return period [years]			Return period [years]	
A1_R7.1	6,185	>1,000,000	1,580	5,115	> 1,000,000	1,435
A1_R7.2	91,690	>1,000,000	4,545	75,780	> 1,000,000	4,135
A1_R7.3	64,380	>1,000,000	5,685	53,205	> 1,000,000	5,170
A1_R7.4	8,505	>1,000,000	730	7,030	> 1,000,000	660
Total	110	20,450	20	90	18,590	20

Table 53. Bay of Bothnia, collision results for sensitivity analysis +10%.

Default traffic, Section 8.1.2				+10%		
Routes	Ship collisions	Allisions		Ship collisions	Allisions	
		Powered	Drifting		Powered	Drifting
	Return period [years]				Return period [years]	
A2_R1.1	875	> 1,000,000	385	720	> 1,000,000	350
A2_R2.1	1,475	> 1,000,000	610	1,220	> 1,000,000	555
A2_R2.2	11,915	> 1,000,000	7,605	9,845	> 1,000,000	6,915
A2_R3.1	5,920	> 1,000,000	850	4,890	> 1,000,000	775
A2_R4.1	1,460	> 1,000,000	920	1,205	> 1,000,000	835
A2_R4.2	4,740	> 1,000,000	2,935	3,915	> 1,000,000	2,670
A2_R4.3	2,210	> 1,000,000	1,025	1,825	> 1,000,000	930
A2_R4.4	2,175	> 1,000,000	1,605	1,795	> 1,000,000	1,460
A2_R5.1	169,720	> 1,000,000	37,110	140,265	> 1,000,000	33,740
A2_R6.1	49,735	> 1,000,000	6,965	41,105	> 1,000,000	6,335
A2_R7.1	7,530	52,705	925	6,225	47,915	840
A2_R7.2	4,620	125,185	985	3,815	113,805	895
A2_R8.1	26,535	> 1,000,000	4,850	21,930	> 1,000,000	4,410
Total	235	36,005	90	190	32,730	80

Overall, it is seen that all return periods decrease as expected, i.e., there will be fewer years between accidents. All return periods are rounded to nearest 5 years, and for the overall results, the change is seen to be limited. The overall return period for drifting ship turbine allisions is still estimated to about 20 years in the Bothnian sea, and now about 80 years in the Bay of Bothnia. Comparing to the size of the areas, this is still assessed to be generally acceptable. Powered allisions are still assessed to be rare, and there is a smaller decrease in the return period for ship-ship collisions which will also decrease even without wind farms in the area. In an open water season, the area will therefore be able to accommodate such a

moderate increase in ship traffic, and the modelling results are robust towards smaller changes to the amount of ship traffic.

8.3.2 Collision and allision frequencies – 10 times increase in ship traffic

A tenfold increase in ship traffic was mentioned at the HAZID workshop as a possible worst-case scenario in case ports in the Bothnian Sea and the Bay of Bothnia must be more extensively used than today taking over traffic from the Gulf of Finland. Also, a geopolitical situation could result in need for more intensive ship traffic between Finland and Sweden across the Bothnian Sea and the Bay of Bothnia. Indicative results using the same idealized ship traffic routes are therefore presented in Table 54 and Table 55 based on a rather extreme tenfold, general increase in ship traffic on all routes.

Table 54. Bothnian Sea, collision results for sensitivity analysis x 10.

Default traffic, Section 8.1.2				Tenfold increase in ship traffic		
Routes	Ship collisions	Allisions		Ship collisions	Allisions	
		Powered	Drifting		Powered	Drifting
	Return period [years]				Return period [years]	
A1_R1.1	250	44,215	45	≤ 1	4,420	5
A1_R2.1	2,580	133,045	440	25	13,305	45
A1_R2.2	2,335	121,220	400	25	12,120	40
A1_R3.1	765	>1,000,000	305	10	128,020	30
A1_R3.2	5,265	279,365	725	55	27,935	70
A1_R3.3	1,890	>1,000,000	715	20	293,915	70
A1_R3.4	3,150	>1,000,000	855	30	230,695	85
A1_R4.1	1,185	>1,000,000	180	10	> 1,000,000	20
A1_R4.2	7,755	>1,000,000	1,975	80	972,740	195
A1_R4.3a	18,040	>1,000,000	5,645	180	> 1,000,000	565
A1_R4.3b	11,635	>1,000,000	2,960	115	> 1,000,000	295
A1_R5.1	5,575	>1,000,000	1,190	55	> 1,000,000	120
A1_R6.1	22,135	>1,000,000	2,425	220	> 1,000,000	240
A1_R6.2	22,970	287,340	1,500	230	28,735	150
A1_R6.3	6,665	>1,000,000	910	65	> 1,000,000	90
A1_R7.1	6,185	>1,000,000	1,580	60	> 1,000,000	160
A1_R7.2	91,690	>1,000,000	4,545	915	110,700	455
A1_R7.3	64,380	>1,000,000	5,685	645	152,210	570
A1_R7.4	8,505	>1,000,000	730	85	845,195	75
Total	110	20,450	20	≤ 1	2,045	≤ 1

Table 55. Bay of Bothnia, collision results for sensitivity analysis x 10.

Default traffic, Section 8.1.2				Tenfold increase in ship traffic		
Routes	Ship collisions	Allisions		Ship collisions	Allisions	
		Powered	Drifting		Powered	Drifting
	Return period [years]				Return period [years]	
A2_R1.1	875	> 1,000,000	385	10	152,555	40
A2_R2.1	1,475	> 1,000,000	610	15	> 1,000,000	60
A2_R2.2	11,915	> 1,000,000	7,605	120	> 1,000,000	760
A2_R3.1	5,920	> 1,000,000	850	60	> 1,000,000	85
A2_R4.1	1,460	> 1,000,000	920	15	> 1,000,000	90
A2_R4.2	4,740	> 1,000,000	2,935	45	> 1,000,000	295
A2_R4.3	2,210	> 1,000,000	1,025	20	> 1,000,000	100
A2_R4.4	2,175	> 1,000,000	1,605	20	> 1,000,000	160
A2_R5.1	169,720	> 1,000,000	37,110	1,695	> 1,000,000	3,710
A2_R6.1	49,735	> 1,000,000	6,965	495	> 1,000,000	695
A2_R7.1	7,530	52,705	925	75	5,270	95
A2_R7.2	4,620	125,185	985	45	12,520	100
A2_R8.1	26,535	> 1,000,000	4,850	265	> 1,000,000	485
Total	235	36,005	90	≤ 1	3,600	10

Overall, the results show that such an increase in ship traffic will be a challenge to the area even in the open-water situation with ship-ship collisions occurring on an annual basis both in the Bothnian Sea and in the Bay of Bothnia. Moreover, also drifting ship-turbine allisions may occur on an annual basis in the Bothnian Sea. Powered allisions are still assessed to be relatively rare. However, this is based on the assumption that the same ship traffic routes are used, and that ships are only rarely on collision course with the wind farms. In an extreme situation with such an increase in ship traffic, this may not be the case, and such a situation will likely require special risk reducing measures. The challenge with such an increase in ship traffic is not only the presence of wind turbines, but even the increase in ship traffic on its own.

8.3.3 Increased consequences for SAR and environmental cleanup

Concerns were raised at the HAZID workshop on the difficulties in performing SAR operations and environmental cleanup within larger areas with wind farm development. Moreover, the assessment of consequences in Section 7.3 are based on overall statistics, and indeed fatality and environmental costs are uncertain. Additional risk results are therefore estimated by assuming double consequences for accidents occurring in the central part of the Bothnian Sea where access from both Sweden and Finland in case of an emergency may be challenged. The areas with increased

consequences are illustrated in Figure 78, and the risk results are seen in Table 56. There are only changes for fatalities and environment as the property cost resulting from a collision or allision is assumed not to be impacted by more difficult SAR and environmental cleanup.

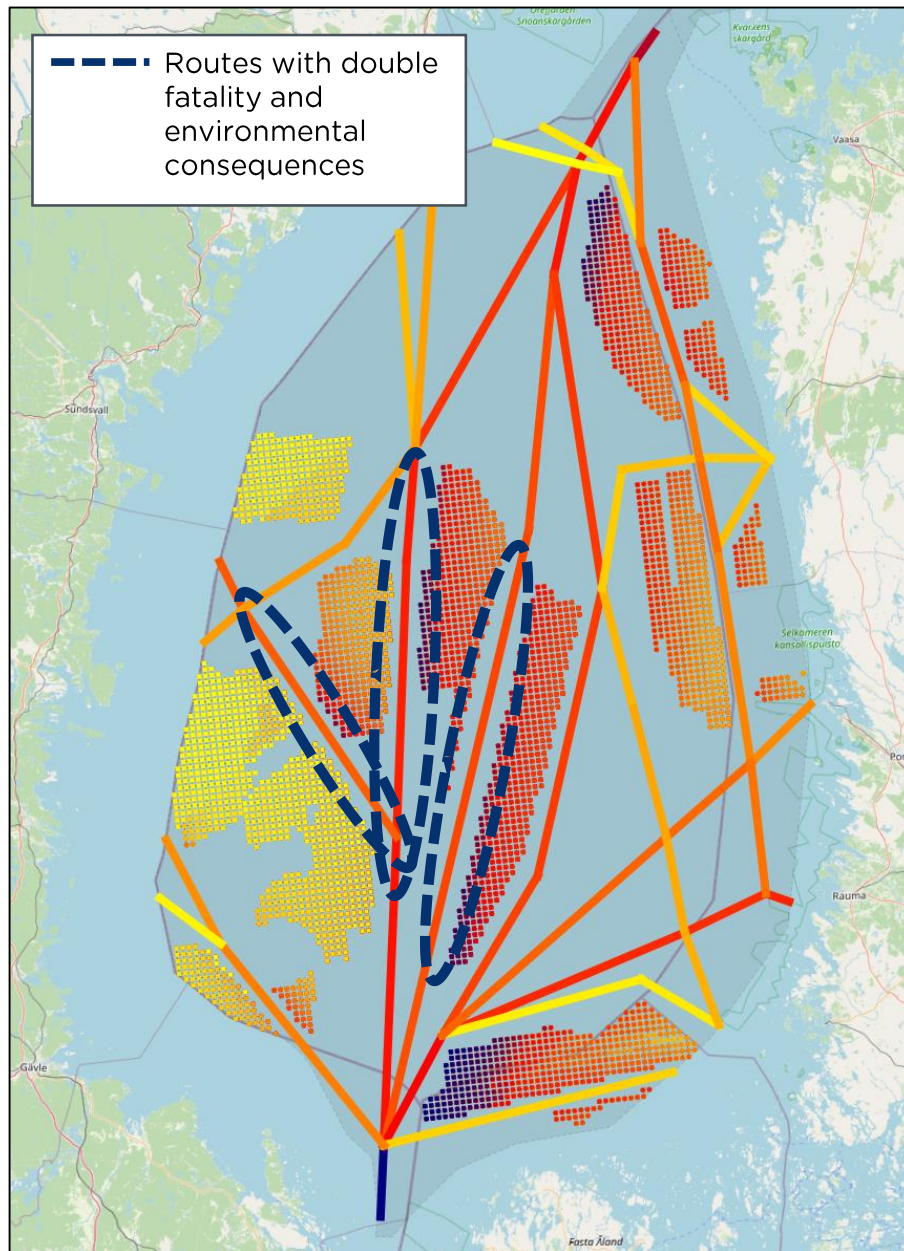


Figure 78. Parts of routes with double consequences for fatalities and environmental cleanup.

Table 56. Risk costs for sensitivity scenarios - increased fatality and environmental damage in central parts of the Bothnian Sea.

Route	Indicative annual risk [EUR per year] (% indicate increase from default scenario, Section 8.2.2)			
	Fatalities	Property damage	Environmental damage	Total
A1_R1.1	(37%) 4,816	43,134	(37%) 14,803	(9%) 62,752
A1_R2.1	(62%) 601	4,408	(63%) 1,458	(14%) 6,467
A1_R2.2	(62%) 671	4,851	(62%) 2,108	(16%) 7,630
A1_R3.1	(0%) 735	7,652	(0%) 2,168	(0%) 10,555
A1_R3.2	(0%) 216	1,767	(0%) 373	(0%) 2,356
A1_R3.3	(0%) 313	2,945	(0%) 933	(0%) 4,191
A1_R3.4	(0%) 218	2,155	(0%) 564	(0%) 2,938
A1_R4.1	(57%) 1,393	9,030	(57%) 2,646	(13%) 13,069
A1_R4.2	(0%) 98	908	(0%) 172	(0%) 1,178
A1_R4.3a	(0%) 37	234	(0%) 46	(0%) 318
A1_R4.3b	(0%) 68	315	(0%) 45	(0%) 427
A1_R5.1	(6%) 154	1,161	(8%) 242	(2%) 1,557
A1_R6.1	(0%) 61	487	(0%) 117	(0%) 665
A1_R6.2	(0%) 92	910	(0%) 159	(0%) 1,162
A1_R6.3	(0%) 166	1,482	(0%) 281	(0%) 1,929
A1_R7.1	(0%) 112	715	(0%) 120	(0%) 947
A1_R7.2	(0%) 30	310	(0%) 52	(0%) 393
A1_R7.3	(0%) 25	235	(0%) 40	(0%) 300
A1_R7.4	(0%) 195	1,891	(0%) 330	(0%) 2,417
Total	(30%) 10,000	84,593	(31%) 26,658	(8%) 121,251

Overall, the annual risk is still moderate and increasing only 8% from about 112,600 EUR to about 121,250 EUR. Also, the property costs are still assessed to represent the highest risk value with an annual risk of about 84,600 EUR. This is due to most impacts imposing some property damage while fatalities and environmental damage are not expected to occur for all accidents. However, we also note that doubling the fatality and environmental consequences only in the central part of the area leads to a 30% increase in fatality costs and environmental cleanup costs for the entire Bothnian Sea. This is due to the routes in the central part generally carrying substantial traffic and that these routes are surrounded by a significant amount of wind turbines. While the risk in the open-water season can still be assessed to be moderate, uncertainties on SAR and environmental cleanup may render central areas and extended areas with turbines around ship traffic corridors a challenge to be considered.

9 Risk control options and cost-benefit (FSA step 3 and 4)

The purpose of step 3 of the FSA process is to first identify Risk Control Measures (RCMs) and then to group them into a limited number of Risk Control Options (RCOs) for use as practical regulatory options. Step 3 comprises the following four stages:

1. Focusing on risk areas needing control;
2. Identifying potential RCMs;
3. Evaluating the effectiveness of the RCMs in reducing risk by re-evaluating step 2; and
4. Grouping RCMs into practical regulatory options.

The purpose of step 4 of the FSA process is to identify and compare benefits and costs associated with the implementation of each RCO identified and defined in step 3.

For the present study, identifying concrete risk control measures and risk control options recommended for implementation is challenging for two main reasons:

- The wind farm areas being developed in the future are not yet known. Therefore, depending on specific developments, some risk control options may or may not be relevant.
- The winter season affects the navigational situation, and an assessment of the impact on ship traffic during winter is not included in the present study.

It has not been neither possible nor practical within the present study to model all possible combinations of wind farm developments, and the impacts of winter conditions are not included. It is therefore not possible to provide a basis for identifying specific risk areas needing control. Similarly, detailed cost-benefit calculations will depend on several factors not covered within the present study, and concrete ranking of measures and specific recommendations will depend also on these factors. However, the results do indicate some main challenges, and the most critical areas in case of full wind farm development.

Initial risk results for the idealized model were therefore used as basis for identifying and discussing potential risk control measures at an extended steering group meeting on January 29, 2025, Ref. /34/. Some of these measures are selected in the following to assess the risk reducing effect given the open water situation addressed in the current study, and a

qualitative cost-benefit assessment is performed as input to general conclusions and recommendations.

9.1 Potential risk control measures

Several, possible risk control measures were identified and discussed in connection with an extended Steering Group meeting, January 29, 2025, Ref. /34/. The meeting was attended by:

- Valtteri Laine, Traficom
- Lauri Kuuliala, Finnish Transport Infrastructure Agency
- Niklas Hammarkvist, Swedish Maritime Administration
- Ulf Siwe, Swedish Maritime Administration
- Matti Utriainen, Ramboll
- Louise Bjerrum Paillet, Ramboll
- Christian Mathias Faber, Ramboll
- Toke Koldborg Jensen, Ramboll

The measures discussed at the meeting are summarized in Table 57, and relevant locations are illustrated in Figure 79 and Figure 80. The two figures show the preliminary results used at the meeting as basis for discussing risk control measures.

Table 57. Summary of possible risk control measures.

ID	Risk Control Measure	Discussions / comments
RCM1	Tug assistance	Placing a tug to assist in case of blackout is seen elsewhere, e.g., in the German Bight. It is initially assessed to be an expensive measure, and with more limited ship traffic in the area compared to the German Bight, it may not be a feasible risk control measure. Also, a tug needs to be available fast in case of a drifting ship which seems to be a challenge in central areas of both the Bothnian Sea and the Bay of Bothnia, and if ship traffic routes are located close to wind farms only leaving a short time from a blackout to a potential wind turbine allision. Maybe the only relevant area for placement of a tug could be the southern part of the Bay of Bothnia; see Figure 80. The cost for extra tug(s) is uncertain, but the cost could be allocated to the wind farm developers.
RCM2	Marking of wind farm areas	Marking of wind farm areas is required in sea charts, as notice to mariners, and physical markings. Specific marking such as synchronized lighting like indicating an "airport runway" could be considered as well as coloured towers of the wind turbines.

ID	Risk Control Measure	Discussions / comments
RCM3	VTS reporting area	In the Gulf of Finland, there is a VTS reporting area – GOFREP mandatory ship reporting system. Such a system could maybe also be made in the Bothnian Sea and the Bay of Bothnia. There were discussions on the possibilities for such a system. It could be an informative system, but it is probably not possible (or desirable) to take responsibility for specific routing of ship traffic. Furthermore, there were questions if the area is too large, to make such a solution feasible.
RCM4	Advising or re-quiring specific routing	During winter conditions, icebreakers effectively decide on routing for ships needing assistance. In open waters, it may be more difficult to require a specific routing. However, a possibility could be to create a routing for one-directional ship traffic in the central part of the Bothnian Sea during normal conditions to avoid bi-directional ship traffic through a potential corridor, see example in Figure 79. The measure could be linked to measure RCM3 and RCM5.
RCM5	Ship traffic routing system	A formal ship traffic routing system (TSS) could be established one or more places in the area. With the relatively limited amount of ship traffic, it may not be required strictly for routing and ship-ship collision avoidance. However, such a routing system would formally ensure a room for the ship traffic in the area with sufficient space towards potential wind farm developments. Most optimal places for such routing systems could be the northern part of the Bothnian Sea and the southern part of the Bay of Bothnia, see Figure 79 and Figure 80.
RCM6	Additional radars	It may be necessary to install additional radars to support any additional ship traffic surveillance related to measures RCM3, RCM4, and RCM5. Installing radars could be done on service platforms to cover areas further from the coastlines. If radars are to be installed on wind turbines/service platforms, then these must be installed by the wind farm developers. Authorities will not place equipment on turbines but can require developers to do so. Maybe more radars and better surveillance will also be needed in case of increasing amounts of ship traffic.
RCM7	Removal of wind farm development areas	The indicative results show most exposed wind turbines north and northeast of the most trafficked routes; mainly due to drifting ship allisions and the prevailing wind directions. One could consider avoiding placing wind turbines in the most exposed areas such as indicated in Figure 79 and Figure 80.
RCM8	Crash barriers	New innovations in offshore crash barriers could be considered for protecting the most exposed wind farm areas against drifting ships, see Figure 79 and Figure 80. However, the technology is uncertain, and it is not known how such systems will work in ice conditions, or which damages such a system would sustain during harsh winter conditions. Like for the placement of extra tug(s) this is potentially also a cost, which can be transferred to the wind farm developers. SMA provided a link to an online article describing Dutch research developments on crash barriers, Ref. /35/.

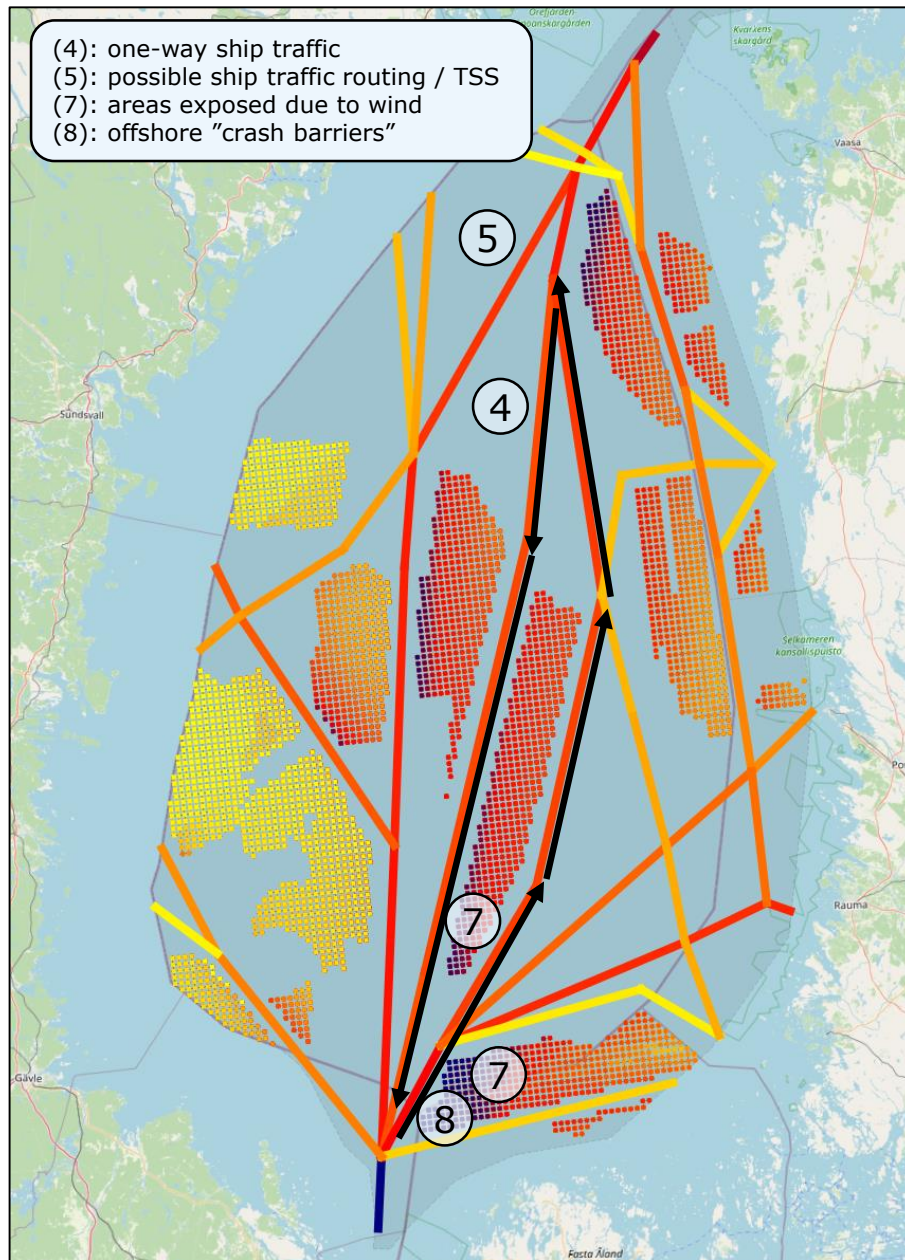


Figure 79. Illustration supporting description of risk control measures in the Bothnian Sea.

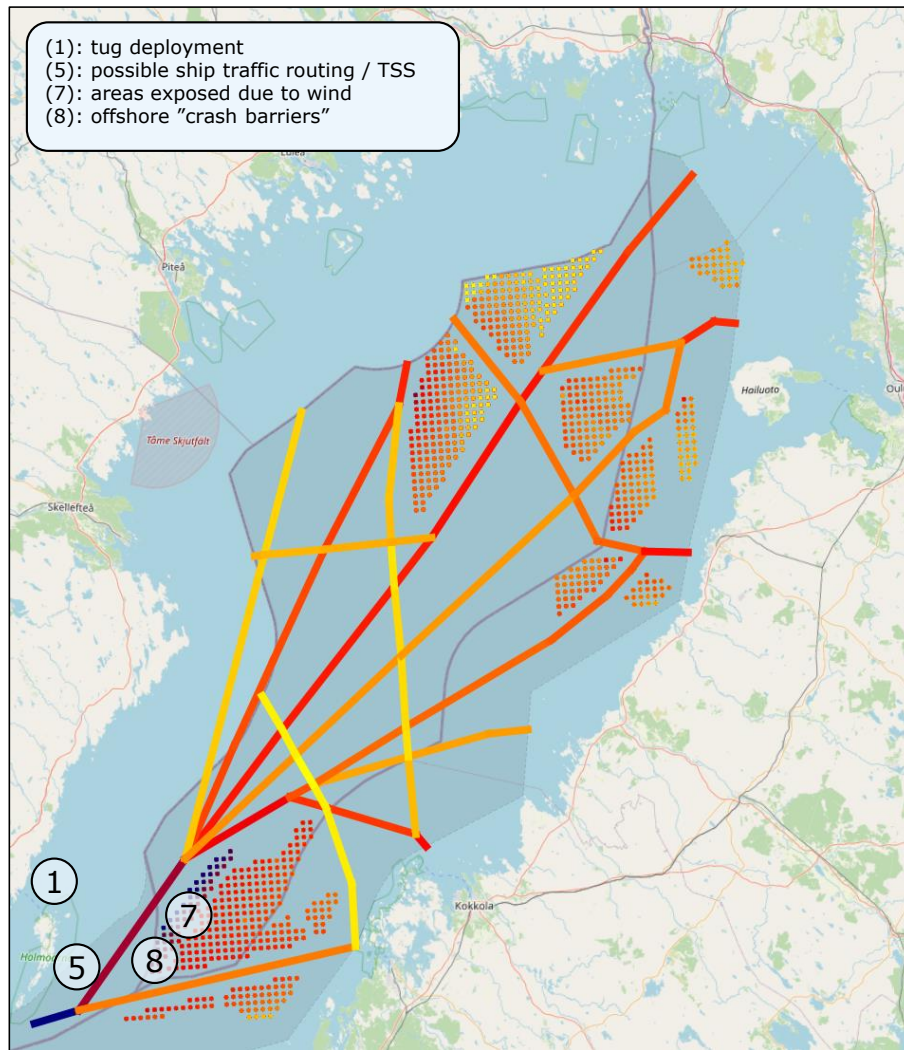


Figure 80. Illustration supporting description of risk control measures in the Bay of Bothnia.

Measures RCM3, RCM4, RCM5, and RCM6 are all related to ship traffic surveillance and possibilities for routing ship traffic. To qualify and add to the understanding of the possible risk reducing measures covering VTS, traffic separation and radars, Ramboll conducted an interview on February 27, 2025, with Sari Talja, Operative Director, Fintraffic Vessel Traffic Services Ltd. A summary of the interview is given below.

Overall, in Finland the Vessel Traffic Service (VTS) covers the Finnish coastline. Additionally, there is the Gulf of Finland Reporting System (GOFREP) with Estonia and Russia. Finland and Sweden have established a Traffic Separation Scheme for the Åland Sea (Åland Sea TSS). A traffic separation scheme (TSS) is a maritime traffic-management route-system ruled by the International Maritime Organization or IMO. In the southern part of the area, Åland Sea Traffic in Fintraffic Vessel Traffic Services controls the vessel traffic. On the Swedish side, VTS areas are currently limited to some ports only.

While the risk in all the planned wind farm areas can likely be mitigated somehow, special consideration for navigational safety is needed. Therefore, more detailed studies are required for all OWF projects as they are developed.

In addition to increased risk due to vessel traffic concentration and collisions, also impacts on electric systems, such as radars, VHF/AIS, and radio communications should be studied. It was commented that using AIS in the open sea to support radar might be possible, but that radar is essential close to land. Hence, the situation and the needs for additional technical means for surveillance may differ between locations. Currently, GOFREP in Estonia is relying mainly on AIS, but AIS is also prone to interference. A large wind farm will likely create blind sectors and interference; compensation radar investments by the wind farm developers might be necessary.

VTs can be established in international waters as a voluntary reporting service. The GOFREP in the Gulf of Finland is a good example of how traffic could be controlled by reporting service, e.g., in the central Bothnian Sea. Such a reporting service is associated with costs. Typically, traffic controlling measures are budgeted by governments. However, it is unclear if wind farm developers should compensate for the costs, and to which extent.

Preventing the concentration of vessel traffic is beneficial to avoid risks, and Traffic Separation Schemes are good means of directing vessel traffic to appropriate routes.

9.2 Effectiveness of risk control measures

The effectiveness of some of the risk control measures is estimated by implementing updates to the risk model, presented in Chapter 8. Based on this the difference in risk cost is estimated following implementation of the risk control measure. The basis for the model updates for each risk control measure is described in Table 58 together with reasons for not evaluating some of the measures.

Table 58. Description of modelling of risk control measures.

ID	Risk Control Measure	Included in cost-benefit	Basis for model update
RCM1	Tug assistance	Yes	IWRAP is used to model the effect of a tug on the collision frequency in the southern part of the Bay of Bothnia. The tug is inserted at the Swedish coast just north of TSS Norra Kvarken, and default parameters on mobilisation time and sailing speed from IWRAP are used in the modelling.
RCM2	Marking of wind farm areas	No	This is a measure that can be implemented for the specific wind farm and is not evaluated further here in relation to ship traffic routing.

ID	Risk Control Measure	Included in cost-benefit	Basis for model update
RCM3	VTS reporting area	Yes	A VTS system improves the awareness of the navigators and hence reduces the human failure frequency. A VTS system may also be able to guide ships in case of bad weather, advice alternative routing (in combination with RCM4 and RCM5), and provide an overview for better information in case of SAR operations and environmental cleanup. However, a VTS system will not have a direct effect on ship blackout and drifting allisions. For the present study, the VTS in the open water situation is modelled conservatively as a 60% reduction of all human failures (ship-ship collisions and powered allisions) in the area to indicate the potential effect in risk cost of reducing the hazard frequency in the area in general. A 60% reduction is considered a conservative number based on a study of the VTS in Great Belt in Denmark, Ref. /36/.
RCM4	Advising or requiring specific routing	Yes	This measure is mainly related to weather situations where specific routes may be advised, e.g., in connection with a VTS system. A specific routing is here modelled as indicated in Figure 79 where one-way ship traffic through the long, central corridor is enforced. Part of the ship traffic on route A1-1 will still go straight north-south together with ship traffic on routes A1-2.1 and A1-2.2.
RCM5	Ship traffic routing system	Yes	An example of a ship traffic routing system is included for area 2 establishing traffic separation east of the wind farm area and in connection with the already existing TSS Norra Kvarken. The modelling is illustrated in Figure 81.
RCM6	Additional radars	No	Additional radars will improve surveillance capabilities and hence be a measure to potentially improve or ensure VTS efficiency. The effect of adding additional radars is not assessed separately as sufficient coverage of technical systems are assumed part of ensuring risk control measures RCM3, RCM4, and RCM5.
RCM7	Removal of wind farm development areas	Yes	The overall effect in reducing the extension of a wind farm area near the main ship traffic areas is assessed by increasing the distance from main ship traffic routes to the turbines. In the model, the distance between individual turbines is assumed to be 1nm. The effect of removing turbines is estimated by extending the safety zone outside the ship traffic route by 2.5nm, effectively removing minimum two rows of turbines both in the southern part of the Bothnian Sea, and in the southern part of the Bay of Bothnia, see (7) in Figure 79 and Figure 80. In the Bothnian Sea, only the most exposed area north of Åland is reduced.
RCM8	Crash barriers	No	Three potential types of crash barriers were proposed and tested in a demonstration environment in 2022 by the Dutch maritime research institute, MARIN, /35/. The status of such systems is not known, and further development is needed before they may be applied. The efficiency of the measure is not known, and hence the effect of crash barriers is not modelled.

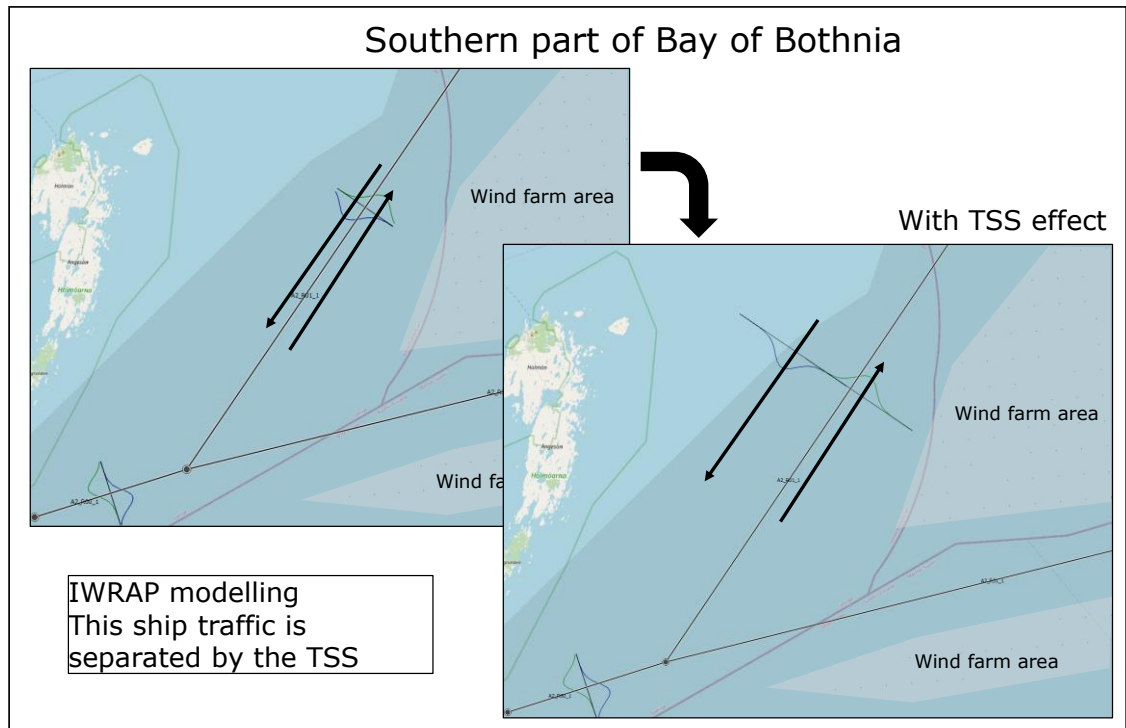


Figure 81. Illustration of the modelling of a TSS north of Kvarken.

The overall collision frequencies are in general acceptable as shown under the main results in Chapter 8, and most accidents are related to drifting speed collisions between ships with blackout and turbines. This leads to a low risk in terms of average, annual risk costs. The effects of the risk reducing measures is therefore a further reduction of a relatively low capitalized risk.

The average difference in risk per year is estimated as shown in Table 59. The most efficient risk reducing measure is the introduction of a tug to standby to assist ships in case of blackout. However, the annual decrease in risk is only estimated to about 16,000 EUR.

Introducing VTS surveillance, one-way ship traffic centrally in the Bothnian Sea, or a ship traffic routing system north of TSS Norra Kvarken only lead to minor risk reductions. These measures mainly affect ship-ship collisions and powered collisions as they direct ship traffic, but do not avoid engine blackout. The effect may even be evaluated slightly on the higher side as the effect of the existing Finnish VTS system covering the Finnish territorial waters is not explicitly included in the risk assessment before introduction of the risk control measures. In the open water situation, and with the relatively limited amount of ship traffic, there is sufficient room for manoeuvring, and hence the additional risk reducing measures only have a limited effect.

Removing turbines along the ship traffic routes has an effect which depends on the number of turbines being removed. In the estimated examples,

expanding the safety zone in the most exposed areas with 2.5nm results in an annual risk reduction of only about 3,500 to 4,000 EUR.

Table 59. Indicative risk reduction from risk control measures.

Risk Control Measure	Location	Indicative risk reduction from risk control measures		
		Risk before RCM [EUR per year]	Risk after RCM [EUR per year]	Risk difference [EUR per year]
RCM1 – Tug assistance	Area 2	33,858	18,260	15,598
RCM3 – VTS reporting	Area 1	112,593	102,122	10,471
RCM3 – VTS reporting	Area 2	33,858	28,677	5,181
RCM4 – Oneway ship traffic routing	Area 1	112,593	111,842	751
RCM5 – Ship traffic routing	Area 2	33,858	32,235	1,623
RCM7 – Removing wind farm development areas	Area 1	112,593	108,999	3,594
RCM7 – Removing wind farm development areas	Area 2	33,858	29,988	3,870

It should be emphasized here that the above assessments are modelled for open-water conditions scaled to a full year. The historical accident statistics presented in Section 4.2.1 show that the number of accidents under winter conditions are far higher than in open water conditions. Considering winter conditions, the above picture will therefore change, showing both higher initial risk and a higher, absolute effect of the risk reducing measures – given that the measures are also effective in ice conditions.

9.3 Cost-benefit assessments

The benefit of introducing specific measures will depend on the specific wind farm development areas to be developed, and also to a high degree on factors not covered within the present study; most importantly winter conditions and ice formation. A qualitative cost-benefit assessment of the proposed risk mitigation measures is given in the following.

9.3.1 Tug assistance (RCM 1)

The most efficient risk reducing measure is assessed to be an emergency tug as this may reduce the risk from drifting ships.

In overall terms, Traficom informs that a tug service provider estimates a daily cost of about 15,000 EUR + cost for bunker oil and costs for

maintaining a suitable emergency tug service. Such a tug could be used also to assist with other maintenance operations, transports, etc. Also, a combination of using idle icebreakers to eventually perform emergency tug operations could be considered. Standby icebreakers are assessed to be more costly than emergency tugs, e.g., up to 50,000 EUR per day. However, multiple use of tugs and icebreakers could lower the cost related to maintaining such an emergency tug.

In open-water conditions, the annual risk reducing effect of placing a tug in the southern and most densely trafficked part of the Bay of Bothnia is estimated to about 16,000 EUR. Considering the cost of 15,000 EUR per day, and that the risk level is initially assessed to be acceptable in open water conditions, it is obviously not cost-beneficial to introduce a 24/7 standby emergency tug.

An emergency tug may be relevant in combination with icebreaker service in ice conditions, and if a wind farm development is proposed close to the main ship traffic routes.

9.3.2 Marking of wind farm areas (RCM2)

A general effect of marking of wind turbines is not assessed. For a specific wind farm, detailed studies shall be performed, but marking options are not assessed to render an area not suitable for a wind farm. The specific requirements for marking of wind turbines will therefore not affect the overall risk picture in the area. Furthermore, the design of the individual wind farm must follow applicable recommendations, see e.g., IALA guideline on marking of man-made offshore structures, Ref. /37/. Additional markings may be cost-beneficial for the individual wind farm.

9.3.3 VTS and ship traffic routing (RCM 3, RCM4, RCM5, RCM6)

The effect of establishing additional VTS coverage, ship traffic surveillance and ship traffic routing systems including additional radar coverage (RCM3, RCM4, RCM5, and RCM6) in the open water season is assessed to be very small. With sufficient width of ship traffic lanes and relevant safety space between ship traffic and wind turbines, there is generally sufficient room for the ship traffic to navigate the area. Moreover, surveillance is assessed not to have a significant effect on blackout and ship turbine collisions at drifting speed which account for most of the risk.

On the Finish side of the Gulf of Bothnia, VTS services already cover the territorial waters, and extending this coverage will come with a cost. The cost is not elaborated further, but with an annual risk reduction effect estimated for the open water season to only 15,000 to 20,000 EUR for RCM3, RCM4, and RCM5, it is assessed that such an extension is not cost-beneficial considering only the collision and collision risk in open water conditions.

As mentioned in the interview with Fintraffic, specific assessments must be performed for each proposed wind farm. Depending on the layout and proximity to ship traffic, specific measures related to radar coverage and visibility may be needed. However, it is assessed that the risk for all individual wind farms can be mitigated somehow, and hence potential radar challenges do not affect the overall ship traffic routes but must be mitigated as relevant for the individual project.

Establishment of a formal traffic separation scheme under the IMO may have additional benefits not related specifically to reduction of collision and allision risk. A formal system will be visible in sea charts and function as a reserved area which cannot be used for other purposes such as additional wind farm development. In addition to the cost-benefit assessment, establishment of formal routing measures may therefore be relevant to enforce free areas for ship traffic in critical areas. In the recommendations, critical areas needed for ship traffic are identified, and formal routing schemes may be considered in the future decision-making to ensure sufficient space for the ship traffic in these areas.

9.3.4 Removing wind turbines

Reducing the size of wind farm areas will potentially increase the safety space around the ship traffic routes and reduce the number of obstacles in form of wind turbines. This will proportionally reduce the risk. The cost of reducing the number of turbines lies with the developers as an impact on the business case for the individual wind farm, and as an impact on the potential sustainability gain by introducing wind farms.

In the open water season, the overall situation with indicatively placed turbines throughout the area show a generally acceptable risk. For the individually proposed wind farms, a specific assessment may therefore lead to locally reducing the number of turbines or increasing the safety distance. However, in general, the limited risk reduction estimated for RCM7 indicate that it is not cost-beneficial to right-away restrict the use of certain areas outside the default assigned safety areas.

On the other hand, the risk assessment indicates the most exposed areas due to most intense ship traffic, prevailing wind directions, and the risk for drifting ship impacts. In a planning phase and from a ship traffic perspective, it is recommended to focus on first developing the least exposed areas. Alternatively, if a wind farm is developed in a more exposed area, the cumulative analysis for this area may indicate that the room for more turbines is reduced.

9.3.5 Crash barriers

Protection systems to stop or slow down ships on impact course with turbines are being studied together with detailed impact analyses. A recent

review of offshore wind turbines subjected to ship impacts and the corresponding protection measures is seen in Ref. /38/. The review provides references to impact analyses of various types of wind farms, but also concludes that although there has been some research into proposed anticollision measures to protect wind turbines, this area remains relatively unexplored. This is in line with the potential crash barriers suggested by Marin, Ref. /35/. An additional challenge is to understand how a protection system, a crash barrier, advanced fender, etc. will behave under winter conditions in terms of efficiency and need for maintenance.

As for the potential risk reducing effect, also the cost of such innovative systems are relatively unexplored. With a generally acceptable situation for the open water situation, crash barriers are assessed not to be cost-beneficial in general at the current stage. However, it is a highly interesting research field both as turbine protection systems related to allisions, and in combination with ice protection systems.

In case crash barrier systems are further considered, the most obvious locations with highest effect will be in connection with wind turbines located northeast of main ship traffic routes.

10 Recommendations for decision-making (FSA step 5)

The main purpose of the study is to identify critical/key areas in the Gulf of Bothnia that need to be preserved for future shipping activities, ensuring the continued safety, sustainability, and efficiency of maritime transport.

The current Finnish and Swedish Maritime Spatial Plans indicate areas for various purposes including areas for shipping routes, areas for offshore energy production, and other significant areas. However, the markings in the plan are not intended to reserve areas for a particular purpose and should not be interpreted as such. Activities may also take place other than in the areas identified in the plan.

The current study has addressed the ship traffic in relation to potential wind farm development areas, some of which overlap with currently used ship traffic routes. The potential wind farm development areas therefore do not necessarily align with the Maritime Spatial Plans and current ship traffic routes. In a future planning process where wind farm development areas are selected or commissioned through public processes, it is important to consider also the interests of the ship traffic.

In general, the study shows that for the open water situation, wind farm development could possibly occur in all the currently proposed areas. With the relatively limited ship traffic density in the area – as compared to the North Sea or the southern part of the Baltic Sea – the overall collision and allision frequencies are generally assessed to be at an acceptable level. However, the ship traffic needs to pass around or through certain wind farm areas, and there must be sufficient safety space around the ship traffic routes. It is recommended that this safety space is considered as early in the planning process as possible, e.g., by commissioning out only areas where at least a minimum safety space has already been reserved for nearby ship traffic routes. It is emphasised that the idealized route layout studied as basis for the present risk assessment will most likely not be seen in practise. The final ship traffic routes will depend on the actual developed wind farm areas commissioned which may be a subset of the currently studied wind farm areas, or even include new areas.

It is also emphasized that a future, moderate increase in amount of ship traffic following the main routes is assessed not to drastically change the conclusions. However, in case of a significant increase in ship traffic, e.g., due to changes in the geopolitical situation, the area may be challenged not only by the presence of the wind farms, but by the traffic density as such.

The current study therefore leads to the following general recommendations as input to a future planning process. It is emphasized that the recommendations are based on open water conditions as covered by the

study. However, each section also briefly addresses further considerations to be done in relation to winter navigation.

10.1 Route redundancy

The primary recommendation is to ensure redundancy in the ship traffic routes, i.e., at least two possible routes to access each port within the study area. This recommendation is primarily based on input from the HAZID workshop and considerations related to bad weather and winter navigation. In open water conditions, the most direct route between two points will often be preferred for fuel efficiency and travel time. It is therefore recommended to ensure a direct route for the main ship traffic. In case of harsh weather, and especially in winter conditions with ice buildup, ships may be forced to use alternative routes. It is therefore recommended also to ensure alternative routes, both centrally in the Bothnian Sea and the Bay of Bothnia and along the coastlines.

The idealized route network is based on this basic feature, and the open water situation is modelled within the study area showing acceptable collision and allision frequencies. A recommendation to also ensure routes closer to the coastlines are for the Bothnian Sea included in the model along the Finnish coast whereas the study area does not include the territorial waters along the Swedish coast. However, it is recommended to ensure a coastal route both on the Finnish and the Swedish side as illustrated in Figure 82 (left). In the Bay of Bothnia, there must also be a possibility for using redundant routes as the winter conditions and ice buildup are even more severe here compared to the Bothnian Sea. In the very northern part of the Bay of Bothnia, the current loop described as the “banana” in Figure 33 results in a sometimes ice-free route closer to land allowing for an alternative route as indicated in Figure 82 (right).

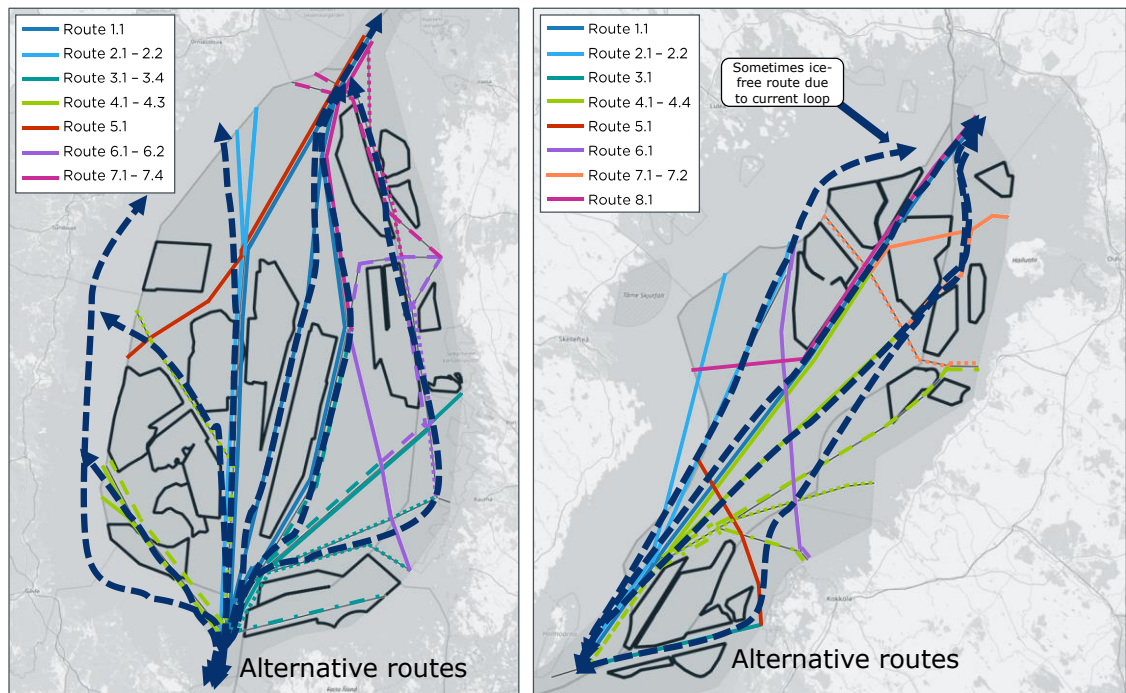


Figure 82. Illustration of redundant routes.

The need for redundant routes in the northern part of the Bay of Bothnia is a challenge for the wind farm development. Hence, even if the open water conditions indicate an acceptable risk for the area, winter conditions and ice buildup may require use of additional navigational space which may be severely challenged if wind farms are present in the area.

In the open water situation as well as in a situation with more challenging weather conditions, all routes – primary central routes and redundant and more coastal routes must have a sufficient width to carry the ship traffic.

10.2 Most exposed areas and ship traffic corridors

Using the idealized route network and modelling turbines in all areas – ensuring at least minimum safety distances – shows a picture with the most exposed areas. Areas of special concern are indicated in Figure 83. Except from the northern part of the Bay of Bothnia, all the marked areas are exposed mainly due to the risk for drifting ship allisions. The areas are exposed due to their location east or northeast of main ship traffic paths. due to the prevailing wind directions.

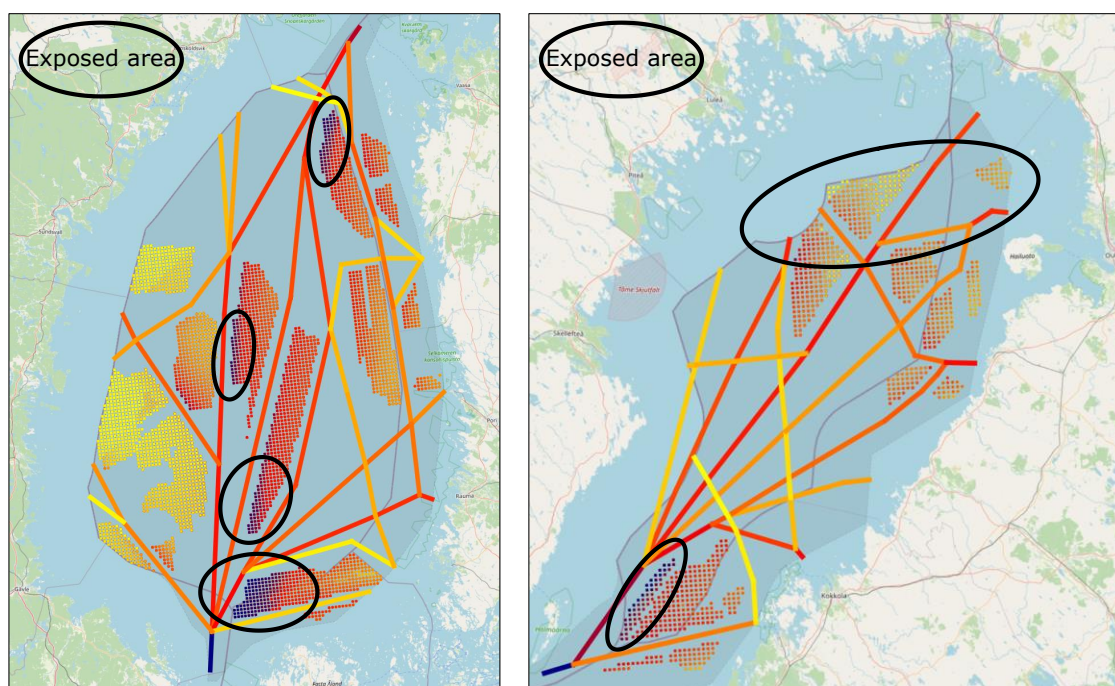


Figure 83. Exposed areas.

The risk assessment indicates that it is possible to place wind farms in these areas, and that the risk is generally acceptable in the open-water situation. However, to ensure an acceptable, cumulative risk for the areas, it may be necessary to limit the size of the development areas when considering the more challenging winter conditions. Focusing first on less exposed areas will leave more room for an acceptable, cumulative risk. It is therefore recommended that commissioning of larger areas for wind farm development is primarily done away from these most exposed areas in order to leave as much room for an acceptable, cumulative risk. Especially considering that winter conditions will probably further challenge these areas as well as the cumulative risk within the wider area.

Alternatives such as a larger distance between the ship traffic and the turbines could be ensured by establishing formal ship routing systems. However, in the open water situation, it is not assessed to be cost-beneficial to introduce further ship traffic routing and monitoring, and a further assessment is recommended for the more challenging winter situation before deciding on establishing specific routing systems or further surveillance.

The northern part of the Bay of Bothnia is not particularly exposed to drifting allisions, and the risk is generally acceptable in the open water situation. However, the area is marked as an area of concern due to winter conditions and the need for redundant routes outside the project area.

Worst-case extensive development of wind farms as assumed for the present study requires ship traffic to pass between wind farm areas through corridors. While the overall risk modelled for the idealized ship traffic routing is generally assessed to be acceptable, it was a concern at the HAZID

workshop that bad weather and winter conditions will make it more challenging to pass through corridors. One remedy is to use an alternative route, e.g., along the coast. However, this incurs a longer distance, and the navigator may choose to go through the corridor anyway imposing a risk, and potentially an increased risk in case SAR and environmental cleanup is challenged as addressed by the sensitivity analysis in Section 8.3.3. It is therefore recommended to keep the corridors as short as possible. Limiting longer corridors may be combined with avoiding more exposed areas by developing only part of the areas. This can be considered early when commissioning of the areas or specifically by developers addressing the cumulative risk in an area for a specific wind farm development. An illustration of avoiding the most exposed areas is shown in Figure 84. It is emphasized that this is for illustrative purposes only, and that several other factors influence how attractive specific areas are for wind farm development. Moreover, further analyses of winter conditions may show specific challenges and lead to additional recommendations.

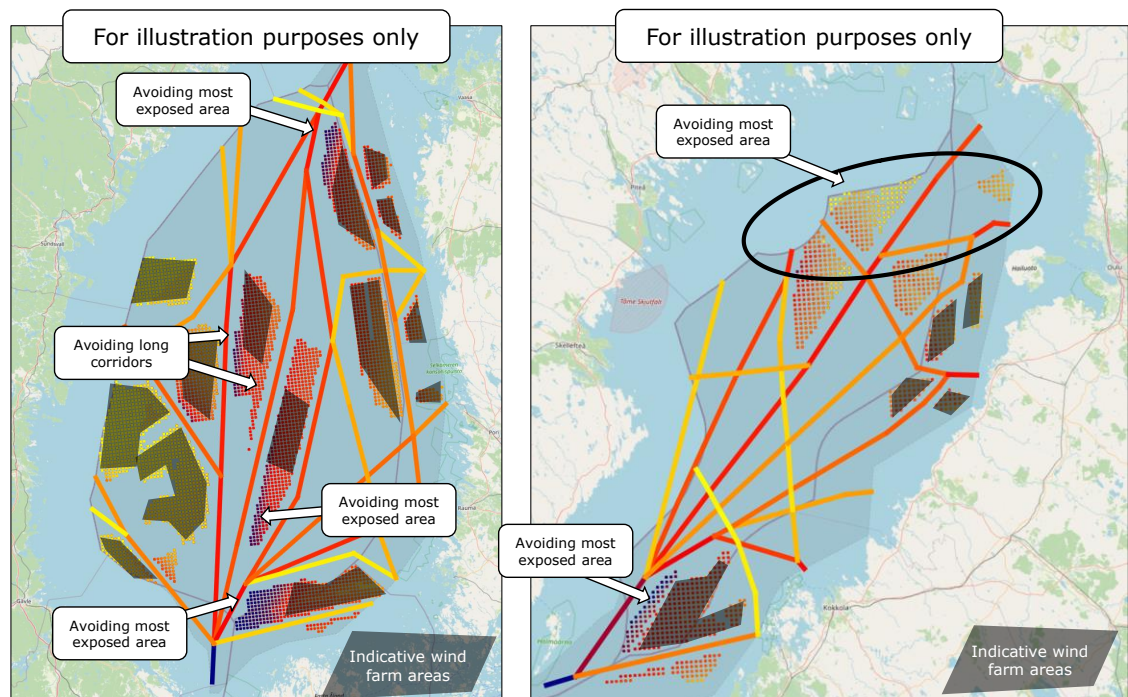


Figure 84. Indicative wind farm development avoiding most exposed areas.

Avoiding the most exposed areas will result in less area for wind farm development and hence an impact on sustainability related to the amount of green energy potentially installed. The impact from ensuring minimum safety distances for the idealized ship traffic routing was in Section 8.2.3 shown to take up about 8% of the gross wind farm development areas in the Bothnian Sea, and about 18% of the gross wind farm development areas in the Bay of Bothnia. Avoiding larger areas will further reduce the wind farm development areas. This reduction shall primarily be seen in relation to the potential challenges induced by winter navigation. Again, especially

in the northern part of the Bay of Bothnia where several areas may be challenged.

10.3 Risk control measures

Based on the present study and the open-water conditions, it is not recommended to implement additional risk control measures on top of sufficient route redundancy, and safety distances as recommended above. The cost of implementing any additional measure is assessed to be high compared to the relatively low risk level and the risk gain in implementing the measure. However, the analysis indicates that availability of an emergency tug to assist drifting ships will have a significant risk reducing effect, and that further measures related to ship traffic routing and monitoring (VTS) can be used to ensure a certain ship traffic routing. It is recommended to consider these measures further in a winter navigation setting.

More innovative risk control measures include crash barriers. The cost-benefit of such barriers has not been assessed, and further research is recommended, both considering the efficiency of the barriers themselves in preventing drifting ship-turbine collisions, and their use and required maintenance in the challenging environment in the area. In case of positive results, crash barriers may be suggested by specific wind farm developers to reduce the cumulative risk in an area – especially if turbines are proposed in the areas more exposed to drifting ship collisions.

10.4 Summary and conclusions

By ensuring adequate safety distances and widths of ship traffic routes, the risk level within the study area is generally assessed to be acceptable in an open-water situation, even with quite extensive wind farm development. The ship traffic can be maintained at main ship traffic routes, and it is possible to let the ship traffic use various routes through the area. Introducing additional risk reducing measures specifically for the open-water situation is therefore assessed not to be cost-beneficial.

The main concern as identified and discussed at the HAZID workshop and throughout the report is the challenges that may occur during winter and in harsh weather. The degree to which this changes the conclusions is not within the scope of the present study. However, winter conditions will give rise to significant challenges, and the following recommendations carry over to further analyses during winter conditions:

- Ensure sufficient route redundancy to allow ship traffic to pass through the area and access ports through more than one route in case parts of the area are challenged by severe weather conditions or ice buildup. Alternative routes should also be available in more

coastal areas to seek shelter in case of hard weather. This is relevant for the Bothnian Sea, but especially for the northern part of the Bay of Bothnia with frequent ice buildup.

- Focus on wind farm development in less exposed areas first and leave sufficient safety space between turbines and near-by ship traffic routes. It is recommended to take a minimum safety distance into account early in the planning process while defining the boundaries of possible wind farm development sites. The most exposed wind farm areas are assessed to be located north/northeast of the main ship traffic lanes due to prevailing wind directions and the main risk resulting from blackout and drifting ship allisions. If wind farms are suggested and developed in more exposed areas, a relevant mitigation may be to reduce the extent of the wind farm development to reduce the cumulative effect of many turbines. That is, larger wind farm areas may be possible if most exposed areas are avoided.
- Ensure – as far as possible – a layout of wind farm areas avoiding long, confined corridors for the ship traffic. This is both to ensure freedom of navigation and evasive manoeuvres, and to ensure easier access for SAR and environmental cleanup operations in case of accidents. The effect of turbines on ice buildup is also not known in detail, and there may be additional challenges going through corridors during winter.
- The order of wind farm development is unknown, and hence also the future cumulative situation. It is therefore important that wind farm developers produce a specific risk assessment for each proposed wind farm considering the actual, cumulative situation. Additional risk mitigation measures such as specific marking, additional radars, and crash barriers can be included in detailed risk assessments.
- While additional risk mitigation measures such as extending VTS surveillance – including additional radar coverage, etc. – is not initially assessed to be cost-beneficial in open-water conditions, such measures may prove beneficial in combination with winter navigation, use of icebreakers, etc. Additional tug assistance is also assessed to be an efficient means of reducing the risk for drifting ship-turbine allisions, and while not cost-beneficial for open-water conditions, it may prove valuable in combination with use of icebreakers to handle the winter situation.

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Appendix 1 – Ship routing and scenarios

Many potential scenarios for the ship traffic in the Bothnian Sea and the Bay of Bothnia were defined prior to performing the HAZID workshop. Moreover, the scenarios were extended with a few additional scenarios for further evaluations afterwards. All the scenarios are based on the currently observed main ship traffic routes and defined based on a worst-case assumption on full development of all currently known areas for wind farm development. Scenarios are defined either leaving the ship traffic routes as they are seen today, or with rerouted ship traffic around the wind farm developments. Corridors through wind farm areas are introduced when ship traffic routes are maintained or routed through wind farm areas.

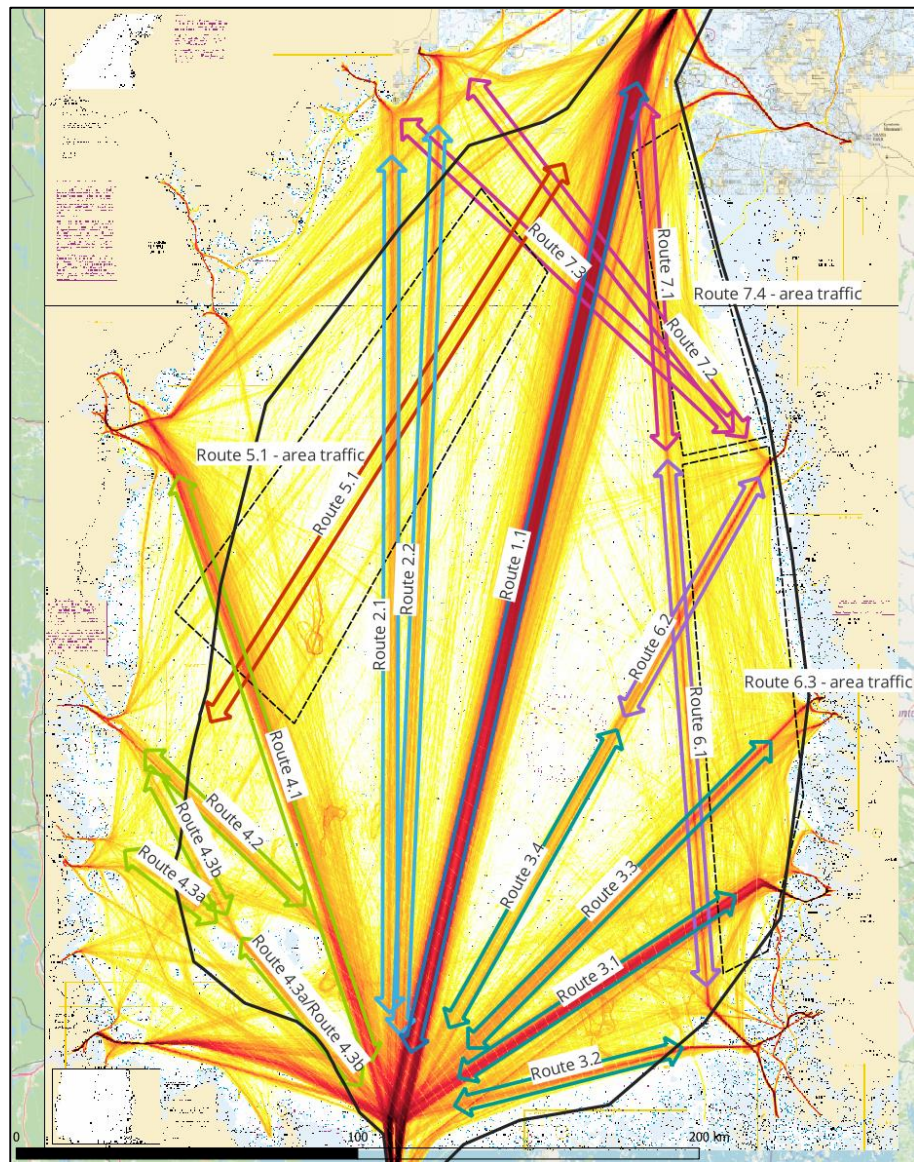
List of scenarios Scenarios marked in red were added after the HAZID workshop	
Subareas: routes	Scenarios
Bothnian Sea (Area 1)	
A1-1: Route 1.1	5 scenarios: A1-1A - A1-1C + A1-1D - A1-1E
A1-2: Routes 2.1, 2.2	2 scenarios: A1-2A - A1-2B
A1-3: Routes 3.1, 3.2, 3.3, 3.4	6 scenarios: A1-3A - A1-3F
A1-4: Routes 4.1, 4.2, 4.3a, 4.3b	4 scenarios: A1-4A - A1-4D + A1-4E
A1-5: Routes 5.1	2 scenarios: A1-5A - A1-5B + A1-5C
A1-6: Routes 6.1, 6.1, 6.3	4 scenarios: A1-6A - A1-6D
A1-7: Routes 7.1, 7.2, 7.3, 7.4	4 scenarios: A1-7A - A1-7D
Bay of Bothnia (Area 2)	
A2-1: Route 1.1	2 scenarios: A2-1A - A2-1B
A2-2: Route 2.1, 2.2	3 scenarios: A2-2A - A2-2C
A2-3: Route 3.1	1 scenario: A2-3A
A2-4: Route 4.1, 4.2, 4.3, 4.4	3 scenarios: A2-4A - A2-4C
A2-5: Route 5.1	2 scenarios: A2-5A - A2-5B
A2-6: Route 6.1	2 scenarios: A2-6A - A2-6B
A2-7: Route 7.1, 7.2	2 scenarios: A2-7A - A2-7B + A2-7C
A2-8: Route 8.1	2 scenarios: A2-8A - A2-8B

The main ship traffic routes and all the defined scenarios are shown in the following.

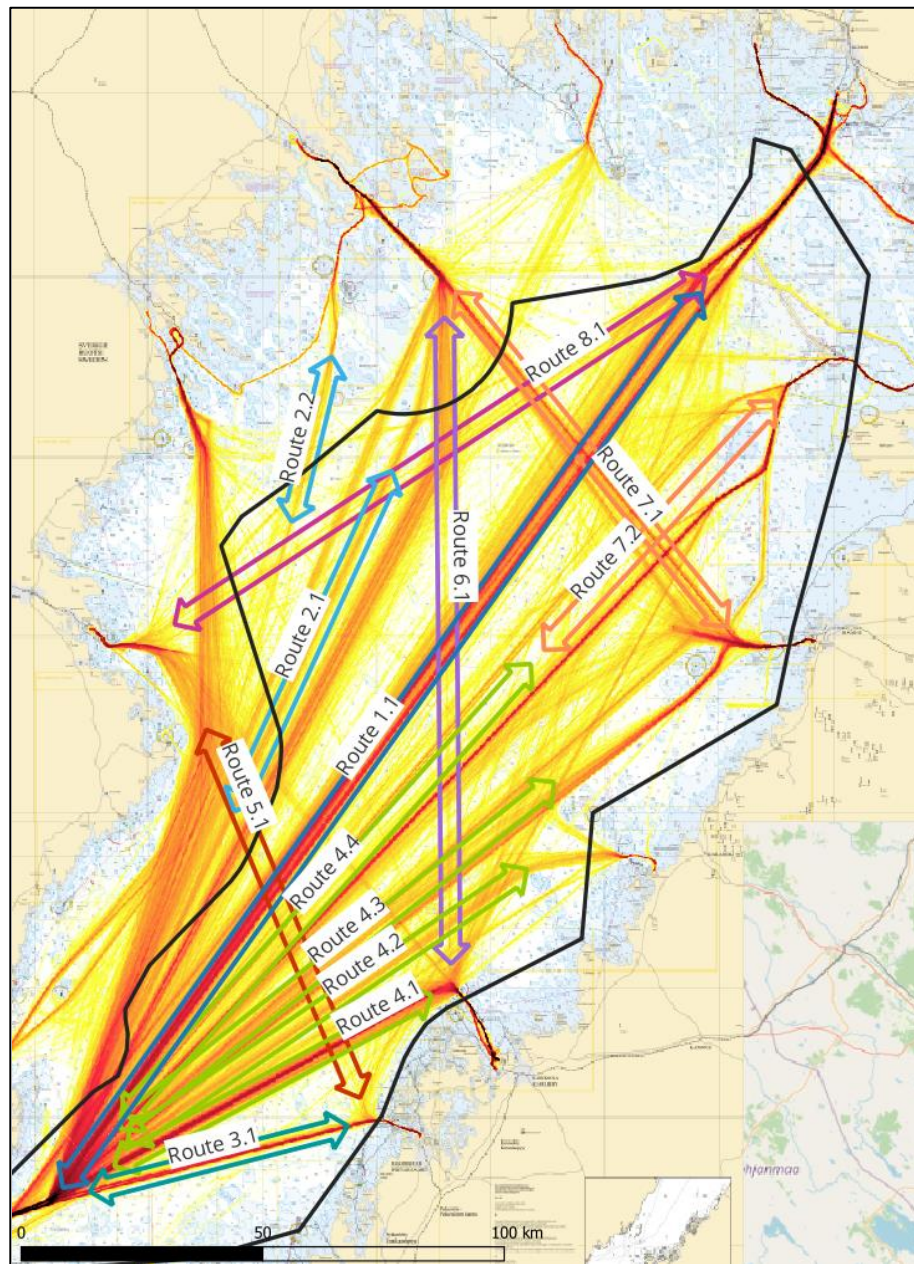
A1-1 Ship traffic routes

All the defined ship traffic routes are shown below for the Bothnian Sea (area 1) and the Bay of Bothnia (area 2), respectively.

Area 1 – Bothnian Sea – Ship traffic routes

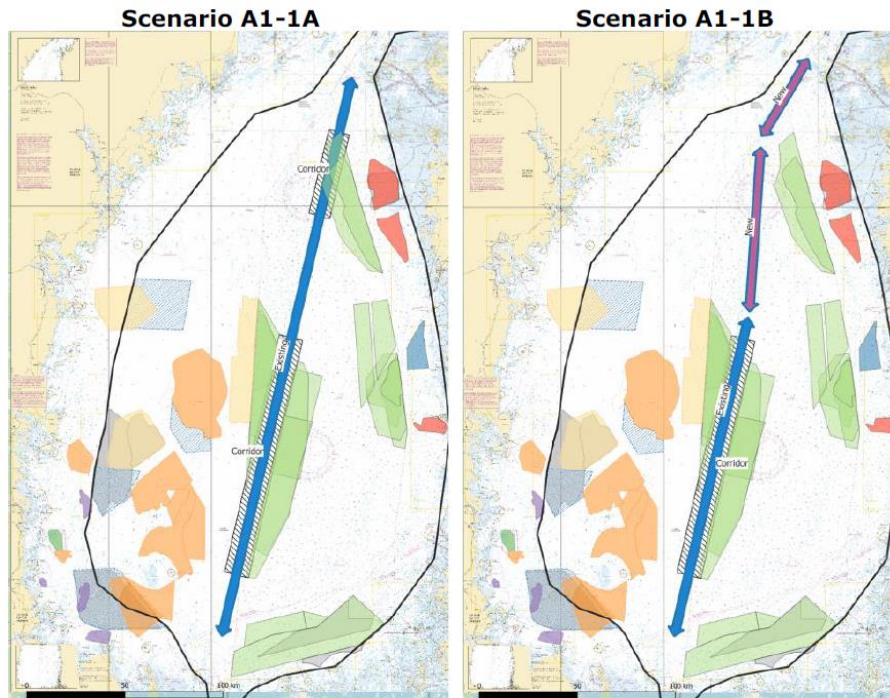


Area 2 – Bay of Bothnia – Ship traffic routes



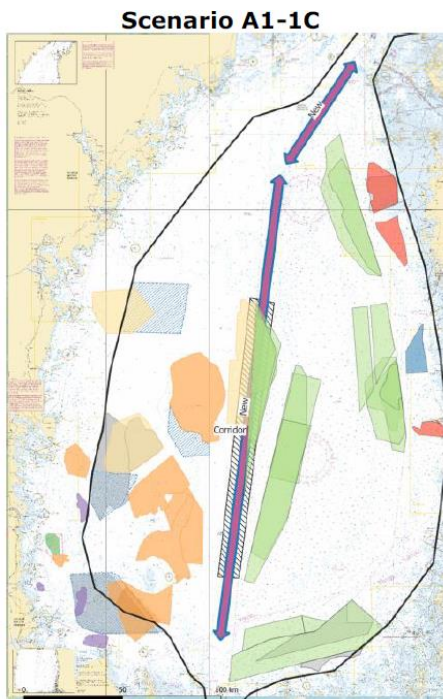
A1-2 Scenarios for the analysis

A1-2.1 Area 1, subarea 1 – route 1.1



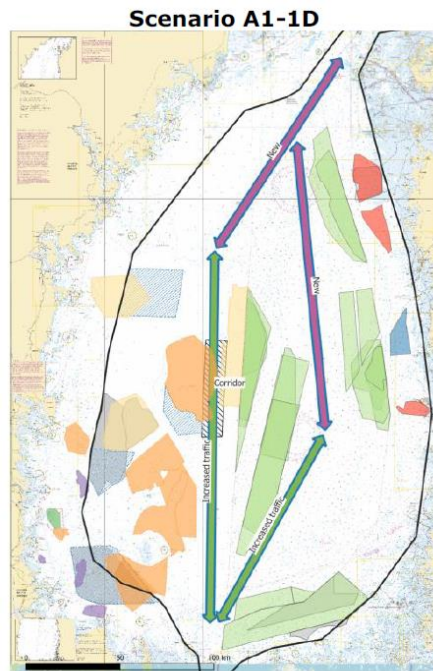
Straight route as today. Long corridor (approx. 75 km) through central Sea of Bothnia. Northern wind farm reduced to allow for passing ship traffic

Long corridor (approx. 75 km) through central Sea of Bothnia.
Bend on route to allow full development of northern wind farm area

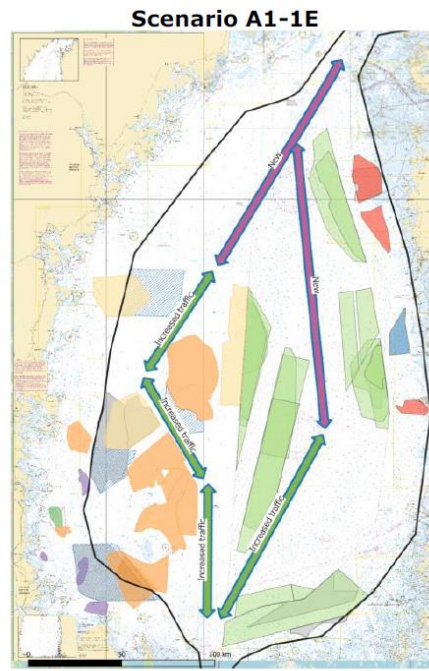


Shorter corridor (approx. 65 km) placed at the border between Swedish and Finnish EEZ.

Additional scenarios defined after the HAZID workshop

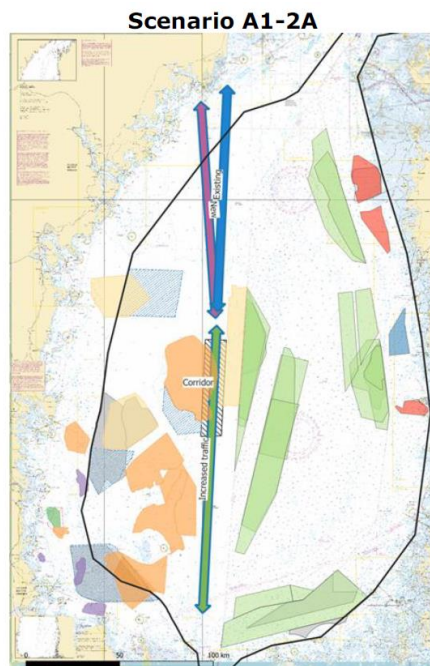


North/south corridor (approx. 35 km) between Swedish wind farm development areas allowing for main ship traffic and other north/south traffic. Possibility to use longer, eastern path.

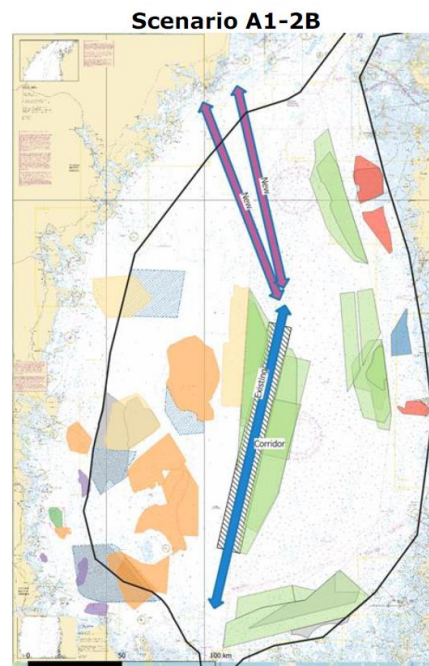


Entire central area reserved for wind farms. Shorter corridor west (approx. 15 km), and possibility to use open water in Finnish EEZ.

A1-2.2 Area 1, subarea 2 – routes 2.1, 2.2

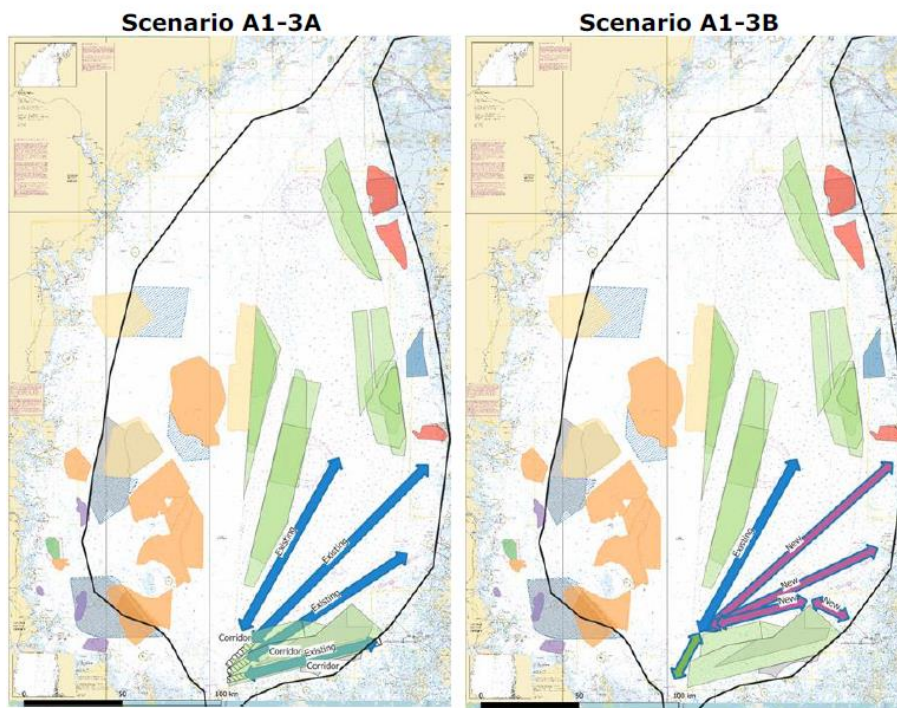


Straight route as today. Corridor (approx 35 km) through central Sea of Bothnia.



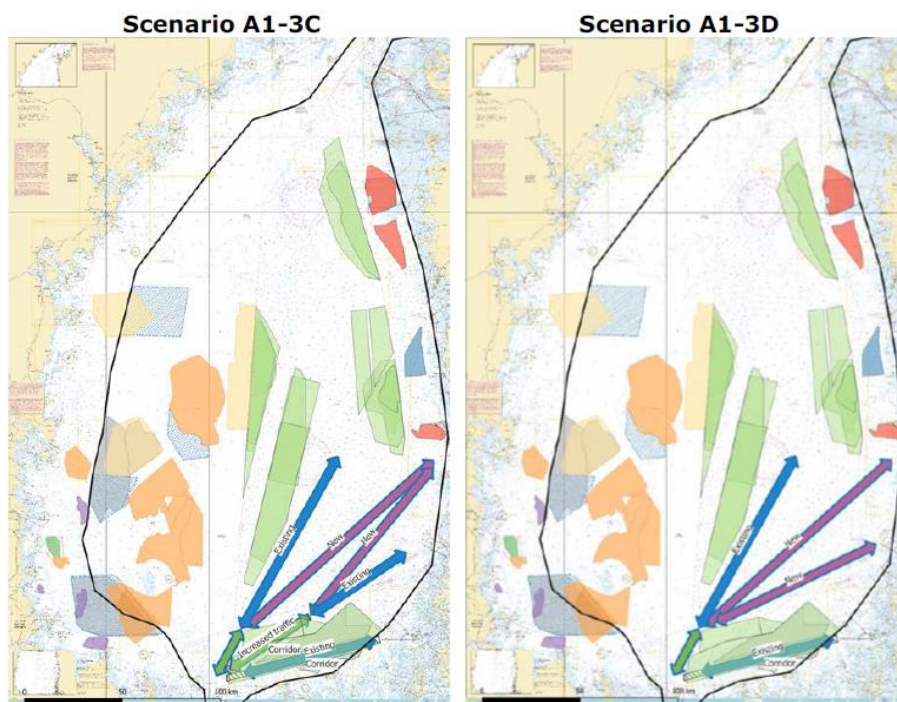
Traffic following main traffic through long corridor (approx 75 km) through central Sea of Bothnia.

A1-2.3 Area 1, subarea 3 – routes 3.1, 3.2, 3.3, 3.4



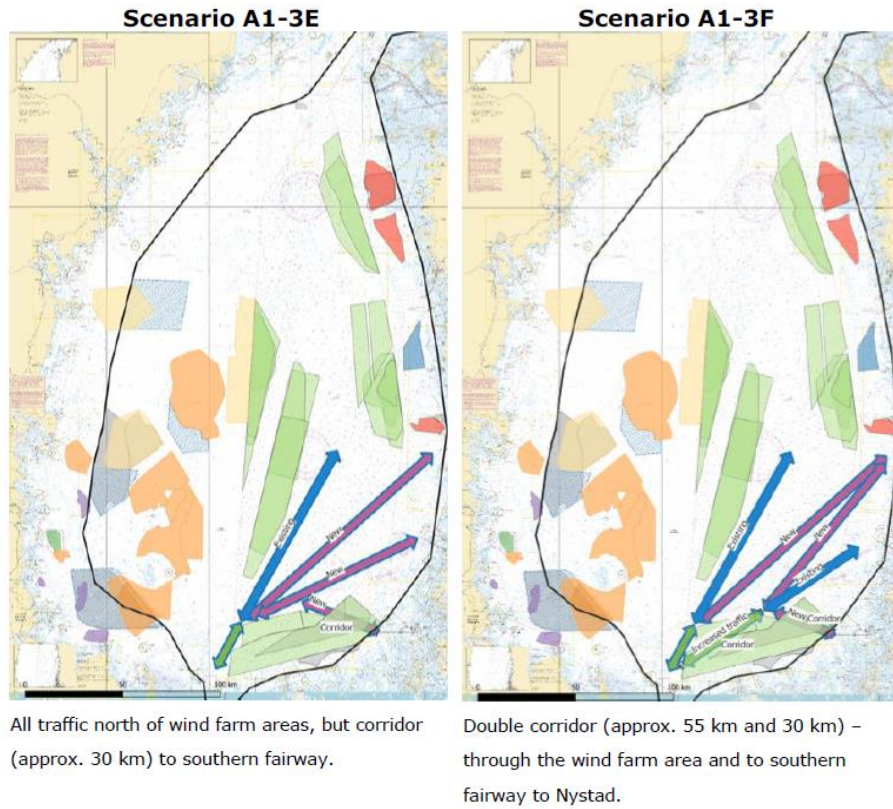
All routes maintained through corridors in wind farm areas. For reference, diagonal corridor approx. 55 km.

All traffic routes north of wind farm areas.
Southern fairway to Nystad not accessible

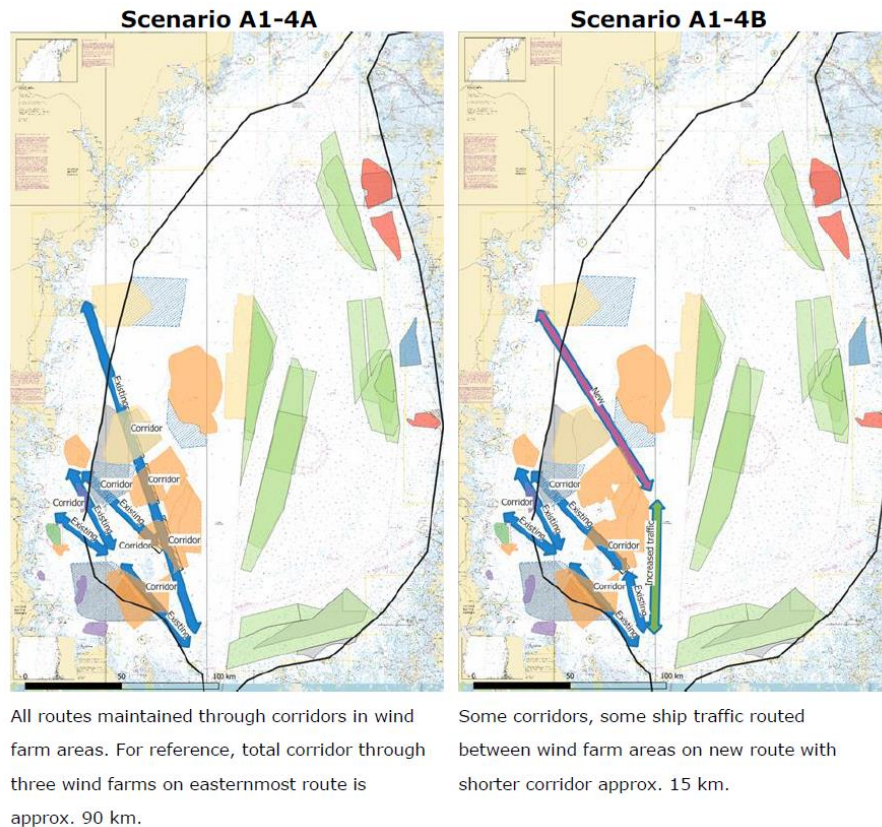


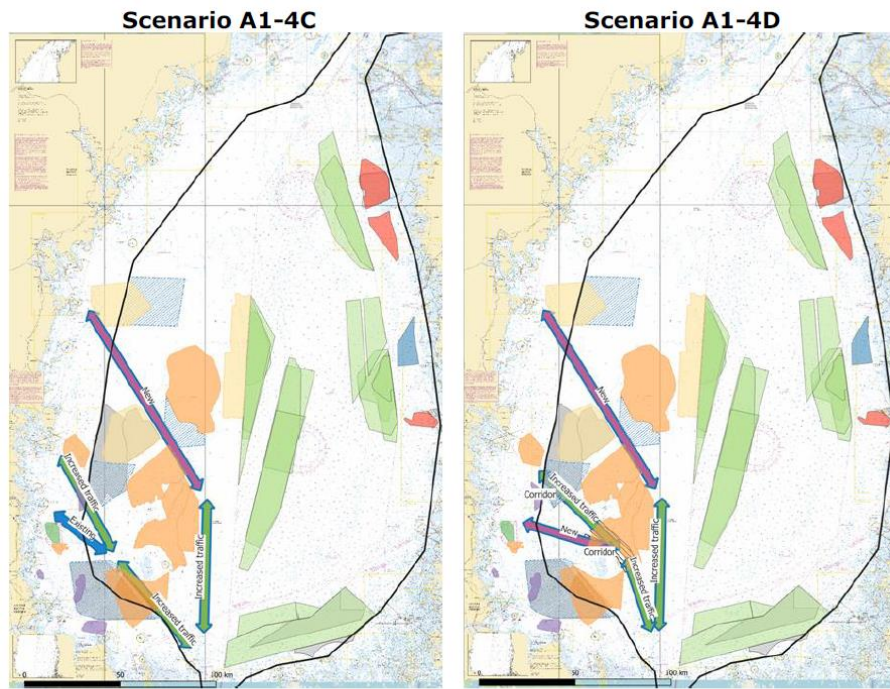
Southern and central corridor (approx. 55 km).

Only southern corridor for local traffic to Nystad.
Other ship traffic pass north of wind farm areas



A1-2.4 Area 1, subarea 4 – routes 4.1, 4.2, 4.3a, 4.3b

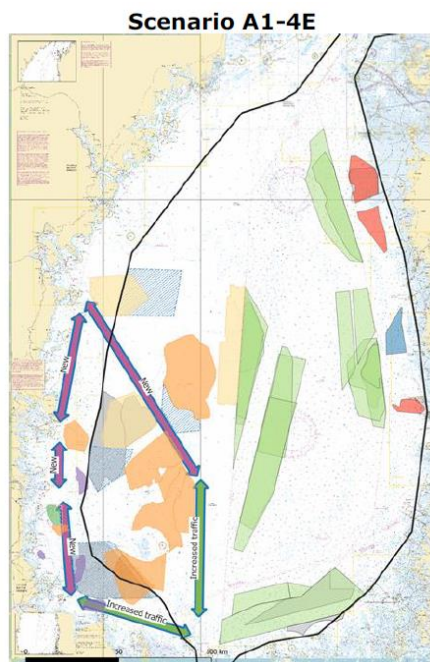




Fewer corridors. Longest through southernmost wind farm area is approx. 25 km.

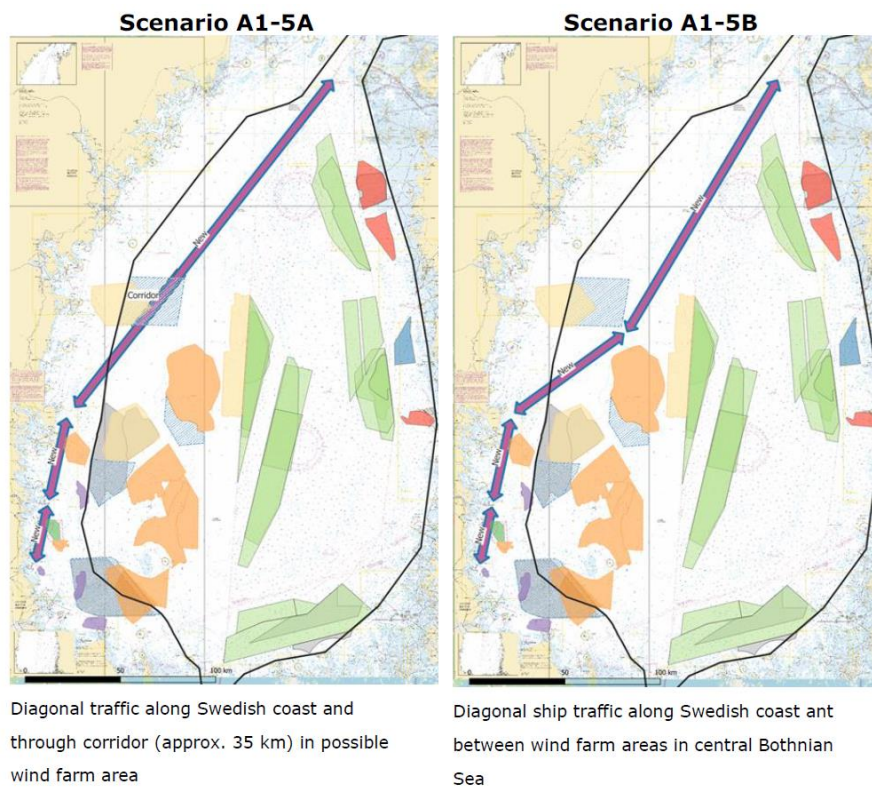
Fewer corridors – alternative.

Additional scenario defined after the HAZID workshop

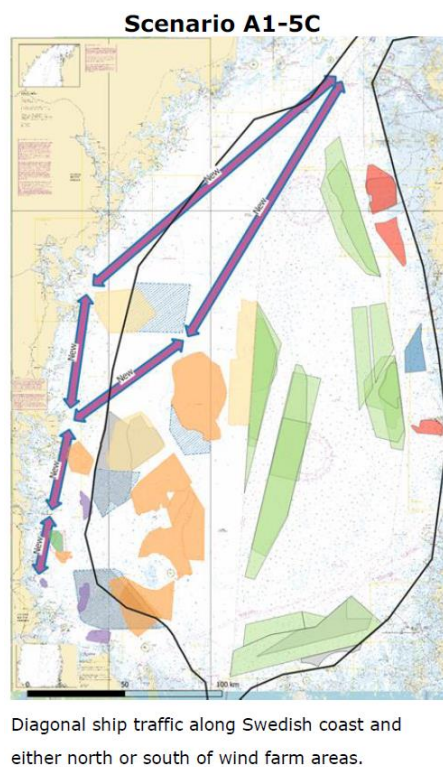


Ship traffic must go either more centrally in the Sea of Bothnia (shorter corridor approx. 15 km) or closer to the Swedish coast.

A1-2.5 Area 1, subarea 5 – route 5.1

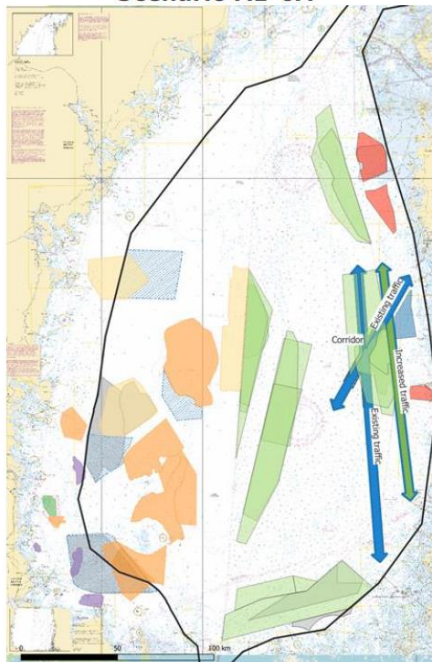


Additional scenario defined after the HAZID workshop



A1-2.6 Area 1, subarea 6 – routes 6.1, 6.2, 6.3

Scenario A1-6A



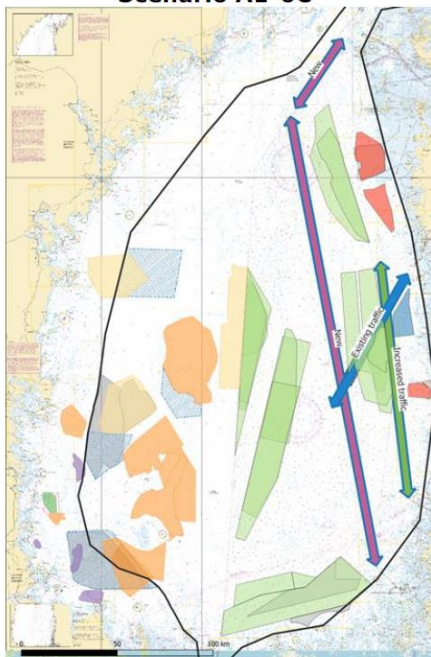
All routes maintained through corridors in wind farm areas. North/south corridor approx. 70 km, diagonal corridor approx. 40 km.

Scenario A1-6B



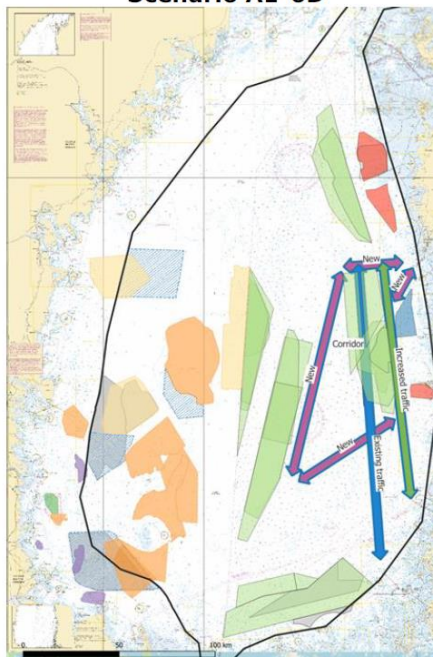
All ship traffic avoiding the wind farm development areas.

Scenario A1-6C



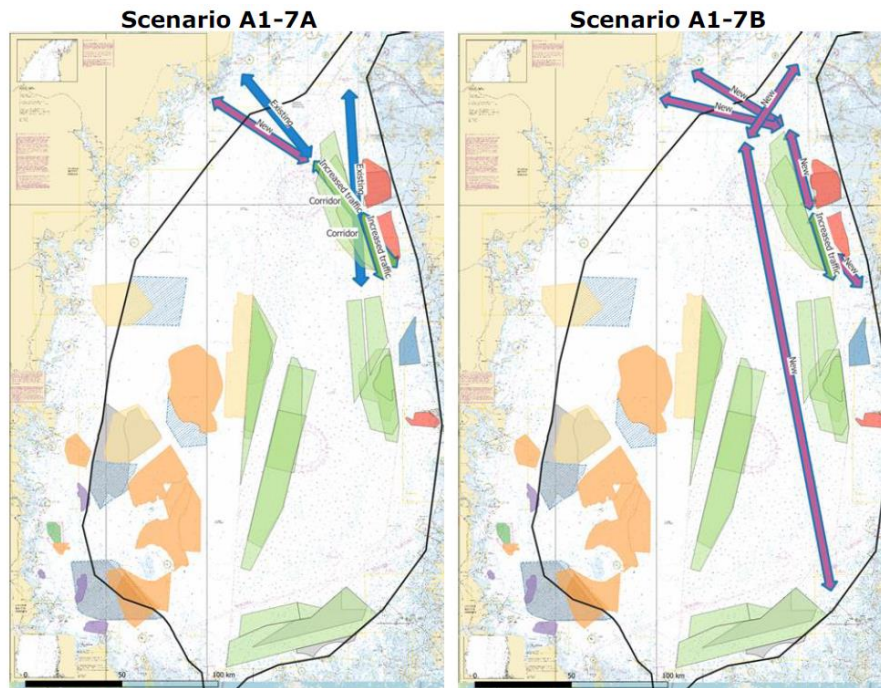
One diagonal corridor (approx. 40 km) for ship traffic to Kaskinen.

Scenario A1-6D



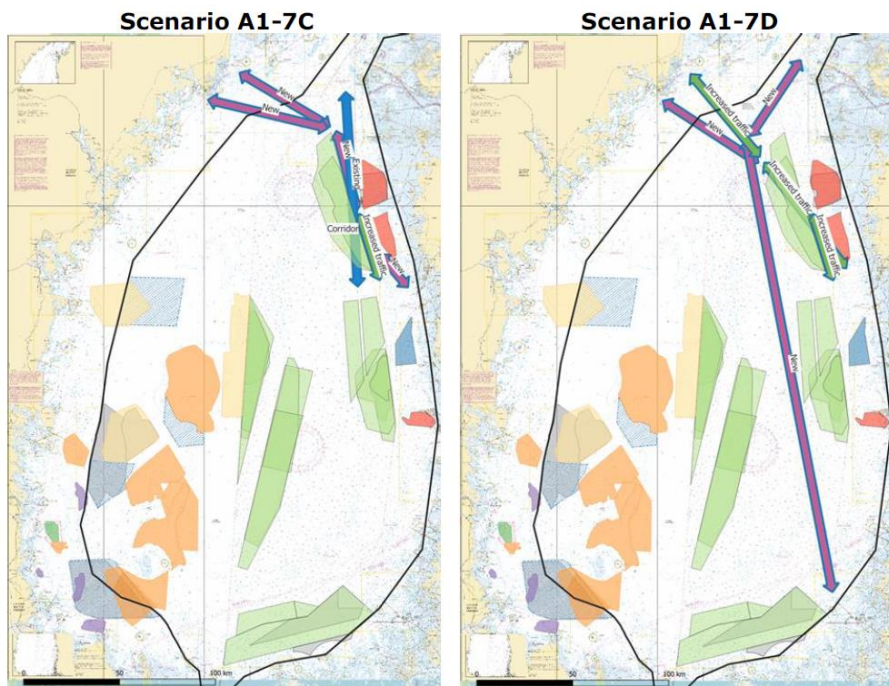
One north/south corridor (approx. 70 km) for ship traffic; primarily to/from Nystad.

A1-2.7 Area 1, subarea 7 – routes 7.1, 7.2, 7.3



All routes maintained through corridors in wind farm areas. North/south and diagonal corridors – both approx. 30 km.

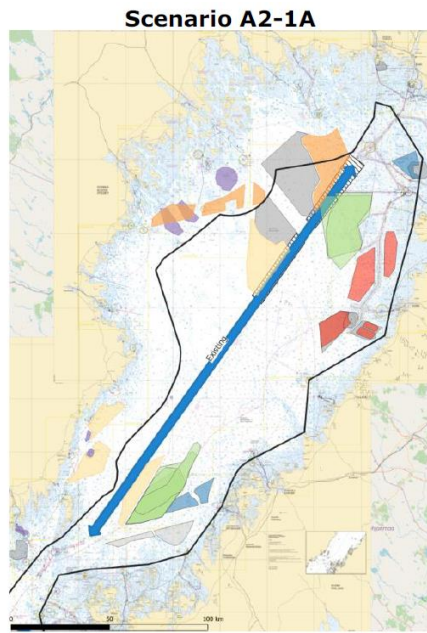
All ship traffic avoiding the wind farm development areas.



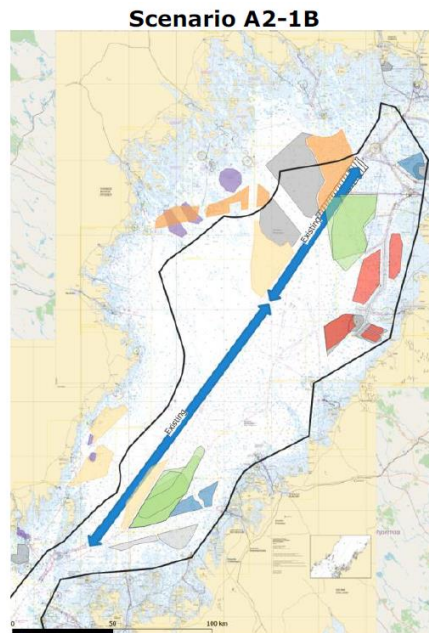
One north/south corridor (approx. 30 km) for ship traffic primarily coming from Nystad in south.

One diagonal corridor (approx. 30 km) for ship traffic, mainly between Kaskinen and Sweden.

A1-2.8 Area 2, subarea 1 – route 1.1

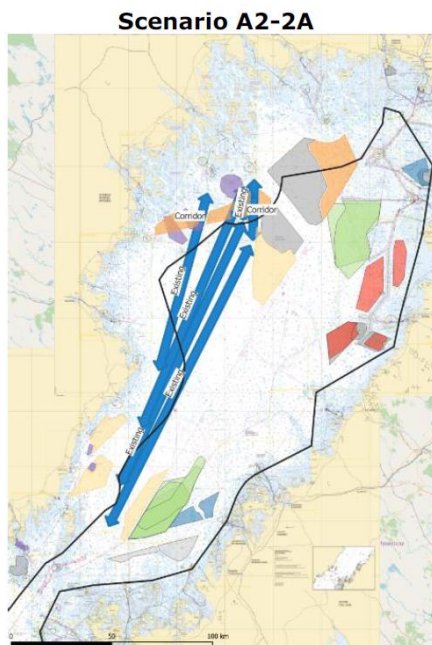


Main route maintained as it is – limiting central wind farm to allow for safety space and providing a wide corridor (at least 6nm, maybe wider – length approx. 20 km) between northern wind farm areas.

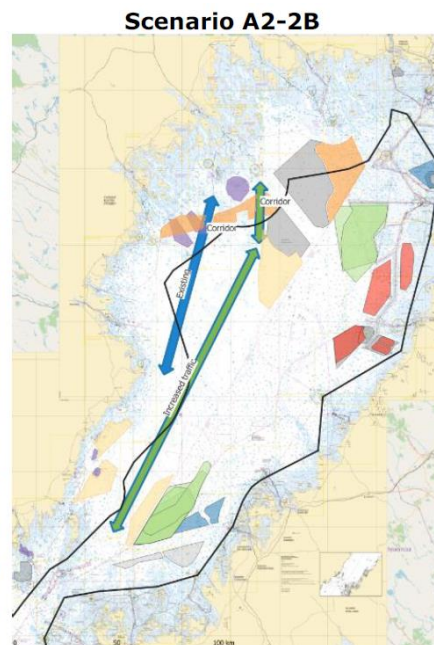


Leaving central wind farm area for development and letting ship traffic divert slightly eastward to go around. Wide corridor between (at least 6 nm, maybe wider – length approx. 20 km) between northern wind farm areas.

A1-2.9 Area 2, subarea 2 – routes 2.1, 2.2

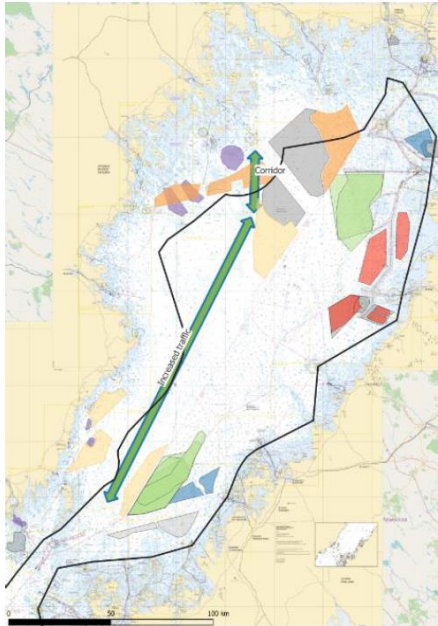


Maintaining ship traffic as seen today. Several corridors (approx. 7-12 km) through wind farms in Swedish territorial waters.



Maintaining two corridors (approx. 7 and 12 km) as currently planned through wind farm areas in Swedish territorial waters.

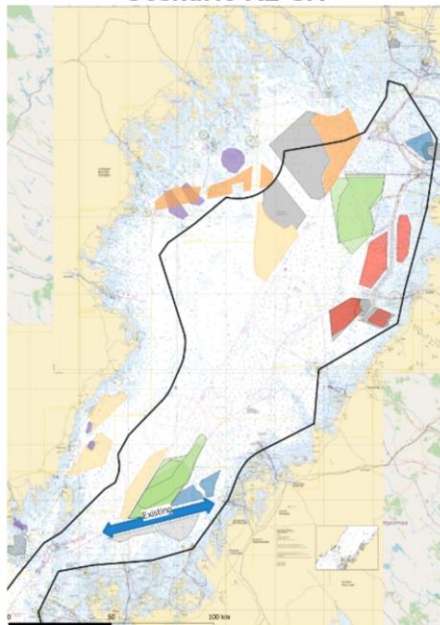
Scenario A2-2C



Allowing for further wind farm development (purple areas) and leaving one corridor (approx. 12 km) for all ship traffic.

A1-2.10 Area 2, subarea 3 – route 3.1

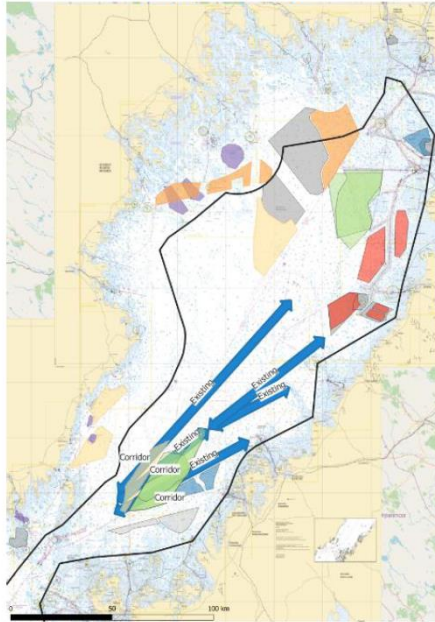
Scenario A2-3A



Ship traffic unchanged – potentially through corridor depending on wind farm development.

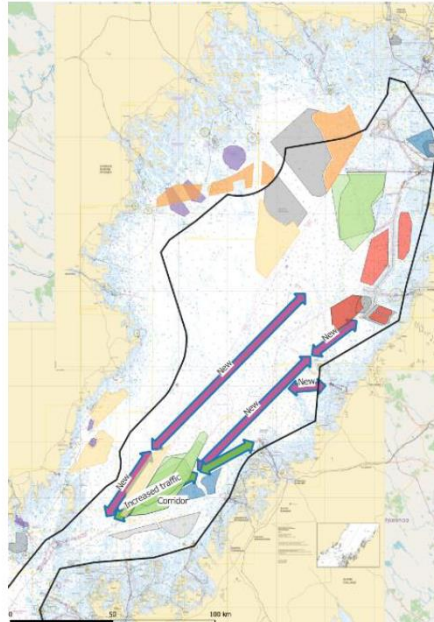
A1-2.11 Area 2, subarea 4 – routes 4.1, 4.2, 4.3, 4.4

Scenario A2-4A



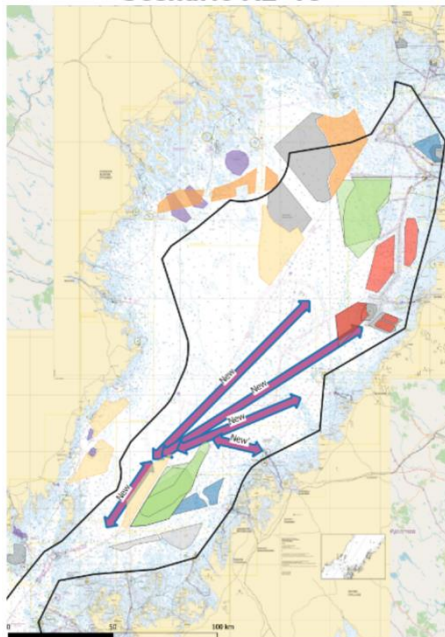
Maintaining ship traffic as seen today. Limiting external parts of wind farm area and several corridors – length up to approx. 40 km.

Scenario A2-4B



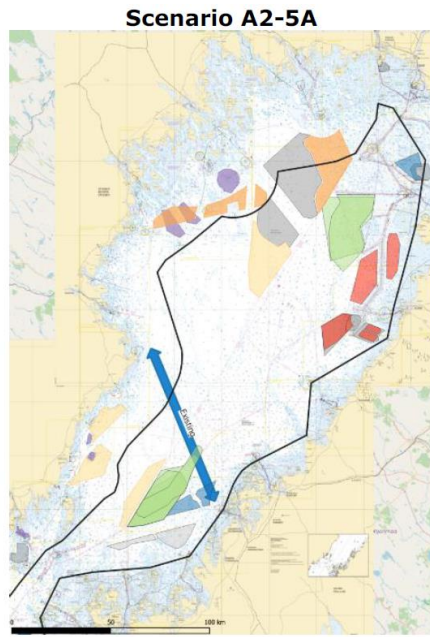
One corridor (approx. 40 km), and routing ship traffic through or around wind farm areas.

Scenario A2-4C

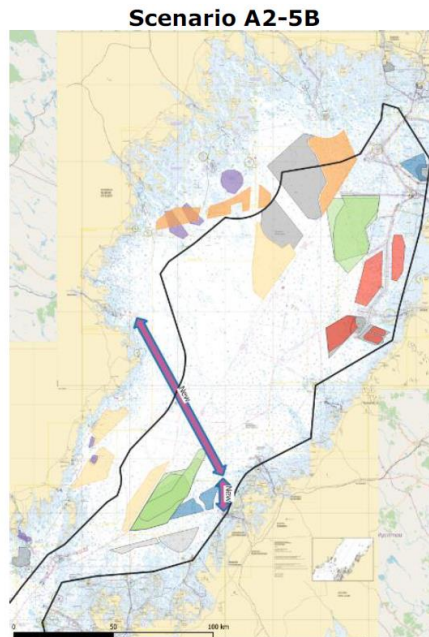


All ship traffic going around wind farm areas.

A1-2.12 Area 2, subarea 5 – route 5.1

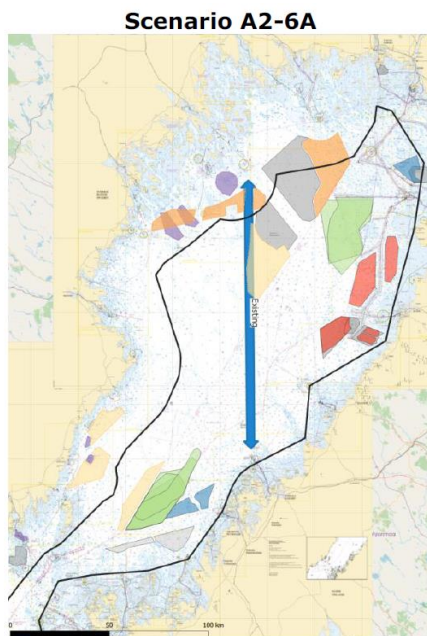


Limiting wind farm areas to allow for a straight route through the area. Blue wind farm areas are further into the planning stage.

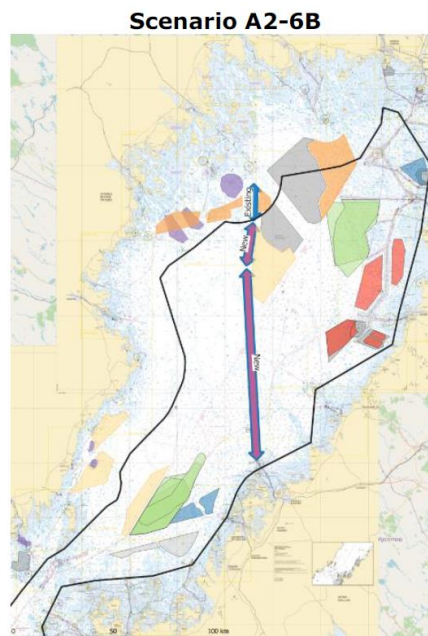


Letting the (limited) ship traffic pass around the wind farm areas.

A1-2.13 Area 2, subarea 6 – route 6.1



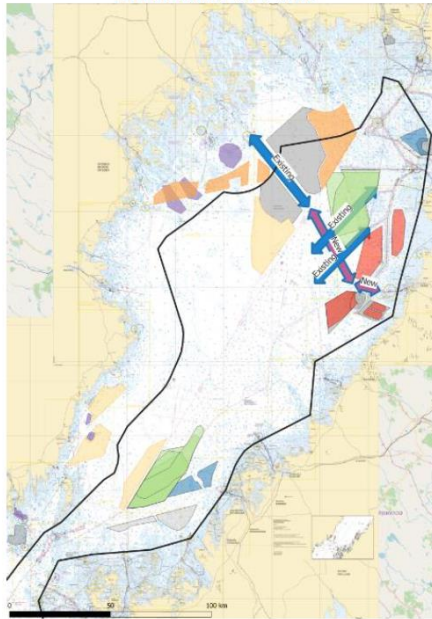
Letting north/south bound ship traffic go straight, cutting off western part of potential wind farm development.



Letting ship traffic pass east of possible wind farm development area before entering the corridor.

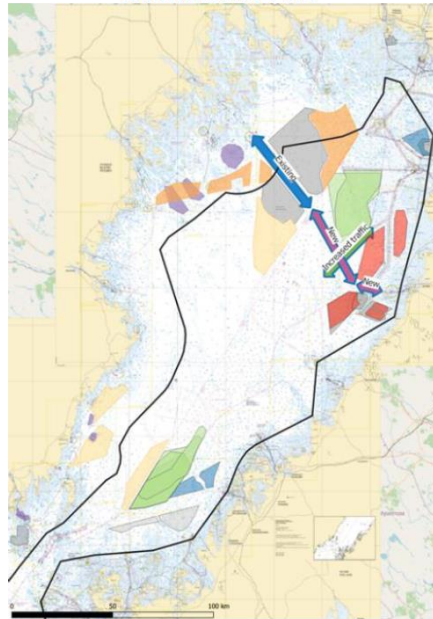
A1-2.14 Area 2, subarea 7 – routes 7.1, 7.2

Scenario A2-7A



Maintaining ship traffic as seen today. Several corridors through wind farm areas to maintain access to Finnish fairways. Through grey areas (approx. 35 km), through green area (approx. 30 km), and between green and red areas (approx. 5 km)

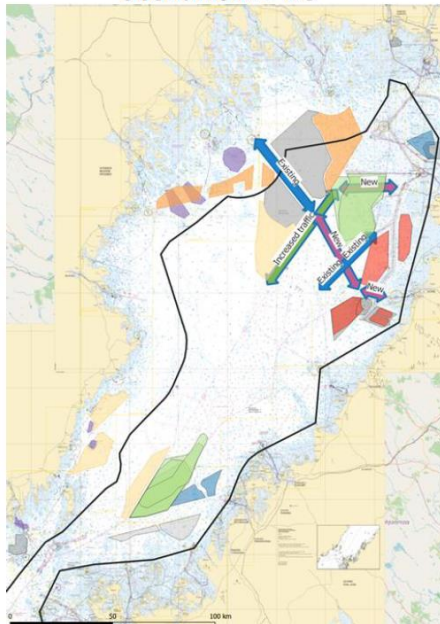
Scenario A2-7B



Allowing wind farm development in the green area prohibiting access to east/westbound fairway.

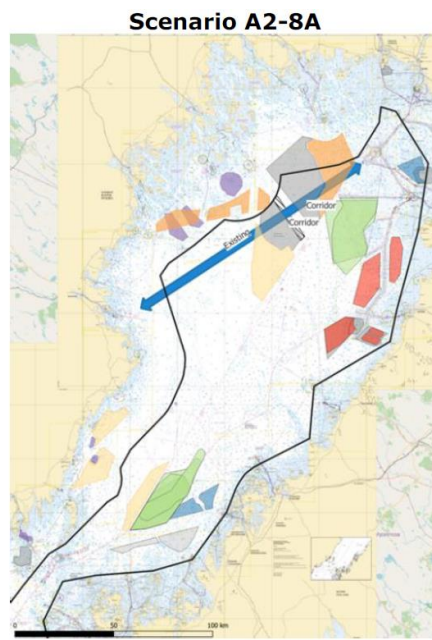
Additional scenario defined after the HAZID workshop

Scenario A2-7C

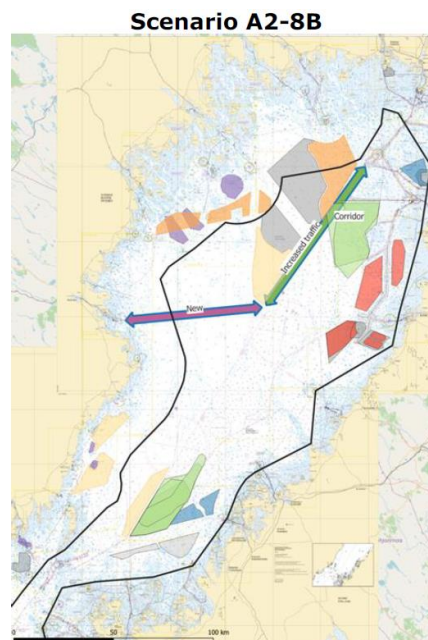


Removing the entire northern part of the green area (no corridor) to allow for ship traffic east/west to access Finnish fairway from the main route.

A1-2.15 Area 2, subarea 8 – route 8.1



Maintaining diagonal ship traffic as today, through possible corridors in wind farm areas (total approx. 60 km).



Letting ship traffic go around the wind farm areas and follow the main north/south route through shorter corridor (approx. 20 km).

Appendix 2 – Detailed ship traffic route counts

The appendix shows the ship traffic in the Bothnian Sea and Bay of Bothnia for each of the identified routes. The ship traffic is based on three years of AIS data for five months during summer from June to October where there are ice-free conditions for the two areas. The number in the tables shows the average number of ships for five months across all three years, also split into ship types and into groups of ship lengths. At last is a column for the indicative annual traffic, which is a scaling of the total number for the five month and adjusted to 12 months, to give an idea of the annual ship traffic numbers for each routes given the assumption of even traffic during a year across all routes, ship types and lengths.

A2-1 Ship traffic in the Bothnian Sea (Area 1)

The following table shows the ship traffic in the Bothnian Sea.

Routes	Avg. number of ships, 2019, 2022, and 2023					Indicative annual traffic
Ship length (m)	0-50	50-100	100-200	200-300	Total	
Route 1.1	15	385	885	55	1,340	3,240
- Fishing ship	5	0	0	0	5	20
- General cargo ship	0	360	655	50	1,065	2,560
- Oil products tanker	0	20	205	0	225	540
- Passenger ship	0	0	5	5	10	30
- Support ship	10	5	20	0	35	90
Route 2.1	15	35	115	5	170	430
- Fishing ship	10	0	0	0	10	30
- General cargo ship	0	30	85	0	115	280
- Oil products tanker	0	5	20	0	25	60
- Passenger ship	0	0	5	5	10	30
- Support ship	5	0	5	0	10	30
Route 2.2	10	60	105	10	185	470
- Fishing ship	5	0	0	0	5	20
- General cargo ship	0	50	75	10	135	330
- Oil products tanker	0	5	25	0	30	80
- Passenger ship	0	0	0	0	0	0
- Support ship	5	5	5	0	15	40
Route 3.1	40	150	440	35	665	1,610
- Fishing ship	35	0	0	0	35	90
- General cargo ship	0	130	415	35	580	1,400
- Oil products tanker	0	10	15	0	25	60
- Passenger ship	0	0	0	0	0	0
- Support ship	5	10	10	0	25	60

Routes Ship length (m)	Avg. number of ships, 2019, 2022, and 2023					Indicative annual traffic
	0- 50	50- 100	100- 200	200- 300	Total	
Route 3.2	5	125	60	5	195	490
- Fishing ship	5	0	0	0	5	20
- General cargo ship	0	105	45	5	155	380
- Oil products tanker	0	15	10	0	25	60
- Passenger ship	0	0	0	0	0	0
- Support ship	0	5	5	0	10	30
Route 3.3	25	70	185	10	290	710
- Fishing ship	20	5	0	0	25	60
- General cargo ship	0	50	95	10	155	380
- Oil products tanker	0	10	80	0	90	220
- Passenger ship	0	0	0	0	0	0
- Support ship	5	5	10	0	20	50
Route 3.4	10	75	75	10	170	430
- Fishing ship	5	0	0	0	5	20
- General cargo ship	0	65	55	5	125	300
- Oil products tanker	0	5	15	0	20	50
- Passenger ship	0	0	0	5	5	20
- Support ship	5	5	5	0	15	40
Route 4.1	25	165	265	5	460	1,120
- Fishing ship	20	0	0	0	20	50
- General cargo ship	0	150	200	0	350	840
- Oil products tanker	0	5	55	0	60	150
- Passenger ship	0	0	5	5	10	30
- Support ship	5	10	5	0	20	50
Route 4.2	15	20	75	0	110	290
- Fishing ship	10	0	0	0	10	30
- General cargo ship	0	15	70	0	85	210
- Oil products tanker	0	0	5	0	5	20
- Passenger ship	0	0	0	0	0	0
- Support ship	5	5	0	0	10	30
Route 4.3a	10	20	20	0	50	150
- Fishing ship	5	0	0	0	5	20
- General cargo ship	0	15	15	0	30	80
- Oil products tanker	0	5	5	0	10	30
- Passenger ship	0	0	0	0	0	0
- Support ship	5	0	0	0	5	20

Routes Ship length (m)	Avg. number of ships, 2019, 2022, and 2023					Indicative annual traffic
	0- 50	50- 100	100- 200	200- 300	Total	
Route 4.3b	15	45	15	0	75	200
- Fishing ship	10	0	0	0	10	30
- General cargo ship	0	35	10	0	45	110
- Oil products tanker	0	5	0	0	5	20
- Passenger ship	0	0	0	0	0	0
- Support ship	5	5	5	0	15	40
Route 5.1	15	55	60	0	130	320
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	45	40	0	85	210
- Oil products tanker	0	5	20	0	25	60
- Passenger ship	0	0	0	0	0	0
- Support ship	15	5	0	0	20	50
Route 6.1	10	80	25	5	120	320
- Fishing ship	5	0	0	0	5	20
- General cargo ship	0	65	15	5	85	210
- Oil products tanker	0	5	10	0	15	40
- Passenger ship	0	5	0	0	5	20
- Support ship	5	5	0	0	10	30
Route 6.2	10	80	55	5	150	390
- Fishing ship	5	0	0	0	5	20
- General cargo ship	0	70	45	0	115	280
- Oil products tanker	0	5	10	0	15	40
- Passenger ship	0	0	0	5	5	20
- Support ship	5	5	0	0	10	30
Route 6.3	70	100	100	10	280	700
- Fishing ship	5	0	0	0	5	20
- General cargo ship	5	85	75	0	165	400
- Oil products tanker	0	10	20	0	30	80
- Passenger ship	0	0	5	10	15	40
- Support ship	60	5	0	0	65	160

Routes Ship length (m)	Avg. number of ships, 2019, 2022, and 2023					Indicative annual traffic
	0- 50	50- 100	100- 200	200- 300	Total	
Route 7.1	5	85	35	0	125	320
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	70	25	0	95	230
- Oil products tanker	0	5	10	0	15	40
- Passenger ship	0	5	0	0	5	20
- Support ship	5	5	0	0	10	30
Route 7.2	5	15	25	0	45	120
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	5	15	0	20	50
- Oil products tanker	0	5	5	0	10	30
- Passenger ship	0	0	0	0	0	0
- Support ship	5	5	5	0	15	40
Route 7.3	5	10	15	0	30	90
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	10	10	0	20	50
- Oil products tanker	0	0	5	0	5	20
- Passenger ship	0	0	0	0	0	0
- Support ship	5	0	0	0	5	20
Route 7.4	45	80	105	5	235	590
- Fishing ship	5	0	0	0	5	20
- General cargo ship	5	70	90	0	165	400
- Oil products tanker	0	5	10	0	15	40
- Passenger ship	0	0	0	5	5	20
- Support ship	35	5	5	0	45	110

A2-2 Ship traffic in the Bay of Bothnia (Area 2)

The following table shows the ship traffic in the Bay of Bothnia.

Routes Ship length (m)	Avg. number of ships, 2019, 2022, and 2023					Indicative annual traffic
	0- 50	50- 100	100- 200	200- 300	Total	
Route 1.1	5	125	385	10	525	1,270
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	115	305	5	425	1,020
- Oil products tanker	0	5	70	0	75	180
- Passenger ship	0	0	0	5	5	20
- Support ship	5	5	10	0	20	50
Route 2.1	5	120	195	30	350	860
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	110	155	25	290	700
- Oil products tanker	0	5	30	0	35	90
- Passenger ship	0	0	5	5	10	30
- Support ship	5	5	5	0	15	40
Route 2.2	5	20	30	5	60	160
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	15	20	5	40	100
- Oil products tanker	0	0	5	0	5	20
- Passenger ship	0	0	0	0	0	0
- Support ship	5	5	5	0	15	40
Route 3.1	15	55	145	10	225	550
- Fishing ship	0	0	0	0	0	0
- General cargo ship	5	45	125	10	185	450
- Oil products tanker	0	5	15	0	20	50
- Passenger ship	0	0	0	0	0	0
- Support ship	10	5	5	0	20	50
Route 4.1	15	135	200	20	370	900
- Fishing ship	0	0	0	0	0	0
- General cargo ship	5	125	130	20	280	680
- Oil products tanker	0	5	60	0	65	160
- Passenger ship	0	0	0	0	0	0
- Support ship	10	5	10	0	25	60

Routes Ship length (m)	Avg. number of ships, 2019, 2022, and 2023					Indicative annual traffic
	0- 50	50- 100	100- 200	200- 300	Total	
Route 4.2	10	45	55	10	120	300
- Fishing ship	0	0	0	0	0	0
- General cargo ship	5	40	35	10	90	220
- Oil products tanker	0	0	15	0	15	40
- Passenger ship	0	0	0	0	0	0
- Support ship	5	5	5	0	15	40
Route 4.3	5	105	95	0	205	510
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	95	80	0	175	420
- Oil products tanker	0	5	5	0	10	30
- Passenger ship	0	0	5	0	5	20
- Support ship	5	5	5	0	15	40
Route 4.4	5	80	200	10	295	720
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	60	110	5	175	420
- Oil products tanker	0	10	80	0	90	220
- Passenger ship	0	5	5	5	15	40
- Support ship	5	5	5	0	15	40
Route 5.1	5	10	10	5	30	90
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	5	10	5	20	50
- Oil products tanker	0	5	0	0	5	20
- Passenger ship	0	0	0	0	0	0
- Support ship	5	0	0	0	5	20
Route 6.1	5	15	20	5	45	130
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	10	15	5	30	80
- Oil products tanker	0	5	5	0	10	30
- Passenger ship	0	0	0	0	0	0
- Support ship	5	0	0	0	5	20

Routes Ship length (m)	Avg. number of ships, 2019, 2022, and 2023					Indicative annual traffic
	0- 50	50- 100	100- 200	200- 300	Total	
Route 7.1	5	25	155	10	195	490
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	20	145	5	170	410
- Oil products tanker	0	0	5	0	5	20
- Passenger ship	0	0	0	5	5	20
- Support ship	5	5	5	0	15	40
Route 7.2	10	80	205	10	305	750
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	60	120	5	185	450
- Oil products tanker	0	10	75	0	85	210
- Passenger ship	0	5	5	5	15	40
- Support ship	10	5	5	0	20	50
Route 8.1	5	15	30	10	60	160
- Fishing ship	0	0	0	0	0	0
- General cargo ship	0	10	20	10	40	100
- Oil products tanker	0	5	5	0	10	30
- Passenger ship	0	0	0	0	0	0
- Support ship	5	0	5	0	10	30

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