Nautical Risk Assessment of Halla OWF

Layout with 120 WTGs

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Table of contents

Abbreviations and concepts

AIS	Automatic Identification System
ALARP	As Low As Reasonably Practicable (area where risks can be tolerated if all reasonable measures are taken)
Allision	IWRAP distinguishes between collision (where two moving vessels collide) and allision where a moving vessel bumps into a stationary object – a bridge, pier, dock or oil platform. Two types of allision are covered by IWRAP: • Powered allision (manoeuvrable vessel bumps into a stationary object). Occurs either in the absence of a ship's manoeuvre when the fairway turns, or for vessels positioning themselves outside the fairway. • Drifting allision (drifting ship bumps into a stationary object).
Causation factor	Assumption in IWRAP of the probability of causality falling out. A causation factor is the conditional probability of a human error or technical error in an accident that could otherwise have stopped the accident
Collision	For the purposes of this report, collision refers to collisions between ships unless otherwise stated. IWRAP distinguishes between collision (where two moving vessels collide) and allision where a moving vessel bumps into a stationary object – a bridge, pier, dock or oil platform. Five types of collision are covered in IWRAP: • Head-on collision • Overtaking collision • Crossing collision • Merging collision • Bend collision
Concept design	Includes preliminary design of windfarm and navigation areas layout using data and formulae given in design guidelines together with other relevant data relating to ships and environment. At the very first design stage only rough estimates of the safety distance are determined. The process is intended to be rapid in execution and not require excessive input data, so that alternative options (for trade-off studies) can be evaluated rapidly (PIANC, 2018)
Detailed design	Is a more rigorous process intended to validate, develop, and refine the Concept Design. The methods used in Detailed Design rely on numerical analysis (for example simulation) and therefore require more extensive and detailed input, as well as proper judgement and experience in the interpretation of their output. The outputs of the Detailed Design may be subjected to further checking for acceptability by means of marine traffic analysis, risk analysis and cost/benefit estimates. The results of these checks may lead to adjustments and a further cycle of Detailed Design (PIANC, 2018)
EEZ	Exclusive Economic Zone
Fairway	Seaway in inland waters, inland or near the coast, designated by maritime safety devices or marked on a chart or in a nautical publication
FI	Frequency Index, a number representing the accident frequency (Maritime Safety Committee, 2018)
FSA	Formal Safety Assessment
Gross tonnage (GRT)	Measure of the size of a vessel (the total internal volume of a vessel)

GW	gigawatt
HEP	Human Error Probability
HRA	Human Reliability Assessment
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IMO	International Maritime Organization
IWRAP	IALA Waterway Risk Assessment Program (modelling tool for calculating accident frequencies for ships)
kV	kilovolt
leg	sailing segment between two waypoints
M	nautical mile (1,852 meters)
MW	megawatt
OWF	Offshore Wind Farm
Platform	Hub for collecting and transforming the electricity generated by the WTGs. It typically houses transformers, switchgear, and, if applicable, hydrogen and necessary infrastructure.
RI	Risk Index, a number that represents the magnitude of the risk (Maritime Safety Committee, 2018)
SI	Severity Index; a number that represents the severity of the consequence of an accident (Maritime Safety Committee, 2018)
Shipping area	The maritime spatial planning identifies significant trafficked areas as seafaring areas. Seafaring areas play a crucial role in the current and future use of the marine areas (Maritime Spatial Plan 2030). In this report, the term shipping area is used synonymously with seafaring area.
TSS	Traffic Separation System – an area where oncoming traffic is separated into different traffic routes
Traffic lane	A traffic lane is a defined area where one-way traffic is established. Natural obstacles, including those forming separation zones, may constitute a boundary (IMO, n.d.)
waypoint	Reference point in navigation; node point in IWRAP
WTG	Wind Turbine Generator

Non-technical summary

This report examines events that may emerge with establishment of Halla OWF that could pose a danger to navigational safety, thus environmental and human safety.

The project area for Halla OWF is located about 60 km off the coast of Oulu in the region of North Ostrobothnia in Finland. In the area adjacent to Halla, there are generally 1-3 vessel transits per day in the various routes, with shipping traffic mainly dominated by cargo vessels. During winter, the Bothnian Bay is annually characterized by ice conditions that affect patterns in the maritime traffic, leading to continuous icebreaker operations and assistance of vessels. With establishment of Halla OWF, navigational patterns are assumed to change.

Hazard identification was conducted in a HAZID (Hazard Identification workshop), in addition to the general hazards included in a nautical risk assessment. Hazards during winter conditions were pointed out as important in the HAZID.

Several different analysis cases have been conducted and compared, with focus on analysing how the risk level in the area changes with Halla OWF established versus not established (the zero alternative). Emphasis has been given to compiling changes in risk level with establishment of Halla, Polargrund and Omega OWF. This due to establishment of all three parks implies additional risk objects in the area, as well as it changes conditions for navigation, thus, affecting traffic patterns and congesting the traffic in a narrower route.

All total, 25 nautical hazards have been identified, analysed, and evaluated.

Halla OWF impacts the risk profile for ship traffic in the Bothnian Bay as follows:

- **Allision:** Halla OWF introduces the risk for allision with WTGs and platforms. This risk is present also during winter conditions, when vessels can get seized and drift with the ice.
- **Collision:** The risk for collision increases, mainly since Halla OWF will cause more traffic to use the shipping area Nordvalen – Kemi/Ajos, leading to more collisions. During the construction phase, there is also risk for collision with working vessel en route to/from port.
- **Grounding:** Halla OWF does not significantly change the risk for drifting grounding, however, the risk for powered grounding increases.
- **Vessel radar:** OWFs may cause disturbances on vessel radar.
- **Winter conditions:** OWFs may affect how ice is built up, affecting the navigation conditions for winter traffic. Halla OWF may block winter navigation routes, forcing vessels to take longer routes where they are more exposed to hazards.

Most risks were concluded to be negligible or were categorized as *acceptable*. No *unacceptable* risks were found. Risks that in certain aspects have been classified as *ALARP*, meaning that the risks can be tolerated if reasonable measures are taken, were found:

- Inoperable ship drifts into a WTG (drifting allision)
- Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)
- A ship passing through the OWF collides with a WTG
- Limited visibility causes a ship to navigate into a WTG
- Total collisions (all collision types)
- Overtaking collision
- Head-on collision
- Merging collision
- Bend collision
- Collision with working vessel en route to/from port
- Powered grounding
- Vessel radar disturbance (target loss)
- The OWF complicates search and rescue operations
- The OWF affects ice buildup
- The OWF blocks winter navigation routes (longer routes resulting in grounding, collision and allision)

Recommendations on risk mitigating measures are given in this report.

The overall conclusion is that the risk induced by Halla OWF is *acceptable*, presuming that mitigating measures are taken. Risks related to winter navigation and ice are not assumed to have severe consequences for human health and safety or for the environment but are classified as *ALARP* to assure that the uncertainties do not lead to underestimation of risks.

1. Introduction

OX2 plans to apply for a permit for the construction of an offshore wind farm, Halla, located about 60 km off the coast of Oulu in the region of North Ostrobothnia in Finland. Between the coast and the wind farm is the island Hailuoto. The island is about 20 km from the wind farm. The wind farm area is about 550-575 km^2 in size and is planned for approximately 120-160 wind turbines (WTGs) with a total height of 370 metres. This report encompasses the smaller project area of 575 km^2 and layout with 120 WTGs.

The project area is illustrated in Figure 1 below.

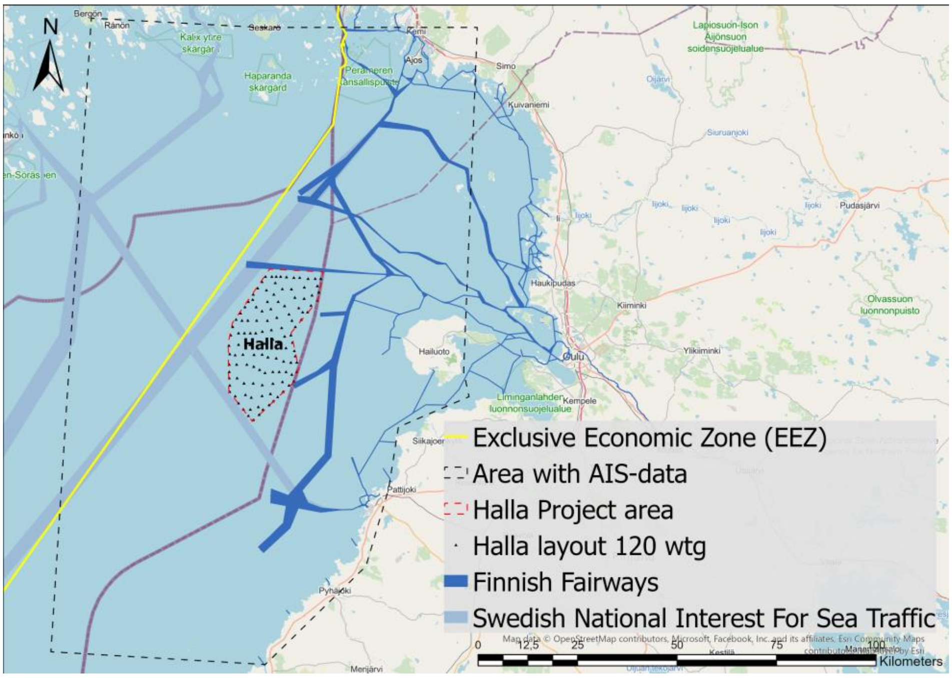

Figure 1. Map showing the Halla Project Area and area with AIS-data, analysis area.

1.1 Purpose

The purpose of the risk assessment is to analyse what impact establishment of Halla OWF has on the navigational safety, considering environmental and human safety.

The risks of establishing Halla OWF are analysed based on Traficoms and Väylävirastos guidance for spatial planning (Traficom and Väylävirasto, 2023)[1].

1.2 Objective

The objective of this study is to identify and describe hazards that may emerge with establishment of Halla OWF which could hamper navigational safety, thus pose a risk for human safety and the environment. The focus is on analysing the *change* in the risk level that the OWF contributes with.

The risk assessment covers the construction phase, operational phase, and decommissioning phase of the OWF.

The structure of the following risk assessment is formulated by the inquiries that emerge from guiding documents and through site-specific conditions. The report adheres to the following overall structure:

- Site description
- Hazard identification
- Risk estimation (risk analysis and assessment)
- Risk mitigation measures
- Uncertainty analysis
- Conclusions

The site description provides the prerequisites which are used as a basis when relevant hazards are identified. The risks are undesirable events that are estimated to occur at some point which could affect the navigational safety, thus human safety, and the environment. Based on the events that are identified, as well as data of shipping accidents and information on how OWFs could affect navigation equipment. The consequences that the events could give rise to and the probability of them occurring are estimated. The risk is defined as a combination of the probability of, and the consequence of a given event. The assessed risks and possible risk mitigating measures are discussed.

Input data to the risk assessment such as statistics and expert assessments are always subject to various types of uncertainty. For this reason, the uncertainties that are considered relevant for this analysis and how it may affect the results are described.

1.3 Method

The risk assessment of nautical risks follows the methodology of a FSA (Formal Safety Assessment) described in *Revised Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process* (Maritime Safety Committee, 2018). However, the report does not cover a cost-benefit analysis of potential risk mitigation measures.

1.3.1 Risk concept

Risk is defined as the combination of the probability of an undesirable event, and the consequence of that event. The probability describes the frequency for a

[1] *Merituulivoiman ja merenkulun sekä merenkulun infrastruktuurin yhteensovittaminen*

given event to occur, and the consequence describes the severity of the damage that may occur.

Figure 2 illustrates how the risk increases with increasing probability and/or consequence of an event.

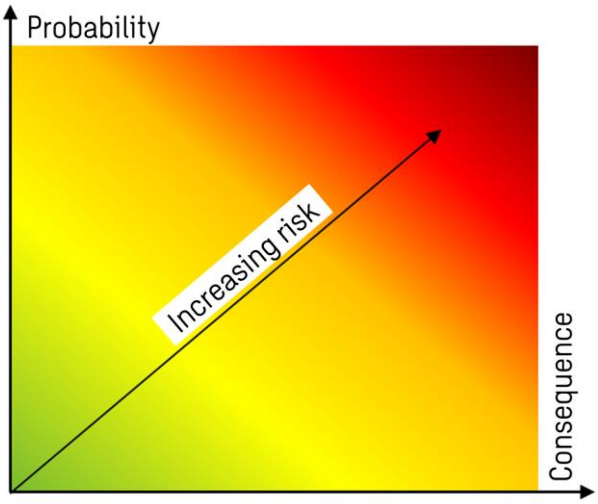

Figure 2. Increasing risk dependent on probability and consequence.

1.3.2 Process

This study follows the steps of the risk management process:

- **Risk assessment** – includes hazard identification, risk analysis and risk assessment
    - *Hazard identification* – inventory of events (scenarios) that may entail undesirable consequences.
    - *Risk analysis* – qualitative or quantitative estimation of probability and consequence for each scenario
    - *Risk assessment* – After the risk analysis, a valuation is made to determine whether the risks can be accepted or not. As part of the risk assessment, proposals for risk-mitigating measures can also be given.
- **Risk reduction/control** – the last step in the risk assessment process includes the decisions taken concerning potential risk mitigating measures that effectively could be taken to achieve an acceptable level of risk.

Thus, the risk management process includes risk assessment (hazard identification, risk analysis and risk assessment) as well as risk reduction/control.

The present risk analysis is carried out using different methods depending on the identified event being analysed. Frequencies are primarily quantified by modelling in the IWRAP Mk2 software[2]. Frequencies for events that cannot be calculated in IWRAP are quantified by desktop study and calculation or expert judgement.

[2] IWRAP is a modelling tool for nautical risk analyses and is used to assess the frequency of collision, grounding and allision based on different conditions.

For events that cannot be analysed quantitatively, a qualitative assessment is made based upon the place bound geographical conditions, previously conducted investigations with similar conditions, research and available statistics.

1.3.3 Risk assessment criteria

The risk assessment is carried out using a risk matrix (Figure 3) where each risk is ranked based on the frequency and severity of the consequence on a logarithmic scale. The matrix is based upon parts from the FSA-methodology proposed by IMO (Maritime Safety Committee, 2018). The ranking is undertaken using available data, supported by judgement, on the scenarios. The risk level is calculated as the sum of the frequency index and the severity index. Matrices of this type are commonly used in nautical risk assessments of environmental impacts or impacts on third party (the public).

			Severity			
			1 *Minor*	**2** *Significant*	**3** *Severe*	**4** *Catastrophic*
Frequency	**6**	**Probable** *Once per year*	7	8	9	10
	5	**Reasonably probable** *Once per 10 years*	6	7	8	9
	4	**Unexpected** *Once per 100 years*	5	6	7	8
	3	**Remote** *Once per 1 000 years*	4	5	6	7
	2	**Very remote** *Once per 10 000 years*	3	4	5	6
	1	**Extremely remote** *Once per 100 000 years*	2	3	4	5

Figure 3. Risk matrix for valuation of navigation risks for the OWF. RI, Risk index[3], is given by the values in the color-coded fields.

- Red risks (events with risk index ≥8) are assessed as unacceptable. Scenarios classified as red involve such risk that risk mitigation measures must be taken to achieve an acceptable level of risk.
- Yellow risks (events with risk index ≥5) are assessed as tolerable if technically and economically reasonable measures are taken. Risks in this level shall be addressed using the *As Low As Reasonably Practicable (ALARP)* principle. For scenarios ranked as yellow, the risks must be carefully considered, and reasonable risk reduction measures should be taken.
- Green risks (events with risk index risk index <5) are assessed as acceptable. For scenarios classified as green, the risks levels are considered so low that risk mitigation measures are not needed to be taken.

[3] Risk index is the sum of the frequency index, FI, and severity index, SI. Risk is usually expressed as Probability x Consequence, and the risk index in this case is the 10-logarithm of Probability x Consequence.

Probability is ranked according to a scale of occurrence frequency, see Table 1. The six-pointed scale range from *extremely remote* to *probable* for events to occur. The scale is commonly used to rank various events in shipping and is also acknowledge by IMO (Maritime Safety Committee, 2018).

Table 1. The table is showing the ranking of events based on frequency of occurrence made in risk analysis and reflects an expected probability of an event to occur that may affect the environment or hamper human safety.

Index (FI)	Frequency	Occurrence	Definition
6	Once per year (*f*=1)	Probable	Events that are expected to occur every year.
5	Once per 10 years (*f*=0.1)	Reasonably probable	Events that are expected to occur each year if 10 OWFs are taken into account, i.e., events that are expected to occur a few times during the lifetime of an OWF.
4	Once per 100 years (*f*=0.01)	Unexpected	Events that are expected to occur every year if 100 OWFs are taken into account, i.e., events that are expected to occur every year in any OWF in the world.
3	Once per 1 000 years (f=10^{-3})	Remote	Events that are expected to occur every year if 1 000 OWFs are taken into account, i.e., events that are expected to occur every ten years in terms of all the OWF in the world.
2	Once per 10 000 years (f=10^{-4})	Very remote	Events that are expected to occur every year if 10 000 OWFs are taken into account, i.e., events that may occur once in terms of all the OWFs in the world during their lifetime.
1	Once per 100 000 years (f=10^{-5})	Extremely remote	Events that are not expected to occur.

Consequences are graded according to a scale of severity regarding safety of human health and the environment, see Table 2. In this study, the scale has four levels ranging from *minor impact* to *catastrophic impact* and is based on examples in the IMO FSA methodology (Maritime Safety Committee, 2018). Scales of this type are commonly used to rank various events in shipping.

Table 2. The table is showing the ranking of events reflecting the severity of the consequence in terms of its impact on the environment and human safety.

Index (SI)	Severity	Effects on human safety (fatalities)	Effects on the environment (oil spill)
1	Minor	Single or minor injuries (0.01)	(1 tonne spill)
2	Significant	Multiple or severe injuries (0.1)	(10 tonnes spill)
3	Severe	Single fatality or multiple severe injuries (1)	(100 tonnes spill)
4	Catastrophic	Multiple fatalities (10)	(1 000 tonnes spill)

When the various events have been indexed with probability and consequence indices, a risk index can be calculated. For details on this, please refer to Appendix A.

1.4 Scope and limitations

The risk assessment covers risks for the maritime traffic during the construction phase, the operation phase, and the decommissioning phase of the OWF. The focus is on analysing if there is a *change* of the level of risk generated by the OWF.

This investigation follows the methodology of an FSA (Formal Safety Assessment) with the exception that cost-benefit analysis of potential risk mitigation measures is not performed (it can be performed later if necessary).

Only the hazards to maritime traffic caused by the OWF are analysed. The analysis focuses on WTGs and hydrogen platforms.

The accidents involving merchant vessels and other large vessels is mainly analysed, and to a lesser extent accidents relating to fishing and pleasure boats is studied. Risks emerging from the OWFs working vessels are analysed to the extent that they affect merchant vessels and non-commercial vessels passing through the OWF.

The study does not include:

- Consequences for the operation of the OWF (e.g., damage to property or production loss)
- Occupational hazards (including collisions between working vessels)
- Hazards to occupational health and economic risks not directly linked to human safety and the environment.
- Non-nautical risks that may occur from the OWF operation.
- Risks for small vessels including pleasure boats and small fishing boats, navigating outside established routes or in the OWF.
- Other objects than WTGs and platforms

Frequencies for allision with platforms are included in this report. Risk assessment of hazards involving hydrogen is presented in a separate Seveso report.

Halla OWF impact on vessel radar is analysed based on general knowledge about radar disturbances and OWFs. The exact disturbances to vessel radar systems and at what distances it occurs can only be assessed with sufficient accuracy when the final design of the OWF and WTG placement is known.

2. Site description

2.1 The OWF and its surroundings

Halla OWF is planned about 60 km off the coast of Oulu in the region of North Ostrobothnia in Finland. The wind farm is about 550 km^2 in size and is planned for approximately 120 WTGs with a total height of 370 metres. The technology that is planned to be used are bottom fixed offshore WTGs with a total installed capacity of approximately 2.4 GW. Other structures within the offshore wind farm are substations for hydrogen production, pipelines, array, and export cables.

The layout is not laid out in a regular grid pattern (see Figure 1 on page 8) but instead the WTGs are more scattered. In order to maximize the energy production, wind turbines could not be placed in straight lines. It would increase the wake effect remarkably and reduce the annual energy production as well as shorten the WTG lifetime.

There are several planned wind farms in the area near Halla OWF (see Figure 4). The cumulative effect of these wind farms are all studies and assessed in the project's Environmental Impact Assessment (EIA), but only some of them are assumed to (together with Halla) have cumulative effects regarding the nautical risks and are accounted for below.

Polargrund Offshore (henceforth referred to as Polargrund OWF) is planned and located approximately 7 kilometres northwest of the Halla OWF, hence it is the closest OWF. The shipping lane Nordvalen – Kemi/Tornio is also located between Halla and Polargrund OWF and is the shipping lane with most traffic in the area. The establishment of Halla and Polargrund OWF is assumed to result in higher traffic density (both more traffic as well as congested traffic) due to traffic currently passing through the OWFs will have to use the shipping lane as well as keeping a safe distance to the OWFs. Thus, the cumulative effects of Polargrund OWF will be included in the assessment of the nautical risks.

Bothnia Offshore Omega (henceforth referred to as Omega OWF) is planned and located approximately 19 kilometres southwest of Halla OWF. It is also located close to the shipping lane Nordvalen – Kemi/Tornio, and there is a possibility that it can affect the traffic to move closer to Halla OWF. Traffic currently passing though Omega OWF will also have to use Nordvalen – Kemi/Tornio, hence increasing traffic in the shipping lane. Thus, the cumulative effects of Omega OWF will be included in the assessment of the nautical risks.

Bores Krona 1, 2, 3 OWF is planned and located approximately 33 kilometres west of Halla OWF. Due to the long distance from Halla OWF, the cumulative effects of Bores Krona 1, 2, 3 OWF are assessed to be negligible regarding nautical risks.

Suurhiekka OWF is planned and located approximately 20 kilometres northeast of Halla OWF. Between Suurhiekka and Halla OWF 3-4 fairways are located. Traffic currently passing through the OWFs is likely to use the closest fairway to navigate around the OWFs once established. Due to the location of the fairways between the OWFs, the traffic changes for Halla OWF are not assessed to affect the nautical risks for Suurhiekka OWF, and vice versa. Thus, the cumulative effects of Suurhiekka OWF are assessed to be negligible regarding nautical risks.

MH OWF is planned and located approximately 20 kilometres south of Halla OWF. The fairway Farstugrunden – Raahe is located between MH and Halla OWF. The location of MH OWF is not expected to affect the traffic in Farstugrunden – Raahe notably, and thus the cumulative effects of MH OWF are assessed to be negligible regarding nautical risks.

Maanahkiainen OWF is planned and located approximately 27 kilometres south of Halla OWF. Maanahkiainen OWF is located close by MH OWF, but even further from Halla OWF. Thus, the cumulative effects of Maanahkiainen OWF are assessed to be negligible regarding nautical risks.

Kappa OWF is planned and located approximately 130 kilometres southwest of Halla OWF. The cumulative effects of Kappa OWF are assessed to be negligible regarding nautical risks, due to the long distance from Halla OWF.

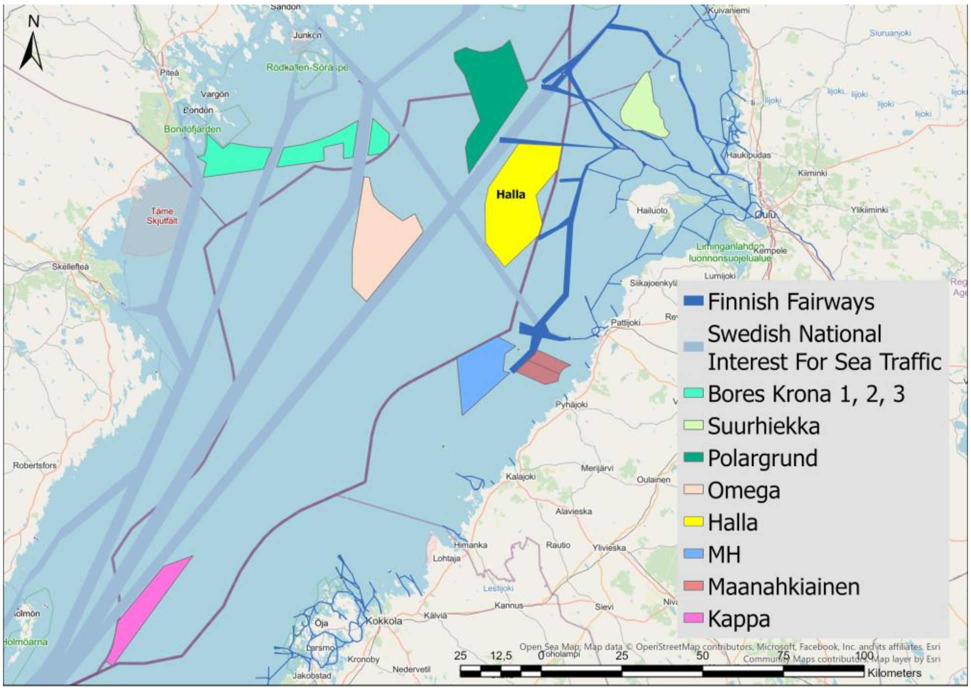

Figure 4. Map showing the Halla Project Area and nearby offshore wind farm projects.

The risk assessment extends to the area within which AIS data is collected and amounts to an area of approximately 14 300 km^2, which is shown in the map below (Figure 5).

The area of AIS data will henceforth be referred to as the analysis area.

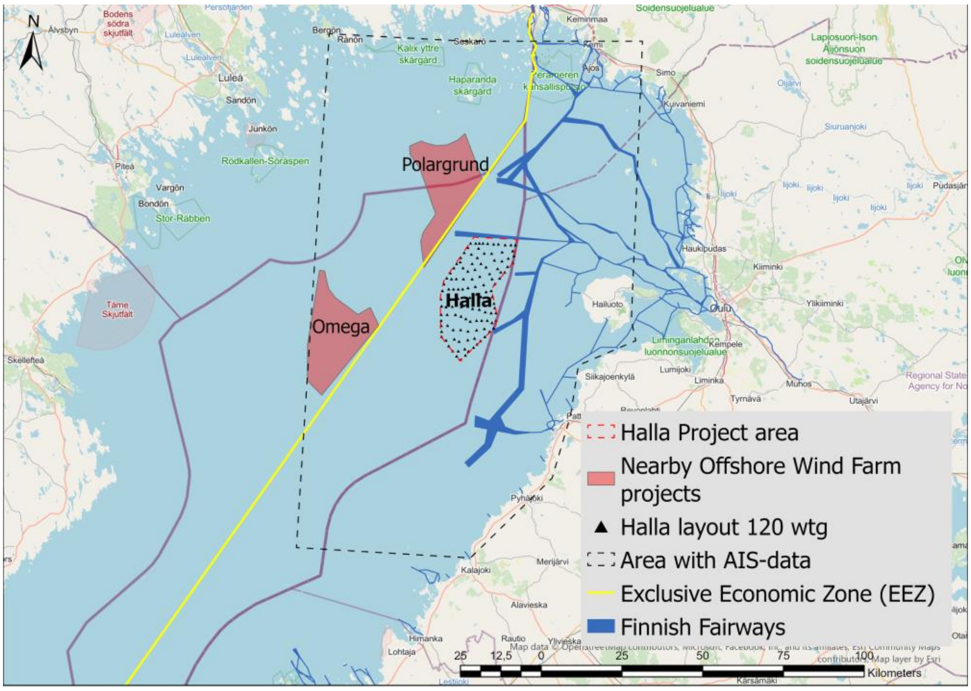

Figure 5. Map showing the Halla Project Area, nearby offshore wind farm projects (of relevance for this NRA) and area with AIS-data, analysis area.

Prevailing wind direction in the area is from the south-southwest (SSW) with an average wind speed that amounts to 6.8 m/s. The mean water depth in the northern part of the project area is around 53 meters and is surrounded by a greater depth further north towards the Gulf of Bothnia. The mean water depth in the project area is in average 31 metres, with a greater depth in the western parts, and shallower in the eastern parts. Further description of wind and water depth conditions, see Traffic analysis: Offshore wind Farm, Halla (Sweco, 2023a).

2.1.1 Ice conditions and ice management

The fact that large parts of the waters of the Baltic Sea, especially the Bothnian Bay, freeze every year affects shipping.

In general, in the vicinity of the Halla project area, the ice conditions are such that drift ice are common and ice ridges occur occasionally, which are difficult to pass through and constitute an obstacle to navigation according to the Finnish Transport Infrastructure Agency (Finnish Transport Infrastructure Agency, 2023). The 2021–2022 ice winter, the year, which is analysed in the following risk analysis, was a mild ice winter, but it lasted longer than usual in the Gulf of Bothnia. Maximum ice extent occurred on February 4, 2022, when the ice covered an area of 93 000 km^2. For detailed information about ice winters and different types of ice, see Traffic analysis: Offshore Wind Farm, Halla (Sweco, 2023a).

Vessels frequently become dependent on icebreaker assistance. Ice buildup and coverage during winter and spring months often forces ships to take different routes than during months without sea ice. Different types of ice cover can also affect sea traffic in different ways. In harsh weather conditions, the role of ice management becomes important to ensure the safety of navigation and fluent flow of traffic calling at ports.

Physical Ice Management by icebreakers allows operations to be conducted safely throughout the ice season. Ice monitoring and evaluating the ice conditions of local areas provide crucial decision-making support for the icebreaker operations[4]. Icebreakers operating in the area is hence a prerequisite for the continuation and safety of shipping in the area, and thus a risk-reducing measure already in place around Halla[5].

2.2 Shipping lanes and traffic patterns

The planned OWF is surrounded by several traffic lanes (see Figure 6). Along the northern edge of the project area runs the Oulu 1 fairway. Further north goes Kemi/Ajos/Tornio, which leads into the shipping lane Nordvalen – Kemi/Tornio (recognized within the Swedish national interest for sea traffic) also passes directly adjacent to the project area in the northwest. Southwest of Halla OWF there passes a shipping lane Farstugrunden – Raahe (also recognized within the Swedish national interest for sea traffic). Outside Hailuoto and east of the Halla project area, the Raahe-Oulu-Kemi fairways run north-westwards.

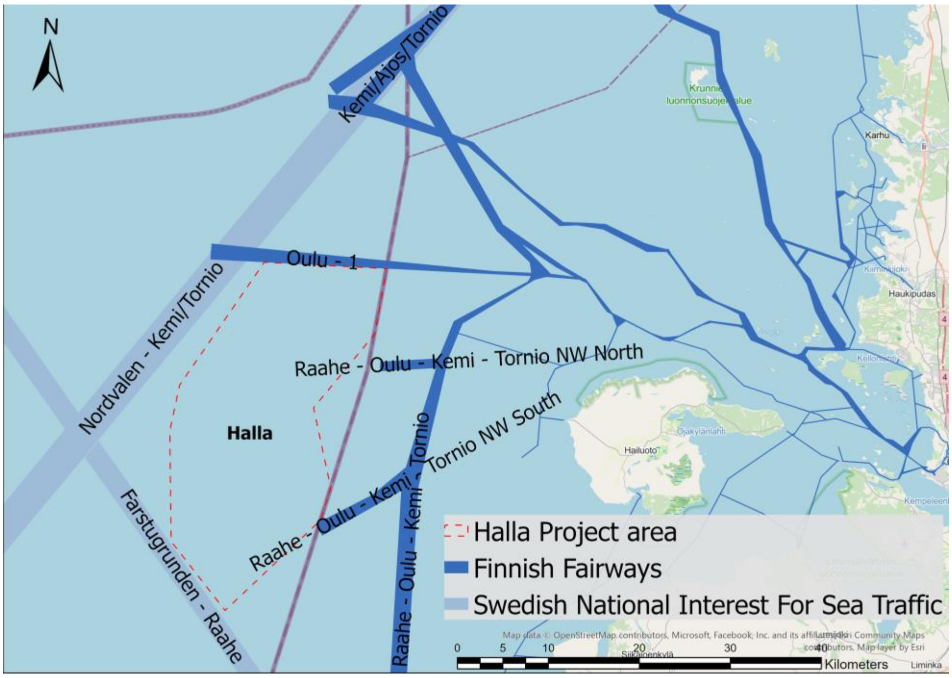

Figure 6. Map showing traffic lanes and fairways adjacent to Halla project area.

In addition, according to Traficom, a so-called pilotage route, however it does not have right of way, runs through the Halla OWF (Traficom, 2022a). As it is not an established link, it is therefore not illustrated in Figure 6 above. The pilotage route

4 Icebreakers have the monitoring tools to analyse existing ice conditions and predictions for future ice situations based on satellite images, weather predictions and shipping traffic predictions. There are a variety of ways to break or deflect ice, with the optimal of which depends on the specifics of the operation being supported and the available vessels.

5 Markku Mylly, Master Mariner / Safety and Security, October 7th, 2023.

is designated for piloting of vessels with the largest draughts since it is a water-depth-secured area.

Maritime traffic in the area is analysed in the traffic analysis for Halla OWF (Sweco, 2023a).The traffic analysis shows that there are relatively few vessels within the traffic lanes in the analysed area, usually about 1-3 vessels per day within each traffic lane/fairway.

The AIS-data used for the traffic analysis is from year 2022. Traffic patterns in 2022 during months with sea ice and months without sea ice are illustrated in Figure 7 and Figure 8 below.

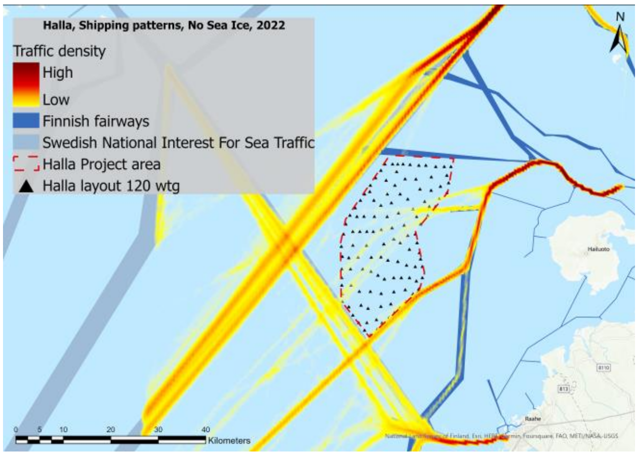

Figure 7. Heatmap of shipping patterns around Halla during periods with no sea ice (2022-06-01 – 2022-12-31).

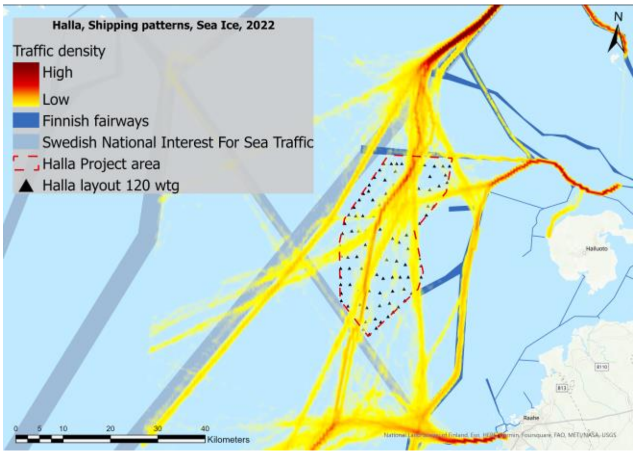

Figure 8. Heatmap of shipping patterns around Halla during periods with sea ice (2022-01-01 – 2022-05-31).

With establishment of Halla OWF, the traffic that currently passes through the project area will instead, in most cases, assumably choose a route that goes outside of the project area. Hence, in the risk modelling, the traffic within the project area will be moved to traffic lanes and fairways outside of the project area. The unofficial pilotage route that runs in the south-north direction, will be moved to Nordvalen – Kemi/Tornio and the traffic that runs from Raahe – Oulu – Kemi – Tornio NW North, will be moved to Raahe – Oulu – Kemi – Tornio NW South.

More information about the traffic conditions and patterns in the area can be found in the traffic analysis (Sweco, 2023a).

2.3 Shipping accidents

Traficom compiles maritime safety related issues in Finnish water areas and presents various seafaring statistics in Finnish waters. Among other things, the number of accidents that have occurred in Finland's water areas examined over a period between 2010 and 2022 is summarized, as illustrated in Figure 9. According to the compilation, an average of between 25–43 maritime accidents occurred annually in Finland's waters, not counting accidents with casualties. The annual variation is large but random and should therefore not be seen as a contributor to maritime accidents.

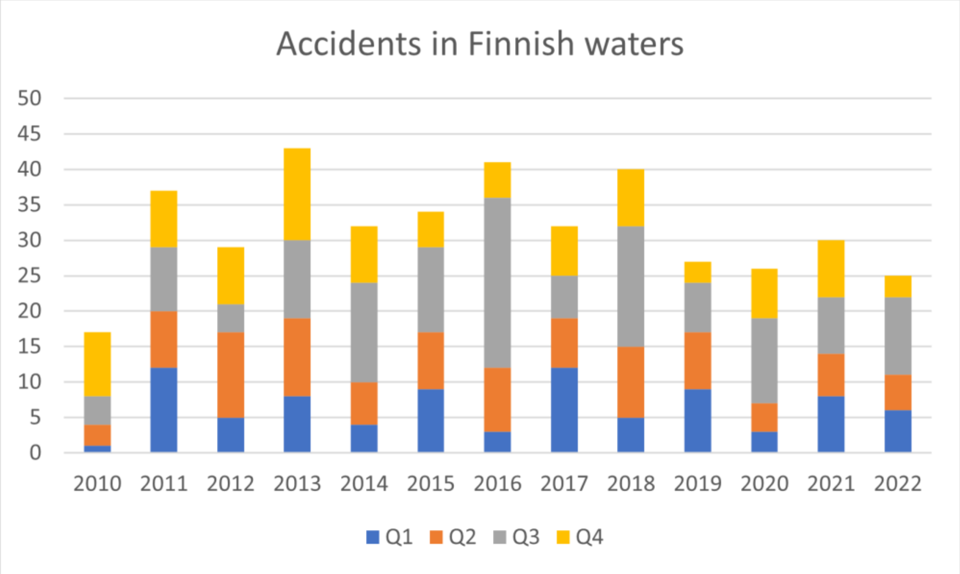

Figure 9. The figure shows accidents that have occurred in Finnish waters between 2010 and 2022. The information for the figure is taken from Traficom (2023a).

The accidents presented are grounding/stranding, collision, contact, fire/explosion and other accidents. The most common type of accidents during the period are grounding/stranding, and the number has generally remained the same from year to year.

In 2022, there were 10 grounding/strandings, accounting for 40% of accidents, five contacts, accounting for 20% of all accidents, while the number of collisions was three, accounting for 12% of all accidents. Figure 10 provides illustrates accidents that have occurred in Finnish water areas in 2022 by accident class.

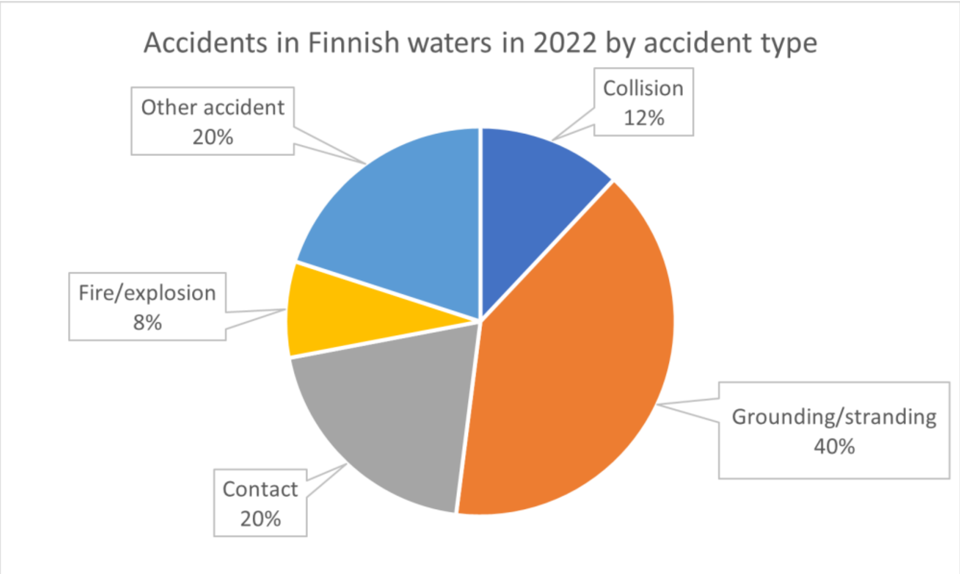

Figure 10. The figure shows accidents that occurred in Finnish waters in 2022 by accident type.

The majority of accidents that occurred in Finnish waters involved mainly Ro-Ro passenger ships (24%), followed by passenger ships (16%), other vessels (16%) and Ro-Ro- cargo ships (12%). Figure 11 below shows accidents that occurred in Finnish territorial waters in 2022 by vessel class.

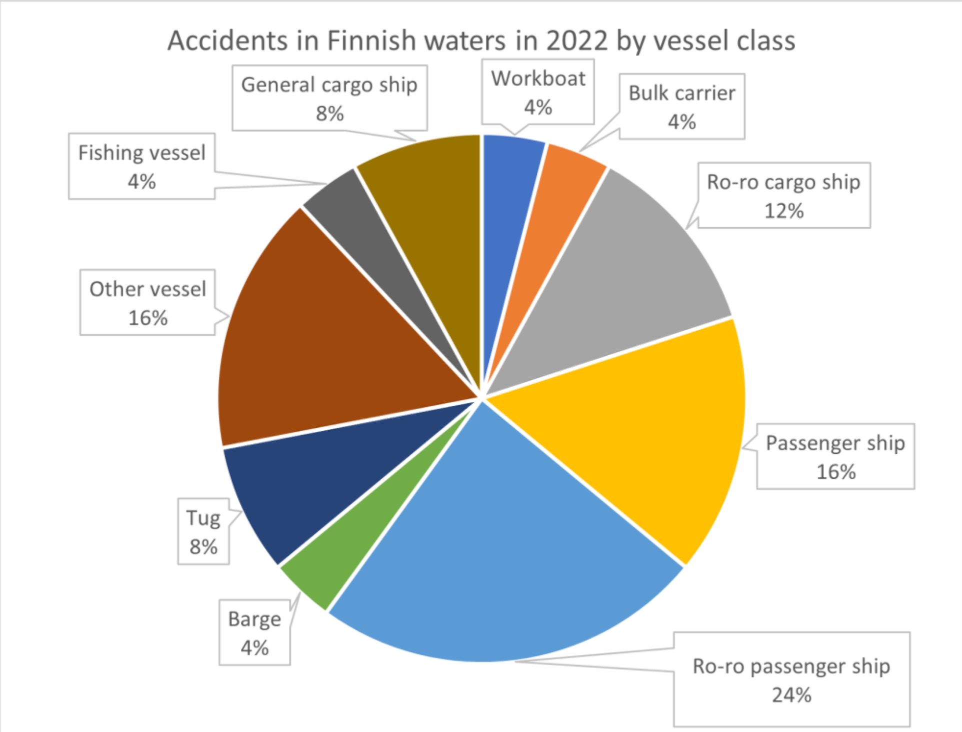

Figure 11. The figure shows accidents that occurred in Finland's territorial waters in 2022 by vessel class.

HELCOM (2022) presents accident statistics in the Baltic Sea during the period 1989 to the end of 2020. In the area of analysis for Halla (i.e., the same area where AIS data was collected), 60 accidents were reported during the period. In 2022, Figure 12, next page, shows the types of accidents and their positioning. The accidents are generally scattered but mainly occurs near or in shipping areas, for example around the fairway and ports of Kemi/Ajos/Tornio. In the area of analysis, 29 of the reported accidents are collisions and seven of the reported accidents are groundings.

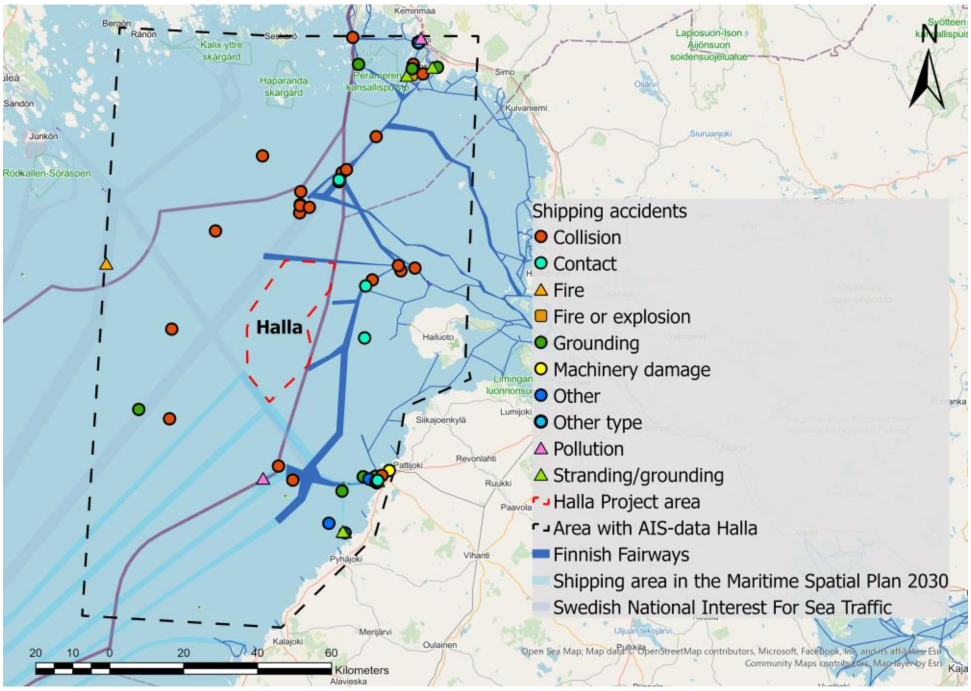

Figure 12. Accidents registered in the vicinity of the Halla project area between 1989-2020, a total of 60 accidents. The area in which accident statistics have been compiled is marked with a black, dashed line. The accidents are divided into different types. The information is obtained from HELCOM (2022).

2.3.1 Shipping accidents in OWFs

Table 3 gives an overview of reported events where ships have drifted or navigated into WTGs. Accidents have been identified by research of different databases, articles, and accident investigations. The purpose of the overview is to study the course and possible consequences of accident scenarios including OWFs. The list does not claim to be comprehensive.

Table 3. Accidents with WTGs involving maritime traffic.

Event	Description	Consequence human safety	Consequence environment
Work vessel in the park collided with a WTG (MAIB, 2013)	2012-11-21: The personnel vessel Island Panther navigated into an unlit part of a WTG at Sheringham Shoal wind farm at a speed of 12 knots. It was night and rough weather, and the officer did not rely on radar due to the risk of interference.	Both staff and passengers suffered injuries that were not life-threatening (concussion, broken arm, injuries from broken glass, jaw injuries, injuries to chest and back)	Damage to bow and stern but no oil spills.
Work vessel in the park collided with a WTG (Federal Bureau of Maritime Casualty Investigation, 2019)	2018-04-10: The service vessel Vos Stone collided with a WTG during the construction phase of the Arkona Becken Südost wind farm in the Baltic Sea. The reason is stated to be a test of the emergency management system that led to loss of control of the ship.	Three crew members on board the ship suffered minor injuries.	Damage to ship and platform but no spills.
Work vessel in the park collided with a WTG (Jersey Maritime Administration, 2020)	2020-04-23: The service vessel Njord Forseti drives at a speed of 20 knots into the foundation of a WTG at the Borkum Rifgrund wind farm in the North Sea. The master is reported to have adjusted the VHF and thereby been distracted from his primary task in violation of rule 5 of COLREG.	Two passengers were evacuated to hospital, and a third later underwent medical examination. All left the hospital within a day.	Hull damaged but no spills.
A Cargo vessel became unmaneuvreable and drifts into a foundation (Vattenfall, 2022)	2022-01-31: The bulk carrier Julietta D drifted into a monopile foundation of a planned WTG in the Hollandse Kust Zuid wind farm and bumped into a jack to a platform in the park. The ship had been drifting for several hours after a collision with another ship.	The ship had been evacuated of its 18 passengers by helicopter before the collision, with no one injured in the wind farm. However, personnel were injured during rescue and towing.	The ship was damaged since the previous collision and took in water, but no spills was reported.
Navigating vessels collided with a WTG (under investigation of BSU, the German Federal Bureau of Maritime Casualty Investigation)	2023-04-05: The Cargo vessel Petra L. navigated into a WTG. Preliminary information indicates that the ship was on the wrong course and navigated into a WTG. Accident investigation is ongoing.	No casualties were reported.	A 3x5-meter hole in the hull but no reported spills.

2.4 Future traffic

Traficom states in its report of national traffic forecasts (Traficom, 2022b) that freight transport by sea is expected to increase and has produced forecasts until 2060. According to foreign maritime traffic forecasts for 2060, total exports in the maritime traffic in Finland will by 2060 be approximately 9 percent greater in terms of tonnage than in 2021. Correspondingly, according to the forecast, total imports will be approximately 19 percent greater. Total exports are expected to remain stable until 2035, after which they are expected to start growing. Total imports are expected to increase significantly in the next few years, as imports from Russia transported by rail are replaced by imports from other countries transported by sea. After this, total imports are expected to decrease due to decreasing crude oil imports, among other factors. However, there are significant uncertainties in the starting points of traffic forecasts due to major changes in the operating environment.

The Swedish Transport Agency's forecasts indicate that freight transport by sea is expected to increase by approximately +1.7 % per year until 2040 (Trafikverket, 2023) in terms of the number of tonne kilometres per year. This means that freight transport (measured in the number of tonne kilometres) in 2040 will increase by approximately 33.2 % compared to 2023.

There are several reasons for the increased share of traffic and larger vessels. Traficom points out (Traficom, 2022a) that the draught on the new Oulu Strait and the deepening of Kemi Ajos fairway will increase maritime traffic and enable larger vessels. Furthermore, traffic to Ajos will increase significantly following the completion of Metsä Group’s new bio-factory, which will use a larger vessel fleet.

As stated in traffic analysis (2023a), establishment of the Halla OWF would lead to some changes in traffic and patterns. Potential scenarios could mean that even more traffic will concentrate in Nordvalen – Kemi/Tornio, and in Raahe – Oulu – Kemi/Tornio NW South.

Considering the above information, it is likely that the vessels in the area around Halla OWF will rather increase in size and not as much in number. However, it is uncertain whether the expected increase in transport work leads to a greater number of ships or to the ships themselves becoming larger and heavier.

This study considers future vessel traffic in two ways:

- Frequencies are calculated for a baseline case (current traffic based on AIS data) and an uncertainty analysis case where future traffic flows are set to increase by 35% for forecast year 2060.
- Consequences of accidents are chosen conservatively based on assumptions about future, larger vessels.

2.5 Safety distances

The right of innocent passage is regulated in the United Nations Convention on the Law of the Sea (UNCLOS) (United Nations, 1994). In this agreement there is, among other things, article 60.7 "Artificial islands, facilities and constructions and safety zones around them may not be established where they can impede the use of recognized waterways of essential importance for international shipping".

In addition to UNCLOS, there is also the International Law of the Sea or International Law of the Sea for the Prevention of Collisions at Sea (COLREG) (IMO, 1972). These are rules according to the convention that regulate the obligations of vessels in terms of avoiding collisions. COLREG describes the obligations of larger merchant vessels to avoid manoeuvres required to avoid collisions at sea. In order to create opportunities for these vessels to fulfil their obligations for evasive manoeuvres, a safety distance between maritime traffic and fixed foundations at sea, including WTGs, is often recommended.

The safety distance is determined on a case-by-case basis, depending on, among other things, the location of the wind farm, geographical aspects, and vessel traffic in the area.

PIANC is a global organization that develops recommendations to achieve sustainable transport at sea and on other waterways (PIANC, 2023). The conservative assessment of distance recommendations and space requirements, as specified by PIANC, can be achieved by outlining their recommendations and showcasing the available manoeuvre space in open water. In winter, when ice conditions prevail, authorities may impose specific traffic restrictions. Depending on ice conditions, the Finnish Transport Infrastructure Agency (Väylä) applies size and ice class restrictions to vessels eligible for icebreaker assistance (Traficom & Swedish Transport Agency, 2019). Furthermore, based on the Maritime Traffic Act, Traficom closes certain fairways during the winter season to ensure traffic connections in the archipelago while the fairways are covered with ice. (Traficom, 2023b). However, there are no official guidelines or recommendations given regarding safety distances during ice-covered conditions.

In the report *MarCom Wg 161: Interaction Between Offshore Wind Farms and Maritime Navigation* (2018), PIANC presents recommendations regarding safety distances to WTGs. The recommendations are based, among other things, on COLREG and its rules regarding safe passages at sea. There are two methods for producing safety distance recommendations:

- Concept design, providing a conservative recommendation of safety distance between WTGs and vessels.
- Detailed design, where the safe distance can possibly be changed after an in-depth nautical risk analysis.

The recommendation, according to Concept design, means that the distance from the vessel to a wind farm should be such that a vessel should be able to perform a complete evasive manoeuvre (360° turn). Such a distance is estimated to be achieved at 5 vessel lengths. To allow room for possible complications, a manoeuvring distance is conservatively estimated to be about 6 vessel lengths. In addition, a security zone for the wind farm of a maximum of 500 metres must also be added (UNCLOS security zone). This distance can be shorter but must not exceed 500 metres. To ensure that a safe evasive manoeuvre can be made in connection with other vessels being nearby, 0.3 M is added to the safety distance on the starboard side. This means that the minimum safety distance (safety zone excluded) between the vessel and the closest WTG in the OWF is recommended to be as follows (see also Figure 13, where d is the shortest recommended distance):

- On the starboard side of the vessel d = 556 metres (0.3 M) + 6 vessel lengths
- On the port side of the vessel d = 6 vessel lengths

The above safety distance is recommended between the closest WTG in an OWF and the nearest Traffic Separation System (TSS). The distance is illustrated in Figure 13. For a TSS, it is clear where the distance is to be measured from. However, this is not specified for national interests for shipping or traffic lanes without TSS.

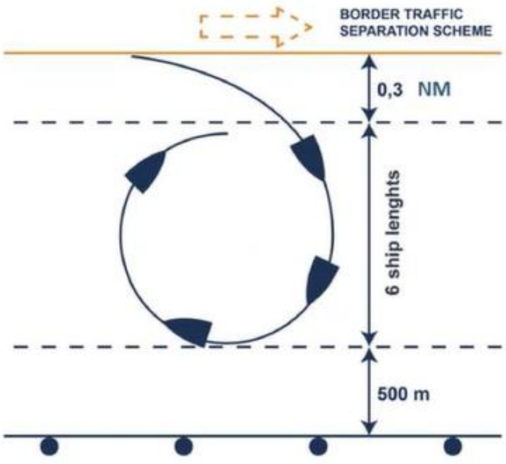

Figure 13. Illustration of distance between TSS and wind farm according to PIANC (the round turn to starboard side) (PIANC, 2018).

PIANC gives examples of how wide a traffic lane could be. The traffic lane should be assigned an appropriate width based on the amount of traffic in the traffic lane (PIANC, 2018). Appropriate width of traffic lane depends on the number of vessels operating in the route, and is compiled below:

Number of vessels using the route, allowing 2 ship lengths per vessel:

<4 400 vessels per year	2 vessels side to side
> 4 400 vessels and <18 000 vessels per year	3 vessels side to side
> 18 000 vessels per year	4 vessels side to side

The vessel length is based on the largest length of vessels using the route, taking into account future traffic and developments in ship size[6].

The Ministry of Infrastructure and the Environment in the Netherlands (2014) also mentions the traffic lane widths according to the guidelines above as suitable.

[6] Example: a traffic lane which accommodates 18,000 vessels per year with a maximum size of 400 metres should be at least 3 200 metres wide (= 4 x 2 x Length = 4 x 2 x 400)

They state that the length of a reference vessel corresponding to the 98.5 percentile, i.e., only 1.5% of other vessels are longer, operating the lane is appropriate to use when deciding on the width of the lane.

It is important to take into account the boundary conditions to ensure safety and operational capacity for shipping. Traficom (2022a) states that this requires ensuring a safety distance of 1.5 kilometres between the fairway areas and OWFs. Traficom and Väylävirasto (2023) refer in their document with instructions on risk assessment in spatial planning of offshore wind power to “The Spatial Planners’ guide to distances between Shipping & Offshore Renewable Energy Installations” which incorporates, inter alia, PIANCs recommendations as well as Dutch guidelines.

According to the guidelines regarding the width of a traffic lane based on PIANC (2018) and The Ministry of Infrastructure and the Environment, Netherlands (2014), the future shipping lanes for transport to and from the Bothnian Bay, require a width of around 916 metres[7]. All transits within the area of analysis amounts to 4 052 (2023a), which requires 2 vessels side to side (less than 4 400 vessels per year using the route). Hence, the calculation considers potential increase in number of transits. Therefore, the vessels using each fairway or shipping lane, will not exceed 4 400 vessels per year taking into account Traficom (2022b) and the Swedish Transport Agency’s (2023) forecasts.

There are different ways to define a safety distance. Traficom (2022a) and PIANC (2018) are presented and compiled below. For more information about how the safety distances where calculated, see the Traffic Analysis (Sweco, 2023a).

Traficom safety distance

To meet Traficom’s (2022a) desire of 1.5 km safety distance between fairway areas and OWF, in combination with a recommended width of the shipping area being 916 metres, the total distance between Halla OWF and Polargrund OWF is recommended to be 3 916 metres.

PIANC safety distance

Considering guidelines of PIANC (2018) the recommended safety distance amounts to 1 930 metres[8]. In total, the recommended width, including shipping lane and a safety distance on each side of the shipping lane, results in a minimum distance of about 4 776 metres[9].

The distance between Halla OWF and Polargrund OWF is approximately 7 400 metres, and thus the recommended safety distance of Traficom’s (2022a) as well as PIANC (2018) is fulfilled. This is also valid concerning future traffic volumes and vessel sizes. Note that the recommended safety distance is for open water. There are no guidelines for safety distances in ice conditions.

Note that through a *Detailed design* PIANC (2018) a shorter safety distance, than the one given by *Concept design,* can be proven to be acceptable. This report and its appendixes constitute such a *Detailed design*.

[7] 2 x 2 x 229 (98,5 percentile) = 916. 98.5 percentile is based upon all traffic within area of analysis which is described in (Sweco, 2023a).

[8] PIANC:s recommended safety distance = 556 metres (0,3 M for starboard manoeuvres) + 229 (98,5 percentile vessel) x 6 = 1 930 metres

[9] Total width = Shipping lane + safety distance on each side of the shipping lane = 916 + 1 930 x 2 = 4 776 metres

3. Hazard identification

A nautical risk assessment generally includes risks concerning allision, collision and grounding.

Site-specific input on possible hazards related to Halla OWF was obtained in a digital HAZID workshop (Sweco, 2023b). The HAZID took place on April 19th, 2023, together with a team representing the different stakeholders in the field, to ensure all relevant hazards were identified. The method for the formal HAZID was based on HAZIDs from other similar wind power projects. Hence, relevant keywords were chosen and used to guide the participants through possible nautical hazards and outer conditions that could affect the risks in the area. An additional informal HAZID were held only for the purpose to identify and discuss hazards regarding the ice conditions in the area, both how the ice conditions could affect the OWF and vice versa. Table 4 shows the participants on the HAZID workshops.

Table 4. Participants on the HAZID-workshops.

Name	Organisation	Ice HAZID	Formal HAZID
Ilari Rainio	Alfons Håkans		x
Jari Talja	Alfons Håkans		x
Kimmo Lehto	Alfons Håkans		x
Kari Pohjola	Arctia Meritaito		x
Jussi Vaahtikari	ESL-Shipping		x
Amund Lindberg	Isbreakers Swedish Maritime Administration		x
Sami Järvenpää	Finnish Border Guard / MRCC - Maritime Rescue Coordination Centre		x
Markku Mylly	Sea Focus International	x	x
Anneli Borg	Swedish Maritime Administration		x
Karl Herlin	Swedish Maritime Administration		x
Jani Koiranen	Traficom / Finnish Transport and communications Agency		x
Laine Valtteri	Traficom / Finnish Transport and communications Agency		x
Jarkko Toivola	Väylävirasto / Finnish Transport Infrastructure Agency		x
Taivi Toumas	Väylävirasto / Finnish Transport Infrastructure Agency		x
Frank van der Anker	Wagenborg		x
Mathias H. Arnbert	Wallenius Sol Lines		x
Axel Stenhammar	Wallenius-Sol Lines		x
Carlo Giesecke	OX2	x	x
Ian Bergström	OX2		x
Janne Lamberg	OX2		x
Malgorzata Zorawinska	OX2	x	x

Name	Organisation	Ice HAZID	Formal HAZID
Mathias Skog	OX2		x
Olli Takalammi	OX2	x	x
Patrick Lees	OX2		x
Sara Jarmander	OX2	x	x
Anna Bjereld	Sweco	x	x
Emelie Lernbom	Sweco	x	x
Johan Nimmermark	Sweco		x
Lars Grahn	Sweco		x
Matti Lindgren	Sweco	x	x
Seppo Virtanen	Sweco		x
Sara Hammar	Sweco	x	

The key findings from the HAZIDs about hazards which could impact human safety and environment are:

- Unauthorized traffic in the wind farm during winter conditions
- Need for assistance (ice breakers) in case of emergency
- More hummocking ice due to the WTGs
- Unmanoeuvrable ships, winter conditions
- Vessel caught in the ice and drifts with the ice field into a WTG
- OWF blocks the default winter navigation route
- More unfavourable winters with less ice and more wind
- Larger vessels with less power

After sorting the lists of general hazards and hazards identified during the workshop, the hazards in Table 5 are selected as relevant for further analysis.

Table 5. Nautical hazards identified for Halla OWF and reference to sections of this report where the hazards and risks are further analysed.

Id.	Hazard	Referencing
1.1	Ship navigates into a WTG (powered allision)	6.1.1
1.2	Inoperable ship drifts into a WTG (drifting allision)	6.1.2
1.3	Ship navigates or drifts near a WTG and gets hit by blade	6.1.3
1.4	Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)	6.1.4
1.5	Ship navigates or drifts into a platform	6.1.5
1.6	A ship passing through the OWF collides with a WTG	6.1.6
1.7	Limited visibility causing a ship to navigate into a WTG	6.1.7
2.1	Total collision (all collision types: 2.2-2.6) (additional with OWF)	6.2.1
2.2	Overtaking collision (additional with OWF)	6.2.2
2.3	Head-on collision (additional with OWF)	6.2.3
2.4	Crossing collision (additional with OWF)	6.2.4
2.5	Merging collision (additional with OWF)	6.2.5
2.6	Bend collision (additional with OWF)	6.2.6
2.7	Collision with working vessel en route to/from port (additional with OWF)	6.2.7
3.1	Powered grounding	6.3.1
3.2	Drifting grounding	6.3.2

Id.	Hazard	Referencing
4.1	Vessel radar disturbance (target loss)	6.4.1
4.2	Vessel radar disturbance (navigation disturbance)	6.4.2
4.3	Vessel radar disturbance within the OWF	6.4.3
4.4	The OWF complicates search and rescue operations	6.4.4
5.1	The OWF affects ice buildup	6.5.1
5.2	The OWF blocks winter navigation routes	6.5.2
5.3	Falling objects or ice throw from WTGs	6.6
6.1	Transmission cable damage	6.7.1
6.2	Cables prevent emergency anchoring	6.7.2

4. Frequencies

The frequencies of collision, grounding and allision have been calculated with IWRAP. The calculation is based on modelling made for the zero alternative (no OWF) and for the baseline case (OWF represented by the example layout with assumptions about how the OWF will affect the traffic patterns). In addition, uncertainty analysis cases have been calculated. The modelling is presented in Appendix C. A summary of the frequencies used in the risk assessment can be found in Table 6. The results can be broken down into frequencies for different vessel types, vessel sizes and shipping routes, as well as individual WTGs, which are used in the risk calculations in chapter 6.

For scenarios where IWRAP could not be used, frequencies have been estimated or calculated by desktop calculations. A justification for why certain frequencies have been selected can be found in chapter 6.

Table 6. The calculated or estimated accident frequencies used in the analysis. The relationship between the calculated frequency (annual probability) and the frequency index (1-6) is defined in Table 2 in section 1.3.3.

Id.	Scenario	Frequency		
		Probability (per year)	**Return time period (years)**	**(FI)**
1.1	Ship navigates into a WTG (powered allision)	6.8E-05	14 679	1.8
1.2	Inoperable ship drifts into a WTG (drifting allision)	3.5E-04	2 829	2.5
1.3	Ship navigates or drifts near a WTG and gets hit by blade	1.0E-05	100 000	1.0
1.4	Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)	1.5E-02	65	4.2
1.5	Ship navigates or drifts into a platform	1.6E-04	6 327	2.2
1.6	A ship passing through the OWF collides with a WTG	1.5E-03	673	3.2
1.7	Limited visibility causing a ship to navigate into a WTG	-	-	-
2.1	Total collision (all collision types) (additional with OWF)	3.2E-04	3 096	2.5
2.2	Overtaking collision (additional with OWF)	3.1E-05	31 880	1.5
2.3	Head-on collision (additional with OWF)	2.1E-04	4 737	2.3
2.4	Crossing collision (additional with OWF)	Frequency lower with OWF	-	-
2.5	Merging collision (additional with OWF)	6.6E-05	15 142	1.8
2.6	Bend collision (additional with OWF)	1.5E-04	6 783	2.2

Id.	Scenario	Frequency		
		Probability (per year)	**Return time period (years)**	**(FI)**
2.7	Collision with working vessel en route to/from port	1.0E-02	100	4.0
3.1	Powered grounding (additional with OWF)	2.6E-02	38	4.4
3.2	Drifting grounding (additional with OWF)	Frequency lower with OWF	-	-
4.1	Vessel radar disturbance (target loss)	1.0E+00	1	6.0
4.2	Vessel radar disturbance (navigation disturbance)	1.0E-04	10 000	2.0
4.3	Vessel radar disturbance within the OWF	1.6E-04	6300	2.2
4.4	The OWF complicates search and rescue operations	-	-	-
5.1	The OWF affects ice buildup	-	-	-
5.2	The OWF blocks winter navigation routes	-	-	-
5.3	Falling objects or ice throw from WTGs	1.0E-05	100 000	1.0
6.1	Transmission cable damage	-	-	-
5.1	Cables prevent emergency anchoring	-	-	-

5. Consequences

This risk assessment focuses on the consequences for human health and safety and for the environment. Table 2 in section 1.3.3 explains how the magnitude of a consequence, expressed in number of fatalities and equivalent tonnes of oil spill, is mapped to a severity level from 1-4, ranging from *minor impact* to *catastrophic impact*.

Different consequences are expected for different types of vessels and events. The consequences that are assumed in this risk assessment are documented in Table 7. The following rules were applied for choosing consequences:

- The same consequences are assumed regardless of the vessel size.
- The same consequences are assumed for all WTG fundament types, floating included.
- Consequences for human health and safety are assumed to be more severe if a passenger ship is involved.
- Consequences for the environment are assumed to be more severe if a tanker is involved.
- Damage to property (vessels, cargo, and WTGs) and other economic consequences are not estimated.
- Consequences for a powered striking event are assumed to be more severe than for a drifting striking event.[10]
- Consequences are conservatively chosen.

[10] The reason is that an accident with a navigating vessel generally occurs at high speed, resulting in a strong collision force. Due to the higher speed of a navigating vessel the chance of implementing risk mitigating measures are reduced.
A collision with a drifting vessel is likely to occur at a speed of 1-2 knots, which means less force compared to a striking event at full speed. While the vessel is drifting, there may be more time to evacuate the crew and passengers and prepare for the cleanup of a potential spill. Additionally, there may be more time for another vessel to provide assistance in stopping the drifting vessel's movement.

Table 7. Consequences assuming a probable worst-case scenario.

Accident	Consequence to human health and safety (SI)	Consequence to the environment (SI)
Powered allision* Ship hit by WTG blade Collision Powered grounding	Passenger ships: multiple fatalities (4) Other ships: single fatalities or multiple severe injuries (3)	Tankers: equivalent to more than 1 000 tonnes of oil spill (4) Other ships: equivalent to up to 10 tonnes of oil spill (2)
Drifting allision* Drifting grounding	Passenger ships: single fatalities or multiple severe injuries (3) Other ships: multiple or severe injuries (2)	Tankers: equivalent to more than 100 tonnes of oil spill (3) Other ships: equivalent to up to 10 tonnes of oil spill (2)

*The force at an allision is distributed between the vessel and the WTG in such a way that no oil leakage occurs in 90% of cases. This is not reflected in the consequence, but in the risk assessment.

No recommendations for risk-mitigating measures are taken into account when considering the consequences. However, the following basic assumptions are made, which affect the likelihood of the consequence occurring:

- Tankers are equipped with double hulls in accordance with the MARPOL convention.
- Drifting vessels can be restarted with a time-dependent repair probability as presented in Appendix C.
- WTGs can be stopped when vessels approach[11].
- Evacuation of crew and passengers is initiated in the event of an incident.
- Preparations to handle an oil spill are initiated in the event of an incident.

[11] If a vessel enters the OWF area, the WTGs can be stopped, and the rotor blades can be placed in a 'Bunny-ear position' with one blade straight down and two blades slanted upward. Full crew and monitoring are in place, and a WTG can be stopped and brought to a halt in a short time (on a minute scale).

6. Risk analysis

The hazards that were identified in chapter 3 are described and assessed in the sections below with focus on the likelihood of their occurrence and their consequences. The probability is estimated/calculated without any risk mitigating measures included.

The sections are structured in such a way that the type of event (accident) is described first, then the probability and consequence of the event. The consequences are described separately depending on what they affect (human safety or environment). Finally, the resulting risk is reported, calculated based on probability and consequence for the event in question. In cases where the risk consists of risk contributions from several different events in the same category but with different consequences (e.g., powered grounding by oil tankers or passenger ships), the total risk of is calculated as the sum of the constituent risk contributions.

Based on the probability and consequences of each event, the risk is assessed as the increased risk from the establishment of an OWF in the area compared to the current risk level (zero alternative).

For the hazards identified in section 2.5, the probability of their occurrence and their consequences are described and assessed below. The probability is estimated/calculated based on the assumption that no risk-mitigating measures are taken.

6.1 Allision (ship collision with stationary object)

When Halla OWF is established, there is a possible increase in the likelihood of different types of allision. Allision refers to a ship navigating or drifting into a stationary object. Stationary objects associated with Halla OWF include platforms, Wind Turbine Generators (WTG) and the rotating blades. The calculated probability of different types of allisions with establishment of Halla OWF, and Halla, Omega and Polargrund OWF are illustrated in Figure 14, and described and assessed further in section 6.1.1 and 6.1.2.

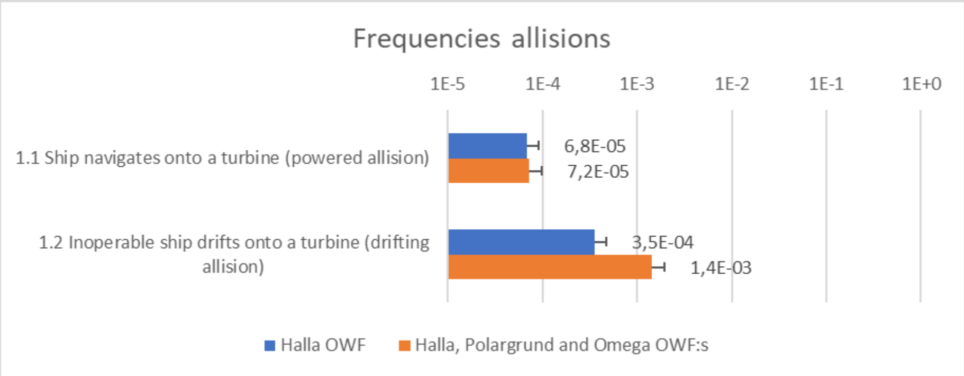

Figure 14. shows the frequency of allision scenarios per year (bars and numbers) with establishment of Halla OWF, and Halla, Omega and Polargrund OWF. Uncertainty bars (black lines) indicate frequency in a future traffic scenario for 2060 where the number of vessels is assumed to increase by 35%. Note that the scale is logarithmic, for return period and further detailed information of frequency, see chapter 1.3.3

6.1.1 Ship navigates into a WTG (powered allision)

Navigating ships navigating around Halla OWF may, due to human, technical or environmental factors, accidentally navigate into the OWF. The probability that an evasive manoeuvre will not be successful in such a situation is assumed in the modelling to be $1.6 \cdot 10^{-4}$ (Engberg, 2019).

Since collisions occur quickly, no remedial or mitigating measures are included in the risk assessment.

The following assessment has been made of the consequences and resulting risk for ship navigating into a WTG (powered allusion).

- **Scenario 1.1 Ship navigates into a WTG (powered allision):** Ship navigating into WTG (within a diameter of 16 meters) are assumed to collide with the WTG at full speed. The frequency for this event with Halla OWF established is estimated to $6.8 \cdot 10^{-5}$ per year (of which 6% involves oil product tankers and 94% are other vessels (mostly general cargo ships)). With the establishment of Halla, Omega and Polargrund OWF the frequency of the event is estimated to $7.2 \cdot 10^{-5}$ (of which 6% involves oil product tankers and 94% other vessels (mostly general cargo ships)).

  Occurrence of the event is expected to be *extremely remote* to *very remote* (Frequency Index = 1,8), but if occurring, result in *single fatality or multiple severe injuries* (Severity Index for Human safety = 3). Every ten times the event is expected to lead to an oil spill with an extent to *10 tonnes* but not more than *100 tonnes* with Halla established (Severity Index for Environment = 2.9). Similar estimates are made with Halla, Omega and Polargrund established.

The resulting risk is assessed to be *acceptable* for all calculated scenarios.

Table 8 summarize the frequency, severity, and risk index for scenario 1.1.

Table 8. Calculated risk for total collision (all collision types). The indices and colour codes are described in 1.3.3

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
1.1	Halla	Ship navigates into a WTG (powered allision)	1.8	3	2.9	4.8	3.7
1.1	Halla, Omega and Polargrund	Ship navigates into a WTG (powered allision)	1.9	3	2.9	4.9	3.8

6.1.2 Inoperable ship drifts into a WTG (drifting allision)

Navigating vessels passing along Halla OWF may, due to technical failure, lose manoeuvrability and start drifting (for example, blackout or rudder failure). Depending on the wind direction, the ship can drift towards a WTG. The process can be interrupted if the fault is repaired, or the vessel is stopped by successful anchoring or emergency towing of the vessel.

Most ships experience about one blackout per ship year (the number of stops for a particular vessel will usually be in the range from 0.1 to 2 blackouts per year). The actual frequency of blackouts depends on the degree of redundancy and the maintenance status of the vessel. Ferries and Ro-Ro vessels generally have a high degree of built-in redundancy in the engine room (2 to 4 engines) and therefore have a low frequency of stops (~0.1 per year). For other vessel types, the frequency of stops is higher (~0.75 per year) (Engberg, 2019).

In the modelling of Halla, ship repair and emergency anchoring have been considered as recovery actions with some probability of success. See Appendix C for details.

For a drifting vessel, there is time available to take actions such as evacuating the crew and passengers from the drifting vessel and preparing for life-saving and oil spill response measures if the ship were to drift towards a WTG.

The following assessment has been made of the consequences and resulting risk for inoperable ship drifting into a WTG (drifting allision).

- **Scenario 1.2 Inoperable ship drifts into a WTG (drifting allision):** Ships drifting into a WTG (within a diameter of 16 metres) are assumed to collide with the WTG at a speed of 1-2 knots. The frequency of this when establishing Halla is calculated at $3.5 \cdot 10^{-4}$ per year (of which 9% oil tankers and 91% other vessels). Establishment of Halla, Omega and Polargrund, the frequency is calculated to $1.4 \cdot 10^{-3}$ (of which 15% oil tankers and 85% other vessels).

  With Halla established, occurrence of the event is expected to be *very remote* to *remote* (Frequency Index = 2.5), but if occurring, result in *multiple or severe injuries* (Severity Index for Human safety = 2). In a case of occurrence, every ten times the event is expected to lead to an oil spill with an extent to *10 tonnes* but not more than *100 tonnes* with Halla established (Severity Index for Environment = 2.3). Similar estimates are made with Halla, Omega and Polargrund established, however, with a higher frequency (Frequency index = 3.2) of the event to happen.

The resulting risk is assessed to be *acceptable* for most of the calculated scenarios. In a scenario where Halla, Omega and Polargrund are established, the risk to human safety is assessed as *ALARP.*

Table 9 summarize the frequency, severity, and risk index for scenario 1.2.

Table 9. Calculated risk for human safety and the environment regarding scenario 1.2 Inoperable ship drifts into a WTG (drifting allision). The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
1.2	Halla	Inoperable ship drifts into a WTG (drifting allision)	2.5	2	2.3	4.5	3.8
1.2	Halla, Omega and Polargrund	Inoperable ship drifts into a WTG (drifting allision)	3.2	2	2.4	5.2	4.6

6.1.3 Ship navigates or drifts near a WTG and gets hit by blade

There are many factors that prevent a vessel from being struck by a blade. Few vessels reach the height of the WTGs sweeping surface, which reduces the candidates of vessels that can get hit by a blade. When a vessel is approaching an emergency shutdown function, on-site or remotely operated, for WTGs is actuated with high reliability. Drifting ships typically take enough time, on average, before they reach a wind tower to allow for preparatory measures such as passenger evacuation or oil spill management.

The following assessment has been made of the consequences and resulting risk for ship that navigates or drifts near WTG and gets hit by blade:

- **Scenario 1.3 Ship navigates or drifts near WTG and gets hit by blade:** The occurrence of ship getting hit by blade is expected to be *extremely remote* (Frequency Index < 1) but if occurring, result in *single fatality or multiple severe injuries* (Severity Index for Human safety = 3). Events involving passenger ships, the consequence for human safety is expected to result in *multiple fatalities* (Severity Index for Human safety = 4). In a case of occurrence of an event, every ten times the event is expected to lead to an oil spill with an extent to *10 tonnes* (Severity Index for Environment = 2). Events involving oil tankers[12] is expected to lead to an oil spill every ten times, with an extent to 1 000 tonnes (Severity Index for Environment = 4).

The resulting risk is assessed to be *acceptable*.

Table 10 summarize the frequency, severity, and risk index for scenario 1.3.

[12] The category” oil tankers” in the data set also includes, among other, chemical tankers and LNG transports.

Table 10. Calculated risk for human safety and the environment regarding scenario 1.3 Ship navigates or drifts near a WTG and gets hit by blade. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
1.3	Halla	Ship navigates or drifts near a WTG and gets hit by blade	<1	4	4	Acceptable	

6.1.4 Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)

Ice floes driven by wind, currents, or drift ice can cause ships to become trapped, and in turn, drift into the wind farm. Drift can occur when there are some ice-free areas in the sea ice cover. However, if the sea is completely covered with ice, it is still possible that the ice layer is broken and compressed into pack ice, if the wind (or current) speed is high enough. The ice velocity can be approximately 2-3% of the wind speed. The ship is likely to be carried by the ice floe at a slow drift rate during severe ice conditions (Finnish Maritime Administration, 2005).

IWRAP is made for calculating frequencies on open water, not for ice conditions. To be able to calculate the frequency of the scenario in IWRAP, parameters and settings have been adjusted based on available data to reflect winter conditions, hence deviating from the official parameters. The IWRAP default blackout probability is increased by a factor 2, to reflect both the fact that winter conditions might induce more incidents with manoeuvrable vessels, and that vessels can get stuck in the ice when waiting for icebreaking assistance. The IWRAP drift speed is set from 1 knot to 2 knots, representing the speed for vessels drifting with the ice. 2 knots are quite a conservative assumption since ice velocity is estimated to 2-3% of the wind speed. This means that 2 knots represent a wind speed above 30 m/s[13]. The average wind speed in the region is 6.2 m/s, and wind speed is often lower for harsh winters. The same wind direction distribution is assumed during months with no sea ice as during months with sea ice. Recovery of vessel (anchoring or repair after blackout) is not accounted for, even though it could be possible to anchor in some cased where the ice is not that thick and water depth not to deep or shallow, and repair of vessel could be possible. These assumptions and adjustment of parameters are therefore considered as worst case since a vessel caught in ice (blackout in IWRAP) will both drift with a higher speed, and for a longer time, than expected. Hence, a higher probability to drift into a WTG. The traffic data used is from 2022 which were a mild winter, and thus involving more traffic than a harsh winter. More traffic leads to higher probability for collision, allision and grounding. Therefore, the use of traffic from a mild winter is conservative when modelling and calculating ice condition in IWRAP.

The following assessment has been made of the consequences and resulting risk for Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)

[13] 2 knot ≈ 1 m/s
Wind speed = (2 knots) / (3%) = (1 m/s) / (0.03) = 33.33 m/s

- **Scenario 1.4 Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision):** The frequency for this event is not directly affected by the construction of an OWF, but the consequences can be more severe. The frequency of this event when establishing Halla is calculated at $1.5 \cdot 10^{-2}$ per year (of which 9% are constituted by oil tankers and 91% are other vessels).

  The occurrence of ship getting hit by blade is expected to be *unexpected* (Frequency Index = 4.2) but if occurring, result in *multiple or severe injuries* (Severity Index for Human safety = 2). In a case of occurrence of an event, every ten times the event is expected to lead to an oil spill with an extent to *10 tonnes* (Severity Index for Environment = 2.3).

The resulting risk is assessed to be *ALARP.*

Table 11 summarize the frequency, severity, and risk index for scenario 1.4.

Table 11. Calculated risk for human safety and the environment regarding scenario 1.4 Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision). The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
1.4	Halla	Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)	4.2	2	2.3	6.2	5.4

6.1.5 Ship navigates or drifts into a platform

The vessels modelled above can navigate or drift into a platform instead of a WTG.

The following assessment has been made of the consequences and resulting risk for ships steering or drifting into platform:

- **Scenario 1.5 Ship navigates or drifts into a platform:** For a ship that drifts into the park but does not drift into any structures, no human or environmental consequences are obtained. The annual probability of the scenario of a ship navigating or drifting into a platform is $1.6 \cdot 10^{-4}$. The occurrence of ship navigating or drifting into a platform is expected to be *very remote* (Frequency Index = 2.2). Risk assessment of the scenario is not analysed further in this nautical risk analysis but instead in the Seveso assessment for Halla.

Table 12 summarizes the frequency, severity, and risk for scenario 1.5.

Table 12. Calculated risk on effects on human safety and environment for scenario 1.5 Ship navigates or drifts into a platform. The indices are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
1.5	Halla	Ship navigates or drifts into a platform	2.2	-		Evaluated in a separate Seveso assessment	

6.1.6 A ship passing through the OWF collides with a WTG

Traffic within the area where WTGs are planned is currently light (less than 4 ships per day on average) and is expected to be even lower when Halla OWF has been established.

The following assessment has been made of the consequences and resulting risk of ships passing through the OWF colliding with a WTG:

- **Scenario 1.6 A ship passing through the OWF collides with a WTG:** The scenario involves a ship deliberately navigating through the park and colliding with a WTG due to a human or technical error. Only small vessels are expected to take a route through the park. Most vessels that pass through Halla project area does not have a length that exceeds 50 metres, and vessels longer than 50 metres are normally not expected to navigate through the OWF as there is not sufficient manoeuvring space for the so-called round turn. Less than 2 vessel a month with a length under 50 meters passes through the OWF.

  The probability of collision between a smaller external vessel and a WTG is estimated to $1.5 \cdot 10^{-3}$, and occurrence is therefore considered to be *unexpected* (Frequency Index = <4)[14].

  The consequence of a small vessel colliding with a WTG is *multiple or severe injuries* (Severity Index for Human Safety = 2) and for the environment an equivalent to 1 tonne of oil spill every tenth time (Severity Index for Environment = 1).

The total risk for a vessel passing through the OWF to collide with a WTG is estimated to be *ALARP* regarding human safety and acceptable for the environment, see Table 13.

[14] The calculation is based on the following:

- 22 vessels per year with a length <50 meters will pass through the OWF (unchanged from 2022 reported AIS data)
- The average speed is 8.75 knots (unchanged from 2022 reported AIS data)
- The longest passage distance is 20 nautical miles.
- The probability of blackout is the same as in IWRAP, 1.5 per ship year (Engberg, IWRAP Mk2, 2019).
- The probability of human error is $3 \cdot 10^{-5}$ per vessel and nautical mile (SSPA Sweden AB, 2008).
- The frequency of human or technical error is calculated based on the above information to be $7{,}1 \cdot 10^{-2}$ and $8{,}9 \cdot 10^{-3}$ per year, respectively.
- The WTG foundations are approximately 16 meters in diameter, and the distance between the towers is at least one kilometer. Less than 10% of all incidents where a vessel in the OWF experiences a human or technical error are thus expected to result in a collision with a WTG.

Table 13 summarizes the frequency, severity, and risk for scenario 1.6.

Table 13. Calculated risk on effects on human safety and environment for scenario 1.6 A ship passing through the OWF collides with a WTG. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
1.6	Halla	A ship passing through the OWF collides with a WTG	<4	2	1	<6	4

6.1.7 Limited visibility causes a ship to navigate into a WTG

Limited visibility conditions caused by factors such as darkness, rain, fog, snowfall, and ice can increase the risk of ship collisions with WTG. It has been observed that the number of ship groundings is notably higher during October to December, with December compared to the rest of the year, with December having the highest number of cases. This month is characterized by early winter darkness, with rain and snowfall often complicating navigation in narrow fairways with many turns. Snowfall has been noted to impede both visual observations and radar use, although other factors may also contribute to accidents (Finnish Maritime Administration & Swedish Maritime Administration, 2005).

The following assessment has been made of the consequences and resulting risk of limited visibility causing a ship to navigate into a WTG:

- **Scenario 1.7 Limited visibility causes a ship to navigate into a WTG:** entails that WTGs are less visible during fog, rain, snowfall, ice, and darkness, which increases the risk of ships colliding with a WTG.

  Ships are generally equipped with AIS and ship radar, meaning that limited visibility due to weather conditions would require a human or technical error in addition to lead to an allision with a WTG. The scenario can thus contribute to other collision risks, as detailed in sections 6.1.1, 6.1.5 and 6.1.6.

  The impact of visibility is factored into the probability of missing out on an evasive manoeuvre, as describes in section 6.1.1, and is therefore included in the risk assessment for events involving WTG collisions. The extent to which visibility contributes to the risk cannot be easily evaluated, and the risk is conservatively classified as ALARP for further handling.

  Radar interference from WTG may also affect the ability to navigate in conditions that limit visibility. However, this risk is further addressed in section 6.4 of the report.

Table 14 summarizes the frequency, severity, and risk for scenario 1.7.

Table 14. Calculated risk on effects on human safety and environment for scenario 1.7 Limited visibility causes a ship to navigate into a WTG. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
1.7	Halla	Limited visibility causes a ship to navigate into a WTG.	See section 6.1.1, 6.1.5 och 6.1.6			ALARP	

6.2 Ship-ship collision

Collision frequencies have been calculated for vessels in shipping lanes around the Halla OWF based on available AIS data. The calculations are based on the traffic model for months with and without sea ice, where the most conservative ("worst") results are presented. The estimated risk is assumed to conservatively also represent the collision risk during sea ice where the vessel transits are fewer, the velocities are often low and the consequences of the incidents are usually not to severe (Winter Navigation Research Board, 2005).

Frequencies for different collision categories are calculated and compared for three different modelling scenarios: no OWF, Halla OWF and Halla, Omega and Polargrund OWF. These are also documented in Appendix C and illustrated in Figure 15.

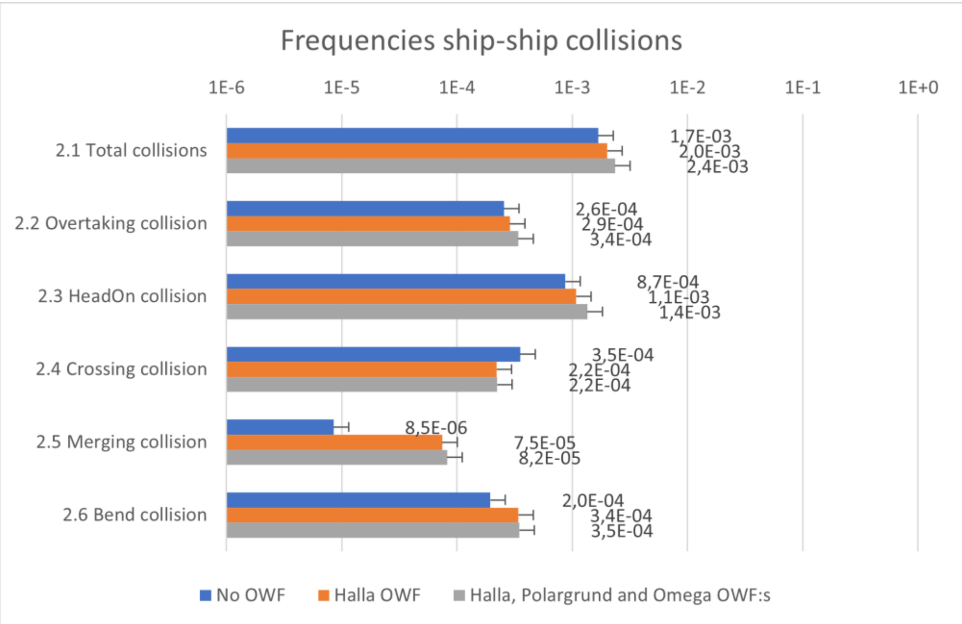

Figure 15. Frequency of collisions per year (bars and numbers) in the area around Halla on a logarithmic scale. Probability of different collision types without OWF, with Halla OWF established and with Halla, Polargrund and Omega OWFs all established. Uncertainty bars (black lines) indicate frequency in a future traffic scenario for 2060 where the number of ships has increased by 35%. For return period and further detailed information of frequency, see chapter 1.3.3

The results indicates that the probability of overtaking, head-on, merging and bend collisions increases, but remain unchanged with a probability level of *very* *remote* to *remote* in absolute terms (see 1.3.3). The increase in merging collision is most significant. Crossing collision appears to decrease.

In a nautical risk analysis for an OWF, it is relevant to study the collision risk contribution from the additional risk generated by the establishment of the OWF (i.e., the risk based on the difference in frequency of ship collisions with and without the OWF). See sections 6.2.1, 6.2.2, 6.2.3, 6.2.4, 6.2.5 and 6.2.6 for risk assessment of OWF-induced collisions.

6.2.1 Total collision (all collision types)

When Halla OWF is established, the traffic pattern will be affected, with less traffic through the OWF and denser traffic around the OWF. Consequently, new situations appear where collisions can occur.

The following assessment has been made of the consequences and resulting risk for total collision (all collision types):

- **Scenario 2.1 Total collisions (all collision types)**: The frequency for this event with Halla OWF established is estimated to $3.2 \cdot 10^{-4}$ per year (of which 17% involves oil product tankers and 83% other vessels (mostly general cargo ships)). With establishment of Halla, Omega and Polargrund OWF, the frequency of the event is estimated to $6.6 \cdot 10^{-4}$ (of which 17% involves oil product tankers and 83% other vessels (mostly general cargo ships)).

  Occurrence of the event is expected to be *very remote* to *remote* (Frequency Index = 2.5), but if occurring, result in *single fatality or multiple severe injuries* (Severity Index for Human Safety = 3). In a case of occurrence, the event is expected to lead to an oil spill with an extent to *100 tonnes* with Halla established (Severity Index for Environment = 3). Similar estimates are made with Halla, Omega and Polargrund established.

The resulting risk is assessed to be *ALARP* both with and without the OWF's.

Table 15 summarize the frequency, severity, and risk index for scenario 2.1.

Table 15. Calculated risk on effects on human safety and environment for scenario 2.1 Total collisions (all collision types). The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
2.1	Halla	Total collisions, windfarm induced	2.5	3	3	5.5	5.5
2.1	Halla, Omega and Polargrund	Total collisions, windfarms induced	2.8	3	3.2	5.8	6.0

6.2.2 Overtaking collision

When Halla OWF is established, it is assumed that more situations appear where overtaking collisions may occur. The risk is even more imminent for shipping routes between two separate OWF:s where traffic navigates with less space.

The following assessment has been made of the consequences and resulting risk for overtaking collision:

- **Scenario 2.2 Overtaking collision:** The frequency for this event with Halla OWF established is estimated to $3.1 \cdot 10^{-5}$ per year (of which 17% involves oil product tankers and 83% other vessels (mostly general cargo ships)). With establishment of Halla, Omega and Polargrund OWF, the frequency of the event is estimated to $8.5 \cdot 10^{-5}$ (of which 17% involves oil product tankers and 83% other vessels (mostly general cargo ships)).

  Occurrence of the event is expected to be *extremely remote* to *very remote* (Frequency Index = 1.5), but if occurring, result in *single fatality or multiple severe injuries* (Severity Index for Human safety = 3). In a case of occurrence, the event is expected to lead to an oil spill with an extent to *100 tonnes* with Halla established (Severity Index for Environment = 3.1). Similar estimates are made with Halla, Omega and Polargrund established, however, with a higher frequency (Frequency Index = 1.9).

The resulting risk is assessed to be *acceptable* for establishment of Halla OWF. The resulting risk for establishment of Halla, Omega and Polargrund OWFs is assessed to be *acceptable* for human safety, but *ALARP* for environment.

Table 16 summarize the frequency, severity, and risk index for scenario 2.2.

Table 16. Calculated risk on effects on human safety and environment for scenario 2.2 Overtaking collision. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency	Severity (SI)		Risk (RI)	
			(FI)	Human safety	Environment	Human safety	Environment
2.2	Halla	Overtaking collision	1.5	3	3.1	4.5	4.6
2.2	Halla, Omega and Polargrund	Overtaking collision	1.9	3	3.2	4.9	5.2

6.2.3 Head-on collision

When an OWF is established, it is generally assumed that ships would position themselves closer to other ships in the opposite direction, which can lead to more situations where head-on collisions between ships can occur. The establishment of Halla OWF also mean that ships currently crossing the project area will have to take new routes around the OWF, therefore increasing traffic slightly in the routes around OWF Halla and thus theoretically increasing the possiblitys for head-on collisions.

The following assessment has been made of the consequences and resulting risk for head-on collision:

- **Scenario 2.3 Head-on collision:** The frequency for this event with Halla OWF established is estimated to $2.1 \cdot 10^{-4}$ per year (of which 17% involves oil product tankers and 83% other vessels (mostly general cargo ships)). With establishment of Halla, Omega and Polargrund, the frequency of the event is estimated to $4.8 \cdot 10^{-4}$ (of which 17% involves oil product tankers and 83% other vessels (mostly general cargo ships)).

Occurrence of the event is expected to be *very remote* to *remote* (Frequency Index = 2.3), but if occurring, result in *single fatality or multiple severe injuries* (Severity Index for Human Safety = 3). In a case of occurrence, the event is expected to lead to an oil spill with an extent to *100 tonnes* with Halla established (Severity Index for Environment = 3.1). Similar estimates are made with Halla, Omega and Polargrund established.

The resulting risk is assessed to be *ALARP,* both for establishment of Halla OWF as well as Halla, Omega and Polargrund OWFs.

Table 17 summarize the frequency, severity, and risk index for scenario 2.3.

Table 17. Calculated risk on effects on human safety and environment for scenario 2.3 Head-On collision. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
2.3	2.3 Halla	Head-on collision	2.3	3	3.1	5.3	5.4
2.3	2.3 Halla, Omega and Polargrund	Head-on collision	2.7	3	3.3	5.7	6.0

6.2.4 Crossing collision

When Halla OWF is established, some of the waypoints (intersections) that ships currently use, when navigating their way across the area of the OWF, would not be used anymore. Instead, new waypoints will be created around the OWF where crossing collisions may occur.

The calculation for crossing collision (**scenario 2.4**) show that no additional risk is expected with Halla OWF establishment, and even indicate that the risk decreases slightly.

Table 18 Calculated risk on effects on human safety and environment for scenario 2.4 Crossing collision. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
2.4	Halla	Crossing collision	-	N.A.	N.A.	No OWF induced risk for human safety or the environment	

6.2.5 Merging collision

When Halla OWF is established, some of the places were merging occurs that ships currently use when navigating their way across the area of the OWF, would not be used anymore. Instead, there will be new places were merging will occur with Halla OWF established.

The following assessment has been made of the consequences and resulting risk for merging collision:

- **Scenario 2.5 Merging collision:** The frequency for this event, with Halla OWF established, is estimated to $6.6 \cdot 10^{-5}$ per year (of which 17% involves oil product tankers and 83% other vessels (mostly general cargo ships). With establishment of Halla, Omega and Polargrund OWF, the frequency of the event is estimated to $7.4 \cdot 10^{-5}$ (of which 17% involves oil product tankers and 83% other vessels (mostly general cargo ships))

  Occurrence of the event is expected to be *extremely remote* to *very remote* (Frequency Index =1.8), but if occurring, result in *single fatality or multiple severe injuries* (Severity Index for Human safety = 3). In a case of occurrence, the event is expected to lead to an oil spill with an extent to *100 tonnes* with Halla established (Severity Index for Environment = 3.3). Similar estimates are made with Halla, Omega and Polargrund OWF established.

The resulting risk is assessed to be *acceptable* for Human safety, but *ALARP* for Environment.

Table 19 summarize the frequency, severity, and risk index for scenario 2.5.

Table 19. Calculated risk on effects on human safety and environment for scenario 2.5 Merging collision. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
2.5	Halla	Merging collision	1.8	3	3.3	4.8	5.1
2.5	Halla, Omega and Polargrund	Merging collision	1.9	3	3.3	4.9	5.2

6.2.6 Bend collision

When Halla OWF is established, traffic that currently cross the project area will have to take new routes. Sometimes the new routes can be longer than the current ones, as well as the vessels have to take more turns around the OWF. These aspects could possibly increase the probability for bending collisions between ships.

The following assessment has been made of the consequences and resulting risk for bend collision:

- **Scenario 2.6 Bend collision:** The frequency for this event with Halla established is estimated to $1.5 \cdot 10^{-4}$ per year (of which 17% involves oil tankers and 83% other vessels (mostly general cargo ships)). With establishment of Halla, Omega and Polargrund, the frequency of the event is estimated to $1.5 \cdot 10^{-4}$ (of which 17% involves oil tankers and 83% other vessels (mostly general cargo ships)).

  Occurrence of the event is expected to be *extremely remote* to *very remote* (Frequency Index = 2), but if occurring, result in *single fatality or multiple severe injuries* (Severity Index for Human Safety = 3). In a case of occurrence, the event is expected to lead to an oil spill with an extent to *100 tonnes* with Halla established (Severity Index for Environment = 3.2). Similar estimates are made with Halla, Omega and Polargrund established.

The resulting risk is assessed to be *ALARP,* both for establishment of Halla OWF as well as Halla, Omega and Polargrund OWFs.

Table 20 summarize the frequency, severity, and risk index for scenario 2.6.

Table 20. Calculated risk on effects on human safety and environment for scenario 2.6 Bend collision. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency	Severity (SI)		Risk (RI)	
			(FI)	Human safety	Environment	Human safety	Environment
2.6	Halla	Bend collision	2.2	3	3.2	5.2	5.4
2.6	Halla, Omega and Polargrund	Bend collision	2.2	3	3.2	5.2	5.4

6.2.7 Collision with working vessel en route to/from port

During the operational, construction, and decommissioning phase, work and service vessel may collide with the regular ship traffic when navigating to or from the OWF. In Table 21, the risk during construction phase and decommissioning phase is assessed.

The service traffic during the operational phase consists of occasional transits per day and is assessed to constitute a very small contribution compared to the total collision risk. The estimated annual number of transits during the operational phase is approximately 300[15].

More traffic is expected during the construction and decommissioning phase, with the annually number of trips estimated conservatively to 500. The port used for these activities will be Raahe[15].

During approximately 2-3 years[15], when the OWF is constructed, the frequency for collisions between working vessels and regular traffic is thus expected to be somewhat higher than the normal collision risk in the area. The same consequences as for other collision types are assumed.

The following assessment has been made of the consequences and resulting risk for bend collision:

- **Scenario 2.7 Collision with working vessel en route to/from port:** The frequency for this event is estimated to $1.8 \cdot 10^{-4}$. Occurrence of the event is expected to be *very remote* (Frequency Index = 2.3), but if occurring, result in *single fatality or multiple severe injuries* (Severity Index for Human Safety = 3). In a case of occurrence, the event is expected to lead to an oil spill with an extent to *100 tonnes* with Halla established (Severity Index for Environment = 3.1).

The resulting risk during construction and decommissioning phase is assessed to

[15] Email communication with Carlo Giesecke, project developer Halla OWF, September 27th, 2023.

be *ALARP.* The collision risk during the operational phase is expected to be *ALARP* (see 6.2.1).

Table 21 summarize the frequency, severity, and risk index for scenario 2.7.

Table 21. Calculated risk on effects on human safety and environment for scenario 2.7 Collision with working vessel en route to/from port during OWF construction and decommissioning phase. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
2.7	Halla	Collision with working vessel en route to/from port	2.3	3	3.1	5.3	5.4

6.3 Grounding

A new traffic pattern due to park establishment can lead to more situations where grounding occurs. Figure 16 shows the calculated frequency of grounding for three different scenarios. The case if no OWFs are established, if Halla OWF is established, or if Halla OWF, Polargrund OWF and Omega OWF are established in the area.

Grounding frequencies have been calculated for vessels within the area with available AIS-data and data for bathymetry, see section 2.

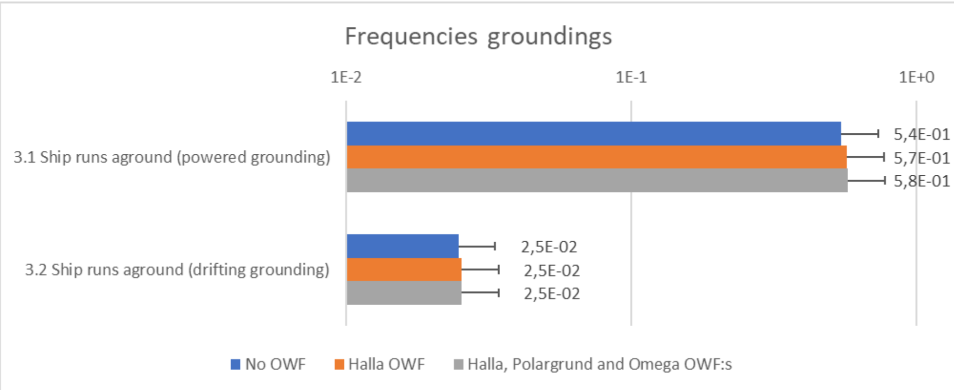

Figure 16. Frequency of grounding per year (bars and numbers) in the area around Halla on a logarithmic scale. Probability of different grounding types without the OWF, with Halla OWF and with Halla, Polargrund and Omega OW, summer conditions. Uncertainty bars (black lines) indicate frequency in a future traffic scenario for 2060 where the number of ships has increased by 35%. For return period and further detailed information of frequency, see chapter 1.3.3

According to the IWRAP calculations, grounding represents the highest frequency of all accident categories in the area. A major part of the frequency is powered grounding for vessels travelling close to the shallows around the Finnish and coastal areas. Only a fraction of the groundings occurs adjacent to Halla OWF, where the majority are east of Halla OWF, closer to the coast. To compare with actual statistics for incidents in the area, see section 2.3.

6.3.1 Powered grounding

The following assessment has been made of the consequences and resulting risk for powered grounding.

- **Scenario 3.1 Powered grounding:** The frequency for this event, with Halla OWF established, is calculated to $2.6 \cdot 10^{-2}$ per year (of which 24% involves oil tankers and 76% other vessels (mostly general cargo ships)). With establishment of Halla, Omega and Polargrund OWF, the frequency of the event is calculated to $3.3 \cdot 10^{-2}$ (of which 24% involves oil tankers and 76% other vessels (mostly general cargo ships)).

  Occurrence of the event is expected to be *unexpected* to *reasonably probable* (Frequency Index 4 = once per 100 years), but if occurring, result in *single fatality or multiple severe injuries*. In a case of occurrence, the event is expected to lead to an oil spill with an extent to *10 tonnes* but not more than *100 tonnes* with Halla OWF established. Similar estimates are made with Halla, Omega and Polargrund OWF established, *10 tonnes* but not more than *100 tonnes* oil spill.

The resulting risk for powered grounding is within *ALARP,* both for Halla OWF and all OWFs.

Table 22 summarize the frequency, severity, and risk index for scenario 3.1.

Table 22. Calculated risk on effects on human safety and environment for scenario 3.1 A navigating ship runs aground (powered grounding). The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
3.1	Halla	A navigating ship runs aground (powered grounding)	4.4	3	2.5	7.4	6.9
3.1	Halla, Omega and Polargrund	A navigating ship runs aground (powered grounding)	4.5	3	2.8	7.5	7.3

6.3.2 Drifting grounding

The following assessment has been made of the consequences and resulting risk for drifting grounding.

- **Scenario 3.2 Drifting grounding:** The scenario involves a vessel experiencing a blackout, and then drifting aground. According to the IWRAP calculations the resulting risk does not change whether no OWF, Halla OWF or all OWFs are established.

Table 23 Calculated risk on effects on human safety and environment for scenario 3.2 Drifting grounding. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Frequency (FI)	Consequence (SI)		Risk (RI)	
			Human safety	Environment	Human safety	Environment
3.2	Drifting grounding	<1	-		Risk does not change whether OWF is established or not.	

6.4 Vessel radar disturbance

Disturbances to radar and navigation systems can result in a hard to interpret, or even a misleading, output from the radar. This means that the basis for decision can be more complex and sometimes incorrect when navigating along an OWF. Some of the important limitations of Radar are as follows:

- Small vessels, ice, other small floating objects may not be detected by the radar.
- Targets in the blind sector and shadow sector of the radar are not displayed.
- Range discrimination – two small targets on same bearing and slight range difference may be shown as on target.
- Bearing discrimination – two small targets on same range and slight bearing difference may be shown as one target.
- False echoes.

The presence of ice can in some cases impair the use of radar. Even snowfall and fog can impair radar use, making it more difficult to see vessels and WTGs. The occurrence of ice can lead to difficulties in seeing a shoreline based on radar information. There are cases where it has not been possible to distinguish echoes from ice floes or ice blocks with echoes from the radar deflector, which impairs the quality of the information on the radar monitor for navigational purposes (Finnish Maritime Administration & Swedish Maritime Administration, 2005).

6.4.1 Vessel radar disturbance (target loss)

The WTGs may impair the ability to use the vessel radar to detect ships in the vicinity of the OWF as well as vessels located in front of and behind the OWF.

The following assessment has been made of the consequences and resulting risk of vessel radar disturbance (target loss))

- **Scenario 4.1 Vessel radar disturbance (target loss):** The scenario encompasses vessel radar disturbance of the type target loss causing a collision between two vessels.

  For traffic passing through Halla at a distance closer to the park than 1.5 M, radar disturbance may occur. Ships can have their S-band radar set so target loss occurs[16]. The event is considered *probable* (Frequency Index 6 = once per year).

[16] Other disturbances such as radar echoes may also occur at this distance but are reported to be problematic for navigation only at distances shorter than 0.25 NM (500 m), thus posing no risk to traffic in the shipping routes.

However, the disruption is not expected to lead to the consequence of ships colliding. Radar disturbances are a well-known phenomenon in commercial traffic and occur regularly. There are routine measures to minimize disruption that an experienced seafarer is aware of.

Large vessels are equipped with several different systems with the purpose to gather information, for further detailed information, see Appendix B. The X-band radar provides more accurate information about nearby targets, as well as using the AIS as a complementary radar in the case of small vessels, close by, would disappearing from the radar screen. Furthermore, there are an average of 1–3 vessels a day in the various shipping routes around Halla OWF, which further reduces the probability that ships will collide as a result of radar impact.

Therefore, radar disruption is not expected to cause a collision between ships passing through the OWF. The consequence is assessed to be *minor* (1). For more information regarding vessel radar disturbance, see Appendix B.

The resulting risk is assessed to be within *ALARP*.

Table 24 summarize the frequency, severity, and risk index for scenario 4.1.

Table 24. Estimated risk on effects on human safety and environment for scenario 4.1 Vessel radar disturbance (target loss). The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
4.1	Halla	Vessel radar disturbance (target loss)	6.0	1.0	1.0	7.0	7.0

6.4.2 Vessel radar disturbance (navigation disturbance)

The following assessment of the consequences and resulting risk has been made for **vessel radar disturbance (navigation disturbance) (scenario 4.2).**

The scenario includes that the OWF creates such major disturbances to vessel radar, AIS, VHS, GPS and other navigation and communication systems that traffic navigates incorrectly and steer into WTGs.

There are many barriers before a disturbance on vessel radar and other navigation equipment causes a vessel that is passing by the OWF to navigate into a WTG:

1. A vessel passes at a distance of <0.25 M and experiences disturbance of the vessel radar and other navigation equipment.[17]

[17] The impact on vessel radar and other navigation equipment is initially considered to be limited for traffic that does not travel directly adjacent to the park. For X-band radar, AIS, GPS and VHS radios, any interference occurs first in the absolute vicinity of the towers (within 0.25 M). Interference with S-band radar may occur and the risks of this are described in sections 6.4.1. The WTGs themselves are not expected to disappear from the radar but can give rise to false echoes and clutters, which provides a more complex information base. Multipath phenomena and radio shadow can occur

Given the amount of traffic in the area and that the majority is expected to comply with the regulations of COLREG, the assessment is that disturbances will affect **<10 passing vessels per year**.

2. The vessel navigates based on inaccurate information and heads for the wind farm. (Incorrect course in another direction leads to reduced disturbance from the OWF and the information picture returns to being unambiguous and correct.)
   Vessels are equipped with several navigation systems based on diversified technical solutions which, taken together, provide sufficient data for determining the position, direction and distance of obstacles such as WTGs, even if one or more systems provide incorrect information or are inaccessible. The occurrence that a vessel with radar interference takes the wrong course, towards the wind farm, is estimated to **1 time in 100**.[18]
3. Failed identification that the vessel is on the wrong course and thus delayed or no action.
   The park is a very clear navigation point and will be marked in accordance with IALA recommendations. During the day, under normal conditions, the park will be visually visible from vessels using surrounding shipping lanes. The WTGs will also be equipped with facade lighting, which increases visibility and orientability even in the dark. Some of the towers are also equipped with obstruction lights. In addition, vessel traffic around the park will be monitored and vessels on the wrong course will be able to be noticed over VHS. That a ship crew fails to notice the WTG and take action is estimated to occur **1 time in 100**.[19]
4. The vessel navigating into a WTG.
   The foundations of the WTGs are about 16 meters in diameter and the distance between the towers is at least 1 kilometre. The probability that a vessel accidentally navigates into the OWF and thereafter collide with a WTG is estimated to **<10%.**

Overall, disturbance of vessel radar leading to the vessel navigating info the WTG is estimated to occur less than **1 time every 10 000 years**[20].

The consequence is assumed to be the same as in scenario 1.1.

In conclusion, the probability that interference from the towers at this distance gives such misleading information that it leads to inaccurate navigation and thereafter collision with a WTG is negligible, compared to other causative factors. The scenario that leads to a collision assumes that a vessel navigates outside the shipping area, as well as poor visibility, as well as that alternative navigation systems are not used, that leads to the vessel accidentally ending up in the OWF and navigates into a WTG.

locally but have little impact on traffic in the ship lanes as the vast majority of vessels are expected to pass the OWF at a distance greater than 0.25 M.

[18] 1/100 is quite a high HEP value for routine navigation and a well-known disturbance where many alternative information sources are available. See Section 8 Uncertainty analysis for further discussion.

[19] 1/100 is quite a high HEP value for the crew to detect the navigation error and correct it with a routine action. See Section 8 Uncertainty analysis for further discussion.

[20] <10 vessels/year · 0,01 · 0,01 · 10% = 0,0001.

The risk that disturbance of vessel radar and other navigation equipment causes vessels in shipping areas to inadvertently navigate into the OWF and collide with a WTG is thus considered *acceptable*.

For more information of radar interference, see Appendix B.

Table 25 summarize the frequency, severity, and risk index for scenario 4.2.

Table 25. Estimated risk on effects on human safety and environment for scenario 4.2 Vessel radar disturbance (navigation disturbance). The indices and colour codes are described in 1.3.3.

Id.	Scenario	Frequency (FI)	Severity (SI)		Risk (RI)	
			Human safety	Environment	Human safety	Environment
4.2	Vessel radar disturbance (navigation disturbance)	<2	3	2.9	<5	<5

6.4.3 Vessel radar disturbance within the OWF

Vessels travelling in the immediate vicinity of WTGs (within 0.25 M) may experience disturbance to vessel radar, AIS, VHS and GPS. In **scenario 4.3,** the OWF creates such major disturbances to radar and other navigation and information systems that vessels in the park navigates into a WTG.

For authorized traffic (working and service vessels), the consequences fall outside the limits of the nautical risk analysis.

The risk of external vessels colliding with a WTG is assessed in sections 6.1.6. It is assumed that smaller vessels are expected to pass through the OWF. If disturbances to radar and other systems are factored in, the risk increases to different extents depending on the size and equipment of the vessel[21]:

- Pleasure boats do not usually navigate using radar. Laymen who nevertheless navigate with radar through the OWF may misinterpret the radar image (just as in the archipelago and in other places where radar disturbance occurs). As very few pleasure boats are located in the area at the same time, this makes a negligible risk contribution that is not taken into account further.
- Vessels with less than 300 gross tonnages have no requirements to have redundant navigation systems or AIS and thus risk, in poor visibility conditions and radar interference, to navigate based on incorrect information.
- Vessels with 300 gross tonnage and above have requirements for AIS. For even larger vessels, there are additional requirements for independent radar and target tracking systems. If vessels of this size decide to navigate through the OWF there are good prerequisites for receiving sufficient information about the surroundings even in the event of poor visibility and disturbances to any system. Disturbances on AIS, VHS and GPS are generally very local and are resolved when the

[21] For professional shipping operation, there are requirements for navigation equipment that apply to all ships over a certain size and to all passenger ships and tankers. The requirements are specified in Chapter V of the SOLAS Convention (IMO, 2002). In short, the requirements mean that the majority of the vessels sailing in Swedish waters are equipped with, among other things, a standard magnetic compass, electronic chart systems, a GPS receiver, AIS and radar (for larger vessels on redundant frequency bands and with plotting functions such as ARPA) or equivalent. (IMO, 2002)

vessels move. As very few large ships are expected to move through the area and have several independent navigation systems, this makes a negligible risk contribution which is not considered further. Large vessels through the OWF pose a risk due to the limited room for manoeuvre, but this risk is not driven by misleading radar information.

In conclusion, the risk consists of external vessels in the OWF with a gross tonnage of about 20–300 tonnes navigating in poor visibility with only a radar as a tool and navigating into a WTG. That a vessel suffers from radar disturbance that leads to wrong decisions is assumed to occur conservatively **10 times a year** (which corresponds to one event during one storm per month and one vessel per storm). As for scenario 4.2 (section 6.4.2), the probability of a vessel navigating into a WTG is set to **<10%**. When the vessel approaches a WTG, it is assumed that the fault can be identified, but the probability that an evasive manoeuvre will not be successful when required is still set to $\mathbf{1.6 \cdot 10^{-4}}$ (Engberg, 2019). The severity index is set to 2 for both effects on human safety and environment based on experiences from similar accidents, se section 2.3.

Table 26 summarize the frequency, severity, and risk index for scenario 4.3.

Table 26. Estimated risk on effects on human safety and environment for scenario 4.3 Vessel radar disturbance within the OWF. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
4.3	Halla	Vessel radar disturbance within the OWF	2.2	2	2	4.2	4.2

6.4.4 The OWF complicates search and rescue operations

Offshore WTGs can, partly due to radar and communication disturbances and partly because the WTGs constitute physical obstacles, have a negative impact on rescue operations (PIANC, 2018). Distress calls risk being more difficult from places that are in shadow loss due to the OWF. Radar disturbance, impact on position reporting including AIS reporting and alternative navigation tools combined with poor visibility can lead to a stressful decision-making situation for a rescue vessel in the occurrence of a search or rescue operation. Radio tracking can be more difficult, see also Appendix B.

The following assessment has been made of the consequences and resulting risk that the OWF complicates search and rescue operations:

- **Scenario 4.4 The OWF complicates search and rescue operations:** The scenario itself is not an initial event, but a factor that may complicate search and rescue operations. Currently, it is common to have icebreaker assistance and pilotage in the area. Considering the hypothesis that the construction of an OWF increases the risk of accidents, the need for rescue operations may also increase.

In the case of an accident in or near the OWF, navigation can be more difficult, both for rescue vessels and helicopters. This also means that the search for accident victims is limited as parts of the rescue crew need to focus on navigating past the WTGs rather than searching for people and/or vessels in need. The crew of the vessel in need also needs to focus more on its surroundings in order not to risk colliding with a WTG.

Despite this, the WTGs are not expected to be a major obstacle to search and rescue operations as the distance between the turbines are at least 1 kilometre and the distance between the sea surface and the lowest wingtip are mote than 30 meters. This provides space for rescue boats to drive between and below the WTGs. WTGs can also in some cases simplify a sea rescue operation because the towers are clear reference points.

According to PIANC (2018), OWFs should, wherever possible, be laid out in a regular grid pattern (this is not always possible for engineering and construction reasons, e.g. seabed conditions and water depths, preventing turbines being laid in a regular pattern). The layout of 120 WTGs that being analysed is not laid out in a regular grid pattern, but instead the WTGs are more scattered. In order to maximize the energy production, wind turbines could not be placed in straight lines. It would increase the wake effect remarkably and reduce the annual energy production as well as shorten the WTG lifetime. It is difficult to estimate how much the scattered WTGs affect the possibility for search and rescue operations, but it is clear that a more regular grid pattern would facilitate search and rescue operations, and navigation in general within the OWF.

Since there are great uncertainties, neither probability nor consequence can be quantitatively estimated with sufficient accuracy to allow conclusions to be drawn for this scenario. The probability is contingent for the scenario for search and rescue operations. The consequence could change to a somewhat more difficult search and rescue operation if another accident scenario should occur.

In summary, the risk is regarded as an aggravating circumstance for some of the other accident scenarios brought up in this report. It cannot easily be evaluated on the same scale as other risks but is classified as risk level *ALARP* to be addressed further, see summary of risk in Table 27.

Table 27. Estimated risk of the OWF complicates search and rescue operations. The colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
4.4	Halla	The OWF complicates search and rescue operations	-	-	-	ALARP	

6.5 Winter conditions

6.5.1 The OWF affects ice buildup

When establishing offshore wind power, the ice formation in the area may change. However, it is not yet known what the change in ice formation and ice coverage may look like. No studies of how offshore wind power may change the forming of sea ice have been identified.

The following assessment has been made of the consequences and resulting risk of the OWF changing ice formation:

- **Scenario 5.1 The OWF affects ice buildup:** When an OWF is established it leads to more fixed points in the sea where ice can build up at the surface on the WTGs. At the same time, establishment of WTGs could lead to drifting ice breaking up against the foundations of the WTGs.

The Swedish Transport Agency (2022) lists the following scenario regarding sea ice and the establishment of a OWF that could potentially be featured:

- The ice may be broken by the foundations of the WTGs and drift ice could get stuck in the area. Ice ridges could form when the ice sheet pushes on from behind and compresses the ice.
- The ice may be broken by the foundations of the WTGs and passes the wind farm, which lead to ice being compressed and form large areas with ice ridges.
- Ice could drift back and forth in the area of the wind farm, leading to ice being broken and compressed on several occasions, forming a thick ice barrier which gets stuck in the area.

Furthermore, ice that has been affected by the wind farm can also drift and hamper ship traffic at other locations. This can lead to aggravated ice conditions elsewhere and pose limitations in shipping and calling at ports in the Gulf of Bothnia

Depending on ice conditions, Väylä applies size and ice class restrictions to vessels eligible for icebreaker assistance. Winter traffic restrictions are to ensure safe navigation at sea in ice conditions. The icebreakers provide assistance to the vessels by monitoring, directing, leading and towing (Traficom & Swedish Transport Agency, 2019).

The risk for ice throws from the WTGs' blades is regarded in section 6.6.

In summary, the risk is regarded as an aggravating circumstance for some of the other accident scenarios brought up in this report. It cannot easily be evaluated on the same scale as other risks but is classified as risk level *ALARP* to be addressed further, see summary of risk in Table 28.

Table 28. Estimated risk of the OWF affects ice buildup. The colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
5.1	Halla	The OWF affects ice buildup	-			ALARP	

6.5.2 The OWF blocks winter navigation routes

The fact that large parts of the waters of the Baltic Sea, especially the Bothnian Bay, freeze into ice every year affects shipping. This leads to vessels sometimes become dependent on icebreaker assistance. Where ice obstacles occur, traffic during the ice-covered months at sea is often forced to take different routes than during months without sea ice. Different types of ice cover can also affect sea traffic in different ways.

The following assessment has been made of the consequences and resulting risk of the energy park obstructing winter navigation routes (**scenario 5.2**):

If the OWF blocks the fastest and easiest winter navigation routes, icebreakers or other tugboats will need to take a different route, potentially delaying or complicating assistance to vessels. This risk is primary a risk with administrative and economic consequences, not included in this nautical risk assessment.

However, there are also potential consequences for human safety and the environment. Vessels that must travel longer distances in winter conditions might be more exposed to the risks of grounding, collision and allision since the travelled distance is longer. The likelihood of encountering massive ice ridges becomes bigger and stationary vessels waiting for assistance are subject to forces in the ice and the risk of hull damage.

Longer travel distances are considered in the risk calculations for grounding, collision and allision, since they are based on a model of the new, longer expected winter navigation routes. For risk assessment, see sections 6.1.4, 6.2.1 and 6.3.1. How much blocked routes contribute to the overall winter risks cannot be easily quantified, but the risk is conservatively classified as *ALARP* to be addressed further.

Ice damages have occurred quite frequently in ships for winter navigation. The typical ice damages resulting from exposure are considered non-severe in accordance with Winter Navigation Research Board (2005). The risk for OWF blocking winter navigation routes is in this aspect estimated to be *acceptable*, see Table 29.

Table 29. Estimated risk of the OWF blocks winter navigation routes. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
5.2	Halla	The OWF blocks winter navigation routes (longer routes resulting in grounding, collision and allision)	Refer to sections 6.1.4, 6.2.1 and 6.3.1.			ALARP	
5.2	Halla	The OWF blocks winter navigation routes (more exposure to ice forces)	6	No consequence for human safety or the environment		No significant risk for human safety or the environment	

6.6 Falling objects or throws from WTGs, including ice

Tower breakdown and throws from a WTG may damage vessels passing through or past the Halla OWF. In the report *Wind Turbine Tower Collapse Cases: A Historical Overview* (Ma, Martinez-Vazquez, & Baniotopoulos, 2018) blade failure is identified as the most frequent WTG failure (18%). Structural failure, which includes tower collapse and turbine breakdown, accounts for 9%. Ice-throw from blade accounts for 2%. Wind load in combination with human or mechanical failure are reported as the most common underlying causes.

Although ice-throw can be expected to make up a larger share than 2% in regions with colder and more humid climate (as in Bothnian Bay), ice-throw incidents in general are uncommon.

The following assessment has been made of the consequences and resulting risk for falling objects or throws from WTGs, including ice:

- **Scenario 5.3 Falling objects or throws from WTGs, including ice** means that a tower failure or throw from WTGs occurs and hits a passing vessel.

There is no overall accident reporting for WTGs in the shipping industry. A Dutch compilation encompassing statistics for 43 000 turbine years from WTGs in Germany, Denmark and the Netherlands are used to determine failure probabilities (Braam, van Mulekom, & Smit, 2005). In total, the average probability for turbine failure is $2.2 \cdot 10^{-3}$ per turbine per year[22].

In wind power failure events, parts are generally not thrown longer distances. Besides, the distance between shipping routes and the OWF are so long that possibly only a few throws would be able to reach a vessel passing the OWF, and within the safety zone of an WTG no unauthorized vessel is supposed to be. Considering the low traffic volume in the area (1-3 vessels a day in every shipping route surrounding OWF Halla and one vessel every two-week passing through OWF Halla), there is an even lower probability that a vessel would be in an area where throws from WTG can hit a vessel.

The probability that ice-throws or throws of other objects would cause a serious accident on passing vessels is thus considered to be so low that the risk is *acceptable* even if serious consequences are assumed.

Table 30. Estimated risk on effects on human safety and environment for scenario 5.3 Falling objects or throws from WTGs, including ice. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
5.3	Halla	Falling objects or throws from WTGs, including ice	<1	4	4	<5	<5

6.7 Cables

6.7.1 Transmission cable damage

The following assessment has been made of the consequences and resulting risk of damage to transmission line:

- **Scenario 6.1 Transmission cable damage:**

Ship anchors may hook on to, and tear up or damage, transmission lines or other cables on the seabed. Unjustified anchoring or emergency anchoring may cause an interruption in the OWF's operation and require extensive repair work.

[22] Ice throw is not included among the observations but is still considered to be representative since ice throw accounts for a smaller part of reported WTG failures.

Consequences for health and the environment are excluded [23]:

- In the event of a cable break, the power transmission is cut off and thus does not affect the vessel.
- In case of damaged cable insulation there is a possibility that electric current can flow through the anchor. Since the electrical current seeks the lowest resistance path to return to Earth, it is not expected to follow a path leading up through the anchor to the vessel and then down again.
- If a ship anchors and pulls the cable up towards the ship that is damaged in close proximity to the underside of the ship, an impact or a minor explosion is likely to occur that could affect the ship. Such an impact/explosion is not considered to be powerful enough to do any damage to larger vessels, such as tankers or cargo ships. A smaller vessel, such as a fishing boat, is not expected to haul heavy cables all the way up to the boat.

The risk of damage to transmission cables affecting ships is assessed as negligible from a nautical perspective. No extended risk analysis is deemed necessary, see Table 31.

Table 31. Estimated risk of transmission cable damage. The colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
6.1	Halla	Transmission cable damage	-			Negligible risk	

6.7.2 Cables prevent emergency anchoring

The following assessment has been made of the consequences and resulting risk for cables preventing emergency anchoring:

- **Scenario 6.2 Cables prevent emergency anchoring:**
  The scenario comprises that the presence of transmission cables might affect the willingness to use emergency anchorage, when necessary, which makes it more difficult to stop ships from drifting.

According to (DNV, 2021). it is very unlikely that a ship needs to anchor directly above a transmission cable. The assessment is that anchoring is attempted in case of an emergency, also in places where cables are present. Drifting is also a slow event, meaning there is a lot of time to take action and space for anchoring after passing the cable areas. Vessels normally drift, on average, for one hour according to a study referred by SSPA (2008) before hitting an object or restarting. Considering the low volume of traffic in the area, combined with the fact that it is very unlikely that ships will need to anchor directly above a transmission cable, the risk is not considered to need further analysis, see Table 32.

[23] Simon Lindroth, M.Sc. and Ph.D. in Engineering Physics with a focus on electricity, and Torsten Björn, Engineer in Electrical Engineering, both employed at Sweco Sverige AB, 2022-01-27.

Table 33 Estimated risk of cables preventing emergency anchoring. The colour codes are described in 1.3.3.

Id.	Scenario	Hazard	Frequency (FI)	Severity (SI)		Risk (RI)	
				Human safety	Environment	Human safety	Environment
6.2	Halla	Cables prevent emergency anchoring	-			Negligible risk	

6.8 Cumulative effects

Calculated accident frequencies for grounding, allision, and ship collision when Halla and nearby OWFs (Omega and Polargrund) are considered versus not considered are studied as uncertainty analysis cases (see section 2.1 for information about cumulative effects of nearby OWFs in the region). The frequency for grounding, allision, and ship collision are presented in Figure 14, Figure 15, and Figure 16 in chapter 6. The frequency index (FI), severity (SI) and resulting risk for the cumulative effects from Halla, Omega and Polargrund are presented in tables in the subchapters to 6.1, 6.2, and 6.3.

The cumulative impact from several OWFs, compared to only Halla OWF, is that the navigational risk in the area increases, which is intuitive. However, most of the risks only increases slightly and the risk classification are thus the same. As a clarification, most of the risks that are *acceptable* or *ALARP* for Halla are assessed the same for Halla, Omega and Polargrund. There are two exceptions. The risk to human health and safety of drifting allision and risk to environment from overtaking collision that is classified as *acceptable* if only Halla is built, and *ALARP* if more OWFs than Halla are built. The risk of drifting allusion explained by the higher number of WTGs for vessels to collide with and the expected traffic patterns. The risk of overtaking collision explained by higher traffic density (both more traffic as well as congested traffic) in general but particularly in the shipping lane between Halla and Polargrund. No cumulative effect has been assessed as unacceptable.

In conclusion, the cumulative effects of the establishment of several parks in the area do not entail any additional risks beyond those identified when analysing the parks individually.

6.9 Risk matrix

The magnitude of the quantified risks presented in chapter 6 is summarized in the risk matrix in Figure 17

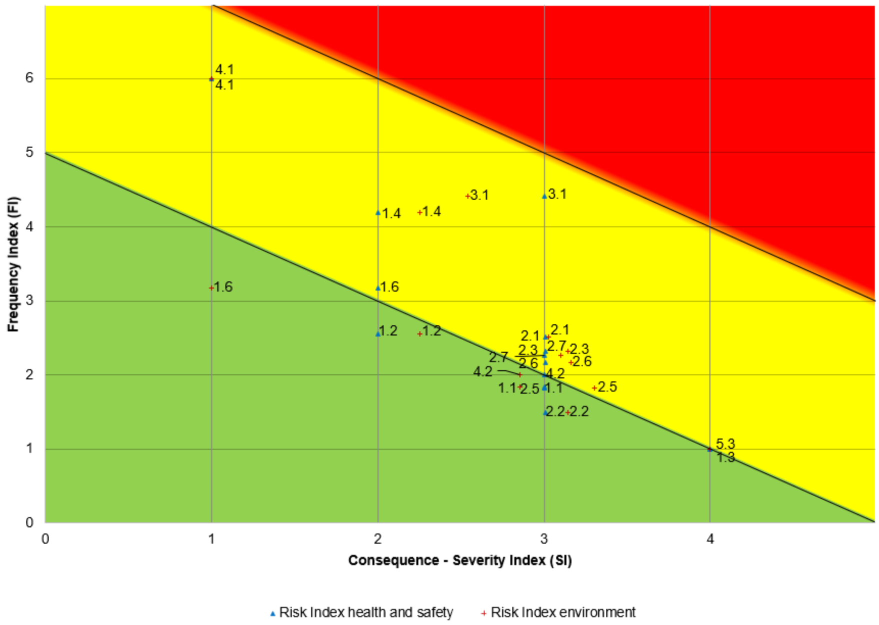

Figure 17. Risk matrix illustrating calculated risk index for both environment and human health and safety, based on frequency and consequence.

Risks within the green zone are classified as *acceptable*. Risks within the yellow zone are classified as *ALARP* (As Low As Reasonably Practicable, meaning reasonable measures should be applied). Risks in the red zone are classified as *unacceptable*.

Table 34 Nautical risks identified for Halla presented in the risk matrix in Figure 17.

ID	Scenario
1.1	Ship navigates into a WTG (powered allision)
1.2	Inoperable ship drifts into a WTG (drifting allision)
1.3	Ship navigates or drifts near a WTG and gets hit by blade
1.4	Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)
1.6	A ship passing through the OWF collides with a WTG
2.1	Total collisions (all collision types) (additional with OWF)
2.2	Overtaking collision (additional with OWF)
2.3	Head-on collision (additional with OWF)
2.5	Merging collision (additional with OWF)
2.6	Bend collision (additional with OWF)
2.7	Collision with working vessel en route to/from port (additional with OWF)
3.1	A navigating ship runs aground (powered grounding)
4.1	Vessel radar disturbance (target loss)
4.2	Vessel radar disturbance (navigation disturbance)
5.3	Falling objects or ice throw from WTGs

Only risks that are quantified in the risk assessment are plotted in the risk matrix in this section. The total summary of risks and their classifications is found in chapter 7.

7. Risk mitigating measures

Table 35 lists the hazards identified for Halla together with a summary of the risk index (RI) estimated or calculated for each scenario. For the scenarios where the risk is classified as ALARP, the recommended mitigation strategy to reduce the risk is also listed. Measures may be taken to reduce unacceptable risks to an acceptable level or to further reduce already acceptable risks if, for example, it is considered reasonable regarding the extent of the measures (ALARP). The recommended mitigation strategies in the table are more clearly described further down in this chapter.

Figure 3, on page 11 illustrate which risk index (RI) that are defined as *acceptable*, *ALARP* and *unacceptable*.

Table 35. Nautical risks identified for Halla together with a summary of the estimated or calculated risk index for each risk to human safety and environment. The indices and colour codes are described in 1.3.3.

Id.	Scenario	Risk (RI)		Recommended mitigation strategy (for *unacceptable* or *ALARP* risk level)
		Human safety	Environment	
Allision (ship collision with stationary object)				
1.1	Ship navigates into a WTG (powered allision)	4.8	3.7	
1.2	Inoperable ship drifts into a WTG (drifting allision)	4.5	3.8	
1.3	Ship navigates or drifts near a WTG and gets hit by blade	<5	<5	
1.4	Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)	6.2	5.4	A. Emergency shutdown procedures for WTGs. B. Procedures for environmental accidents. C. Emergency preparedness plan. D. Dialogue with maritime stakeholders. E. Marine coordinator. I. Ice management. J. Enhancing winter traffic collaboration, coordination, and regulation. K. Emergency shutdown function for WTGs. L. Equipment for spills.
1.5	Ship navigates or drifts into a platform	Evaluated in a separate Seveso assessment		-

Id.	Scenario	Risk (RI) Human safety	Risk (RI) Environment	Recommended mitigation strategy (for *unacceptable* or *ALARP* risk level)
1.6	A ship passing through the OWF collides with a WTG	6.2	3.2	A. Emergency shutdown procedures for WTGs. C. Emergency preparedness plan. D. Dialogue with maritime stakeholders. E. Marine coordinator. K. Emergency shutdown function for WTGs. M. Visual marking. N. Radio and radar marking. T. Layout.
1.7	Limited visibility causes a ship to navigate into a wind tubine	A contributing factor in other accident scenarios. Therefore, the risk cannot be easily categorized on the same scale but is classified as ALARP to be addressed.		O. Foghorn. Q. Measures against radar interference (lost target). R. Navigation lights. S. Virtual fairway. T. Layout. The impact of radar disturbances cannot be investigated in detail at this stage but needs to be analysed when the final design is established. See also the measures listed in scenario 1.6.
	Ship-ship collision			
2.1	Total collision (all collision types)	5.5	5.5	D. Dialogue with maritime stakeholders. The risk is dominated by vessels that at present take the route over the Halla OWF area and are expected to take new routes south of Halla.
2.2	Overtaking collision	4.5	4.6	
2.3	Head-on collision	5.3	5.4	Refer to the measures listed in scenario 2.1.
2.4	Crossing collision	No OWF induced risk for human safety or the environment		
2.5	Merging collision	4.8	5.1	Refer to the measures listed in scenario 2.1.
2.6	Bend collision	5.2	5.4	Refer to the measures listed in scenario 2.1.
2.7	Collision with working vessel on route to/from port	7.0	7.0	B. Procedures for environmental accidents. C. Emergency preparedness plan. D. Dialogue with maritime stakeholders. E. Marine coordinator. F. Construction risk analysis. G. Work vessel procedures. H. Information. L. Equipment for spills.
	Grounding			
3.1	Ship runs aground (powered grounding)	7.4	6.9	B. Procedures for environmental accidents. L. Equipment for spills.
3.2	Ship runs aground (drifting grounding)	Risk decreases with OWF		
	Vessel radar disturbance			
4.1	Vessel radar disturbance (target loss)	7.0	7.0	Q. Measures against radar interference (lost target). R. Navigation lights. S. Virtual fairway. The impact of radar disturbances cannot be investigated in detail at this stage but needs to be analysed when the final design is established.

Id.	Scenario	Risk (RI) Human safety	Risk (RI) Environment	Recommended mitigation strategy (for *unacceptable* or *ALARP* risk level)
4.2	Vessel radar disturbance (navigation disturbance)	<5	<5	-
4.3	Vessel radar disturbance within the OWF	4.2	4.2	
4.4	The OWF complicates search and rescue operations	A contributing factor in other accident scenarios. Therefore, the risk cannot be easily categorized on the same scale but is classified as ALARP to be addressed.		A. Emergency shutdown procedures for WTGs. K. Emergency shutdown function for WTGs. M. Visual marking. N. Radio and radar marking. P. ID tagging. R. Navigation lights. T. Layout.
Winter conditions				
5.1	The OWF affects ice buildup	The risk is subject to ongoing research and cannot be quantified. Classified as ALARP to be addressed.		I. Ice management. J. Enhancing winter traffic collaboration, coordination, and regulation.
5.2	The OWF blocks winter navigation routes	A contributing factor in other accident scenarios. Therefore, the risk cannot be easily categorized on the same scale but is classified as ALARP to be addressed.		I. Ice management. J. Enhancing winter traffic collaboration, coordination, and regulation.
5.3	Falling objects or ice throw from WTGs	<5	<5	-
Cables				
6.1	Transmission cable damage	Negligible risk to people and the environment		-
6.2	Cables prevent emergency anchoring	Negligible risk to people and the environment		-

The development of measures that can be taken is categorized into administrative/organizational and technical/physical measures.

Administrative and organizational measures:

A. Emergency shutdown procedures for WTGs. Emergency shutdown procedures should be developed and be available locally and remotely, for example in a control centre.
B. Procedures for environmental accidents. Mitigation measures and procedures for environmental accidents and spills should be developed.
C. Emergency preparedness plan. An emergency preparedness plan should be developed and regularly updated to prepare the operations organization for potential emergencies that may occur, such as collisions.
D. Dialogue with maritime stakeholders. Risk-driving maritime actors, such as shipping companies that operate in the area with passenger and tanker vessels, should be engaged in dialogues on risks.
E. Marine coordinator. The energy park will have a dedicated marine coordinator responsible for monitoring and coordinating all marine operations. This individual is responsible for vessel traffic monitoring within the energy park and its vicinity using tools like radar and AIS. The marine coordinator is also responsible for alerting FIRCC (Finnish International Rescue Coordination Centre).
F. Construction risk analysis. A supplementary risk analysis is conducted for the construction phase.

G. Work vessel procedures. Prior to construction, procedures are developed for the safe navigation of work vessels. These procedures are developed in consultation with relevant stakeholders, such as VTS (Vessel Traffic Service).
H. Information. Information about the facility should be announced and communicated well in advance to relevant parties before the construction or decommissioning of the energy park begins.
I. Ice management. Vessels might need to wait for ice breaker assistance in a safe place. Authorities define when the vessels are allowed to go through certain difficult areas alone or only when assisted by ice breakers. Those areas are changing from time to time due to changing ice conditions.
J. Enhancing winter traffic collaboration, coordination, and regulation. Authorities and other concerned stakeholders should be engaged in dialogue about strategies for adequate ice management in the Baltic Sea, e.g. enhanced icebreaker collaboration Finland/Sweden, prepared routines for ice breakers, coordination of vessels and icebreakers, anchor/waiting areas further out in the sea area, where there is no risk to drift towards the OWF, planning of shipping routes, and enhancing rules and regulations about how to manage vessels in icy conditions.

Technical and physical measures:

K. Emergency shutdown function for WTGs. Emergency shutdown functionality should be available locally and remotely, for example in a control centre.
L. Equipment for spills. Maintenance and service vessels should be equipped with gear to delay and limit environmentally hazardous spills.
M. Visual marking. Ensure the marking of WTGs and platforms in accordance with applicable legislation or industry standards.
N. Radio and radar marking. To enhance the visibility of the energy park, AIS and Racon[24] marking should be carried out on selected WTGs.
O. Foghorn. Installation of foghorns on all WTGs or selected WTGs.
P. ID tagging. The WTGs should be labelled with a unique ID designation to facilitate rescue operations.
Q. Measures against radar interference (lost target). Installation of reference buoys in established traffic lanes and other measures to reduce the risk of lost targets are considered and decided upon before the final design of the energy park.
R. Navigation lights. Additional navigation lights within the windfarm.
S. Virtual fairway. Pre-defined route set-up close to the OWFs, where vessels shall navigate when they approach the OWF, to counteract fog’s impact on visibility.
T. Layout. A more regular grid pattern with WTGs in straighter lines would facilitate search and rescue operations, and navigation in general within the OWF. Search and rescue actors should be engaged in dialogue regarding to layout.

Since no risks have been classified as *unacceptable*, no measures that are mandatory from a risk perspective are proposed. However, scenarios 1.4, 1.6, 1.7, 2.1, 2.3, 2.5, 2.6, 2.7, 3.1, 4.1, 4.4, 5.1 and 5.2 have been classified as

[24] A Racon (Radar Beacon) is a transponder used for identification and navigation assistance, typically installed on structures such as WTGs or lighthouses.

ALARP. The mitigating measures for these risked are assessed to be of such a nature that they are justified to implement. The extent and exact design of the technical and physical measures (K, L, M, N, O, P, Q, R, S and T) are specified when the final layout of the park is decided. The exception is the mitigating measure Q where a study of possible radar interference will be conducted when the park is established to determine if there is a need to take measures to counter radar interference.

8. Uncertainty analysis

In this section, the uncertainties identified in the analysis are summarized. The conclusion is that although there are many uncertainties, the overall results are robust. The calculated risks are judged to end up in the right range, although the numbers on the decimal place may be interpreted with some caution.

- **Cumulative effects:** The uncertainty in the overall risk profile if several OWFs will be built in the Bothnian Bay is being considered in powered allision, drifting allision, all collision types as well as powered grounding and drifting grounding. Risks if adjacent planned OWFs are constructed (Polargrund OWF and Omega OWF) are compared to the risks if Halla becomes the sole OWF. In conclusion, the cumulative effects of the establishment of several OWFs in the area do not entail any additional risks beyond those identified when analysing the OWFs individually. The conclusion is that the result is robust as the same risk categorizations are obtained regardless of the assumption.
- **Future traffic**: Uncertainty analyses have been carried out (see Appendix C) with the conclusion that the result is robust as the same conclusions are obtained regardless of the assumption about future traffic volumes and vessel sizes. The conclusion is that the uncertainty about future number of vessels has small impact on the numerical risk results and no impact on the risk categorization. The increase in future freight volumes may potentially result in larger vessels instead of an increase in the number of shipments. By adopting a conservative approach in estimating consequences, this uncertainty is considered in the risk assessment.
- **Frequency calculations:** Uncertainties regarding parameters, AIS data, the IWRAP model, and future traffic volumes and routes have been identified.
- **Traffic pattern:** How the traffic pattern will change with the establishment of the OWF is an assumption with big impact on the results. It is uncertain how extensive the change in traffic pattern will be. A review of British OWFs shows examples where OWFs do not affect shipping traffic at all, as well as cases where shipping traffic is affected up to 1.5 nautical miles from the wind farm. The assumptions made in this analysis about changes in routes and lateral distributions affect the results, primarily the calculated risk of powered allision and powered grounding. In the IWRAP modeling, 98.5% of the traffic is assumed to lay at a distance from the OWF that meets safety distances for the reference vessel according to the traffic analysis (2023a). Both the risk of powered allision and powered grounding (resulting from the OWF) have been classified as *ALARP* in the analysis, but if vessels will position themselves further away from the

OWF, the risk may be lower. Further uncertainties regarding frequency estimation are discussed in more detail in Appendix C.

- **Winter traffic:** For analysis of winter navigation and associated risks, the analysis is limited to AIS data from 2022. The winter traffic pattern is different every year, thus the results for winter navigation is only an example of how risks can be affected. The ship traffic intensity around Halla varies from winter to winter. Therefore, the estimated zero alternative is not representative for all winters. The estimated risk of vessels caught in the ice and drifts with the ice field into a WTG (scenario 1.4) is however assumed to be representative, since the assumptions for possible routes after OWF establishment are easier to foresee (around Halla OWF). The parameters are conservatively selected to be within the uncertainty margin.
- **Ice:** There is lack of knowledge about how windfarms contribute to ice buildup of hummocking ice (scenario 3.5). This is treated as an uncertainty, due to the limited research on the potential effects of offshore WTGs on ice conditions in arctic regions, and more comprehensive study would be needed to fully understand the impacts. More knowledge about how OWFs contribute to build up hummocking ice is needed. It is also worth noting that there are many other factors that can influence the formation of hummocking ice and other ice conditions in the arctic, including climate change and natural variability in weather patterns. This area should be subject to dedicated research. These uncertainties gives that the risk will be treated as *ALARP*.
- **Grounding:** The probability of grounding has been calculated based on depth data from open sources , which have been processed and simplified for use as bathymetric layers in the IWRAP model (NOAA, 2022) Based on this information, the probability of successfully anchoring a drifting vessel has also been calculated. The data lacks the level of detail needed to be used for navigation and for example how grounding occurs in individual locations. However, for modeling purposes, the data is considered sufficient to draw conclusions about general grounding patterns.
- **Human errors:** In the assessment of certain risks, including the management of radar interference (risks 3.2 and 3.3), human error probabilities (HEPs) have been estimated in a simplified manner. This is in accordance with the FSA methodology, which states: (Maritime Safety Committee, 2018)
  “Where a fully quantified FSA approach is required, HRA can be used to develop a set of HEPs for incorporation into probabilistic risk assessment. However, this aspect of HRA can be over-emphasized. Experienced practitioners admit that greater benefit is derived from the early, qualitative stages of task analysis and human error identification. Effort expended in these areas pays dividends because an HRA exercise (like an FSA study) is successful only if the correct areas of concern have been chosen for investigation.”
  HEP values have been chosen conservatively due to a lack of detailed information, in order to avoid underestimating the analysed risks.
- **Consequences:** The same consequences are generally assumed for the same type of vessels regardless of size, and regardless of where the accident occurs. To handle the uncertainty associated with consequences, they have been chosen conservatively. As reported in section 2.3.1, none of the historical collisions with WTGs have resulted in

neither fatalities nor emissions. Still, these consequences are conservatively applied in this risk analysis.

- **Accident history:** The accident history in section 2.3.1 confirms the results about where accidents are likely to occur. The dataset is limited which means that there are relatively few data points to draw conclusions from, but it indicates that the calculated collision risk might be underestimated. Since the collision frequency is of the same magnitude for all calculated scenarios, this uncertainty has small impact on the conclusions. The historical data also indicates that the grounding frequency might be overestimated. This can be explained by the fact that accidents may go unreported due to various reasons, such as minor accidents that do not result in significant damage or injuries or that IWRAP might overestimate grounding frequencies.

Overall, uncertainties have been identified, where the most important are:

- What routes ships will take in the future and at what distance they will pass the OWF.
- How OWFs will affect ice formations

Where uncertainties exist, the risk assessment takes a conservative approach, ensuring that risks are not underestimated.

9. Discussion

A total of 25 nautical risks have been identified, analysed, and evaluated. Most risks were concluded to be negligible or were categorized as *acceptable*. No *unacceptable* risks were found. Risks that in certain aspects have been classified as *ALARP*, meaning that the risks can be tolerated if reasonable measures are taken, were found. Recommendations of risk mitigating measures are given in this report.

The results are considered to be robust, and uncertainties are eliminated by using conservative assumptions in the analysis.

Aspects that need further discussion related to time-scale, allision, and winter-related risks are addressed in the next sections.

9.1 Time-scale

The risks are quantified on a yearly basis but represent a risk for conditions that do not exist all the time. The calculated risks thus reflect the risk level if the risk exists the whole year (i.e., the calculated risk level for vessels to get caught in the ice and then drift with the ice field represents the risk if winter conditions prevail year-round). The values should not be used for estimating accumulative risk, unless the risks are scaled down with a factor corresponding to the period that the risks exist.

9.2 Risk per area

The baseline risk for grounding and collision is high in the Bothnian Bay even without Halla OWF. One reason for this is that risk is normally not scaled to the risk per area in maritime risk analysis, and as a result, large areas automatically become higher in risk. Therefore, it is more relevant to look at the additional risk that is induced by the OWF. The problem is also applicable to OWFs, where risk per WTG is seldom calculated.

9.3 Allision

The risk for powered allision is classified as *acceptable*. The results are sensitive to what assumptions about at what distance vessels will pass the OWF. If the vessels are assumed to pass the OWF very closely, the risk for powered allision is much higher. The exact magnitude of the risk depends on how the traffic pattern changes. The probability of collision with navigating vessels decreases if the traffic positions itself farther away from the wind farm. The farther away the traffic closest to the park chooses to position itself, the lower the probability of colliding with a wind turbine, but at the same time, the probability of overtaking collisions and head-on collision with oncoming vessels within the shipping lanes increases.

The risk for drifting allision is classified as *ALARP* with a risk for Human safety with a scenario of Halla, Polargrund and Omega all being established. In all other calculated scenarios, the risk for drifting allision is classified as *acceptable*. The WTGs located on the northern, western, and southwestern side of Halla OWF are subject to a higher risk of drifting allision during both summer and winter. This mainly refers to the scenario with Halla, Omega and Polargrund established where the risk is classified as ALARP for human safety. Meanwhile, the western side of Halla OWF is the most heavily trafficked shipping lane, Nordvalen – Kemi/Ajos with the traffic being more congested in this area in a scenario with Halla, Polargrund and Omega established in comparison to the traffic density with only Halla established as well as the zero alternative. In contrast, the frequency of drifting allision on the eastern side of the OWF is comparatively lower. Additionally, the eastern side of Halla OWF features a shallower area, where drifting vessels tend to run aground rather than colliding with the WTGs to a significant extent. However, regardless of the location of the WTGs, each object is a risk factor for drifting vessels.

9.4 Collision

The total collision risk is classified as *ALARP* in a scenario with only Halla established as well as with Halla, Omega and Polargrund established. In general, the risk level in most of the collision types is classified as *ALARP*, with the most frequent collision type due to the modelling being Merging collisions. Crossing collisions appears to decrease with establishment of OWFs, which could be a result of fewer crossing situations being modelled due to changes in traffic patterns. The risk concerning crossing collisions is considered *acceptable*.

The collision frequency is highest at Nordvalen – Kemi/Ajos and near the waypoint where Raahe – Oulu – Kemi – Tornio leads up towards Oulu and further towards Nordvalen – Kemi/Ajos along Oulu 1, as well as the northbound fairway towards Kemi/Ajos/Tornio.

Overall, the frequency and severity of the consequences of collisions should decrease if given risk mitigating measures listed in chapter 7 are implemented.

9.5 Grounding

The risk of drifting grounding is considered acceptable with the establishment of OWFs, as there is no calculated increased in relative risk associated with the OWFs. The risk concerning drifting grounding is considered *acceptable*.

There modelling shows a notable risk of powered grounding. Considering where the event is expected to occur in the modelling, the frequency may reflect Hallas relative proximity to the coast and the presence of several dredged fairway areas that are adjacent to shallow waters. Reviewing the positioning of modelled events, Halla OWF does not appear to be a significant contributing factor to the overall risk level of powered grounding incidents. However, it should be noted that powered grounding events in the modelling occur at the north-western edge of Halla, near a shallow outside the shipping lane Oulu 1 adjacent to Nordvalen – Kemi/Ajos shipping lane. Hence, it is recommended to remain vigilant considering the risk of powered grounding at this location to prevent any potential accidents. Further detailed information is found in Appendix C.

9.6 Ice-related risks

Since the HAZID pointed out risks related to winter navigation and ice as a certain area of caution, some aspect of how Halla OWF affects the nautical risk profile during ice conditions are listed here.

- **OWF impact on ice formation:** When establishing Halla OWF, the foundations might have impact on ice formation in the area. The OWF may contribute to building up hummocking ice and ice ridges, which is represented by the risk assessed in section 6.5.1. Hummocking ice may cause problems for both vessels and icebreakers. The ridges are difficult to penetrate by ships, especially due to the consolidated layer of the ridges, which is normally thicker than the surrounding field of level ice. The ice ridges form the biggest obstacle for winter navigation. More knowledge about how windfarms contribute to build up hummocking ice is needed. It is also worth noting that there are many other factors that can influence the formation of hummocking ice and other ice conditions in the arctic, including climate change and natural variability in weather patterns. This area should be subject to dedicated research and ins not included in the risk assessment. The risk is classified as *ALARP* to be addressed.
- **Ships get caught in the ice and drift with the ice field:** Every year, ships get caught in the ice and drift with the ice field. The ice velocity can be within the range of about 2-3% of the wind speed. The frequency is not affected by the construction of an OWF, but the consequences are more severe. This risk is studied in section 6.1.4 and is classified as *ALARP*.
- **OWF blocking the default winter navigation route:** This risk is primary a risk with administrative and economic consequences, not included in this nautical risk assessment. There are however also consequences related to human health and safety, and the environment. Vessels that must travel longer distances in winter conditions might be more exposed to the risks of grounding, collision and allision since the travelled distance is longer. This risk is studied in section 6.5.2 and is classified as *ALARP*. The likelihood of encountering massive ridges becomes bigger. There can be delays in assistance in case of emergency and stationary vessels waiting for assistance are subject to forces in the ice and the risk of hull damage. This risk is also studied in section 6.5.2 and is considered a negligible risk to people and the environment.
- **Ice damage of ship hull:** Vessels navigating in a compressive ice field may get stuck, and they may also get ice damages to the hull as a consequence of contact with ice. Ice damage occurs quite frequently in ships in winter navigation. All the vessels navigating in icy waters must be ice classed according to Finnish-Swedish Ice Class rules. In addition, they must comply with traffic restriction set by FTIA, otherwise they are not allowed to navigate in the region and are not entitled for ice breaking assistance. The consequences of typical ice damages are not severe, but ruptures of the hull plating may cause a leakage of water in the ship. This consequence is not considered to be a threat to people or the environment. (Winter Navigation Research Board, 2005)

- **Grounding:** In winter navigation a powered grounding can be caused by ice if it prevents making the intended and necessary manoeuvre to keep the ship on a safe route. Drifting grounding is a consequence when ships get caught in the ice and drift with the ice field but is not expected to be more frequent with the OWF. As stated in section 6.3, Halla OWF does not significantly change the risk for drifting grounding, i.e., the risk with Halla OWF is negligible. This conclusion is assumed to be valid also in the winter.
- **Collision:** The collision risk in section 6.2 is assumed to conservatively also represent the collision risk in winter conditions where the vessel transits are fewer, the velocities are often low, and the consequences of the incidents are usually not so severe. This collision risk is categorized as *ALARP*.
- **Vessel radar:** When justifying the vessel radar to avoid clutter, also ice might get invisible on the radar screen. The risk assessment of vessel radar disturbances in section 6.4 does not look specifically at winter risks. This risk will be assessed more in detail in the radar study.

To summarize, windfarms may affect how ice is built up, affecting the navigation conditions for winter traffic. Halla OWF may block winter navigation routes, forcing vessels to take longer routes where they are more exposed to hazards. Some of the winter-related risks are classified as ALARP and risk mitigating measures to address them are listed in section 7.

10. Conclusion

Halla OWF impacts the risk profile for ship traffic in the Bothnian Bay as follows:

- **Allision:** Halla OWF introduces the risk for allision with WTGs and platforms. This risk is present also during winter conditions, when vessels can get caught and drift with the ice.
- **Collision:** The risk for collision increases, mainly since Halla OWF will congest and cause more traffic to use the shipping area Nordvalen – Kemi/Tornio, leading to more collisions. During the construction and decommissioning phase, there is also risk for collision with working vessel en route to/from port.
- **Grounding:** Halla OWF increases the risk for powered grounding but does not significantly change the risk for drifting grounding.
- **Vessel radar:** Halla OWF may cause disturbances on vessel radar.
- **Winter conditions:** WTGs may affect ice buildup, affecting the navigation conditions for winter traffic. Halla OWF may block winter navigation routes, forcing vessels to take longer routes where they are more exposed to hazards.
- **Cables:** Risk assessed as negligible to people and the environment.

Most risks were concluded to be negligible or were categorized as *acceptable*. No *unacceptable* risks were found. Risks that in certain aspects have been classified as *ALARP*, meaning that the risks can be tolerated if reasonable measures are taken, were found:

- Inoperable ship drifts into a WTG (drifting allision)
- Vessel caught in the ice and drifts with the ice field into a WTG (drifting allision)
- A ship passing through the OWF collides with a WTG
- Limited visibility causes a ship to navigate into a WTG
- Total collisions (all collision types)
- Overtaking collision
- Head-on collision
- Merging collision
- Bend collision
- Collision with working vessel en route to/from port
- Powered grounding
- Vessel radar disturbance (target loss)
- The OWF complicates search and rescue operations
- The OWF affects ice buildup
- The windfarm blocks winter navigation routes (longer routes resulting in grounding, collision and allision)

Recommendations on risk mitigating measures are given in this report:

Administrative and organizational measures	**Technical and physical measures**
A. Emergency shutdown procedures for WTs. B. Procedures for environmental accidents. C. Emergency preparedness plan. D. Dialogue with maritime stakeholders. E. Marine coordinator. F. Construction risk analysis. G. Work vessel procedures. H. Information. I. Ice management J. Enhancing winter traffic collaboration, coordination, and regulation.	K. Emergency shutdown function for WTs. L. Equipment for spills. M. Visual marking. N. Radio and radar marking. O. Foghorn. P. ID tagging. Q. Measures against radar interference (lost target). R. Navigation lights. S. Virtual fairway. T. Layout.

The cumulative effects of the establishment of several parks in the area do not in general entail any additional risks beyond those identified when analysing the parks individually. However, there is an increased risk for *Human safety* inoperable ship drifting into a WTF (drifting allision) with Halla, Omega and Polargrund established all together in comparison to with only Halla established.

The overall conclusion is that the risk induced by Halla OWF is *acceptable*, presuming that mitigating measures are taken. Risks related to winter navigation and ice are not assumed to have severe consequences for human health and safety or for the environment but are classified as *ALARP* to assure that the uncertainties do not lead to underestimation of risks.

11. References

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Appendix A. Calculation of the risk index

In a risk analysis, it is well established to define risk as a product of probability and severity of the consequence:

$$\text{Risk} = \text{probability} \times \text{consequence}$$

Equation 1

According to the FSA methodology, it is advisable to define the severity index (SI) and frequency index (FI) on a logarithmic scale. The definitions are found in the main report (section 1.3.3). A risk index (RI) is established by adding frequency and severity indices. (Maritime Safety Committee, 2018)

$$\text{RI} = \text{FI} + \text{SI}$$

Equation 2

The risk index for an event ranked as *remote* (FI=3) and with a severity of *significant* (SI=2) is then given the risk index RI=5 (see the risk matrix in Figure 3. Risk matrix for valuation of navigation risks for the OWF. RI, Risk index, is given by the values in the color-coded fields.)

The relationship between risk and risk index can be expressed as follows:

$$\log_{10}(\text{Risk}) = \log_{10}(\text{probability}) + \log_{10}(\text{consequence})$$

Equation 3

For some events, different consequences are expected depending on the type of ship(s) involved (e.g., collision with a passenger ship may lead to more fatalities while collision with an oil tanker may lead to more oil spillage). For such events, the risk index is calculated as the sum of the risk contributions from each type of event:

$$\text{RI} = \log_{10}(f_1 c_1 + \ldots + f_n c_n) + K$$

Equation 4

where RI is the risk index as assessed above, f_i is the frequency (per year) of event i, c_i is the consequence (expressed in safety index) of event i, and K is a constant integer for the calculated risk index to correspond to the correct risk level in the matrix in Figure 3.

Example

Suppose that a certain type of accident occurs with a frequency of $f = 5 \cdot 10^{-5}$ per year. This corresponds to a return time of 20,000 years (that is, an accident is expected to occur on average once every 20,000 years). The frequency includes all accidents of a certain type, regardless of the ship category. In this example, it is assumed that oil tankers (oil) account for 10% of all accidents, passenger ships (pass) account for 1% and cargo ships (cargo) for 89% of this type of accidents. Depending on the type of vessel, the accident leads to different consequences. An accident involving an oil tanker is assumed to result in an oil spill of 1,000 tonnes of oil, while an accident involving other types of vessels is assumed to result in a spill of 10 tonnes of oil. The environmental risk for the individual categories of vessels is then calculated as follows:

$Risk_{oil} = f_{oil} \cdot c_{oil} = 10\% \cdot 5 \cdot 10^{-5} \cdot 1{,}000 = 5.0 \cdot 10^{-3}$ [tonnes of oil per year]

$Risk_{pass} = f_{\mathrm{pass}} \cdot c_{\mathrm{pass}} = 1\% \cdot 5\ 10^{-5} \cdot 10 = 5.0 \cdot 10^{-6}$ [tonnes of oil per year]

$Risk_{cargo} = f_{cargo} \cdot c_{cargo} = 89\% \cdot 5 \cdot 10^{-5} \cdot 10 = 4.45 \cdot 10^{-4}$ [tonnes of oil per year]

To move the environmental risk to fit into the risk matrix in Figure 3, $K_{\mathrm{environment}}=7$ is applied and, using the expression in *Equation* 4, risk index concerning environment is calculated:

$\mathrm{RI} = \log_{10}(Risk_{oil} + Risk_{pass} + Risk_{\mathrm{cargo}}) + K_{\mathrm{environment}} = \log_{10}(5{,}45 \cdot 10^{-3}) + 7 \approx 4.7$

The calculated risk in this example, RI=4.7, is less than 5 and would thus be placed slightly below the ALARP level in the risk matrix in Figure 3. Risk matrix for valuation of navigation risks for the OWF. RI, Risk index, is given by the values in the color-coded fields.

in the main report. When plotting the risk in the risk matrix, $f = 5 \cdot 10^{-5}$ per year is applied, which on the frequency axis is less than 1 time in 10,000 years, but more than 1 time in 100,000 years.

Exactly calculated, the occurring index $\mathrm{FI}=\log_{10}(5 \cdot 10^{-5})+6 \approx 1.7$. The "typical" consequence of an accident can be expressed as a risk-frequency ratio, SI = RI-FI ≈ 4.7-1.7 ≈ 3.03 which on the impact axis would be placed in the left part of the consequence "Severe impact" corresponding to an oil spill of just over 100 tonnes of oil. Thus, the typical frequency does not represent any individual case but is an average of several sub-scenarios, weighted according to the proportion of different vessel types in the total accident rate.

Appendix B. Radar interference – knowledge overview

In addition to radar, modern ships are often equipped with navigation systems where radio signals, satellite navigation systems and signals from other sensors on board are linked to the radar image on ARPA or separately on an electronic chart display (ECS or ECDIS). OWFs can have an impact on these navigation systems as well as on visual sight.

The Chapter V of SOLAS (IMO, 2002) details the carriage requirement of Radar and ARPA onboard ships

- All ships of 300 GRT and above and all passenger vessels shall be fitted with a 9 GHz Radar and an electronic plotting aid.
- All ships of 500 GRT and above shall be fitted with an automatic tracking aid to plot the range and bearing of other targets.
- All ships of 3,000 GRT and above, a 3 GHz Radar or a second 9 GHz Radar which are functionally independent of the first 9 GHz Radar. A second automatic tracking aid to plot the range and bearing of other targets, which is functionally independent of the first electronic plotting aid.

Ship radar

Ship radar is an important tool for maritime safety and navigation at sea. There are two main types of ship radar: X-band radar and S-band radar. These two radar systems complement each other.

X-band radar is a high-frequency radar (9 GHz) commonly used for short-range detection of objects and to assist in navigation and positioning of the ship.

S-band radar (3 GHz) is effective at longer distances and can be used to detect both objects that are close to the ship and objects that are far away.

Alongside AIS, ship radar is an important tool for both navigation and collision avoidance, especially in poor visibility.

WTGs can reflect radar signals and can thus interfere with radar systems in the immediate area. It is well known that offshore wind power has an impact on ship radar, which can affect the ability to locate, detect and identify signals in the vicinity of WTG. Blind areas can occur in the shadow of a WTG.

The most common impact is an increase in signals that are reflected and cause strong echoes on the radar display, which complicates the decision basis for navigation. Within 1.5 M of WTGs there is a risk of multiple echoes, indirect echoes, and side lobe echoes. **Multiple echoes** occur when the radar signal bounces between the WTG and the ship a few times before it is picked up by the radar antenna. Multiple echoes can also arise from many different targets in the same direction as the ship's main target. **Indirect echoes** occur when the radar pulse is reflected off several objects before reaching back to the radar antenna. **Side lobe echoes** are echoes that exist outside the main lobe of the radar antenna, i.e. echoes from radar targets that are in the antenna's side lobes. (Committee on Wind Turbine Generator Impacts to Marine Vessel Radar, 2022) (MCA, 2008)

The radar equipment is adjusted by the OOW navigating the vessel to minimize interference. Echoes can be reduced by adjusting the settings. The OOW should be able to set-up and configure the radar settings if needed. Some of the important basic Radar controls are:

A) Clutter controls – Rain, Gain, Sea
B) Pulse controls, Range controls
C) Performance monitor
D) Manual tuning

Since the measure at the same time reduces the possibility of detecting weak echoes such as smaller boats and buoys, there is a trade-off to make between too much and too little echoes. (Snöberg, 2002)

Newer vessels are equipped with navigation aids such as ARPA (Automatic Radar Plotting Aid) or radar plotters that provide information about the direction of movement of other objects such as ships. A modern ARPA includes a set of features to determine the risk of collision, including information on CPA (closest point of approach) and TCPA (time to closest point of approach). For example, the system can alert when TCPA falls below a threshold set by the user. When ARPA is used to follow radar targets near a OWF, the ARPA can lose its target (lost target) or jump to another target (target swap).

Studies conducted on the OWF at Kentish flats, England, show that sailors were able to observe and follow other vessels that were both inside and on the other side of the OWF using radar despite the above effects. (BWEA, 2007)

PIANC indicates that there is a high probability[25] of **ghost echoes** on X-band radar at distances shorter than 0.25 M (500 m). There is also a high probability[25] that loss of target (smaller targets) can occur at distances shorter than 1.5 M (2,778 m). Safety distances to avoid interference have been set by naval officers to 0.8 M. Overall, PIANC recommends a minimum distance of 1.5 NM between vessel traffic and OWFs to minimize interference to ship radar and ARPA. The report emphasizes that anyone navigating the vessel should adjust their radar equipment to obtain accurate results when using ARPA. In case of incorrect setting on the radar, echoes and lost targets can occur, regardless of distance from the OWF, according to PIANC (2018).

In radar watch keeping, it is essential to understand the limitations of the equipment. Over reliability on radar and ARPA has been a reason for many accidents at sea. The radar users should understand the fact that it is equipment that has its own limitations and troubleshooting, and the accuracy of the data

[25] Not defined

largely depends on the performance standard of the equipment. Timely check on the performance of the radar is of high priority. In case of incorrect setting on the radar, echoes and lost targets can occur, regardless of distance from the OWF, according to PIANC (2018).

Satellite navigation

Reflections from buildings and other large, massive objects can lead to precision problems with GPS. The phenomenon when the GPS signal from the satellite is reflected in a tall building before it reaches the receiver is called multipath, and it occurs on merchant ships even without WTGs nearby. Disturbances resulting from the multipath are generated by cranes and masts on the ships at sea. It is possible to minimize interference on the receiver through specific settings. (Sjöfartsverket, 2022) (PIANC, 2018)

For better positional accuracy, a Differential Global Positioning System (DGPS) receiver can be installed. The Swedish Maritime Administration has, in cooperation with neighbouring countries and following IALA's recommendations, established a reference station network for GPS. According to PIANC, a safety distance between WTGs and ships as well as between WTGs and DGPS reference station is needed to maintain the accuracy of the DGPS. For 160m high WTGs, the distance is given as 1.2km. This distance is calculated based on conditions regarding angles and WTG heights that may deviate slightly from the current project area and can therefore be seen as an indication. The safety distance only applies to interference with the signal from the reference station, which means that the position accuracy with GPS is expected to be maintained even within this distance. (Sjöfartsverket, 2021)

Radiocommunication

VHF are radio frequencies that are used in shipping for communication, including distress calls.

AIS uses two channels on the VHF band for the transmission of digital information. AIS is an autonomous system that makes it possible to identify and follow vessel movements from a ship and from land. Position, heading and speed are retrieved from the same system used for the ship's navigation, normally a GPS or DGPS receiver (Sjöfartsverket, 2022). The IMO requires AIS use by all vessels >500GT, for any vessel >300GT that is on an “international voyage” and for all passenger vessels (IMO, 2002). AIS should always be in operation when ships are underway or at anchor (IMO, 2015).

The global maritime emergency radio system, GMDSS, has been mandatory for all commercial shipping since 1999. Equipment requirements depend on the waters to be operated. The current project area is within VHF coverage from a coastal station with continuous fitting of digital distress calls via the VHF system (over so-called DSC). Maritime and air rescue centres are alerted either by VHF radio, telephone, or satellite (Sjöfartsverket, 2022).

According to PIANC (PIANC, 2018), the establishment of OWFs affects the coverage area of VHF when ships are beyond an OWF. There are studies confirming interference with VHF, which under certain circumstances can affect not only analogue voice communication, but also DSC and AIS signals. However, the significance of the interference with VHF communication including AIS is considered to be insignificant according to studies that have been done. Experiences from, among others, North Hoyle show that communication works well over VHF and mobile phones inside the park. However, problems with direction finding of the VHF signal occurred when the sounding ship was closer than 50 meters to a WTG that shaded the radio transmitter (Howard, 2004).

Terrestrial navigation

The construction of a OWF means that the visual information changes. The WTGs act as clear navigation signs at sea, which facilitates navigation in general and when conducting sea rescue operations. The WTGs will be equipped with flood lights according to IALA's recommendations. At the same time, the WTGs risk obscuring existing navigation marks. Out at sea, there are no nautical signs or other solid objects to navigate by within the nearest kilometres from the park. The WTGs are thus not expected to immediately obscure any navigation mark.

Compasses are not expected to be significantly affected by the energy park. According to PIANC, it is unlikely that the WTGs and power lines could affect magnetic compasses. Larger vessels generally have gyrocompasses that are not affected by magnetic interference (PIANC, 2018).

Appendix C. IWRAP calculation of accident frequencies

This appendix presents the frequency calculations that form the basis for the risk assessment for Halla OWF (henceforth referred to as Halla) regarding collision risk, risk of grounding and risk of ships navigating or drifting into Halla and colliding with a wind turbine generator (WTG).

Frequency calculations for allision with a platform are also reported. These results are used in the Seveso report.

Purpose

The following probabilities are calculated:

- The probability of ships navigating into a WTG
- The probability of ships drifting into a WTG
- The probability that ships in sea ice conditions (henceforth referred to as winter) drift with the ice and drift into a WTG
- Probability of collision between ships
- Probability of grounding
- The probability of ships drifting into a platform (input to the Seveso report)

The calculations are made for an example layout for Halla with 120 WTGs of 20 MW.

There is a possibility that two other OWFs close to and adjacent to Halla might be established. These are Omega OWF and Polargrund OWF (henceforth referred to as Omega and Polargrund).

The main purpose is to calculate the OWF-induced risk for Halla, but also to calculate the OWF-induced risk for Halla, Omega and Polargrund as a “possible worst-case”-scenario.

Method

Quantitative estimates of frequencies for navigation risks are made in accordance with the *Revised Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process* (Maritime Safety Committee, 2018). For the calculations, IWRAP is used, which is a tool for applying FSA methodology.

IWRAP calculates collision, allision and grounding frequencies for vessels travelling along defined routes. The input data is based on historical AIS data as well as expert estimates where data are missing.

The calculations are made using a probabilistic model that is developed for vessel traffic in the area in question. The model is based partly on the probability that ships lose steering or maintain a course and speed that could result in an accident if no avoiding action is performed, and partly on the probability that all measures to avoid an accident will fail when the ship is in such a position*. Using the model, the probability of collision, allision and grounding with and without WTGs is calculated.

IWRAP

Frequencies are calculated using the commercial version of the IWRAP Mk II software.

In IWRAP, ship routes are modelled in the form of sections called *legs*. For traffic along each leg, the probability of collisions between ships of the type head-on collision and overtaking collision is calculated.

Points where the ship paths change direction, merging or crossing are modelled in IWRAP with a *waypoint*. For traffic through a waypoint, the probability of a bend collision, merging collision and crossing collision respectively is calculated.

A detailed description of the theory and working methods for IWRAP is given in IWRAP Mk (Engberg, 2019).

Analysis cases

A summary of the analysis cases is presented in Table 36.

* The likelihood that ships lose ability to steer or maintain a course and speed that can end in an accident is modelled with lateral distributions that represent traffic and that bases on statistics in the form of AIS data of actual vessel traffic, taking into account position, size and other relevant parameters. The conditions for avoiding an accident are based on assumptions about the chances of succeeding with, for example, evasive maneuvers where required (so-called Causation Factor) or emergency anchoring. These assumptions are made in IWRAP and are presented at the end of this appendix.

Table 36. Analysis cases and description of modelling.

ID#	Description	Modelled structures	Traffic model
0.S	Accident frequencies with no OWF (summer)	No parks	ZERO (summer)
0.W	Accident frequencies with no OWF (winter)	No parks	ZERO (winter)
1.S	Accident frequencies with Halla (summer)	Halla (120 WTGs of D=16 m)	EXPC (summer)
1.W	Accident frequencies with Halla (winter)	Halla (120 WTGs of D=16 m)	EXPC (winter)
2.1.S	Accident frequencies with Polargrund and Omega (summer)	Polargrund (120 WTGs of D=16 m) and Omega (70 WTGs of D=16 m)	UNC1 (Polargrund and Omega, summer)
2.1.W	Accident frequencies with Polargrund and Omega (winter)	Polargrund (120 WTGs of D=16 m) and Omega (70 WTGs of D=16 m)	UNC1 (Polargrund and Omega, winter)
2.2.S	Accident frequencies with Polargrund, Omega and Halla (summer)	Halla (120 WTGs of D=16 m), Polargrund (120 WTGs of D=16 m) and Omega (70 WTGs of D=16 m)	UNC2 (Halla, Polargrund and Omega, summer)
2.2.W	Accident frequencies with Polargrund, Omega and Halla (winter)	Halla (120 WTGs of D=16 m), Polargrund (120 WTGs of D=16 m) and Omega (70 WTGs of D=16 m)	UNC2 (Halla, Polargrund and Omega, winter)
3.S	Accident frequencies with Halla platforms (summer)	Halla incl. platforms (120 WTGs of D=16 m and 6 rectangular platforms with dimensions 100 x 250 m^2)	EXPC (summer)
3.W	Accident frequencies with Halla platforms (winter)	Halla incl. platforms (120 WTGs of D=16 m and 6 rectangular platforms with dimensions 100 x 250 m^2)	EXPC (winter)
4.0.W	Accident frequencies with no OWF, ice drifting (winter)	No parks. Blackout probability increased by 2. Winter drift speed increased from 1 to 2 knots, representing drifting with ice. Recovery of vessel (anchoring or repair after blackout) is not credited	ZERO-ICE (Zero, ice, winter)
4.1.W	Accident frequencies with Halla, ice drifting (winter)	Halla (120 WTGs of D=16 m). Blackout probability increased by 2. Winter drift speed increased from 1 to 2 knots, representing drifting with ice. Recovery of vessel (anchoring or repair after blackout) is not credited	EXPC-ICE (Halla ice, winter)

Uncertainty analysis

Uncertainty analysis is performed to study how different assumptions affect the result:

- Cumulative effects: Assumption about establishment of additional OWFs (Omega and Polargrund). IWRAP analysis cases #2.1.S, #2.1.W, #2.2.S and #2.2.W, are set up to study the impact of nearby OWFs.
- Future traffic volumes: Assumption about future traffic volumes (unchanged versus +35%) according to section 2.6 Future maritime traffic in the main report on traffic forecast for year 2060. This uncertainty is quantified by re-scaling IWRAP results for analysis cases #0.S, #0.W, #1.S, #1.W, #2.2.S and #2.2.W. The factor represents an increase in number of vessels by 33.2% compared to the AIS data.

Given the fairly conservative assumptions that are already made, the uncertainty cases present a worst case, thus showing an outer limit of what is reasonable to expect about the risks after the OWF establishment.

Traffic data

AIS data for the period 1 January - 31 December 2022 is used as input to create the model of the extent and traffic patterns of the shipping areas. The dataset includes data on 658 vessels and a total of 4 052 transits in the area between the following coordinates:

24,8986082°E, 65,7460629°N

22,7946669°E, 64,2928896°N

The traffic is described in the Traffic analysis (Sweco, 2023a).

Validation

IWRAP Mk2 is a software that is validated by International Association of marine aids to navigation and Lighthouse Authorities (IALA). The accuracy of this project specific model is ensured by performance review and comparison with statistics of actual accidents that has occurred in the area.

Modelling assumptions – summer conditions

All IWRAP models for traffic during periods with no sea ice (1st June – 31st December 2022, referred to as "summer conditions") are based on the following principles:

- Default parameters and settings in IWRAP have been used (ensuring that expert assessments by IALA underlie several choices made).
- Frequencies are calculated for the following events:
    - Powered grounding
    - Drifting grounding
    - Powered allision (ship-WTG collision)
    - Drifting allision (ship-WTG collision)
    - Ship-ship collision

Modelling assumptions – winter conditions

All IWRAP models for traffic during periods with sea ice (1st January – 31st May 2022, referred to as "winter conditions") are based on the following principles:

- Parameters and settings in IWRAP have been adjusted to reflect winter conditions:
    - Blackout probability increased by a factor 2
    - Winter drift speed increased to 2 knots, representing vessels drifting with the ice
    - Same wind conditions are assumed for summer and winter
    - Recovery of vessel (anchoring or repair after blackout) is not credited
- Frequencies are calculated for the following events[26]:
    - Drifting grounding (for vessels drifting with the ice)
    - Drifting allision (ship-WTG collision) (for vessels drifting with the ice)

Water depth is modelled using polygons based on open bathymetry data from NOAA National Centres for Environmental Information (2022), see Figure 18 below.

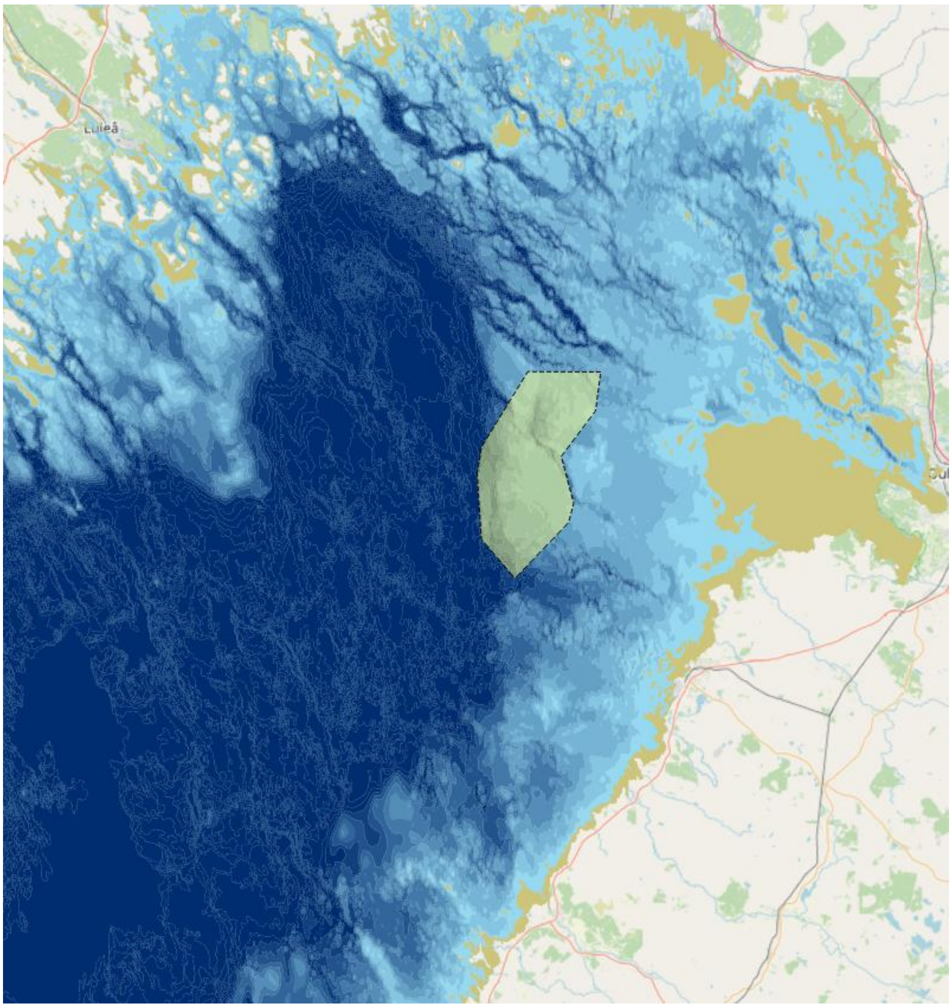

Figure 18. Representation of bathymetry in IWRAP (NCEI, 2022).

[26] Frequencies are not calculated for powered grounding, ship-WTG collision, or ship-ship collision since the IWRAP rules for calculating those probabilities are not applicable in winter traffic and results would thus be misleading.

Modelled structures

Different areas are used in IWRAP representing the OWFs and other structures that cause collision if struck by vessels:

- No OWF — Figure 19
- Halla OWF — Figure 20
- Halla, Omega, Polargrund OWFs — Figure 21
- Halla with platforms — Figure 22

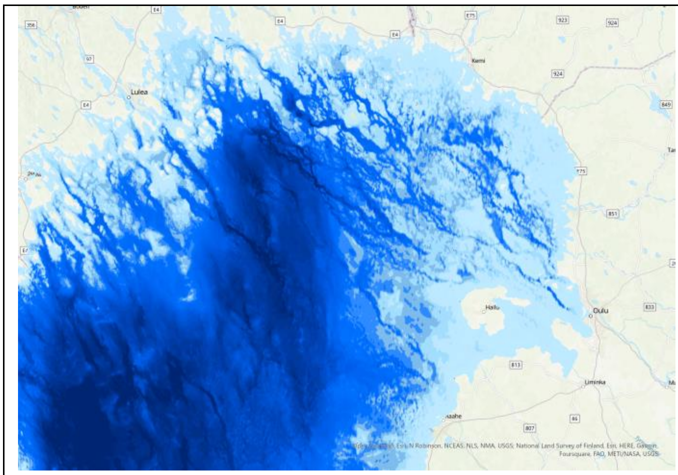

Figure 19. No areas represent the case with no OWF.

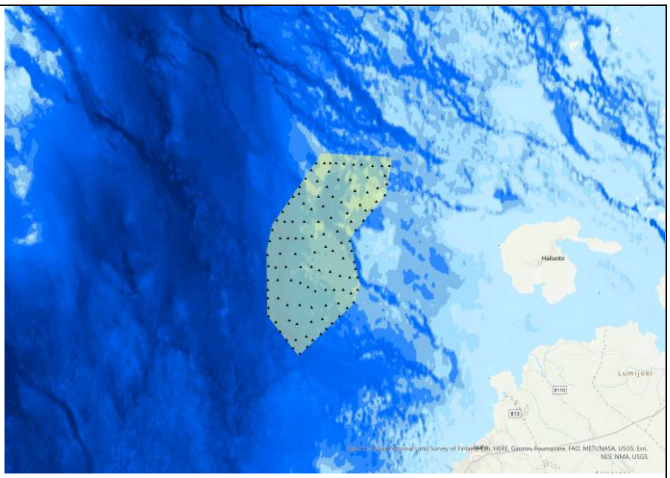

Figure 20. Halla is represented by a layout with 120 WTGs with a foundation diameter of Ø=16 m at sea level. (The WTGs are enlarged in the figure to be visible).

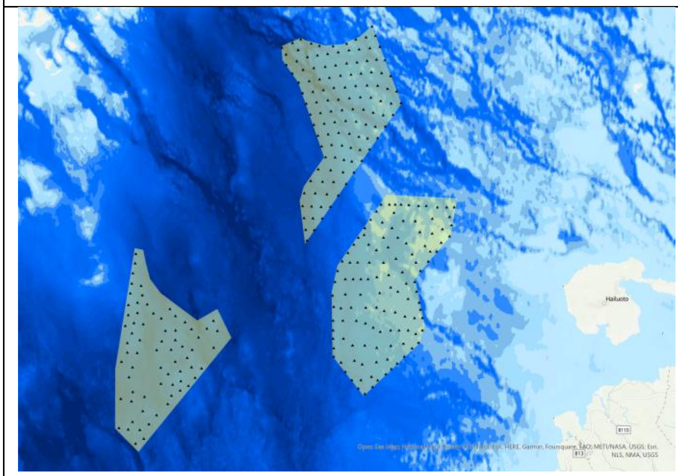

Figure 21. The reference risk for nearby OWFs is represented by analysis case #2.2.S and #2.2.W where nearby OWFs (Polargrund and Omega) are represented with WTGs with a foundation diameter of Ø=16 m at sea level. (The WTGs are enlarged in the figure to be visible.) Traffic model UNC2 (summer and winter) is used.

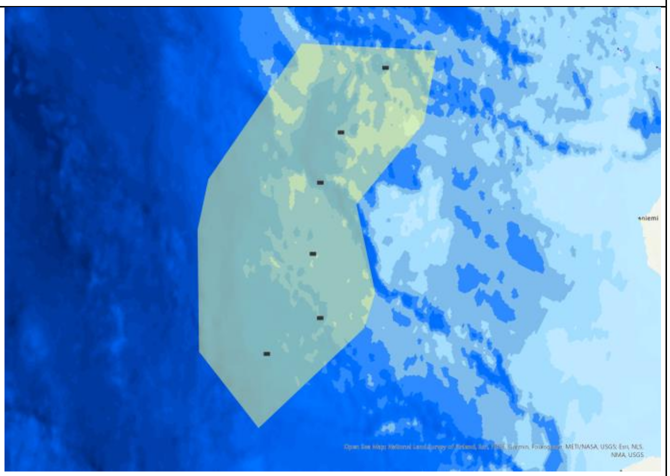

Figure 22. Platforms are represented by a layout with [6] rectangular areas of 100 × 250 m^2 in analysis case #3.S and #3.W. Traffic model EXPC is used. (The platforms are enlarged in the figure to be visible.)

Traffic models

Models of ship traffic for different scenarios are set up in IWRAP. The models include lateral distributions for the ships based on AIS data and assumptions about future traffic and are used to calculate frequencies for ship grounding, ship-ship collision, and ship-WTG collision.

- Present traffic from AIS data (ZERO model)

The present traffic in the area, without an OWF, is modelled in IWRAP by defining legs that represent ship routes in the area, see Figure 23 and Figure 24. Differences in traffic pattern for summer and winter conditions are modelled by varying legs and traffic volumes.

IWRAP summer model

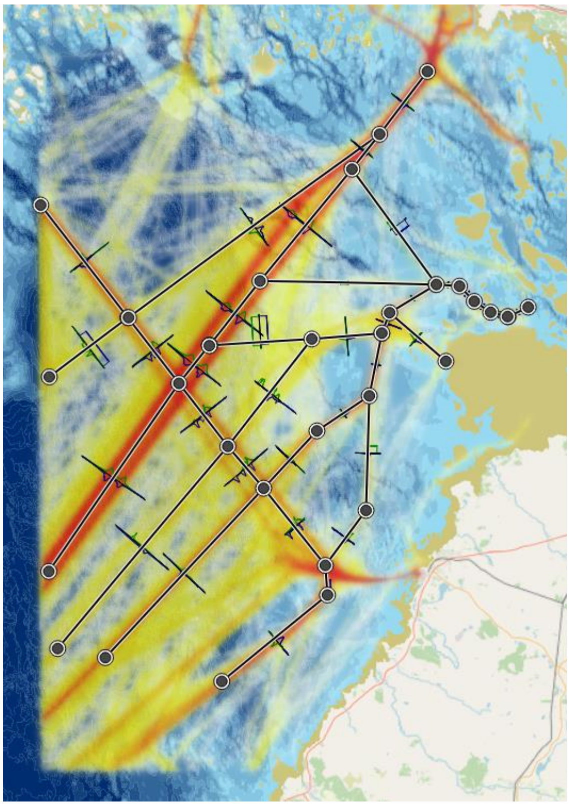

Figure 23. IWRAP model representation of current ship traffic, summer conditions. The density plot represents 2022 **summer** AIS data. The traffic distributions are modelled with curve fitting of AIS data from the period June 1st – December 31st, 2022.

IWRAP winter model

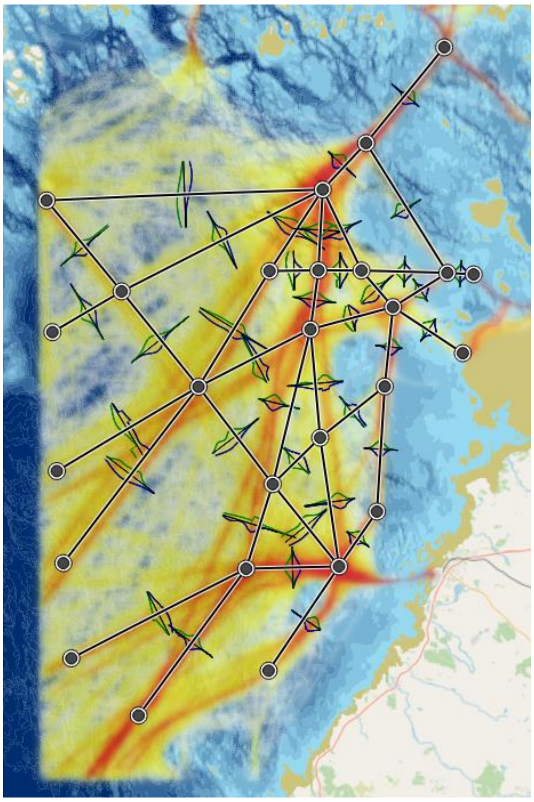

Figure 24. IWRAP model representation of current ship traffic, winter conditions. The density plot represents 2022 **winter** AIS data. The traffic distributions are modelled with curve fitting of AIS data from the period January 1st – May 31st, 2022.

- Expected traffic after Halla establishment (EXPC model)

Traffic over the Halla project area is assumed to mostly take new routes north and west of Halla after OWF establishment. Differences in traffic pattern after Halla establishment are modelled by varying legs and traffic volumes, based on the assumptions in Traffic analysis (Sweco, 2023a, mainly achieved by relocating traffic from impacted legs to legs north and west of Halla. The lateral distributions within the legs adjacent to Halla are assumed to congest, and thus the standard deviation modelled to decrease after OWF establishment, based on the assumption that vessels will want to keep a safe distance to Halla and therefore congesting traffic. The “EXPC” state traffic volumes and pattern are consequently modelled to represent traffic after Halla establishment, see Figure 25 and Figure 26.

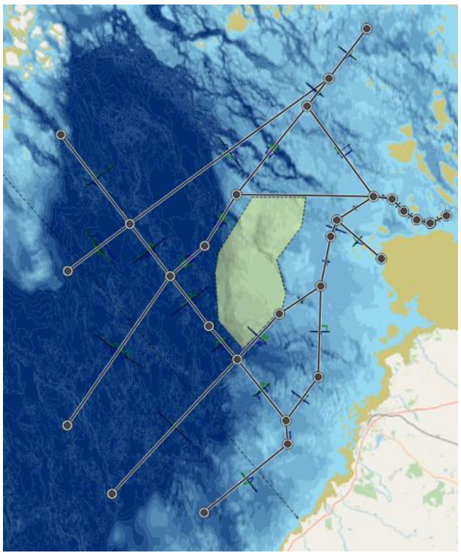

Figure 25. With Halla (traffic model EXPC), summer conditions.

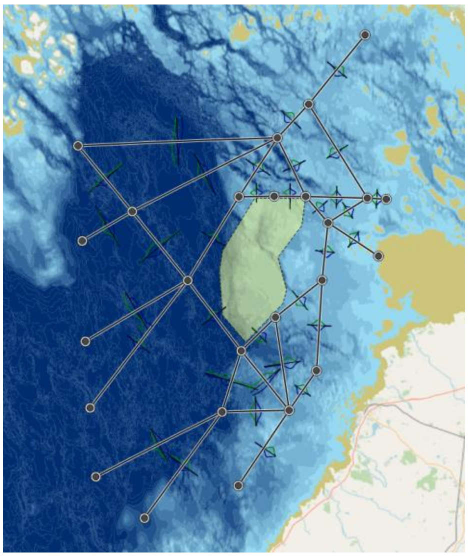

Figure 26. With Halla (traffic model EXPC), winter conditions.

- Traffic after establishment of nearby OWFs (UNC2 models)

  The establishment of nearby OWFs (Omega and Polargrund) will impact the risk level for Halla since more traffic in the area will have to take routes between the OWFs. Differences in traffic pattern with Halla, Omega and Polargrund OWFs are modelled according to description in Traffic analysis (Sweco, 2023a). The lateral distributions within the legs adjacent to Halla, Omega and Polargrund are assumed to congest, and thus the standard deviation modelled to decrease after OWF establishment, based on the assumption that vessels will want to keep a safe distance to Halla and therefore congesting traffic. The traffic is assumed to congest even more between Halla and Polargrund for "UNC2" state than "EXPC" state. The "UNC2" state traffic volumes, density and pattern are therefore modified to represent traffic after Halla, Omega and Polargrund establishment.

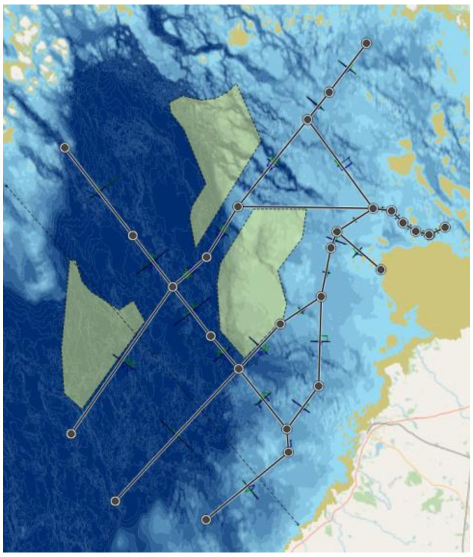

Figure 27. With Halla, Polargrund and Omega (traffic model EXPC), summer conditions.

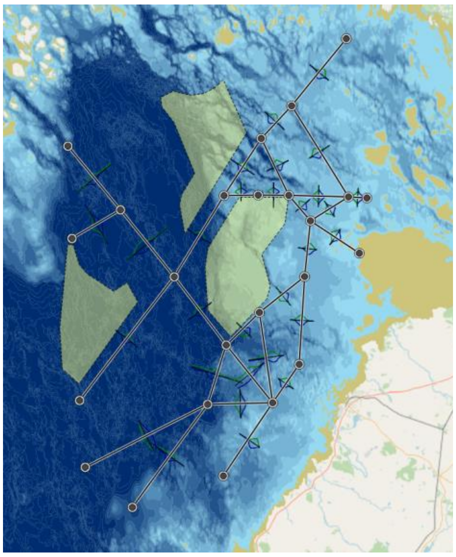

Figure 28. With Halla, Polargrund and Omega (traffic model EXPC), winter conditions.

Sensitivity analysis

No sensitivity analysis is performed.

IWRAP result

Following section presents the calculated probabilities for grounding, collision, and ship collision based on the models in IWRAP, for the main analysis cases. A result overview is found in Table 37. For all analysis cases, see Table 40 in *Uncertainty analysis cumulative effects* further down in Appendix C.

Table 37. Results for grounding, collision and allision. Calculated accident frequencies for alternative ZERO (no OWF) and EXPC (Halla), summer and winter. Note that the frequencies are yearly probabilities.

Analysis case	**Summer**			**Winter**		
	No OWF (traffic model ZERO) 0.S	With Halla (traffic model EXPC) 1.S	With Halla, Polargrund and Omega (Traffic model UNC2) 2.2.S	No OWF (traffic model ZERO) 0.W	With Halla (traffic model EXPC) 1.W	With Halla, Polargrund and Omega (Traffic model UNC2) 2.2.W
Total Groundings	**5.7E-01**	**6.0E-01**	**6.0E-01**	**2.4E-01**	**2.6E-01**	**2.6E-01**
Powered Grounding	5.4E-01	5.7E-01	5.8E-01	2.3E-01	2.4E-01	2.4E-01
Drifting Grounding	2.5E-02	2.5E-02	2.5E-02	1.9E-02	2.0E-02	2.0E-02
Total Allisions	**---**	**3.8E-04**	**1.5E-03**	**---**	**4.2E-04**	**1.3E-03**
Powered Allision	---	4.8E-05	4.8E-05	---	6.8E-05	7.2E-05
Drifting Allision	---	3.4E-04	1.4E-03	---	3.5E-04	1.2E-03
Total Collisions	**1.7E-03**	**2.0E-03**	**2.4E-03**	**9.8E-04**	**1.1E-03**	**1.3E-03**
Overtaking	2.6E-04	2.9E-04	3.4E-04	5.5E-05	8.7E-05	1.1E-04
HeadOn	8.7E-04	1.1E-03	1.4E-03	5.5E-04	7.0E-04	7.9E-04
Crossing	3.5E-04	2.2E-04	2.2E-04	1.7E-04	1.6E-04	1.6E-04
Merging	8.5E-06	7.5E-05	8.2E-05	7.8E-05	7.3E-05	7.3E-05
Bend	2.0E-04	3.4E-04	3.5E-04	1.3E-04	1.2E-04	1.2E-04

The figures illustrated of grounding, allision, and collision (both legs and waypoints), further down in this appendix, are represented by different colours/gradients. The colour/gradient for the relative difference of allision for different WTGs are represented in Figure 29, see also Figure 36 for example of how allision is presented. The colour/gradient for the relative difference of collision is also represented in Figure 29, see also Figure 38 for example of how collision is presented. The colour/gradient for the relative difference of where grounding occurs is represented in Figure 30, see also Figure 32 for example of how grounding is presented.

Note that the colours/gradients in Figure 29 and Figure 30 are not relatable to the risk assessment criteria in section 1.3.3 in the main report. The colours/gradients in the figures are only a way to compare the relative frequencies of grounding, allision and collision separately. For example, to see which WTGs that have higher or lower frequencies of being struck by a vessel.

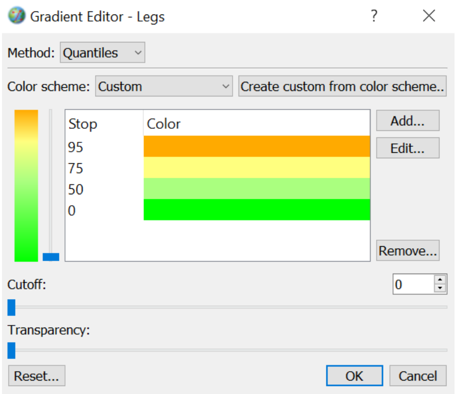

Figure 29.Colour/gradient of allision and collision.

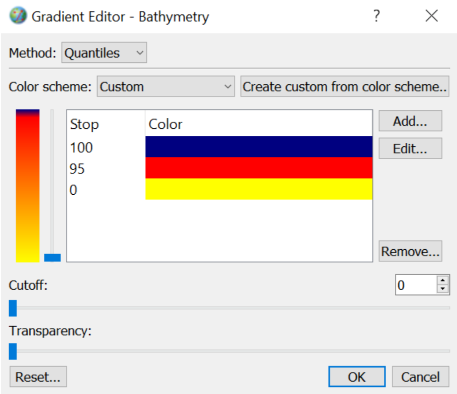

Figure 30. Colour/gradient of grounding.
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Grounding

Grounding makes up the highest accident frequency in the area, see Table 37. The frequency for powered grounding increases marginally with establishment of Halla, while drifting grounding is more or less the same with or without Halla.

A major part of the frequency is constituted by powered grounding for vessels travelling close to the grounds around the Finnish and Swedish coastal areas, see Figure 31. Some of the powered grounding appears in the northwest corner of Halla (near Oulu 1 fairway) and east of Halla (near Rahe-Oulu-Kemi-Tornio waterway). For the northwest corner precautions have been made by removing the first line of WTGs in the north part of Halla, making more room for traffic in Oulu 1 fairway. Regarding grounding east of Halla, the groundings occur between Halla and Rahe-Oulu-Kemi-Tornio waterway, therefore establishment of Halla has no major impact on grounding in this area (compare Figure 33 and Figure 34).

Drifting grounding stands for a smaller part of the frequency but as can be seen in Figure 32, drifting vessels can run aground all around Bothnian Bay.

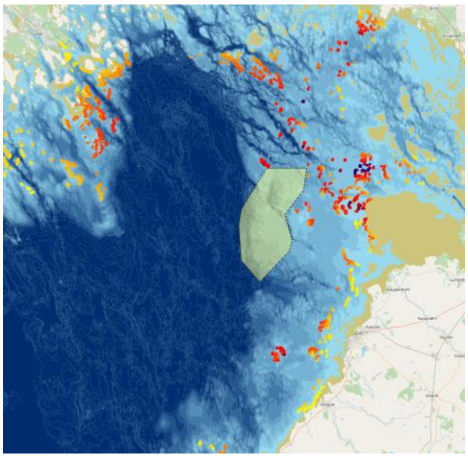

Figure 31. Powered grounding, with Halla (traffic model EXPC), winter conditions.

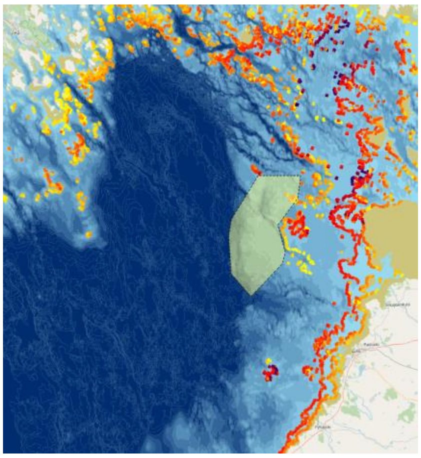

Figure 32. Drifting grounding, with Halla (traffic model EXPC), winter conditions.

The grounding frequency is quite constant during winter conditions before and after establishment of Halla (see Figure 33 and Figure 34), even if grounding occurs on more different locations after establishment of Halla. A small increase in powered grounding frequency can be noted, resulting in a small total increase (~5%) in overall grounding frequency.

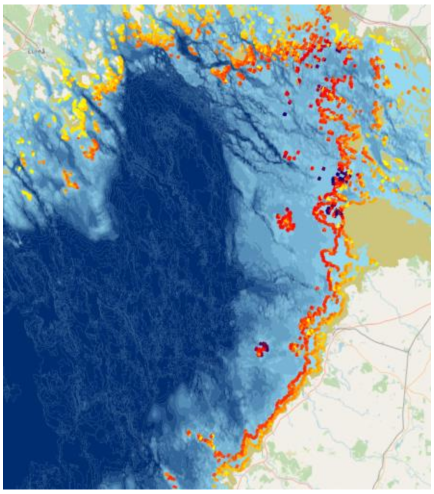

Figure 33. Total grounding result, no OWF (traffic model ZERO), winter conditions.

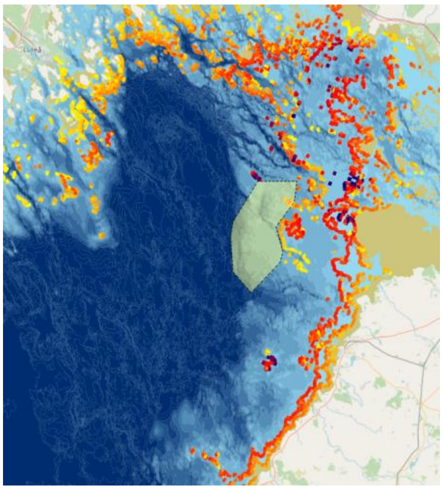

Figure 34. Total grounding result, with Halla (traffic model EXPC), winter conditions.

Allision (with WTG)

The frequency for a vessel to strike a WTG can be read from Table 37, analysis case 1.S. Note that the result represents the frequency if winter conditions would exist all year.

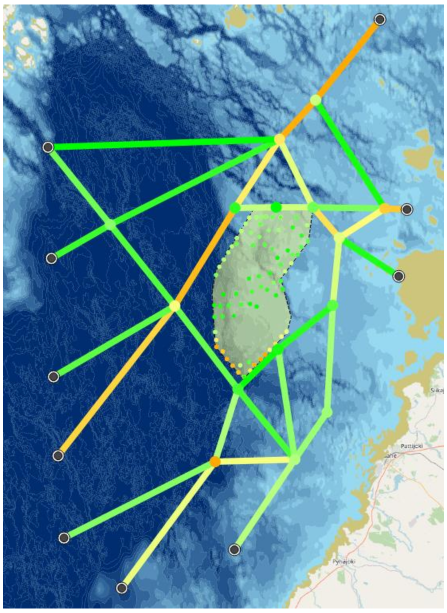

Figure 35. Powered allision, with Halla (traffic model EXPC), winter conditions.

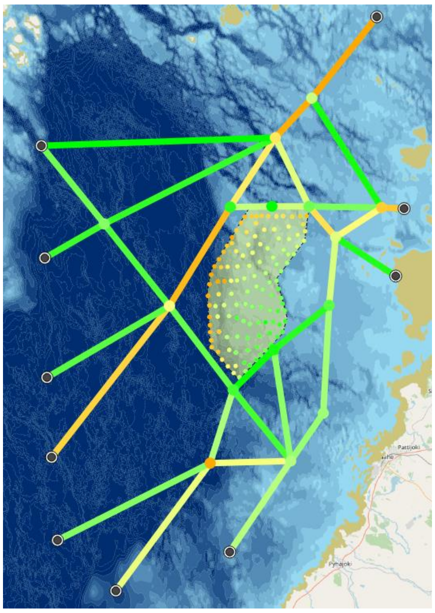

Figure 36. Drifting allision, with Halla (traffic model EXPC), winter conditions.

The results for powered allision are very sensitive to what assumptions that are made about at what distance vessels will pass the OWF. If the vessels are assumed to pass the OWF very closely, the frequency for powered allision is much higher, as can be seen in the south corner of Halla.

The WTGs on the western sides of the OWF are more exposed to drifting allision, considering the most probable wind direction, and thus drift direction. It should be noted that the frequency of drifting allision has decreased on the east side due to shallower sea depth, leading to drifting vessels being more likely to run aground than drift into a WTG. Any WTGs can however be struck by a drifting vessel.

Collision

When establishing the OWF, it is assumed that ships will take new routes and position themselves at greater distances from the OWF. For Halla, the probability of collision for ships in the area will increase slightly since traffic will be more concentrated outside the OWF.

The probability of two vessels colliding in the area can be read from Table 38.

Table 38. Results collision frequency and difference without and with OWF.

Collision type [per year]	**No OWF**	**Halla**	**Δ*f***
Overtaking	2.6E-04	2.9E-04	3.2E-05
Head-on	8.7E-04	1.1E-03	2.1E-04
Crossing	3.5E-04	2.2E-04	-1.3E-04
Merging	8.5E-06	7.5E-05	6.6E-05
Bend	2.0E-04	3.4E-04	1.5E-04
TOTAL	**1.7E-03**	**2.0E-03**	**3.3E-04**

How different shipping areas and waypoints contribute to the result is indicated in Figure 37 and Figure 38. The shipping area Nordvalen – Kemi/Tornio and the fairway at Kemi/Ajos/Tornio have the highest collision frequency, especially after OWF establishment when the traffic density is assumed to increase due to traffic in the project area is moved to shipping areas around the project area and therefore be congested. Before establishment of Halla, collisions mostly occur in shipping areas and fairways closer to the ports.

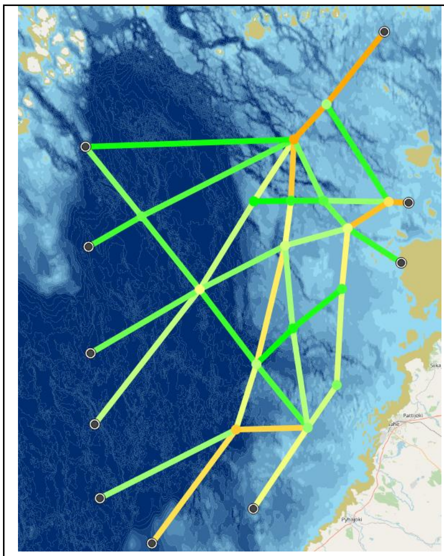

Figure 37. Total collision frequency, no OWF, (traffic model ZERO), winter conditions

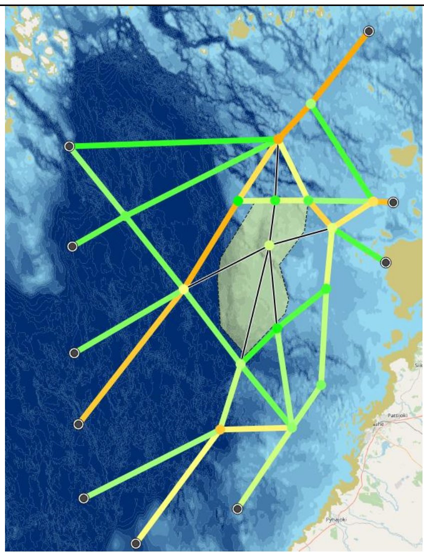

Figure 38. Total collision frequency, with Halla, (traffic model EXPC), winter conditions. Shipping areas through the project area are not used. The traffic has been moved to shipping areas adjacent to Halla.

The increase in head-on collision is most significant in both absolute and relative terms, resulting from vessels in the shipping area Nordvalen – Kemi/Tornio and fairway at Kemi/Ajos/Tornio. The traffic density has been increased for these areas as a precaution if Omega and Polargrund OWF were established northwest of Nordvalen – Kemi/Tornio (scenario 2.2.S). In case that Omega and Polargrund would not be established the traffic can keep a larger distance from Halla and spread out more, decreasing the risk for head-on collisions.

Allision (with platform)

The yearly probability for a vessel striking a platform is found in Table 39 and illustrated in Figure 39. What kind of platforms are not decided upon completion of this report but they could for instance be platforms for hydrogen production.

Table 39. Calculated frequency for a vessel to navigate into a platform. The total results correspond to the difference between analysis case 3.S and 1.S. To be clear, modelling includes 120 WTGs as they in this case may be a mitigating measure for ships navigating into WTGs instead of the platforms.

Platform	Powered allision [per year]	Drifting allision [per year]
1	0	1.92E-05
2	0	1.45E-05
3	6.97E-13	1.73E-05
4	1.42E-13	3.82E-05
5	4.88E-11	2.13E-05
6	6.77E-12	4.75E-05
TOTAL	**<<1E-06**	**1.58E-04**

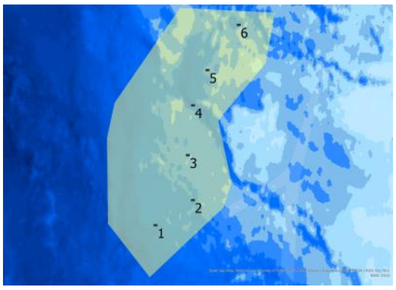

Figure 39. Frequency for allision with platforms (winter conditions). Shipping areas through the project area are not used. The traffic has been moves to shipping areas adjacent to Halla.

As indicated in Table 39, drifting allision makes up a major part of the result. The contribution from powered allision events is negligible.

Uncertainties and uncertainty analysis cases

The following sections describe the sources of uncertainty regarding data, parameters, programs, and models that have been identified to be linked to the analysis.

Most of the uncertainties are known in the industry and are handled in a similar way (e.g. through uncertainty analysis cases), which ensures comparability between different OWF and analyses. It can also be noted that the accidents reported for the area and reported in the main report are in line with the calculated frequencies, which indicates that the model result gives a good approximation of the reality.

The conclusion is that although there are many uncertainties, the overall results are robust and the calculated frequencies are judged to end up in the right range, although the exact numbers may be interpreted with some caution. For some choices in modelling, uncertainty analysis cases have been produced with the conclusion that the significance of most assumptions is small.

However, assumptions about changes in traffic patterns have a major impact on the likelihood that a manoeuvrable vessel will navigate aground (powered grounding) or navigate into a WTG (powered allision). However, the calculated frequencies for such events are small.

Parameters

In IWRAP, many assumptions are made, including probabilities of human error and malfunction on ships as well as conditions for repair and emergency anchoring. A selection of assumptions made is presented at the end of this document together with brief justifications for why they have been chosen.

For most values, the default settings in IWRAP have been used. Thus, IALA expert assessments are behind several choices made, which ensures that the right skills are behind the decisions and thus reduced margin of uncertainty. Using the default settings also means that industry standards are followed, which ensures that there is comparability between different studies. Where the default settings have been deviated from, this is reported and justified.

Tests have been done to study the significance of the uncertainty of different assumptions in IWRAP. Several of the parameters are in direct proportion to the analysis results, which means that uncertainty about the parameters leads to just as much uncertainty in the result. The conclusion is that for those parameters that have a major impact on the result (such as *blackout frequency*), the impact strikes proportionally on all layouts. This means that even if the calculated absolute risk is associated with some uncertainty, the relative result is more reliable. For those parameters that have little impact on the result, the uncertainty is of little importance to the result.

AIS data

The information on vessel traffic on which the analysis is based, the AIS data, has a high time resolution (5 minutes) and is based on both satellite and terrestrial information. The uncertainty of the data on ships and their positions is therefore considered to be very low. Instead, the uncertainty is that the AIS data lacks data on smaller, non-commercial traffic. The risk of accidents for and by merchant vessels and other large vessels is mainly analysed, and to a lesser extent the risk of accidents relating to fishing and recreational boats is studied. The routes of fishing and recreational boats are difficult to assess and predict. However, recreational boats and local fishing boats may disrupt commercial traffic and thus pose an indirect risk and may affect the ability of a larger vessel to make an evasive manoeuvre. The significance of the lack of data on the movements of small boats is considered to be small (Transportstyrelsen; Sjöfartsverket, 2009), as it is heavy traffic that constitutes the primary threat in the nautical risk analysis.

IWRAP model

The results in IWRAP are sensitive to the definition of legs. Small variations in assumptions can have a major impact on the modelling regarding powered *grounding* and *powered allision*. Therefore, great care has been taken to define legs so that their width matches the traffic surface.

The results for overtaking collision and head-on collision are sensitive to curve alignment of the lateral distributions. Careful examination of the distribution functions is therefore carried out. However, the sum of the two collision types is more robust.

The assumptions about the new routes that traffic across Halla is expected to take after the establishment of the OWF are a source of uncertainty. When the park is built, traffic is expected to move west and north of Halla, leading to a higher accident rate at the established crossings of the shipping areas, but a lower accident rate at the informal crossing points.

The result for navigating with a manoeuvrable vessel is sensitive to how the model has been defined with respect to the width of legs. Regardless of this, frequency is estimated to be at low levels and thus make a small contribution to the overall accident rate, which reduces the significance of this uncertainty.

Uncertainty analysis cumulative effects

Calculated accident frequencies for grounding, allision, and ship collision for all scenarios are represented in Table 40.

The cumulative effects of several OWFs are illustrated in Figure 39, Figure 40, Figure 41, Figure 42 and Figure 43. The results in Table 40 show that the cumulative effects of several OWFs have no significant impact on the frequency of grounding.

The allision frequency consists of powered or drifting allision. Drifting allision increases with a higher number of OWFs. The cumulative effects of Halla, Polargrund and Omega are however not linear. The powered allision frequency both increases and decrease with more OWFs, assumed to depend on the traffic configuration which differ for both summer and winter conditions. As brought up before, IWRAP is very sensitive to placement of legs, and it might have had an effect on the results.

The collision frequency depends on the assumed routes for each configuration of parks. Considering the cumulative effects of Halla, Polargrund and Omega together, the collision frequency increases compared to the frequency without OWFs, mainly because head-on collisions increase.

In conclusion, the cumulative effects of the establishment of several parks in the area do not imply any additional risks beyond those identified when analysing the parks individually.

Table 40. IWRAP results for grounding, collision and allision with and without nearby OWFs.
Calculated accident frequencies for alternative ZERO (no OWF) and EXPC (Halla) UNC1 (Polargrund and Omega) and UNC2 (Halla, Polargrund and Omega) summer and winter conditions.

Analysis case	No OWF (traffic model ZERO) (summer)	No OWF (traffic model ZERO) (winter)	With Halla (traffic model EXPC) (summer)	With Halla (traffic model EXPC) (winter)	With Polargrund and Omega (traffic model UNC1) (summer)	With, Polargrund and Omega (traffic model UNC1) (winter)	With Halla, Polargrund and Omega (traffic model UNC2) (summer)	With Halla, Polargrund and Omega (traffic model UNC2) (winter)	Platforms and Halla (traffic model EXPC) (summer)	Platforms and Halla (traffic model EXPC) (winter)	Zero alternative, ice drifting (traffic model ZERO) (winter)	Halla, ice drifting (traffic model EXPC) (winter)
#ID	0.S	0.W	1.S	1.W	2.1.S	2.1.W	2.2.S	2.2.W	3.S	3.W	4.0.W	4.1.W
Total Groundings	**5.7E-01**	**2.4E-01**	**6.0E-01**	**2.6E-01**	**6.0E-01**	**2.5E-01**	**6.0E-01**	**2.6E-01**	**5.7E-01**	**2.6E-01**	**8.2E-01**	**8.2E-01**
Powered Grounding	5.4E-01	2.3E-01	5.7E-01	2.4E-01	5.8E-01	2.3E-01	5.8E-01	2.4E-01	5.5E-01	2.4E-01	---	---
Drifting Grounding	2.5E-02	1.9E-02	2.5E-02	2.0E-02	2.5E-02	1.9E-02	2.5E-02	2.0E-02	2.6E-02	2.0E-02	8.2E-01	8.2E-01
Total Allisions	**---**	**---**	**3.8E-04**	**4.2E-04**	**1.1E-03**	**1.3E-03**	**1.5E-03**	**1.3E-03**	**1.5E-04**	**5.8E-04**	**---**	**1.5E-02**
Powered Allision	---	---	4.8E-05	6.8E-05	>1E-6	7.5E-04	4.8E-05	7.2E-05	3.5E-05	6.8E-05	---	---
Drifting Allision	---	---	3.4E-04	3.5E-04	1.1E-03	5.4E-04	1.4E-03	1.2E-03	1.2E-04	5.1E-04	---	1.5E-02
Total Collisions	**1.7E-03**	**9.8E-04**	**2.0E-03**	**1.1E-03**	**2.4E-03**	**1.0E-03**	**2.4E-03**	**1.3E-03**	**1.8E-03**	**1.1E-03**	**---**	**---**
Overtaking	2.6E-04	5.5E-05	2.9E-04	8.7E-05	3.4E-04	6.2E-05	3.4E-04	1.1E-04	2.6E-04	8.7E-05	---	---
HeadOn	8.7E-04	5.5E-04	1.1E-03	7.0E-04	1.4E-03	5.8E-04	1.4E-03	7.9E-04	9.1E-04	7.0E-04	---	---
Crossing	3.5E-04	1.7E-04	2.2E-04	1.6E-04	2.2E-04	1.7E-04	2.2E-04	1.6E-04	3.8E-04	1,6E-04	---	---
Merging	8.5E-06	7.8E-05	7.5E-05	7.3E-05	8.2E-05	7.7E-05	8.2E-05	7.3E-05	8.5E-06	7.3E-05	---	---
Bend	2.0E-04	1.3E-04	3.4E-04	1.2E-04	3.5E-04	1.3E-04	3.5E-04	1.2E-04	2.0E-04	1.2E-04	---	---

No nearby OWFs

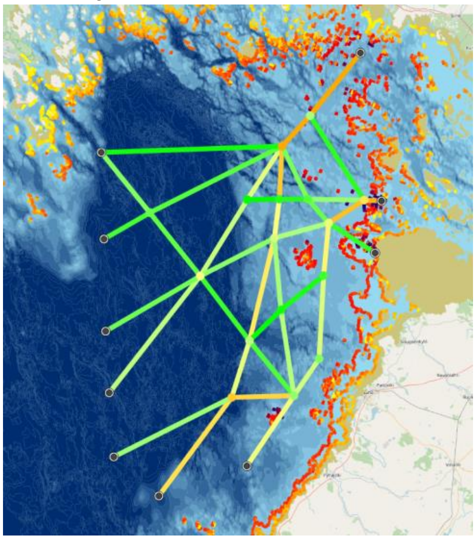

Figure 40. Without Halla, without nearby OWFs (ZERO, 0.W). IWRAP model representation of current ship traffic, winter conditions.

Omega and Polargrund

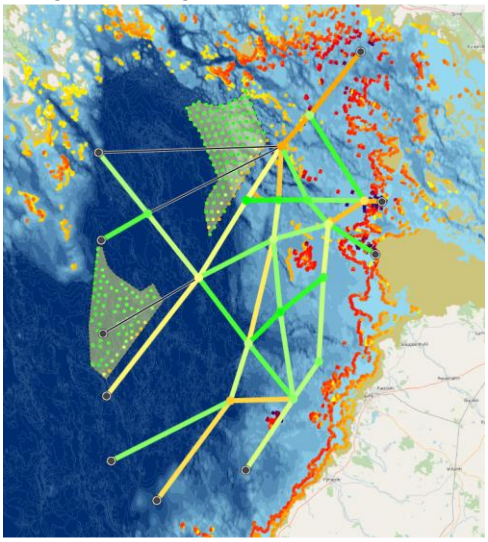

Figure 41. Without Halla, with nearby OWFs (UNC1, 2.1.W). IWRAP model representation of expected ship traffic around Polargrund and Omega, winter conditions.

Halla, without nearby OWFs

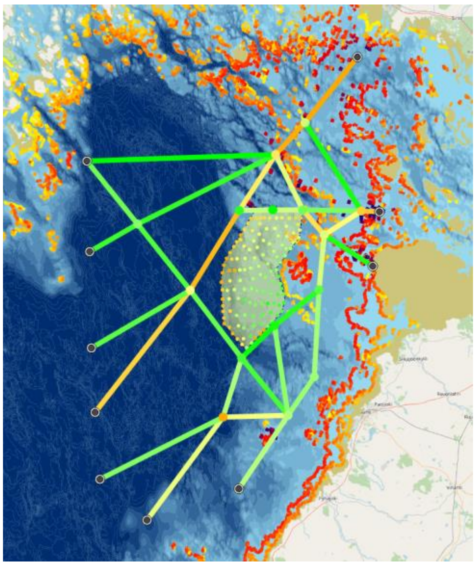

Figure 42. With Halla, without nearby OWFs (EXPC, 1.W). IWRAP model representation of expected ship traffic around Halla, winter conditions.

Halla, Polargrund and Omega

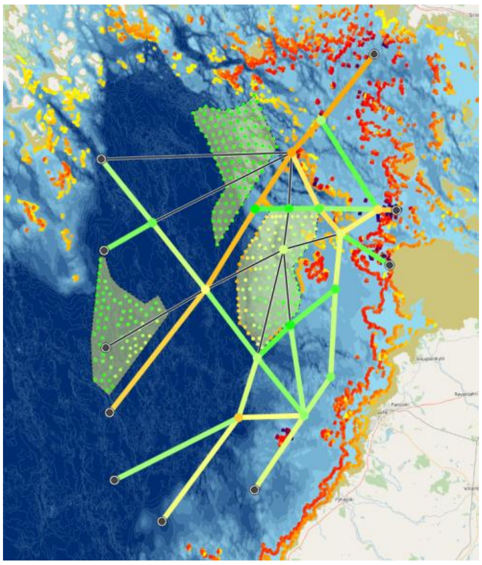

Figure 43. With Halla, with nearby OWFs (UNC2, 2.2.W). IWRAP model representation of expected ship traffic around Halla, Polargrund and Omega, winter conditions.

Uncertainty analysis future traffic flows

Transport freight volumes in the Baltic Sea are expected to increase and Traficom has produced forecasts until 2060 (for more information, see 2.4 in the report). The increase regards both larger and heavier vessels, and an increase in number of vessels:

- Heavier vessels that have worse consequences in the event of a allision or collision. This uncertainty is already considered in all the modelling cases, and thus in the calculated risks since consequences have been chosen conservatively.
- Increase in the number of transports is studied through uncertainty analysis cases and is described below.

The uncertainty in the assumption of future traffic flows is investigated through uncertainty analysis cases where the risk addition for the OWF at today's traffic flow is compared with the risk addition at 35% more traffic. Traficom estimate an increase in number of transports to 19%, but to be conservative, 35% is studied and assessed in the uncertainty analysis cases.

The results are presented in Table 41 and can be summarized as follows:

- The probability of grounding increases by 35% when traffic increases by 35%.
- The probability of allision increases by 35% when traffic increases by 35%. This only applies if a park is established because the risk of allision does not exist without a park.
- The probability of collision increases by 82% when traffic increases by 35%. This applies regardless of whether a park is established or not.

The result is intuitive because grounding and allision is an event that affects ships individually. The frequency is expected to be proportional to the amount of traffic, which the result also indicates. The probability of collision, on the other hand, involves two vessels. The frequency is therefore expected to increase proportionally to the square of the increase in traffic, which the result also indicates.

Table 41. Results of frequencies for uncertainty analysis of future traffic volumes. Current traffic (2022) and 35% (2060) increase in traffic volumes. Frequencies per year with the OWF and the zero alternative, represented by analysis case 1.S (Halla, summer) and analysis case 0.S (no OWF, summer). The percentages in parentheses show the difference in results for a configuration when traffic increases by 35%.

Frequencies	**Traffic volumes 2022**		**Maximum traffic volumes 2060 (+35%)**	
	No OWF	**With Halla**	**No OWF**	**With Halla**
	0.S	1.S	0.S- FuturTr	1.S-FuturTr
Grounding [per year]	5.7E-01	6.0E-01	7.7E-01 (+35%)	8.0E-01 (+35%)
Allision [per year]	---	3.8E-04	---	5.2E-04 (+35%)
Collision [per year]	1.7E-03	2.0E-03	3.1E-03 (+82%)	3.7E-03 (+82%)

The conclusion is that the increase in the number of collisions due to increased traffic flows is to be expected regardless of whether the OWF is built or not. The amount of traffic depends on the assumption of future traffic volume where the frequency is directly proportional to the amount of traffic.

The risk for the different types of accidents (grounding, allision and collision) are not significantly affected by traffic change of this size (35%), as can be seen in Table 42. Since collision is the accident that increases most (82%) from traffic changes it is shown as an example for how it affects the risk. The risk for collision increases with less than 5%. This imply that grounding and allision will increase by even less than 5%, hence not presented in Table 42 or assessed further.

Table 42. Result for risk of collision for uncertainty analysis of future traffic volumes. Current traffic (2022) and 35% (2060) increase in traffic volumes. The percentages in parentheses show the difference in results for a configuration when traffic increases by 35%.

Risk health and safety	**Traffic volumes 2022**		**Maximum traffic volumes 2060 (+35%)**	
	No OWF	**With Halla**	**No OWF**	**With Halla**
	0.S	1.S	0.S- FuturTr	1.S-FuturTr
Collision [per year]	6.2	6.3	6.5 (<5%)	6.6 (<5%)

References

See main report.

Assumptions and parameters in IWRAP

- ### Drift parameters

  In the analysis for summer conditions, IWRAP's default parameters are used for the probability that a ship will blackout or regain manoeuvrability*, see Figure 44.

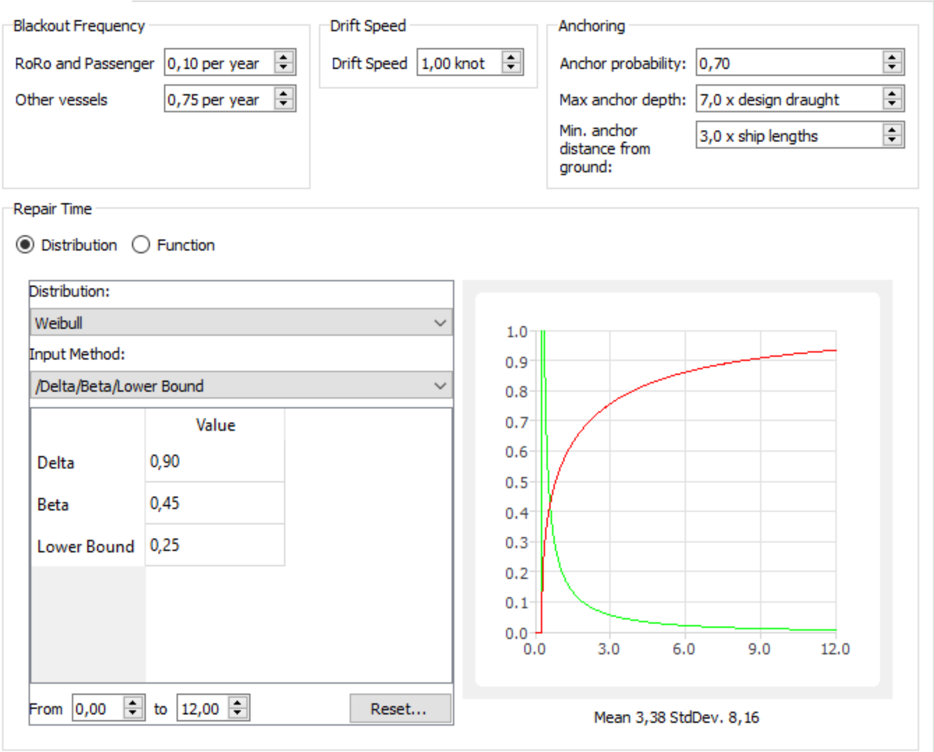

Figure 44. Operating parameters in IWRAP (summer). The value of the parameters affects the probability that the ship will start drifting and how far it is drifting.

* The values are based on expert judgements which are assumed to be taken from the methodological study at Kriegers Flak (SSPA Sweden AB, 2008).

The operating speed is in reality determined by many parameters such as currents and wind speed. However, IWRAP is determined in accordance with IWRAP's default parameter values to maintain a constant operating speed of 1 knot.

For winter conditions, IWRAP's default parameters have been adjusted to reflect winter conditions. Blackout probability has been adjusted up by a factor of 2, which represents the probability of a ship getting stuck in the ice. Winter drift speed is set to 2 knots, see Figure 45. Repair and emergency anchoring are not credited.

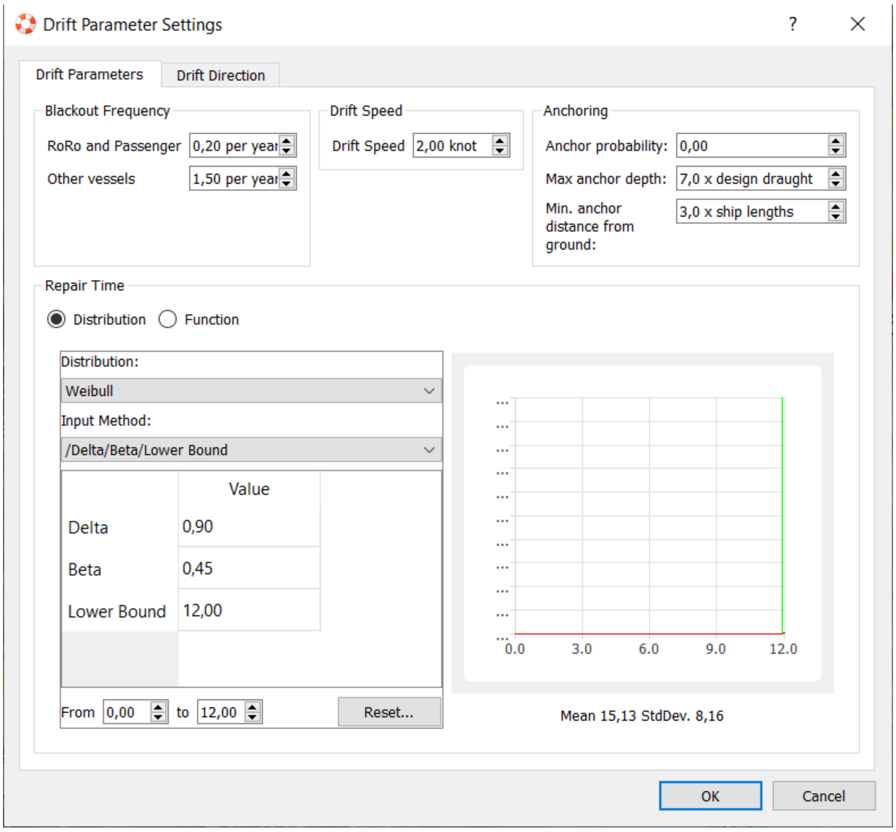

Figure 45. Operating parameters in IWRAP (winter). The value of the parameters affects the probability that ships will start drifting with the ice and how far it is drifting.

- ## Drift direction

The main report presents wind data for Halla. According to the data, the average wind speed in the region is 6,2 m/s and the prevailing wind direction is from the south to southwest. Consequently, the most likely drift direction for vessels is to the north to northeast. Figure 46 shows the drift direction set in IWRAP for both summer and winter. Each drift direction has a probability based on how often that drift direction has been observed in the wind data, and a maximum drifting distance that is weighted against the average wind strength in the current drifting direction.

The maximum drifting distance is on average 50 km, which is considered very conservative. However, conservatism is compensated by the fact that the drifting speed in IWRAP can be somewhat low. According to a study reported in PIANC (2018), 90% of vessels drift for an hour, resulting in an average operating distance of 1,7 M (just over 3 km).

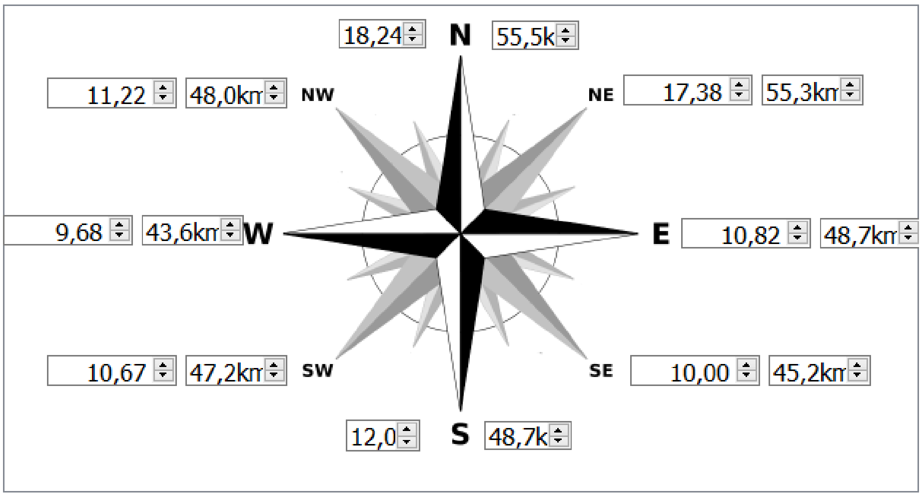

Figure 46.Drift direction with weighting of probability based on observation outcome and maximum drift distance. Note that the figure does *not* represent a wind rose but a "drift rose" where the direction of drift is the reverse of the wind direction. The values on the left indicate the proportion of times a ship drifts in each direction.

- ## Causation factors

IWRAP uses the default parameter values for all *causation factors*, i.e., the probability that an evasive manoeuvre will fail. The values are presented in Figure 46. The magnitude of the factors is derived by IALA, supported inter alia by expert judgements. See (Engberg, 2019) for a more detailed description of the derivation.

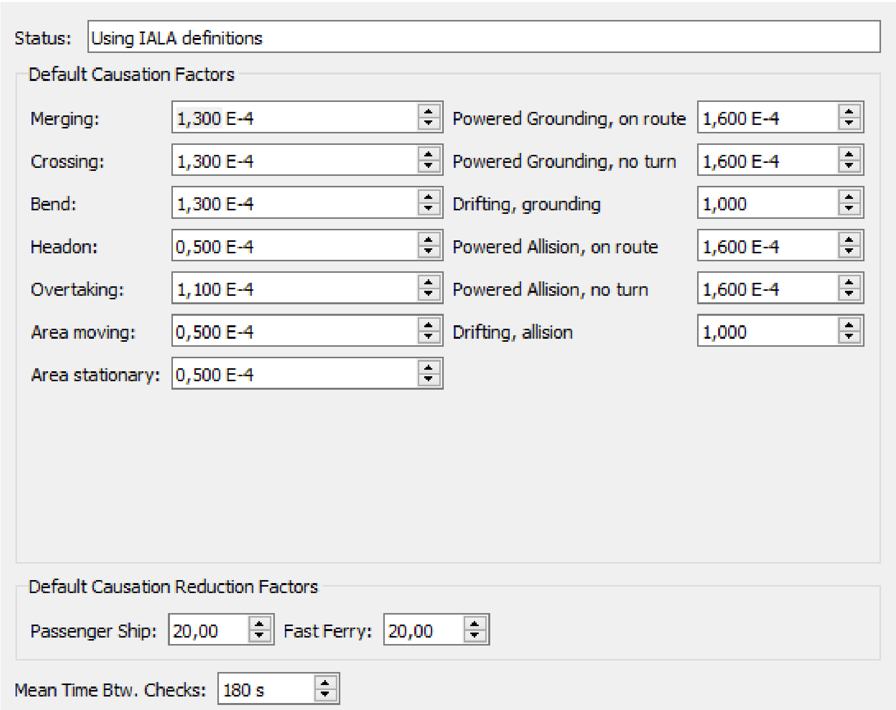

Figure 47. Default values of Causation Factors in IWRAP.

The analysis is made for summer and winter traffic, as the traffic pattern changes during the year. In winter, ice affects ship traffic. Ships that get stuck and drift with the ice into a WTG are modelled as a particular accident risk.

As described in the main report, traffic flow can be expected to increase by 35% by 2060. How such an increase affects the frequencies is studied with a sensitivity analysis.

In IWRAP, so-called legs are defined, which are stretches along which traffic is modelled. Only the traffic represented in legs is included in the calculation of accident risks in IWRAP.

- ## Distribution

The lateral distribution of traffic in the shipping areas around Halla is assumed to follow a normal distribution in each direction of travel. In IWRAP it is possible to make even more detailed curve adjustments. In the case of Halla, deviations from the normal curve in the dataset are estimated to stem from temporary variations that are not part of future traffic patterns.

The lateral distributions are determined based on the traffic pattern, which means that they are defined free of fairways, and other traffic routes shown in charts. The main value of the normal distributions for legs adjacent to the OWF are not assumed to be closer than approximately 1,550 meters from the WTGs as ships are not allowed to travel too close to an OWF[27]. When the possible, regarding sea depths, the main value is set to 2000 meters and with a standard deviation of 750 meters. For the leg between Halla and Polargrund, the main value is right between the OWFs. This distance is kept when modelling only Halla, which is fairly conservative.

Traffic that currently passes over the OWF area is assumed to move north and west of Halla and position itself according to the current lateral distribution.

[27] Lateral distributions are chosen so that its center line runs at a distance of D=6L+0.3 M from the foundation area to follow COLREG where L is the length of the area's "representative vessels" according to the traffic analysis. Standard deviation σ is chosen so that σ=D/2.8 whereby 98.5% of traffic ends up outside the OWF. (For Halla, the representative vessel is L=229 m long according to the traffic analysis, which gives D=1541 m and σ=550 m.)