ANALYSIS OF ALTERNATIVES FOR PROVIDING ICEBREAKING SERVICES IN ESTONIA

Final Report

October 2023

The study has been completed in collaboration with Tallinn University of Technology (TalTech), Aker Arctic Technology Inc, logscale oy and Saaresalu OÜ and is commissioned by the Estonian Transport Administration

Authors of the study

- **Ulla Pirita Tapaninen (TalTech Eesti Mereakadeemia)**, Professor, Principal Investigator
- **Riina Palu (Saaresalu OÜ)**, Project Manager
- **Pentti Kujala (TalTech)**, Analyst
- **Rivo Uiboupin (TalTech Meresüsteemide Instituut)**, Analyst
- **Sander Rikka (TalTech Meresüsteemide Instituut)**, Analyst
- **Ilja Maljutenko (TalTech Meresüsteemide Instituut)**, Analyst
- **Tõnis Hunt (TalTech)**, Analyst
- **Mashrura Musharraf (TalTech)**, Analyst
- **Aleksandr Kondratenko (TalTech)**, Analyst
- **Liangliang Lu (TalTech)**, Analyst
- **Markku Mylly (logscale oy)**, Expert of Icebreaking Management
- **Lauri Ojala (logscale oy)**, Expert of Icebreaking Management
- **Teemu Heinonen (Aker Arctic)**, Ship Control Expert
- **Reko-Antti Suojanen (Aker Arctic)**, Ship Building Engineer

Referring to the study

Tapaninen, U. P., Palu, R., Kujala, P., Uiboupin, R., Rikka, S., Maljutenko, I., Hunt, T., Musharraf, M., Kondratenko, A., Lu, L., Mylly, M., Ojala, L., Heinonen, T., Suojanen, R-A. (2023) Analysis of Alternatives for Providing Icebreaking Services in Estonia. Final Report. Tallinna Tehnikaülikool, Aker Arctic Technology Inc, logscale oy, Saaresalu OÜ

Tallinn University of Technology Estonian Maritime Academy
Phone: 613 5500
E-mail: emera@taltech.ee
Kopli 101, 11712 Tallinn

TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

INTRODUCTION

The development of powerful icebreakers and ice-strengthened cargo vessels has made winter navigation possible in the northern parts of the Baltic Sea as well as in some other seasonally, or even permanently, ice-covered sea areas. Thus the ice barriers, which previously closed these coasts and sea areas from shipping, have been mostly overcome.

Briefly, the consequences of the current hazards of winter navigation seem to be limited to minor structural damage. No ice related ship disasters with large-scale consequences measurable in human or environmental losses have taken place in the Baltic Sea during the last decades. However, it should not be forgotten that some of the worst accidents in the history of shipping are closely related to ice. Titanic hit an iceberg in 1912 with the loss of life over 1500 persons. Exxon Valdez was grounded in 1989 when trying to avoid ice on its route with the result of more than 40 000 tons of spilled oil. This kind of huge disasters must be avoided in the Baltic Sea by careful risk management. On the other hand, the ability to counteract small but frequently occurring accidents, oil spills for instance, is important, too.

The amount and patterns of traffic in the Baltic Sea have been in a process of a rapid and remarkable change after 1990. The ship traffic in the Gulf of Finland has grown considerably during the last decades, and it is still growing, which is a result of growing economic activity in the area. Covid-19, war in Ukraine and related sanctions have had a decreasing effect on the traffic, but recovery is expected.

The objective of the current study is to analyse alternatives and propose an optimal solution for icebreaking services in Estonia for the period of 2029-2054, incl. which vessels or combinations of vessels the state should prefer to ensure an optimal solution that is technically and economically feasible. Also, ownership of any potential new icebreakers is to be analysed.

The analysis takes into account the traffic flows of Estonian ports receiving icebreaking services, assess the impacts of the different scenarios proposed (incl. the expediency of providing icebreaking services to ports) on the private sector and the state, highlight the investments needed for and the expected lifetime of existing icebreakers, assess the cost of different forms of ownership of the icebreakers, IMO and EU regulations, propose the optimal solutions and recommended actions for the future for the Estonian Transport Administration and other parties involved (e.g. Ministry of Climate).

The objective of organising icebreaking services in Estonia is to make sure the service and the ports using it are economically sustainable and to do so in a manner that is optimal for the economy of the entire state.

THE TEAM

The report was written by a consortium consisting of four organizations with different competencies relevant for the analysis of alternatives for providing icebreaking services in Estonia.

The consortium is led by Tallinn University of the Technology (TalTech), where Estonian Maritime Academy (EMERA) leads the work and is sided by the Marine Systems Institute (MSI). TalTech is supported by a consultancy Saaresalu, which carries out project management and stakeholder involvement while executing the tender contract. In addition to Estonian counterparts, knowledge is involved from Finland, where Aker Arctic and a Finnish consultancy logscale oy contribute to the fulfilment of the contract by specific knowledge.

TalTech EMERA

EMERA is the only center of maritime excellence of its kind in Estonia. The maritime research group is led by Professor Ulla Tapaninen with help of early-stage researcher Tõnis Hunt. Ulla Tapaninen has 30 years of experience in Finnish shipping companies, universities and public sector in the areas of logistics and maritime transport. She was named as the logistics professional of the year in 2022 in Finland. Tõnis Hunt has been over 25 years in charge of the port and shipping management education in Estonia.

For the current project, expertise of the system level simulation of the winter navigation system in the Baltic Sea is brought into the project by Professor Pentti Kujala, who has long background in Finnish ice breaker building both in shipyards and academy. Professor Pentti Kujala won the Transportation Research Award 2020 in the field of waterborne transportation for his extensive track record of projects aimed at improving the safety of shipping in ice-covered waters of the Baltic Sea as well as Arctic and Antarctic waters. These projects were funded by the European Commission, the Lloyd's Register Foundation and the Finnish government. Professor Kulaja is supported by Assistant Professor Mashrura Musharraf as an expert especially on data science and analytics, and Aleksandr Kondratenko and Liangliang Lu.

TalTech MSI

Department of Marine Systems (MSI) carried out the task related to calculating the statistics of sea ice conditions in the Gulf of Finland and Gulf of Riga. The group is led by head of department Rivo Uiboupin and assisted by Senior researcher Sander Rikka.

SAARESALU

Saaresalu OÜ, founded in 2010, is an Estonian consultancy in the field of maritime and logistics. The project manager Riina Palu has more than 20 years of experience in Estonian logistics and maritime sector project both national and international context.

AKER ARCTIC

Aker Arctic Technology Inc is a Finnish engineering company specializing in the technology development, design, engineering, special products, consulting and testing services for ice-going vessels and icebreakers. Aker Arctic has made plans for 60% of all the worlds ice breakers, lately the new Swedish breakers that will be funded by EU. CEO Reko-Antti

Suojanen has over 20 years of experience in ice breaker design and M.Sc Teemu Heinonen has been specialized for example in studies of EEDI vessels' need for ice breakers.

LOGSCALE

logscale oy is a Finnish logistics consultancy company focusing on studies and analysis both for businesses and public sector administration in particular in Transport Sector Governance, Maritime Policy & Safety, National Security of Supply Issues, Logistics Performance. Professor Lauri Ojala has worked as a Trade and Transport Facilitation expert for e.g. The World Bank, Asian Development Bank and OECD. He has also worked as an expert on transport, logistics and maritime policy issues for Transport Ministries of several countries. Markku Mylly is former Executive Director of the European Maritime Safety Agency (EMSA), Director General of Finnish Maritime Administration, developer of Vessel Traffic Management Systems in Finland and the EU, CEO of a shipping company and of the Finnish Port Association, and furthermore Markku has worked as a Captain in cross-trade shipping pilot in Finland.

THE STRUCTURE OF THE REPORT

The seven-chapter structure for the Final Report of the study contains the following parts:

Introduction
Chapter 1. Analysis of present and historical situation
Chapter 2. Ice conditions in the Gulf of Finland and Gulf of Riga
Chapter 3. Governance options
Chapter 4. Scenarios for icebreaking need and vessel options
Chapter 5. Options for the icebreakers and cost and effectivity analysis
Chapter 6. Financial analysis of the alternatives
Chapter 7. Stakeholder Management Process
Conclusions

Current report is the Final Report and presents the full body of research on the alternatives for providing icebreaking services in Estonia.

1. ANALYSIS OF PRESENT AND HISTORICAL SITUATION

1.1 ESTONIAN FOREIGN TRADE AND VESSEL MOVEMENT

ESTONIAN FOREIGN TRADE

Estonia's main trading partners are its neighbours, mainly other EU countries. In 2022 export volumes reached 21,3 billion Euros, with main export partners Finland 14,5%, Latvia 14,1%, Sweden 9,18%, Lithuania 6,11%, Germany 5,74%, USA 5,45%, Netherlands 4,18%, Russia 3,57%, Norway 3,54% and Denmark 3,04%. Import was 24,9 billion Euros in 2022. Main, top 10, import partners were Finland 16,9%, Lithuania 10,2%, Germany 9,91%, Latvia 9,63%, Russia 7,24%, Sweden 6,93%, Poland 6,55%, Netherlands 4,3%, China 3,83% and Italy 2,5%. Looking at the trading partners of Estonia, it is obvious that maritime transport is the main link and, in some cases, the only possible link in trading with these countries. Therefore, year-round maritime connection and freely operable ports are essential for trade. 55% of Estonia's foreign trade takes place by sea (Statistics Office, 2023).

OVERVIEW OF CARGO FLOWS THROUGH ESTONIAN PORTS

Main Estonian cargo ports Port of Tallinn (with its main cargo harbours Muuga, Old City and Paldiski South), Sillamäe, Kunda, Vene-Balti, Paldiski North are located in northern coast of Estonia (Figure 1). Rest of important cargo ports like Pärnu and three harbours of AS Saarte Liinid – Virtsu, Roomassaare and Heltermaa, are located in southwestern coast and big islands.

There are several ports that are part of the TEN-T port network Heltermaa, Kuivastu, Pärnu, Paldiski South Harbour, Rohuküla, Sillamäe, Port of Tallinn harbours (Old City Harbour, Muuga Harbour), Virtsu. Out of those Port of Tallinn is in this network as a core network port. Other ports are part of the comprehensive network.

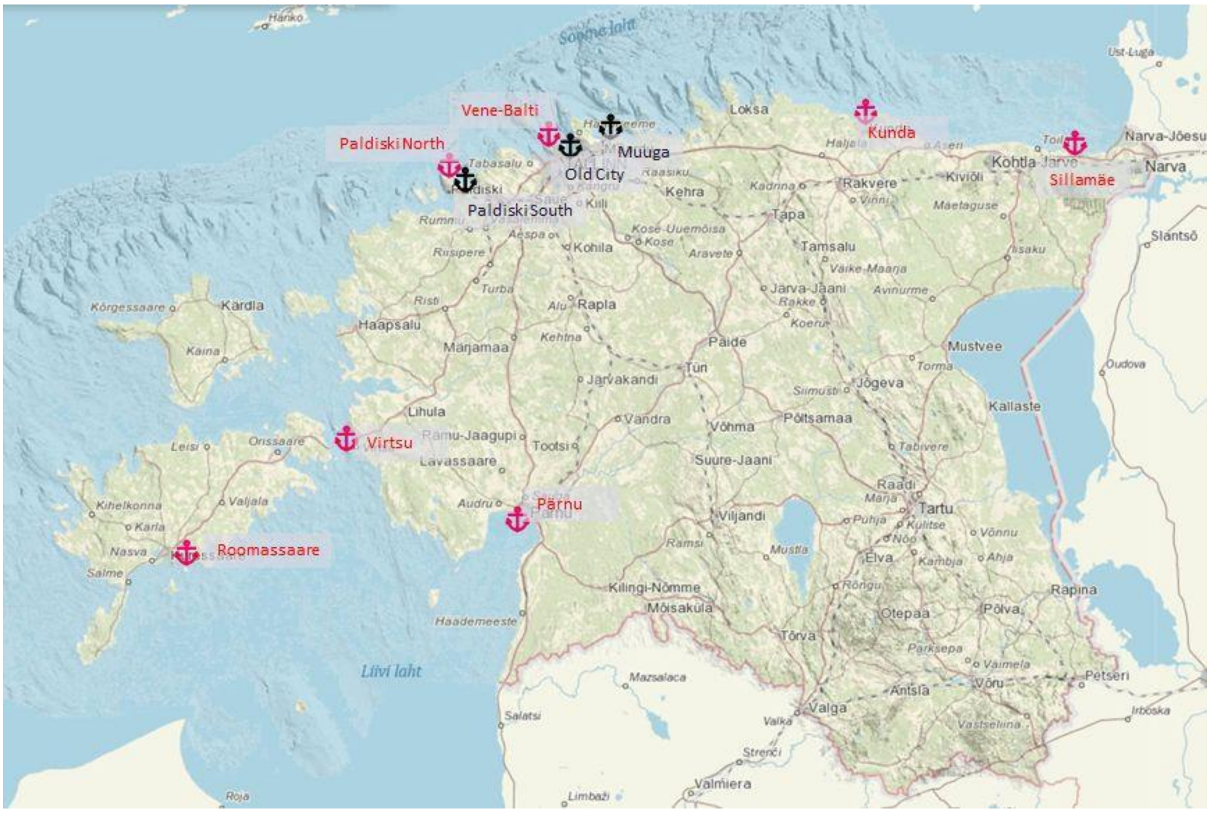


Figure 1. Main Estonia Cargo Ports. TEN-T Core Network Ports in Black. (Base-Map Source: https://xgis.maaamet.ee/xgis2/page/app/maainfo)

Majority of cargoes are handled in harbours of Port of Tallinn and port of Sillamäe (Figure 2). Other ports' cargo turnovers haven't exceeded the 2 million ton mark in recent years.

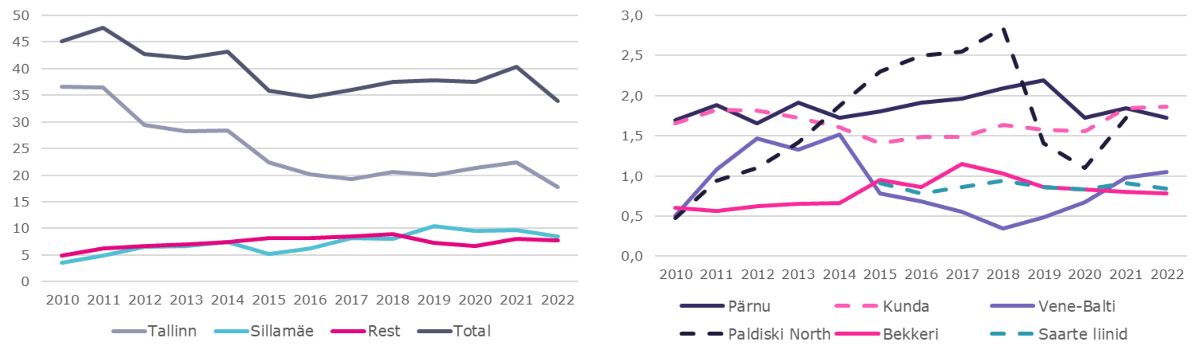


Figure 2. Cargo flows of Estonian ports, 2010–2022, mln t. (Sources: Estonian Ports Association, Port of Tallinn, Statistics Estonia, AS Saarte Liinid)

Since regaining independence cargo flows handled by Estonian ports have been heavily affected by the transit, mainly east-west direction (Figure 3). East-west transit has been heavily influenced by the political relations between Russia and Estonia or EU. Major shift in share of transit began in 2015 (after the annexation of Crimea by Russia in 2014). Last year, 2022, was the first year when import-export cargo flows exceeded the transit cargo flows (57,4% vs 42,6%). Last year was also the year when Russia started the war and heavy sanctions were imposed against Russia.

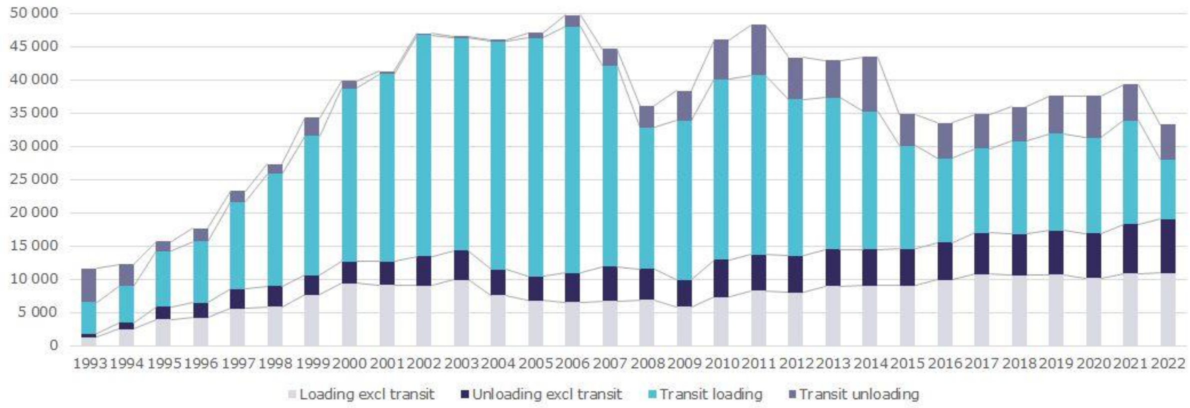


Figure 3. Loading and unloading of export-import and transit goods through Estonian ports, 1993–2022, th. t. (Source: Statistics Estonia)

Over the years liquid and dry bulk cargoes have been main cargo groups handled by Estonian ports (Table 1). Vast majority of those have been the transit cargo. Ro-ro cargo, containers and forestry products are main import-export cargo flows.

Table 1. Division of cargo flows of Estonian ports, 2002–2022, mln t. (Source: Eurostat)

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Dry bulk Agricultural products	***1 615***	***1 081***	182	285	441	1 106	562	177	361	394	361	423	514	803	730	884	594	***1 084***	***1 224***	768	***1 015***
Coal	1 183	1 815	2 287	***3 945***	***7 340***	***3 797***	315	1 587	1 452	345	39	65	127	13	0	0	0	0	0	0	879
Dry bulk other	4 606	3 832	3 810	3 615	3 535	3 258	2 195	2 935	4 655	4 400	4 908	4 052	4 182	4 205	4 940	5 394	5 989	***6 999***	***7 642***	***8 600***	5 665
Large containers	921	1 012	1 008	1 120	1 381	1 364	1 366	1 188	1 296	1 528	1 641	1 777	***1 976***	1 743	1 790	***1 996***	***1 995***	***1 960***	***1 808***	***1 892***	***2 215***
Crude oil	***6 939***	***8 035***	***7 051***	2 825	325	690	233	40	873	951	314	3	72	32	5	66	0	173	278	141	32
Liquified gas	0	0	0	0	0	2	3	13	153	290	240	419	541	679	398	517	444	768	***920***	***927***	369
Refined oil products	20 834	19 663	22 258	24 364	25 354	23 106	20 905	23 037	***27 378***	***29 345***	24 765	24 041	23 756	14 842	12 393	11 988	12 363	11 979	12 709	13 304	10 315
Liquid bulk other	31	17	103	1 670	1 657	576	326	111	686	726	966	1 239	1 619	1 357	1 588	1 364	***1 918***	***2 177***	1 479	1 773	818
Forestry products	2 756	***3 378***	***2 972***	2 507	2 098	2 465	1 867	1 496	2 466	***2 828***	2 603	***3 046***	2 648	2 652	***2 919***	***3 023***	***3 245***	***3 035***	2 408	***2 913***	***2 848***
Iron and steel products	142	556	***854***	387	412	305	342	135	304	384	248	262	260	230	206	234	188	232	204	306	317
Other general cargo	1 307	721	1 208	1 218	***4 968***	***4 724***	***4 679***	***3 705***	460	754	416	380	380	454	641	560	330	443	354	352	219
Ro-Ro mobile non-self-propelled units	11	0	0	0	40	1	1	0	687	674	631	605	600	504	561	620	644	623	591	***747***	***816***
Ro-Ro mobile self-propelled units	4 313	***5 167***	3 051	3 109	2	42	20	6	2 849	3 017	3 209	3 138	3 438	3 876	4 025	4 447	4 702	4 741	4 973	***5 741***	***6 080***
TOTAL	44 659	45 278	44 783	45 044	47 546	41 458	32 813	34 431	43 619	45 636	40 339	39 451	40 114	31 389	30 195	31 092	32 413	34 217	34 590	37 462	31 589

INFLUENCE OF WAR

Economic and political factors have a major impact on the flows of maritime goods and therefore on the throughputs of ports. Due to its geographical location Estonia and its ports have been heavily impacted by the economic and political relations with Russia.

There has been a major shift in cargo flows since 2022, when Russia started the war against Ukraine. The overall cargo flows through ports have fallen (Figure 4).

War has meant big disruptions of cargo flows on Black Sea. Though the normal economic activity is also disrupted in Ukraine, there are still cargo flows which need to be exported/imported. For example, grain flows. One theoretical possibility is to handle such flows through Estonian ports. Of course, such rerouting adds extra cost to grain price and there are also alternative routes available.

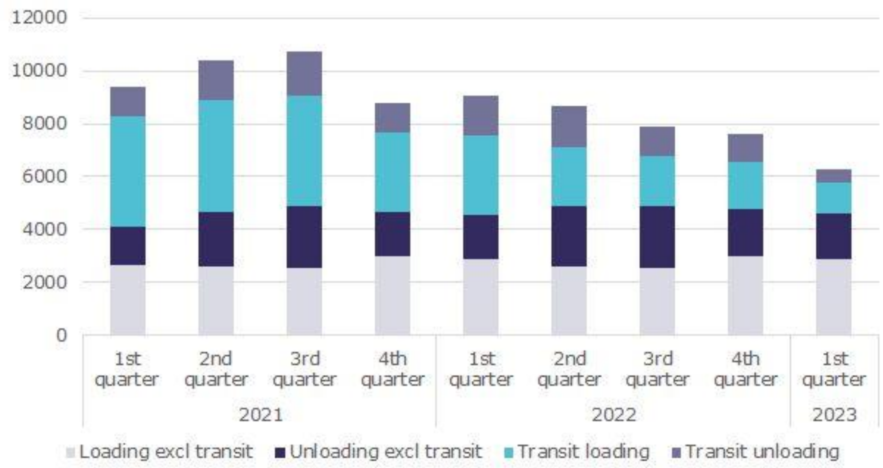


Figure 4. Cargo flows of Estonian ports by quarters, 2021–2023 1st q, th. t. (Source: Statistics Estonia)

When we take a more detailed look at the cargo flows, at some of the cargo groups which have been more impacted by the war, we see some interesting developments. While some of the cargo groups like "coke and refined petroleum products" (which has been biggest cargo group handled in Estonian ports) and "chemicals and chemical products …" have fallen heavily (Figure 5), other cargo groups like "coal and lignite, crude petroleum and natural gas, oil shale" and "Metal ores and other mining and quarrying products …" transit flows have risen (Figure 6). For cargo group "transport equipment" transit flows have fallen down to zero (2023 1st quarter) while import-export flows have risen at the same time (Figure 7).

Figure 5. Dynamics of Estonian ports cargo flows of two cargo groups between 2021 and 2023 1st quarter, th. t. (Source: Statistics Estonia)

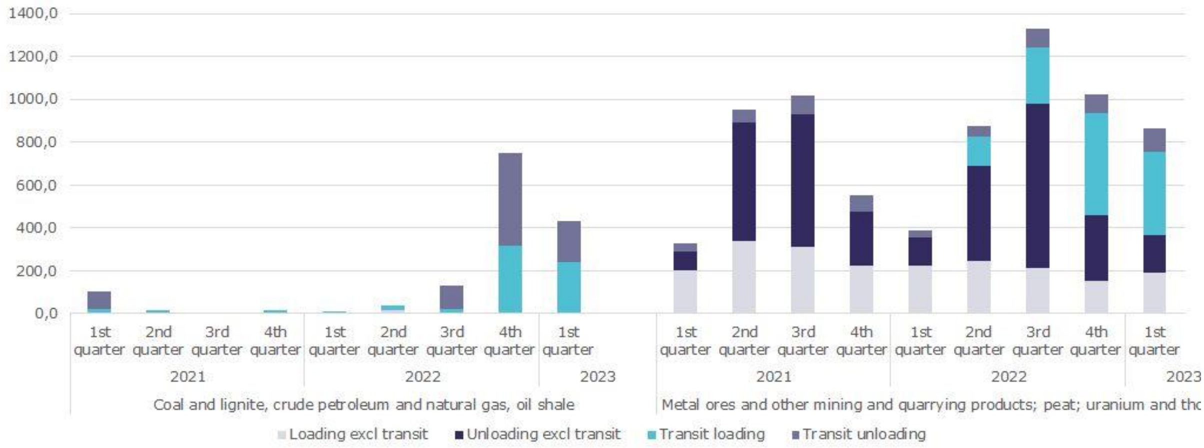


Figure 6. Dynamics of Estonian ports cargo flows of two cargo groups between 2021 and 2023 1st quarter, th. t. (Source: Statistics Estonia)

Figure 7. Dynamics of Estonian ports cargo flows of transport equipment cargo group between 2021 and 2023 1st quarter, th. t. (Source: Statistics Estonia)

1.2 HISTORICAL ANALYSIS OF ICEBREAKER USAGE

Electronic Maritime Information System (EMDE) data is used in the current work. EMDE data is more precise than AIS data. In the AIS information system there can be short-term gaps as per the AIS system itself and AIS data is only partially available for the years covered by the current study.

VESSEL TRAFFIC IN PORTS

Vessel traffic has been stable in recent years in the main ports of Estonia. According to EMDE, before the COVID pandemic the numbers of annual vessel movement reached 12,1 th. Since the pandemic, 2020–2022, vessel movements have been between 10…11 th. (Table 2).

Table 2. Vessel traffic in Estonian ports (Source: EMDE)

	2014	2015	2016	2017	2018	2019	2020	2021	2022
Vessel traffic	11 573	11 634	11 837	12 139	11 673	12 108	10 958	11 056	10 729
…, in ice breaking serviced ports	10 133	10 289	10 485	11 051	11 015	11 539	10 394	10 373	9 919
… (without ro-ro and ro-pax)	4 387	3 848	3 981	4 229	4 338	4 653	3 980	3 948	3 804

Remark:

- Icebreaking serviced ports are Muuga, Kunda, Sillamäe, Old City, Paldiski South, Paldiski North, Miiduranna, Paljassaare (not significant cargo port), Vene-Balti, Bekkeri, Meeruse and Pärnu. (*Jäämurdetööde kord–Riigi Teataja*, n.d.).
- Ro-ro and ro-pax vessels are mainly regular liners.

From the ice-breaking aspect vessel traffic should be looked at not for full year but for winter and early spring months. Therefore, following analysis of vessel traffic is for the months from December to April and for the cargo vessels.

Paldiski area

There are two harbours in Paldiski area, Paldiski North and Paldiski South Harbour. Pakrineeme Harbour will be added to this list in coming months.

Majority of the vessels that visit these two ports are different types of ro-ro vessels – ro-ro, ro-pax, vehicle carrier (

Table 3), and that mainly sail as liner vessels. Aside from these vessels, the ports are mainly visited by general cargo vessels (Table). COVID pandemic and war in Ukraine have significant effect on cargo vessel traffic of Paldiski North. At the same time Paldiski South has been able to maintain the vessel traffic and increasing the ro-ro traffic.

Table 3. Cargo vessel traffic by total and main cargo vessel types in Paldiski area cargo ports from December to April. (Source: EMDE)

	Paldiski North Harbour			Paldiski South Harbour			
WINTER	**Total**	**Ro-ro**	**General Cargo**	**Total**	**Ro-ro**	**General Cargo**	**Tanker**
2014/2015	***337***	302	32	***323***	165	65	67
2015/2016	***355***	322	31	***330***	166	79	63
2016/2017	***394***	345	47	***356***	162	101	65
2017/2018	***380***	350	28	***371***	189	114	57
2018/2019	***385***	348	35	***345***	188	99	50
2019/2020	***370***	341	26	***326***	204	58	58
2020/2021	***238***	221	16	***321***	221	62	32
2021/2022	***174***	152	20	***333***	214	66	47
2022/2023	***150***	141	8	***354***	229	66	53

For Paldiski South harbour different types of tankers accounted for a significant share of vessel traffic, though it has decreased from 18…20% to around 15% in the last two winters.

Main IA Super and IA ice class vessels visiting Paldiski North are ro-ro vessels (Figure 8). Between 2015/16 and 2019/20 roughly 65% of ro-ro vessels had either ice class IA Super or IA. In following winters share of vessels with ice class IA Super drastically dropped, reaching 0 in 2020/21. At the same time share of vessels with ice class IA increased but mainly on the expense of decreasing vessel traffic. During the studied period, no other vessel that visited Paldiski North had ice class IA Super. On average over the winters, 42% of the other than ro-ro vessels were in ice class IA.

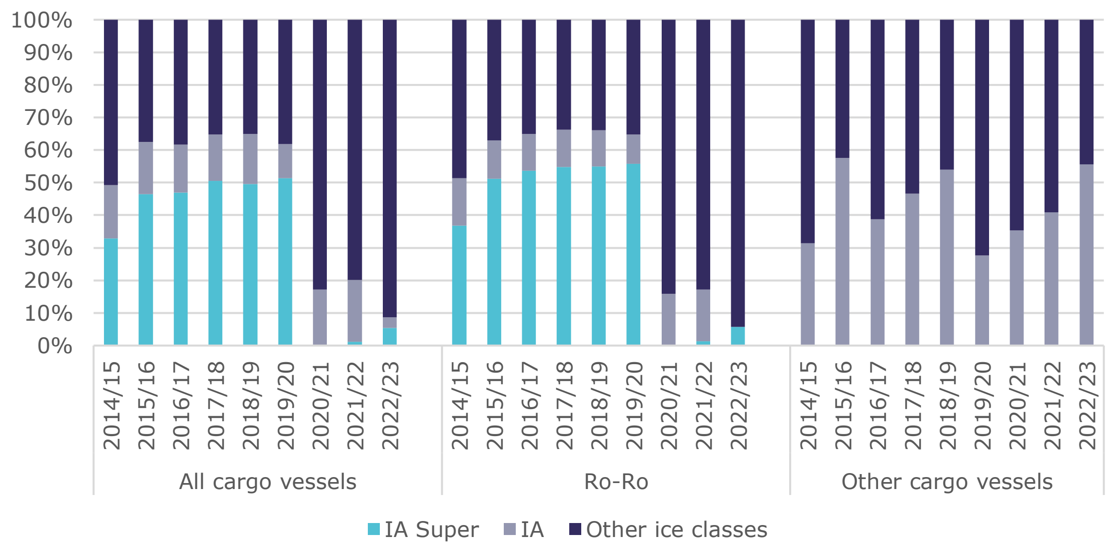


Figure 8. Share of vessels of ice class IA Super or IA calling at the Paldiski North harbour by different types of vessels. (Source: EMDE)

Paldiski North ro-ro vessels have grown in average GT and average length during last three years, with GT from around 20…21,2 th to 22…23 th and length from 165…170 m to over 180 m. At the same time average deadweight has decreased from 7..8 th to 5,7…6,4 th. General cargo vessels average parameters are GT ≈3,4 th, LOA ≈97 m, dwt ≈4,5 th. There isn't significant size differences of general cargo vessels with different ice classes. (EMDE, 2023)

Biggest vessels that have visited Paldiski North are ro-ro vessels, the largest of which was 238 m long, width 34,6m, draft 7,2 m. Among other types of vessels, the length of vessels has not exceeded 150 m recent years. (EMDE, 2023) According to State Port Register maximum dimensions of vessel that can visit Paldiski North harbour are – length 250 m, width 36 m and draft 12 m (Estonian Transport Administration, 2023a).

All ro-ro vessels that visited Paldiski South harbour had either ice class IA Super or IA (Figure 9) and they represent most vessels of calling at this port with such ice classes. During last 5 winters, more than a half of general cargo vessels have ice class IA. Amongst tankers, only few IA Super ice class vessels has been calling at Paldiski South harbour. Though number and share of IA ice class vessels have decreased, they still constitute more than 20% of all tanker visits (excl. winter 2020/21). In other cargo vessels group IA Super ice class vessels were mostly container vessels between 2014/15 and 2016/17.

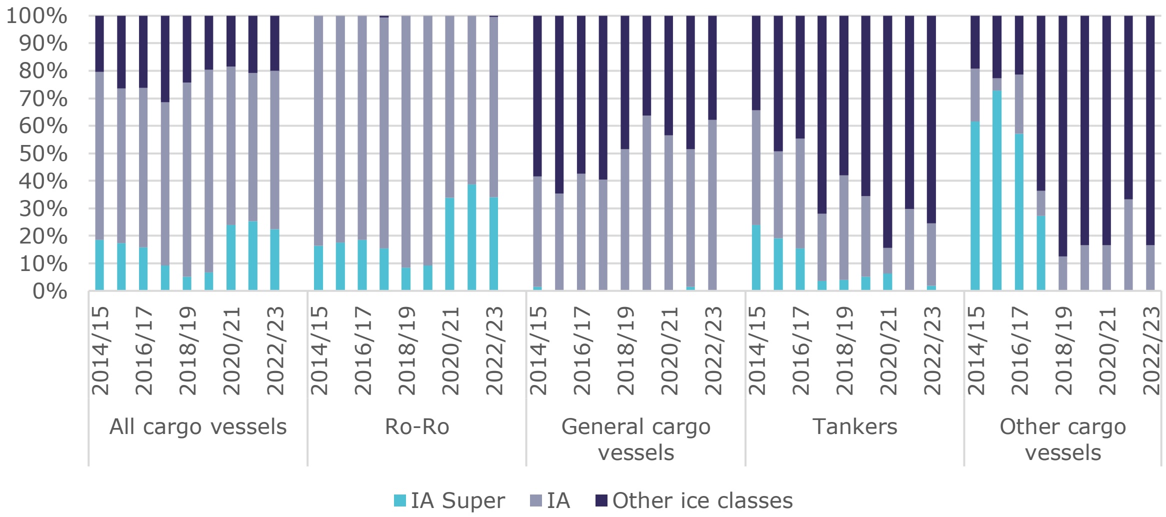


Figure 9. Share of vessels' ice class IA Super or IA calling at the Paldiski South harbour by different types of vessels. (Source: EMDE)

Ro-ro vessel sizes in Paldiski South have been stable in recent years (last 6 years) with the average GT between 20…22 th, average length 168…171 m and average deadweight between 9…10 th. (EMDE, 2023)

General cargo vessels visiting Paldiski South have increased last years. Average GT has increased from around 2,8...3,8 th to 3,9 th and 4,3 th in winter 2022/23. Average length has grown from 92…98 m to over 100 m in winters 2020/2021 and 2021/2022 and reaching 104,8 m this winter. Deadweight has increases from around 3,8…4,9 th to around 5,4 th and over 6 th respectively. There is also difference of vessels' average sizes between ice class IA/IA Super and other ice classes. Vessels with higher ice class are bigger. IA Super ice class vessels are with the length around 130 m, draft 7,8 m, GT 6,4 th and dwr 6,4 th t. Ice class IA vessels are with the length of 107…110 m, draft between 6…6,5 m, GT 4,3…5,3 th and deadweight between 5,8…7,3 th t. While general cargo vessels with lower ice class are 92…95 m long, with draft around 5,5 m, GT 3…3,3 th and deadweight 4,2…4,8 th t. (EMDE, 2023)

Tankers visiting Paldiski South harbour are mainly product tankers and chemical tankers. Average length of product tanker has been 161 m, draft 10,5 m, GT 20,6 th, deadweight 33,1 th t. Vessels with lower ice class than IA and IA Super have been bigger than vessels with such ice class. Average length of lower ice class product tankers has been 170 m, draft 11,4 m, GT 24,8 th and deadweight 40,6 th t. (EMDE, 2023)

Ro-ro vessel has been the biggest that has visited Paldiski South harbour in this year with 205 m of length, 25,5 m of width and 8,5 m of draft. Before that, since 2014, crude oil tanker with 256 m of length, 43 m of width and 22 m of draft has been the biggest. (EMDE, 2023) Maximum dimensions of vessel that can visit Paldiski South harbour are – length 250 m, width 45 m and draft 14,5 m, with entrance channel minimal width is 180 m and depth 15,5 (EH2000) (Estonian Transport Administration, 2023a).

Tallinn area

In smaller cargo ports of Tallinn area, Bekkeri, Meeruse, Vene-Balti and Miiduranna, main cargo vessels are general cargo vessels and tankers (Table 4). In table is clearly seen effects of latest developments in the world (eg COVID, war in Ukraine, slowing economy).

Table 4. Winter cargo vessel traffic by total and main cargo vessel types in Tallinn area cargo ports – Bekkeri, Meeruse, Vene-Balti, Miiduranna (Source: EMDE)

	Bekkeri		Meeruse		Vene-Balti			Miiduranna	
WINTER	**Total**	**General cargo**	**Total**	**General cargo**	**Total**	**General cargo**	**Tanker**	**Total**	**Tanker**
2014/2015	***47***	45	***35***	33	***93***	44	36	***9***	9
2015/2016	***51***	47	***21***	19	***75***	45	22	***9***	9
2016/2017	***59***	55	***42***	42	***72***	41	16	***9***	8
2017/2018	***52***	50	***40***	39	***81***	52	22	***11***	3
2018/2019	***55***	53	***32***	31	***85***	59	19	***2***	1
2019/2020	***56***	53	***33***	33	***99***	65	21	***10***	9
2020/2021	***59***	56	***8***	8	***95***	52	32	***7***	7
2021/2022	***48***	48	***10***	10	***155***	48	94	***29***	28
2022/2023	***44***	42	***3***	2	***70***	37	22	***6***	6

Ro-ro vessels, mainly ro-paxes, are dominating Old City harbour's vessel traffic as Old City is main harbour for liner passenger traffic (Table 5). As main and biggest cargo port of Estonia, vessel traffic in that port is most diversified. Ro-ro, general cargo and container vessels form majority of the vessel traffic of Muuga harbour. Before the war in Ukraine, also tankers played important role but after imposed sanctions on Russia due to war tanker traffic has decreased significantly. Old City an Muuga harbour have linked with each other through ro-ro traffic as during unsuitable weather in Muuga ro-ro traffic is rerouted to Old City harbour.

Table 5. Cargo vessel traffic by total and main cargo vessel types in Tallinn area cargo ports – Old City and Muuga. (Source: EMDE)

	Old City		Muuga					
WINTER	**Total**	**Ro-Ro**	**Total**	**Ro-Ro**	**General cargo**	**Tanker**	**Bulker**	**Container vessel**
2014/2015	***1899***	1891	***468***	0	114	184	20	150
2015/2016	***1958***	1954	***450***	1	130	155	34	130
2016/2017	***2050***	2044	***451***	0	117	135	34	165
2017/2018	***1902***	1898	***568***	206	91	104	35	132
2018/2019	***1826***	1818	***635***	203	139	119	25	149
2019/2020	***1720***	1719	***582***	174	110	143	29	126
2020/2021	***1600***	1600	***897***	480	116	123	43	131
2021/2022	***1706***	1704	***793***	408	148	96	24	116
2022/2023	***1939***	1938	***533***	223	121	43	17	128

There isn't unified pattern in ice class division of visiting vessels of smaller cargo ports in Tallinn area (Figure 10). Visiting vessels are either with ice class IA or less.

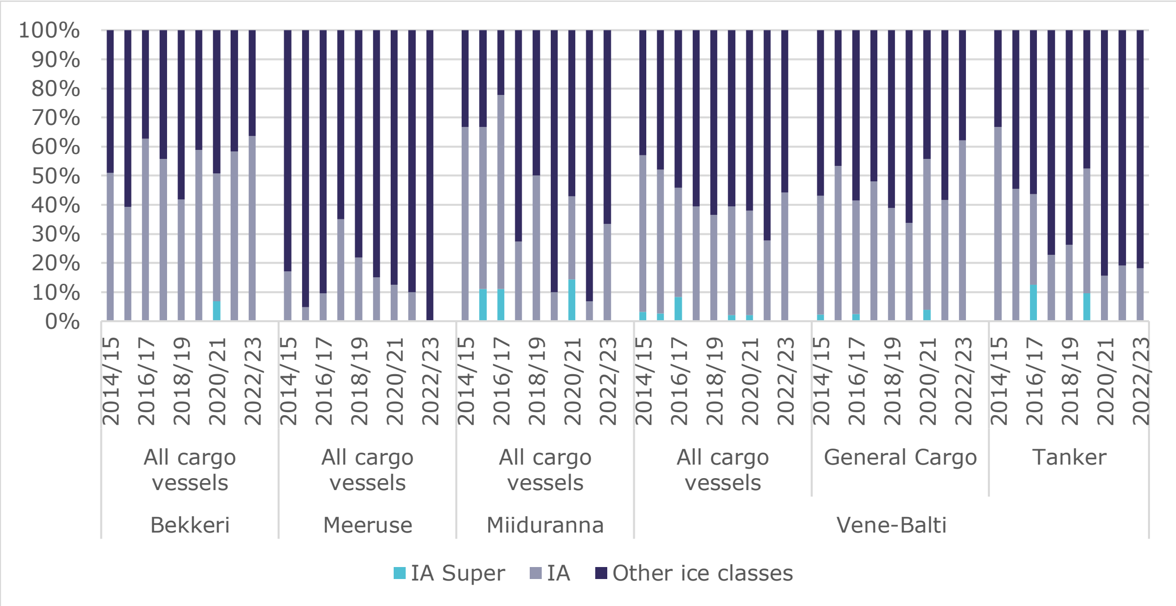


Figure 10. Share of vessels' ice class IA Super or IA calling at Tallinn area cargo ports – Bekkeri, Meeruse, Vene-Balti, Miiduranna. (Source: EMDE)

Liner vessels visiting Old City harbour vessel traffic is formed mostly by same vessels and since in recent years they all have either ice class IA or IA Super, the statistics for the ice class harbour's vessel traffic is atypical to other Estonian cargo ports (Figure 11). Most liner vessels, ro-ro and container vessels, in Muuga harbour have ice class IA or IA Super.

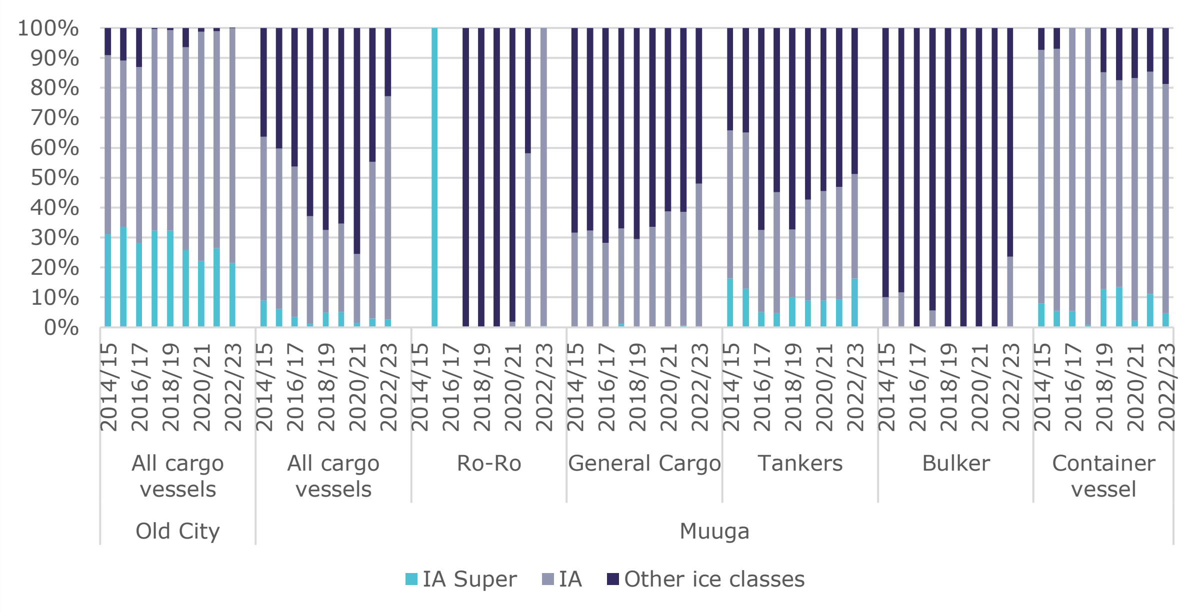


Figure 11. Share of vessels' ice class IA Super or IA calling at Tallinn area cargo ports Old City and Muuga. (Source: EMDE)

- Like in Paldiski, also Tallinn area's small cargo ports have differences in general cargo vessel sizes when comparing average sizes different ice class vessels. For example, in port of Bekkeri IA ice class vessels have length around 108 m, draft 6,4 m, GT 4,4 th and dwt 6,3 th t. Vessels with lower ice class are with average length between 90… 103 m, draft 5,5…5,7 m, GT 3,1…4,1 th and deadweight 4,3…5,6 th t. In Vene-Balti ice class IA vessels calling at port are with the average length around 110 m, with the draft 6,6 m, GT a little bit less than 5 th and deadweight between 6,9…7,3 th t. At the same time vessels with lower level ice class calling at the port are with length of around 92 m, draft 5,3 m, GT around 2,9 th and deadweight usually less than 4 th t. In Muuga general cargo vessels with ice class have average length of 102,5 m, draft 6,2 m, GT around 4 th and deadweight between 5...6,4 th t. Vessels with lower ice class have average length of 92,5 m, draft 5,1 m, GT usually less than 3 th and deadweight less than 4 th t. In last years general cargo ships that visit Muuga harbour have decreased in size. (EMDE, 2023)

- Average size of tankers doesn't represent very well the "normal" liquid bulk carrier calling at the port of Muuga as there are different types of tankers in this group. Biggest in size are crude oil tankers with average length of around 230 m, draft 14 m, GT over 56 th t and deadweight around 102 th t. Product tankers are next in size with average length around 150 m, draft 8,6 m, GT 15,7 th and deadweight almost 24 th t. Chemical tankers what also notably contribute to vessel traffic have average length 135 m, draft 8,2 m, GT 9,7 th and deadweight 14,6 th t. In last two years with decreasing cargo flows of liquid bulk, vessel number and sizes have decreased significantly, expect of chemical tankers where size has been fluctuating over the years. Interestingly, contrary to general cargo vessels, average sizes of ice class IA and IA Super vessels are smaller than lower ice class vessels. (EMDE, 2023)

- Tankers calling at ports of Vene-Balti and Miiduranna are quite similar, with vessels in Vene-Balti slightly bigger and serving also crude oil and chemical tankers in addition to product tankers. Average sizes vessels visiting Vene-Balti port with ice classes IA and IA Super are, length around 144 m, draft 8,7 m, GT 11,6 th and deadweight 17,5 th t. In Miiduranna average vessel parameters are, 141 m, 8,6 m, 10,3 th and 15,1 th t respectively. Lower ice class vessels are smaller with average sizes of vessels visiting Vene-Balti port are, length around 106 m, draft 6,3 m, GT 5,7 th and deadweight 8,6 th t. In Miiduranna average vessel parameters are, 97 m, 6,1 m, 5,1 th and 7,8 th t respectively. (EMDE, 2023)
- As ro-ro type vessels are visiting Muuga harbour as liners, variety of different vessels are limited. In those lines IA ice class vessels, with average length 179 m, draft 6,5 m, GT 22 th and deadweight 7,6 th t, have been bigger than lower ice class vessels, with average length 160 m, draft 5,4 m, GT 17,5 th and deadweight 4,9 th t. (EMDE, 2023)
- Recent years only handful of ro-pax vessels calling at Old City harbour aren’t ice class IA nor IA Super. Based on last three years average length of IA Super ro-pax vessel is 189 m, draft 6,7 m, GT 38,7 th and deadweight 5,3 th t. Average length of IA ro-pax vessel at same time is 193 m, draft 6,95 m, GT 41,3 th and deadweight 5,5 th t. (EMDE, 2023)
- Bulkers calling at Muuga harbour are mainly without ice class IA or IA Super. These vessels’ average length is 186 m, draft 11 m, GT 25,6 m and deadweight 43 th t. (EMDE, 2023)
- Average length of container vessel calling at Muuga harbour is 168 m, draft 9,4 m, GT 15,8 th and deadweight 19,1 th t. (EMDE, 2023)
- In Bekkeri port dimensions of largest vessel that can visit the port are with length 190 m, width 31 m and draft 10,2 m, with entrance channel minimal width is 114 m and depth 10,5 (EH2000) (Estonian Transport Administration, 2023). Largest vessel that visited Bekkeri has been 190 m long, 28,54 m wide and with draft of 10,4 m. (EMDE, 2023)
- In Meeruse port dimensions of largest vessel that can visit the port are with length 140 m, width 24 m and draft 6,3 m, with entrance channel minimal width is 50 m and depth 7,9 (EH2000) (Estonian Transport Administration, 2023). Largest vessel that visited Meeruse has been 136,4 m long, 19 m wide and with draft of 8,5 m. (EMDE, 2023)
- In Miiduranna port dimensions of largest vessel that can visit the port are with length 195 m, width 32 m and draft 12,3 m, with entrance channel minimal width is 110 m and depth 12,8 (EH2000) (Estonian Transport Administration, 2023). Largest vessel that visited Miiduranna has been 195 m long, 32,2 m wide and with draft of 12,5 m. (EMDE, 2023)
- In Vene-Balti port dimensions of largest vessel that can visit the port are with length 200 m, width 35 m and draft 10,6 (Estonian Transport Administration,

2023a). Largest vessel that visited Vene-Balti has been bulk carrier with 197,1 m of length, 32,3 m of width and with draft of 13 m. (EMDE, 2023) Entrance channel minimal width is 120 m and depth 8,7 (EH2000) (Estonian Transport Administration, 2023a).

- In Old City harbour largest vessels have been cruise vessels amongst those the largest has been vessel with 333,3 of length, 37,9 m of width and 8,65 m of draft. Such large cruise ships visit the harbour during summer. During winter period biggest vessels are ro-pax liners 212 m of length, 30,6 m of width and 7,1 m of draft. (EMDE, 2023) Dimensions of largest vessel that can visit the port are with length 340 m, width 42 m and draft 10,3 m, with entrance channel minimal width is 265 m and depth 9,8 (EH2000) (Estonian Transport Administration, 2023a).
- Crude oil tankers are largest that have called at Muuga harbour with 330 m of length, 60 m of width and 21,5 m of draft of being the largest. This vessel has been by far the largest in Muuga harbour. Next by size have been considerably shorter, 285 m (50 of width and 16,5 m of draft). (EMDE, 2023) Dimensions of largest vessel that can visit the port are with length 300 m, width 50 m and draft 16,9 m, with entrance channel minimal width is 200 m and depth 17,6 (EH2000) (Estonian Transport Administration, 2023 a).

Eastern part of Gulf of Finland

For Kunda port, general cargo vessels is the main vessel type. Last winter, the general cargo was also the most frequent type of vessel in the port of Sillamäe. Before tankers formed majority. (Tabel 6)

Table 6. Cargo vessel traffic by total and main cargo vessel types in Kunda and Sillamäe. (Source: EMDE)

	Kunda		Sillamäe					
WINTER	**Total**	**General cargo**	**Total**	**Ro-Ro**	**General cargo**	**Tanker**	**Bulker**	**Container vessel**
2014/2015	***208***	194	***277***	100	54	103	19	0
2015/2016	***183***	173	***268***	125	46	80	17	0
2016/2017	***178***	169	***244***	0	66	150	11	16
2017/2018	***169***	158	***262***	0	65	161	16	20
2018/2019	***181***	170	***272***	0	64	167	23	18
2019/2020	***148***	143	***293***	0	85	176	28	4
2020/2021	***156***	151	***286***	0	92	160	34	0
2021/2022	***150***	144	***232***	3	52	157	17	3
2022/2023	***170***	167	***102***	0	51	16	32	3

More than 60% of vessels calling at Kunda have ice-class IA (Figure 12). In Sillamäe some 30% or more have ice class at least IA. Container vessels which called at port during 2016–2020 had ice class IA. Same goes to ro-ro vessels that called at port between 2014–2016.

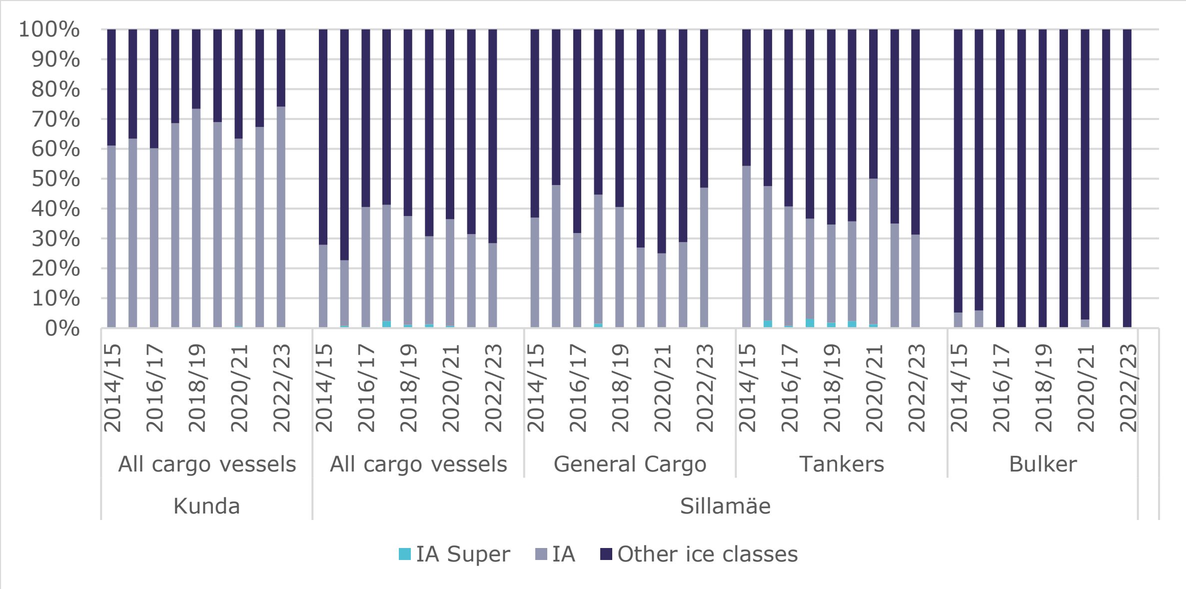


Figure 12. Share of vessels' ice class IA Super or IA calling at ports of Kunda and Sillamäe. (Source: EMDE)

There is slight difference between vessels sizes of ice class IA or IA Super vessels and vessel sizes of lower ice class vessels calling at the port of Kunda. Vessels with ice class IA/IA Super are bigger, length slightly over 100 m, maximum draft 5,8…5,9 m, GT between 3,8…4,1 th, deadweight 5,2…5,6 th t. Vessels with lower ice classes have average parameters length 90…94 m, draft between 5,0…5,4 m, GT around 3 th, deadweight around 4 th t. Largest vessel that visited Kunda has been bulker with 199,9 m of length, 32,3 m of width and with draft of 11,3 m. (EMDE, 2023) Dimensions of largest vessel that can visit the port are with length 150 m, width 30 m and draft 8,6 m, with entrance channel minimal width is 70 m and depth 9,4 (EH2000) (Estonian Transport Administration, 2023a).

In Sillamäe the difference of average size of the general cargo vessels with different ice classes is not so big. Interestingly during last two winters average vessel sizes of lower ice classes have been slightly bigger than average sizes of vessels with ice class IA, which have decreased. Over the years average sizes of IA ice class vessels are length 103 m, draft 6 m, GT less than 4 th and deadweight over 5,4 th t. (EMDE, 2023)

Size pattern of tankers visiting Sillamäe is similar to Muuga with crude oil tankers as the biggest, then product tankers and then chemical tankers. Average sizes of crude oil tankers are, length 243 m, draft 14,7 m, GT 57,8 th and deadweight 104,5 th t. Ice class IA and IA Super average crude oil tankers are slightly longer (248 m) with slightly bigger GT (60,4 th) and deadweight (almost 109 th t). Product tankers average GT and deadweight are similar amongst different ice class vessels calling at Sillamäe port. Differences are in length and draft. While vessels with ice class IA and IA Super are with bigger draft, they are shorter. For all product tankers average length is 148 m, draft 8 m, GT 13,4 th and deadweight 20,5 th t. Chemical tankers average sizes are, length 130 m, draft 8 m, GT 9,5 th and deadweight 13,6 th t. Ice class IA and IA Super vessels are slightly smaller than average and vessels with lower ice classes slightly bigger. (EMDE, 2023)

In Sillamäe, like in Muuga, bulkers are mostly lower ice class vessels. Average length of bulkers calling at Sillamäe is 180 m, draft 11 m, GT 24,4 th and deadweight 41,3 th t. (EMDE, 2023)

Product tankers are largest that have called at Sillamäe harbour with 280,5 m of length, 50 m of width and 16,5 m of draft of being the largest (EMDE, 2023). Dimensions of largest vessel that can visit the port are with length 275 m, width 56 m and draft 15,2 m, with entrance channel minimal width is 300 m and depth 16,3 (EH2000) (Estonian Transport Administration, 2023a).

Gulf of Riga, Port of Pärnu

Port of Pärnu is the only big cargo port of Estonia in the Gulf of Riga. The main vessel type calling at the port of Pärnu is general cargo vessel (Table 7). Some 70% of the vessels have ice class IA.

Table 7. Cargo vessel traffic by total and main cargo vessel types in Pärnu port. (Source: EMDE)

	Pärnu		Vessels with Ice class IA	
WINTER	**Total**	**General cargo**		**% of total**
2014/15	***211***	206	146	69,2%
2015/16	***215***	212	140	65,1%
2016/17	***268***	264	190	70,9%
2017/18	***245***	239	153	62,4%
2018/19	***265***	263	157	59,2%
2019/20	***208***	207	119	57,2%
2020/21	***207***	204	149	72,0%
2021/22	***189***	189	132	69,8%
2022/23	***223***	219	160	71,7%

In last three years average size of the visiting vessel in the port of Pärnu is length 108 m, draft 6 m, GT 4,4 th and deadweight around 6 th tonnes. Vessels with ice class IA are slightly bigger, with the average length in last years 110 m, draft 6,2 m, GT over 4,5 th and deadweight over 6,3 th t. Vessels with lower ice classes are slightly smaller in size. (EMDE, 2023)

Largest vessel that visited Pärnu has been 145,6 m long, 18,25 m wide and with draft of 7,35 m (EMDE, 2023). Dimensions of largest vessel that can visit the port are with length 140 m, width 25 m and draft 6,8 m, with entrance channel minimal width is 45 m and depth 7 (EH2000) (Estonian Transport Administration, 2023 a).

VESSELS WIDTH DISTRIBUTION

On separate analysis vessels width and distribution of width was looked at, as vessels' width is an important parameter for ice breaking. In that analysis ports were grouped to regions. The regions were Archipelago (Figure 13), Gulf of Riga (Figure 14), Western Gulf of Finland (Figure 15), Tallinn area, Eastern Gulf of Finland (Figure 16) and Whole Gulf of

Finland (Figure 17). The analyzed data is based on vessel traffic in Estonia from 2014 to 2022.

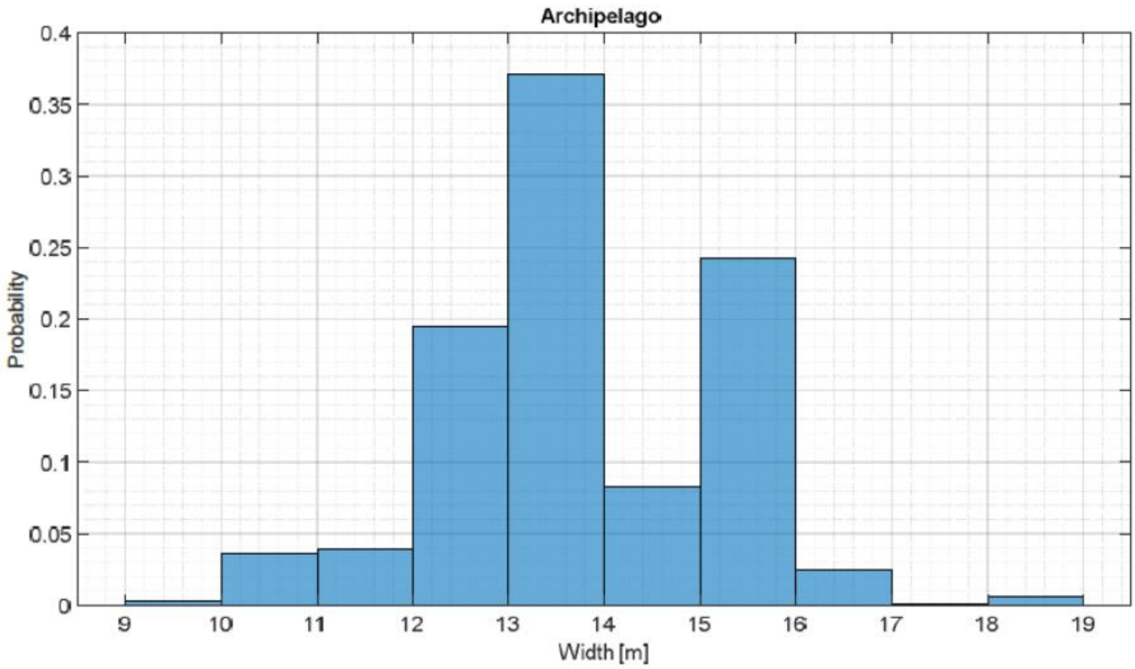


Figure 13. Distribution of vessels (excl ro-ro and ro-pax vessels) width in the Archipelago. (Source: EMDE, Aker Arctic Design)

In the Gulf of Riga Estonian part main port is Pärnu.

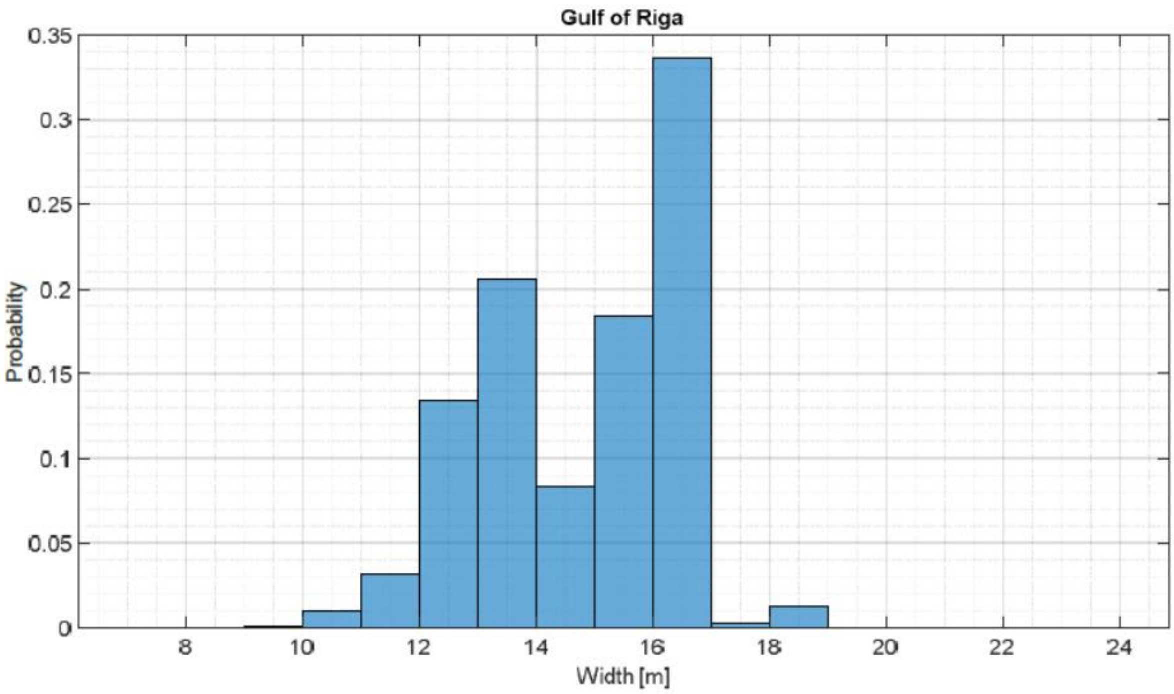


Figure 14. Distribution of vessels (excl ro-ro and ro-pax vessels) width in the Gulf of Riga. (Source: EMDE, Aker Arctic Design)

Ports of the Western Gulf of Finland are both Paldiski ports, Paldiski South and Paldiski North.

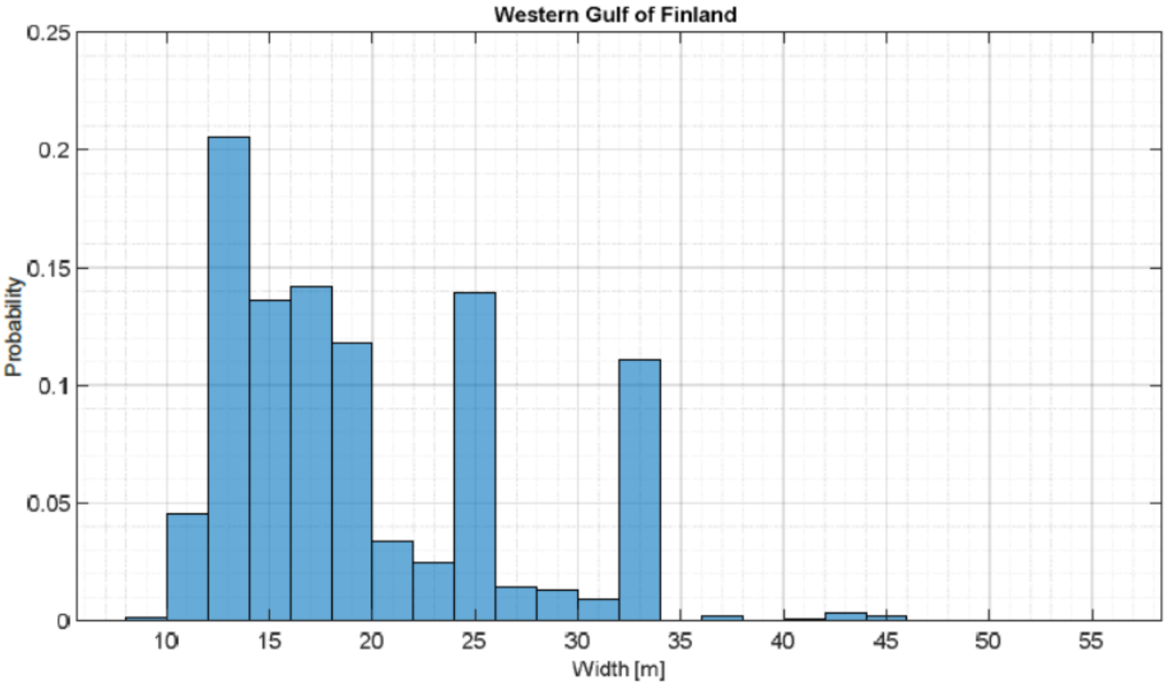


Figure 15. Distribution of vessels (excl ro-ro and ro-pax vessels) width in the Western Gulf of Finland. (Source: EMDE, Aker Arctic Design)

For the Tallinn area cargo ports like Muuga, Old City, Vene-Balti, Bekkeri, Meeruse, Paljassaare and Miiduranna are included.

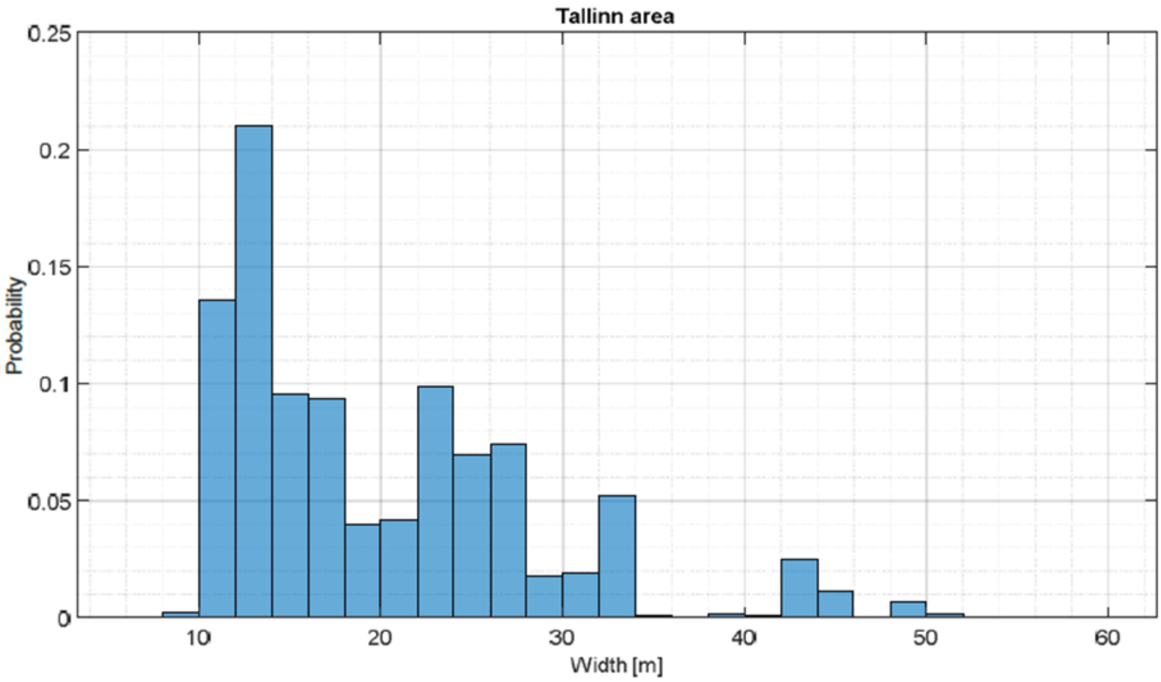


Figure 16. Distribution of vessels (excl ro-ro and ro-pax vessels) width in Tallinn area. (Source: EMDE, Aker Arctic Design)

Port of Sillamäe and Kunda are main cargo ports in the Eastern Gulf of Finland.

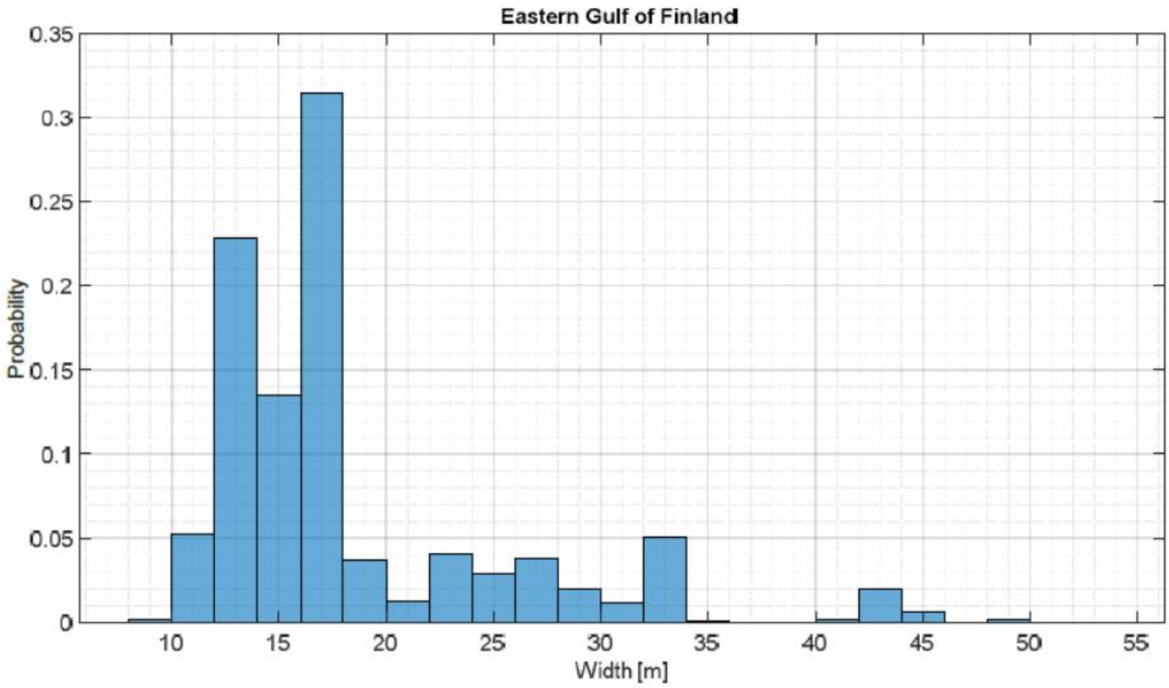


Figure 17. Distribution of vessels (excl ro-ro and ro-pax vessels) width in the Eastern Gulf of Finland. (Source: EMDE, Aker Arctic Design)

For the whole Gulf of Finland distribution of vessels width is seen in Figure 18.

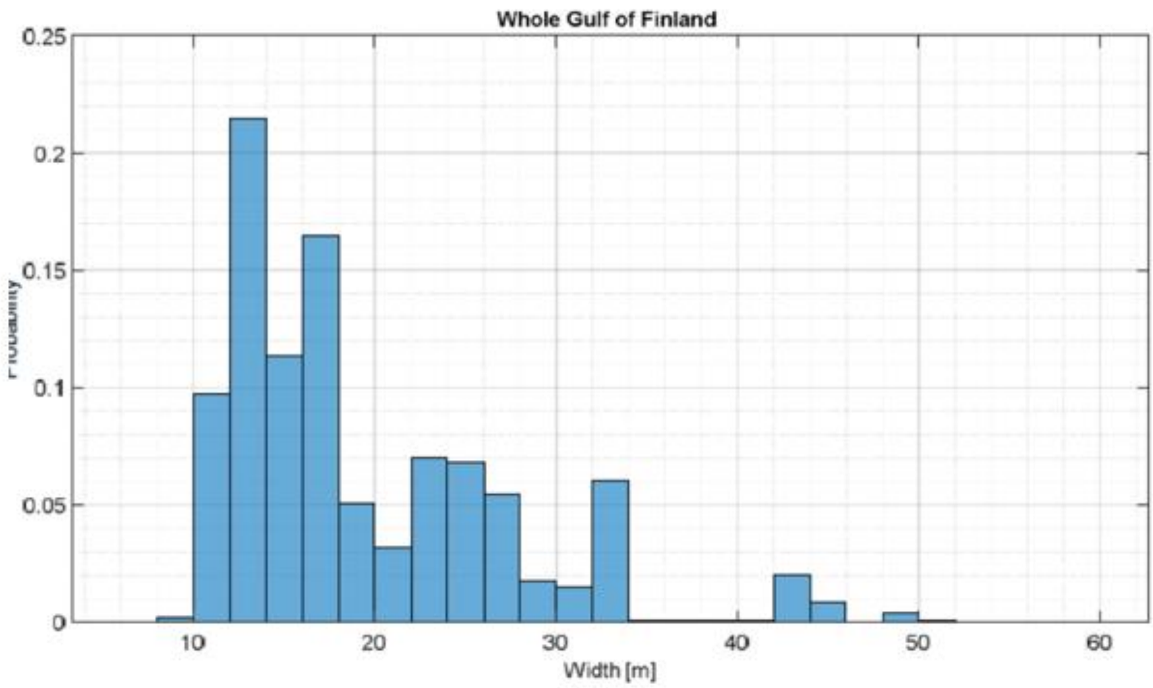


Figure 18. Distribution of vessels (excl ro-ro and ro-pax vessels) width in the whole Gulf of Finland. (Source: EMDE, Aker Arctic Design)

Summary of cargo ships' width distribution by regions is shown in Table 8. In 95% of cases, the ship is narrower than 32.26 meters.

Table 8. Summary of cargo ships width in meters

	Archipelago	**Gulf of Riga**	**Western Gulf of Finland**	**Tallinn Area**	**Eastern Gulf of Finland**	**Whole Gulf of Finland**
70th percentile	14,4	16,0	23,2	23,4	17,0	23,0
75th percentile	15,21	16,3	25,0	25,0	18,25	24,5
80th percentile	15,45	16,5	25,0	27,0	23,0	25,4
85th percentile	15,45	16,5	27,34	27,6	26,0	27,4
90th percentile	15,45	16,5	32,2	32,0	28,5	31,0
95th percentile	15,46	16,5	32,2	32,26	32,24	32,26

ICE BREAKING FLEET

According to the procedure for ice breaking, *Jäämurdetööde kord – Riigi Teataja*. (n.d.), the ports served by the state with icebreakers are Muuga harbour, the ports of Tallinn and Kopli Bay, Paldiski North harbour, Paldiski South harbour, Kunda harbour and Sillamäe harbour, which are served up to the aquatorium, and Pärnu harbour is served from the open sea up to the point defined by the coordinates 58º 21',4 N and 24º 27',0 E. Ice breaking is carried out by the Transport Authority.

Icebreaking is carried out by the state with the vessels Tarmo, EVA-316 and Botnica. The latter is owned by TS Shipping (a subsidiary of Port of Tallinn) and the service is provided under a charter contract (Estonian Transport Administration, 2023b). The State also operates a multi-purpose/icebreaking vessel Sektori. Tarmo and EVA-316 are old vessels (Table 9), 60 and 43 years respectively. Tarmo and Botnica are serving northern coast ports and EVA-316 is serving vessels in the Gulf of Riga and Pärnu bay. There aren't any icebreakers dedicated to Moonsund and the archipelago.

Table 9. Vessel technical data

	Tarmo	EVA-316	Botnica
Year of Built	1963	1980	1998
GT	3916	907	6370
Deadweight	1585 dwt	266 dwt	2890 dwt
Length	84,5 m	57,9 m	96,7 m
Beam	21,2 m	12,2 m	24,0 m
Draft	7,4 m	3,8 m	7,8 m
Main Engine	10120 kW	3x 1717 kW	12x 1258 kW
Speed	15,5 knots	12 knots*	16,5 knots / 8 knots (ice)
Crew	33	13	19…23

In addition, a number of companies have icebreaking/ice-class vessels:

- TS Vessels (five passenger ferries serving the main islands);
- Alfons Hakans (ice-class 1A tugs in Sillamäe, Kunda, Muuga, Paldiski and Pärnu);
- Port of Sillamäe (tug Arno);
- Port of Kunda (tug Kunda);
- Saarte Liinid (tug Panda);
- Kihnu Veeteed (passenger ferries serving small islands);
- Tallink, Viking Line, Eckerö Line (passenger ferries and ro-ro vessels sailing on the routes from Vanasadam and Muuga);
- Navy (Kindral Kurvits, Raju, Valve).

1.3 ESTIMATIONS OF FUTURE TRAFFIC TAKING INTO ACCOUNT TRADE VOLUMES AND VESSEL AND PORT DEVELOPMENT

As illustrated in Table 10 there isn't unified, single pattern in change of vessel dimensions during last five years. Only remarkable change is Muuga port, where due to war vessel traffic and dimensions of vessels decreased significantly. Looking back further the negative change for Muuga and Sillamäe happened after 2014, when Russia occupied Crimea and sanctions were imposed against Russia.

Table 10. Comparison of parameter change of vessels visiting ports between 2018 and 2022 (excl ro-ro and ro-pax vessels)

	Vessel traffic	Av GT	Av LOA	Av Dmax	Av dwt
Paldiski North	↓	≈	≈	≈	≈↑
Paldiski South	≈	≈↓	≈↓	≈↓	↓
Muuga	↓	↓	↓	≈↓	↓
Old City	↑	↑	↑	↑	↑
Vene-Balti	↑	≈	≈↑	≈↑	≈
Bekkeri	≈	↑	≈	≈	≈
Meeruse	↓	≈	≈	≈	≈
Miiduranna	↑	↑	≈↑	↑	↑
Sillamäe	↓	↑	≈	≈	↑
Kunda	↓	≈	≈	≈	≈
Pärnu	↓	↑	≈	≈	≈↑

Remarks:

10%...	↑
5…10%	≈↑
5…-5%	≈
-5…-10%	≈↓
-10%...	↓

Looking to the future, it can be said that for ports serving east-west transit cargo flows, all depends on political relations between Estonia and its eastern neighbour Russia. As relations normalise, trade flows increase and vessel traffic as well. When will it happen it's hard to predict. For other ports, which serve mainly import-export cargo flows economic development of the country and trading partners is the key. Alternative logistical solutions, e.g. land transport, must also be considered.

From ice-breaking point of view ports in Estonia can divide into four areas Paldiski, Tallinn, eastern part of Estonia and Gulf of Riga. Based on the recent years' statistics, ports in Tallinn area handle roughly 50% of the Estonian ports' cargo flows, Paldiski 12…15%, eastern part of Estonia 28…30% and Gulf of Riga around 7%.

Recent years show that icebreaking capability is needed in eastern part of Estonia and in the Gulf of Riga and Pärnu. Though there hasn't been demand for icebreaker services in Tallinn and Paldiski areas, where important ports for Estonia are situated and therefore there should be readiness to offer ice-breaking services in these regions in some form.

Cargo flows served by ports are dependent on economic situation of its hinterland and foreland and political relations with its neighbours and possible partners. For many years, transit has accounted for a large share of port cargo flows. Due to war in Ukraine these flows have been and will be affected for years to come. Though first months since the start of war showed increase in some cargo flows, in longer term, transit flows decrease.

As vessel traffic serves these cargo flows, it increases or decreases in line with changes with cargo flows. Changes in vessel size can change it some extent. According to vessel traffic statistics in Estonian ports, there hasn't been considerable changes in vessel sizes visiting Estonian cargo ports in the recent decade.

In 2011, the IMO set goals by which the structure of new ships must be designed in such a way that ships' fuel consumption and thus greenhouse gas emissions are reduced. EEDI stands for Energy Efficiency Design Index, i.e. it is used to calculate the ship's energy efficiency index (carbon dioxide emissions per tonne-mile). For the ship to operate, the index value must be lower than the reference value set by the IMO. They are gradually becoming stricter, so new ships gradually become less emitting. The regulation has already had a significant impact on the energy consumption of ships, for example by designing the hull shapes, as well as the fact that the newest ships usually have less engine power than the older ones.

In 2021, the IMO set a requirement that existing ships must also meet the energy efficiency requirements set by the IMO. And like EEDI, this EEXI gradually tightens.

The EEDI regulation has already change and also coming EEXI regulation will change the new vessels operating in the Baltic Sea. The new vessels are weaker and therefore, they need more ice breaker assistance in winters (See 4.1.5 Vessels Ice-Going Capacity Based on New IMO Rules).

KEY TAKEAWAYS

No	Task/ question*	Answer
1	What changes have taken place in vessel traffic in the past five years in Estonian waters (use AIS datasets provided by the contracting entity) and in expectations for icebreaking services (incl. any expected changes in the needs of vessels over the next 25 years in relation to icebreaking services)?	Several factors affect ports' cargo throughput – economic factors, mainly economy of ports' hinterlands and forelands; political factors, e.g political relations with neighbours or political situation in hinterland and foreland; climate, weather conditions; technological factors; and logistics factors. During past five years vessel traffic in Estonian waters has been influenced by two major events – COVID pandemic starting 2020 and war initiated by Russia in Ukraine and following sanctions against Russia and Belarus, starting 2022. While pandemic had worldwide economic affect and in Estonia context affected basically all ports, imposed sanctions due to war has affected Estonian ports through which east-west transit cargo was handled – mainly Muuga, Sillamäe and ports in Paldiski. From vessel traffic standpoint, year 2020, when pandemic started, number of visiting vessels dropped altogether and almost in every ice breaking serviced port (Table 2-14). Due to war, big drop in vessel traffic was in ports of Muuga and Sillamäe, i.e the main transit ports. There isn't unified, single pattern in change of vessel dimensions during last five years (Table 10). Only remarkable change is Muuga port, where due to war vessel traffic and dimensions of vessels decreased significantly. Looking back further the negative change for Muuga and Sillamäe happened after 2014, when Russia occupied Crimea and sanctions were imposed against Russia. Solutions related to future icebreaking need are discussed in the chapters below.
2	Which Estonian ports need icebreaking services and how much, given the ice conditions? Which goods and in what quantities are loaded/unloaded in these ports during the winter (data can be downloaded from the Electronic Marine Information System)? What alternatives are available for the transport of goods and what are the impacts if the port is closed?	Recent years show that icebreaking capability is needed in eastern part of Gulf of Finland and in the Gulf of Riga and Pärnu. Though there hasn't been demand for icebreaker services in Tallinn and Paldiski area, where important ports for Estonia are situated and therefore there should be readiness to offer ice-breaking services in these regions in some form. Cargo flows served by ports are dependent on economic situation of its hinterland and foreland and political relations with its neighbours and possible partners. As vessel traffic serves these cargo flows, it increases or decreases in line with changes with cargo flows. Changes in vessel size can change it some extent. According to vessel traffic statistics in Estonian ports, there hasn't been considerable changes in vessel sizes visiting Estonian cargo ports in the recent decade. Year-round operable ports are needed to ensure cargo movement to/from/through Estonia. 55% of Estonian foreign trade moves through sea. In case of disturbance on land transport routes there is need to also reroute the cargo traffic by sea. In extreme cases, like during COVID pandemic, sea transport could be only possible solution to transport people and cargo to/from Estonia.

SOURCES & REFERENCES

Aker Arctic Design (2023) Statistics of the Merchant vessels visiting Estonian ports.

EMDE (2023) *Vessel Traffic* public report, database, from 01 May 2022 available at https://www.emde.ee

Estonian Ports Association (2023) Statistics, website from 05 May 2023 available at https://www.estonianports.com/statistics/

Estonian Transport Administration (2023a) *State Port Register* , database, from 05 June 2022 available at https://www.sadamaregister.ee/

Estonian Transport Administration (2023b) Jäämurdetööd ja talvine navigatsioon from 10 June 2022 available at https://www.transpordiamet.ee/jaamurre-ja-talvine-navigatsioon

Eurostat (2023) *Gross weight of goods transported to/from main ports – Estonia – quarterly data*, database, website from 28 May 2023 available at https://ec.europa.eu/eurostat/databrowser/view/MAR_GO_QM_EE__custom_6678848/default/table

Jäämurdetööde kord–Riigi Teataja. (n.d.). website from 10 June 2023, available at https://www.riigiteataja.ee/akt/103022022006

Port of Tallinn (2023) Key Figures; website from 05 May 2023 available at https://www.ts.ee/en/investor/key-figures/

Saarte Liinid (2023). Aruanded, majandustegevuse ülevaade ja ainuaktsionäri otsused, website from 05 May 2023 available at https://saarteliinid.ee/ettevottest/

Statistics Estonia (2023) *Statistical database*, database, from 15 May 2022 available at https://andmed.stat.ee/et/stat

2. ICE CONDITIONS IN THE GULF OF FINLAND AND GULF OF RIGA

2.1 BACKGROUND AND DATA USED

The study utilizes Copernicus Marine Environment Monitoring Service (CMEMS) reanalysis data (Ringgaard et al., 2023) to assess ice characteristics around the Estonian coast. The dataset encompasses 29 years, from January 1993 to December 2021, covering multiple ice seasons. Ice concentration and ice thickness data from the reanalysis model is specifically employed for the analysis.

The CMEMS Baltic Sea Physical Reanalysis product (Ringgaard et al., 2023) provides a comprehensive physical reanalysis for the entire Baltic Sea region. To produce this product, the ice-ocean model NEMO-Nordic, based on NEMO-4 (Nucleus for European Modelling of the Ocean), is utilized in conjunction with a PDAF data assimilation scheme. The data assimilation incorporates observations of sea surface temperature and profiles of salinity and temperature.

The NEMO-Nordic model is coupled with a sea-ice and thermodynamic model, SI3, and the validation of this coupled system is provided by CMEMS (Panteleit et al., 2023). Pemberton et al. (2017) have previously demonstrated the suitability of a similar modeling system for accurately representing seasonal ice cover across the entire Baltic Sea.

The CMEMS product offers a horizontal resolution of 2 km, presenting sea ice concentration and total ice thickness for each grid cell on a daily basis. However, for this study, seasonal mean values are utilized, calculated as averages of the daily values to provide a more comprehensive analysis. Moreover, only areas around Estonia is used for the study to calculate respective ice parameters.

SEA ICE CONCENTRATION

The estimation of ice concentration is dependent on the size of the grid cell area over which it is calculated. Different products may provide ice concentration values for varying sizes of grid cell areas. When dealing with very low ice concentration, which indicates high uncertainty about the presence of ice, the grid cell is considered ice-free.

Sea ice concentration represents the estimated fraction of an area covered by ice within a specific grid cell. A grid cell is classified as ice-covered when its sea ice concentration exceeds a threshold value, which is set at 0.15 for the current study. These threshold values for sea ice concentration are calculated, ensuring that the minimum ice concentration corresponds to an ice sheet with an approximate size of 380x380 meters (0.144 square kilometres). This approach allows for a more standardized representation of sea ice presence across the study area.

SEA ICE THICKNESS

In numerical implementations, the thickness distribution is discretized into several thickness categories, with specific ice concentration and ice volume per area. Ice volume per area is the extensive counterpart for ice thickness, connected with volume. Evolution equations for extensive variables can be readily derived by integration between thickness boundaries of the thickness category.

Modelled ice thickness values are validated with ice charts that are generated by combining the most up-to-date ice charts with data from a Synthetic Aperture Radar (SAR) image. The SAR data plays a crucial role in enhancing the accuracy of the ice information presented in the ice charts.

However, it's important to note that the observations and validation of ice thickness, both in the models and satellite remote sensing, are quite limited. Significant efforts are made to derive ice thickness data from satellite remote sensing. Nevertheless, validation is primarily reliant on explicit ice thickness measurements, which are challenging to conduct due to the lack of area-covering equipment and advanced measurement technologies.

CALCULATED PARAMETERS

In the Gulf of Finland and Gulf of Riga, four parameters calculated from ice concentration are utilized to describe past ice conditions:

1. Ice days: This parameter is obtained by calculating the mean of the ice binary (sea ice concentration > 0.15) over the entire ice season and then multiplying it by the length of the ice season, which spans from 1st October to 31st May (a total of 243 days).
    a. Ice binary: It represents a binary value (0 or 1) denoting the presence or absence of sea ice. A grid cell is considered to have ice if its sea ice concentration exceeds the threshold value of 0.15.
2. T1 (First ice day): This refers to the initial day when sea ice becomes persistent for at least three consecutive days.
3. T2 (Last ice day): This corresponds to the final day when sea ice persists for at least three consecutive days.
4. Ice period: This measure refers to the time difference in days between first and last ice day.

Additionally, statistical descriptions of ice thickness are calculated for the entire dataset and on a yearly basis:

1. Mean ice thickness: The average thickness of ice across the dataset or for each year.
2. Maximum ice thickness: The highest recorded ice thickness value observed in the dataset or within a specific year.
3. Standard deviation of ice thickness: A measure of how much variation or dispersion exists in ice thickness values, indicating the spread around the mean thickness.
4. Probabilities of different ice thicknesses: The likelihood of different ice thickness categories, specifically:

a. Ice thickness less than 20 cm
b. Ice thickness between 20 and 40 cm
c. Ice thickness more than 40 cm

By considering these parameters and statistical descriptions, past ice conditions in the Gulf of Finland and Gulf of Riga can be comprehensively characterized and analyzed.

2.2 ICE CONDITIONS IN THE GULF OF FINLAND AND GULF OF RIGA

The long-term data analysis spanning from 1993 to 2021 reveals significant ice occurrences throughout the study region, as illustrated in Figure 19. Notably, even the areas between Baltic Proper and Gulf of Finland have consistently exhibited ice concentration above the defined threshold for more than 10 years. Additionally, the north-eastern regions of the Gulf of Finland have experienced ice cover every single year during this period.

Furthermore, Väinameri and Pärnu Bay have consistently been ice-covered each winter, except for the 2019/2020 winter when ice did not form in these specific areas.

These findings from the long-term data analysis provide valuable insights into the historical patterns of ice presence and concentration in the study region. The observations highlight the persistence of ice in various areas and can contribute to a better understanding of ice dynamics and climate trends in the Gulf of Finland and Gulf of Riga over the examined period.

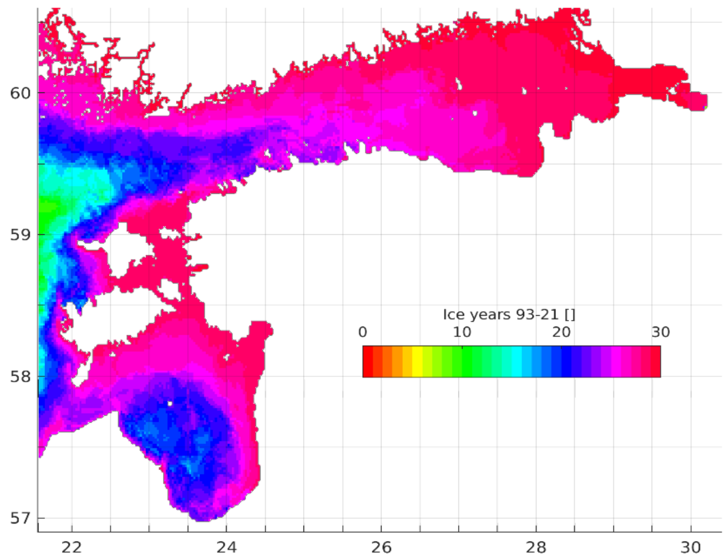


Figure 19. Number years between 1993 and 2021 that sea ice concentration has exceeded the threshold. Data that is shown also represent the study; integrated parameters (e.g., sea ice extent;) are derived using the model grid points within this area

In 20(a) the average ice season length in days and Figure 19(b) the number of ice days within the ice season are presented separately. An evident trend in Gulf of Finland is observed, where the ice season tends to be longer in regions east of the Tallinn-Helsinki line, and shorter in areas west of this line, typically ranging from about 40 to 60 days. The eastern parts of Gulf of Finland experiences the longest ice seasons lasting up to 120 days.

The Gulf of Riga and Pärnu Bay stand out with notably longer ice seasons, surpassing 100 days. However, in the open areas of the Gulf of Riga, the ice season lasts approximately 40 to 60 days. Notably these areas are more open to wind forcing and ice is not as persistent as in closed bays which might affect the results.

Figure 19(b) represents the average duration of individual ice days within the ice season across the entire dataset. Despite ice seasons lasting more than 60 days east of the Tallinn-Helsinki line, persistent ice coverage occurs for a much shorter period. Only in the area east of Kunda, do persistent ice days extend beyond 60 days.

Pärnu Bay 20(b) experiences ice cover for more than 100 days, starting from around Kihnu island. On the other hand, the open areas of the Gulf of Riga have less than about 50 days of persistent ice cover on average.

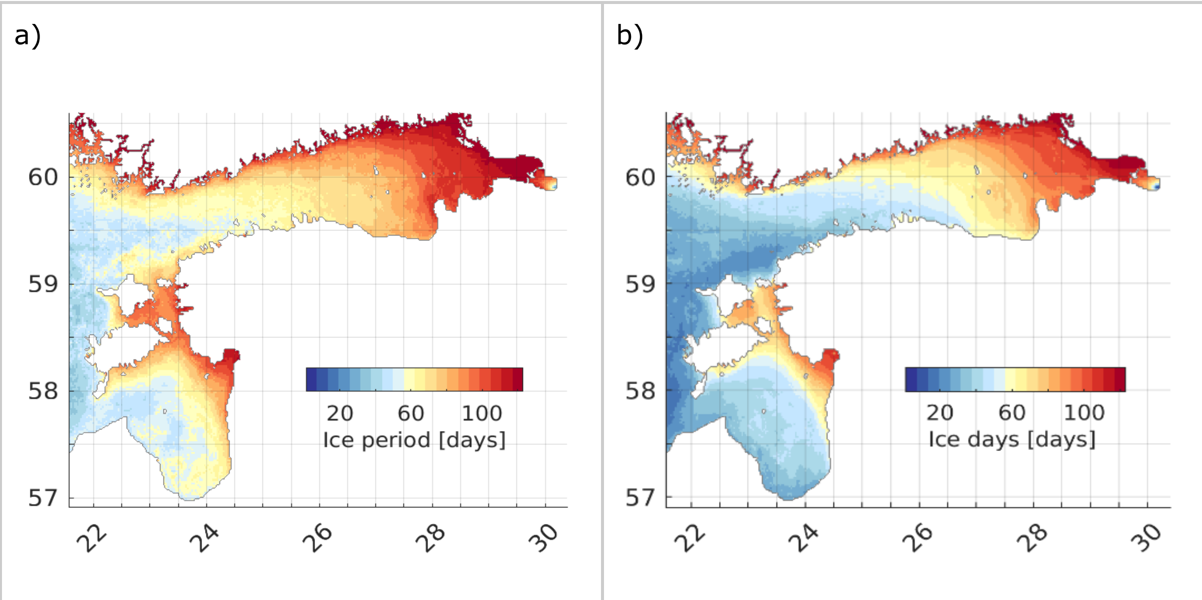


Figure 20. (a) Average ice season length (i.e., period) and (b) number of days when ice has existed during the ice period. The data is retrieved by calculating averages over the entire dataset between 1993 and 2021

Based on the comprehensive data spanning nearly 30 years, the onset of the ice season is typically observed around the end of December (as shown in Figure 21(a)). However, in relatively enclosed areas like Väinameri and Pärnu Bay, the ice season tends to start earlier than in other regions. These areas may experience ice formation before the end of December.

On the other hand, the end of the ice season exhibits more variability depending on the specific region (as depicted in Figure 21(b)). For instance, the north-eastern parts of the Gulf of Finland can retain ice cover up until the very end of the ice season, which lasts until 31st May for the current study. In contrast, the areas situated between the Baltic Proper and Gulf of Finland have shorter ice periods, with ice cover dissipating earlier.

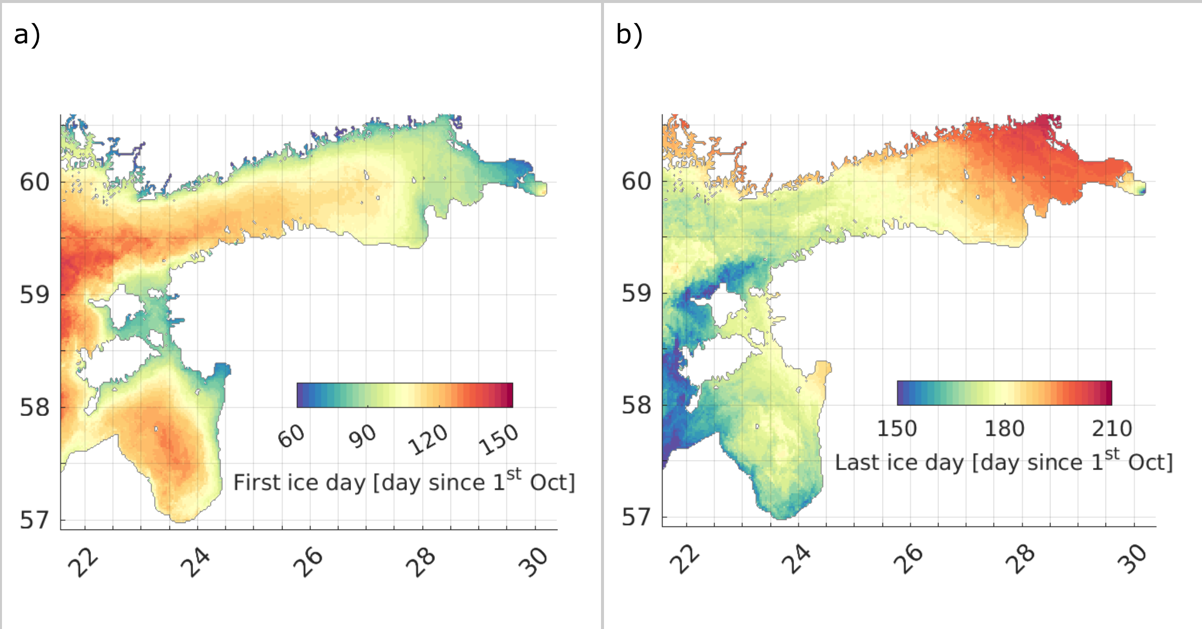


Figure 21. (a) Average ice period starting and (b) end day calculated from 1st October. The value is retrieved as an average over the entire dataset between 1993 and 2021

Based on the data analysis, the average ice thickness around the Estonian coast remains consistently around 10 cm or even less, as indicated in Figure 22(a). The only exception to this trend is Pärnu Bay, where the ice thickness averages around 15 cm.

On the other hand, Figure 22(b) illustrates that the maximum ice thickness exhibits much more spatial variability. In the north-eastern parts of the Gulf of Finland, ice thickness can reach up to about 80 cm during the coldest winters. Conversely, the southern coast of the Gulf of Finland has experienced maximum ice thickness around 40 cm within the analyzed data.

In the Gulf of Riga, the maximum ice thickness typically falls within the range of 40 to 60 cm. Similar patterns to ice concentration are observed in Pärnu Bay and other more enclosed areas, where thicker ice is found. In contrast, the open parts of the Gulf generally do not experience very thick ice. Note that the maximum ice thickness does not include ridging which can increase the local ice thickness significantly in the Baltic Sea (Leppäranta and Myrberg, 2009).

The standard deviation of ice thickness (Figure 22(c)) shows relatively consistent variability of around 10 cm in most regions. However, the Finnish coast of the Gulf of Finland exhibits higher variability in ice thickness.

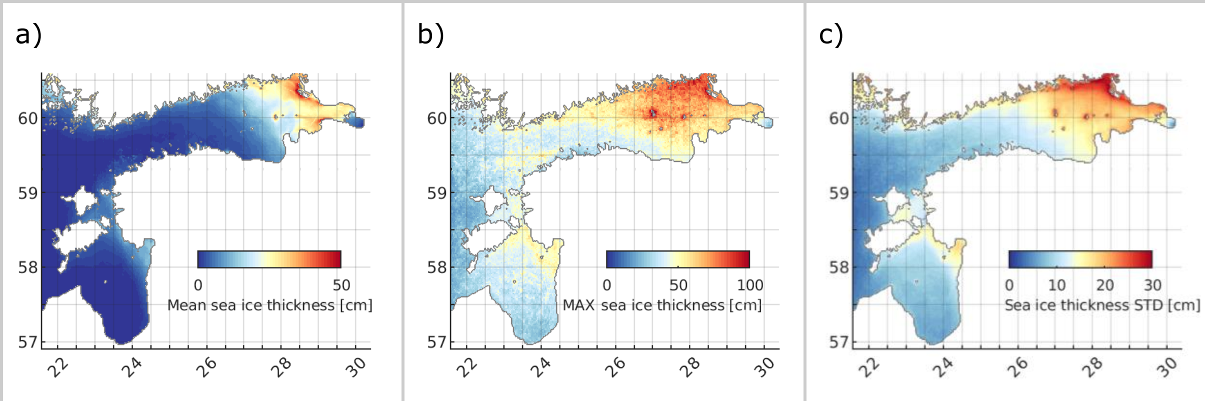


Figure 22. (a) Mean, (b) maximum and (c) standard deviation of ice thickness. The values are retrieved from data between 1993 and 2021

The analysis indicates that the highest probabilities for ice thickness are generally observed for ice that is less than 20 cm thick (Figure 23(a)). However, two exceptions stand out: Pärnu Bay and the eastern Gulf of Finland, which exhibit higher probabilities for ice thickness ranging between 20 and 40 cm (Figure 23(b)). Moreover, the regions with the most substantial probabilities for ice thicker than 40 cm are predominantly situated in the north-eastern parts of the Gulf of Finland (Figure 23(c)).

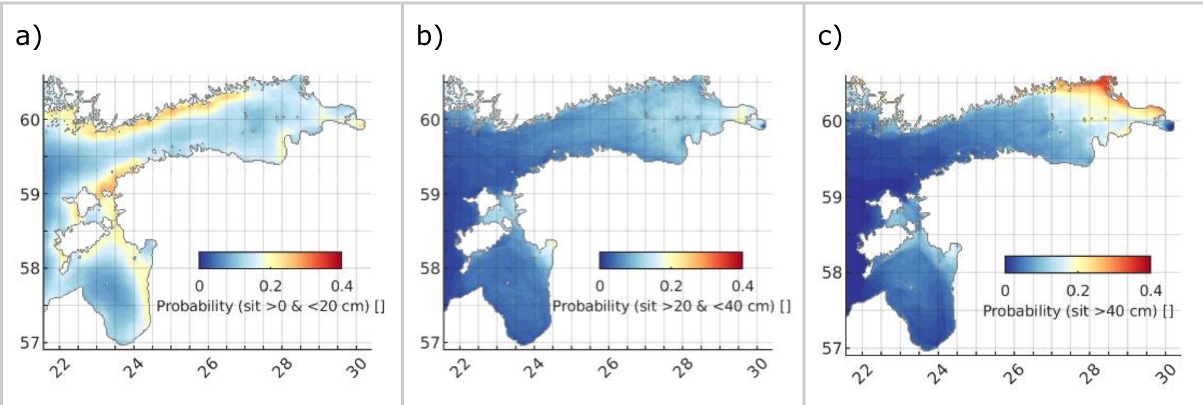


Figure 23. (a) Probability of ice thickness less than 20 cm, (b) probability of ice thickness between 20 and 40 cm, (c) probability of ice thickness over 40 cm. The values are retrieved from the data between 1993 and 2021

Figure 24 provides insights into the mean, maximum, and standard deviation of sea ice extent, measured in square kilometers. Note that sea ice extent calculation includes area within Väinameri as well. According to the data, the average sea ice growth initiates towards the end of December, gradually expanding until it reaches its peak extent of approximately 40,000 square kilometers by the end of February or the beginning of March.

Notably, only during the coldest winters, the ice season begins as early as the middle of November, leading to a more extensive ice coverage. In these exceptional cases, the sea ice reaches its maximum extent, encompassing around 100,000 square kilometers. This significant variation in sea ice extent between regular and coldest winters highlights the influence of temperature conditions on the duration and expansion of the sea ice season.

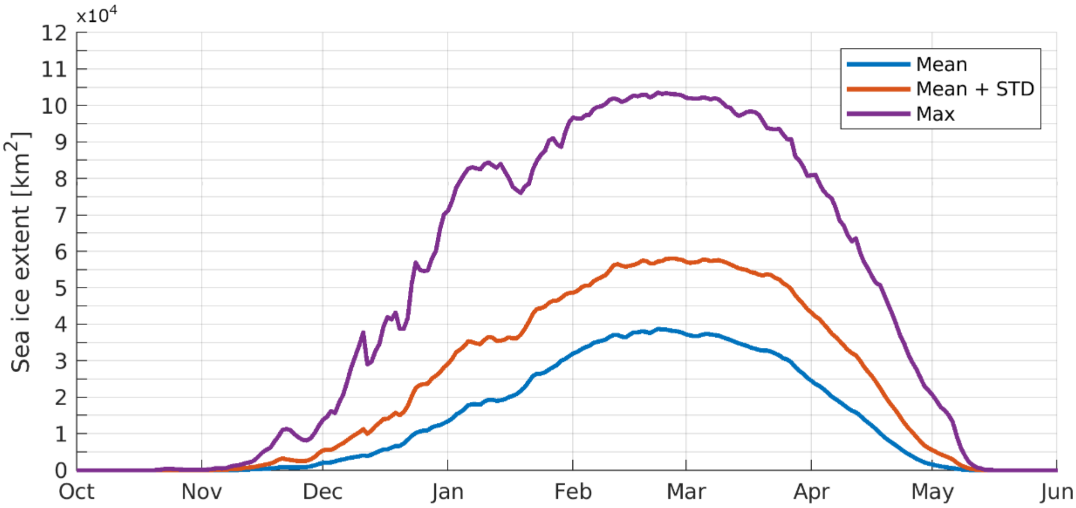


Figure 24. Sea ice extent mean (blue), maximum (purple) and standard deviation (red) over the study area. The data is retrieved from the data between 1993 and 2021. Note that sea ice extent values include area inside Väinameri as well

On the other hand, Figure 25 reveals substantial variability in sea ice extent both between different winters and within each winter. For instance, the winters of 1993, 1995, and 2002 exhibit relatively consistent ice growth, peaking around the beginning of March. In contrast, the winters of 1996, 2000, and 2003 show a more complex pattern, with periods of ice growth followed by partial melting (including other processes related to ice melting) and subsequent regrowth, resulting in multiple ice extent peaks within a single winter.

These observations emphasize the dynamic and unpredictable nature of sea ice extent, where various factors, including temperature fluctuations and weather patterns, contribute to the seasonal variations.

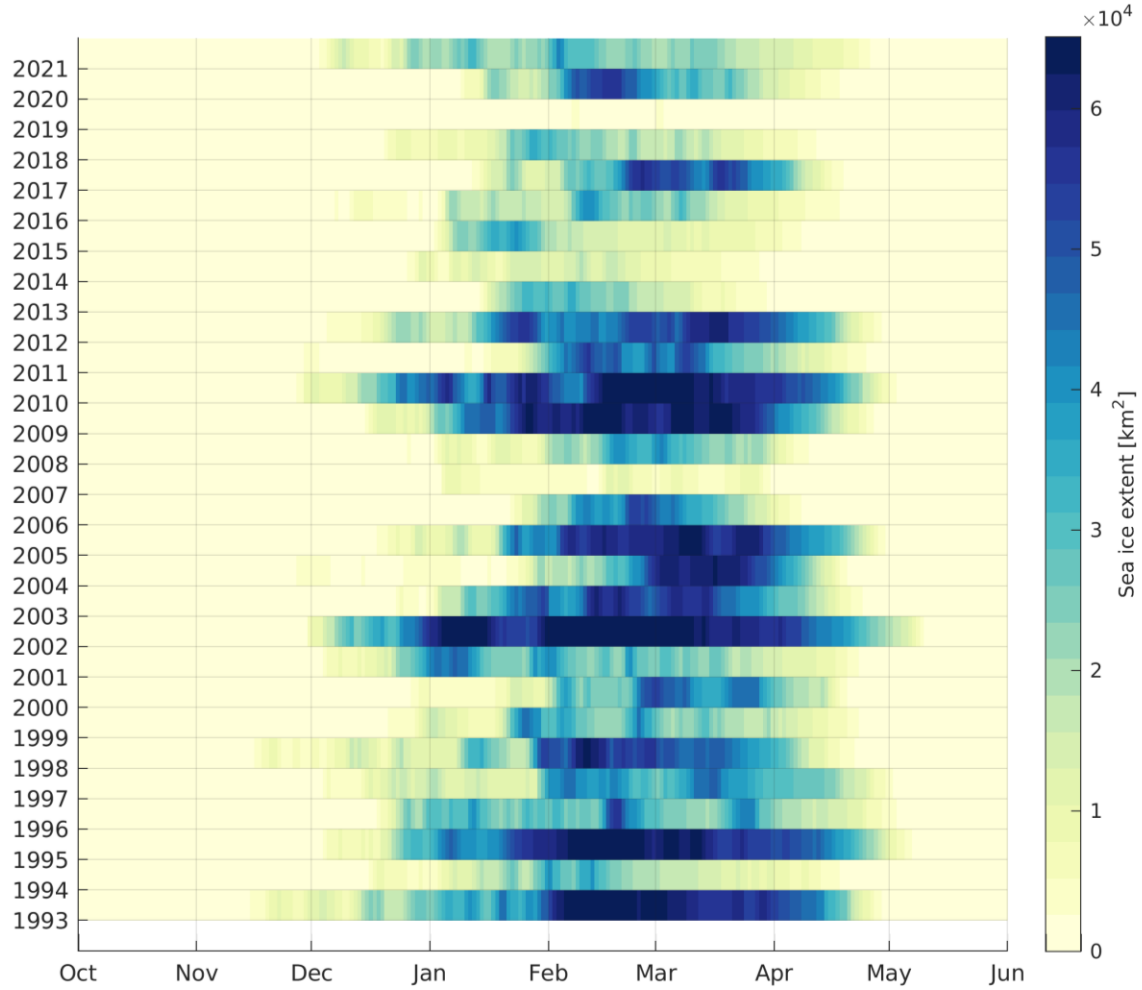


Figure 25. Sea ice extent for individual winters. The color signifies the increase in sea ice extent for each winter revealing the complex nature of ice growth and melting. Note that sea ice extent values include area inside Väinameri as well

2.3 ESTIMATION FOR FUTURE ICE CONDITIONS

REFERENCE CLIMATE

ERA5 (Hersbach et al., 2023) data, that is used as baseline climate for the current study, is a comprehensive dataset provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) that offers a wealth of climate and atmospheric information. Among the various variables it provides, the 2 m air temperature is a significant parameter in understanding climate conditions. This variable represents the air temperature measured at a height of 2 meters above the surface of the Earth.

The ERA5 2 m air temperature dataset offers extensive spatial and temporal coverage, providing hourly data on a global scale. It incorporates various observational sources, including satellites, weather stations, and other instrumental measurements, using advanced data assimilation techniques to produce highly accurate and reliable estimates.

Researchers and climate scientists frequently utilize ERA5 2 m air temperature data to analyse and study long-term trends, climate patterns, and changes in temperature over different regions. It plays a crucial role in climate modelling, weather forecasting, and studying the impacts of climate change on a local and global scale.

USED CLIMATE SCENARIOS

The climate dataset used in this study comes from the CMIP6 (Coupled Model Intercomparison Project Phase 6) experiment. CMIP6 is a collaborative international initiative that involves multiple climate modelling groups worldwide. Its primary objectives are to enhance climate models, evaluate their performance, and generate robust projections of future climate change. By providing a standardized framework, CMIP6 facilitates simulations of past, present, and future climates under various scenarios.

One of the participating climate models in CMIP6 is NorESM2-MM (Norwegian Earth System Model 2 - Medium-resolution version, Seland et al., 2020), developed by the Norwegian Climate Centre. Climate models like NorESM2-MM employ a comprehensive approach to simulate the Earth's climate system, incorporating representations of various physical processes, including interactions between the atmosphere, ocean, land, and ice.

Through CMIP6, researchers gain access to a diverse range of climate model outputs, allowing them to explore and compare different model simulations. This collaborative effort contributes significantly to advancing our understanding of climate dynamics and the potential impacts of future climate change.

SHARED SOCIOECONOMIC PATHWAYS (SSP)

The pathways (O'Neill et al., 2017) described below are instrumental in exploring diverse potential futures for climate change, considering varying socioeconomic and policy decisions. Here is a summary of each scenario:

1. **SSP245** (Shared Socioeconomic Pathway 2.4 – "Middle of the Road"):

- Represents a future scenario with moderate efforts to mitigate greenhouse gas emissions and adapt to climate change.
- Involves a gradual transition to cleaner and more sustainable energy sources and technologies, leading to a moderate increase in global average temperatures by the end of the century.
- Socioeconomic development is moderate, emphasizing balanced economic growth and sustainable practices.
- Global population growth is relatively controlled, and there are improvements in education, health, and governance.
- The temperature increase associated with SSP245 is generally in the range of approximately 1.5°C to 2.5°C above pre-industrial levels by 2100.

2. **SSP370** (Shared Socioeconomic Pathway 3.7 – "Regional Rivalry"):

- Envisions a future where global efforts to mitigate climate change are limited, leading to high greenhouse gas emissions and less focus on sustainability.

- Fossil fuels continue to dominate the energy mix, resulting in a significant increase in global average temperatures by the end of the century.
- Socioeconomic development is fragmented and regionally focused, with less international cooperation on climate and environmental issues.
- Global population peaks and gradually declines, but there are substantial regional variations, and equitable development is challenging.
- The temperature increase associated with SSP370 is typically in the range of approximately 2.6°C to 3.7°C above pre-industrial levels by 2100.

3. **SSP585** (Shared Socioeconomic Pathway 5.8 – "Fossil-fuelled Development"):

- Represents a future scenario with high population growth, rapid economic development, and heavy reliance on fossil fuels.
- Greenhouse gas emissions increase substantially, leading to a significant rise in global average temperatures by the end of the century. This scenario corresponds to the highest emissions trajectory among the SSPs.
- Socioeconomic development is market-driven, with rapid technological progress that may not be sustainable from a climate perspective.
- Limited emphasis on environmental and climate policies results in increased pressure on ecosystems and natural resources.
- The temperature increase associated with SSP585 is generally in the range of approximately 3.3°C to 5.7°C above pre-industrial levels by 2100.

These scenarios provide critical insights into the potential outcomes of different climate actions and policy choices, guiding policymakers and researchers in understanding the implications of their decisions on future climate change and global warming.

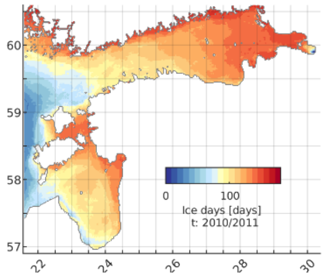
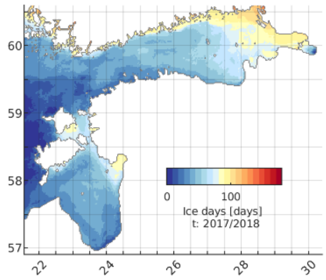
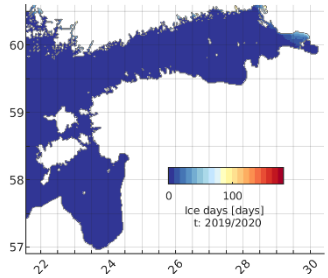
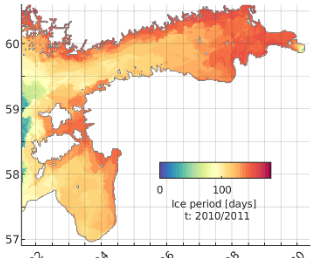
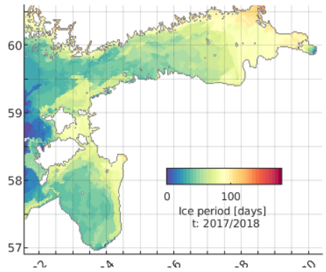
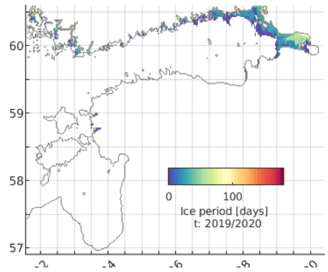
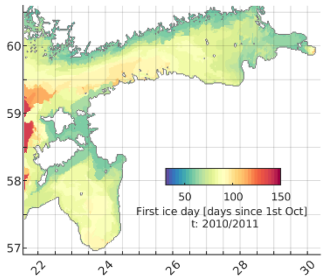
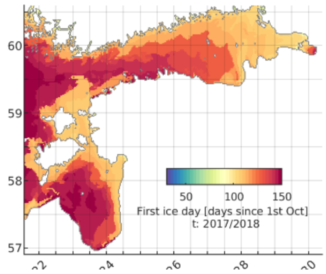
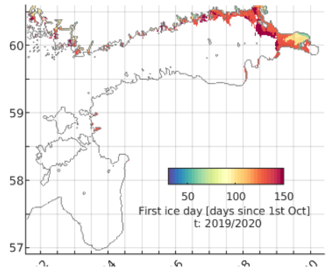
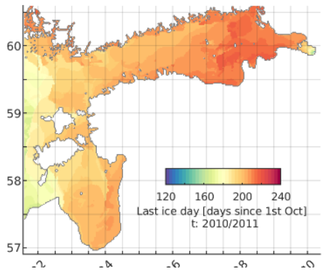
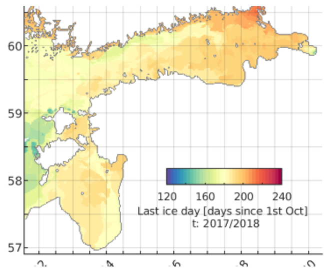
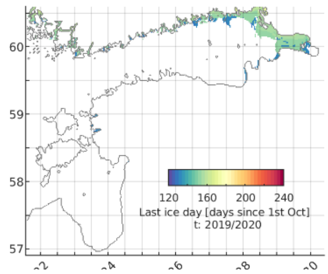
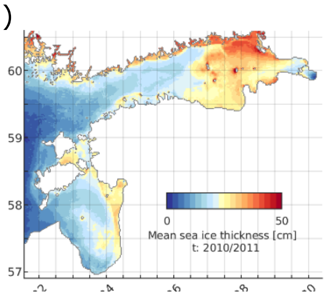
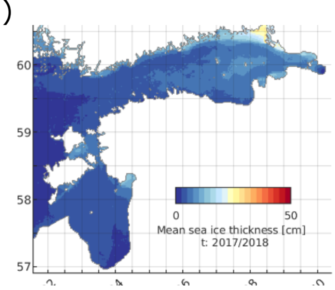
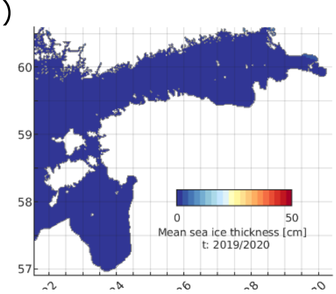
ICE CLIMATE PROJECTIONS

To assess climate scenarios accurately, a comparison cannot be made directly with the past reference climate (ERA5 for current study). Instead, it is necessary to compare them with the historical climate control period (ccp) of the respective climate model. Ideally, the past reference climate data should statistically match with climate model control period output.

To estimate the changes in occurrences of severe, average, and mild winters, firstly seasonal mean air temperature from the reference (ERA5) are utilized and compared with mean sea ice extent of the corresponding winters. Then the same is conducted for the air temperatures from climate model control period. Bias correction for climate model control data is carried out if needed. Lastly, climate projections can now be analysed as they have been put into the same reference system as past climate.

Table 11 provides examples of severe, average, and mild winter conditions, illustrating the criteria used to classify these different types of winters.

Table 11. Representative ice seasons for severe, average and mild winters: 2010/2011, 2017/2018 and 2019/2020 respectively. Ice days, period length, start of the season, end of the season and mean thickness as rows of the table

	2010/2011 – severe	2017/2018 – average	2019/2020 – mild
Ice days	a) 	b) 	c) 
Ice period length	d) 	e) 	f) 
Start of ice season	g) 	h) 	i) 
End of ice season	j) 	k) 	l) 
Mean ice thickness	m) 	n) 	o) 

In the study, the ERA5 dataset is utilized to represent the atmospheric climate reference conditions. Specifically, 2 m air temperature timeseries is extracted from the ERA5 dataset from the longitude 25.0 and latitude 57.95.

During the analysis, it was found that the mean air temperature demonstrated the most promising scaling results (correlation *r* = 0.92, RMSD = 0.34) when compared to the seasonal mean ice extent (Figure 26). These results indicate a strong correlation between mean air temperature and the seasonal mean extent of sea ice, providing valuable insights into the interplay between atmospheric conditions and sea ice dynamics.

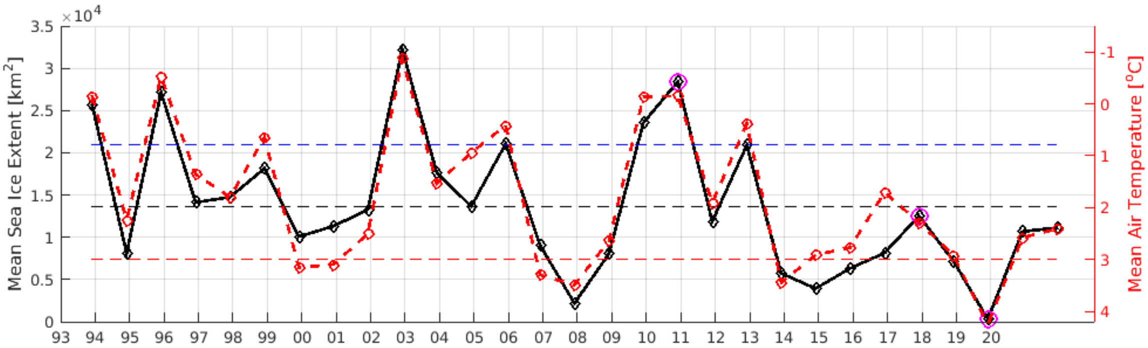


Figure 26. The seasonal mean ice extent (left axis) and the mean air temperature on the right axis (axis direction reversed). Characteristic severe, medium and mild winters of 2010/2011, 2017/2018, 2019/2020 are highlighted

Considering the high similarities between the patterns of 2 m temperature and sea ice extent (as shown in Figure 26), it is possible to estimate future ice extent based solely on temperatures from different climate projections. Figure 27 illustrates the seasonal mean 2m air temperature for the reference climate and various climate scenarios.

In the SSP370 and SSP585 scenarios, the temperature shows a linear growth trajectory until the end of the century, indicating a continuous warming trend. On the other hand, the mildest climate scenario, SSP245, suggests a slight decrease in 2m air temperature towards the end of the century.

For the current study, which aims to provide ice climate estimations until 2050, the differences between which climate scenario will unfold appear to be minimal. In each scenario, the 2 m air temperature can fall close to 0 degrees Celsius or lower, indicating severe or average winter conditions.

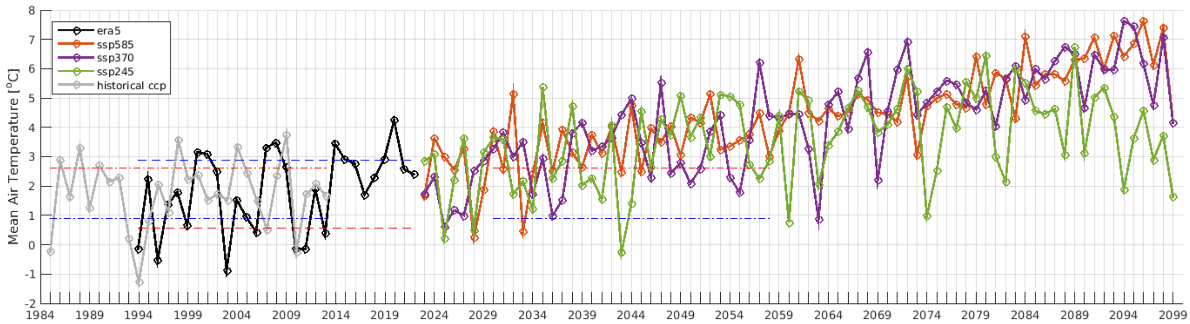


Figure 27. Seasonal mean 2 m air temperature for reference climate and for different climate scenarios

Table 12 concludes the changes in sea ice extent depending on the climate scenario. All scenarios predict a reduction in the occurrence of severe winters. As a result, severe winters are expected to be significantly less frequent. In the SSP370 and SSP245 scenarios, severe winters are evident, occurring up to the 2070s in SSP370 and likely towards the end of the century in the SSP245 scenario as well.

The increase in mild winters is more pronounced in the SSP370 and SSP245 scenarios, showing a rise of approximately 10%. However, the SSP585 scenario predicts a decrease in the frequency of mild winters by 7%.

The proportion of medium winters increases in all climate scenarios, with the most substantial rise observed in the SSP585 scenario. As the warmest climate scenario, SSP585 exhibits more extreme weather conditions, particularly at the beginning of the century when the climate experiences a significant shift. This implies that severe winters could also occur under these extreme weather conditions in warmer climate scenarios.

These findings suggest that the choice of climate scenario has implications for the frequency of severe, average and mild winters (Table 1, Table 2). Additionally, the warming trend observed in the SSP370 and SSP585 scenarios could lead to more pronounced shifts in climate patterns, impacting the occurrence of extreme weather events. Table 11 provides examples of severe, average, and mild winter conditions, illustrating the criteria used to classify these different types of winters. Ice period length (second row) also illustrates the ice extent of respective winter: any regions with more than zero ice days indicate the presence of ice in those winters.

Table 12. Share of severe, average, and mild winters for different set of scenarios and periods

Climate	**Share of winters [%]**					
	Severe	Average	Mild			
ERA5	21	59	21			
ccp	21	59	21	% Changes compare to ccp		
SSP585 (2030–2055)	3	79	17	-18	20	-4
SSP370 (2030–2055)	0	69	31	-21	10	10
SSP245 (2030–2055)	3	66	31	-18	7	10

WIND CLIMATE PROJECTIONS

There is growing concern that wind patterns are also changing with general climate change which in turn would change the ice dynamics. To assess changes in wind speed and direction, CMIP6 and ERA5 data is used. In the following figures black represents ERA5 wind speed data, blue represents the climate model control data. Green, red, and purple are SSP245, SSP370, and SSP585 pathways respectively.

Figure 28 represents projections for future wind speed conditions for different SSPs (average wind speed values are averaged again over five winters to reduce noise). There does not appear to be large trends in wind speed over the study area.

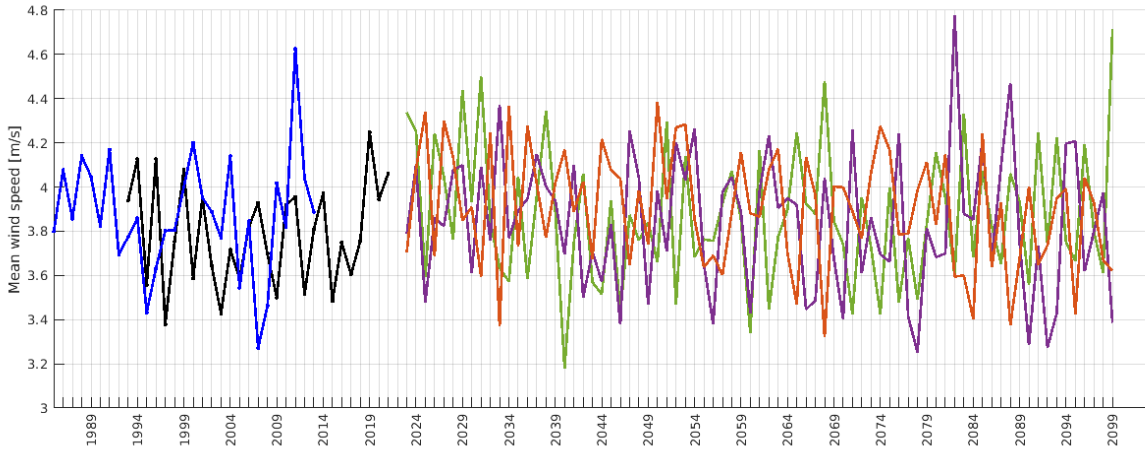


Figure 28. Black line represents ERA5 wind speed, blue line represents CMIP6 wind speed, green, red, and purple are SSP245, SSP370, and SSP585 pathways respectively. Note that wind speed values are averaged over five winter to make data more readable

Estimation of wind direction is even more challenging than wind speed. Figure 29 represents wind roses for ERA5 (black), climate model control (blue), SSP370 (red), SSP585 (purple), and SSP245 (green). It is clearly seen that there exists a mismatch in prominent wind direction between ERA5 (black) and climate model control (blue) wind directions. However, to accurately estimate wind patterns for different climate scenarios, the climate model control and ERA5 (for the current study) should statistically match. Therefore, comparing wind directions for different SSPs with climate model control values is not entirely accurately represented in real world. Note that data from global model (with much lower resolution of about 100km) is used which might not represent the local conditions correctly. Much deeper analysis or even local high resolution climate modelling is needed to answer these questions.

In terms of the wind directions, the control scenario indicates that the prevailing wind direction is southwest (SW). However, this changes noticeably in the various SSP scenarios. Under the SSP585 scenario, the wind direction shifts more to west (W), a trend that remains consistent in both the SSP370 and SSP245 scenarios. This collective shift highlights the alteration in prevailing wind patterns compared to the baseline control scenario. The data suggests a potential transition towards a more prominent westward wind direction across the SSP scenarios, signifying a noteworthy change in wind patterns that could have implications for local climate and weather conditions.

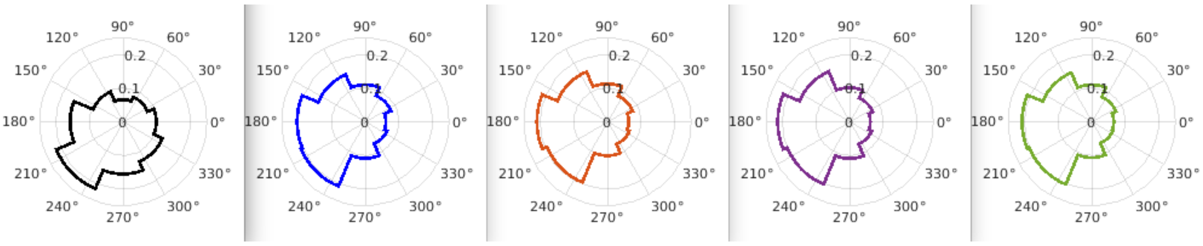


Figure 29. Wind roses for ERA5 (black), climate model control (blue), SSP370 (red), SSP585 (purple), and SSP245 (green). Note that directions are not in nautical convention

KEY TAKEAWAYS

No	Task/ question*	Answer
1	What are the impacts of climate change (more frequent storms and formation of conglomerated ice) on ice conditions in the Gulf of Finland and the Gulf of Riga?	As temperatures are projected to increase in all climate scenarios, both in the mid-century and beyond, we can anticipate a rise in the occurrence of average and mild ice conditions. Consequently, severe winters are expected to become significantly less frequent (about 3% of winters will be severe, 71% will be average, and 26% will be mild in the next coming decades). Nevertheless, it's important to note that under extreme weather conditions in warmer climate scenarios, there remains a possibility for severe winters to occur as well.

SOURCES & REFERENCES

Ringgaard, I., Korabel, V., Spruch, L., Lindenthal, A., Huess, V. Product User Manual, Tech. rep., Copernicus Marine Environment Monitoring Service, https://catalogue.marine.copernicus.eu/documents/PUM/CMEMS-BAL-PUM-003-011_012.pdf, 2023

Panteleit, T., Verjovkina, S., Jandt-Scheelke, S., Spruch, L., Huess, V. Quality Information Document, Tech., rep., Copernicus Marine Environment Monitoring Service, https://catalogue.marine.copernicus.eu/documents/QUID/CMEMS-BAL-QUID-003-011.pdf, 2023

Pemberton, P., Löptien, U., Hordoir, R., Höglund, A., Schimanke, S., Axell, L. and Haapala, J., 2017. Sea-ice evaluation of NEMO-Nordic 1.0: a NEMO–LIM3. 6-based ocean–sea-ice model setup for the North Sea and Baltic Sea. Geoscientific Model Development, 10(8), pp.3105–3123.

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., Thépaut, J-N. (2023): ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), DOI: 10.24381/cds.adbb2d47

Leppäranta, Matti, and Kai Myrberg. Physical oceanography of the Baltic Sea. Springer Science & Business Media, 2009.

Seland, Ø., Bentsen, M., Olivié, D., Toniazzo, T., Gjermundsen, A., Graff, L. S., Debernard, J. B., Gupta, A. K., He, Y.-C., Kirkevåg, A., Schwinger, J., Tjiputra, J., Aas, K. S., Bethke, I., Fan, Y., Griesfeller, J., Grini, A., Guo, C., Ilicak, M., Karset, I. H. H., Landgren, O., Liakka, J., Moseid, K. O., Nummelin, A., Spensberger, C., Tang, H., Zhang, Z., Heinze, C., Iversen, T., and Schulz, M.: Overview of the Norwegian Earth System Model (NorESM2) and key climate response of CMIP6 DECK, historical, and scenario simulations, Geosci. Model Dev., 13, 6165–6200, https://doi.org/10.5194/gmd-13-6165-2020, 2020.

O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., Van Ruijven, B.J., Van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M. and Solecki, W., 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global environmental change, 42, pp.169–180.

3. GOVERNANCE OPTIONS

3.1 INTRODUCTION

The assessment of governance options for providing necessary icebreaking services is produced in such a way that it provides a sound basis for decision-making. It provides an impartial expert assessment of the potential and realistic options available for Estonian Government in this matter, where the strengths and weaknesses as well as risks of the options or alternatives are weighted both in a qualitative and quantitative manner.

The Chapter comprises the following elements, which are coordinated with the other elements (Chapters) of the study.

1. Overview of potential governance options providing necessary icebreaking services based on key theoretical constructs and with practical international examples.
2. Outlining the governance options that could be considered possible and valid for managing and operating the Estonian icebreaking service and/or fleet and vessel(s).
3. Analysing the necessary administrative, management and other essential resources in the outlined governance options in view of Estonian icebreaking service needs.

It is based both on literary and documentary analysis as well as the long-term expertise of the authors in administration and governance of icebreaking services completed with interviews of key stakeholders and experts in Estonia, Finland and Sweden.

3.2 INTERNATIONAL COOPERATION IN ICEBREAKING IN THE BALTIC SEA REGION

MULTILATERAL TREATY ON ICEBREAKING COOPERATION BETWEEN THE NORDIC COUNTRIES FROM 1961

Already in 1961, Finland, Denmark, Norway and Sweden signed a treaty[1] on icebreaking cooperation. Its purpose is to facilitate the maintenance of shipping and promote maritime safety during the winter in the navigational waters of the Nordic countries through the cooperation of icebreakers and uniform regulations on icebreaker operations.

According to the original text in the 1961 treaty, Nordic icebreaker cooperation takes place in the North Sea, the Åland Sea between Sweden and the Åland Islands, the Baltic Sea north of Bornholm and in the Öresund, Kattegat and Skagerak. The contracting state must use all state-owned or leased icebreakers that are not necessarily needed for icebreaker operations in its own coastal waters for Nordic icebreaker cooperation.

[1] The version of the Treaty in Finnish is available here.

The icebreakers of the contracting state are primarily used for tasks in waterways bordering their own country. Regional cooperation is mainly organized, if necessary, between:

- Finland and Sweden in the Gulf of Bothnia, the Åland Sea and the northern Baltic Sea,
- Denmark and Sweden in the waterways in and south of the Öresund, in the Kattegat and in the southern part of the Skagerak, and
- Norway and Sweden in the northern part of the Skagerak.

BALTIC ICE MANAGEMENT (BIM)

Baltic Icebreaking Management (BIM), founded in 2003, is an organisation with members from all the Baltic Sea states. BIM is a result of the annual meetings of the Baltic states icebreaking authorities which have assembled for more than 25 years. After a difficult winter navigation season 2002/2003, a project was launched within the framework of HELCOM aiming at improving the safety of winter navigation in the Baltic Sea. The HELCOM Recommendation on the Safety of Winter Navigation in the Baltic Sea Area was adopted in March 2004.

The overall objective of BIM is to ensure a well-functioning, year-round maritime transport system in the Baltic Sea through enhancing the strategic and operational cooperation between the Baltic Sea countries in the area of winter navigation assistance.

The member countries of BIM are Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russia and Sweden. Since 2022, Russia has not participated in BIM's activities, and the network is currently somewhat dormant. BIM has issued 16 annual winter navigation reports since the winter period 2005–2006. The latest available edition is from period 2020–2021, and the reports are available here.

FINNISH-SWEDISH WINTER NAVIGATION RESEARCH BOARD SINCE 1972

In 1972, the Finnish and Swedish Maritime Administrations signed an agreement on cooperation in research related to technical conditions for winter navigation, named the Finnish-Swedish Winter Navigation Research program (WNRB). It is still overseen by the Finnish and Swedish authorities dealing with winter navigation.

The total annual budget is currently EUR 200,000, which is funded by equal shares between the two countries. The annual budget is used to fund 3 to 6 separate studies based on a competitive tendering. To date, WNRB has funded over 120 studies from Finnish or Swedish Universities, research institutions and consultants. The reports deal almost exclusively with applied and pragmatic real-world phenomena and target contemporary and needs-based issues as defined by the Board. They have a strong linkage to contemporary regulatory issues or technological challenges in winter navigation, including icebreakers and icebreaker operations. The reports can be accessed here.

Perhaps one of the most significant achievements of WNBR has been the support to the development of the so-called Finnish-Swedish Ice Class Rules (FSICR). The development of the rules began as early as the 1930s, and the rules have been amended several times during the past years, for example in 1971, 1985, 1999, 2003, 2010 and 2017. FSICR has become a worldwide standard in classification of ice-going vessels.

BILATERAL FINNISH-SWEDISH AGREEMENT ON ICEBREAKING COOPERATION SIGNED IN 2012

The aim of the agreement is to improve the availability of icebreakers and reduce waiting times and costs. The agreement deepens cooperation between Finland and Sweden in the planning and organization of winter shipping services. In this way, even in difficult icy winters, more efficient and economical icebreaking services are secured than at present.

The agreement will result in savings, as the closest breaker will assist ships regardless of their destination port. Because of this, the empty displacements of breakers and the resulting fuel costs and expectations are reduced. In the long term, the total costs of breaking ice in the contract area will be reduced, when the parties do not have to reserve equipment alone and independently to cope with the worst ice situations.

The contract is valid for 20 years until year 2032. The agreement requires Finland to have the capacity of five icebreakers. Four of these must be so-called Class A icebreakers and one Class B icebreaker. Finland has the breakers required by the agreement.

Cooperation has been carried out primarily in the Gulf of Bothnia, but during difficult ice winters also in the entire Baltic Sea basin to assist traffic to Finland or Sweden. The principles of the cooperation are as follows:

- Both reserve required icebreaking capacity
- Common management of the operations and assigning assistance via IBnet
- Common principles of setting restrictions and issuing dispenses based on HELCOM recommendations
- Common prioritization of winter navigation assistance
- Cost sharing principles.

BILATERAL FINNISH-ESTONIAN ICEBREAKING COOPERATION

A Memorandum of Understanding (MoU) was signed between Estonian and Finnish transport authorities on icebreaking cooperation in the early 2010s, but there is no formal agreement or treaty on this between the two countries. Discussions of the need of such have been going on with alternating intensity after the signing of the MoU.

In practice, no Estonian icebreakers have been used to assist winter navigation in Finland, nor Finnish icebreakers of Arctia Icebreaking Oy for assistance in Estonia. However, a Finnish-based company Alfons Håkans has deployed its sea-going large tugboats in Estonian waters already since the mid-1990s. The current contract with the Estonian government has a readiness fee of approximately 200,000 euros per year plus daily remuneration.

EU-FUNDED WINTER NAVIGATION PROJECTS WITH SWEDEN, FINLAND AND ESTONIA

Since the first Winter Navigation Motorways of the Sea project WINMOS I till 2015, WINMOS projects have aimed to ensure sustainable efficient maritime transports all year round and mitigate the barrier-effect caused by the sea ice by:

- Foreseeing possible changes in the future and analysing the impact on the winter navigation system and the requirements for icebreaking capacity;
- Working out proposals for different concepts and designs of icebreakers and composition of the icebreaker fleet that meet industrial and environmental demands on maritime transports;
- Reducing emissions from existing icebreakers;
- Modernisation of the existing Finnish-Swedish Icebreaking Management System (IBNet), and improving the accessibility to the information for all relevant stakeholders within maritime shipping;
- Developing training methods for navigation in sea ice; and
- Ensuring sufficient icebreaking resources.

Two WINMOS projects are completed, and the third one was granted Connecting Europe Facility (CEF) funding in July 2023:

- WINMOS I (till end-2015), budget EUR 139 million, of which EUR 29.6 million was received from TEN-T's Motorways of the Seas
  - Lead Partner: Swedish Maritime Administration; other partners Finnish Transport Agency, Finnish Meteorological Institute, Aalto University, Novia University of Applied Sciences (Finland), ILS Ship Design & Engineering (Finland), Image Soft Ltd., Aker Arctic Technology Inc. (Finland) and **Estonian Maritime Administration**
- WINMOS II (2016–2019), the budget was EUR 19 million, of which EUR 6.6 million was funded by the CEF
  - Lead Partner: Finnish Transport Infrastructure Administration (FTIA); other partners Swedish Maritime Administration, Arctia Icebreaking Ltd., Aalto University, Novia University of Applied Sciences (Finland), ILS Ship Design & Engineering (Finland), and **Estonian Maritime Administration**
- WINMOS III (2023–2027) project with budget about EUR 186.9 million, of which approximately EUR 30 million was funded by the CEF
  - Majority of the funds will be used in connection to the new Swedish icebreaker to be completed in 2027
  - Lead Partner: Swedish Maritime Administration, other partners FTIA (Finland's share of the budget EUR 2.9 million), and **Estonian Transport Administration** as an associated partner

Sweden is also planning to apply for financial assistance for its second new icebreaker from the EU's new Military Mobility program. Its next application expires on Sept. 21, 2023, where a total of EUR 790 million will be distributed. If Sweden is successful in its application, substantial funding might be available from this program also to Estonia, should it decide to procure new icebreakers.

EUROPEAN MARITIME SAFETY AGENCY (EMSA) AND ITS ROLE IN THE BALTIC SEA REGION

EMSA is not active in icebreaking operations or cooperation, but it is engaged in oil recovery arrangements in ice conditions. It has occasionally organized tenders for providing these services for a period of 4 years (maximum two consecutive contracts are possible). Multipurpose icebreakers may be used for these purposes, provided they are equipped with necessary equipment and capacity.

In EMSA's latest 5-year strategy 2020–2024, the Agency has a goal to Intensify pollution prevention activities by building Member State capacity and developing practical guidance and tools for the wider maritime cluster.

EMSA's role in oil pollution response is to offer a range of services to help coastal States around Europe respond quickly, effectively, and efficiently to oil or chemical marine pollution incidents from ships and oil and gas installations. The services offered by EMSA can be described as a "toolbox" from which the requesting State can pick and choose the most suitable response means. Through these services, EMSA aims to complement and top-up existing response resources at national and regional level.

EMSA has established a network of stand-by oil spill response vessels through contracts with commercial vessel operators. EMSA's contracted vessels have been specifically adapted for oil spill response operations and are on stand-by, carrying out their usual commercial activities.

In the event of an oil spill, the selected vessel will cease its normal activities and will be made available to the requesting party fully-equipped for oil spill response services under established terms and conditions and tariffs. Following a request for assistance, the maximum time for the oil spill response vessel to be ready to sail is 24 hours.

Regardless of their area of commercial operations, all vessels in the EMSA network can be mobilised for response to an oil spill anywhere in European waters and shared sea basins. EMSA covers the costs of fitting the commercial vessels with oil recovery equipment and tools. The average individual oil storage capacity of EMSA's contracted vessels is approximately 3,600 m^3.

Each of EMSA's contracted vessels has the following characteristics:

- Speed of 12 knots for prompt arrival on scene as well as low speed manoeuvrability for response operations
- On-board capability to decant excess water thereby maximising the use of on-board storage capacity
- Large storage capacity for recovered oil
- Ability to heat recovered cargo and use high capacity pumps to facilitate the discharging of heavy viscous oil mixtures to facilities ashore

- Oil slick detection system to facilitate the positioning of the vessel in the thicker oil slicks, and to enable operations at night.

All vessel arrangements comprise of two different containment and mechanical recovery options available for response operations depending on the weather conditions and type of pollutant:

- Sweeping arms
- Ocean-going booms and an offshore skimmer (on certain vessels there are also high-capacity skimmers and weir booms available).

To analyse the suitability of current Estonian vessels to take part in EMSA tenders for oil recovery arrangements in ice conditions goes beyond the scope of this study. It can generally be said that MPSV Botnica might, in principle, be suitable provided it is fitted with the necessary equipment and required storage space. The same applies for any potential future vessel(s) used in or procured for Estonian icebreaking.

3.3 OVERVIEW OF GOVERNANCE OPTIONS FOR ICEBREAKING SERVICES

A starting point in considering the available options for providing necessary partly or wholly publicly funded icebreaking assistance and related services, is to assess the:

i) nature of the provided service;

ii) volume of service events, and the corresponding capacity needed to provide these services;

iii) the geographical coverage of service needs; and

iv) the predictability of these needs.

NATURE OF THE PROVIDED SERVICE

This study deals exclusively with services that are provided to assist winter navigation of commercial vessels in ice-infested maritime fairways or routes outside seaports. Seaports that need icebreaking within the port area have their own or contracted port tugs or smaller icebreakers. Sea-going icebreakers enter port areas only in exceptional cases.

The services under study comprise several elements, such as:

- icebreakers that maintain navigable routes and assist commercial vessels by escorting a convoy or towing an individual vessel to reach their destination in ice-infested waters,
- rules, procedures and oversight systems to ensure navigational safety in ice-infested waters in view of ice conditions, including setting minimum technical requirements such as the ice class of vessels eligible for assistance,

- operational system of assigning icebreakers to dedicated regions and routes, and operating the ship-shore-icebreaker communication efficiently so that the available icebreakers can assist vessels in the best possible manner in view of traffic situation and ice conditions, and
- ownership and management of icebreakers and icebreaker fleets.

While essential in providing winter navigation assistance, icebreakers need also these other components to be able to provide smooth services to shipping companies and ultimately also to shippers.

OVERVIEW OF ICEBREAKERS IN THE WORLD FLEET

In 2016, a total of 22 countries had vessels which could be labelled as icebreakers in one way or the other. This listing naturally excludes ice-classed merchant vessels[2]. Of the listed 152 operational vessels in 2016, 92 were categorized as icebreakers built for and engaged primarily in icebreaking and escort operations (Aker Arctic 2016). Approximately 60 per cent of all active icebreakers in the world have been built and 80 per cent designed in Finland.

The largest fleet of the 92 listed icebreakers in operation in 2016 was in Russia (52), followed by Finland (8), Canada (7) and Sweden (5).

Estonia had two icebreakers in this listing: the government owned I/B Tarmo and MPSV Botnica owned by the TS Shipping OÜ (Port of Tallinn). They are both used in the Gulf of Finland. EVA 316, now in State Fleet Agency fleet together with I/B Tarmo, was categorised as "Other". She is used in the Gulf of Riga. Examples of vessels used for icebreaking services in the Baltic Sea region in Figure 30.

The remaining 40 vessels out of the list of 152 vessels were primarily engaged in offshore operations, including ice management operations, 11 were research vessels engaged primarily in scientific missions, and 9 were other vessels such as salvage or naval ships.

[2] In the world fleet, there were about 2,100 merchant vessels with a Finnish-Swedish ice class of IA or IA Super (the two highest classes), and about 120 IA or IA Super newbuildings under construction in autumn 2022. Of the total, about 40% were dry bulk vessels, 23% chemical or product tankers, 17% container vessels, and 11% ro-ro or ro-pax vessels. The remaining 9% were crude oil or gas tankers.

Figure 30. Examples of vessels used for providing icebreaking services in the Baltic Sea region.

Top left: M/V Hermes, an icebreaking Anchor Handling Tug Supply (AHTS) vessel, owned and operated by Alfons Håkans, LOA = 71.5 m, Beam = 16.0 m, Built = 1983; Flag = Cyprus; photo = Alfons Håkans

Top right: motorised bow Saimaa, owned by FTIA. Built for and operated originally in Lake Saimaa with a tugboat by Alfons Håkans, but moved to Eastern Gulf of Finland in 2022. Beam = 12.6 m, Built = 2020; Flag = Finland; photo = FTIA. This novel solution might be suitable also for Gulf of Riga

Bottom left: MPSV Botnica, owned by TS Shipping (Port of Tallinn) and contracted to Transpordiamet, LOA = 97.3 m, Beam = 24.3 m, Built = 1998; Flag = Estonia, photo = ESTOFENNIA

Bottom right: IB Polaris, owned and operated by Arctia Icebreaking Oy, LOA = 110.0 m, Beam = 24.0 m, Built = 2016; Flag = Finland; photo = Arctia

VOLUME OF SERVICE EVENTS AND THE CORRESPONDING CAPACITY NEEDED

The volume of service events depends greatly on vessel traffic volume, length of fairways and routes to be assisted and the severity and length of ice conditions during the winter. This is then reflected in the corresponding icebreaking capacity needed. (Figure 31)

Accordingly, Russia has the overwhelmingly largest icebreaking fleet in the world given the length of its ice-infested coastline especially in the Arctic Sea. Also its Baltic Sea ports in eastern Gulf of Finland are very important gateways for Russia’s maritime trade. After Russia, also Finland and Sweden need extensive icebreaking services.

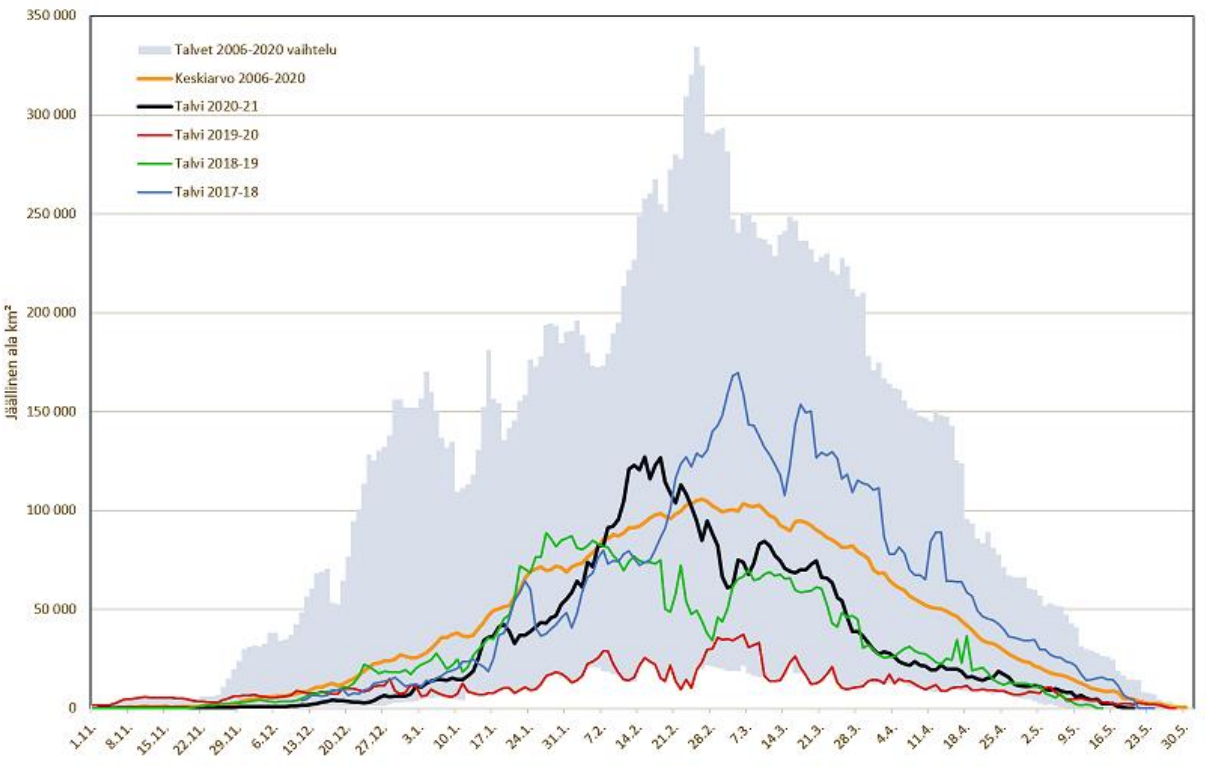


Figure 31. The extent of ice coverage in the Baltic Sea during recent winter periods in km². (Source: Finnish Transport Infrastructure Administration (FTIA) 2021)

The variation in the severity of the winter is naturally reflected in the number of icebreakers engaged, which is illustrated in Figure 32. It shows that in a "normal" period as in 2020–2021, Sweden and Finland engaged up to 9 or 10 icebreakers during the peak weeks, and the duration of the entire period was 20 weeks in both countries, whereas Estonia employed MPSV Botnica (built in 1998; 97.3 meter long and 24.3 meter wide) and a smaller I/B Tarmo (built 1963, 84 meter long and 21 meter wide) for 14 weeks.

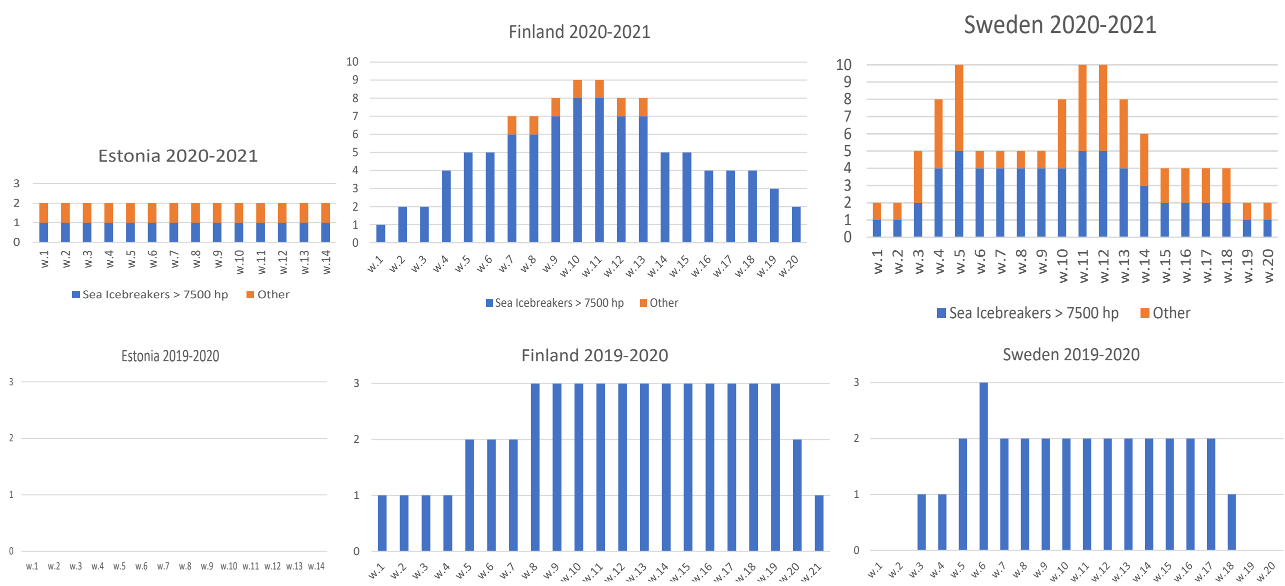


Figure 32. The number of icebreakers engaged in Estonia, Finland and Sweden during the seasons 2019–2020 and 2020–2021. (Source: BIM 2020 and 2021)

During a mild winter period 2019–2020, Estonia did not have to employ icebreakers at all. Both Finland and Sweden had maximum three icebreakers assigned; Finland for a consecutive 12 weeks, but Sweden only during one week. The entire period lasted for 21 weeks in Finland and 16 weeks in Sweden. Ice coverage on the Estonian coast is analysed in more detail in Chapter 2.

GEOGRAPHICAL COVERAGE OF SERVICE NEEDS

In the Baltic Sea, the operational area for Finnish icebreakers comprises both the Gulf of Bothnia[3], Archipelago Sea between Åland Islands and mainland Finland and the Gulf of Finland. For Sweden, the needs are mainly in the Bay of Bothnia.

During a rather typical ice winter 2021, for example, the sailing distance from ice edge during maximum ice extension to the northernmost ports in Bay of Bothnia was about 200 NM, and about 100 NM in ice thicker than 15 cm (Figure 33).

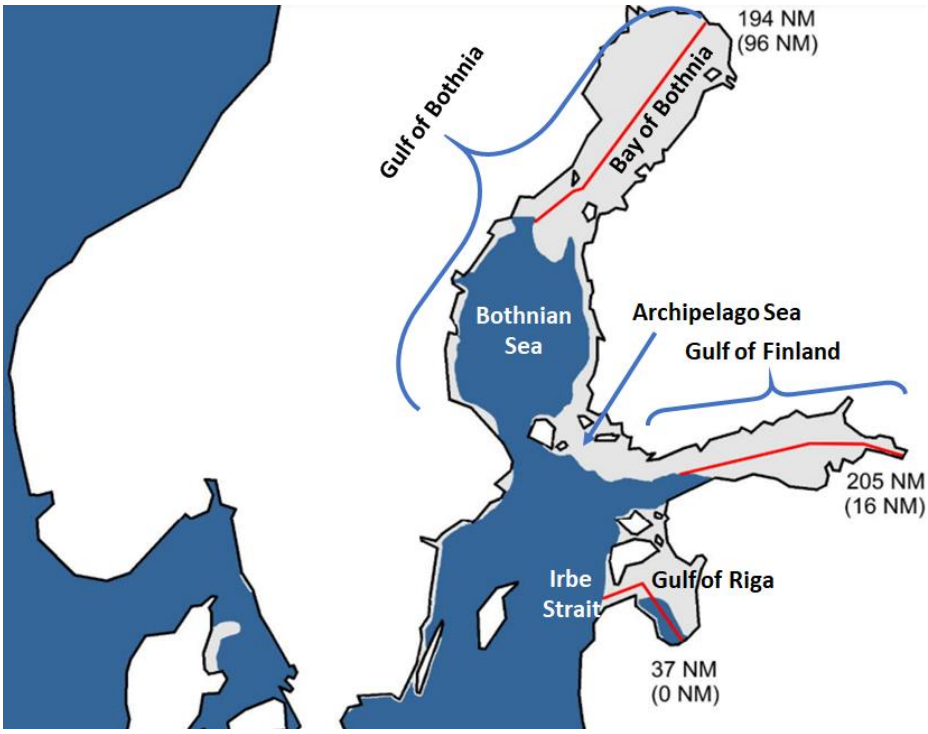


Figure 33. Selected sailing distances in nautical miles (NM) from ice edge during maximum ice extension on 15th of February 2021, which as an average ice year. The figures in parenthesis refer to ice over 15 cm thick. Based on: Finnish Meteorological Institute, data available here

Annual variations in the ice coverage can be very large. Since 2003, the widest coverage (309,000 km^2) occurred in 2010–2011, when the sailing distance to Riga was 206 NM and to Kemi 565 NM from ice edge during maximum ice extension. The smallest coverage

[3] The Gulf of Bothnia (Pohjanlahti) is divided into i) the Bay of Bothnia (Perämeri) roughly north of Vaasa and ii) Bothnian Sea (Selkämeri) south of Vaasa to the Åland Islands.

(37,000 km²) was in 2019–2020, when there was ice only in the Bay of Bothnia. (Figure 34)

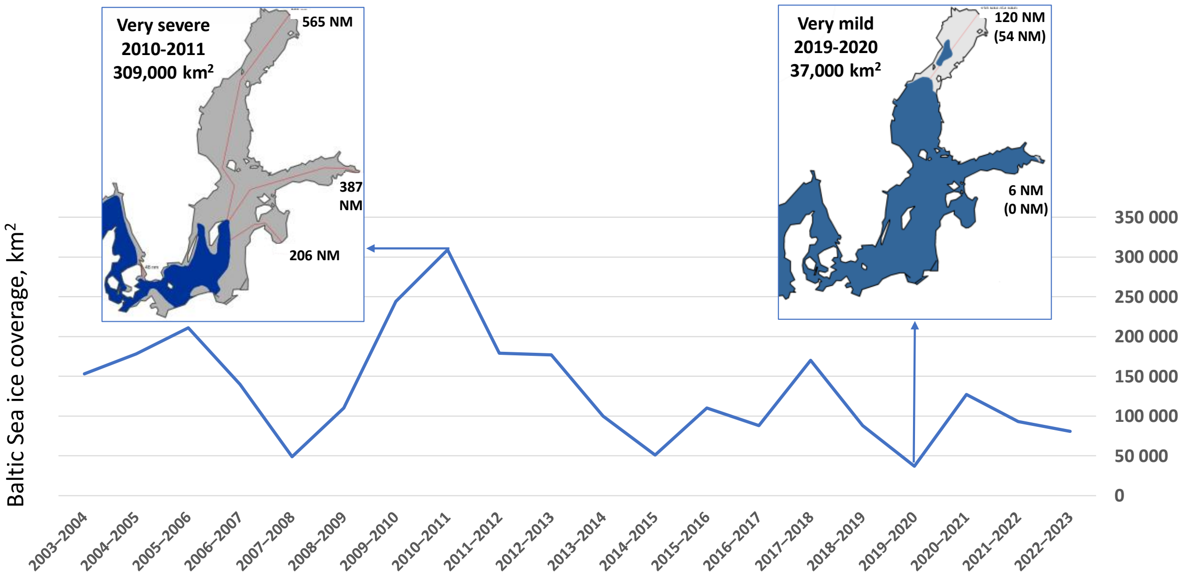


Figure 34. The Baltic Sea ice coverage in 2003–2023 in km², and maps for the most severe and mild ice years. Selected sailing distances in nautical miles from ice edge during maximum ice extension. The figures in parenthesis refer to ice over 15 cm thick. Based on: Finnish Meteorological Institute, see here

The two separate regions in Estonia, where ice breaking assistance may be needed are ports in the Gulf of Finland, and those in the Gulf of Riga area, such as Pärnu, Kuivastu, Virtsu and Roomassaare.

In the Gulf of Riga in 2021, the sailing distance from ice edge during maximum ice extension to Riga was about 40 NM, all of which was in ice under 15 cm of thickness. The distance to port of Pärnu was even longer (Figure 33).

The ice period in Pärnu is usually longer than in the Estonian Gulf of Finland ports, because it lies in a bay and a river estuary, where sweet water freezes easier than more saline sea water. The effect of wind to dispel ice is also much weaker in a secluded bay than at sea.

PREDICTABILITY OF ICEBREAKING NEEDS

As shown in Figure 31, there are large variations from one year to another as to the extent of ice coverage. Also weather conditions affect the need for icebreaking assistance, especially when the ice coverage moves by wind and/or sea currents.

Especially during the end of the winter ice period, the formation of pack ice and slush may cause very severe ice conditions for merchant vessels and for icebreakers too. Thus, even during a rather "mild" winter, the demand for icebreaking assistance may occasionally be high. This is particularly true along the Finnish coast in the northernmost parts of Bay of Bothnia, as the prevailing wind direction is westerly. This means that several meters high ice ridges can start to form. A similar phenomenon may also happen in the Gulf of Riga area, albeit in smaller scale.

Overall, the predictability of ice formation and the need for icebreaking assistance varies significantly from country to another and from one year to another. Generally speaking, Estonian ports rarely witness very harsh ice conditions.

The situation for Swedish and Finnish ports especially in the Bay of Bothnia is much more challenging, because formation of packed ice and even several meter high ice ridges are common. This happens particularly on the Finnish coast, since the predominant wind direction is westerly. During the last weeks of the winter season, the melting ice turns into a slush, which can severely affect the vessels propulsion, i.e. the forward pushing force of the propellers. On the other hand, ice conditions are rather predictable in Bay of Bothnia, because it is covered with ice during all average and even during most mild winters.

Practically every winter, 1,000 to 2,000 assistances are performed to and from Finnish ports and slightly less to Swedish ports in the Bay of Bothnia (see also Figure 36).

In addition, the frequent ferry and vessel traffic in Port of Tallinn and also in Muuga mean that the fairway is largely kept open by this traffic. The situation is different in less frequently visited ports in the Gulf of Finland. In addition to north-south direction, there are also needs to maintain east-west fairways navigable. In the Gulf of Finland, Estonia, Finland and Russia have set up a mandatory ship reporting system in the Gulf of Finland, GOFREP (Gulf of Finland Reporting). The system covers the international waters of the Gulf of Finland east of the western reporting line especially for east-west traffic. In addition, Estonia and Finland have implemented this mandatory ship reporting system in their territorial waters outside their VTS areas.

Estonian ports in Gulf of Riga have shallower fairways and are visited by smaller tonnage, which means that the need of icebreaking services is significantly different than in the Gulf of Finland.

ESTONIAN, FINNISH AND SWEDISH ICEBREAKING VOLUME AND COSTS

Winter navigation assistance needs in Estonia differ substantially from those in Sweden or Finland in terms of predictability, duration, coverage and capacity of the needed services in any one year. This is illustrated in Figure 37.

In Estonia, the period within which icebreaking services are needed is shorter than in Finland or Sweden. There are also years, when icebreaking services outside Estonian port are not needed at all, such as in 2019–2020 (Figure 32). This is also reflected in the annual costs for icebreaking services borne by the Government. In Finland it varies from 40 to 65 million euro depending on winter, and from 20 to 40 million euro in Sweden. In Estonia, the cost is typically between 5 to 7 million euro (BIM 2020 and 2021).

ESTONIA

In Estonia previously, the annual cost of icebreaking in Estonia has remained between 5-7 million euros (BIM 2022), but in recent years it has increased to approx. 8 million euros. Fairway due income has varied a lot: in 2004–2012, it was at around EUR 10 million, and in 2013-2019 it rose to EUR 15 to 20 million. COVID-19 and related decisions to temporarily cut the dues had a significant impact on fairway due income, which sank to

EUR 4.7 million in 2020, but has since bounced to EUR 8.2 million in 2022; see Figure 35. Also the rapid diminishing of Russian transit cargoes has affected fairway dues.

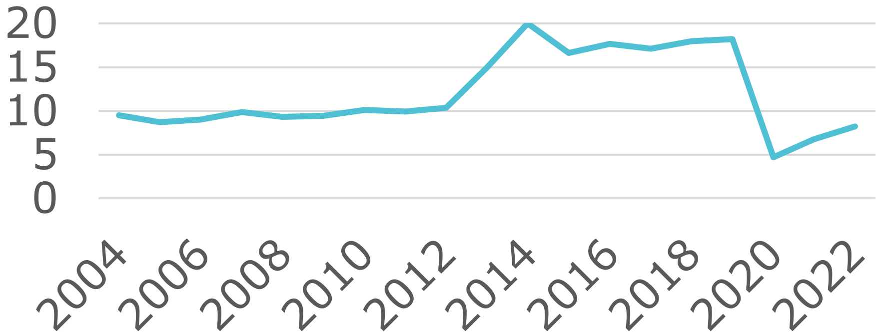


Figure 35. Fairway due income in Estonia 2004–2022 in EUR million. (Source: Estonian Ministry of Finance)

FINLAND

About 75% to 80% of Finland's icebreaking costs can be covered with fairway due revenue, but also other fairway maintenance tasks are covered with these revenues. When these other tasks are accounted for, the cost coverage varies from 45% to 55%. Since 2015, the annual income from fairway dues in Finland has been approximately 45 million euro, when actual costs for icebreaking services have been between 40 to 65 million euro.

Before 2015, annual fairway due revenue was between 80 to 90 million euro. The significant drop in 2015 was due to the government decision to compensate for the anticipated rise in shipping costs, when IMO's new sulphur emission rules (SECA) became effective in the Baltic Sea.

Table 13 provides some financial data on Finnish icebreaking operations. A more detailed cost structure is not available from government sources, except for fuel costs. In 2022, icebreakers fuel costs paid by FTIA were about EUR 12.9 million, which was about EUR 5.7 million higher than in 2021, and about EUR 10.1 million higher than in 2021. The large variations are mainly due to differences in the severity of ice winters in addition to changes of fuel prices.

Table 13. Income and expenses of activities covered by faiway dues in Finland, EUR million. (Source: State budgets for 2020–2024 and FTIA financial statements for 2021 and 2022)

	2020	2021	2022 (Target)	2022 (Actual)	2023 (Budget)	2024 (Estimate)
Revenues						
Fairway due revenue	46,7	44,7	47,8	51,7	45,0	51,0
Other income	1,6	0,8	0,3	0,9		
Total income	**48,3**	**45,5**	**48,1**	**52,6**		
Total cost						
Total separate costs (incl. icebreaking)	74,3	92,9	84,0	103,8		
Share of total joint costs	15,1	4,3	4,7	5,0		
Total costs as a whole	89,4	97,2	93,7	108,8		
Surplus (+) / Deficit (-)	-41,1	-51,7	-45,6	-56,2		
Cost coverage of all activities under Fairway Due Act	**54 %**	**47 %**	**51 %**	**48 %**		
State budget allowance for icebreaking services to FTIA	*64,0*	*62,0*	*60,0*	*n.a.*		
Fairway dues % of allowance for icebreaking in the state budget	*75 %*	*73 %*	*80 %*	*n.a.*		

Usually, over 80% of all operational days and the number of assistances of Finnish icebreakers take place in the Bay of Bothnia. This is illustrated in Figure 36 for the period 1996–2012, where the large variations depend on the severity and length of ice winters.

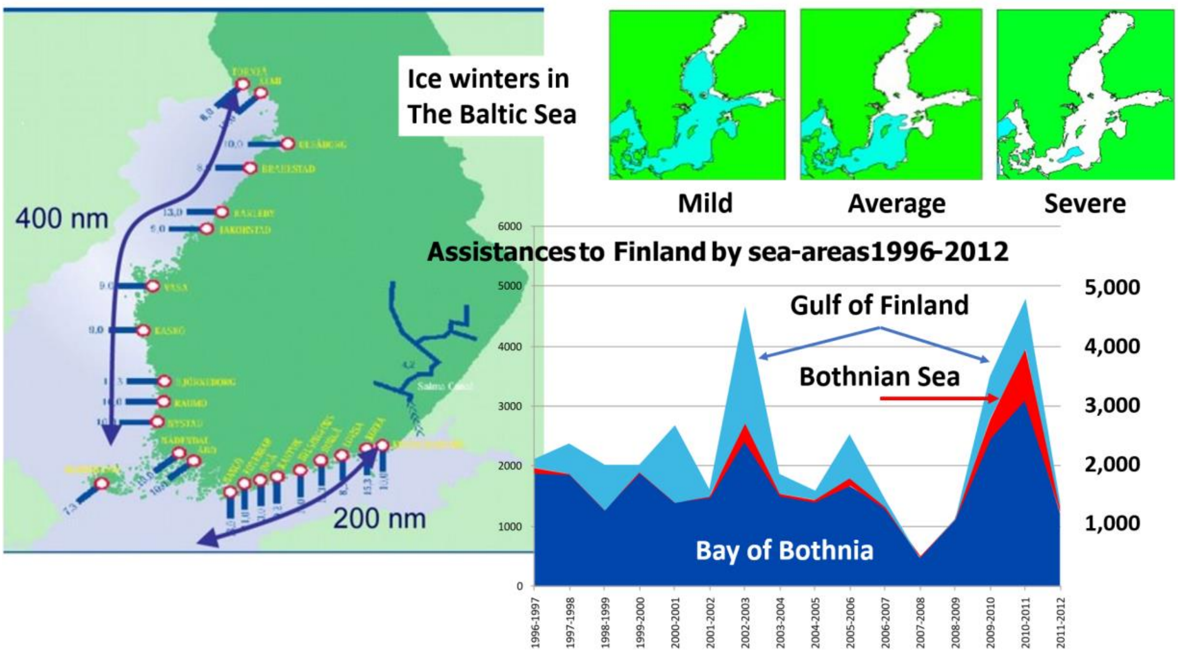


Figure 36. Icebreaker assistances to Finnish ports by sea area in 1996–2012. (Source: FTIA)

Cost structure of Arctia Icebreaking is somewhat more detailed (Table 14). During a mild winter, Arctia provides all of required icebreaking services in Finland. In a severe winter this share can be 80%; the rest relies on the Swedish-Finnish cooperation or is procured from the private sector.

Table 14. Income statement figures of Arctia Icebreaking Oy, which is the icebreaking subsidiary in Arctia Oy. (in EUR million). (Source: Finder.fi)

Arctia Icebreaking Oy	2022	2021	2020	2019
Turnover ('000 €)	47 467	43 998	43 258	43 603
Change of turnover in %	7,9 %	1,7 %	-0,8 %	-3,1 %
Operating margin in %	33,3 %	36,4 %	35,2 %	32,7 %
Operating profit ('000 €)	2 403	2 903	8 402	7 482
Operating profit in %	5,1 %	6,6 %	19,0 %	17,2 %
Result for the financial year ('000 €)	37	2 382	1 959	14
Personnel	206	191	180	173

Arctia Oy is a non-listed commercial company wholly owned by the state, and it is overseen by the Ownership Steering Department of the Prime Minister's Office. However, it is not entrusted with special state assignments, unlike, for example, pilotage company Finnpilot Pilotage Oy or Traffic Management Finland Oy, which manages road, rail and shipping (VTS) traffic.

Arctia's business operations are divided into three operative areas: 1) icebreaking, 2) fairway maintenance and 3) hydrographic surveying. The two latter ones were incorporated into Arctia in 2019, when another state-owned company Meritaito Oy merged with Arctia Oy.

Arctia's Board has currently six members, which are nominated by the Prime Minister's Office. One of the Members represents the Ownership Steering Department, while the other five are experienced business professionals and come from commercial and/or other state-owned firms. As a state-owned company, Arctia is also subject to governance and Corporate Responsibility auditing done by the National Audit Office of Finland (see e.g. Corporate Responsibility Audit conducted by VTV in 2020).

SWEDEN

Key financial data on Swedish icebreaking services provided by Swedish Maritime Administration (SMA) is shown in Table 15. SMA owns and operates the five Swedish icebreakers, which are used within the Baltic Sea. IB Oden is occasionally chartered out for scientific missions outside the winter period. More detailed cost structure of Swedish icebreaking operations is not available.

Table 15. Income and costs of icebreaking operations in Sweden (in SEK million). (Source: Swedish Maritime Administration annual report (Årsredovisning) for 2022)

	2022	2021	2020
Direct operating income	**in SEK million**		
Allowance	40	-	-
Other external income	66	85	58
Total direct operating income	**106**	**85**	**58**
Direct operating costs			
Personnel costs	-28	-25	-33
Other external costs	-314	-319	-274
Depreciation	-21	-21	-17
Total direct operating cost	**-363**	**-365**	**-324**
Profit before indirect operating items	-257	-280	-266
Indirect operating costs	4	8	4
Indirect operating income	-34	-39	-42
Operating result	-287	-311	-304
SEK to EUR at the end of the year	*0,090*	*0,097*	*0,100*

All of Sweden's icebreaking costs can be covered by fairway dues collected from commercial shipping in international traffic. In Sweden, fairway due income for 2023 is expected to reach about 100 million euro, while costs for icebreaking services are between 20 to 40 million euro. (SMA 2022, Merkel and Vierth 2022 and BIM 2022).

LATVIA

Data on icebreaking costs is not available for Latvia. Icebreaking in the port of Riga and the Gulf of Riga to Irbe Strait or Cape Kolka is done with the I/B Varma (LOA = 86.5 m, breadth = 21.2 m, built in Finland in 1968; sister ship of I/B Tarmo) and Foros (LOA = 71.6 m, breadth = 18.0 m, built in Finland in 1983).

These are owned by limited liability company SIA "LVR Flote". Company's sole shareholder is Freeport of Riga Authority, which is fully owned by the Government of Latvia. LVR Flote was established on 13 September 2010. (LVR Flote 2023)

ON FAIRWAY DUE COLLECTION IN ESTONIA, FINLAND AND SWEDEN

The competent authorities of collecting fairway dues are Transpordiamet[4], Finnish Customs and Swedish Maritime Administration, respectively. While the principle of collecting fairway dues from vessels entering territorial waters is similar in the countries applying these dues, the basis of calculating them differs between Estonia[5], Finland and Sweden.

[4] From 1 January 2023 to 31 December 2023, all ships arriving at an Estonian port or the roadstead of an Estonian port are exempted 37,5% from paying fairway dues. The exemption is granted to all ships irrespective of type and the flag flown by the ships. (See here)

[5] According to Chapter 11 "Fairway dues" in the Estonian Maritime Safety Act (see here): "Fairway dues are dues for navigational organisation, and the use of icebreaking and information services on public waterways, as well as for the use of the infrastructure installed on public waterways to ensure maritime safety"

Only about half a dozen EU countries collect fairways dues, because in most other countries, fairways are easier to maintain with few or no islands, and no winter navigation.

Apart from the type and size of the vessel and the number of entries per year, Estonia and Finland also use vessel's ice class as a criterion for the dues. In Finland, the difference in dues between the highest and the lowest ice class is very substantial, but rather small in Estonia. Sweden, on the other hand, emphasizes the vessel's environmental impact, and uses a so-called Clean Shipping Index (CSI) scores as an important component to determine fairway dues. Other fairway due components in Sweden are the volume of goods or passengers and a security of supply charge.

By comparison, there are about 75,000 annual ship calls in international traffic in Sweden, but less than 10,000 of these are in the Gulf of Bothnia ports north of Stockholm, where icebreaking is needed practically every winter. The corresponding total number is about 30,000 in Finland and about 10,000 in Estonia. (Merkel and Vierth 2022, Ojala et al. 2023 and Statistics Estonia 2023)

KEY PERFORMANCE INDICATORS (KPIS) OF ICEBREAKING ASSISTANCE

The three Key performance indicators (KPIs) of icebreaking assistance are as follows:

- Average waiting time on icebreaker assistance
- Availability (open ports)
- Availability (ship received assistance without waiting time)

It is important to note that the average waiting time KPI is calculated only for those vessels that are actually assisted. In a mild winter almost all vessels manage to sail without assistance, as has been the case in 2020–2022 in Sweden, Finland and Estonia.

ICEBREAKING ASSISTANCE KPIs IN ESTONIA

In Estonia, the KPI on waiting time for vessels requiring icebreaking service is 72 hours. The actual performance of icebreaking assistance in Estonia in 2018–2022 is shown in Table 16.

Table 16. Key performance indicators (KPIs) for icebreaking in Estonia in 2018–2022. (Source: Transpordiamet, Juhtkonnapoolne ülevaatus 14.04.2023)

	2018	2019	2020	2021	2022
Gulf of Finland	Up to 4 hours	0 hours	No icebreaking assistance needed		
Gulf of Riga	Up to 48 hours	Up to 4 hours	No icebreaking	Up to 4 hours	Up to 4 hours

ICEBREAKING ASSISTANCE KPIs IN SWEDEN

Swedish Maritime Administration has three key performance indicators (KPIs) for icebreaking, as shown in Table 17. KPI on average waiting time on icebreaker assistance is max. 4 hours, which is the same value used also in Finland. Also the KPI on ship receiving assistance without waiting time is set at 90% both in Sweden and Finland.

Table 17. Key performance indicators (KPIs) for icebreaking in Sweden in 2020–2022. (Source: Swedish Maritime Administration annual report for 2022)

	Target	Achieved in 2022	2021	2020
Average waiting time on icebreaker assistance	Max. 4 hours	2 h 54 min.	2 h 24 min.	2 h 36 min.
Availability (open ports)	100 %	99.9 %	99.9 %	100 %
Availability (ship received assistance without waiting time)	90 %	98.4 %	99.0 %	99.4 %

ICEBREAKING ASSISTANCE KPIs IN FINLAND

KPI on average waiting time on icebreaker assistance is max. 4 hours, which is the same value used also in Sweden. Also the KPI on ship receiving assistance without waiting time is set at 90% both in Finland and Sweden.

In Finland, the average waiting time for icebreaking assistance was 3.7 hours in 2022, which increased slightly from the previous year's winter due to the challenging conditions, so the 4.0 h target required by the service level promise was achieved. The completion rate of vessels that were assisted within the target (max. 4.0 h waiting time) remained at the level of the previous year, at 95.5%. The target (90%) was exceeded.

Although winter period 2021/2022 was classified as mild, it was challenging for icebreaking operations e.g. due to packed ice. In addition, the big icebreakers had quite a few technical problems, some of which were long-lasting.

Operational icebreaking assistance days overseen by FTIA were 888 in 2022 (710 in 2021 and 325 in 2020). Of these, 177 days were performed in 2022 by other service providers than Arctia Icebreaking; in 2021 that number was 83 and in 2020 only 3.

Arctia Oy performed almost 2,100 icebreaking assistances in 2022 in Finland, while the number was about 1,500 in 2021, 700 in 2020, and about 1,700 in 2019. Seven of its eight icebreakers had 627 operational icebreaking days in 2021, while the number was 322 days in 2020 and 547 days in 2019, respectively, which reflects the large variations in the severity of winters (Arctia 2022; see also Appendix 1 and Appendix 2 on Arctia).

ESTONIA, LATVIA, SWEDEN AND FINLAND IN VIEW OF WINTER NAVIGATION ASSISTANCE NEEDS

In summary, winter navigation assistance needs in Estonia and Latvia differ markedly from those in Sweden and Finland. This is illustrated in Figure 37, which takes into account the

- Predictability of IB assistance needs,
- Predictability of geographical coverage of ice and
- Needed icebreaking capacity.

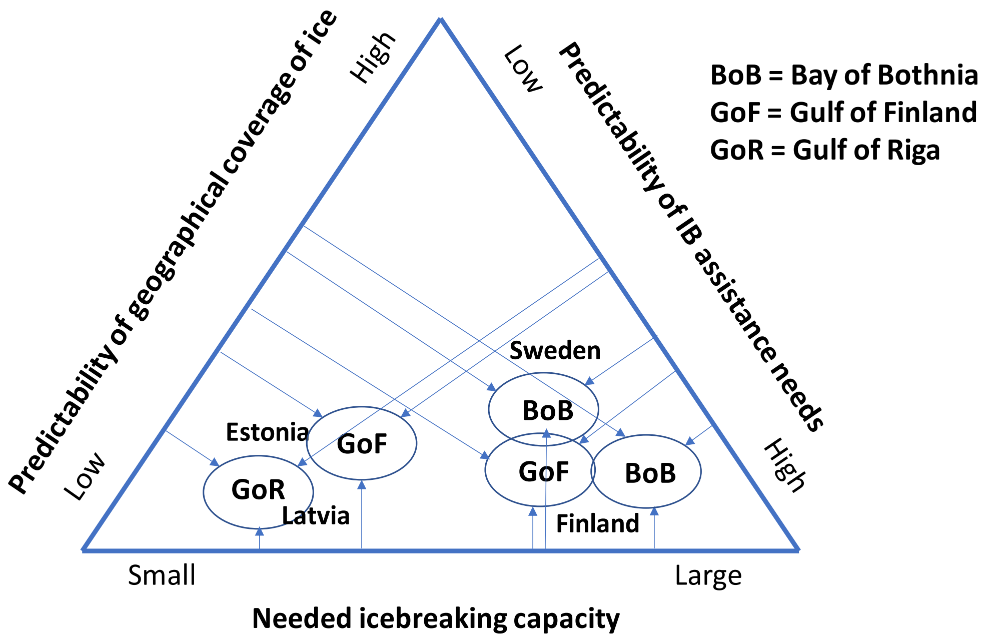


Figure 37. Positioning Estonia, Latvia, Sweden and Finland in view of volume and predictability of their winter navigation assistance needs.

The graph uses indicative and generic scales from Low to High and Small to Large. As shown with the numbers of icebreaking assistance and related annual costs, the needs are the highest in Finland, where the annual costs are typically two times higher than in Sweden and about ten times higher than in Estonia.

NOTIONS ON THE AVAILABILITY OF SECOND-HAND ICEBREAKERS

The Estonian Transport Administration has recently signed a 10 year contract with TS Shipping OÜ for the provision of icebreaking services and navigation in the Gulf of Finland in the period 20.12.2022–20.04.2032. This service is provided with MPSV Botnica, as in the previous 10-year charter agreement, annually from December 20 to April 20. (Port of Tallinn 2021)

The total estimated cost of the agreement is EUR 54.2 million, i.e. EUR 5.4 million per year or about EUR 44,600 per day. From the 2025/2026 working period, the contract fee may be indexed with the Estonian consumer price index, but not more than 3% annually. The contract fee is fixed, i.e. the Transport Administration pays for all charter days, regardless of the actual use of the icebreaker. (Port of Tallinn 2021)

Thus, the core of service provision in the Gulf of Finland has already been procured till year 2032, because MPSV Botnica has been the main Estonian icebreaker in this region, while the 60 year old I/B Tarmo has been the secondary provider. The main question is how to replace this capacity in the future.

The situation is less tight with smaller icebreakers or vessels with a necessary icebreaking capacity that could be used in shallower fairways in the Gulf of Riga, where ice is also considerably thinner than in Gulf of Finland. Within 10 years, there is also a need to replace EVA 316 or to provide additional capacity with seagoing tugs with or without a loose motorized bow like (see Figure 30). The suitability of such a solution to sea conditions would require further testing, as the stationary ice conditions in Lake Saimaa differ a lot from sea conditions, where the ice is moving.

The worldwide fleet of icebreakers is very small. This also means that the market for available large sea-going icebreakers suited for winter navigation assistance in Gulf of Finland is very limited. However, the on-going procurement process in Sweden for two new icebreakers to be delivered by the end of this decade might make the currently used vessels (such as Ymer, Atle and Frej, all built in Finland in mid-1970s) available for sale within 5 to 7 years. If Finland initiates a newbuilding process of its own within the next few years, a similar possibility might arise also with existing Finnish icebreakers.

One option for Estonia is to study the possibility to purchase one or some of these vessels in the future. Another option could be an arrangement, where Estonia would procure the necessary winter navigation assistance during peak demand weeks as a service from existing Finnish or Swedish service providers without having to invest in and manage an icebreaker of its own. One problem with peak demand is that also Finnish and Swedish icebreakers may be fully occupied during this time.

The third, and most expensive but also a much more long-term, option would be to procure a newbuilding to replace I/B Tarmo. A new icebreaker could be in use well into the 2070s or longer.

In conclusion, the most imminent decision towards the end of this decade in Estonia is how to best replace the winter navigation assistance capacity provided by I/B Tarmo.

3.4 OUTLINE OF GENERIC GOVERNANCE OPTIONS FOR ESTONIAN ICEBREAKING SERVICES

KEY GOVERNANCE CONSIDERATIONS IN VIEW OF WINTER NAVIGATION ASSISTANCE NEEDS

The most important task of well-functioning icebreaking services is to secure smooth commercial shipping to a country’s seaports in ice-infested waters. Whether the Government decides to order a newbuilding, purchase a second-hand icebreaker or procure the service from an external provider, or come up with a combination of these, key governance considerations revolve around a) funding of the assets or the service; b) inter-agency cooperation between Ministries and Government agencies; and c) how to manage the process and the ensuing operations. (Figure 38)

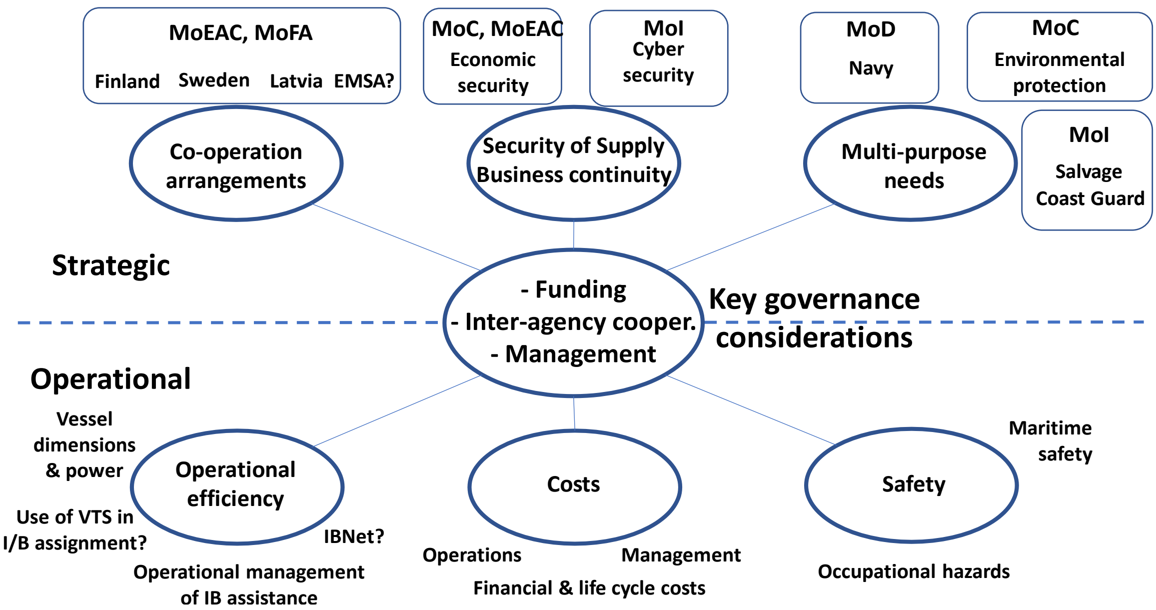


Figure 38. Key governance considerations and strategic & operational issues when deciding on long-term winter navigation assistance needs

MoC = Ministry of Climate; MoD = Ministry of Defence; MoEAC = Ministry of Economic Affairs and Communications; MoFA = Ministry of Foreign Affairs; MoI = Ministry of Interior

As outlined in Figure 38, the three key considerations a) to c) are linked to more strategic level and long-term issues, such as:

i) co-operation arrangements especially with neighbouring countries Finland, Latvia and Sweden;

ii) Security of Supply needs to ensure uninterrupted maritime services to and from Estonia, which is also linked to concerns on business continuity of icebreaker service provision; and

iii) decisions on other tasks that icebreakers should be able to perform with the various multipurpose capabilities and equipment required for these tasks. These are particularly valid questions when deciding on a new icebreaker.

Of the more operational issues, especially iv) arrangements to ensure high operational efficiency and effectiveness are crucial. These require good cooperation between Government agencies that fall under separate Ministries, and also with external service providers, such as TS Shipping.

Other operational governance issues include, for example, the possibility to use Estonian VTS[6] staff and capacity more widely in assigning icebreakers to specific assistance tasks. A related issue are the costs and benefits for Estonia should it join the Finnish-Swedish

[6] Vessel traffic services are shore-side systems which range from the provision of simple information messages to ships, such as position of other traffic or meteorological hazard warnings, to extensive management of traffic within a port or waterway. Estonian VTS in managed by Transpordiamet.

icebreaker information system IBNet[7]. These questions, such as v) safety issues both at sea and on land will be discussed separately later on in the study.

Finally, a central decision parameter is vi) costs. These refer to operational costs, be they charter fees, fuel, manning or other daily running costs. Other important cost categories are financial and life cycle costs of the assets. As evidenced by the now 60 years old I/B Tarmo, with proper maintenance, icebreakers can stay in service very long. Given the high price of new[8] or even second-hand icebreakers, and their very long life cycles, also financial arrangements need to be made carefully. Also available funding sources for critical transport infrastructure investments e.g. from the EU need to be identified especially for a newbuilding.

In addition to these, also the costs of the overall management of the winter navigation assistance system need to be considered. These depend largely on the number of people employed in managing and running the system, but they include also various hardware and software costs.

KEY GOVERNANCE CONSIDERATIONS IN VIEW OF ESTONIAN ICEBREAKER CAPACITY IN 2023

In July 2023, all Government-owned vessels and boats of e.g. Coast Guard, Police, Customs and pilotage belong to the State Fleet Agency fleet, except for naval vessels. The prevailing decision is that all new vessels ordered or procured by the state will come under State Fleet Agency ownership, including any potential new icebreakers.

Allocation of icebreaker service capacity is currently handled by Estonian Transport Administration irrespective of ownership of the icebreakers. The agency is under the Ministry of Climate.

OUTLINE OF GENERIC GOVERNANCE OPTIONS FOR WINTER NAVIGATION ASSISTANCE IN ESTONIA

This section presents generic governance options for Estonian icebreaking services and winter navigation assistance, which are subsequently assessed against factual evidence. These options are closely linked to the discussion above on key governance considerations, and can be divided into three main types, each with more detailed variations, as follows:

1. The Estonian Government procures an icebreaker either as a newbuilding or second-hand vessel, and manages the operation itself.

2. The Government engages in a Public-Private- type of arrangement in provision of the necessary winter navigation assistance.

[7] IBNet contains information about the weather, ice conditions and traffic situation, and transmits the information between the different connected units (icebreakers, coordination centres, VTS etc.).
[8] It is difficult to estimate the cost of a new icebreaker, because it is determined by many factors, such as the dimensions, level of equipment and choice of propulsion system(s) of the vessel, and where and when it would be constructed. However, a rough order of magnitude for a 100 meter long new icebreaker is approximately EUR 100 million or more.

3. The Government procures the necessary winter navigation assistance from a commercial provider without engaging in ownership, manning or technical management of the vessel.

In each of the three options presented above, the key elements for the Government to consider are the following:

a) Financing of the vessel(s) or the procured service

- The rough order of the magnitude of a newbuilding investment is EUR 100+
- Price of a second-hand vessel depends greatly on the age, size and condition of the vessel, but is easily tens of millions of euros; as a reference, the price of then 14 years old MPSV Botnica was EUR 50 million in 2012[9]
- For procured service, one indication is for MPSV Botnica's annual charter fee from EUR 5.6 million. Depending on the nature and length of an icebreaking or winter navigation service contract, the annual cost is single-digit millions of euros

b) Ownership of the vessel(s)

- Vessel owner is held liable for the damages caused by the vessel in case of accidents, so the owner must ensure sufficient knowledge of the responsibilities, including access to necessary legal expertise in case of litigation
- A state-owned vessel is subject to different regulation under International (Maritime) Law than a commercial vessel. This may affect the usage of a state-owned vessel in certain situations, such as entering another state's territory

c) Maintenance of the vessel(s), which comprises two central elements:

- Technical maintenance, including vessel and liability insurance, (dry)docking, running maintenance and repairs, inspections and classification of the vessel(s) and related reporting responsibilities
- Safety management and maintaining a sound safety culture in the operations both on land and onboard the vessel(s), including compliance to binding Flag State and relevant international regulations such as ISM and ISPS
- Manning of the vessel(s), and ensuring professional standards of the crew.

d) Operating the vessel(s) to ensure efficient use of the assets

- Managing the contracts for bunkering the vessel, which is the most important component of the vessel's running costs

[9] Another reference for a second-hand ocean-going icebreaker is the USD 150 million (approx. EUR 135 million) the US Coast Guard estimates to need to purchase an existing commercial icebreaker to bridge the gap of delay in its newbuilding delivery. The amount is very high partly due to the legal restriction that US government vessels should be built in the United States. Furthermore, Jones Act, also known as the Merchant Marine Act of 1920 law requires that all cargo or passenger ship transport between domestic U.S. ports be on U.S. flagged vessels.

- The navigational responsibility relies always with the Captain and the crew of the vessel(s)
- The direction of how and where to use the vessel(s) in best possible manner is supposed to come from a competent authority, i.e. a government agency, now Transpordiamet.

GENERIC GOVERNANCE OPTIONS FOR WINTER NAVIGATION ASSISTANCE

Table 18 presents possible governance options for providing winter navigation assistance, in which the Government and external service providers can assume various roles. These options are assessed in more detail for Estonia in Chapter 3.3, but examples of the options in other countries are presented below.

The fully governmental option 1. is used, for example, in Sweden, Denmark, Canada and the U.S. The Swedish Maritime Administration (SMA) has full responsibility of the five Swedish icebreakers from ownership to maintenance, manning and operations. The home port of these icebreakers is Luleå in northern Bay of Bothnia. SMA is also the national competent authority in overseeing winter navigation assistance and responsible also for operational assignment of icebreakers.

Table 18. Generic governance options for winter navigation assistance

Option	Type or note	Vessel		c) Maintenance, safety and manning			d) Operating the vessel(s)*
		a) Financing	b) Ownership	Technical maintenance	Safety management	Manning	Navigational responsibility
1. Fully governmental operation		Gov:t agencies finance, own, maintain and operate the vessel(s)					
2. Public-Private-arrangements	2 a) Time chartering to an external service provider (SP)	Gov:t agencies finance, own and maintain the vessel(s)					SP
	2 b) Bareboat chartering to an external service provider	Gov:t finances and owns the vessel(s)		An external service provider maintains and operates the vessel(s)			
	2 c) Theoretically possible, but a risky option for the Government.	Gov:t finances the vessel(s)	The vessel is owned and operated by an external service provider; a highly trusted partner and a mutual long-term committment is required				
3. Procuring the service from the market either short or long term	3 a) A fully state-owned company	The vessel is financed, owned and operated by the provider of icebreaking and winter navigation assistance services					
	3 b) A company, where the state has a majority ownership						
	3 c) A fully privately owned commercial company						
	3 d) A company, where the state has a minority ownership						

*) Bunkering of the vessel is part of operating duties, but the cost of bunker is usually separately negotiated between the Gov:t and SP

The two larger Danish icebreakers, the 75 meter long Danbjørn and Isbjørn are both built in the mid-1960s. They belong to the Danish Navy. The 65 meter long expeditionary icebreaker Thorbjørn is privately held.

In Canada[10], icebreaker operations on the coast and in the Great Lakes are run by the Coast Guard. US Coast Guard (USCG) has currently one Polar Class icebreaker, the 121 meter long Coast Guard Cutter Polar Star commissioned in 1976, and a 128 meter long medium icebreaker Coast Guard Cutter Healy, commissioned in 2000.

USCG is in process of ordering or planning to order up to six new open-sea icebreakers, but the new Polar Security Cutter is unlikely to enter into service before 2027, a delay from the original 2024. USCG is now looking to purchase an existing commercial icebreaker for USD 150 million (approx. EUR 135 million) to bridge the gap (High North News 2023).

Public-private options 2 a) through 2 c) refer to cases, where state-owned icebreakers are chartered out for shorter or longer periods. These assignments could also be outside actual winter months, as icebreakers can be used to support also cable laying, platform or wind park construction, for example (See Box 1 for more detail).

[10] See more at: https://www.ccg-gcc.gc.ca/icebreaking-deglacage/program-programme-eng.html

Box 1. Overview of offshore markets in view of multi-purpose icebreakers

Offshore segment is a heterogenous and volatile part of shipping markets, where various types and sizes of Offshore Supply Vessels (OSV) or Service Operation Vessels (SOV) are used.

Definitions of OSV and SOV vessels or markets can differ, but generally they refer to Anchor Handling Tug Ships (AHTS), Platform Supply Vessels (PSV), Standby & Rescue Vessels, Crew Vessels servicing offshore platforms, and various other offshore survey and exploration vessels. Also heavylift vessels may be used in offshore operations, for example as wind turbine installation vessels (WTIVs; see examples from e.g. Wärtsilä).

These purpose-built or specialized vessels perform tasks related to, for example, oil or gas platforms, cable laying, wind parks or other offshore construction projects.

Offshore Supply Vessel market size and development

According to Fortune Business Insights, a consultancy, the global OSV market is projected to grow from USD 14.5 billion in 2021 to USD 23.6 billion by 2028. The market is dominated by 4-5 global service providers with fleets up to 40 large sea-going SOVs with annual revenue in the tune of USD 3 to 5 billion.

The big providers are capable of signing also long-term contracts up to 10 years or more with several SOVs, such as the 10+3 year and approximately EUR 100 million contract of four vessels in a large North Sea wind mill area (see e.g. the UK-based North Star Shipping).

There is also room for small, nimble and cost-efficient "niche" providers, but their assignments are typically project-based with limited long-term visibility of the demand.

Over the past decades, offshore markets have been turbulent, as demand for services in oil and gas field construction as well as cable-laying have faltered. At the same time, a large number of new or retrofitted older vessels have entered the market, creating oversupply of SOVs and OSVs (Markets and Markets 2023). Lately, wind farm construction has generated new demand, where also multi-purpose icebreakers could be used.

In 2022, about 60% to 70% of global SOV capacity was used in wind farm activities, where the North Sea is overwhelmingly the largest market. Oil & gas activities took up 10% to 20% of the capacity, while 10% to 15% of vessels were off hire, that is available, but without a contract. Less than 5% of SOVs were under modification, maintenance or laid up (Spinergie 2023).

The Finnish experience

Finnish multipurpose icebreakers MPSV Fennica and MPSV Nordica built in 1993 and 1994, respectively, for the Finnish Maritime Administration was largely motivated by the possibility to utilize opportunities in the offshore markets. However, their commercial success remained smaller than expected. The disappointing experience is linked, among others, to the significantly higher crew costs of Finnish icebreakers than, for example, in an Estonian one.

Today, MPSV Fennica and MPSV Nordica owned and operated by Arctia Icebreaking Ltd are rather old and ill-suited vessels for most offshore duties compared with the existing newer ones in the market. During the past 2–3 years, they have not been chartered out for multipurpose functions.

In August 2023, Arctia Icebreaking Ltd announced that it had signed a contract for an annual charter for the 2023 to 2025 shipping seasons with the Canadian firm Baffinland Iron Mines Corporation. The contract covers icebreaking services with one multipurpose icebreaker. The chartering will not affect Arctia's icebreaking capacity in the Baltic Sea, as the operations will be completed prior to Finnish ice breaking season. Botnica has been contracted for similar tasks by the same client in 2018-2022.

The Estonian experience

Over the past years from June to the end of October, MPSV Botnica has been assisting Panamax-size merchant vessels in the Canadian Arctic in the export of iron ore from the port of Milne Inlet to the high seas. She has also been deployed in European wind farm construction sites (Port of Tallinn 2021 and interviews).

The conditions in the Canadian Arctic are demanding due to prevalence of very hard multi-year ice, for example. Operations in these waters cause much more wear and tear to the vessel and its hull than the conditions in the Gulf of Finland. This can shorten the economic life-time of the vessel and over time cause higher than expected maintenance and repair costs.

Conclusion

The ability to operate in this challenging market over time requires highly skilled and business-minded management and active outreach to prospective customers. This also means that commercial operation of a multipurpose icebreaker cannot be effectively run by a government agency. Instead, it requires a commercially oriented company and management with appropriate incentives.

For a small multipurpose vessel provider, customers are often large OSV service providers, who may need sub-contracted inputs in their assignments, but may also be large industrial or minin firms with activities in the Arctic. In order to stay in this business, skilled crews and well-maintained vessels are naturally needed too.

In summary, the offshore market is a very volatile and high-risk business segment, especially for small providers. The predictability of demand is low, and the visibility of future contracts is seldom longer than 1 to 2 years. Compared to the investment needs and the long lifetime of vessels, this is a very short period.

In other words, caution is required when offshore activities are included in profitability and cost calculations for a multi-purpose icebreaker with an economic life time of 50+ years.

Option 2 a) can also be used for short-term icebreaking assistance from one country to another, such as in the case when Swedish icebreakers are deployed in Finnish (or in exceptional cases in Estonian) waters. It is conceivable that also Estonian icebreakers could be used to assist traffic in Finland, or *vice versa*. This would require an agreement between the countries on mutual icebreaking services, where the legal form is not necessarily a formal chartering contract.

Option 3 a) is used in Finland and Latvia. The Finnish icebreaking fleet previously held by the Finnish Maritime Administration (FMA) was first transferred into a new state-owned enterprise Finstaship in year 2004. It became the owner, manager and operator of this fleet together with the staff previously employed by the FMA. Finstaship was subsequently turned into a 100 per cent state-owned limited liability company Arctia Shipping Oy in 2010, now Arctia Ltd. (Oy). Home ports of Arctia's icebreakers are Helsinki and Kotka in the Gulf of Finland.

In Latvia, icebreaking is done by SIA "LVR Flote" with I/B Varma (sister ship of I/B Tarmo) and Foros (built in Finland in 1983). SIA "LVR Flote" is a subsidiary of Freeport of Riga Authority, which, in turn, is fully owned by the Government of Latvia.

In addition to Option 1 a), also Options 3 b) and 3 c) are used in Estonia. The state has a majority stake in the stock-listed Port of Tallinn, to which TS Shipping OÜ belongs. It owns MPSV Botnica, which provides icebreaking services in the Gulf of Finland, including Muuga Harbour, harbours of Tallinn and Kopli Bay, Paldiski North and South, Kunda and Sillamäe Harbours under a 10 year contract with Transpordiamet. In practice, MPSV Botnica is mainly assisting traffic to ports of Sillamäe and Kunda.

In 3 c), private service providers, such as sea-going tugs of Alfons Håkans Ltd. with which the Estonian government has a readiness contract, are occasionally used in winter navigation assistance in Gulf of Riga.

Options 2 c) and 3 d) are hypothetical ones, so they will be left out in subsequent discussion.

3.5 GOVERNANCE OPTIONS FOR WINTER NAVIGATION ASSISTANCE IN ESTONIA

Based on the generic governance options for winter navigation assistance presented in, the current situation in Estonia with the remaining other potential options is shown in Table 19.

The Fully governmental operation (Option 1) is divided here into three variants, where the current arrangement is exemplified in Option 1 a). Option 1 b) envisages the sitation, where the Government decides to order a newbuilding or a second-hand icebreaker from the markets.

In 2023, the newly established State Fleet Agency took ownership of all other government-owned vessels and crafts, except for larger vessels previously belonging to the Estonian Border Guard, which were transferred to Estonian Navy. These include smaller vessels such as as the 45-meter-long Raju, the 36 meter long Pikker, but also the 63.9 meter long Kindral Kurvits, which is capable also of pollution contol tasks.

Table 19. Basic governance options for winter navigation assistance in Estonia

<table>
<tr><th rowspan="2">Option</th><th rowspan="2">Type or note</th><th rowspan="2">Assigning the vessel(s)</th><th colspan="2">Vessel</th><th colspan="3">c) Maintenance, safety and manning</th><th>d) Operating the vessel(s)*</th></tr>
<tr><th>a) Financing</th><th>b) Ownership</th><th>Technical maintenance</th><th>Safety management</th><th>Manning</th><th>Navigational responsibility</th></tr>
<tr><td rowspan="2">1. Fully governmental operation</td><td>1 a) Current arrangement</td><td rowspan="8">Transpordiamet</td><td rowspan="4">Government</td><td colspan="5">Riigilaevastik (RL) vessels Tarmo and EVA 316</td></tr>
<tr><td>1 b) Gov:t purchases a new or used icebreaker</td><td colspan="5">The new vessel would go to Riigilaevastik</td></tr>
<tr><td rowspan="2">2. Public-Private-arrangements</td><td>2 a) Time chartering to an external service provider (SP)</td><td colspan="4">Riigilaevastik</td><td>SP</td></tr>
<tr><td>2 b) Bareboat chartering to an external service provider</td><td>RL</td><td colspan="4">External service provider</td></tr>
<tr><td rowspan="4">3. Procuring the service from the market either short or long term</td><td>3 a) A fully state-owned company or state agency</td><td colspan="6">In use in Finland (Arctia Oy) and Latvia (LVR Flote)</td></tr>
<tr><td>3 b) A company, where the state has a majority ownership</td><td colspan="6">TS Shipping as a service provider with a 10 year contract on Botnica in the Gulf of Finland</td></tr>
<tr><td>3 c) A fully privately owned commercial company</td><td colspan="6">This option has been used for short term peak demand assignments with e.g. Alfons Håkans in Gulf of Riga</td></tr>
<tr><td>3 d) A company, where the state has a minority ownership</td><td colspan="6">Not applicable</td></tr>
</table>

*) Bunkering of the vessel is part of operating duties, but the cost of bunker is usually separately negotiated between the Gov:t and SP

[shaded box] = Shaded fields indicate an option currently used in Estonia

The main options in Table 19 are populated in Table 20 with an assessment of the current situation in Estonia. This assessment provides the basis for a more detailed analysis, with is completed with interviews of key stakeholders.

Table 20. Governance options for winter navigation assistance in Estonia

<table>
<tr><th colspan="2">Option</th><th colspan="2">1. Fully governmental operation</th><th>2. PPP option</th><th colspan="3">3. Procuring the service from an external provider either short or long term</th></tr>
<tr><th colspan="2">Governance considerations</th><th>1 a) Current set-up with IB Tarmo and EVA 316</th><th>1 b) Purchase of a new or used icebreaker</th><th>2 a) T/C or 2 b) B/B out to a service provider</th><th>3 a) A fully state-owned company or state agency</th><th>3 b) State majority ownership; TS within the T/C period</th><th>3 c) Privately owned company</th></tr>
<tr><td colspan="2">Co-operation arrangements</td><td>Managed by TA (MoTC) or RL (MoC)</td><td>Managed by RL and TA with MoC and MoTC</td><td rowspan="11">As long-term solutions, options 2 a) and 2 b) are rather risky. As a short-term solution, these options may be utilised during off-season periods. These short-term contracts may also be a possibility in option 1 b)</td><td colspan="3">Managed by TA and MoTC / MoC</td></tr>
<tr><td colspan="2">Security of Supply and business continuity</td><td>Secure service provider; only two vessels</td><td>Secure service provider</td><td>Secure, if from FIN or SWE</td><td>Secure service provider</td><td>Limited risks in short term</td></tr>
<tr><td colspan="2">Preconditions for operational efficiency</td><td>On system level depending on the cooperation b/w TA, RL and VTS</td><td>Set-up as with Tarmo and EVA 316</td><td>A new interface; possible effects</td><td>As in 1 a), but with TS instead of RL</td><td></td></tr>
<tr><td rowspan="3">Multipurpose features</td><td>Environ-mental</td><td>Limited capacity</td><td>Depending on N/B layout and S/H equipment</td><td rowspan="3">As in option 1 b)</td><td rowspan="3">As in option 1 a)</td><td>Limited or no capacity</td></tr>
<tr><td>Coast Guard or Navy</td><td>Not included</td><td>Unlikely</td><td>Not possible</td></tr>
<tr><td>Salvage</td><td>Not included, but according to int'l maritime law</td><td>Possible, and according to int'l maritime law</td><td>Limited capacity, depending on contract</td></tr>
<tr><td rowspan="2">Safety</td><td>At sea</td><td rowspan="2">RL responsibility</td><td>RL responsibility</td><td rowspan="2">Main responsibility with the service provider</td><td rowspan="2">Mainly TS respons-ibility</td><td rowspan="2"></td></tr>
<tr><td>On land</td><td>RL and TA responsibility</td></tr>
<tr><td rowspan="3">Costs</td><td>Purchase price or T/C costs</td><td>Capital value of current ships is low</td><td>Very high for a N/B, S/H price depending on availability</td><td colspan="3">Depending on contract and market situation</td></tr>
<tr><td>Manage-ment</td><td>For RL and TA in their own costs</td><td rowspan="2">Mainly RL responsibility; L/C costs (very) high for a N/B</td><td colspan="3" rowspan="2">Main responsibility with the service provider</td></tr>
<tr><td>Life cycle</td><td>RL responsibility</td></tr>
</table>

MoC = Ministry of Climate; MoTC = Ministry of Transp. & Comm.; PPP = Public-Private Partnership;
TA = Transprodiamet; TS = TS Shipping OÜ; RL = Riigilaevastik
T/C = Timecharter; B/B = Bareboat charter; N/B = Newbuilding; S/H = second hand; L/C = life cycle
= Shaded fields indicate an option currently used in Estonia

Should Estonia decide to procure new icebreakers, EU's Connecting Europe Facility (CEF) or its new Military Mobility program could be a source of substantial funding for such vessels. Both funding sources limit the use of vessels outside their intended operational area or use. This means that multipurpose assignments outside Estonia would most likely not be possible, and this type of funding could therefore be suitable only for conventional icebreakers. In any case, the financing conditions and limitations need to be well understood.

In July 2023, Sweden received approximately EUR 90 million from the CEF in connection to its new icebreaker to be completed in 2027. Sweden is also applying for financial assistance for its second new icebreaker from EU's Military Mobility program in September 2023, where a total of EUR 790 million will be distributed.

KEY TAKEAWAYS

No	Task/ question*	Answer
4	What alternatives are available for organizing the financing of icebreaking? What impact does the provision of icebreaking services have on the receipt of waterway charges and vice versa?	Please see **Table 18 Generic governance options for winter navigation assistance** for reference
9	What changes could be made to make the organization of icebreaking in Estonia more efficient?	Please see Conclusions on **Other considerations** (p 149)
10	Taking into account that the lifetime of an icebreaker is 50 years and the economically rational lifetime of a multipurpose vessel is 25 years, what is the most reasonable scenario from the viewpoint of the state?	Please see Chapter 3 **Box 1. Overview of offshore markets in view of multi-purpose icebreakers** (p 79-80), **Chapter 5** and Conclusions on **Pros and cons of a new multipurpose icebreaker** (p 148)

SOURCES & REFERENCES

Arctia (2022) 2021 Vuosikatsaus (Annual report). https://www.arctia.fi/media/vuosikertomukset/vuosikertomus-2021/arctia_vuosikatsaus_2021.pdf

Aker Arctic (2016) List of operational icebreakers as per 28 Nov. 2016 collected by Aker Arctic for Baltice.org (BIM), available at: https://baltice.org/app/static/pdf/operational_icebreakers.pdf

BIM (2020) Baltic Sea Icebreaking Report 2019-2020 by Baltic Icebreaking Managemen; available at: https://baltice.org/app/static/pdf/BIM%20Report%202019-2020.pdf

BIM (2021) Baltic Sea Icebreaking Report 2020-2021 by Baltic Icebreaking Management; available at: https://baltice.org/app/static/pdf/BIM%20Report%202020-2021.pdf

High North News (2023) "New US Icebreaker Delayed Until 2027, Russia Orders 6th and 7th Nuclear Icebreaker", published 9 Feb. 2023, available at: https://www.highnorthnews.com/en/new-us-icebreaker-delayed-until-2027-russia-orders-6th-and-7th-nuclear-icebreaker

LVR Flote (2023) Company website: RIGA FREEPORT FLEET (lvrflote.lv)

Merkel, A. and Vierth, I (2022) Granskning av förslag till modell för farledsavgifter, VTI PM 2022:2, available at: https://www.diva-portal.org/smash/get/diva2:1652402/FULLTEXT01.pdf

Ojala, L, Solakivi, T, Helminen, R, Kajander, S and Paimander, A (2023) Suomen merikuljetusten huoltovarmuuskapasiteetti, Huoltovarmuuskeskus (National Emergency Supply Agency of Finland) available at: https://www.huoltovarmuuskeskus.fi/files/f8a073d180b1e9990749032249c30520b7ed28cc/suomen-merikuljetusten-huoltovarmuus.pdf

Port of Tallinn (2021) MPSV Botnica's 10-year icebreaking service to the Transport Administration; website from 3 February 2021 available at: https://www.ts.ee/en/mpsv-botnicas-10-year-icebreaking-service-to-the-transport-administration/

SMA (2022) Konsekvensutredning angående förslag till ändringar av föreskrifter om farledsavgift, Swedish Maritime Administration, availabe at: https://www.sjofartsverket.se/globalassets/om-oss/lagrum/aktuella-remisser/konsekvensutredning-farledsavgifter-2023.pdf

Statistics Estonia (2023) TS154: INTERNATIONAL SHIPPING TRAFFIC THROUGH PORTS, available at: https://andmed.stat.ee/en/stat/majandus__transport__veetransport/TS154

Finnish Transport Infrastructure Administration/ Väylävirasto (2021) 142 vuorokautta kestänyt jäänmurtokausi päättyi, (FTIA, Finnish Transport Infrastructure Agency) at https://www.epressi.com/tiedotteet/logistiikka-ja-liikenne/142-vuorokautta-kestanyt-jaanmurtokausi-paattyi.html

VTV (National Audit Office of Finland, 2020) Jälkiseurantaraportti: Yritysvastuun ohjaus ja toteutus valtionyhtiöissä Case: Arctia Oy, Kemijoki Oy, Vapo Oy. https://www.vtv.fi/julkaisut/jalkiseurantaraportti-yritysvastuun-ohjaus-ja-toteutus-valtionyhtioissa-case-arctia-oy-kemijoki-oy-vapo-oy/

4. SCENARIOS FOR ICEBREAKING NEED AND VESSEL OPTIONS

Current chapter gives an overview of the context of Estonian icebreaking and draws together 11 scenarios (nine base case scenarios and two additional) for alternatives for providing icebreaking services in Estonia.

4.1 CONTEXT

4.1.1 OVERVIEW OF THE CARGO AND VESSEL MOVEMENT

KEY TAKEAWAYS FROM CHAPTER 1

Recent years show that icebreaking capability is needed in eastern part of Estonia and in the Gulf of Riga and Pärnu. Though there hasn’t been demand for icebreaker services in Tallinn and Paldiski area, where important ports for Estonia are situated and therefore there should be readiness to offer ice-breaking services in these regions in some form.

Cargo flows served by ports are dependent on economic situation of its hinterland and foreland and political relations with its neighbours and possible partners.

As vessel traffic serves these cargo flows, it increases or decreases in line with changes with cargo flows. Changes in vessel size can change it some extent. According to vessel traffic statistics in Estonian ports, there hasn't been considerable changes in vessel sizes visiting Estonian cargo ports in the recent decade.

4.1.2 OVERVIEW OF THE ICE CONDITIONS

KEY TAKEAWAYS FROM CHAPTER 2

Over the years 1993–2022, the mean ice extent reaches its maximum coverage of about 40 000 km^2 around end of February or beginning of March (Figure 39). However, sea ice extent is strongly dependent on mean temperature over the entire winter (average of 5 months). Therefore, the variability of sea ice extent has been large ranging from the maximum of about 100000 km^2 to less than 1000 km^2 (winter 2019/2020).

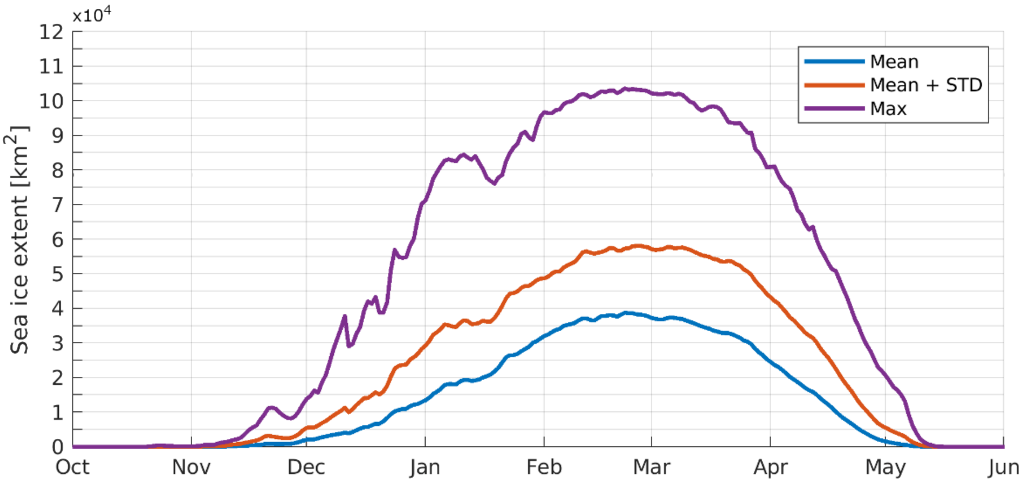


Figure 39. Sea ice extent mean (blue), maximum (purple) and standard deviation (red) over the study area. The data is retrieved from the data between 1993 and 2021

Over the years 1993–2022 the average ice thickness around Estonian coast remains consistently around 10 cm or less (Figure 40a). The only exception to this trend is Pärnu Bay and other closed areas, where the ice thickness is greater. The maximum ice thickness exhibits much more spatial variability and can reach up to about 80 cm during the coldest winter. However, the analyzed data does not include any ridging which can cause much greater thicknesses locally.

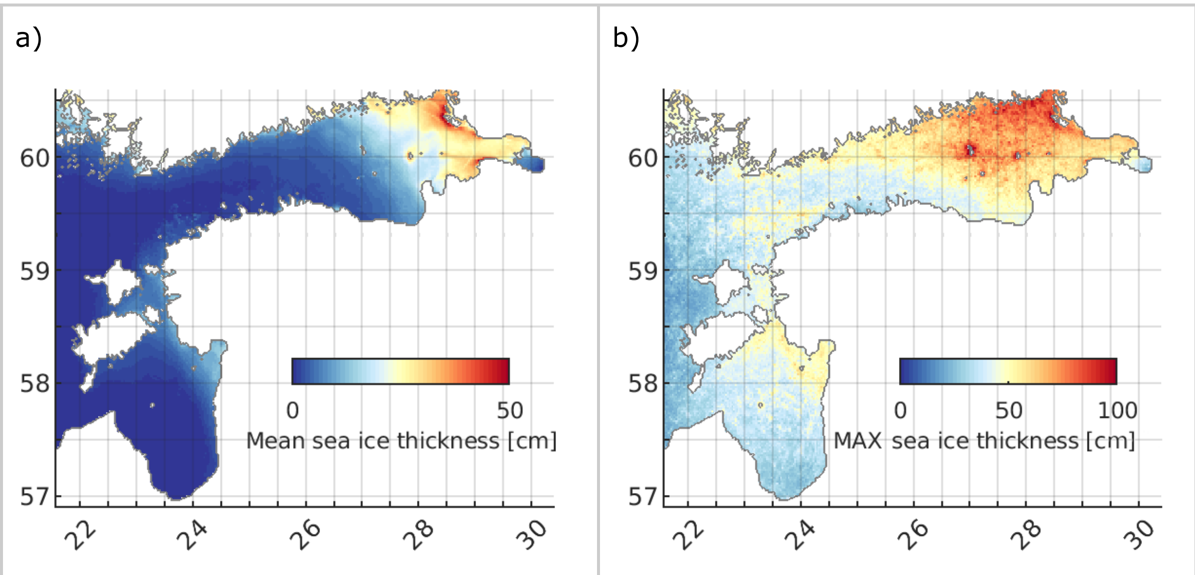


Figure 40. (a) Mean and (b) maximum of ice thickness. The values are retrieved from data between 1993 and 2021

Over the years 1993–2022 about 20% winters have been sever, 60% have been average, and 20% have been mild winters (Figure 41). As temperatures are projected to increase in climate scenarios, a rise in occurrence of average and mild winters is anticipated. Consequently, severe winters are expected to become significantly less frequent. Nevertheless, under extreme weather conditions in warmer climate scenarios, there remains a possibility for severe winters to occur.

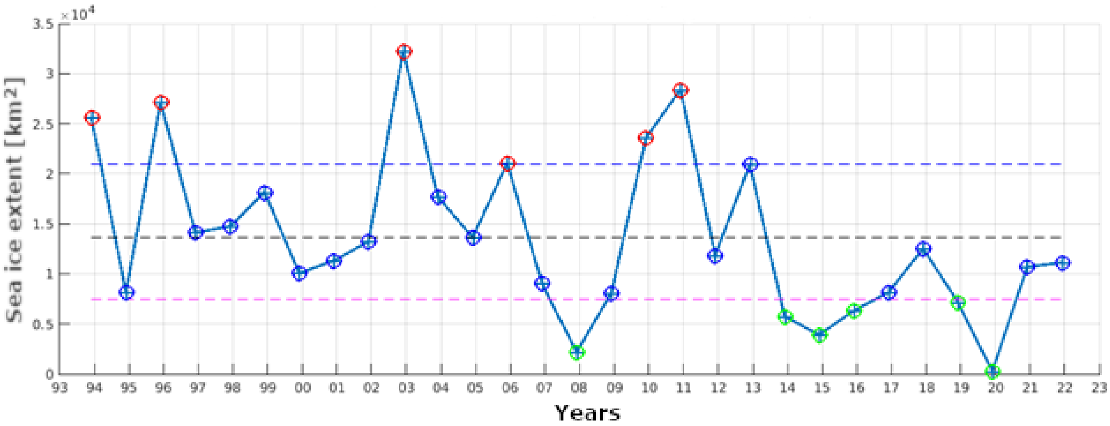


Figure 41. Seasonal mean sea ice extent over the years based on the Copernicus Marine Service reanalysis data. Red circles mark the severe winters, green circles correspond to mild winters, and blue circles mark the average winters. The separation is done based on percentiles 20 and 80

WINDPARK LOCATIONS AND ICE

There is a long history of lighthouses, pillars, and other structures in sea ice conditions, how to build them so that the structures would withstand the forces of sea ice. Conversely, estimation of ice formation and melting conditions within and around wind parks (close-by array of basement pillars for wind towers) is largely unknown. Figure 42 depicts areas where wind farm building permits have been applied for (highlighted areas). Significant portion of developments in the Gulf of Riga are in areas where ice is dependent on wind conditions and therefor dynamic. Only during the severe winters ice might become land-fast for the easternmost areas of planned windfarms. Otherwise, the probability of ice floes moving through the wind farms is greater.

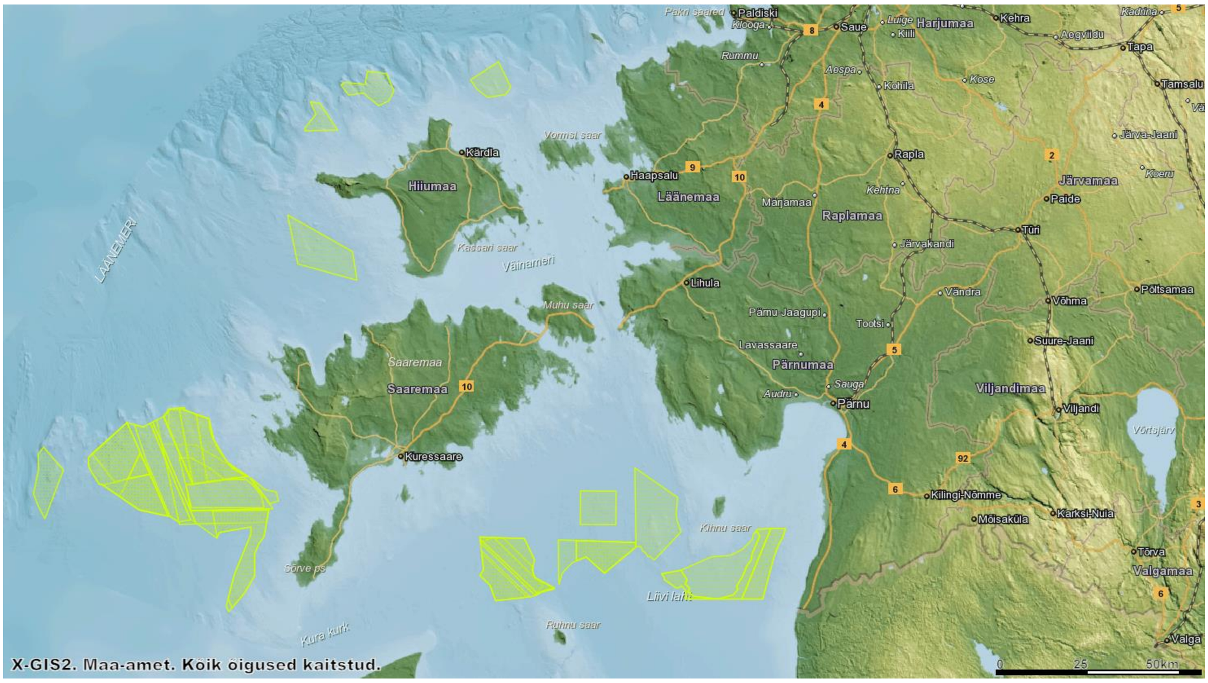


Figure 42. Highlighted locations show the areas where wind farm building permits have been applied for. (Source: Land Board 2023)

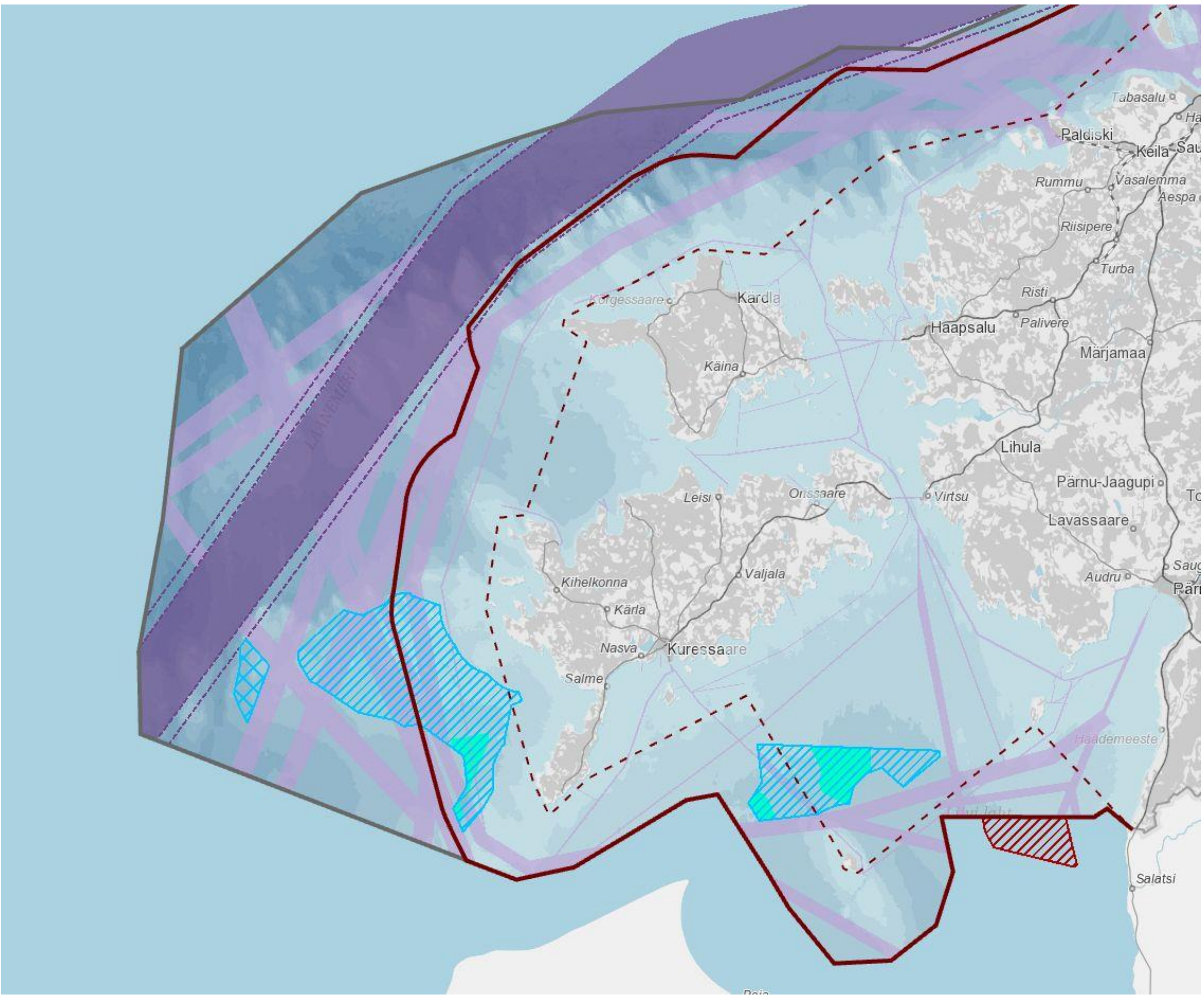


Figure 43. Estonian Maritime Spatial Plan's Offshore Wind and Maritime Traffic Areas. Allikas: https://mereala.hendrikson.ee/kaardirakendus.html (29.08.2023)

On one hand, it is meaningful to estimate that array of pillars would increase the probability for ice to form and become land-fast during the severe winters. On the other hand, the pillars would increase the chance of ice floes to be broken into smaller floes or increase of ridging during the windy conditions. In any case, wind farms would change the natural ice dynamics in the Gulf of Riga which in turn would probably affect ice breaking needs. It is important subject that requires high-resolution hydrodynamic- and ice modelling and deeper analysis which is not in the scope of this study.

4.1.3 ENVIRONMENTAL CHANGES AND REGULATIONS

By 2050, shipping will change more than it has in decades due to stricter environmental regulations.

BACKGROUND FOR TIGHTENING REGULATIONS

In 2018, the International Maritime Organization (IMO) set a goal of reducing shipping's greenhouse gas emissions by 50 percent by 2050, and in July 2023, the IMO made significant tightening of its goals. The revised IMO GHG Strategy includes an enhanced common ambition to reach net-zero GHG emissions from international shipping close to

2050, a commitment to ensure an uptake of alternative zero and near-zero GHG fuels by 2030, as well as indicative checkpoints for 2030 and 2040.

In July 2023, the European Parliament also finally decided on the maritime Fit for 55 package, which stipulated the carbon content of shipping fuels, fuel distribution and taxation, and included shipping as part of the emissions trading system.

However, these are only the latest changes in greenhouse gas emissions regulations. The first international regulations to reduce shipping's greenhouse gases came into force more than a decade ago.

THE SHIP'S TECHNICAL AND OPERATIONAL REGULATIONS

In 2011, the IMO set goals by which the structure of new ships must be designed in such a way that ships' fuel consumption and thus greenhouse gas emissions are reduced. EEDI stands for Energy Efficiency Design Index, i.e. it is used to calculate the ship's energy efficiency index (carbon dioxide emissions per tonne-mile). For the ship to operate, the index value must be lower than the reference value set by the IMO. They are gradually becoming stricter, so new ships gradually become less emitting. The regulation has already had a significant impact on the energy consumption of ships, for example by designing the hull shapes, as well as the fact that the newest ships usually have less engine power than the older ones.

In 2021, the IMO set a requirement that existing ships must also meet the energy efficiency requirements set by the IMO. And like EEDI, this EEXI gradually tightens.

The EEDI regulation has already change and also coming EEXI regulation will change the new vessels operating in the Baltic Sea. The new vessels are weaker and therefore, they need more ice breaker assistance in winters (See 4.1.5 Vessels Ice-Going Capacity Based on New IMO Rules).

In 2021, the IMO also approved the much more controversial regulation CII – i.e. carbon intensity indicator. It moved from the ship's structures to the ship's operation, i.e. the ship must reduce certain amounts of greenhouse gas emissions in relation to the transport performance.

EMISSIONS TRADING

This year, the EU will also introduce a market-based control tool – ETS – emission trading system. ETS means that after each year, an operator must surrender enough allowances to cover fully its emissions, otherwise heavy fines are imposed.

In practice, the more greenhouse gases are released into the atmosphere, the more emission rights must be purchased, and the higher their price rises. The goal is therefore a situation where it is most economical for the shipping company to reduce its emissions, instead of buying emission allowances. Since the carbon emission market is shared with other industrial sectors as well, the system also directs activities in which emissions are reduced where it's the easiest or cheapest to do, and those companies then sell the rights to companies in other industries.

Emissions trading will be introduced for shipping the first time 2023, taking into account some of this year's emissions, and will be tightened in the following years. It is difficult to estimate what the price of emission rights will be in the future, and how it will affect the development of the industry.

The decarbonising actions are particularly difficult for Baltic Sea shipping, because there is ice cover every year. It means, that the vessels have to be stronger and have more power to be able to continue sailing also in winter – and emit more CO2 when using fossil fuels. This means that Baltic Sea shipping and the export and import industry in Baltic Sea area is in worse competitive position than shipping in Southern Europe. Therefore, ice-strengthened ships will receive a five percent relief in EU maritime emissions trading system until 2030. Unfortunately, this is by no means sufficient to level the fuel consumption due to ice and – in any case- this relief is valid only for 6 years and thereafter there has to be solutions available how Baltic Sea shipping can remain competitive.

REGULATIONS FOR FUELS

The EU has also set a goal that the annual calculated carbon content of the fuel used at sea should decrease. This FuelEU Maritime means that part of the fuel used must be carbon-free, in which case either biofuels or other new non-fossil fuels such as methanol are used. This regulation is also gradually tightening, and it is likely to have a significant impact on shipping. However, it should be noted that even one ship running on fossil-free fuel reduces the emissions of the entire fleet of a shipping company, and thus the shipping company can switch to emission-free ships one at a time over several years.

4.1.4 NEW FUELS

There are various alternative low- and zero-carbon fuels for shipping. When comparing fuel solutions, the most important long-term perspective is how much greenhouse gases its use produces.

Fuel energy sources can be divided into two categories based on their basic energy: non-renewable and renewable energy sources. Non-renewable energy sources include coal, lignite, oil, natural gas and nuclear power. Renewables are wind, sun and biofuels.

Some of these energy sources can be used as such as marine fuel, such as oil or natural gas. Some energy sources, such as wind energy or biomass, are converted into another form instead. This second form is currently usually electricity.

Several forms of transport, such as road or rail transport, are becoming electrified at a rapid pace. However, it is difficult to store electricity for a long sea voyage, so instead hydrogen or some other chemical compound derived from it is used. Hydrogen-based fuels can be stored for a long time, hydrogen is like a more efficient battery than traditional batteries.

ALTERNATIVE FUELS

Electricity – electricity is one of the most potential low-emission fuels for shipping in the future. At the moment, the most common electrical solutions are shore power, i.e. the ship is in port while connected to the power grid, and it does not need to use separate auxiliary machines in the port.

Ships require considerable amount of energy, and on longer journeys and especially in ice conditions or even ice breakers, the amount of batteries required for electricity is significant. Electricity as such is best suited for short-distance transport, such as archipelago or urban water transport.

Biofuels – the easiest solution for shipping would be if current fossil fuels could be replaced directly with biodiesel or gas. Unfortunately, production of biofuels is significantly less than consumption. It is assumed that those forms of transport, such as air transport, where the energy density of the fuel is important, will use most of the future biofuels. Then there would not be enough of it for maritime use.

Hydrogen – the problem with using hydrogen is its low energy density, even when liquefied, hydrogen requires more than three times more space than heavy fuel oil to produce the same amount of energy. Because of this, pure hydrogen is no longer often seen as a potential fuel, but instead people think about converting hydrogen into ammonia, methane or methanol, which have more energy in a smaller space. This change can happen either by using electricity or biological fuels. Unfortunately, some energy is also always lost in this change, so every hydrogen-based fuel is inevitably a slightly worse solution – on the other hand, it solves the hydrogen space problem.

Ammonia – when liquefied, is already significantly better in terms of energy density than hydrogen, so it does not need as much space on the ship. On the other hand, the liquid tank itself requires a lot of space on board. However, the problem with ammonia is its toxicity, which places slightly more demands on it as a fuel.

Methane, LNG, biogas – LNG, liquefied natural gas, is already a commonly used fuel in shipping, especially because it contains no sulphur at all, so no sulphur scrubbers are needed for its use. However, it produces almost the same amount of carbon dioxide a than heavy fuel oil, and in addition, low-pressure engines also release pure methane, a greenhouse gas even more significant than carbon dioxide, into the air. Methane can also be produced from hydrogen by adding carbon.

Methanol, ethanol – are other liquids where hydrogen has been converted into an energy form with a higher density, thus requiring less storage capacity than hydrogen. At the moment, the world largest shipping companies are building their new vessels to be methanol-ready.

Nuclear power – has served as a shipping fuel for decades, for example in the icebreaking of Russia's Arctic regions. So-called small reactors are now being worked on as an alternative fuel, but there are many risks associated with nuclear power, and it is still uncertain whether commercial solutions that can be used in general can be obtained with the help of nuclear power.

4.1.5 VESSELS ICE-GOING CAPACITY BASED ON NEW IMO RULES

The IMO regulations for reducing carbon intensity (MARPOL Annex VI, chapter 4) are applicable for merchant vessels with ice class PC6 (corresponds to FSICR IA super) or lower. Basically, this means that all regular merchant vessels visiting Estonian ports which have sufficient size and relevant ship type shall comply with the IMO's regulations for reducing carbon intensity. The regulations do not apply to Category A vessels defined in the Polar Code; however, typical merchant vessels operating at the Baltic Sea do not have such high ice classes.

Reduction of the installed power has clearly negative impact to the merchant vessels ice-going capability as the need for icebreaker assistance is heavily linked to the power-deadweight ratio of the merchant vessel. In addition, the reduction of installed power is often accompanied with heavily open-water optimized hull forms which will further decrease the ice-going capability of the merchant vessels. Finally, it is possible that the design of the propellers and propulsion is focused on optimizing the propulsive efficiency at open-water speeds and the functionality in ice conditions is potentially reduced. Even though the EEDI and EEXI regulations have ice class correction factors in them, it is expected that the future merchant vessel fleet will be further open-water optimized as majority of the operation occurs in open-water even for ice-classed merchant vessels. In addition to IMO's environmental regulations, also economic factors lead the merchant vessels to be more open-water optimized. It could be estimated that the importance of economic factors could increase in the future with use of new, potentially expensive alternative fuels.

As a summary, it can be concluded that the ice-going capability of merchant vessels is expected to decrease in the future and therefore the merchant vessels will need more icebreaker assistance. Past studies have shown that the EEDI Phase 0 and 1 vessels need more icebreaker assistance when compared to vessels built before EEDI regulations. Now Phase 2 vessels are just entering service and Phase 3 will be introduced in the future meaning that the ice-going capability of the merchant vessels is expected to further decrease. The influence of EEXI and CII is yet to be demonstrated as these regulations are so new. However, the impact is expected to be negative in respect of ice-going capability of the merchant vessels.

4.1.6 OTHER TECHNLOGIES FOR CARGO VESSELS ICE GOING CAPABILITY

Good ice-going capability of merchant vessel is characterized by low ice resistance, which could be achieved by using icebreaking bow shapes, and/or by increased power of machinery and improved propulsion efficiency for ice conditions. Application of dedicated icebreaking bow-shape allowed such vessels to operate efficiently in the Baltic during wintertime and to be utilized additionally in seasonal operations in the Arctic (Figure 44).

Figure 44. IA Super ice class product tanker with icebreaking bow.

However, the requirement for good ice-going capability leads to hull shapes that are not typically optimal for open water. Especially the seakeeping characteristics may suffer and the open-water resistance increase. Due to these reasons, the use of icebreaking bows on the merchant vessels operating at the Baltic Sea is becoming more and more rare, even for the highest Finnish-Swedish ice classes IA and IA Super. On the other hand, majority of existing IA Super ice class passenger and cargo ferries have sufficient propulsion power to operate independently (without icebreaker assistance) on the regular routes of Baltic Sea characterized by old brash ice channels even though equipped with bulbous bows (Figure 45).

Figure 45. IA Super ice class ferry with bulbous bow in independent operation in ice

Another way of ensuring a possibility of independent operation, without significant increase of machinery power, is the 'double acting ship' (DAS) design concept. The idea of the DAS concept is to design the vessel's stern to break ice when the vessel would operate astern in difficult ice conditions. Then the bow of the vessel can be better suited for open-water conditions when compared to a typical icebreaking bow. The first and only realization of DAS concept for non-Arctic freezing seas are Aframax tankers *Tempera* and *Mastera* which were delivered by Sumitomo shipyard in 2002–2003 for Neste. Already the very first voyages of tanker *Tempera* demonstrated the unique possibilities of double-acting vessels for independent navigation in the ice conditions of the Gulf of Finland, where some 30–40 ships were trapped in ice (Figure 46). For many years, both tankers transported crude oil on the regular route from Primorsk, Russia to Porvoo, Finland.

Figure 46. Double acting tanker Tempera moving astern in the ice conditions of Gulf of Finland

4.1.7 OFFSHORE WIND

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. Sea ice can be divided into different types of ice, and national meteorological institutes and ice researchers predict how sea ice exists as either fast and or drift ice depending on its mobility. Fast ice is situated in coastal and archipelago areas, and for example Gulf of Riga has mostly fast ice.

When drift ice moves away from the fast ice, or consolidated ice, it creates a lead in the ice field. During strong winds the width of the lead can reach 10–30 km in about 24 hours. If the wind direction remains constant in a vast area, the lead can become very long. During spring in the Gulf of Finland and in parts of the Gulf of Riga, a lead shaped like a crescent is usually being formed.

Drift ice can easily become packed when it reaches an obstacle. Typically, this occurs when the ice field moves towards the fast ice edge. In the shallows, ridges get anchored to the bottom and the visible parts can grow to tens of meters high. Ridged ice appears also in the middle of seas where the ice floes get pressed against each other and break into pieces. The pieces of ice pile up over and under the sea surface forming meandering ice ridges and these ridges are in many cases very challenging for commercial vessels to penetrate. Normally ice breaker assistance is needed for commercial ships to be able to navigate in packed ice conditions.

The wind may disperse or pack the sea ice, generating conditions that affect the marine traffic, for example through ice ridges and packed ice along the coast and harbor entrances. At the Baltic Sea, the prevalent winds are south-westerly. This causes the sea ice moving towards the Finnish coast in the Gulf of Finland and towards the Estonian coast in the Gulf of Riga.

The movement of large sea ice areas is possibly a dangerous phenomenon. Drift ice can create such pressure on vessels that they either drift with the ice and lose control to manoeuvre/steer or freeze in the ice. For shipping, it is primarily brash barriers, ice ridges, hummocked ice and drift ice that might pose a danger to traffic where these types of ice are created. The ridges and brash ice barriers are the most significant obstructions to navigation in the Baltic Sea and Gulf of Riga. Powerful, ice-strengthened vessels can break though ice up to almost one meter thick, but they are not capable of navigating through ridges without icebreaker assistance. Ice dynamics affect navigation considerably. High pressure in the ice fields can be dangerous to the vessels, and it may at least cause time delays from hours up to days.

The most dangerous situation for commercial shipping is created when ship gets stuck to the drifting ice field and there is no ice breaker assistance in the vicinity. Vessel can drift with ice drift towards the wind turbine and get damaged. It is also possible that vessels is drifting with ice inside the wind farm and then the situation gets even more challenging from salvage point of view.

4.2 ESTONIAN WINTER NAVIGATION SYSTEM MODEL

4.2.1 THE GENERAL PRINCIPLES

The simulation approach and framework for Estonian Winter Navigation System (EST WNS) are based on the method of Kulkarni et al. (2022 a). Figure 47 shows the main elements and organizational principles of the framework, which is implemented using the Anylogic® software. According to the multi-level simulation approach (Delbrugger et al. 2019), environmental and traffic details of the EST WNS are modelled on separate layers called "levels". Each level can function independently and can be run as an individual simulation.

The level *Environment* captures the details of the environmental aspects of the system, which include geographical coordinates (latitude-longitude) and ice information (ice concentration, thickness, and pre-calculated equivalent ice thickness). The level *Traffic flows* models the movement of vessels and icebreakers following their itineraries, specified based on historical AIS data.

The two levels are linked using vessel-specific h-v curves – polynomial expressions determining the attainable vessel speed in ice with specific equivalent ice thickness. The h-v curves are defined for different power outputs as described in (Kulkarni 2022 a). The speed of icebreakers and transport vessels changes in response to the ice conditions they encounter during their journey. The model uses a combination of discrete-event and agent-based simulation paradigms to capture the dynamics of maritime traffic flows, ice conditions, and their interaction.

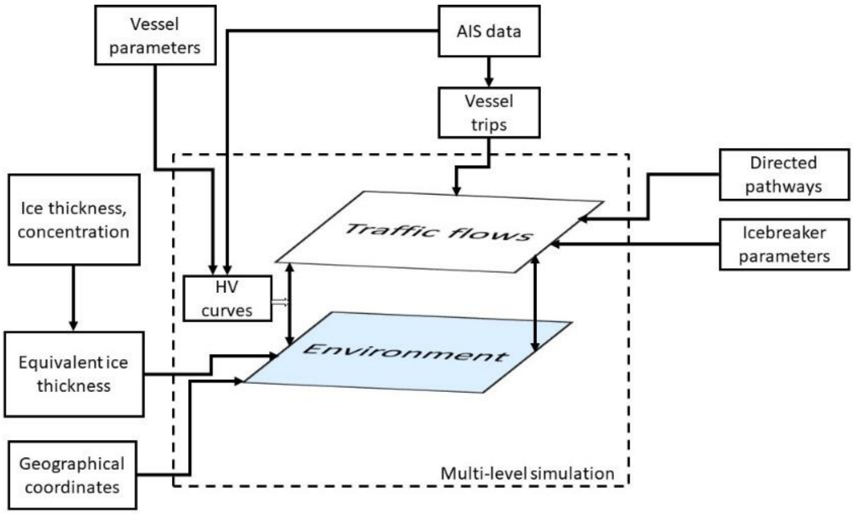


Figure 47. The organizational scheme of the modelling framework for the EST WNS (Kulkarni et al. 2022b).

The spatial ice conditions are represented by latitude-longitude coordinates and are mapped to a row (r) -column (c) grid. Each cell on the grid (r, c) is an agent in the model, characterized by the ice properties of the corresponding point of the map. The ice properties are continuous in time and are updated every virtual day. Each cell is coloured in a shade of blue, whose darkness is proportional to the equivalent ice thickness, defined as the total ice volume divided by its area (see Milaković et al. 2020). The vessels in the model move along the doorways in the ice fields. The vessels and icebreakers are modelled as agents guided by state charts, determining how they respond to runtime events (see Kulkarni et al. 2022 a).

4.2.2 ICEBREAKER DECISION-MAKING

The operation logic of icebreakers influences the EST WNS performance, e.g., the total waiting time. While vessel itineraries (origin and destination of trips) are governed by historical AIS data, the icebreaker trips are dynamic, resulting from a series of responses to runtime events. The icebreaker decision-making aims to minimize the total waiting time of transport vessels for icebreaking assistance in the operating zone. Each icebreaker is responsible for all vessels within its operating zone and vessels entering the operating zone within a specific time horizon. A vessel requests icebreaker assistance when it cannot independently maintain the minimum required speed (3 knots is assumed in the model as the initial value). In the model, icebreakers may receive multiple assistance requests simultaneously and prioritize the vessel with the longest waiting time.

In practice, icebreaker decision-making is based on the experience of the captains. The captains decide which vessel(s) to prioritize based on satellite images of ice conditions and expected traffic movement in the next few hours (typically 8–12 hours). The icebreakers may make certain vessels wait to combine assistance trips and reduce the total waiting time in the system.

In the current version of the simulation framework, a simplified icebreaker decision-making approach is employed. The steps involved are as follows:

1. Each icebreaker maintains a list of assistance requests received;
2. The icebreaker assists the vessel that has been waiting for the longest;
3. The icebreaker checks if any other vessel can be assisted along with the chosen vessel as part of a convoy;
4. The chosen vessel or the potential convoy is assisted until the end of the operating zone to the closest safe stopping waypoint;
5. The icebreaker updates its list of vessel requests and chooses the next vessel to assist;
6. If an icebreaker is not busy, it may assist vessel requests belonging to a neighbouring operating zone of another icebreaker.

When incorporating all features into the model, the EST WNS model functions as shown in Figure 48, with ice equivalent thickness indicated by the degree of the colour.

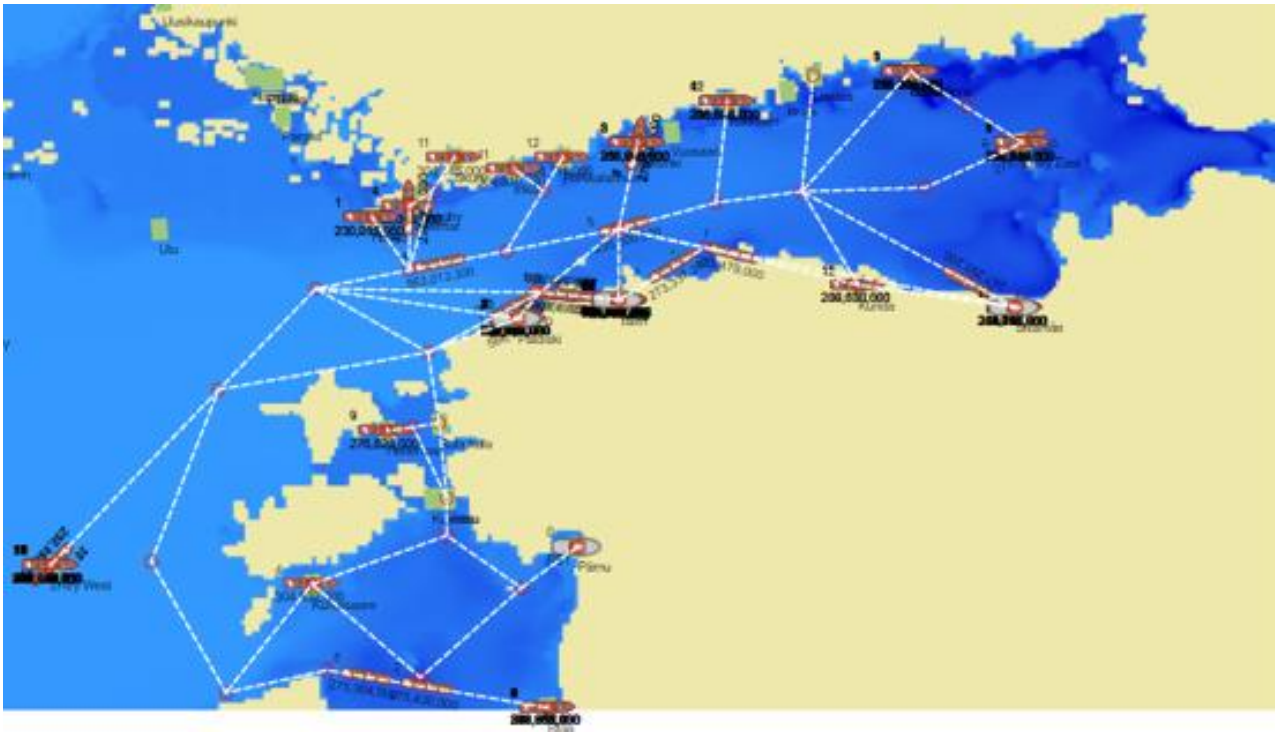


Figure 48. A demonstration of the Estonian Winter Navigation System (EST WNS) model

4.3 SIMULATION SCENARIOS AND RESULTS

4.3.1 WINTER-ICEBREAKER-TRAFFIC SCENARIOS

BASE ICEBREAKER-WINTER SCENARIOS

In order to simulate the effects of the different combinations of icebreakers. The following icebreakers are utilized and constitute three scenarios as shown in Table 21. Icebreaker scenarios. Three of them will be delegated to Gulf of Finland and one to Gulf of Riga. IB scenario 1 includes two icebreakers and scenario 2 have three and scenario 3 will activate all four icebreakers.

Table 21. Icebreaker scenarios

Icebreakers	ME Power (kW)	Shaft Power (kW)	IB Scenario 1	IB Scenario 2	IB Scenario 3
Gulf of Finland primary IB	13000	10000	+	+	+
Gulf of Finland secondary IB	9100	7000		+	+
Gulf of Finland third IB	6250	5000			+
Gulf of Riga IB	5500	4400	+	+	+

Note: '+' means the IB is included in the scenario

In addition to the icebreaker scenarios, winter scenarios are selected to consider the different performances under varying ice conditions. Mild, average, and severe winter month are considered correspondingly. The representative ice conditions/charts in beginning, middle and end of the month period are shown in to represent the ice situations the ships will encounter. Winter scenarios are summarized as in Table 22. Winter scenarios Table 22.

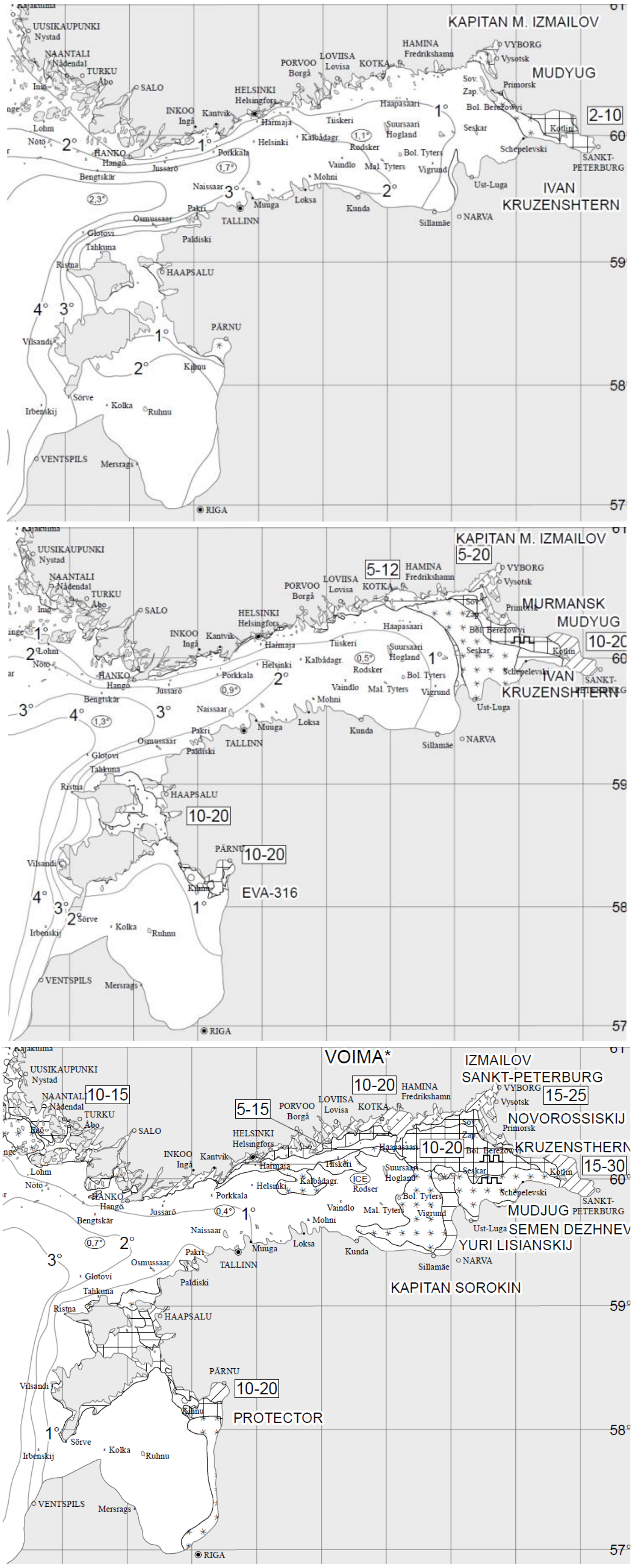
Table 22. Winter scenarios

Winter	Representative ice charts	Winter scenario 1	Winter scenario 2	Winter scenario 3
Mild winter	Figure 3 (a)	+		
Average winter	Figure 3 (b)		+	
Severe winter	Figure 3 (c)			+

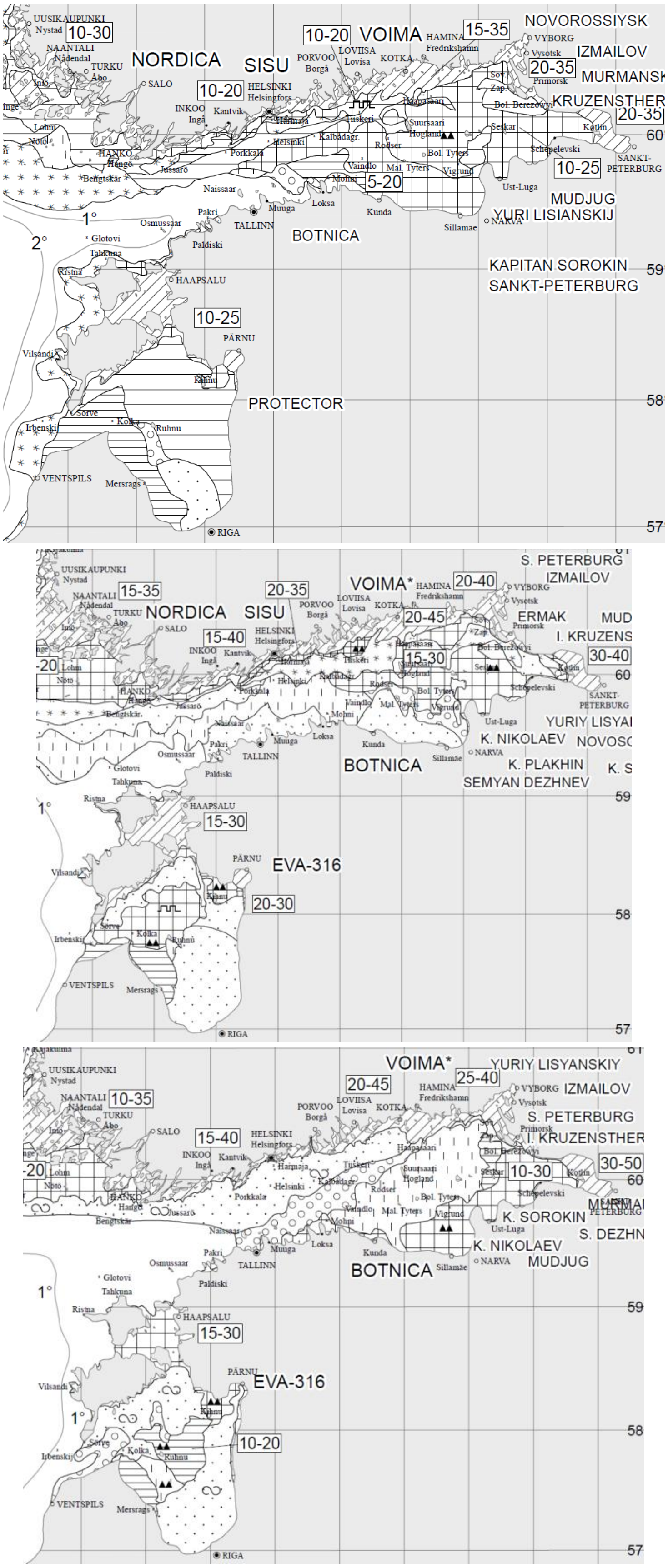
By combing icebreaker scenarios and winter scenarios, Table 23 gives a summary of the study matrix of the base icebreaker-winter scenarios to investigate the different behavior of winter navigation and assistances under the effect of different icebreaker combinations and ice conditions.

Table 23. Matrix of combined icebreaker-winter scenarios

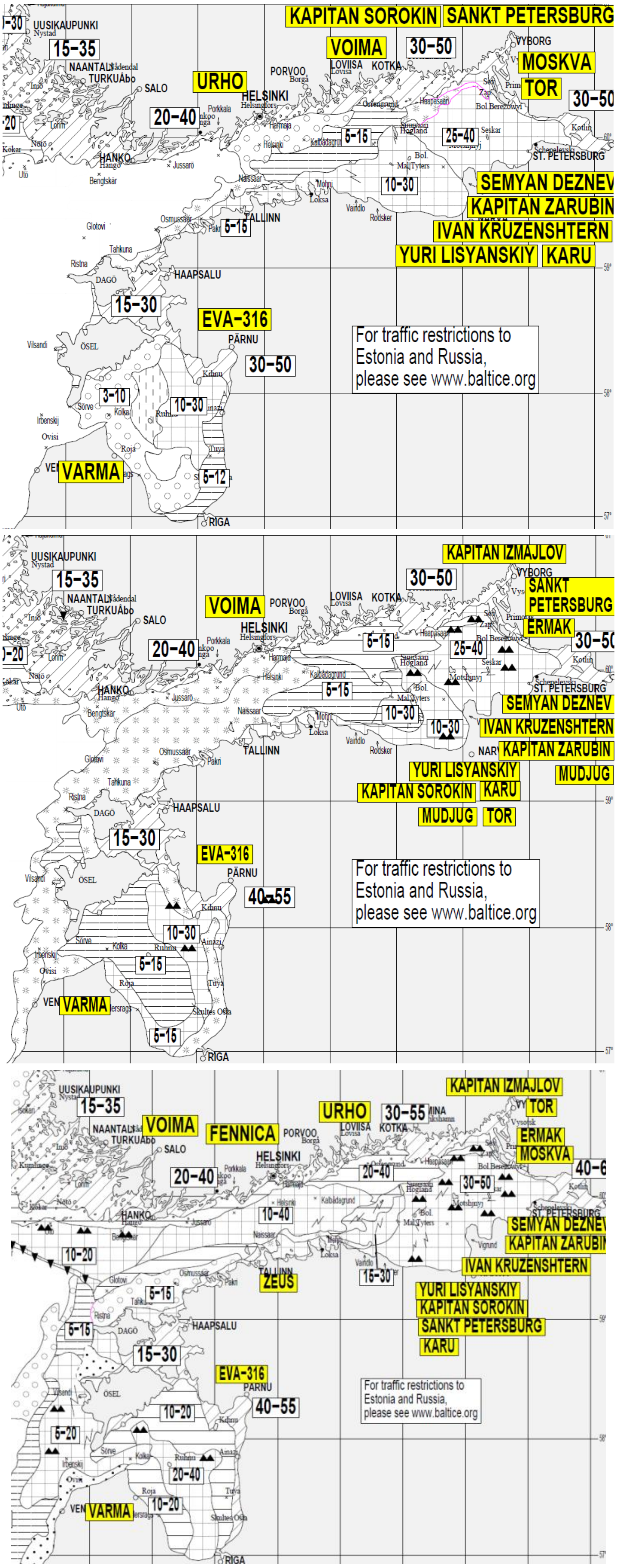
	Mild winter	Average winter	Severe winter
IB Scenario 1	IB S1 – WS1	IB S1 – WS2	IB S1 – WS3
IB Scenario 2	IB S2 – WS1	IB S2 – WS2	IB S2 – WS3
IB Scenario 3	IB S3 – WS1	IB S3 – WS2	IB S3 – WS3



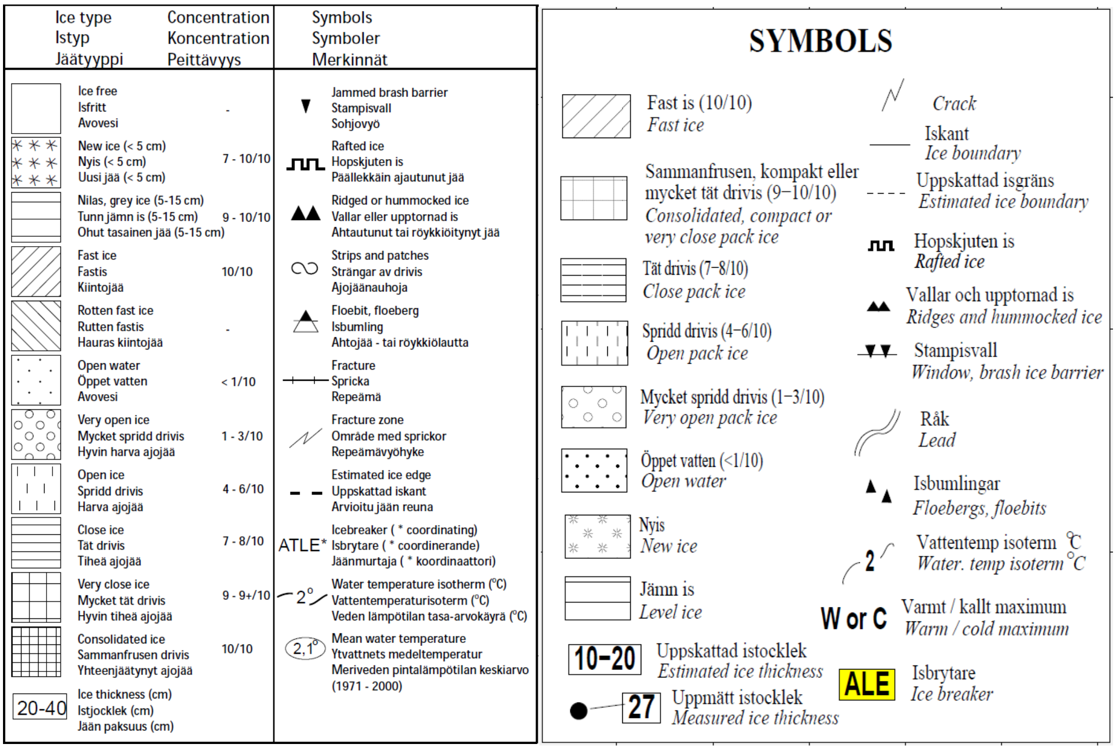
(a) Mild winter month: begining-middle-end period ice condition



(b) Average winter month: begining-middle-end period ice condition



(c) Severe winter month: beginning-middle-end period ice condition



(d) Ice chart symbols: left one for mild and average winter, right one for severe winter

Figure 49. Figure 3. (a)-(c) winter scenarios representative ice charts and (d) symbols

ADDITIONAL LOW TRAFFIC AND NO ICEBREAKER SCENARIOS

To further investigate the effect of changing traffic, additional scenario is implemented based on the IB S2 – WS2 case (2 icebreakers in Gulf of Finland and 1 icebreaker in Gulf of Riga, average winter), forming so called LT – IB S2 – WS2 scenario (LT-low traffic). The traffic amount is reduced by 20% randomly to present a possible future traffic case.

In addition, another no icebreaker scenario (NIB – WS2) is set up to represent no icebreaker situation in the condition of WS2 (average winter). This is implemented by forcing all icebreakers to get zero speed all the time in the simulation. A matrix of all scenarios are summarized in Table 24.

Table 24. Matrix of all scenarios

	Mild winter	Average winter	Severe winter
IB Scenario 1	IB S1 – WS1	IB S1 – WS2	IB S1 – WS3
IB Scenario 2	IB S2 – WS1	IB S2 – WS2	IB S2 – WS3
IB Scenario 3	IB S3 – WS1	IB S3 – WS2	IB S3 – WS3
Low Traffic		LT – IB S2 – WS2	
No Icebreaker		NIB – WS2	

4.3.2 RESULTS FOR WINTER-ICEBREAKER-TRAFFIC SCENARIOS

RESULTS FOR ICEBREAKER-WINTER SCENARIOS

To simulate the results for different icebreaker-winter scenarios, the level *Traffic flows* are kept same using historical AIS traffic data from 2018 Jan 15th to Feb 15th, as illustrated in Figure 1. The level *Environment* and icebreakers vary according to the scenario sets in Table 1-3. By inserting the inputs in turn, results are simulated separately. One of main KPIs for icebreaker assistance is average waiting time for each assisted ship, i.e., how much time is needed for merchant ships to wait for icebreaker assistance. Therefore, this will be one of the main outcomes. In addition to this, the icebreaker operation time used in winter navigation system and corresponding fuel consumption are also outputs from the modelling.

Table 25–28 show the results of IB scenario 1 (IB S1) under varying winter conditions. IB S1 include two icebreakers. It can be seen from tables that with the ice condition becoming severe, the average time of ships waiting for icebreaker assistance increase dramatically and the working time for icebreakers also increase, as well as the fuel consumptions.

Table 28–31 show the results of IB scenario 2 (IB S2) under changing winter conditions. IB S2 contain three icebreakers, in which cases, the average waiting time for ships to be assisted have relatively mild increasing trend with the ice condition becomes severe. Specifically, comparing to IB S1 cases, the average waiting time for mild winter is roughly at same level, slightly reduced. However, the average winter condition is different comparing IB S1. The increasing ice condition from mild to average winter does not increase the waiting time too much (~160 mins) for three icebreaker scenario, until the severe winter brings a bit more waiting time (~400 mins).

Table 31–34 show the results of IB scenario 2 (IB S3) under different winter conditions. IB S3 has four icebreakers which makes it possible for all winter scenarios that the average waiting time does not change largely with the changing winter conditions, keeps in a level below ~150 mins.

Table 25. IB scenario 1 – mild winter (IB S1 – WS1)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	57.0	91.6	~130
Gulf of Riga IB	8.6	6.23	

Table 26. IB scenario 1 – average winter (IB S1 – WS2)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	661.3	1063.4	~500
Gulf of Riga IB	172.4	125.0	

Table 27. IB scenario 1 – severe winter (IB S1 – WS3)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	757.6	1218.3	~1000+
Gulf of Riga IB	245.6	178.0	

Table 28. IB scenario 2 – mild winter (IB S2 – WS1)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	4.5	7.2	~110
Gulf of Finland secondary IB	38.3	61.6	
Gulf of Riga IB	0	0	

Table 29. IB scenario 2 – average winter (IB S2 – WS2)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	318.2	511.7	~160
Gulf of Finland secondary IB	273.9	303.2	
Gulf of Riga IB	171.7	124.5	

Table 30. IB scenario 2 – severe winter (IB S2 – WS3)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	532.3	856.0	~400
Gulf of Finland secondary IB	302.5	334.9	
Gulf of Riga IB	235.8	170.9	

Table 31. IB scenario 3 – mild winter (IB S3 – WS1)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	0	0	~110
Gulf of Finland secondary IB	51.3	82.5	
Gulf of Riga IB	6.6	10.6	
Gulf of Finland third IB	1.9	3.1	

Table 32. IB scenario 3 – average winter (IB S3 – WS2)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	177.0	284.6	~140
Gulf of Finland secondary IB	272.1	301.2	
Gulf of Riga IB	170.7	123.7	
Gulf of Finland third IB	157.1	126.4	

Table 33. IB scenario 3 – severe winter (IB S3 – WS3)

	Time in system (h)	Fuel consumption (ton)	Average waiting time/ship (mins)
Gulf of Finland primary IB	295.6	475.4	~150
Gulf of Finland secondary IB	302.0	334.3	
Gulf of Riga IB	258.6	187.5	
Gulf of Finland third IB	276.1	222.1	

RESULTS FOR ADDITIONAL LOW TRAFFIC AND NO ICEBREAKER SCENARIOS

In the low traffic case (LT – IB S2 – WS2), around 20% of traffic is cut, which results that the average waiting time reduces from ~160 to ~150 mins, while the total fuel consumption stays similar level.

In the no icebreaker case (NIB – WS2), as the icebreaker is not able to move and assist merchant ships, the average waiting time is not applicable. With the development of time, more ships get stuck and send signals for assistance. Figure 50 demonstrate qualitatively the evolution of ships get stuck in ice without icebreaker assistance.

Figure 50. Evolution of ships get stuck in ice conditions

Table 34 summarizes the results for all scenarios and gives an overview of how the Estonian winter navigation system (EST WNS) may behave under different winter-icebreaker-traffic combinations. In IB Scenario 2, the primary IB and secondary IB is used in Gulf of Finland. In order to identify how different if applying the primary IB and third

IB, another additional scenario is set up for this combination, modelled as IB Scenario 2* in severe winter. The result of estimated waiting time is slightly increased to ~470 mins in this case, with slightly increased operation time and fuel consumptions for all three IBs in this scenario.

Although the simulation results show reasonable trend for the scenarios, the modeling of the EST WNS still has many limitations and simplifications comparing to the practical working system. The absolute values of the waiting time need to be referred to carefully. The icebreaker assistance logic still needs improvements, and the practical icebreaker assistance is affected by more factors in reality. The average waiting time is likely to decrease if optimal home port or waiting point can be identified like the case in practice. Especially in IB Scenario 1, only one icebreaker in Gulf of Finland and Gulf of Riga respectively, the waiting time is likely to reduce dramatically. In addition, near coastline, there are possible icebreaking assistance from tugs and channels left by other ships, which are not able to be included in the simulation. This also reduces the waiting time in practice.

Table 34. Summary of the main KPI-average waiting time (mins) for all scenarios

	Mild winter	Average winter	Severe winter
IB Scenario 1	~130	~500	~1000+
IB Scenario 2	~110	~160	~400
IB Scenario 2*	-	-	~470
IB Scenario 3	~110	~140	~150
Low Traffic		~150	
No Icebreaker		N/A	

Additionally, the cooperation logic of the different operating zone for the icebreakers may still not reflect the reality as the practical icebreaker may not be able to enter certain regions due to technical characteristics. However, this effect is minor in the simulations, therefore does not have an obvious effect on the main outcomes. In general, further validation and comparisons with the practical cases are planned in future research for improving the accuracy and resilience of the model.

REFERENCES TO CHAPTER 4.2

Delbrugger, T., Meißner, M., Wirtz, A., Biermann, D., Myrzik, J., Rossmann, J., Wiederkehr., P., 2019. Multi-level simulation concept for multidisciplinary analysis and optimization of production systems. The International Journal of Advanced Manufacturing Technology 103, 3993-4012. doi:10.1007/s00170-019-03722-1.

Kulkarni, K., Kujala, P., Musharraf, M., Rainio, I., 2022. Simulation Tool for Winter Navigation Decision Support in the Baltic Sea. Applied Sciences 12: 7568. doi:10.3390/app12157568.

Kulkarni, K., Li., F., Liu, C., Musharraf, M., Kujala, P., 2022. System-level simulation of maritime traffic in northern Baltic Sea. In: Proceedings of the 2022 Winter Simulation Conference B. Feng, G. Pedrielli, Y.Peng, S. Shashaani, E. Song, C.G. Corlu, L. H. Lee. and P. Lendermann, eds.

Milaković, A.-S., Li, F., von Bock und Polach, F., Ehlers, S., 2020. Ship Technology Research, 67(2), 84-100. doi.org/10.1080/09377255.2019.1655260.

5. OPTIONS FOR THE ICEBREAKERS AND COST AND EFFECTIVITY ANALYSIS

5.1 TECHNICAL ASPECTS OF THE MULTIPURPOSE ICEBREAKERS

When evaluating different icebreaker designs in respect of multipurpose functions, it should be kept in mind that the other “multifunctions” can typically be performed also with other, non-icebreaking vessels and often more economically, because an icebreaker is somewhat heavy, powerful, and expensive by nature. In addition, in some cases the multipurpose functions can influence to the icebreaking capability of the vessel. On the other hand, icebreaking cannot be performed by other vessels, at least if the purpose is to escort larger vessels in difficult ice conditions. Further on, even though icebreakers are equipped to be efficient in various different tasks, their main difference and benefit compared to ‘normal’ ships is that they can perform their ‘multipurpose tasks’ also in ice: they can reach the operation site also in difficult ice conditions and are able to operate at the site despite ice. In addition, the multipurpose icebreaker may carry pilots, work as a tug or as rescue vessel in difficult ice conditions.

Ideas of different multipurpose functions may vary to large extent. Some of the considered functions can be easily installed, or do not add costs significantly, while some are large, heavy, expensive, and may also affect considerably the size, shape, and cost of the vessel itself. Obviously, it is financially feasible to keep the price of the vessel as low as possible.

The more additional tasks and functions are required for multi-purpose icebreaker, the more its main characteristics will differ from a ‘pure icebreaker’. Main technical features for additional purposes of icebreakers are:

- equipment for fighting external fires (Fi-Fi)
- oil spill combatting systems
- emergency towing systems
- towing equipment, towing notch
- large open aft deck for carrying cargo or other equipment
- working crane(s) designed for handling cargo and equipment
- tanks for small volumes of liquid or dry bulk cargoes
- additional accommodations for special personnel
- Scientific instruments and research equipment

Basically, these features are reflected in the vessel design through an increase in its size and displacement.

5.1.1 EXISTING EXPERIENCE ON MULTI-PURPOSE ICEBREAKERS

FINNISH/ESTONIAN MULTI-PURPOSE ICEBREAKERS

The development of the Finnish multipurpose icebreakers began in the mid-1980s when the Finnish Maritime Administration launched a project to find secondary uses for the new vessels it was planning to build as a replacement for some of the oldest icebreakers. A multipurpose application of the new icebreakers would thus result in a better utilization of the vessels and improve the economics of the state-owned fleet by assuming that the vessels would be chartered by a commercial third party during the summer. Finally, in the early 1990s, the summer period operational profile of new icebreakers was defined by the offshore markets' needs. Most of all, there was a demand for vessels that could conduct flexible pipe and cable laying and trenching and ploughing of cables and pipelines. Other defined tasks were e.g. cable repair work, anchor handling and the moving of offshore oil drilling platforms, semi-submersible units, and other offshore units, and transportation of deck cargo.

The first Finnish multipurpose icebreaker, Fennica, was delivered in 1993 by Aker Finnyards shipyard in Rauma, and her sister ship, Nordica, in the following year. When Fennica and Nordica entered service, it was agreed that the multipurpose icebreakers would be chartered for offshore duties about 180 days per year during the ice-free season. For the winter months, they would return to Finland for escort icebreaking duties or for lay-up in a Finnish port if there was no need to deploy the whole state-owned icebreaker fleet during particularly mild winters.

Although the shipowner has been generally satisfied with the vessels' operational capabilities, the multipurpose icebreakers have also been perceived as compromise designs due to the conflicting requirements of icebreaking and offshore operations. The vessels have been criticized for their lower icebreaking capability and ability to operate in the Bothnian Bay ice conditions characterized by heavy ridging when compared to traditional icebreakers built in the 1970s. In open water, the multipurpose icebreakers have not been competitive against purpose-built offshore vessels due to their higher fuel consumption. Unable to compete commercially against purpose-built offshore vessels, the multipurpose icebreakers would be the last ones to be hired unless they were offered at significantly reduced day rates. Sometimes the ships were left without contracts and spent long periods of time in foreign ports even during the Baltic Sea winter navigation season.

In 1997 a third multipurpose icebreaker was ordered from Finnyards. The ship, Botnica, was delivered in 1998 and it is slightly smaller and less powerful than the previous Finnish multipurpose icebreakers and has also several other differences. On 24 October 2012, the Port of Tallinn purchased Botnica for 50 million euro. According to Arctia Shipping, the newest state-owned icebreaker was sold because the company had been unable to find profitable long-term charters for it. Botnica changed her port of registry to Estonia on 28 November 2012 and Botnica has been contracted to provide icebreaking services in the Gulf of Finland until 20 April 2032. The current operator of Botnica is TS Shipping Ltd.

Since the change of ownership, Botnica has been chartered for various tasks. In 2013 Botnica was involved in air diving works in the North Sea renewables sector, and in 2014 it was supporting a drilling campaign in Kara Sea by conducting ice management, accommodation, and ROV duties.

In 2018, Botnica was chartered to Baffinland Iron Mines to escort iron ore shipments from Baffin Island from July until the end of October. The contract had an option for summers 2019–2022, all of which were utilized. At Baffinland Botnica assists Panamax-type merchant vessels in the Arctic waters of northern Canada in the export of iron ore from the port of Milne Inlet to the high seas. According to the charter agreement, Botnica provides escort and ice monitoring vessel service, pollution monitoring and emergency services. The total number of charter days for Botnica was 249 days in 2020 and the annual utilization rate of the ship was 68%. In 2019, 261 days and 72% accordingly.

Summer 2021 was Botnica's fourth summer working in Canada. In addition to icebreaking and ice monitoring work, various surface and underwater surveys of the Canadian Arctic were conducted by Canadian scientists onboard Botnica. The ship's positioning capabilities and flotation devices were fully utilized in the installation of the various monitoring devices.

US MULTI-PURPOSE ICEBREAKER FOR GREAT LAKES (GLIB) MACKINAW

The U.S. Coast Guard is required by law to maintain a heavy icebreaking capability at the Great Lakes to assist in keeping channels and harbors open for navigation to meet the winter shipping needs of industry. The USCGC Mackinaw (WLBB-30) is the U.S. Coast Guard's only icebreaker on the Great Lakes and was designed to provide multi-mission capabilities and it features a diesel-electric propulsion system with electric podded propulsors and a hull form optimized for both icebreaking and open water performance. The vessel, built by Marinette Marine Corporation, replaced the old Mackinaw built in 1944.

The GLIB Request for Proposals (RFP), issued on December 21, 2000, provided for a multi-purpose cutter, capable of heavy icebreaking and also functioning as a buoy tender in the Great Lakes. The Coast Guard awarded Marinette Marine Corporation with a contract to construct a new multi-purpose icebreaking vessel on Oct 15 2001. The USCGC Mackinaw was launched on April 2, 2005, and delivered in October of 2005.

The new Mackinaw greatly enhanced the Coast Guard's ability to conduct essential icebreaking activities while remaining multi-mission capable. In addition to icebreaking, the new Mackinaw maintains aids to navigation, assists with search and rescue as needed, and conducts port security and law enforcement operations as required.

CANADA'S COAST GUARD MULTI-PURPOSE VESSELS

Canada has a project to replace a large part of the Canadian Coast Guard fleet with up to 16 Multi-purpose Ships, with the first ship planned to be delivered in 2029.

The multi-purpose vessels (MPV) will allow the Canadian Coast Guard to carry out multiple missions, including:

- icebreaking in moderate ice conditions and assisting in shipping, and springtime flood control in the St. Lawrence waterway and Great Lakes region
- search and rescue, emergency response, and security and protection missions
- maintaining Canada's marine navigation system composed of approximately 17,000 aids to navigation.

The MPVs are planned to replace up to three classes of older ships in one platform. The target is to develop a compact ship with multiple operational roles. The sixteen vessels will mainly replace the Type 1100-class built in the late 70s and early 80s, often called as the “work horses” of the CCG fleet, doing the day-to-day work of supporting shipping by maintaining fairways, aids to navigation, and icebreaking.

In addition to icebreaking, the MPVs will also perform cargo missions, bringing supplies to northern communities, carry out search & rescue and patrol missions. Most of their time will be spent on the St Lawrence River, the Great Lakes, and along the Canadian East Coast. Additionally, they will have a summer Arctic mission leaving from Victoria in British Columbia and navigating north around Alaska to the Canadian Arctic.

Due to the wide variety of tasks, the long-distance missions in the Arctic, and the fact that some of the waterways have a limited depth, the vessel shall be compact with a shallow draught, narrow beam, high endurance, and with a large cargo capacity.

RUSSIAN ICEBREAKING MULTI-PURPOSE SALVAGE VESSELS

In the beginning of the 2000s, Russia planned to build small and medium-sized icebreakers (with a shaft power of about 4 and 7 MW) for the freezing non-Arctic seas and harbour areas, and their multi-purpose use was also considered. Finally, icebreaking ships with similar sizes and power levels, but with the main purpose as rescue vessels, were implemented through a state program for the construction of new fleet for State Marine Rescue Service (Gosmorspassluzhba), with the construction of MPSV06-class and MPSV07-class vessels.

The bigger vessels of MPSV06-class of 7 MW shaft power have a proper icebreaker class of ‘Icebreaker6’, and have been employed from time to time for icebreaker escort services, e.g. at the Russian Far East. The first vessel of the class was reportedly laid down at Amur Shipyard in Russia, already in 2010, but the construction was later suspended, and the vessel still not delivered so far. The second and third vessels, Beringov Proliv and Murman were built in Germany at Nordic Yards in Wismar after some improvements made in the design and delivered in December 2015 (newbuilding price of 75 MEUR for one ship). Two more vessels of modernized design of MPSV06M are now under construction at the Yantar Shipyard.

In addition, the concept of ‘oblique’ icebreaker developed by Aker Arctic was also implemented within the same program for the construction of 7 MW rescue vessels. Multi-functional icebreaking rescue vessel Baltika was built by Arctech Helsinki Shipyard (Finland) in co-operation with Yantar Shipyard (Russia) and delivered to the ship operator Gosmorspassluzhba in May 2014.

MPSV07 class vessels are series of four icebreaking salvage vessels, which were delivered between 2012 and 2015. MPSV07-class of 4 MW shaft power have ice class Arc5, meaning that they are not designed to work as an escorting icebreaker as their main task.

5.2 SUMMARY ON MULTIPURPOSE USE OF ESTONIAN ICEBREAKERS

Due to the nature of icebreaking service which is needed only for a short period in a year, it is natural and wise to try to find other uses for the icebreaker vessels during off-season. The attractiveness of the “other” use is mainly dependent on the length of the off-season.

If the icebreaking season is long the attractiveness to use the vessel in multipurpose uses is lower. Naturally the best results have been the cases in which the icebreaker has been utilized in icebreaking activities during the summertime. This has been the case sometimes in arctic research, oil/gas exploration, offshore support in the arctic and escort icebreaking in the arctic. Then there is less need for compromises, and icebreakers valuable features are used in the summertime as well.

Icebreaking in Estonian waters and ports is characterized by a short winter season. This means that there is good reasons and potentially high benefit for finding multipurpose uses for the icebreaker. It is to be kept in mind that icebreaking is a task which has to be done during the wintertime, and the vessel must comply with sufficient technical requirements for icebreaking, which are defined in this study (Chapter 0 5.4 Icebreaking scenarios) and have good operational capability for icebreaking.

Some major technical aspects, which influence the icebreakers operational capability, are related to sea keeping behavior, cargo spaces and hullform and these will influence negatively for icebreakers agility and icebreaking capability. Escort icebreaker needs constantly to start and stop assistance operations and escorted distances are quite short. Therefore, the icebreakers agility is very important factor for successful and efficient icebreaking. Secondly, if "multipurpose" hullform reduces vessel's nominal icebreaking capability, it have to be compensated with higher engine power, thus also increasing operational cost and emissions.

Table 35 identifies the main requirements for a pure icebreaker and requirements for different multipurpose uses. Some vessel-types require more functions and some less. Further, the Table 36 shows which requirements have negative influence for icebreaking or if some features can even have positive effect.

Table 35. Vessel requirements in the various multipurpose uses

	Escort icebreaker	CG patrol vessel OPV	SOV (Offshore Wind)	Fairway maintenance	Navy Support Ship	Search and rescue
Level icebreaking capability	YES	YES	YES	SOME	SOME	SOME
Good manoeuvring/agility	YES	YES	YES	SOME	YES	YES
High engine power	YES	YES	NO	NO	NO	NO
Good seakeeping capability	NO	YES	YES	YES	YES	YES
High openwater speed	NO	YES	NO	NO	NO	NO
Dynamic positioning	NO	YES	YES	YES	YES	YES
Cargo capacity	NO	NO	SOME	SOME	SOME	SOME
Cargo handling	NO	NO	YES	SOME	YES	YES
Personnel requirement >20	NO	YES	YES	NO	YES	YES
Oil spill	NO	YES	NO	NO	NO	YES
Fi-Fi	NO	YES	SOME	NO	SOME	YES
Emergency towing	NO	SOME	NO	NO	SOME	YES
Work boat landing system	NO	YES	YES	YES	NO	NO
Helicopter operations	NO	YES	YES	NO	YES	YES

Table 36. Other requirements impact to ship as an icebreaker and cost impact

FEATURES IMPACT TO VESSEL AS ICEBREAKER			COST IMPACT
Level icebreaking capability	POSITIVE		
Good manoeuvring/agility	POSITIVE		
High engine power	POSITIVE		
Good seakeeping capability	NEGATIVE		HIGH
High openwater speed	NEGATIVE		HIGH
Dynamic positioning	NEUTRAL		MEDIUM
Cargo capacity	NEGATIVE		MEDIUM
Cargo handling	NEUTRAL		MEDIUM
Personnel requirement >20	NEUTRAL		LOW
Oil spill	NEGATIVE		MEDIUM
Fi-Fi	NEUTRAL		LOW
Emergency towing	NEUTRAL		MEDIUM
Work boat landing system	NEUTRAL		MEDIUM
Helicopter operations	NEUTRAL		MEDIUM

As a conclusion we can see that OPV vessel actually have lot of requirements, but at the same time it is also required to operate in ice conditions. So, there are supporting requirements. The biggest design compromise issues are seakeeping and high open water speed requirements, which can be technically solved but will result additional costs. Features most likely do not increase the icebreaker size but could influence to the icebreaking capability.

Also, the SOV (Offshore Wind Service) vessel has a lot of requirements, and capability to operate in the wintertime is welcomed as well. There are less hullform issues as SOV does not have such a high speed requirement as the OPVs. Cargo capacity can be managed. In open water use the SOVs have typically length of about 80 metres, which is quite close to size of Estonian secondary icebreaker.

Fairway maintenance functions are the easiest to fulfill with pure icebreaker and would bring least additional cost as well. It's worth to note that this function is used in North American icebreakers often.

One option evaluated is also to use the vessel by Navy. Estonian Navy has limited number of vessels, and the largest ones are used for mine hunting but are still smaller in size than icebreaker. Should there be need for larger Navy vessels, the suitable type could be Navy's support vessels (non-combatting vessel). It would also benefit of ice going features, and as a government vessel it could fit well in the Estonian fleet portfolio.

MULTIPURPOSE VESSEL'S AVAILABILITY FOR ICEBREAKING

Icebreaking duties are such that have to be carried out during certain months of the year and the unpredictability of the weather makes is variating from winter to winter. This requirement for availability has caused difficulties for the contracting the vessel. Many multipurpose uses also need vessels all the time or full annual periods of a multiyear contract for example. Practically such cases do not suit for icebreaker multipurpose use.

Then there are functions which are not needed on the wintertime or functions where vessel can operate in icebreaking and same time carry out certain duties (example SAR, Patrol, oil spill preparedness).

Following Table 37 summarizes the potential and typical restriction for multipurpose uses:

Table 37. Vessels availability for the icebreaking

Offshore Patrol Vessel	Coast Guard missions are mostly patrolling and vessel can arrange availability for icebreaking. Can be well combined with icebreaking.
SOV vessel	Wind park SOV vessels typically have commercial 24/7 contracts and therefore is not easily combined with icebreaking.
Fairway maintenance	Operation which is typically done during open water season. Well combined with icebreaking.
Navy Support Ship	Navy operations typically are reduced during ice season. Quite well available for icebreaking.
Search and Rescue	SAR operation has to carried our year around and operation is occasional for bigger SAR vessels. Well suited with icebreaking.

KEY TAKEAWAYS

No	Task/ question*	Answer
8	Are investments in a multipurpose vessel worth it? What uses are necessary/ reasonable for new icebreakers? (incl. is it reasonable to equip icebreakers with the ability to fight marine pollution?)	All multipurpose functions will add some cost on the icebreaker, but it is expected that the size of the icebreaker would not change and important icebreaking requirements can be maintained despite multipurpose use. Recommended multipurpose uses for Estonian governmental functions include mainly the following: Recommended multipurpose uses for Estonian governmental functions: - Coast Guard patrol vessel (with SAR functions) - Fairway maintenance vessel

5.3 DETACHABLE BOW CONCEPT FOR ICEBREAKER

Detachable icebreaking bow concept refers to a solution in which an icebreaking bow is attached (and de-attached) to another vessel referred as pusher (Figure 51). During summer season, the pusher can conduct other tasks on its own without the detachable bow, and during icebreaking season the detachable bow is attached to the pusher and the combination works as an icebreaker.

The detachable bow concept allows to have a multipurpose vessel with somewhat low costs as the detachable bow can be designed basically only for icebreaking and connected to an existing vessel which can be optimized for open-water operations. The bow is typically wider than the pusher which enables good manoeuvrability for the combination in ice but creates some challenges for astern operation and ridge penetration. Ridges also create some challenges to the connection mechanism between the bow and pusher. Detachable bows are typically used at inland waterways (lakes, rivers) where level ice and channels are the dominant ice conditions and waves and winds are not as significant factors as at open sea. The seakeeping characteristics of a pusher – icebreaking bow combination are not as good as for regular icebreaker which limits the combination’s use at open sea conditions at least to some extent.

Tugboats are typically used as the pusher since tugs have high propulsion power and good thrust characteristics per se. It is also possible to motorize the detachable bow to increase the propulsion power if needed. In addition, tanks can be mounted into the bow. In principle the detachable bow could also be attached to an old icebreaker when the detachable bow can be used to increase the width of the icebreaker and/or improve the efficiency of the old icebreaker by equipping it with a modern bow.

Figure 51. Detachable icebreaking bow Saimaa (blue) attached to tug Calypso (black).

The benefits of the detachable icebreaking bow can be summarized as following:

- Low price compared to a complete new icebreaker;
- Small manning compared to a "full" icebreaker;
- The pusher can be optimized more for open-water operations as the bow can be detached and left at the icebreaking site → wide operation area for the pusher;
- The bow can be designed basically only for ice operations. Little need to consider open-water issues → radical bow geometries possible;
- Easy/cheap method to produce wider channel than the pusher alone → Good maneuverability in ice for the combination;
- Fuel capacity and the independence time of the pusher can be increased if fuel is stored in the detachable bow.

Challenges with detachable bow can be summarized as following:

- Works best in level ice and channel conditions. Functionality at open sea conditions not optimal:
    - Performance in ridges;
    - Seakeeping characteristics;
- Icebreaking always needs power and thrust no matter how efficient the bow design is → finding a suitable pusher for difficult ice conditions with thick ice can be challenging;
- The bow is weight-critical which adds some challenge to the design and building of the bow.
- The bow is purposely built for certain tug-type and the possibilities to mount the bow into other vessels without modifications are limited. Basically, this means that the tug probably shall be chartered with a long-term contract.

5.3.1 SUITABILITY OF THE DETACHABLE BOW TO ESTONIAN ICEBREAKING

The size and power level of the pusher are limiting factors for in what kind of conditions the detachable bow can be used. The primary icebreaker needed for Estonia would need propulsion power of about 10 MW (see chapter 5.4) and such powerful tugboats are rare. Additional propulsion motors in the bow could help in this issue to some extent. However, the necessary width of 24 meters (chapter 5.4) would also be required for the detachable bow. The difference of tug's and bow's width is a limiting factor for detachable bow solution. There shouldn't be excessive difference between the pusher and bow width, otherwise there will be issues for astern operations in ice. Considering the above-mentioned limitations, it can be concluded that a detachable bow could considered as a possible solution to Gulf of Riga or as the level three icebreaker (see explanation in chapter 5.4) at Gulf of Finland. However, extra attention is needed for seakeeping characteristics and ability to operate in ice ridges. As discussed in the previous chapter, the detachable bows are typically used at inland waterways and references designed for open-sea use do not exist.

A detachable icebreaking bow and tug combination has been used at the Gulf of Riga. The cost differences between a normal purposely built icebreaker and an icebreaking bow and tug combination are compared in the following chapters for the Gulf of Riga.

5.4 ICEBREAKING SCENARIOS

Currently Estonia has two icebreakers to operate in the Gulf of Finland region and one in the Gulf of Riga. As this study evaluates different options for carrying out icebreaking services and taking into account the future needs for it, several scenarios are needed to be investigated.

Because Gulf of Finland and Gulf of Riga are geographically far apart, and practically there is no possibility for operational support from one region to other, these two regions are considered separately.

Gulf of Finland

The study includes three main scenarios in which the number of icebreakers vary (Figure 52). Either 1, 2 or 3 icebreakers are analyzed. Because icebreakers also vary by their capability, mainly the icebreaking capability, also three different icebreaking requirement levels are created. These levels are based on the existing shipping traffic and ice conditions in the different ports. In the figure below the three icebreaker requirements are shown. Beam requirement of 24 meters is chosen as many assisted cargo vessels are that size. There are also larger vessels, but their number is quite small.

Gulf of Finland icebreaking

ONE icebreaker (primary icebreaker)	TWO icebreakers (second icebreaker)	THREE icebreakers (third icebreaker)
Technical requirements: -IB 60cm/8 kn -Iceridge penetration - Min beam 24m -Towing arr. YES -ice class PC5*	Technical requirements: -IB 60cm/6 kn -Iceridge penetration -Min beam 24m -Towing arr. NO -ice class PC5*	Technical requirements: -IB 50cm/6 kn -Min beam 18m -Towing arr. NO -ice class PC6*

**Additional strengthening above rule minimum level in accordance with anticipated operational scenarios*

Figure 52 Gulf of Finland Icebreaking

Three scenarios are analysed by the simulations according to following arrangements:

CASE 1 icebreaker	Use one Primary icebreaker
CASE 2 icebreakers	Use one Primary and one Secondary icebreaker
CASE 3 icebreakers	Use one Primary, secondary and third level icebreaker

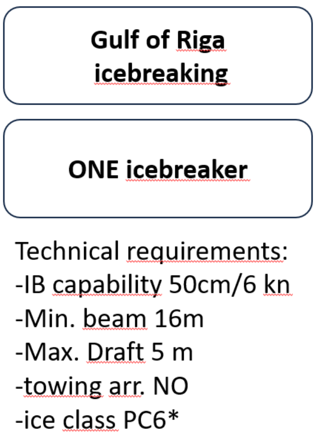
It should be noted that in case there would be only one icebreaker, it's operational area reaches from Paldiski to Sillamäe, with a distance of about 140 nm. Longer distances means that icebreaker is spending more time on sailing as compared to assistance operation. This is partly compensated with higher icebreaker speed what vessel can achieve.

And on the contrary, in the case there would be three icebreakers, sailing distances are smaller and icebreakers can succeed with less speed capability.

It is assumed in this study that icebreakers operate in certain regions, thus avoiding unnecessary sailing with no assistance.

Gulf of Riga

As the number of ports and traffic is somewhat small in the Guld of Riga area, it is reasonable to consider only option with one icebreaker. Based on the traffic, ice conditions and interviews following requirement was derived.



**Additional strengthening above rule minimum level in accordance with anticipated operational scenarios*

Figure 53 Use one Gulf of Riga Icebreaker

The above-mentioned icebreaker requirements are irrespective of what type of icebreaker is used: whether a conventional, multipurpose or detachable icebreaking bow is used, the icebreaker should have the above-mentioned performance. Therefore, differences between different option are mainly related to the costs of the icebreaker.

As mentioned in chapter 5.3.1, a detachable icebreaking bow & tug combination can be considered as a possible solution as the icebreaker for the Gulf of Riga. The above-mentioned requirements can be fulfilled with detachable icebreaking bow. Sufficient performance could be achieved with a tug which has ~55 ton bollard pull capability. The beam of such tug is approximately 12 meters which is reasonable width considering a 16 m wide detachable bow.

Two different scenarios are considered for the Gulf of Riga icebreaking: a normal purposely built icebreaker and a non-motorized detachable icebreaking bow and tug combination. Both solutions are considered to have similar icebreaking capability with azimuthing propulsion. The costs of both scenarios are compared in the next chapters.

5.5 COST OF ICEBREAKERS

5.5.1 CAPITAL COSTS

5.5.1.1 CALCULATION METHOD

In this section the basic assumptions and the method used to estimate the construction costs (newbuilding price) of different scenario-based Estonian Icebreaker options are briefly described.

The calculation method evaluates the total price of the vessel by dividing it into following general categories: hull, ship systems and outfitting, machinery, propulsion, and shipyard related costs. The cost estimation for each category is done by using input data from a reference vessel(s) which price is known. First, the model is applied and tuned to the reference vessel(s), and then reapplied to the new concepts.

The hull costs are evaluated with following method: steel price and labor costs are first evaluated and tuned for the reference vessel, and then scaled for the new design considering weight of the hull and the quantity of steel required by ice class notation. Similar approach is used for outfitting costs, which are scaled with vessel size and ice class notation. The main machinery, electrical systems and ship propulsion component prices are taken, if possible, directly from the supplier or from similar existing ships, or scaled based on the power of machinery installation. The shipyard related costs are calculated as a percentage of the value of the vessel to take in account elements, such as: yard profit, design costs, and capital costs.

It is important to point out how the final price can vary greatly between different shipyards for such special vessels as icebreakers. Two factors have great influence on the quoted shipyard price. The first one is the location of the shipyard which influences the price directly with labour costs. The second one is the experience of the yard which plays a very important role in the final price. Finally, the number of shipyards competing for the vessel newbuilding also influence on their quotation.

The considered reference shipbuilding market is limited to number of dedicated shipyards of the Northern Europe and the Far East (Asia).

Costs of the detachable icebreaking bow & tug combination are estimated by taking an average market price of suitable ice-class tug and estimating the construction costs of a non-self-propellered detachable bow with required icebreaking performance.

5.5.1.2 PRELIMINARY RESULTS

Table 38 shows preliminary main particulars and technical data and the estimated construction costs for different design options of the Estonian Icebreaker. The constructions costs are based on assumption of considering a quotation for a single vessel. The newbuilding price estimation has a ±20% percent margin.

Table 38. Estonian Icebreaker design options and price estimations

Parameter	*Gulf of Riga*		*Gulf of Finland*		
	Icebreaker	*Tug + Detachable bow*	*Primary IB*	*Secondary IB*	*Third IB*
Breadth, m	**16**	**16 (bow)** 12 (tug)	**24**	**24**	**18**
Design draught, m	4.5	4.5	7.5	7.2	6.0
Length (DWL), m	54	40+18	90	86	62
Depth on main deck, m	6.0	6.0	11.0	10.5	8.5
Lightweight (est.), t	1600	1050+750	5700	4900	2500
DWT on design draft, t	700	200	3000	3000	1500
Type of propulsion	2 Z-drive propeller units	2 Z-drive propeller units	2 electrical / Z-drive propeller units	2 Z-drive / electrical propeller units	2 Z-drive propeller units
Propulsion power, MW (estimated)	4.4	4.4	10	7	5
Total ME power, MW (estimated)	5.1	5.1	13	9.1	6.2
Service speed, kn	12	11	14	13	13
Construction cost estimation, million EUR	**40**	18 + 8 = 26	**100**	**85**	**50**
Crew (min)	12	8	20	18	16

5.5.2 OPERATIONAL COSTS

5.5.2.1 BASIC ASSUMPTIONS FOR OPEX CALCULATIONS

Operational expenses (OPEX) in general case include following main items:

- Fixed expenses associated to the maintenance of ships in operation (crew expenses, insurance, technical services, repair, drydocking, management etc.).

- Running (navigation-based) expenses, including fuel expenses, port/waterway/canal dues and possible fees.

For this study, following structure of fixed OPEX is used for the initial estimation of possible level of operational expenses without fuel costs:

- Crew & provision expenses
- Insurance
- Technical services, spare parts, maintenance
- Ship repairs, drydocking, class surveys
- Management expenses

The presented estimates are based on available public statistical data, as well as on previous estimates of operating costs for various types of icebreakers.

5.5.2.2 FIXED OPERATIONAL COSTS ESTIMATION

Crew expenses

Crew expenses consist of the salary of ship crew members including overtime and vacation, training, travel and medical care, taxes and social expenses, food provision onboard, etc. The crew expenses are estimated by estimating the approximate crew composition with the total gross salary and provision expenses. The total salary is estimated based on the minimum salary level established for seafarers by International Transport Workers' Federation. For the present study "ITF International Collective Bargaining Agreement 2022–2023" is used (ITF Seafarers, 2022). The actual level of crew salaries which depend on such factors as required level of experience and nationality of the crew members etc., is taken into account by applying coefficients to the minimum salary level.

It is assumed that the operating period of the icebreaker is year-round, and the estimated salary level covers all needs of the crew during whole year. Two different crew salary levels have been calculated due to high uncertainties.

Insurance expenses

The amount of the annual insurance premium depends on:

- type of vessel
- price of the vessel (vessel's value)
- technical condition
- areas of navigation and type of operation
- number of operational days per year
- set of insurance risks (insurance coverage)

Based on known statistical data for icebreakers, insurance expenses for Estonian Icebreaker options are assumed to be 0.5–1.0% of the vessel price per year.

Technical expenses

For an estimation of the technical expenses in operation of Estonian Icebreaker design options, both known info from suppliers and statistical data are used. The technical expenses include:

- Technical services, spare parts, maintenance of the machinery and propulsion – estimation based on known data from suppliers of machinery, electrical and propulsion installation, in the range of. 0.75–1.5% of the vessel price per year.
- Ship repairs, drydocking, class surveys – roughly estimated as 0.5% (low level) or 1.25% (high level) of the vessel price per year.

Management expenses

Management expenses are the costs related to the operation of the vessel, caused by the need for its maintenance by onshore personnel: superintendents, accountants, commercial department, marketing, etc. In the present estimation this item is taken as 3% of total fixed expenses.

Estimations of fixed OPEX items (without fuel expenses) are presented in Table 39 and Table 40.

Table 39. Low level estimation of operational costs for Estonian Icebreaker design options

	Gulf of Riga		*Gulf of Finland*		
	Icebreaker	*Tug + Detachable bow*	*Primary IB*	*Secondary IB*	*Third IB*
Construction cost, MEUR	40	26	100	85	50
Annual fixed costs estimation, thousand EUR per year					
Crew and provision	609	345	866	774	716
Insurance	200	130	500	425	250
Service, maintenance	300	195	750	638	375
Repairs, drydocking, surveys	200	130	500	425	250
Management	39	24	78	68	48
Total	**1348**	**824**	**2694**	**2329**	**1638**
Total monthly, kEUR/month	112.4	68.7	224.5	194.1	136.5
Total daily, EUR/day	3708	2266	7409	6405	4505

Table 40. High level estimation of operational costs for Estonian Icebreaker design options

	Gulf of Riga		Gulf of Finland		
	Icebreaker	*Tug + Detachable bow*	*Primary IB*	*Secondary IB*	*Third IB*
Construction cost, MEUR	40	26	100	85	50
Annual fixed costs estimation, thousand EUR per year					
Crew and provision	752	421	1053	978	873
Insurance	400	260	1000	850	500
Service, maintenance	600	390	1500	1275	750
Repairs, drydocking, surveys	500	325	1250	1063	625
Management	68	42	144	125	82
Total	**2319**	**1438**	**4947**	**4290**	**2831**
Total monthly, kEUR/month	193.3	119.8	412.2	357.5	235.9
Total daily, EUR/day	6378	3953	13603	11799	7785

5.5.2.3 FUEL COSTS ESTIMATION

Annual fuel expenses were calculated based on the results of simulation output, as presented in Table 25–33. To the fuel consumption value given, which corresponds to the active operation on escorting the cargo vessels in ice, the amount of fuel, burned during stays in port or waiting in sea, is additionally calculated for the rest of time during Icebreaking season. For this purpose, an estimation made of daily fuel consumption for the considered design options of icebreakers. The icebreaking season, defined as period when an icebreaker is technically ready to start assistance immediately, assumed to be 4 months in mild winters, 5 months for average winters and maximum of 6 months – for the severe type of winter.

Further on, for the rest months of the year, an amount of fuel required for the laid-up was calculated, from the estimated daily fuel consumption for the variants of icebreakers during laid-up.

The fuel price used in the calculation is 650 EUR/ton.

5.5.2.4 CAPITAL COST ESTIMATE

As the scheme of organizing of purchase of new Estonian icebreakers is unknown, CAPEX was preliminary estimated according to a formal simple depreciation for 20 years period (no interest rate applied). Service life of icebreakers could be up to 50 years. All possible modernization/renovation costs during the whole service life were not considered. The results given below are intended for general indicative comparison purposes only. Please see financial calculations presented in the WINMOS cost calculation model (Chapter 6) for more details.

5.5.3 SUMMARY OF COSTS

Summarizing values of calculated costs are presented for 2 different approaches: all-year-round costs for the cases of single-purpose icebreaker (Table 41, Table 42, Table 43 and Table 44 for the Gulf of Riga scenario), and winter seasonal costs, related to the expenses for the icebreaking use of multi-purpose icebreaker options (Table 45, Table 46 and Table 47 for 3 different scenarios for the Gulf of Finland, and Table 48 & Table 49 for the Gulf of Riga).

Table 41 Summary of capital and operational expenses estimated for year-round operation (single-purpose) in case of 1 IB in the Gulf of Finland

Winter type	**MILD**	**AVERAGE**	**SEVERE**
Operation months	12	12	12
Annual operative cost	2,694,000 €	2,694,000 €	2,694,000 €
Annual fuel cost	731,000 €	2,212,000 €	2,831,000 €
Annual capital cost	5,000,000 €	5,000,000 €	5,000,000 €
Total	**8,425,000 €**	**9,906,000 €**	**10,525,000 €**

Table 42. Summary of capital and operational expenses estimated for year-round operation (single-purpose) in case of 2 IB in the Gulf of Finland

Winter type	**MILD**	**AVERAGE**	**SEVERE**
Operation months	12	12	12
Annual operative cost	5,023,000 €	5,023,000 €	5,023,000 €
Annual fuel cost	1,290,000 €	2,450,000 €	3,409,000 €
Annual capital cost	9,250,000 €	9,250,000 €	9,250,000 €
Total	**15,563,000 €**	**16,723,000 €**	**17,682,000 €**

Table 43. Summary of capital and operational expenses estimated for year-round operation (single-purpose) in case of 3 IB in the Gulf of Finland

Winter type	**MILD**	**AVERAGE**	**SEVERE**
Operation months	12	12	12
Annual operative cost	6,661,000 €	6,661,000 €	6,661,000 €
Annual fuel cost	1,778,000 €	2,787,000 €	3,635,000 €
Annual capital cost	11,750,000 €	11,750,000 €	11,750,000 €
Total	**20,189,000 €**	**21,198,000 €**	**22,046,000 €**

Table 44. Summary of capital and operational expenses estimated for year-round operation (single-purpose) in case of IB for the Gulf of Riga

Winter type	MILD	AVERAGE	SEVERE
Operation months	12	12	12
Annual operative cost	1,348,000 €	1,348,000 €	1,348,000 €
Annual fuel cost	436,000 €	622,000 €	898,000 €
Annual capital cost	2,000,000 €	2,000,000 €	2,000,000 €
Total	**3,784,000 €**	**3,970,000 €**	**4,246,000 €**

Table 45. Summary of capital and operational expenses estimated for seasonal operation (icebreaking only) in case of 1 IB in the Gulf of Finland

Winter type	MILD	AVERAGE	SEVERE
Operation months	4	5	6
Annual operative cost	898,000 €	1,122,500 €	1,347,000 €
Annual fuel cost	419,000 €	1,939,000 €	2,597,000 €
Annual capital cost	1,666,667 €	2,083,333 €	2,500,000 €
Total	**2,983,667 €**	**5,144,833 €**	**6,444,000 €**

Table 46. Summary of capital and operational expenses estimated for seasonal operation (icebreaking only) in case of 2 IB in the Gulf of Finland

Winter type	MILD	AVERAGE	SEVERE
Operation months	4	5	6
Annual operative cost	1,674,333 €	2,092,917 €	2,511,500 €
Annual fuel cost	666,000 €	1,904,000 €	2,941,000 €
Annual capital cost	3,083,333 €	3,854,167 €	4,625,000 €
Total	**5,423,667 €**	**7,851,083 €**	**10,077,500 €**

Table 47. Summary of capital and operational expenses estimated for seasonal operation (icebreaking only) in case of 3 IB in the Gulf of Finland

Winter type	MILD	AVERAGE	SEVERE
Operation months	4	5	6
Annual operative cost	2,220,333 €	2,775,417 €	3,330,500 €
Annual fuel cost	920,000 €	2,037,000 €	2,991,000 €
Annual capital cost	3,916,667 €	4,895,833 €	5,875,000 €
Total	**7,057,000 €**	**9,708,250 €**	**12,196,500 €**

Table 48. Summary of capital and operational expenses estimated for seasonal operation (icebreaking only) in case of IB for the Gulf of Riga

Winter type	MILD	AVERAGE	SEVERE
Operation months	12	12	12
Annual operative cost	449,333 €	561,667 €	674,000 €
Annual fuel cost	202,000 €	418,000 €	606,000 €
Annual capital cost	666,667 €	833,333 €	1,000,000 €
Total	**1,318,000 €**	**1,813,000 €**	**2,280,000 €**

Table 49. Summary of capital and operational expenses estimated for seasonal operation (icebreaking only) in case of tug & detachable bow for the Gulf of Riga.

Winter type	MILD	AVERAGE	SEVERE
Operation months	4	5	6
Annual operative cost	274,667 €	343,333 €	412,000 €
Annual fuel cost	202,000 €	418,000 €	606,000 €
Annual capital cost	700,000 €	775,000 €	850,000 €
Total	**1,176,667 €**	**1,536,333 €**	**1,868,000 €**

KEY TAKEAWAYS

No	Task/ question*	Answer
3	In what directions could icebreaking services be developed? Propose three (3) scenarios for the Gulf of Finland and the Gulf of Riga and highlight their disadvantages and advantages with investments and running costs of possible new icebreaker(s).	Three base case scenarios are created. Please see **Sub-Chapter 5.4 Icebreaking Scenarios** for details.
5	What is the projectable cost of each scenario and what possible funding models could be utilised? For each option, describe the main parameters of the respective vessels providing icebreaking services and analyse how can current fleet be utilized. Analyse at least the following options to find suitable	Please see Table 54. Summary of estimated costs for winter navigation assistance options in Estonia. Costs for icebreakers are based on the Chapter 5

combinations of vessels for the scenarios:

- suitable icebreakers of different sizes (owned/constructed by the state);
- suitable icebreakers of different sizes (chartered);
- seagoing tug with an attachable icebreaking bow (chartered);
- seagoing tug with an attachable icebreaking bow (constructed by the state);
- two suitable and powerful seagoing tugs working together without an attachable icebreaking bow (owned/constructed by the state);
- two suitable and powerful (for the Baltic Sea) seagoing tugs working together without an attachable icebreaking bow (chartered).

5.6 OFFSHORE WIND FARMS AND SHIPPING – WINTER NAVIGATION

Offshore Wind Power

Offshore wind power is clean energy that has drawn tremendous attention and grown rapidly over the past decade in the world, especially in the North Sea and Baltic Sea areas. In comparison with other energies, offshore wind power has several advantages, inter alia, no occupancy of land space, abundance in wind resource and suitability of large-scale development. However, the development of offshore wind farms (OWFs) unavoidably has profound impacts on navigation environment. A majority of OWFs have been established in the offshore sea areas, meaning territorial seas and EEZ areas. A lot of attention must be paid on commercial maritime activities to avoid insufficient distances to shipping routes, inadequate safety mitigation measures and unsuitable marking of wind turbines are undoubtedly detrimental to safety of navigation.

In Estonian coastline and Gulf of Riga area there are several offshore wind farms under planning, and this is to be considered not only for open water season navigation, but especially during the ice season.

The rapid development of offshore wind industry has posed profound influences to the maritime industry. In the operating phase, the OWF brings the impacts of fragmentation and tridimensional exclusivity to the use of the sea area, leading to the loss of compatibility of the sea resources, and permanently affects the safety of navigation. The presence of OWF will complicate the navigation environment of the adjacent waters. For examples, inadequate distance to shipping routes, waterways and anchorages may present a risk of collision between ship wind turbine, unsuitable establishment, and maintenance of Aids to Navigation (AtoNs) may confuse the navigators and induce improper handling of ships, and the electromagnetic radiation generated during the operating phase of OWF may affect the navigational equipment on board ships.

Winter and ice conditions are very challenging time for navigation of vessels, and they are in many cases assisted by ice breakers on their way to the port and from the port. OWFs close to the winter navigation routes creates an additional risk and challenge for winter navigation, because the areas reserved to wind farms are closed to commercial navigation and in many cases their occupied area are huge. Therefore shipping in winter period is forced to use areas, which in many cases are more challenging for navigation due to harsh ice conditions.

With the traditional traffic patterns, ship types and sizes, the applied winter navigation systems have worked rather well, although the occurrence of some limited ice damages each winter has not been totally eradicated. Therefore, the impression of a high safety level of winter navigation has grown strong during the past long period of mild and normal winters. However, this impression, which may be based too strongly on the favorable accident statistics, may not consider the combined effects of the continuous or occasional changes in the numerous parameters of the whole system. All the accident mechanisms are not too well known and the complexity of the large and both functionally and geographically distributed system of the winter navigation is difficult to grasp.

New infrastructure in maritime domain, namely offshore wind farms (herinafter also OWFs) is in planning, which additionally increases the risks for shipping, especially during the ice period. New operators in shipping in the Baltic Sea may well be aware of the hazards of winter navigation. However, exceptions certainly exist. Even some of the most experienced operators as well as the whole shipping society may not be sufficiently prepared for some of the hazards and possible risks that e.g. a rarely occurring winter storm may introduce.

Offshore Wind Farms (OWFs) have specific issues where they conflict with traditional activities such as navigation. Aspects of OWFs that need to be considered are:

- OWFs are situated in open sea, where mariners do not expect to encounter obstacles
- OWFs have parts both under and above the water surface
- OWFs have fixed parts and moveable parts (the turbine blades)
- OWFs are individual constructions, formed into an array
- OWFs are interconnected with electrical and data transmission cabling

- OWFs are strategic energy infrastructure, making them sensitive to damage
- OWFs generate invisible perturbations in the form of electromagnetic radiation

When a sea area is prepared to produce energy of considerable size of OWFs are located close to a navigation route junction or converging area of ships' routeing or in any other way in the vicinity of ship's routeing systems or shipping lanes, it is necessary to maintain the risk to shipping at a minimum but certainly not higher than the present level of risk. In some countries navigation within the borders of an OWF is allowed; in that case crossing traffic can be expected to emerge from the wind farm. When an OWF is located at the starboard side of a shipping lane, the Collision Regulations (COLREGs) state that vessels in the shipping lane must give way to vessels emerging from the OWF.

5.6.1 LEGAL CONSIDERATIONS – INTERNATIONAL AND NATIONAL

UN (UNCLOS)

The United Nations Convention on the Law of the Sea (UNCLOS), also called the Law of the Sea Convention or the Law of the Sea treaty, is the international agreement that resulted from the third United Nations Conference on the Law of the Sea (UNCLOS III), which took place between 1973 and 1982. The Law of the Sea Convention defines the rights and responsibilities of nations with respect to their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. The Convention, concluded in 1982, replaced four 1958 treaties. UNCLOS came into force in 1994. In this respect, Member States and private companies planning offshore wind farms must comply with UNCLOS for the use of the sea.

Admissibility of offshore wind farms under UNCLOS

The Admissibility of offshore wind farms in the Territorial Sea According to Art. 2 (1) a coastal States' sovereignty extends to its territorial sea. Through this sovereignty a coastal State may also establish offshore installations, such as wind farms. It is important to mention in relation to wind farms, that the sovereignty of the coastal State extends in this area also to air space as well as to its seabed and subsoil. Sovereignty is only limited by the fact that it must be exercised in accordance with UNCLOS and with international law (Art. 2 (3)).

The Admissibility of offshore wind farms in the Exclusive Economic Zone

The coastal States' "sovereign" rights in Part V of UNCLOS In Part V of UNCLOS the coastal State has sovereign rights and jurisdiction around the 200 NM EEZ which allows it to explore and exploit, conserve, and manage the natural resources, whether living or non-living, and regarding other activities for the economic exploitation and exploration of the zone. Under "other activities", the exploitation of energy from wind is exemplary listed but not further regulated. It confirms the coastal States' sovereign rights for all the economic activities that take place in this area, whether in reference to natural resources or other possibilities, at present or in future. They are sovereign rights for special rights and therefore "functionally limited".

IMO (SOLAS, COLREGs, GPSR, ...)

IMO – the International Maritime Organisation – is the United Nations specialised agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships. As a specialised agency of the United Nations, IMO is the global standard-setting authority for the safety, security, and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented. International Convention for the Safety of Life at Sea (SOLAS), 1974 was adopted on 1 November 1974 and entered into force on 25 May 1980. The SOLAS Convention in its successive forms is generally regarded as the most important of all international treaties concerning the safety of merchant ships. The Convention on the International Regulations for Preventing Collisions at Sea (1972), as amended (COLREGs), is published by the IMO. The COLREGs set out, among other things, the 'rules of the road' or navigation rules to follow by ships and other vessels at sea to prevent collisions between two or more vessels. COLREGs is detailed in chapter 4.2.1 for the concept design of OWF and the estimation of the safety distance between the traffic lanes and an OWF, to help OWF developers and planners to understand the risk of collision. The General Provisions on Ships' Routeing (GPSR) aim for improving the safety of navigation in converging areas and in areas where the density of traffic is heavy or where freedom of movement of shipping is inhibited by restricted sea room, the existence of obstructions to navigation, limited depths, or unfavorable meteorological conditions

Sea lanes and traffic separation schemes (TSSs)

Pursuant to Art. 22 (1), the coastal State may, where necessary having regard to the safety of navigation, require foreign ships exercising the right of innocent passage to use sea lanes and traffic separation schemes (TSSs). The establishment of sea lanes and TSSs serves to promote the safety of navigation, where the freedom of movement of shipping is e.g. inhibited by restricted sea-room or the existence of obstruction to navigation.

Traffic Separation Schemes are one way of routing ships

The "routing involves vessels being channeled by more or less 'mandatory' means into lanes or areas of sea so as to reduce risk of collision, grounding or clashes between navigation based and other uses of the sea". This is possible solely in areas where it is "necessary having regard to the safety of navigation" and under conditions laid down in Art. 24 (1). Pursuant to Art. 22(3) coastal States seem not required to submit plans for such routing systems to the IMO. However, recent developments show tendencies that the IMO may be getting more and more a monopoly of routing systems also in the territorial sea.

Laws and regulations of the coastal State

The coastal States power to regulate innocent passage, including in the vicinity of a wind farm, is not limited to the operation of 'positive' routing systems', such as TSS or sea lanes, but comprehend any reasonable 'traffic' measures whether mandatory or voluntary for foreign ships (Art. 21). This may include "safety zones" or "Areas to be Avoided" (ATBAs). Mandatory ATBAs, established by the coastal State, could lead to the result that traffic in fact is banned from these areas. If there are no alternative routes available this would impair the right of innocent passage. Such a measure, of course, results in an infringement of Art. 24 (1). It is questionable however, if a coastal State when providing alternative shipping routes, would be allowed to “shut down” a specific area. According to Art. 25 (3) a coastal State may “suspend temporarily in specified areas of its territorial sea the right of innocent passage if such suspension is essential for the protection of its security, including weapon exercises”. Other relevant traffic measures in the territorial sea which might be useful in relation to wind farms could be “no anchoring areas” (NAAs), “ship reporting systems” (SRSs) and “vessel traffic services” (VTSs). SRS and VTS facilities might be placed in wind farms, perhaps as a condition of the lease, and operated remotely from shore.

Navigational risk assessment

It is widely recognized that the navigational risk assessment should be duly carried out during the design, construction, and operating phase of an OWF, providing valuable information for decision makers on matters of OWF siting and minimum safety distance, etc. The winter navigation risks are to be considered in Estonian waters and this might be a bit challenging task. Today we have very little research or studies, how the big OWF affects on the ice field movements. Therefore certain safety margins must be taken near OWF navigation, not to jeopardize the safety of shipping and operation of OWFs.

Safety of Shipping

The most obvious example of interference with community rights of other States is of course the right of the coastal State to construct, and to authorize and regulate the construction, operation and use of artificial islands, installations, and other structures in the EEZ. Therefore, UNCLOS provides in Art. 60 explicit safeguards for this case to protect the freedom of navigation and other lawful activities. The difficulty in relation to wind farms is obviously the lack of experience with the operation of such farms in this area. Not only that the legal regime is different beyond the territory of the coastal State, but also the conditions are different under which wind farms will operate. All this makes it difficult to assess the impact on the freedoms of other States and the installation as such. Nevertheless, experiences from already existing territorial wind farms as well as experiences from the oil and gas industry may help in finding solutions.

Safety Zones

Especially in the EEZ just warning and notification installations may not be sufficient to warrant security for both navigation and the installation. Therefore, Art. 60 (4) states that a “coastal State may, where necessary, establish reasonable safety zones around such artificial islands, installations and structures in which it may take appropriate measures to ensure the safety […]” of such installations which “all ships must respect” (Art. 60 (6)). These zones do not imply an appropriation of stretches of the high seas, their object is solely to avoid conflicts between their users, and they may be established around fixed as well as mobile platforms. The wording “may where necessary” indicates that the establishment of such safety zones is no obligation for the coastal State. In cases where the wind farm may be situated in shallow waters with only a few meter depths, where even sports shipping is not possible, safety zones may be omitted at all. The wording “reasonable” seems to go to size, configuration, location, and jurisdictional powers exercisable by the coastal State. Each zone’s design is required to be “reasonable related to the [platform’s] nature and function” and its extent is limited to a maximum of (only) 500 meters measured from each point of its outer edge (Art. 60 (5)). But what constitutes the "outer edge" at a wind turbine? Shall the rotor or the blades of the turbine be the starting point? Plant suggests that it seems reasonable to take the "full span of the circuit described by the blades when in motion to represent the relevant part of that outer edge".

The 500 meters limitation

A radius of 500 meters was first suggested in 1953 by the International Law Association because several countries had already adopted this limit for oil rigs onshore, a radius within which it was forbidden to smoke or start a fire. Offshore oil installations are usually protected by 500-meter safety zones, although violations of these zones are a problem. Therefore, the question arises, if they are adequate protection against ship platform collisions when the farms are not manned and the turbines are close together, that especially larger ships are not able to manoeuvre. Although offshore wind farms were probably not conceivable soon by that time, UNCLOS III considered this point, since it had to deal not only with offshore oil rigs but also with other types of structures mentioned in Art. 56 (1). The reason why 500 meters was finally adopted can be seen in the fact that States were not able to agree upon another solution. However, derogation can be considered if they are authorized by international standards or recommended by appropriate international organizations, like the IMO (Art. 60 (5)). International standards allowing wider safety zones than 500 3 meters do not exist yet and accordingly there is no recommendation by the IMO on safety zones wider than that limit. However, recognizing the various violations of safety zones, the IMO had adopted several resolutions in relation to the safety and protection of offshore oil installations, particularly with respect to safety zones around such installations, such as Resolution A. 671 (16) on Safety Zones and Safety of Navigation around Offshore Installations and Structures. The resolution mentions offshore installations and structures as well as the need to ensure safety at sea in general terms in its Preamble. This may include also wind farms which can be considered as being "installations". However, the wording as such does not seem to leave space for implementing wind farms under the resolution. The exploitation of natural resources as well as drilling operations are continuously mentioned which clearly indicates the resolutions orientation. The resolution seems therefore mainly designed for offshore oil and gas rigs and it is questionable if it is also applicable in cases like wind farms. The adoption of another resolution with, for example, wider zones for wind farms as it is sanctioned in Art. 6(0(5), could therefore help to solve this uncertainty. However, today, resolution A.671(16) is the only resolution regarding safety zones around offshore installations as such. And even if the resolution deals mainly with issues concerning petroleum installations, regarding wind farms, it seems to be a helpful tool as well. One could therefore argue to apply resolution A.671(16) with analogy to offshore wind farms.

Recognized sea lanes essential to international navigation

The only exception to the UNCLOSs' "balancing" is mentioned in Art. 60 (7) that the installations and safety zones must not be established "where interference may be caused to the use of recognized sea lanes essential to international navigation". This is the only priority established by UNCLOS. However, this term is not clearly defined in international law; also it is not clear as to who decides upon whether or not a sea lane is essential to international navigation. It is also far from easy to identify areas where the risk of ship collisions with wind farms would be low enough to be "acceptable".

Conclusion of the legal considerations

The existing regulations concerning the accommodation of different rights in the EEZ may be seen as being weak or do not exist at all. Experiences in the petroleum industry show that safety zones as such are not sufficient to warrant the safety of navigation and the installation. Concerning wind farms, additional measures have to be taken with regard to the wind facilities' special circumstances. However, the IMO is hesitant in adopting stronger standards on this issue in general. This may be seen in the fact that the IMO is in the end a maritime organization which main concerns may lie in the further restriction of the freedom of navigation. However, offshore wind parks beyond the territorial sea will become common reality and the IMO as the responsible organization must deal with this issue once inevitable.

Marine Traffic – maritime environment – risk assessment

As a complement to the fleet description, it is important also to analyse the routes and the frequency of the ships since traffic density is an important parameter. This analysis will provide information about the real navigation areas, and it is an important input to the risk analysis. It is recommended to conduct a traffic survey of the area that includes all the vessel types found in the area and cover at least one year of information to account for seasonal variations in traffic patterns, fishing operations and recreational activities. In that respect, AIS data records are very useful for traffic analysis. This study must be complemented by a forecast of future traffic considering market trends, infrastructure investments in the area or changes in traffic routes. One of the aims of this analysis should be to provide a good definition of the different actual shipping routes in the area. In this respect, TSS or marked channels shown on Nautical Charts may provide a first approximation but also, actual shipping lanes should be defined based on recorded traffic statistics. Shipping routes are routes regularly used by ships, which are determined by geographical and hydrographic parameters. These routes cover long distances, particularly between two TSS and include the approaches to the entrance channels of a port as well as passages between two ports. The distance between a wind farm and a shipping route is defined as the distance between the physical boundary of the wind farm and the nearest edge of the shipping route or navigation channel.

Geometric Configuration of the Water (Hydrographic)

A good description of the hydrographic conditions is also needed to identify the areas of interaction between navigation and wind farms installations. Nautical Charts include the most important information related to the hydrographic and marine environment and should be the first reference point for the study of the physical environment. In addition, a detailed bathymetric survey of the whole affected area (wind farm and navigation routes identified in previous section) is recommended. The identification and description of navigation channels will provide good information for the analysis of the interaction areas. It is important to understand the behavior of the ships in the vicinity of the wind farms. TSS (Traffic Separation Schemes), marked channels, approach channels or open water are examples of navigation areas that impose different behavior on the navigation of the ships. Combining bathymetry and navigation area descriptions it is possible to identify the interaction areas that should be analysed. It is important to bear in mind that these areas can be different depending on the ships considered. For example, a large vessel (with deep draft) might ground before entering the wind farm area while a smaller one may not. In another respect, TSS or marked channels impose more discipline on the ships and, in consequence, a lower probability of navigation out of them. Therefore, the analysis of the physical environment for navigation should be made considering the previous analysis of ships and marine traffic.

Aids to Navigation

The existence (or not) of Aids to Navigation (AtoNs) is another factor to take into account in the analysis of interaction between navigation and OWF. AtoN provides information to ships in order to assist them to maintain their desired position and route. A compilation of the existing AtoNs should be made to complement the analysis of marine traffic and to get a good understanding of the restrictions to navigation. IALA distinguishes visual, sound and radio AtoNs. The study of existing AtoNs should be complemented with an analysis of the future configuration of the area (after construction of the wind farm) including any proposal for new AtoNs for OWF marking and new channels or restrictions. There is potential for a wind turbine to actively interfere with certain active AtoNs by producing its own low energy radio frequency (RF) signal. The problem at sea arises because there are many radio communications and radio navigation systems dedicated to safety at sea. These systems are based on terrestrial and satellite radio communications. Chapter 5 deals with this phenomenon in detail. SOLAS V/13.2 states that: "In order to obtain the greatest possible uniformity in aids to navigation, Contracting Governments undertake to take into account the international recommendations and guidelines when establishing such aids". Therefore, IALA recommendations O-139 on the Marking of Man-Made Offshore Structure should be followed.

Maritime and Atmospheric Conditions (Hydrodynamics)

For a good understanding of marine navigation is essential to have a good knowledge of hydrodynamic conditions in the area. Waves, winds, and currents have a great influence in ships' behavior. Also, shallow water effects, such as the bank effect (the tendency for a vessel to stern to steer into a nearby shallow water bank), which might be most noticeable at low tide affect ships behavior. Therefore, hydrodynamic studies should be performed to collect information and to provide a good description of the maritime conditions. In the event of an accident, evasion maneuvering or drifting events are very sensitive to the meteorological and ocean conditions. So, it is important to include these factors. It is important, not only to provide an accurate characterization of the area, but also to identify the risk of bad weather or restricted visibility conditions that could present difficulties to the vessels that might pass close to the wind farm. Also, it is important to identify the local conditions that can cause collision in case of loss of control or power.

Pilotage, Escorting & Towing Requirements

A navigation area where pilotage is mandatory requires a different analysis from the point of view of maneuverability and traffic conditions. Where a pilot has the control of navigation, marine traffic will be more organised and there will be a higher degree of maneuvering safety. In this case, recommended safety distances could be decreased, considering that marine traffic interactions are under tighter control. A similar logic is applicable to areas where escorting or towing is required. These factors are especially relevant in detailed design stage but also can be relevant at the risk assessment stage. Compulsory pilotage, escort or towing could also be used as mitigation or preventive measures if the need is identified in risk assessment.

Risk Assessment

Risk assessment comprises the first step in the development and application of MEP (Maritime Emergency Planning). The aim of the risk assessment is to establish the risks which need to be managed in the area and to identify means to control them to acceptable levels. The risk assessment process should identify the hazards, together with the events or circumstances which may give rise to their realisation, determine the risk posed by them and identify the measures that can be put in place to control the risk by preventing the realisation of the hazard and/or mitigating its effect if it does occur. In the context of this document:

- 'Hazard' is defined as something with the potential to cause härm
- 'Risk' is defined as the combination or product of frequency of occurrence and consequence of a hazard The risk assessment process consists of five parts:
  - Data gathering
  - Hazard identification
  - Risk analysis
  - Assessment of existing mitigation measures
  - Identification of any additional risk control measures/options.

Final conclusions

Due to their character offshore wind turbines and their positioning in an offshore cluster configuration, present new challenges to safe and efficient maritime navigation in their neighbourhood. Interactions between OWF and shipping activities induce an operational need to integrate OWF design and planning with navigational mitigation management and emergency procedures to assure this safe and effective navigational safety and emergency response preparedness. The recommendations which are presented should be used primarily by OWF developers seeking consent to undertake works, but also by Maritime Authorities to ensure safety of navigation and emergency response management.

The basic rule which should firstly be adopted by navigators around or within OWF zones is: 'Navigate with caution and avoid these OWF areas as much as possible'. During all phases of the OWF project (exploration including planning and design, construction, exploitation and maintenance and decommissioning) a dedicated marine navigation safety management plan is to be established, which could include:

- analysis of safety distances between shipping traffic and OWF which requires a good description of the ships involved
- perform a risk analysis of the routes and the frequencies of the ships
- analysis of the geometric [geographic and hydrographic] configuration of the sea area in respect of the shipping traffic
- identify local met-ocean conditions that could present difficulties to vessels
- pilot or towing vessel may be a mitigation or preventive measures
- provisions and regulations for a minimum distance between a shipping route and a wind farm can be determined as follows:

- Starboard side of any route: 0.3 NM + 6 ship lengths + 500 m (i.e. for a ship of 400 m length a minimum distance of 3,456 m, which is almost 2 NM)
- Portside of any route: 6 ship lengths + 500 metres
- In most cases additional detailed design analyses are necessary to determine an optimum design that will be safe and usable
- For the offshore infrastructure of the OWF, marine navigational marking is required according to IALA recommendations O-139 on the Marking of Man-Made Offshore Structures
- The risk assessment process should identify the hazards, together with the events or circumstances which may give rise to their realisation determine the risk posed by them and identify preventative measures that can be put in place to control the risk by preventing the realisation of the hazard and/or mitigating its effect if it does occur.

The fact is that large parts of the waters of the Baltic Sea, and Gulf of Riga, freeze into ice every year. This icing has multitude impacts on shipping, where 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.

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.

Sea ice can be divided into different types of ice, and national meteorological institutes and ice researchers predict how sea ice exists as either fast and or drift ice depending on its mobility. Fast ice is situated in coastal and archipelago areas, and for example Gulf of Riga has mostly fast ice.

When drift ice moves away from the fast ice, or consolidated ice, it creates a lead in the ice field. During strong winds the width of the lead can reach 10-30 km in about 24 hours. If the wind direction remains constant in a vast area, the lead can become very long. During spring in the Gulf of Finland and in parts of the Gulf of Riga, a lead shaped like a crescent is usually being formed.

Drift ice can easily become packed when it reaches an obstacle. Typically, this occurs when the ice field moves towards the fast ice edge. In the shallows, ridges get anchored to the bottom and the visible parts can grow to tens of meters high. Ridged ice appears also in the middle of seas where the ice floes get pressed against each other and break into pieces. The pieces of ice pile up over and under the sea surface forming meandering ice ridges and these ridges are in many cases very challenging for commercial vessels to penetrate. Normally ice breaker assistance is needed for commercial ships to be able to navigate in packed ice conditions.

The wind may disperse or pack the sea ice, generating conditions that affect the marine traffic, for example through ice ridges and packed ice along the coast and harbor entrances. At the Baltic Sea, the prevalent winds are south-westerly. This causes the sea ice moving towards the Finnish coast in the Gulf of Finland and towards the Estonian coast in the Gulf of Riga.

The movement of large sea ice areas is possibly a dangerous phenomenon. Drift ice can create such pressure on vessels that they either drift with the ice and lose control to maneuver/steer or freeze in the ice. For shipping, it is primarily brash barriers, ice ridges, hummocked ice and drift ice that might pose a danger to traffic where these types of ice are created. The ridges and brash ice barriers are the most significant obstructions to navigation in the Baltic Sea and Gulf of Riga. Powerful, ice-strengthened vessels can break though ice up to almost one meter thick, but they are not capable of navigating through ridges without icebreaker assistance. Ice dynamics affect navigation considerably. High pressure in the ice fields can be dangerous to the vessels, and it may at least cause time delays from hours up to days.

The most dangerous situation for commercial shipping is created when ship gets stuck to the drifting ice field and there is no ice breaker assistance in the vicinity. Vessel can drift with ice drift towards the wind turbine and get damaged. It is also possible that vessels is drifting with ice inside the wind farm and then the situation gets even more challenging from salvage point of view.

Safety of shipping personnel, avoiding pollution damage and material damage to vessels and wind farm installations is a priority, and this requires pre planning from all parties concerned.

KEY TAKEAWAYS

No	Task/ question*	Answer
7	What is the icebreaking need/need for vessels able to move through ice of the wind farms (being developed in Estonia)?	The large areas in Riga Bay are suitable for offshore wind power construction. A significant problem is caused by the ice cover in wintertime causing loading on foundations and wind turbines. The most significant loads and breaking the ice is caused by moving ice breaking against the structures. The consequence of this breaking of ice is still unknown and studies for this consequence are ongoing for example in Fin-land, because of planning the offshore wind farms in the Sea of Bothnia and Bay of Bothnia area. The design of the offshore wind farm, the placement of the possible power plants, cables and marine power stations in the area are always adapted to the conditions of the area. Design is the result of many factors considerations, these factors include the area's climate, waves, currents, ice conditions, environ-mental effects, water depth and geological characteristics of the seabed. When offshore wind farms are located near waterways or maritime traffic areas, the wind turbines may cause harm to both ships' radar systems and maritime traffic control radar surveillance or pose a risk to the safety of shipping and the use of waterways, or hinder maritime operations, especially during ice-covered periods. Large-scale offshore wind farms can also affect the accessibility of ports and the operating conditions of shipping more broadly, as offshore wind farms can have significant effects on the routes used by shipping and the routing of winter shipping, which are implemented according to the current ice situation, as well as the need for ice-breaking assistance for merchant ships. There are basically no legal framework related to ship traffic, including icebreaking in the vicinity of the offshore wind farms.

6. FINANCIAL ANALYSIS OF THE ALTERNATIVES

WINMOS model is used to calculate the cash flow of icebreaking as requested in the tender. The Summary-sheet has Executive summary of the calculations, net cash flow of ice breaking and cash flows of different icebreakers.

For the model sheets attached to the Final Report, the following three scenarios involving three different scenarios for Gulf of Finland and two options for Gulf of Riga are calculated. It must be noted that the vessels (five vessels in total are modelled) in each scenario can be combined and re-combined as wished for and the total costs and benefits of the icebreakers for each of the scenarios for both, Gulf of Finland and Gulf of Riga can be found as well as the financing gap that needs to be covered by external financing (possible EU grant) and/ or other income from multipurpose use in private or public activities.

SCENARIO 1:

1 multipurpose icebreaker with offshore functionality in Gulf of Finland (Primary) + 1 multipurpose icebreaker for Gulf of Riga (standard)

SCENARIO 2:

1 multipurpose icebreaker with offshore functionality in Gulf of Finland (Primary) + 1 multipurpose icebreaker in Gulf of Finland (Secondary) + 1 tug with a detachable bow icebreaker for Gulf of Riga

SCENARIO 3:

1 multipurpose icebreaker with offshore functionality in Gulf of Finland (Primary) + 1 multipurpose icebreaker in Gulf of Finland (Secondary) + 1 multipurpose icebreaker in Gulf of Finland (Third) + 1 tug with a detachable bow icebreaker for Gulf of Riga

General Assumptions:

- All figures in the calculation sheet are in thousand euros.
- The icebreakers in three scenarios are all multi-purpose and operated by the private operator as the model itself is designed for calculating for privately operated vessels. The main financial difference between the private and public investment is the cost of capital (equity and debt) and expected rate of return of the investment.
- Average winters are considered for the fuel consumption calculation purposes.
- Costs at low level estimation are considered for the calculation purposes.
- As of 2022 the northern region is ensured by icebreaker Tarmo (until 2028) and the main icebreaker Botnica (contract until 2032). The planned lifetime of icebreaker Tarmo has been extended to the end of 2028.

General Inputs

- Schedule – Start of the model is January 1st, 2029, as required according to the Technical Specifications of the Public Procurement document.

General Cost Inputs

- Price level of cost inputs, date – The price level of which is used in the model is September 1st, 2023, according to Aker Arctic Technology Inc.
- LNG price scenario (Figure 54) – n/a as all the vessels considered in the selected scenarios use diesel fuel.

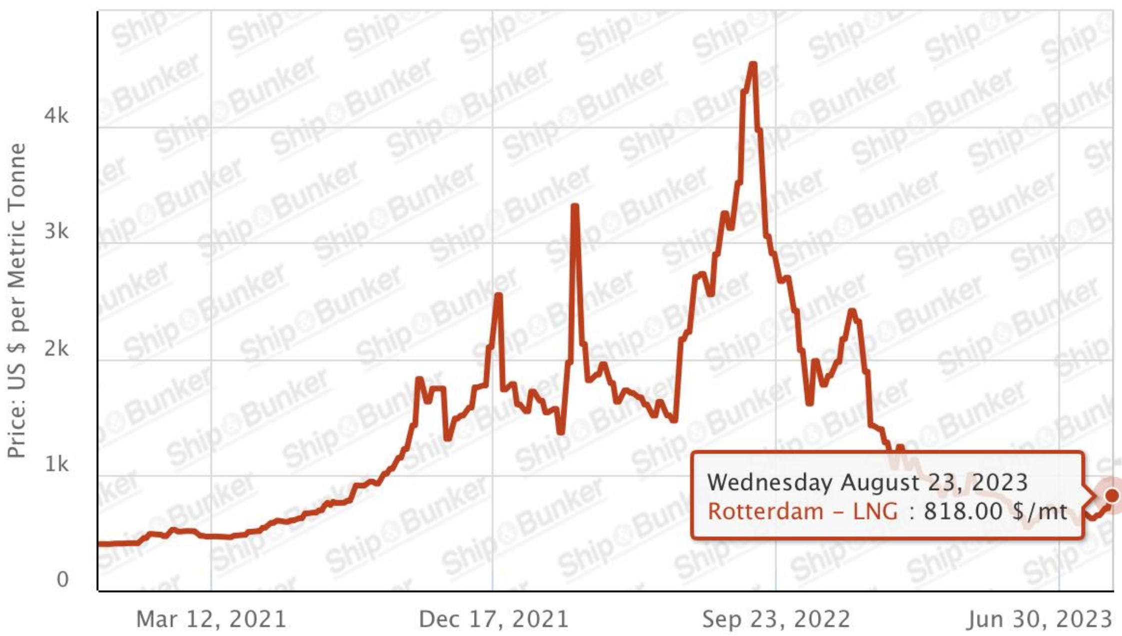


Figure 54. Bunker price evolution of LNG in Rotterdam (in USD). (Source: shipandbunker.com)

- Diesel price scenario (Fingure 55 ja Figure 56) - Bunker prices constantly fluctuate due to market forces and the cost of crude oil. Peaks and lows in the oil price have been moderate most of the time, with the several oil crises as notably exceptions.

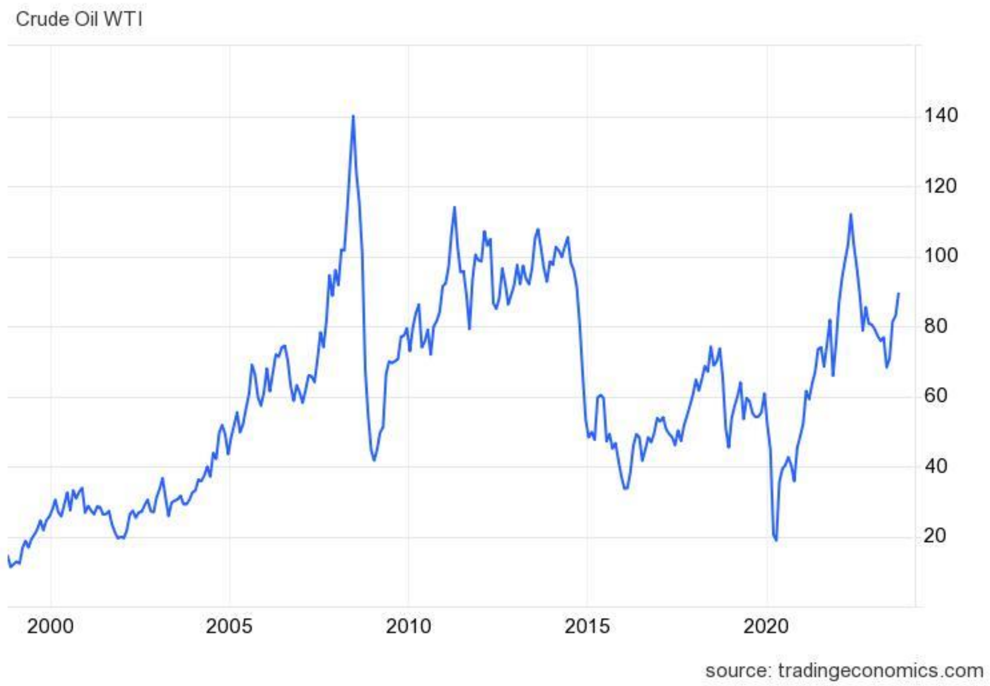


Figure 55. Crude oil price development (USD/Bbl.) (Sept 2023). (Source: tradingeconomics.com)

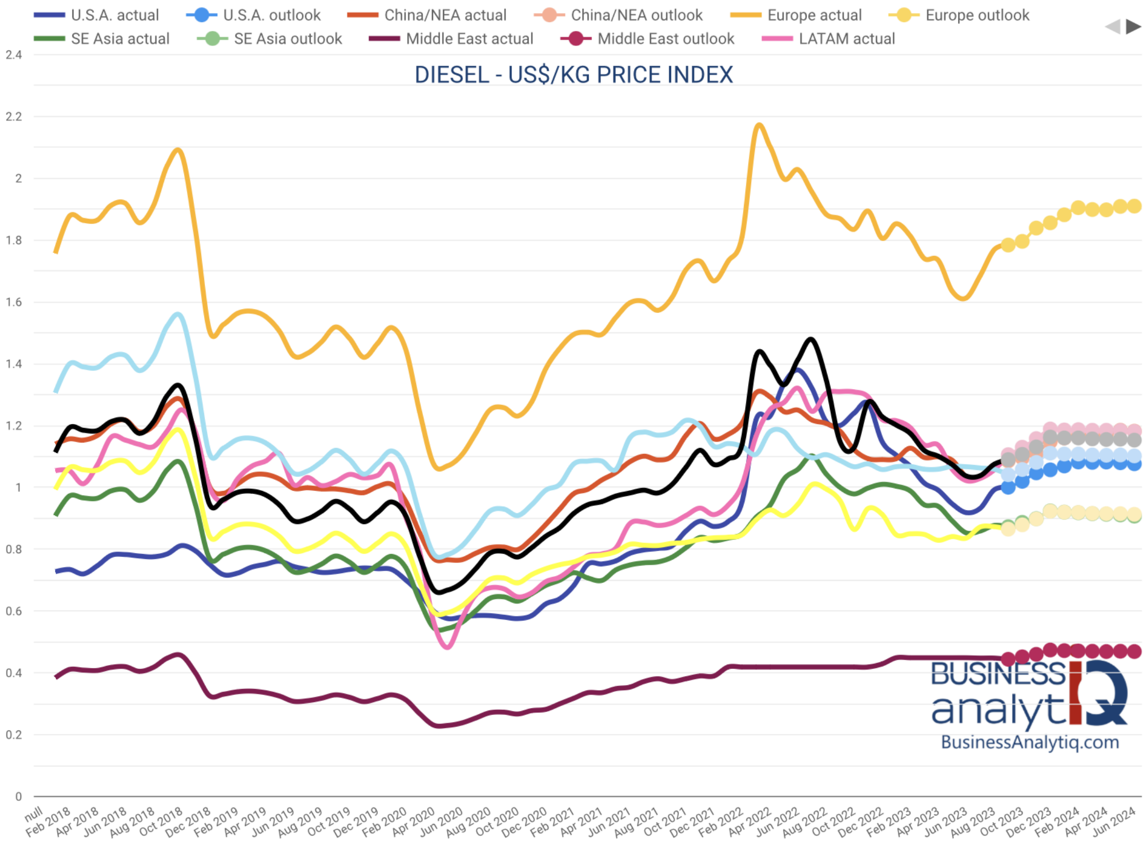


Figure 56. Diesel price trend per region (Sept 2023). (Source: businessanalytiq.com)

According to experts[11] the fluctuations of main end-user petroleum product prices, such as diesel oil used by trucks, are typically less pronounced as crude oil price comprises only part of the final price, the rest being largely determined by the application of taxes. The Market Observatory for Energy reports that the share of taxation (indirect taxes + VAT) in the end- consumer price of automotive diesel oil is decreasing when the crude price and the net product prices are increasing and, conversely, it is increasing when the crude price and the net product prices are decreasing. The price evolution for marine fuel oils is more in line with the oil price and price differences among bunker ports are typically quite moderate. But also here, bunkering decisions are impacted by relative price premiums arising as a result of different fiscal policies across countries and regions, especially in terms of fuel taxes.

The price difference between crude oil and marine fuel oils has varied over time. In the last couple of years bunker prices have risen considerably in line with the crude oil price. Figure 57 below shows the evolution of the bunker price for the commonly used IFO 380 grade[12] in Rotterdam, the main European bunker port.

Figure 57. Bunker price evolution of IFO 380 in Rotterdam (in USD). (Source: shipandbunker.com)

11 schonescheepvaart.nl/downloads/rapporten/doc_1361790123.pdf

12 IFO380 & IFO180 are Max 3.5% Sulfur Bunkers

Figure 58. World bunker prices for IFO 380 (in USD). (Source: shipandbunker.com)

It is very difficult to forecast the evolution of the fuel prices. The oil price is a determining factor together with the demand/supply balance for each of the marine fuel grades (Figure 58). The impact of oil price increases on the bunker cost for shipping is much more direct than in the case of trucking as a large part of the diesel price for trucks consists of taxes.

Usually in cost-benefit analysis the change of relative prices is defined as the total nominal increase (decrease) rate net of the inflation (deflation) factor. However, as the WINMOS model includes the inflation factor, the forecasted fuel prices for the period 2029-2054 will also be corrected by the inflation factor. Estonian Central Bank long-term estimate for the inflation as of September 2023 is applied.

- Icebreaker cost/income growth rate, % p.a. - Inflation on icebreaking costs and income (all the other costs than capital cost and fuel costs). Estonian Central Bank long-term estimate for the inflation as of September 2023 is applied.
- Icebreaker capital cost growth rate, % p.a. - Inflation on icebreaking capital cost and renovation cost. Estonian Central Bank long-term estimate for the inflation as of September 2023 is applied.
- Construction period interest rate, % p.a. - Construction period interests are added to the new icebreaker investments that occur in the future. The construction period is assumed to be 2 years. The interest rates depend on the financing scheme of the project. If we consider the project to be financed by the private sector then the current calculated long-term debt interest rate including the risk-free interest rate, country risk premium and current long-term interest margin provided by the commercial banks is applied.
- Discount factor, % p.a. - The discount factor is used to calculate NPVs of the cash flows. Discount factor is adopted to calculate the present value of the future cash flows. The financial discount rate reflects the opportunity cost of

capital. Applied weighted average cost of capital is 15,6%. If the project is financed by the private sector, then the discount factor calculation is from the point of view of an average investor using the same capital structure and unlevered beta as for the similar companies in the same sector.

Icebreakers

- Vessel type (1= basic icebreaker, 2 = multi-use icebreaker) – Two types of icebreakers: basic icebreaker and multi-use icebreaker. With multi-use icebreaker additional income can be generated. All the icebreakers included in the selected scenarios are multi-use icebreakers.
- Fuel type (1=diesel, 2= LNG) - Two types of fuel can be input for each icebreaker. All the icebreakers included in the selected scenarios use diesel fuel.
- Start of use – Date when the icebreaker is operational is 01.01.2029.
- No. of years in use after start of use - Number of years after the icebreaker is estimated to be removed from operation. The lifetime of an icebreaker of 50 years is applied.
- Capital cost (return requirement), % p.a. - Return requirement. Used to calculate capital costs for icebreakers. If the project is financed by the private sector, then the cost of equity calculations is from the point of view of an average investor using the same capital structure and unlevered beta as for the similar companies in the same sector. Size premium and additional risk premium are applied as the company is dependent on a few key customers.
- Investment cost (remaining unamortized investment cost if existing vessel), € - Used to calculate annual capital cost together with capital amortization period and capital cost. If acquired after year 1, model considers construction interest rate. Does not consider residual value.
- Capital amortization period, years - Used to calculate annual capital cost together with capital amortization period and capital cost.
- Yearly personnel cost (multi-purpose icebreakers), €/year - Fixed personnel cost based on the number of standard crew members and minimum salary.
- Variable personnel cost (basic icebreaker), €/operation day - Variable personnel cost not applicable.
- Yearly maintenance and management cost, €/year - Fixed maintenance and management cost.
- Additional income, €/day (for days in a year excluding stand-by days) - The price used to generate additional income on days that the icebreaker is not in stand-by mode. Additional income is generated from freight activity. The additional income opportunities are recognised, and the daily rate is at the level to have NPV positive but close to 0.
- Stand-by fee, €/day - A fee paid by the Estonian Transport Administration to icebreakers during stand-by days.
- Operation fee, €/day - A fee paid by the Estonian Transport Administration to icebreakers during operation days. Operating fee for each icebreaker is calculated to cover the seasonal operating costs. In addition, the icebreaker investment cost amortization and capital cost are considered proportionally to the icebreaking time for one year.

Time-related inputs

Time-related inputs-sheet includes inputs that vary over time. For each year of the modelling there are the following inputs:

Icebreaking inputs

- Stand-by days, days/year - How many days in a year each icebreaker is in stand-by mode. For multi-purpose icebreakers the remaining days of the year can be used to generate additional income.
- Operation days, days/year - How many days in a year each icebreaker operates. The period from December 1st - April 30th are considered operation days.
- Fuel consumption/year, tons/year (LNG or diesel) - The amount of fuel each icebreaker consumes.

Fuel price inputs

- Fuel price input scenarios, Diesel, €/ton - Diesel prices for the next 50 years. One scenario is inserted. The model does not consider inflation for fuel prices, so possible inflation is included in the input values.

The following tables and figures show the total cost of icebreaking to the public sector during the first five years of operation (Table 50, Table 51, Table 52) and the total cash flow of icebreaking (Figure 59, Figure 60 and Figure 61) for all three scenarios.

Table 50. Scenario 1 Total cost of icebreaking for public sector during the first 5 years of operations

COSTS FOR PUBLIC SECTOR (th EUR)

Scenario 1	2029	2030	2031	2032	2033
TOTAL COSTS OF WINTER NAVIGATION	21 155	21 684	22 226	22 913	23 351
NPV (26 years)	**161 287**				

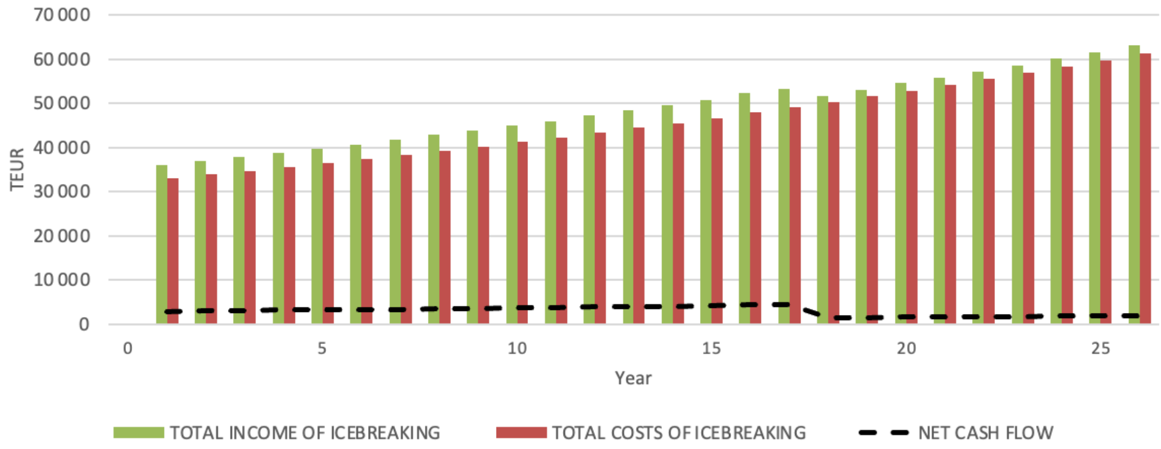


Figure 59. Scenario 1 Total cash flow of icebreaking

Table 51. Scenario 2 Total cost of icebreaking for public sector during the first 5 years of operations

COSTS FOR PUBLIC SECTOR (th EUR)

Scenario 2	2029	2030	2031	2032	2033
TOTAL COSTS OF WINTER NAVIGATION	28 917	29 640	30 381	31 328	31 919
NPV (26 years)	**220 478**				

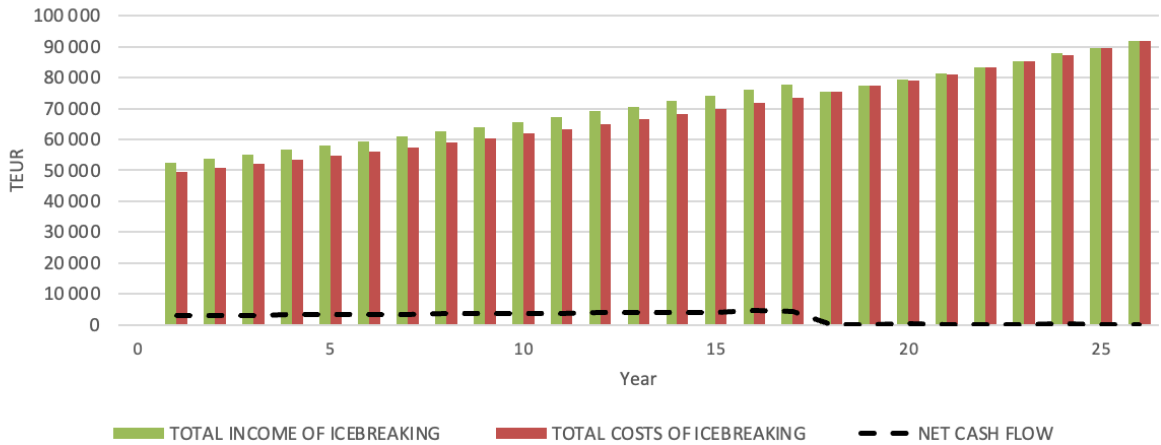


Figure 60. Scenario 2 Total cash flow of icebreaking

Table 52. Scenario 3 Total cost of icebreaking for public sector during the first 5 years of operations

COSTS FOR PUBLIC SECTOR (th EUR)

Scenario 3	2029	2030	2031	2032	2033
TOTAL COSTS OF WINTER NAVIGATION	34 944	35 818	36 713	37 860	38 572
NPV (26 years)	**266 431**				

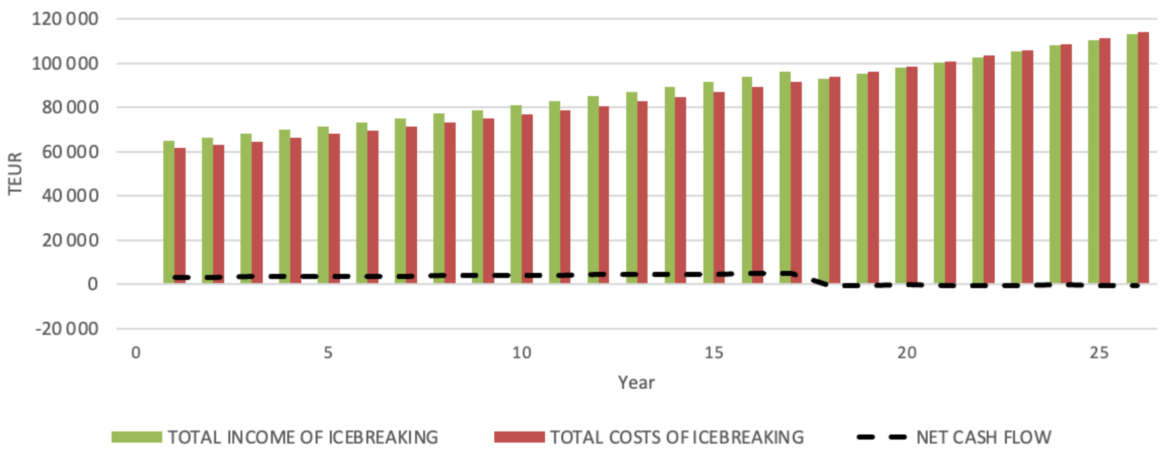


Figure 61. Scenario 3 Total cash flow of icebreaking

In conclusion, it must be noted that the requested WINMOS model is rather general, and the Consultant suggests creating a full-scale Cost-Benefit Analysis (CBA) for the selected icebreaker(s) after the exact functionalities in addition to the icebreaking are identified, which enables to take account of the additional revenues. Also, different financing programs require CBAs on specified templates given in a package with the project application forms, which require taking account of wider economic and social benefits in the particular focus of that financing program.

7. STAKEHOLDER MANAGEMENT PROCESS

Well-conducted stakeholder management is the key to success in consultancy projects in public sector initiatives. Stakeholder management process for the Analysis of Alternatives for Providing Icebreaking Services in Estonia is conducted in two parallel lines. Firstly, involving key public sector stakeholders is carried out through daily project management and coordination involving information gathering and exchange with the help of the project coordinator of the Estonian Transport Administration. Secondly, a wider circle of stakeholders from both public and private sector is involved through stakeholder interviews and dissemination meeting(s).

First Stakeholder Meeting (Opening Meeting) with the Estonian Transport Administration and the Ministry of Economic Affairs and Communications (from 01.07.2023 Ministry of Climate) took place on 16 June 2023. Second Stakeholder Meeting, where options are presented took place on 06 September 2023. Final Meeting, where results are presented to sector stakeholders took place on 28 September 2023.

Three Administrative Meetings have been taken place with the Estonian Transport Administration (31 May, 06 July, 08 August 2023).

Detailed input from the stakeholders for analysing and testing alternatives and designing solutions was acquired through stakeholder interviews (Table 53) that were carried out mainly in August 2023 after the Consultant had executed the initial analysis based on desktop research and input by the officials of the Estonian Transport Administration and the Ministry of Climate (formerly the Ministry of Economic Affairs and Communications).

Key points and feedback by the stakeholders were recorded in written form and used anonymously in the Report.

Table 53 The list of organizations and representatives interviewed

Nr	Organization	Name and Position	Date of Interview
1	Estonian Transport Administration	Martin Kaarjärv, Reet Laos, Maarius Utso – administrative staff	Invited to 31.08 group interview 21.08 TARMO interview was joined by Martin Kaarjärv 31.08 group interview was joined by Maarius Utso and Martin Kaarjärv
2	Estonian Transport Administration	Are Piel, Head of VTS	24.08
3	State Fleet Agency	Andres Laasma, Head	12.07
4	State Fleet Agency	Tõnu Kreos, EVA-316 captain Heiki Mokrik, TARMO captain	21.08 EVA-316 21.08 TARMO
5	Port of Tallinn	Ain Klaus, Chief Harbour Master	Invited to 31.08 group interview
6	Port of Tallinn daughter company TS Shipping	Damir Utorov, Head of Chartering of Botnica, Board Member Siim Sokk, BOTNICA captain	Invited to 31.08 group interview, separate questions sent on 25.08 24.08 BOTNICA
7	Port of Tallinn daughter company TS Laevad	Meelis Mägi, Safety Manager	31.08 group interview
8	Port of Sillamäe	René Sirol, Harbour Master	31.08 group interview
9	Port of Pärnu	Viktor Palmet, Harbour Master	Invited to 31.08 group interview
10	Port of Kunda	Eiki Orgmets, Harbour Master	31.08 group interview
11	Saarte Liinid	Andrus Maide, Head Harbour Master	31.08 group interview
12	Kihnu Veeteed	Jaak Kaabel, CEO	Invited to 31.08 group interview
13	Tallink	Tarvi-Carlos Tuulik, Head Captain	31.08 group interview
14	Estonian Wind Energy Association	Terje Talv, Manager	Invited to 31.08 group interview
15	FTIA	Helena Orädd, Head of Maritime Transport Unit Jarkko Toivola, Senior Expert	25.08 29.08
16	Arctia	Maunu Visuri, CEO Icebreaking	24.08
17	Alfons Håkans	Joakim Håkans, CEO	24.08

8. CONCLUSIONS

Current concluding chapter envisages the most reasonable scenario for Estonian state's icebreaking taking account of the changes that have been taking place in the past five years in Estonian waters (input from Chapter 1 and Chapter 2) and in expectations for icebreaking services (input from Chapter 3 based also on the stakeholder interviews). The ports that need icebreaking as well as data on goods loaded and unloaded in these ports are discussed in relation to the alternatives for the transport of goods in Chapter 1.

Three scenarios involving two icebreaking options for Gulf of Riga and three for the Gulf of Finland (Chapter 5) are proposed and modelled in WINMOS model (Chapter 6). Combinations of different vessels and vessel types – conventional icebreakers in different sizes as well as detachable bow options both owned by the state and chartered are considered while setting the scenarios (Chapters 3, 4, 5, 6). Alternatives for financing the construction of icebreakers are discusses in Chapter 3 and in the Conclusions below, the financing gap is identified in WINMOS modelling.

The impact of climate change is discussed in Chapter 2. Icebreaking need and conditions in relation to wind farms is described in Chapter 4.

Using icebreaking vessels also for other purposes, i.e. using multipurpose vessels is suggested by the Consultant (Chapters 3 and 5, the Conclusions), while these other purposes should be defined by the commissioner of the vessel while making the decision. Table 35 identifies the main requirements for a pure icebreaker and requirements for different multipurpose uses. Some vessel-types require more functions and some less. Further, the Table 36 shows which requirements have negative influence for icebreaking or if some features can even have positive effect.

Changes, that could be made to the Estonian organisation of icebreaking are proposed in the Conclusions under Other Considerations.

Estimated costs and benefits for options stated in the Terms of Reference are summarised in Table 54. It also provides a column indicating the possibility to gain charter income for e.g. offshore activities.

Table 54. Summary of estimated costs for winter navigation assistance options in Estonia. Costs for icebreakers are based on the Chapter 5

			Investment cost, M€	Estimated range of annual operational cost in EUR million with fuel and capital cost (no interest rate)		Possibility for charter in offshore markets	Security of service supply	Duration of the arrangement
	Option	Sub-option		Mild winters	Severe winters			
Gulf of Finland	A. One suitable new icebreaker	A.1. State-owned conventional IB	80	7,1	9,0	No	Very high	~50 years
		A.2. State-owned multipurpose IB	100	8,4	10,5	Maybe*		
		A.3. Chartered		5,5	7,5	Yes, during off-hire	High	5 to 10 years
	B. Sea tug with connectable icebreaker bow; supplement to an icebreaker	B.1. State-owned	30 (with motorised bow > 40)	0,8 (1,1)	1,1 (1,5)	No	Very high	Tug ~50 years, bow 25+ years
		B.2. Chartered		0,3**	0,6**		High	5 to 10 years
	C. Two sea tugs without an icebreaker bow	C.1. State-owned	50	1,0	1,4		Very high	~50 years
		C.2. Chartered		0,4**	0,7**		High	5 to 10 years
	D. Co-operation with Finland during peaks		Upon agreement, tentatively 1+ M€/active month				Very high / very long	
Gulf of Riga	E. One suitable icebreaker	E.1. State-owned conventional IB	40	3,9	4,3	No	Very high	~50 years
		E.3. Chartered		4,0	5,0		High	5 to 10 years
	F. Sea tug with connectable icebreaker bow; supplement to an icebreaker	B.1. State-owned	18+8=26	0,7	1,0		Very high	Tug ~50 years, bow 25+ years
		F.2. Chartered		0,3**	0,6**		High	5 to 10 years
	C. One sea tug without an icebreaker bow	G.1. State-owned	25	0,5	0,7		Very high	~50 years
		G.2. Chartered		0,2**	0,4**		High	5 to 10 years

*) unless limited by funding source, such as EU's CEF or Military Mobility

**) For icebreaking period only (4 months)

***) Fixed annual depriaction over 20 years, no interest cost included

(grey) = Vessels owned by Riigilaevastik

(light green) = Offshore activities would require a commercial operator

The key take-aways on governance models, based on conclusions in all Chapters, are as follows:

General on ice conditions

- In mild and average winters, icebreaking in Gulf of Finland can be done with one modern conventional or multipurpose icebreaker, and with one smaller icebreaker in Gulf of Riga. This is the minimum capacity to ensure smooth shipping to and from Estonian seaports.
- Only in severe winters additional icebreaking capacity on top of the 1 + 1 icebreakers is needed in Gulf of Finland and Gulf of Riga; this peak demand period is seldom longer than 4–5 weeks. Based on past decades, severe winters occur approximately once in a decade.

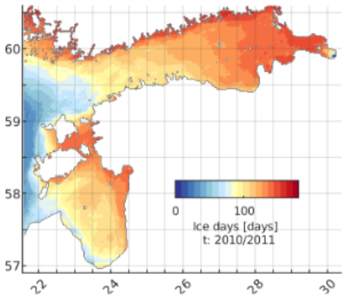
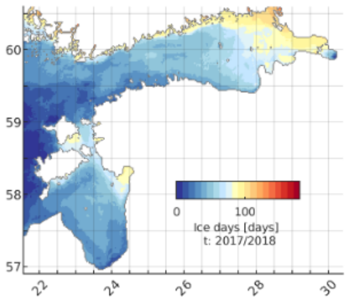
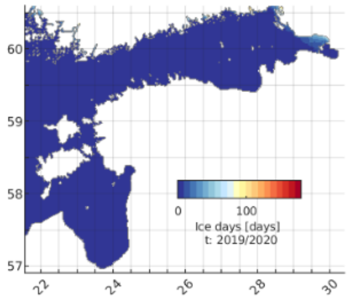
<table>
<tr><th></th><th>2010/2011 - severe</th><th>2017/2018 - average</th><th>2019/2020 - mild</th></tr>
<tr><td>Ice days</td><td>a)

</td><td>b)

</td><td>c)

</td></tr>
</table>

Figure 62. Representative ice seasons for severe (2010/2011), average (2017/2018) and mild (2019/2020) winters in number of ice days. Source: Chapter 2 (TalTech MSI)

- As can be seen in the graph above, port of Pärnu has more ice days than other Estonian ports. There are close to 100 ice days in Pärnu during an average winter, and closer to 150 ice days during a severe winter (Figure 62).
- In addition to ice formation analysis, the work also included detailed wind direction analysis. Generally speaking, winds in Estonian waters are dominantly westerly, but predicting weather, wind and ice conditions is very difficult. These are elaborated in Chapter 2 of the report.
- Icebreaking needs and conditions in Gulf of Finland differ substantially from those in Gulf of Riga, which are also wide apart from each other. Both regions require their own icebreaking solutions, as it is not possible to use large Gulf of Finland icebreakers in Gulf of Riga.

Governance of the Estonian state-owned fleet

- As from 1 July 2023, all new government vessels are owned, managed, and procured by State Fleet Agency, a newly formed government agency under the Ministry of Climate. This does not apply to naval vessels, which are held by the Navy.
- If the Estonian government decides to procure new or second-hand conventional or multipurpose icebreakers, they will be procured, managed and operated by State Fleet Agency.
- If the state decides to procure a new icebreaker, substantial financial support could be received from EU’s Connecting Europe Facility (CEF) or Military Mobility program, but both limit the use of the vessel outside its intended operational area or use.
- This funding could be available only for icebreakers, which are not used outside Estonian waters, or used there only in very limited capacity. This means that extensive commercial exploitation of such vessels in offshore markets is not possible, but the icebreakers could have some multipurpose functions, which are needed in Estonia. This could, in principle, be possible for a new icebreaker both in Gulf of Finland and Gulf of Riga. For example, in 2023 Latvian LVR Flote has been awarded some CEF’s Military

mobility funds for a new tug used (also) for icebreaking activities. At this point it is not possible to estimate the likelihood of receiving such funding for an Estonian icebreaker.

- At least CEF funding requires an undertaking with at least three EU Member States, as in WINMOS II and WINMOS III projects with Sweden, Finland and Estonia. Sweden has received substantial funding for its new icebreakers from WINMOS II and WINMOS III.

Gulf of Finland

- As Botnica is chartered in until year 2032, the most imminent question for Gulf of Finland is how and when to replace the 60-year-old Tarmo, which has a limited icebreaking capability.
- The options for the primary icebreakers in the Gulf of Finland are the following, in both of which also peak demand capacity needs to be secured (the primary most secure long-term alternative in bold; see also Table 20):

  a) **newbuilding as the primary icebreaker**, or

  b) a suitable vessel and reliable service provider to be chartered for a 5-to-10-year period from the market.

- The worldwide second-hand market of suitable icebreakers is practically non-existent. E.g. Swedish icebreakers that will be replaced towards the end of the decade will by then be over 50 years old. They are hardly a feasible long-term option for Estonia in the Gulf of Finland, except for a limited period as an option "of last resort" to bridge the gap between the time before getting a new icebreaker and the period, when Botnica's charter period will end.
- In option a) there are two alternatives (the most secure long-term, yet more expensive option in bold; see also Table 20):
  - **a vessel suitable for certain multipurpose functions**, or
  - a conventional icebreaker.
- For additonal peak demand capacity in Gulf of Finland, the alternatives are the following (the primary long-term yet more expensive ones in bold; see also Table 20):

  i) a state-owned sea-going-tug with connectable icebreaker bow. The bow would be procured and owned by State Fleet Agency, while the tug could be chartered from the market on a stand-by basis. The bow needs to be designed for a specific tug, as it cannot be connected to just any tug;

  ii) two state-owned sea tugs without an icebreaker bow procured and owned by State Fleet Agency;

  iii) acquiring the necessary peak capacity from the market, as is done with tugboats for Gulf of Riga; or

  iv) reaching an agreement with the Finnish government, so that Arctia's icebreakers, which it has contracted, could provide the capacity when needed.

Pros and Cons of a New Multipurpose Icebreaker

- All multipurpose functions add some cost on the icebreaker, even if the size of the vessel would not change and important icebreaking requirements can be maintained despite multipurpose use.
- Depending on the technical specifications and required capabilities, a multipurpose icebreaker is typically 20% more expensive than a similar size conventional icebreaker. This means that there would have to be enough demand for these capabilities in offshore markets or need in other governmental uses, which would pay off the extra cost.
- Based on our cost-benefit analysis, multipurpose capabilities and use is recommended for an Estonian icebreaker to the extent they do not jeopardize icebreaking and winter navigation assistance in Estonian waters. Possible multipurpose uses for Estonian governmental functions include mainly the following:
    - Coast Guard patrol vessel (with Search and Rescue functions)
    - Fairway maintenance vessel
    - Navy service vessel.
- Success in challenging offshore markets requires highly skilled and business-minded management. Commercial operation of a multipurpose icebreaker cannot be effectively run by a government agency. Instead, it requires a commercially oriented company and management with appropriate incentives.
- If a new multipurpose icebreaker is ordered, the process would be managed and the vessel owned and manned by State Fleet Agency. In this case, it needs to be considered carefully to what extent it is possible to combine national icebreaking duties with possible commercial assignments would need a competent commercial middleman (such as a shipbroker) or a shipping company (such as TS Shipping).
- Also, if a new icebreaker is equipped with some multipurpose functionalities, these need to be planned and agreed within the Estonian government before the actual procurement process is started. In this way, the detailed technical planning can be completed with as few changes as possible. Most of these functionalities affect the vessel’s icebreaking capabilities and some of the functionalities also come with considerable costs. In addition, if some of the functionalities are retrofitted to an existing vessel, such changes can be very costly.
- In offshore business, skilled crews and well-maintained vessels are a prerequisite. If a multipurpose icebreaker is manned with State Fleet Agency crew, their skills, working conditions and salaries would have to enable also offshore work. Such opportunities are difficult to be fully exploited, unless the crew and operations are managed by an experienced commercial operator.
- Currently the pool of Estonian seafarers and landside management with experience in icebreaking and especially offshore activities is very small. For example, Botnica has two alternating crews of about 20 plus some reserve crew, and Tarmo’s crew has not been in similar icebreaking operations for many years.

- Offshore markets are a volatile and high-risk shipping business segment, especially for small providers, for which the predictability and visibility of demand is poor. Combined with more expensive investment and long lifetime of vessels, this makes a challenging combination.
- Caution is required when offshore activities are included in profitability and cost calculations for a multi-purpose icebreaker with an economic life time of 50+ years.

Gulf of Riga

- Estonian ports in Gulf of Riga have shallower fairways and are visited by smaller tonnage, so the need of icebreaking services is significantly different from that in the Gulf of Finland.
- The ice period in Pärnu is usually longer than in the Estonian Gulf of Finland ports, because in Pärnu's river estuary bay sweet water freezes easier than more saline sea water. The effect of wind to dispel ice is also much weaker in a secluded bay than at sea.
- During this decade, also the replacement of EVA 316, built in 1986, will become actual. This means that Estonia will need the capacity of two new or second-hand icebreakers replacing both Tarmo and EVA 316.
- For Gulf of Riga, the alternatives are (the primary long-term yet more expensive one in bold; see also Table 20):

    i) a state-owned conventional icebreaker;

    ii) a conventional icebreaker chartered from the market;

    iii) a state-owned sea-going-tug with connectable icebreaker bow. As in the Gulf of Finland case, the bow would be procured and owned by State Fleet Agency, while the tug could be chartered from the market on a stand-by basis. The bow needs to be designed for a specific tug to which it can be connected;

    iv) a state-owned sea tug without an icebreaker bow;

    v) acquiring the necessary tugboat capacity from the market.

Other Considerations

- Estonian Transport Administration should consider using Estonian VTS staff and capacity more widely in assigning icebreakers to specific assistance tasks. In this way, crucial communication between icebreakers and vessels needing assistance could be guaranteed 24/7, backed up with systems enabling excellent situational awareness in Estonian waters and beyond.
- VTS taking the operational role would require clear documented procedures and necessary training of the 20 VTS operators, but no investments in equipment or software are needed, except for access to ice charts.

- Estonian VTS has just taken a new fully digital VTS AIS system by SAAB into use, so taking an active role as a communication link in winter navigation assistance would not be a major undertaking.
- There have been discussion between the Finnish, Swedish and Estonian authorities on Estonia joining the Finnish-Swedish icebreaker information system IBNet[13], which is developed to manage a fleet of over 10 icebreakers and other support vessels to assist traffic to over 50 seaports.
- It appears that IBNet is too heavy and expensive tool for Estonian needs that is also not designed for Gulf of Riga purposes.

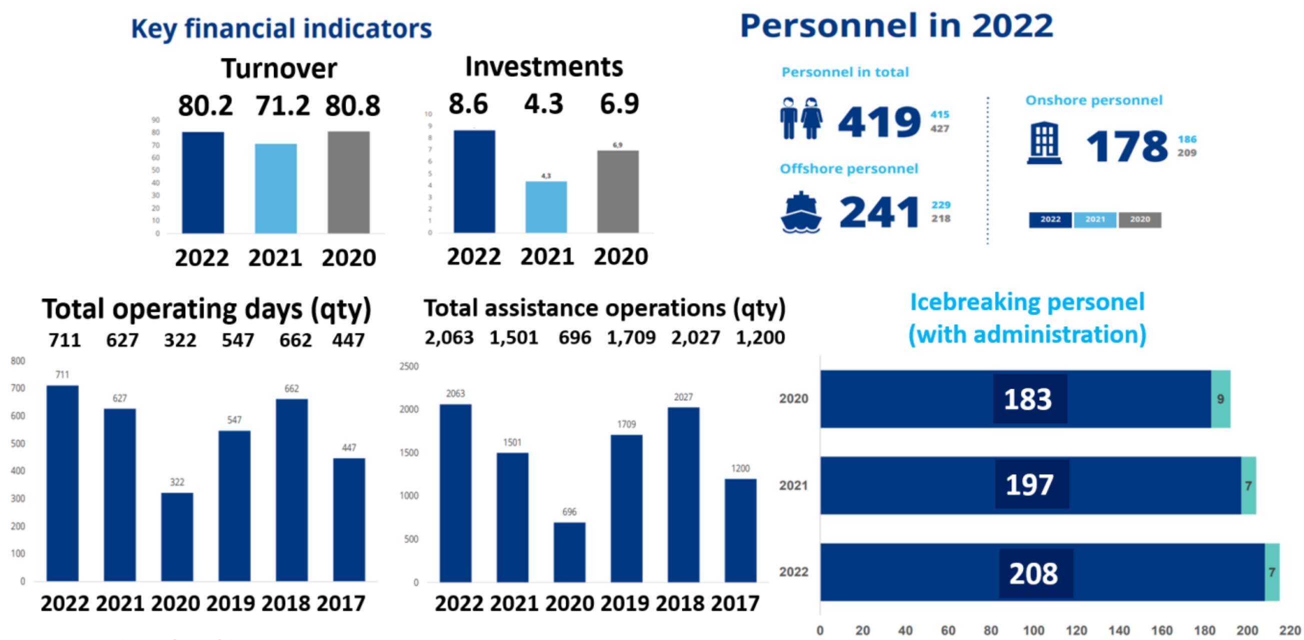
In conclusion, the Consultant suggests the Estonian state to serve the Gulf of Finland waters with a larger primary icebreaker also after 2032, when the current Botnica contract ends. The primary icebreaker could be a multipurpose one taking account other needs and requirements of the state. The Consultant offers alternatives for additional peak demand capacity in Gulf of Finland. For Gulf of Riga the Consultant suggests a state-owned conventional icebreaker.

The Final Report is structured in away that all chapters can be used independently for the purposes of the Estonian state. Thus, while applying for a financing decision by the government or by the EU, these chapters and its content can be combined in the purposes of fulfilling the requirements of specific financing programs.

[13] IBNet contains information about the weather, ice conditions and traffic situation, and transmits the information between the different connected units (icebreakers, coordination centres, VTS etc.).

APPENDICIES

Appendix 1 Key Data for Arctia OY. Source: Arctia Annual Report 2022



Arctia Icebreaking	2022	2021	2020	2019	2018	2017
Assistance operations per operating day	2,9	2,4	2,2	3,1	3,1	2,7

Appendix 2 Arctia's icebreaking fleet in 2022. Source: Arctia Annual Report 2022

Length, m / Beam, m / Draught, m / Power, kW

Arctia's fleet includes the conventional icebreakers Voima (commissioned in 1954, refurbished in 1979 and 2016), Urho (1975) and Sisu (1976, refurbished in 2019), Otso (1986) and Kontio (1987), the multi-purpose icebreakers Fennica (1993) and Nordica (1994), and the port icebreakers Ahto (2014) and Polaris (2016).