STYRELSEN FÖR

VINTERSJÖFARTSFORSKNING

WINTER NAVIGATION RESEARCH BOARD

Research Report No 83

Kaj Riska

ENERGY EFFICIENCY OF THE BALTIC WINTER NAVIGATION SYSTEM

Finnish Transport Safety Agency

Finnish Transport Agency

Finland

Swedish Maritime Administration

Swedish Transport Agency

Sweden

Talvimerenkulun tutkimusraportit – Winter Navigation Research Reports
ISSN 2342-4303
ISBN 978-952-311-032-8

FOREWORD

In its report no 83, the Winter Navigation Research Board presents the outcome of the project on energy efficiency of the Baltic winter navigation system.

The winter navigation system consists of merchant ships that have some ice performance escorted by icebreakers. The system includes ice performance requirements that are set in the Finnish-Swedish Ice Class Rules. The restriction for the attained Energy Efficiency Design Index operates essentially as a power ceiling for ships. The ice classed ships must use higher power than open water ships in order to proceed in ice. This handicap is compensated for with some ice class correction factors introduced into the attained EEDI equation. These factors should convert the power and deadweight of an average ice class ship to be the same as an average open water ship. The effect of the ice class correction factors is largest for an average ice class ship and thus any extra power beyond the minimum ice class requirements is penalized. This will have an impact on the winter navigation system in forcing the designers to find energy efficient designs with a good ice performance and in forcing an increase in icebreaker services in order to maintain an efficient and fluent navigation system.

In this study the energy efficiency of the winter navigation system is calculated. The energy consumption of the winter navigation system to northern Finland is calculated including both the energy consumption of the merchant ships and the icebreakers.

The Winter Navigation Research Board warmly thanks Professor Kaj Riska for this report.

Helsinki and Norrköping

June 2014

Jorma Kämäräinen

Finnish Transport Safety Agency

Peter Fyrby

Swedish Maritime Administration

Tiina Tuurnala

Finnish Transport Agency

Stefan Eriksson

Swedish Transport Agency

Paris 12.10.2012 / KR

ENERGY EFFICIENCY OF THE BALTIC WINTER NAVIGATION SYSTEM

Kaj Riska Total SA / ILS Oy

The winter navigation system consists of merchant ships that have some ice performance escorted by icebreakers. The system includes ice performan ce requirements placed on the merchant ships. These ice performance requirements are set in the Finnish-Swedish Ice Class Rules (FSICR). The rationale is that the number of icebreakers needed is small once the merchant ships can proceed independently in lighter ice conditions and when escorted, can maintain an adequate speed. Thus the number if icebreakers and the merchant ship ice performance influence directly the waiting time of icebreakers.

IMO is developing at the moment restrictions for CO_2 emissions for ships. The measure for emissions is the Energy Efficiency Design Index (EEDI) which is in principle the ratio between CO_2 emissions and the work performed by ships. The work is measured with ton miles. Thus the energy efficiency is calculated in principle by

$$EEDI = \frac{C_F \cdot SCF \cdot 0.75 \cdot MCR}{v \cdot dwt}.$$

The first constant is a conversion factor between fuel consumption and CO_2 emissions and the second one is specific fuel consumption of the engine. The constant 0.75 is included as the open water speed v is commonly achieved using a 75 % power. In the more detailed equation for EEDI there is also the auxiliary engine power and certain constants – here the above simplified form will be used with the constants C_F = 3.1144 gCO_2/gFUEL and SCF = 190 g/kWh. The EEDI value for each ship must be lower than certain pre-set reference line values – these are different for each ship type and the reference line value depends on the ship dead weight.

The restriction for the attained EEDI operates essentially as a power ceiling for ships. If the ship has a high open water speed, it is possible to reduce the speed and this way to reduce the power needed (and energy consumption). The ice classed ships must use higher power than open water ships in order to proceed in ice. This handicap is compensated for with some ice class correction factors introduced into the attained EEDI equation. These factors should convert the power and dead weight of an average ice class ship to be the same as an average open water ship. The effect of the ice class correction factors is largest for an average ice class ship and thus any extra power beyond the minimum ice class requirements is penalized. This will have an impact on the winter navigation system in forcing the designers to find energy efficient designs with a good ice performance and in forcing an increase in icebreaker services in order to maintain an efficient and fluent navigation system.

In this calculation the energy efficiency of the winter navigation system is studied. The energy consumption of the winter navigation system to northern Finland is calculated including both the energy consumption of the merchant ships and the icebreakers. Also the round trip times are estimated in order to get the amount of cargo carried. From these two factors, the energy efficiency measured by the EEDI equation may be calculated. The study is simplified to comparing the emissions of five different versions of a basic 20000 dwt bulk carrier. The versions differ in ice breaking capability and thus in the amount of icebreaker escort needed. The reference line value (dependent only on DWT) for this ship is 8.541. The five ship versions are

1. Ice going ship 10 MW

Ship description: A ship that can operate independently in most Baltic ice conditions. The open water power consumption is based on the ice breaking bow and ice capable propulsion.

Ship data:

Ice class	IA Super
Power	10000 kW
Bow angle φ_1	25°
Length	152 m
v_{ow}	14 kn / 5200 kW
Ice class factor f_j	0.7387
Ice class factor f_i	1.2084
Attained *EEDI*	15.91
Ice class corrected attained *EEDI*	9.97

2. Ice going ship 6.9 MW

Ship description: A ship with ice breaking bow but just the minimum power for ice class. Needs occasional icebreaker assistance.

Ship data:

Ice class	IA Super
Power	6900 kW (ice class minimum)
Bow angle φ_1	25°
Length	152 m
v_{ow}	14 kn / 5200 kW
f_j	0.8290
f_i	1.2084
EEDI	12.29
Ice class corrected *EEDI*	8.55

3. Ice capable ship 7.8 MW

Ship description: A ship with a moderate ice breaking bow and minimum power for the ice class. Needs icebreaker assistance.

Ship data:

Ice class	IA Super
Power	7800 kW (ice class minimum)
Bow angle φ_1	40°
Length	148 m
v_{ow}	14 kn / 4900 kW
f_j	0.7369
f_i	1.2078
EEDI	13.30
Ice class corrected *EEDI*	8.32

4. Open water ship 8 MW

Ship description: Open water ship with the minimum power ice class requires. Needs icebreaker assistance in most ice conditions.

Ship data:

Ice class	IA
Power	8000 kW (ice class minimum)
Bow angle φ_1	Bulbous bow
Length	144 m
v_{ow}	14 kn / 4500 kW
f_j	0.8213
f_i	1.1088
EEDI	12.73
Ice class corrected *EEDI*	9.57

5. Only ice strengthened open water ship 6.0 MW

Ship description: An open water ship with open water power. Only strengthened for ice. Needs constant icebreaker assistance.

Ship data:

Ice class	-
Power	6000 kW
Bow angle φ_1	Bulbous bow
Length	144 m
v_{ow}	14 kn / 4500 kW
f_j	NA
f_i	NA
EEDI	10.23
Ice class corrected *EEDI*	NA

All these ship versions have a dead weight of 20 000 dwt. The ship length is changed slightly to take into account the change in the block coefficient due to the different ship bow types. As is mentioned in the table above, three different ship bows are included:

- Ice breaking bow (ice bow) which is breaking ice well due to small stem angle;
- Ice capable bow which has a moderate stem angle and thus breaks some ice in bending and
- Bulbous bow optimal for open water.

The open water speed of the ship versions is estimated based on the bow type and ship length. The ice performance of each of the ship versions is estimated and given in Fig. 1. The fifth ship version is a ship that is strengthened for ice but has no ice performance. Thus this ship version has no ice going capability and relies on icebreaker escort all the time. The icebreaker escort is assumed to be provided by Urho-class icebreakers having a power of 16.2 MW. Their ice performance in ice is also shown in Fig. 1.

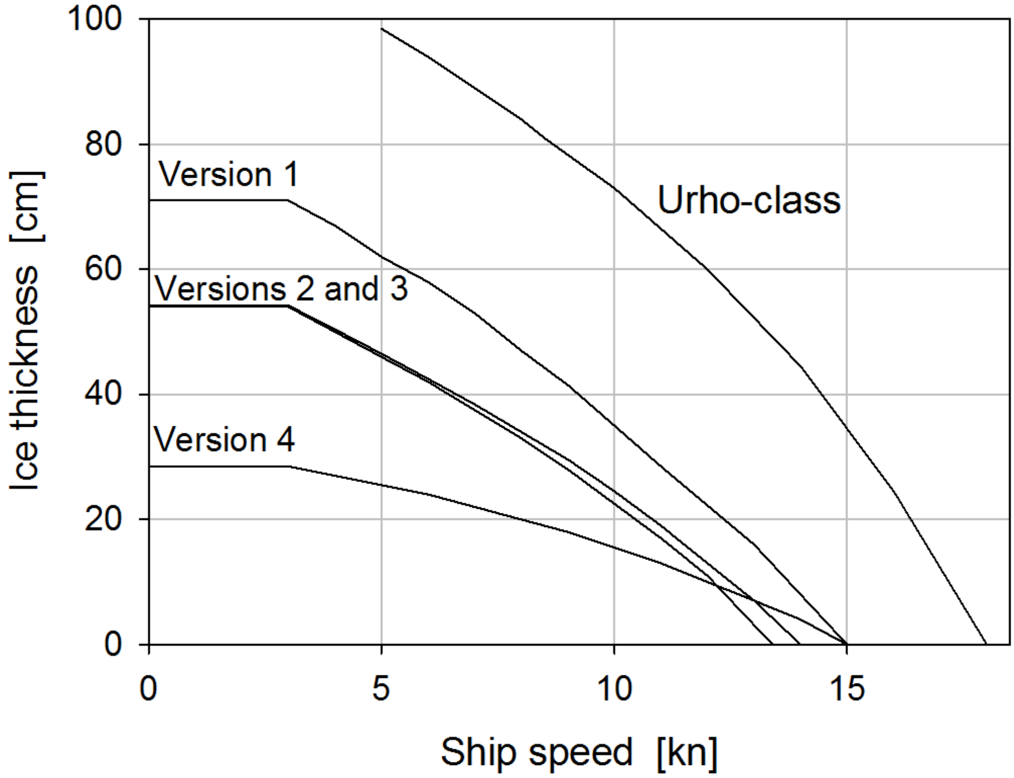

Fig. 1. The ice performance of the escort icebreakers and the different ship versions.

The CO_2 emissions per ton mile of carried cargo of the ship versions are calculated on a monthly basis on a route to Kemi from Rotterdam. The traffic is assumed to be continuous and the carried cargo is measured by the ship dead weight. The calculation is carried out by using the merchant ship power and the icebreaker power; these are slightly modified based on the statistics received from the Finnish and Swedish maritime authorities. Several assumptions are made when calculating the energy consumption of the trade to northern Finland. These can be listed as follows:

- → The average open water speed is assumed to be the speed mentioned in the ship data lists i.e. v_{ow}, this is taken as 14 kn for each ship but the power used to achieve this is the actual power used;
- → The merchant ship power used in ice is 95 % of the MCR (data from maritime authorities);
- → The power used of the icebreaker in escort operation is 10.655 MW;
- → The icebreakers use when in transit between two escort tasks 4.7 MW;
- → The waiting times for an icebreaker is at maximum 6 h and if only a part of the route leg in ice is escorted, the waiting time is adjusted linearly;
- → Cargo is carried both ways and the amount of cargo is the full dead weight;
- → Port time is 24 h and the power used in ports is 1 MW, this is also the power used in waiting for an icebreaker;
- → The open water ship (version 5) can follow the icebreaker only with 60 % of the speed that would be possible based on the icebreaker performance;
- → The escort speed is at maximum 9 kn.

The ice cover is described as a monthly average coverage – this determines the length of the distance to be sailed in ice. The total distance between Kemi and Rotterdam is 1200 nm. The distances in ice are assumed to be the following:

December	30 nm
January	100 nm

February 150 nm
March 220 nm
April 200 nm.

Part of this distance the ships can sail independently and rest of the distance they are escorted. A sketch of the route is shown in Fig. 2. The distances of independent and escorted operation vary for each ship version; these are shown in the calculation table in the Annex 1 and 2.

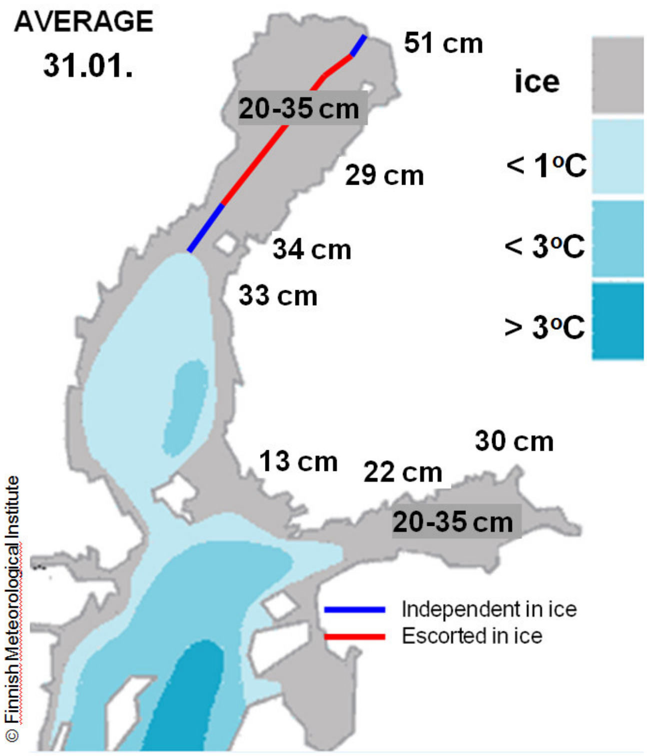

Fig. 2. The average ice extent and thickness in the end of January and the route segments selected (chart from Finnish Meteorological Institute). The colour code for temperatures refers to sea surface temperature.

The basic result of the calculation is the amount of CO_2 emissions per carried ton mile. These results for the basic IA Super ship with an ice breaking bow (ship version 2) are shown in Fig. 3. All the calculations are shown in the Appendix. The efficiency of the icebreaker use is denoted as η; this is the amount of time the icebreaker uses to escort ships in a certain time period. On average the efficiency in the Finnish icebreaking system is 62 %. Thus, if the transit time is equated into the escort power, the escort power (with the assumptions above) is 13.536 MW.

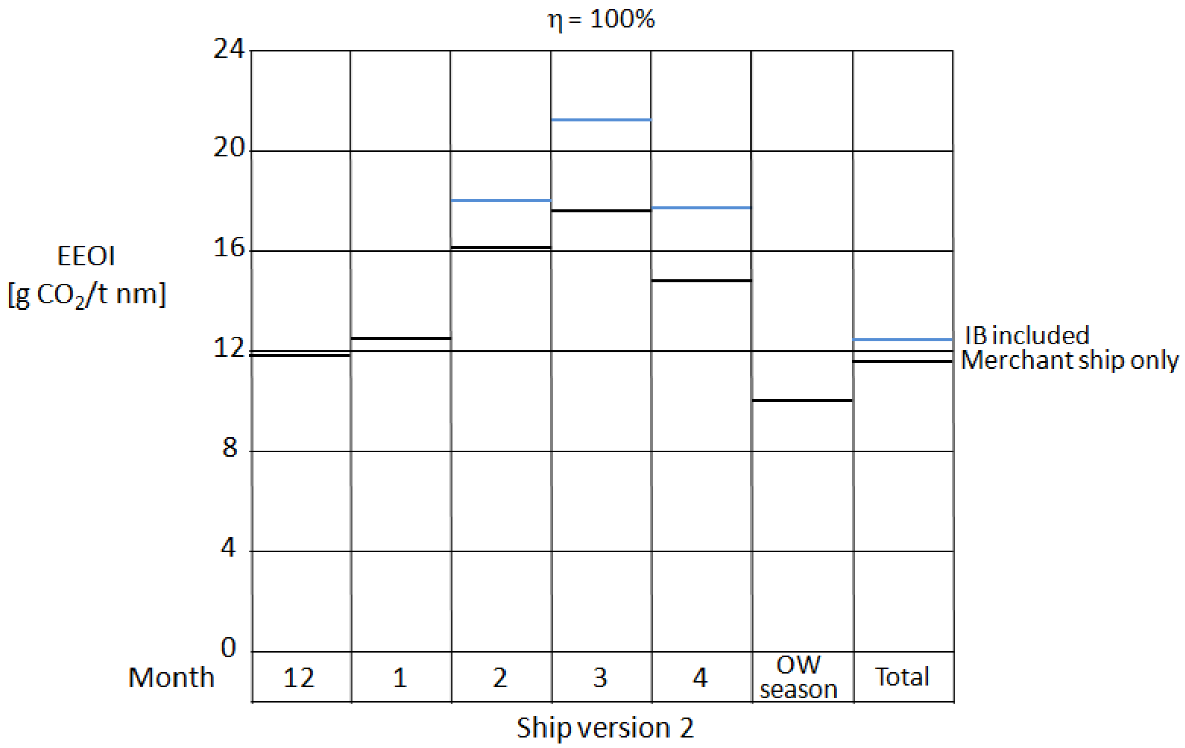

Fig. 3. The CO_2 emissions per carried ton mile for each winter month, open water season and for the whole year. The black lines correspond to the emissions of only the merchant ship and the blue lines include additionally the emissions of the icebreaker.

The attained EEDI is with icebreakers included is about 12.28 whereas the limit is 8.54. It should be remembered that the above calculation was done without including the ice class correction coefficients.

The annual attained EEDI values for each of the ship type are shown in Fig. 4. The calculation is done for the merchant ship emissions only (black lines) and including the icebreaker emissions (blue lines). The most energy efficient solution seems to be the ice strengthened ship which has no ice performance and have to be escorted through all ice – if only the merchant ship energy consumption is taken into account. Once the icebreaker energy consumption is accounted for, the ships having an ice capability become more energy efficient. If the icebreaker energy consumption is also accounted, the most energy efficient solution is the ship that has a moderate ice capable bow, ice class IA Super and just the minimum power that the ice class rules require.

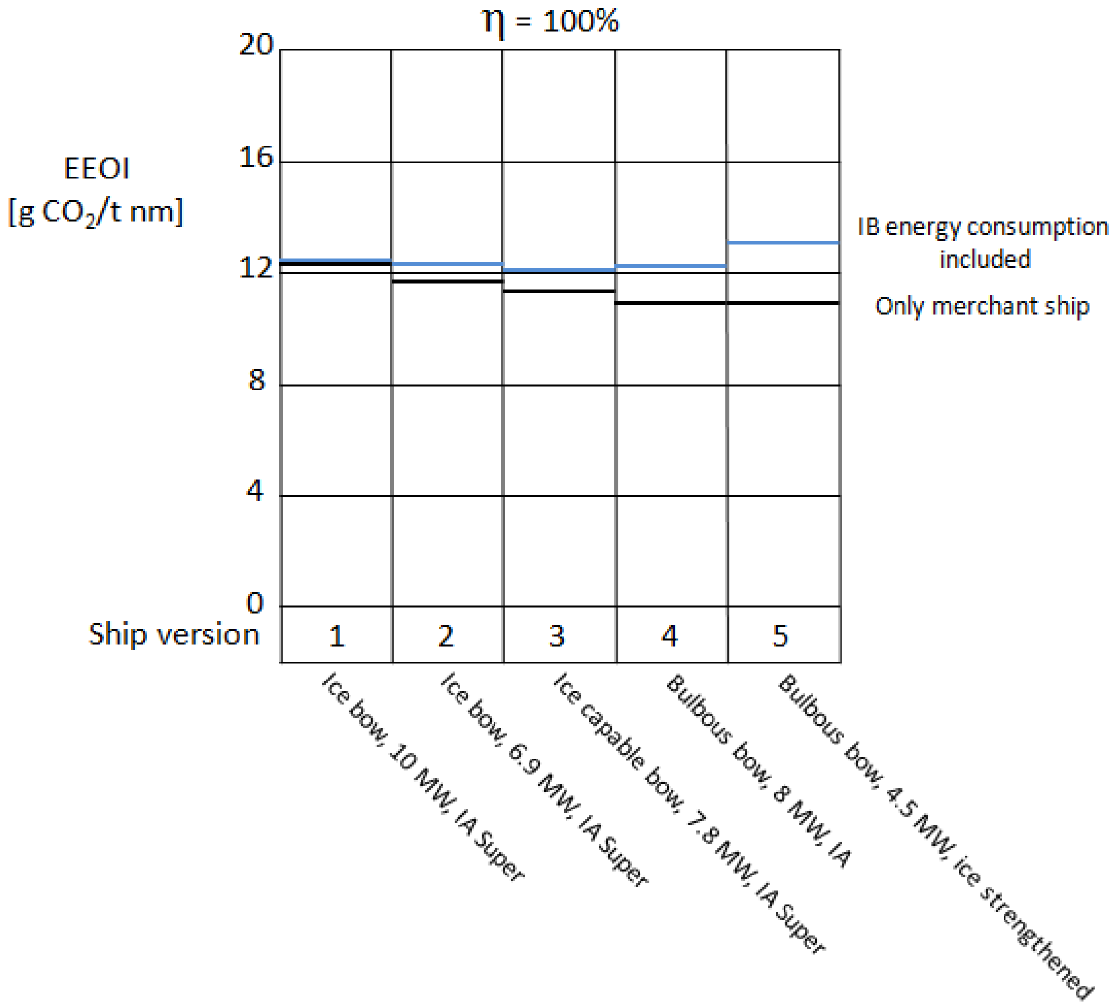

Fig. 4. The annual CO_2 emissions of the ship versions per carried ton mile. Two different calculations are shown; emissions of the merchant ship only (black line), icebreaker emissions included (blue lines).

The above calculations have been carried out assuming the efficiency of the icebreaker use to be 100%. This is not the case as the average efficiency is 62% in the Finnish ice breaking system. If the efficiency is taken into account and if it is assumed that icebreakers use a bit more than 25% of the full power in transit voyages. Thus the icebreaker energy use is to be modified by a factor depending on the transit power and the efficiency. If the efficiency is 62%, and the value of the transit power 4.7 MW, the power consumption for escort is 13.5 MW. The results of a calculation with a realistic icebreaker efficiency are presented in Fig. 5. The icebreaker efficiency does not change the situation, makes only the open water ship even less energy efficient.

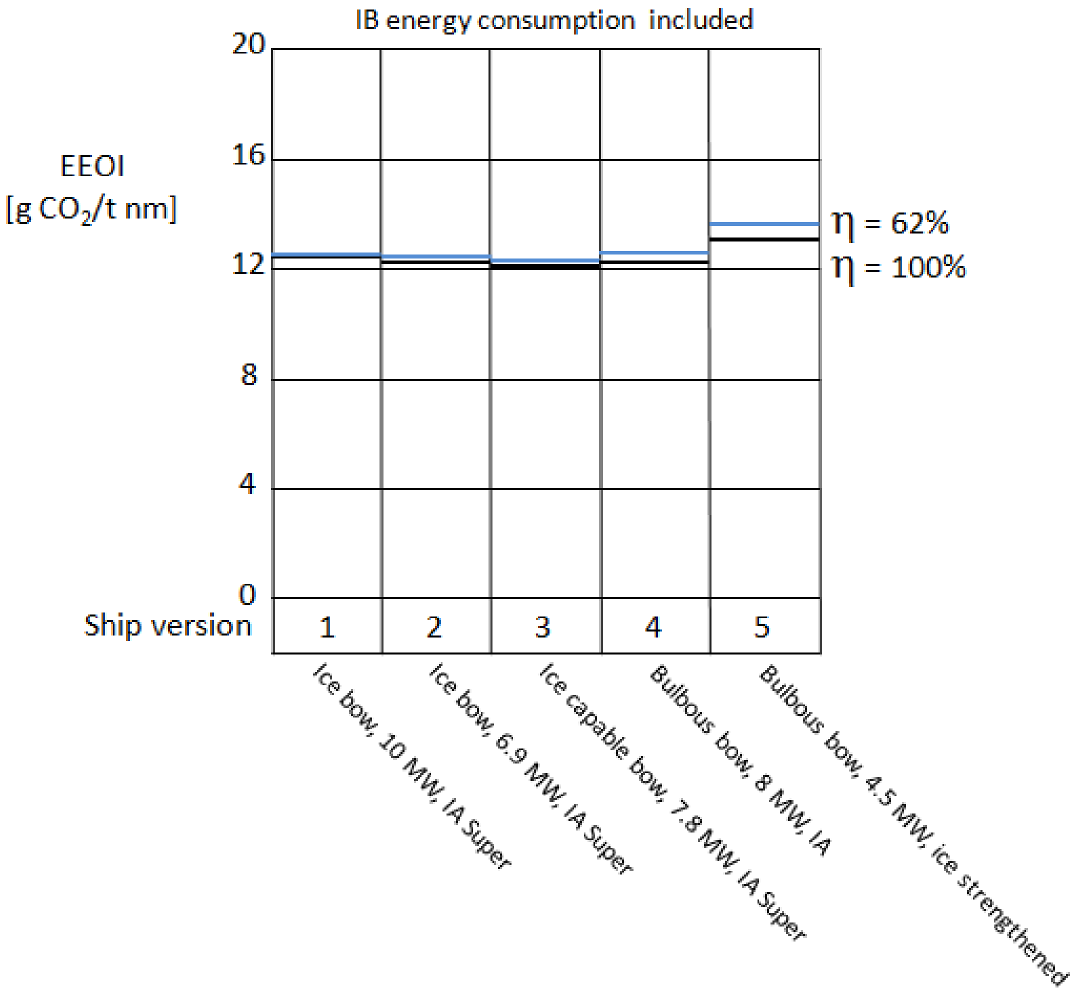

Fig. 5. The CO_2 emissions of the ship versions per carried ton mile with two efficiencies of the icebreaker use.

ANNEX; The EEDI calculation sheets.

1. Ice bow ($\varphi = 25^o$) , 10 MW, IA Super, $P_{OW} = 5200$ kW								
		Month (151 ice days in total)					OW season 214 days	Total
		12	1	2	3	4		
Equivalent ice thickness [cm]		18	38	60	80	80		
Distance nm / speed kn	Independent	30/11	100/9	150/5	180/5	160/5		
	Escorted	0	0	0	40/9	40/9		
	Open water	1170/14	1100/14	1050/14	980/14	1000/14	1200/14	
IB waiting time [h]		0	0	0	2	1	-	
Time in one direction [h]		110.3	113.7	129.0	136.0	132.9	109.7	
Visits per month		3.37	3.27	2.60	2.73	2.71	23.41	38.09
Energy use in ice per visit [MWh]		51.8	211.1	570.0	768.4	692.4		
Energy use in OW per visit [MWh]		869.1	817.1	780.0	728.0	742.9		
Energy use in port and waiting per visit [MWh]		48.0	48.0	48.0	52.0	50.0		
Total energy use per month [MWh]		3265.2	3519.2	3634.8	4227.1	4025.2	19182.8	37854.3
Tons carried		134800	130800	104000	109200	108400	936400	1523600
Ton miles $\cdot 10^{-3}$		161760	156960	124800	131040	130080	1123680	1828320
IB energy use [MWh] , $\eta = 100\%$		0	0	0	258.6	256.7	0	515.3
IB energy use [MWh], $\eta = 62\%$		0	0	0	328.5	326.1	0	654.1
EEDI [g CO_2/t nm]	without IB	11.94	13.27	17.23	19.09	18.31	10.10	12.25
	with IB, $\eta = 100\%$	-	-	-	20.26	19.48	-	12.42
	with IB, $\eta = 62\%$	-	-	-	20.57	19.79	-	12.46

2. Ice bow ($\varphi = 25^o$), 6.9 MW, IA Super, P_{OW} = 5200 kW								
		Month (151 ice days in total)					OW season 214 days	Total
		12	1	2	3	4		
Equivalent ice thickness [cm]		18	38	60	80	80		
Distance nm / speed kn	Independent	30/10	100/8	150/5	180/5	100/5		
	Escorted	0	0	60/9	120/9	100/9		
	Open water	1170/14	1100/14	1050/14	980/14	1000/14	1200/14	
IB waiting time [h]		0	0	2	4	3	-	
Time in one direction [h]		110.6	115.1	137.7	147.3	129.5	109.7	
Visits per month (all OW visits)		3.36	3.23	2.44	2.53	2.78	23.41	37.75
Energy use in ice per visit [MWh]		39.3	163.9	480.7	646.8	407.9		
Energy use in OW per visit [MWh]		869.1	817.1	780.0	728.0	742.9		
Energy use in port and waiting per visit [MWh]		48.0	48.0	52.0	56.0	54.0		
Total energy use per month [MWh]		3213.5	3323.7	3203.0	3619.9	3349.3	19182.8	35892.2
Tons carried		134400	129200	97600	101200	111200	936400	1510000
Ton miles $\cdot 10^{-3}$		161280	155040	117120	121440	133440	1123680	1812000
IB energy use [MWh], η = 100%		0	0	346.6	718.9	658.2	0	1723.7
IB energy use [MWh], η = 62%		0	0	440.3	913.3	836.2	0	2189.8
EEDI [g CO_2 / t nm]	without IB	11.79	12.69	16.18	17.64	14.85	10.10	11.72
	with IB, η = 100%	-	-	17.93	21.14	17.77	-	12.28
	with IB, η = 62%	-	-	18.41	22.08	18.56	-	12.43

3. Ice capable bow ($\varphi = 40^o$), 7.8 MW, IA Super, P_{OW} = 4900 kW								
		Month (151 ice days in total)					OW season 214 days	Total
		12	1	2	3	4		
Equivalent ice thickness [cm]		18	38	60	80	80		
Distance nm / speed kn	Independent	30/10	100/6	90/5	100/5	100/5		
	Escorted	0	0	60/9	120/9	100/9		
	Open water	1170/14	1100/14	1050/14	980/14	1000/14	1200/14	
IB waiting time [h]		0	0	2	4	3	-	
Time in one direction [h]		110.6	119.2	125.7	131.3	129.5	109.7	
Visits per month		3.36	3.12	2.67	2.83	2.78	23.41	38.17
Energy use in ice per visit [MWh]		44.5	247.0	365.6	494.0	461.1		
Energy use in OW per visit [MWh]		819.0	770.0	735.0	686.0	700.0		
Energy use in port and waiting per visit [MWh]		48.0	48.0	52.0	56.0	54.0		
Total energy use per month [MWh]		3062.6	3322.0	3077.4	3497.9	3378.0	19182.8	35521.5
Tons carried		134400	124800	106800	113200	111200	936400	1526800
Ton miles $\cdot 10^{-3}$		161280	149760	128160	135840	133440	1123680	1832160
IB energy use [MWh] , η = 100%		0	0	379.3	804.1	658.2	0	1841.6
IB energy use [MWh], η = 62%		0	0	481.9	1020.5	836.2	0	2338.6
EEDI [g CO_2/ t nm]	without IB	11.24	13.13	14.21	15.24	14.98	10.10	11.47
	with IB, η = 100%	-	-	15.96	18.74	17.90	-	12.07
	with IB, η = 62%	-	-	16.43	19.68	18.69	-	12.23

4. Bulbous bow, 8 MW, IA, P_{OW} = 4500 kW								
		Month (151 ice days in total)					OW season 214 days	Total
		12	1	2	3	4		
Equivalent ice thickness [cm]		18	38	60	80	80		
Distance nm / speed kn	Independent	30/8	20/5	20/5	20/5	20/5		
	Escorted	0	80/10	130/9	200/9	180/9		
	Open water	1170/14	1100/14	1050/14	980/14	1000/14	1200/14	
IB waiting time [h]		0	1	4	6	5	-	
Time in one direction [h]		111.3	115.6	121.4	126.2	124.4	109.7	
Visits per month		3.34	3.22	2.77	2.95	2.89	23.41	38.58
Energy use in ice per visit [MWh]		57.0	182.4	280.4	398.6	364.8		
Energy use in OW per visit [MWh]		752.1	707.1	675.0	630.0	642.9		
Energy use in port and waiting per visit [MWh]		48.0	50.0	56.0	60.0	58.0		
Total energy use per month [MWh]		2862.7	3025.2	2801.6	3211.4	3079.9	19182.8	34163.6
Tons carried		133600	128800	110800	118000	115600	936400	1543200
Ton miles $\cdot 10^{-3}$		160320	154560	132960	141600	138720	1123680	1851840
IB energy use [MWh] , η = 100%		0	548.9	852.6	1397.0	1231.7	0	4030.2
IB energy use [MWh], η = 62%		0	697.4	1083.2	1774.7	1564.8	0	5119.0
EEDI [g CO_2/ t nm]	without IB	10.57	11.58	12.47	13.42	13.14	10.10	10.92
	with IB, η = 100%	-	13.68	16.26	19.26	18.39	-	12.20
	with IB, η = 62%	-	14.25	17.29	20.84	19.81	-	12.55

5. Bulbous bow, 6.0 MW, only ice strengthened (v_{OW} = 14 kn), P_{OW} = 4500 kW								
		Month (151 ice days in total)					OW season 214 days	Total
		12	1	2	3	4		
Equivalent ice thickness [cm]		18	38	60	80	80		
Distance nm / speed kn	Independent	0	0	0	0	0		
	Escorted	30/7	100/7	150/6	220/6	200/6		
	Open water	1170/14	1100/14	1050/14	980/14	1000/14	1200/14	
IB waiting time [h]		4	5	6	6	6	-	
Time in one direction [h]		115.9	121.9	130.0	136.7	134.8	109.7	
Visits per month		3.21	3.05	2.58	2.72	2.67	23.41	37.64
Energy use in ice per visit [MWh]		48.9	162.9	285.0	418.0	380.0		
Energy use in OW per visit [MWh]		752.1	707.1	675.0	630.0	642.9		
Energy use in port and waiting per visit [MWh]		56.0	58.0	60.0	60.0	60.0		
Total energy use per month [MWh]		2751.0	2830.4	2631.6	3013.8	2891.3	19182.8	33300.9
Tons carried		128400	122000	103200	108800	106800	936400	1505600
Ton miles $\cdot 10^{-3}$		154080	146400	123840	130560	128160	1123680	1806720
IB energy use [MWh] , η = 100%		293.2	928.5	1374.5	2125.3	1896.6	0	6618.1
IB energy use [MWh], η = 62%		372.4	1179.6	1746.1	2700.0	2409.4	0	8407.5
EEDI [g CO_2/ t nm]	without IB	10.57	11.44	12.57	13.66	13.35	10.10	10.91
	with IB, η = 100%	11.69	15.19	19.14	23.29	22.11	-	13.07
	with IB, η = 62%	12.00	16.21	20.92	25.90	24.47	-	13.66

5. Bulbous bow, 4.5 MW, only ice strengthened (v_{OW} = 14 kn)								
		Month (151 ice days in total)					OW season 214 days	Total
		12	1	2	3	4		
Equivalent ice thickness [cm]		18	38	60	80	80		
Distance nm / speed kn	Independent	0	0	0	0	0		
	Escorted	30/7	100/7	150/6	220/5	200/5		
	Open water	1170/14	1100/14	1050/14	980/14	1000/14	1200/14	
IB waiting time [h]		4	5	6	6	6	-	
Time in one direction [h]		115,9	121,9	130,0	144,0	141,4	109,7	
Visits per month		3,21	3,05	2,58	2,58	2,54	23,41	37,37
Energy use in ice per visit [MWh]		36,8	128,6	225,0	396,0	360,0		
Energy use in OW per visit [MWh]		564,1	530,4	506,3	472,5	482,1		
Total energy use [MWh]		2114,4	2186,6	2041,4	2395,5	2291,4	14668,0	25697,3
Tons carried		128 400	122 000	103 200	103 200	101 600	936 400	1 494 480
Ton miles $\cdot 10^{-3}$		154 080	146 400	123 840	123 840	121 920	1 123 680	1 793 760
IB energy use [MWh]		445,7	1411,7	2089,8	3678,0	3291,8	0	10917,0
EEDI [g CO_2/ t nm]	without IB	8,12	8,84	9,75	11,45	11,12	7,72	8,48
	with IB	9,83	14,54	19,74	29,02	27,10	-	12,08