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Background

The Finnish Meteorological Institute has made an estimate of exhaust gas emissions from Baltic Sea Shipping in 2006 - 2018, see the attachment. The emission estimates for the year 2018 are based on over 638 million AIS-messages sent by 26 680 different ships, of which 7 914 had an IMO registry number indicating commercial marine traffic. The AIS position reports were received by terrestrial base stations in the Baltic Sea countries and collected to regional HELCOM AIS data server. Emissions are generated using the Ship Traffic Emission Assessment Model (STEAM; (Jalkanen et al., 2009b, 2012b; Johansson et al., 2013, 2017). This document includes a report of modeled airborne emissions from Baltic Sea shipping during the year 2018 and their development over the period of 2006-2018. For the first time this report also includes analysis of development of energy efficiency of ships sailing in the Baltic Sea area over the period of 2006–2018.

Emissions from Baltic Sea Shipping in 2018

Total emissions from IMO-registered vessels in the Baltic Sea in 2018 were 301 thousand tonnes of NO_x, 9 thousand tonnes of SO_x, 9 thousand tonnes of PM, 21 thousand tonnes of CO, 3 thousand tonnes NMVOC and 14 million tonnes of CO_2. The CO_2 amount corresponds to 4.7 million tonnes of fuel, of which 26% was associated to auxiliary engines. These emissions contain only the IMO-registered traffic and do not include any contribution from inland waterway traffic or non-IMO registered vessels. **With all vessels sailing the Baltic Sea (excluding the inland waterway traffic), emission totals are NOx: 330 thousand tonnes, SOx: 10 thousand tonnes, PM: 10 thousand tonnes, CO: 24 thousand tonnes, NMVOC: 3 thousand tonnes and CO2: 15.7 million tonnes.**

The most significant contribution to emissions can be associated with RoPax vessels, cargo ships, tankers and container ships. In terms of fuel consumption, the respective shares for these vessel types in the presented order are 1235 (+4.3% increase from previous year), 967 (-1.6%), 968 (+9.6%) and 769 (-3.6%) thousand tonnes of fuel consumed.

The emissions of SOx have decreased, (-0.2%) but all other emissions have increased; CO (+3.4%) but emissions of NOx (+0.2%), PM (+0.1%) NMVOC (+1.6%) and CO2 (+0.6%) have slightly increased, when compared to year 2017. The emissions of CO_2 from non-IMO registered vessels were 9.1% of total CO_2 emitted from ships. During the 2018 study period, the number of IMO-registered vessels has increased by +3%.

Overall transport work has increased by +2.4% while the total travelling distance of IMO-registered vessels have increased by +6.2%. The transport work of RoPax, dry cargo, vehicle carrier and containership segments increased by +14%, +12%, +7% and +2.1% whereas the transport work of tankers decreased by -0.4%.

Analysis of one decade of CO_2 emissions from Baltic Sea ships reveals a downward trend and indicates a **20% increase in energy efficiency of the Baltic Sea fleet during 2008-2018**. In absolute terms, the CO_2 emissions from ships have decreased by -6.2% and transport work has increased by +12.5% when compared to year 2008 totals. Estimated fleet operational index was 18.7 g ton^{-1} km^{-1} in 2008 and 15.6 g ton^{-1} km^{-1} in 2018.

More detailed information can be found in the attached report of the Finnish Meteorological Institute.

Action requested

The Meeting is invited to take note of the information.

Emissions from Baltic Sea shipping in 2006-2018

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Key Messages

1. **Total emissions from IMO-registered vessels in the Baltic Sea in 2018 were 301 thousand tonnes of NO_x, 9 thousand tonnes of SO_x, 9 thousand tonnes of PM, 21 thousand tonnes of CO, 3 thousand tonnes NMVOC and 14 million tonnes of CO_2.** The CO_2 amount corresponds to 4.7 million tonnes of fuel, of which 26% was associated to auxiliary engines. These emissions contain only the IMO-registered traffic and do not include any contribution from inland waterway traffic or non-IMO registered vessels. **With all vessels sailing the Baltic Sea (excluding the inland waterway traffic), emission totals are NOx: 330 thousand tonnes, SOx: 10 thousand tonnes, PM: 10 thousand tonnes, CO: 24 thousand tonnes, NMVOC: 3 thousand tonnes and CO2: 15.7 million tonnes.**

2. **The most significant contribution to emissions can be associated with RoPax vessels, cargo ships, tankers and container ships.** In terms of fuel consumption, the respective shares for these vessel types in the presented order are 1235 (+4.3% increase from previous year), 967 (-1.6%), 968 (+9.6%) and 769 (-3.6%) thousand tonnes of fuel consumed.

3. **The emissions of SOx have decreased, (-0.2%) but all other emissions have increased; CO (+3.4%) but emissions of NOx (+0.2%), PM (+0.1%) NMVOC (+1.6%) and CO2 (+0.6%) have slightly increased, when compared to year 2017.** The emissions of CO_2 from non-IMO registered vessels were 9.1% of total CO_2 emitted from ships. During the 2018 study period, the number of IMO-registered vessels has increased by +3%.

4. **Overall transport work has increased by +2.4% while the total travelling distance of IMO-registered vessels have increased by +6.2%**. The transport work of RoPax, dry cargo, vehicle carrier and containership segments increased by +14%, +12%, +7% and +2.1% whereas the transport work of tankers decreased by -0.4%.

5. Analysis of one decade of CO_2 emissions from Baltic Sea ships reveals a downward trend and indicates a **20% increase in energy efficiency of the Baltic Sea fleet during 2008-2018**. In absolute terms, the CO_2 emissions from ships have decreased by -6.2% and transport work has increased by +12.5% when compared to year 2008 totals. Estimated fleet operational index was 18.7 g ton^{-1} km^{-1} in 2008 and 15.6 g ton^{-1} km^{-1} in 2018.

1. Emissions of atmospheric pollutants

This work reports the consistent timeseries of ship emissions between 2006-2018 based on vessel specific emission modelling (Jalkanen et al., 2009a, 2012a, 2018; Johansson et al., 2013, 2017). The emissions of all pollutants from Baltic Sea ship fleet have increased from 2017 except for SO_x. Largest relative increase (+3.4%) was observed for CO emissions. Annual totals reported by sea area and vessel type are given in **Table 1**. The transport work of IMO registered ships increased slightly from last year's value (+2.4%) while CO_2 emissions were increased by +0.6%. This continued the improvement of energy efficiency of the Baltic Sea fleet. The total CO_2 emitted in 2018 was 15.7 million tonnes. This corresponds to roughly 1.9% of the global shipping CO_2 emissions in 2018 (using global 2018 AIS data).

Table 1 Summary of atmospheric fuel consumption, atmospheric emissions and transport work for the Baltic Sea fleet during 2018.

Baltic - 2017	MAIN_FUEL [10^3 tonnes]	AUX_FUEL [10^3 tonnes]	NOx [tonnes]	SOx [tonnes]	PM25 [tonnes]	CO [tonnes]	CO2 [10^3 tonnes]	TRAVEL [10^3 km]	TRANSPORT WORK [10^6 tonne km]	VOC [tonnes]	SHIPS
All	3 629	1 533	329 851	10 470	10 057	23 516	15 691	143 585	964 557	2 776	26 680
IMO	3 452	1 243	300 753	9 498	9 152	20 825	14 268	111 167	916 286	2 541	7 914
Baltic Proper	2 185	688	187 985	5 802	5 523	12 935	8 732	83 265	562 145	1553	
Kattegat	652	366	67 277	2 068	2 010	4 914	3 093	30 647	213 788	546	
Gulf of Finland	439	331	47 207	1 560	1 537	3 553	2 341	14 644	132 212	410	
Gulf of Bothnia	312	121	23 163	881	848	1 780	1 318	12 450	45 502	231	
Gulf of Riga	41	27	4 219	159	139	334	206	2 579	10 911	37	
RoPax_vessels	1 053	182	74 417	2 489	2 242	4 351	3 754	15 549	31 400	678	218
Vehicle_carriers	391	63	28 142	871	730	1 688	1 379	7 625	55 278	239	259
Cargo_ships	706	261	64 127	1 990	1 977	5 274	2 941	45 412	350 525	519	4 011
Container_ships	495	273	53 411	1 572	1 625	3 712	2 337	12 158	165 727	421	607
Tankers	628	341	67 416	1 976	2 043	4 395	2 941	19 103	361 628	501	1 911
Passenger_ships	29	21	3 145	101	91	232	150	4 925		26	470
Cruisers	138	35	9 796	333	298	669	526	1 405		105	94
Fishing_vessels	22	22	2 469	91	83	229	134	6 902		22	801
Service_ships	23	33	3 258	116	112	273	170	2 856		31	401

Emission totals reported in **Table 1** include emissions of both the IMO registered traffic and all vessels. The difference of these two is the vessel fleet which is smaller than the IMO registration threshold or operates only on national waters. Regardless, all vessel traffic using Automatic Identification System transceivers is included in the modelling. Vessels traveling inland waterways have been removed from the dataset. The largest emission source in the Baltic Sea fleet are the vessels in the RoPax class, followed by dry and liquid cargo ships.

Figure 1 depicts the emission trends over the study period. Significant decreases in 2010 and 2015 are results of policy changes concerning the limit for sulphur content in fuel oil for ships sailing in the Baltic Sea area. For NOx and CO, both the IMO registered traffic and all emission source cases are reported. This illustrates the magnitude (<10%) of non-IMO traffic contribution to emission totals. However, these numbers do not include contributions from recreational boating which can be a significant source of NMVOC and CO emissions, especially during summer months. The AIS equipment is not mandatory for these vessels and thus they are excluded from the current analysis.

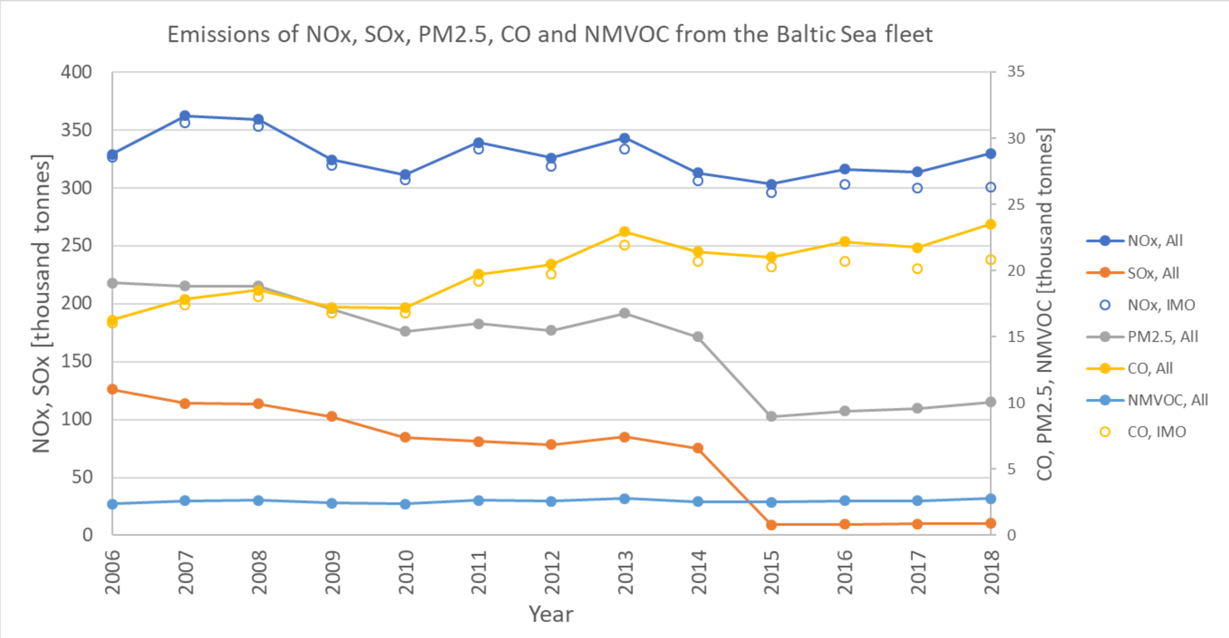

Figure 1 Emissions of NO_x, SO_x, PM2.5, CO and NMVOC from ships in the Balti Sea during 2008-2018. Significant decreases in SO_x and PM2.5 are results of regulatory changes concerning the maximum Sulphur content of fuel. Colored symbols depict total emissions from all vessels with an active AIS transceiver, empty symbols indicate the contribution from IMO-registered ships only.

Decreasing trend in NO_x, SO_x and PM emissions can be observed, but CO emissions are in the increase.

2. CO_2 emissions and energy efficiency

The transport work and CO_2 emissions have developed favourably during the study period. Energy efficiency improvements have reduced the CO_2 emissions while transport work has increased (**Figure 2**). Improvements in energy efficiency have been the largest in the container ship segment and smallest in the case of RoPax ships (**Figure 3**). One reason for improvements of energy efficiency of ships is that new more energy efficient ships have replaced older tonnage sailing in the Baltic Sea area. Another reason is that operating speeds of various ship types have clearly decreased during the period 2006 to 2018, see Figure 4. This may explain the difference in development of energy efficiency of containerships compared to development of energy efficiency of RoPax ships. The comparison is based on modelled fuel consumption of vessels, distances traveled calculated from AIS position reports and modelled cargo amounts as defined in the Second IMO GHG study (Buhaug et al., 2009).

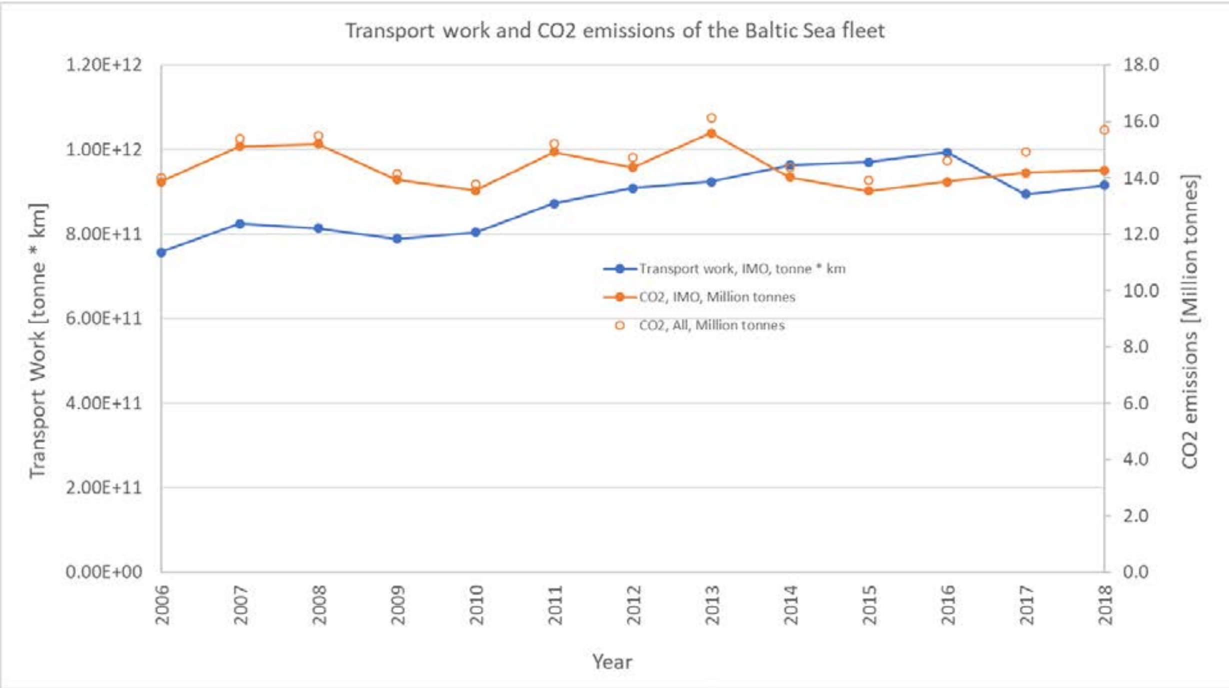

Figure 2 Transport work and CO_2 emissions of the Baltic Sea fleet. Transport work (blue line and blue symbols) has increased by +12.5% during the last decade. The emissions of CO_2 (orange line, orange symbols) have been reduced by -6.2% during the same period. This translates to 20% energy efficiency improvement in the Baltic Sea area. The open symbols indicate CO_2 emission totals including the non-IMO regulated traffic.

The values indicated by **Figure 3** use modelled Energy Efficiency Operation Index of the IMO but are not based on actual amount of cargo transferred, because this data is not openly available. For more detailed work, actual values for cargo carried should be used. However, based on the results of this work, significant improvements in energy efficiency have been observed over the last decade.

Largest improvements were found in case of dry cargo ships and container vessels. The baseline year of 2008 for this comparison matches with that of the IMO.

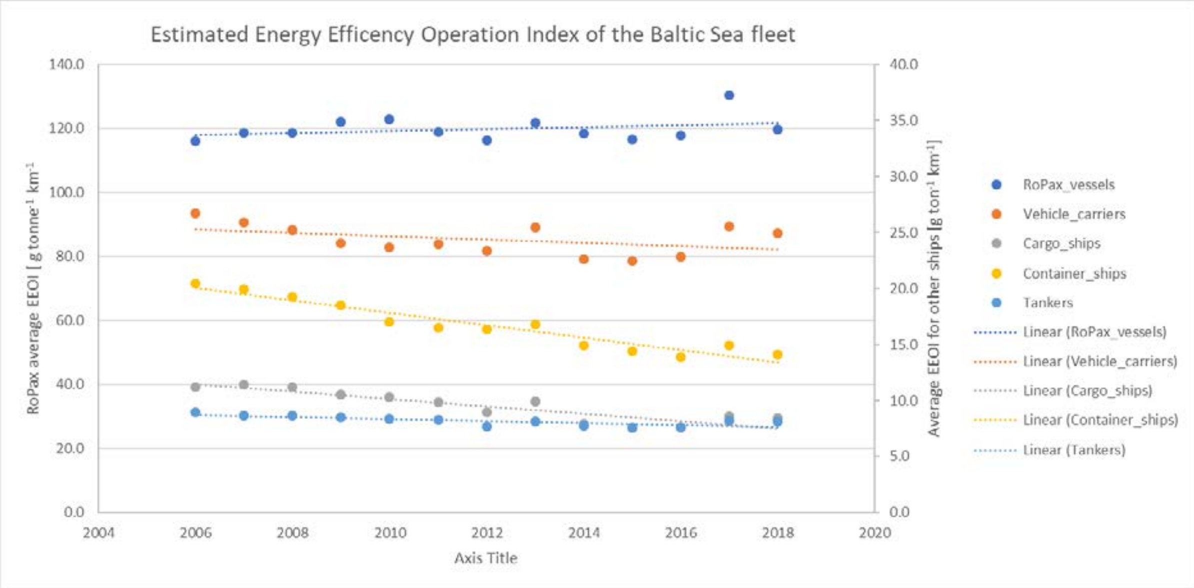

Figure 3 Development of estimated EEOI over the period 2006-2018. Values for RoPax vessels are given in left axis whereas the values for other ship types are indicated on the right axis.

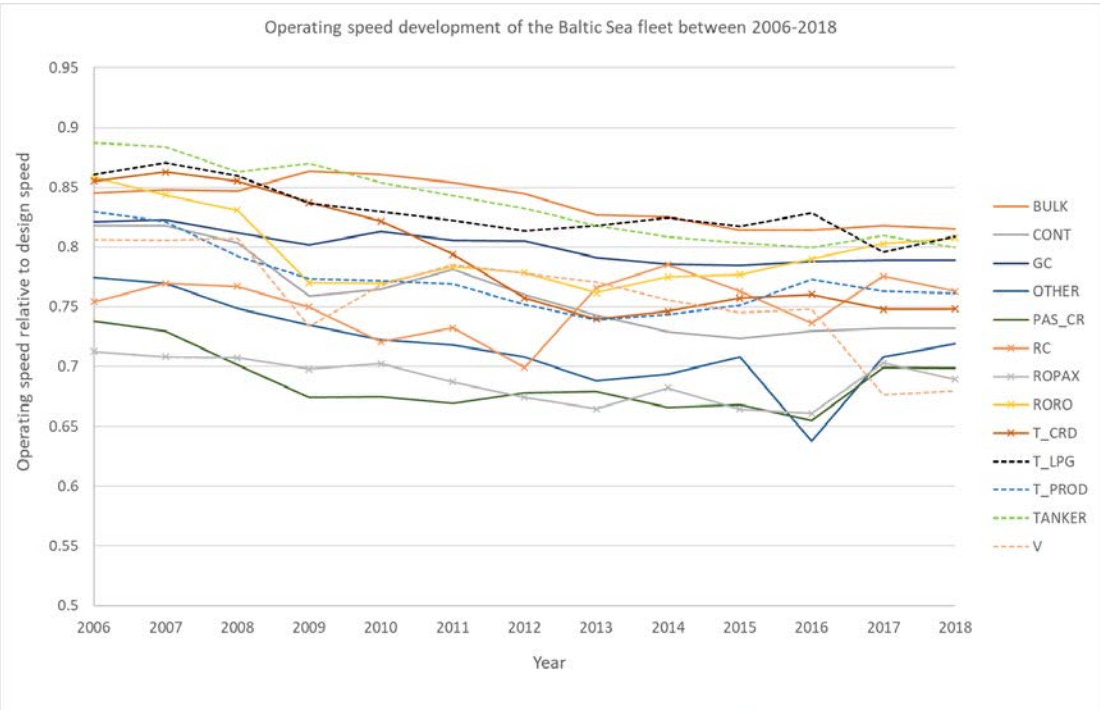

Figure 4 Operating speeds of various types of ships in the Baltic Sea fleet. The numbers presented report the relation between average cruising speed to the design speed of each class. This figure illustrates a widespread use of slow steaming across all ship types in the Baltic Sea fleet.

The emissions from various national fleets are depicted in Figure 5. The boxes report the total emissions of CO_2 of each fleet and the bars illustrate the changes of CO_2 emission levels compared to year 2008 emission totals. As can be seen from Figure 4, several flag states have reduced their CO_2 emissions, most notably Denmark, Panama, Antigua & Barbuda, Liberia and Malta. The vessels in these fleets are quite large, which exemplifies the economy of scale. Larger vessels use less fuel per transport work produced. Unfortunately, there are several fleets which have emitted more CO_2 than in the 2008 baseline. Large emitters, like Sweden, Finland and Germany have performed less well in this regard.

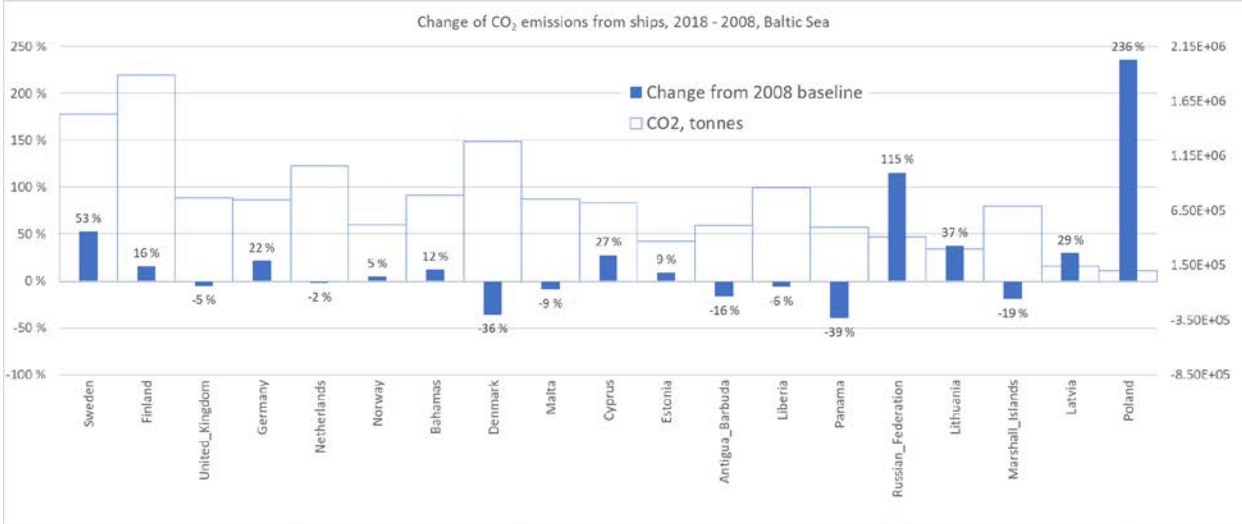

Figure 5 Estimated CO_2 emissions of the Baltic Sea fleet in 2018 (boxes, in tonnes, right axis) and their changes during the last decade (bars, in percent, left axis).

Based on the calculated efficiency index (EEOI), the fleets were grouped in three categories according to their performance. These are illustrated in Figure 6, Figure 7 and Figure 8. The bars of each fleet represent the calculated EEOI each year and allow the determination of the overall performance of the fleet. Panama, Liberia, Marshall Islands and Malta are among the most energy efficient group. The vessels in these fleets are typically quite large and they contribute significantly (38%) to the total transport work.

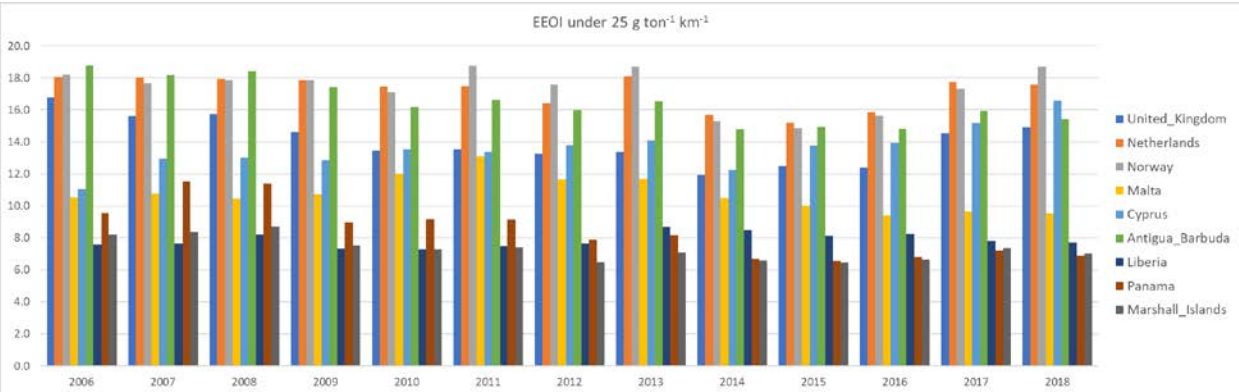

Figure 6 Evolution of the average EEOI of national fleets. These fleets have the smallest EEOI values (under 25 g tonne^{-1} km^{-1}).

The second group of national fleets has EEOI average between 25 and 50 g ton^{-1} km^{-1} (Figure 7). Energy efficiency improvement of the Danish fleet is remarkable. During the previous decade, the Danish fleet has improved its energy efficiency by 36%, even if this fleet is the third highest emitter of CO_2 in the Baltic Sea area. The CO_2 emissions from other fleets in this group have increased during this period.

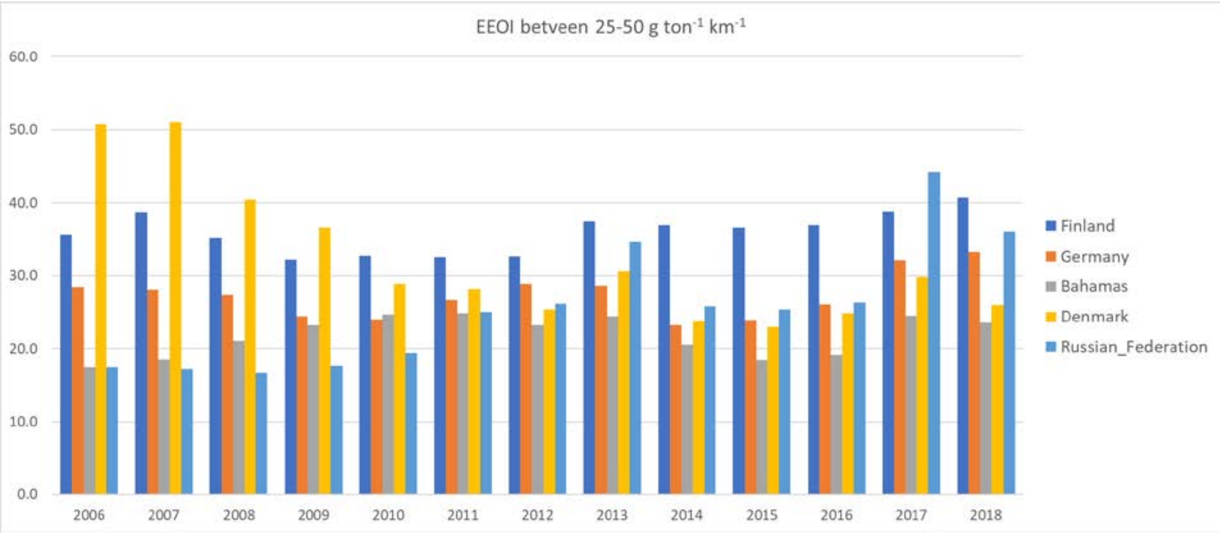

Figure 7 Evolution of the average EEOI of national fleets. This second group of countries have average EEOI between 25 and 50 g tonne^{-1} km^{-1}.

The third group consists of high CO_2 emitting fleets. None of these fleets have managed to decrease their CO_2 emissions during the study period. Strong increase in average EEOI was observed with the Polish fleet, which may be a result of several things. First, number of AIS targets with Polish flag has increased sevenfold during the last ten years. Clear majority of the fleet are small vessels, which may be the primary reason for high EEOI numbers, because small vessels are not as energy efficient as larger ones. The contribution of the Polish fleet to total CO_2 emissions is small, less than one percent, though. Emissions of CO_2 from Swedish and Estonian fleets are in the increase, and both have significant (10% and 2.4%, respectively) shares of total CO_2 emissions.

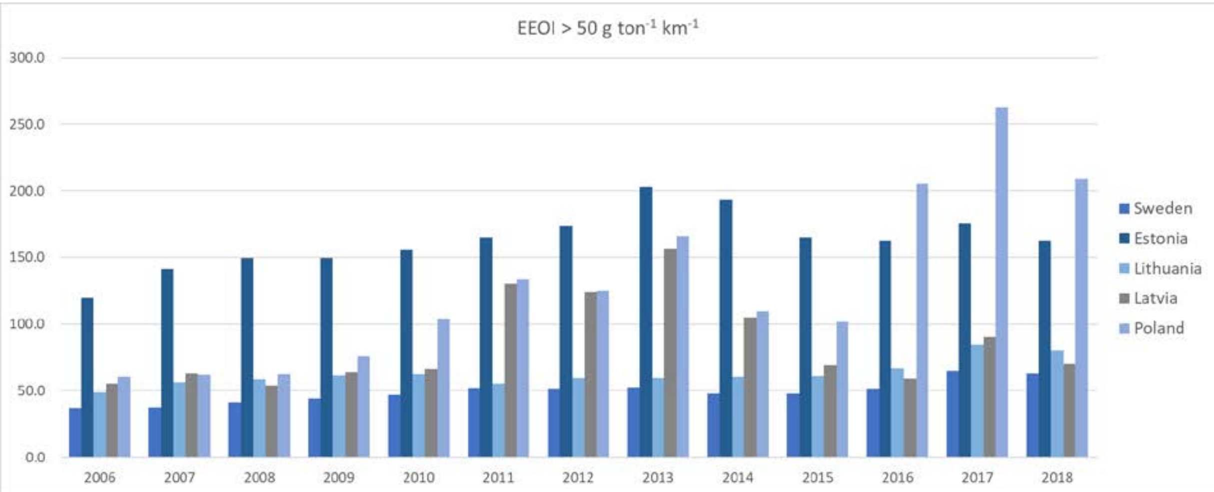

Figure 8 Evolution of the average EEOI of national fleets. This third group of countries have the highest EEOI of the studied fleets, over 50 g tonne^{-1} km^{-1}.

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Data

The emission estimates for the year 2018 are based on over 638 million AIS-messages sent by 26 680 different ships, of which 7 914 had an IMO registry number indicating commercial marine traffic. The AIS position reports were received by terrestrial base stations in the Baltic Sea countries and collected to regional HELCOM AIS data server. Emissions are generated using the Ship Traffic Emission Assessment Model (STEAM; (Jalkanen et al., 2009b, 2012b; Johansson et al., 2013, 2017).

For 2018, the temporal coverage was slightly worse (97.2%) than during the previous year (2017: 99.3%) with significant data gaps occurring during Feb 2nd-Feb 9th 2018. Most of the messages originate from South-Western region of the Baltic Sea near the Danish and southern Swedish sea areas (Figure 9). For the most part of the year 2018, data flow was around 50 000 - 60 000 messages per hour.

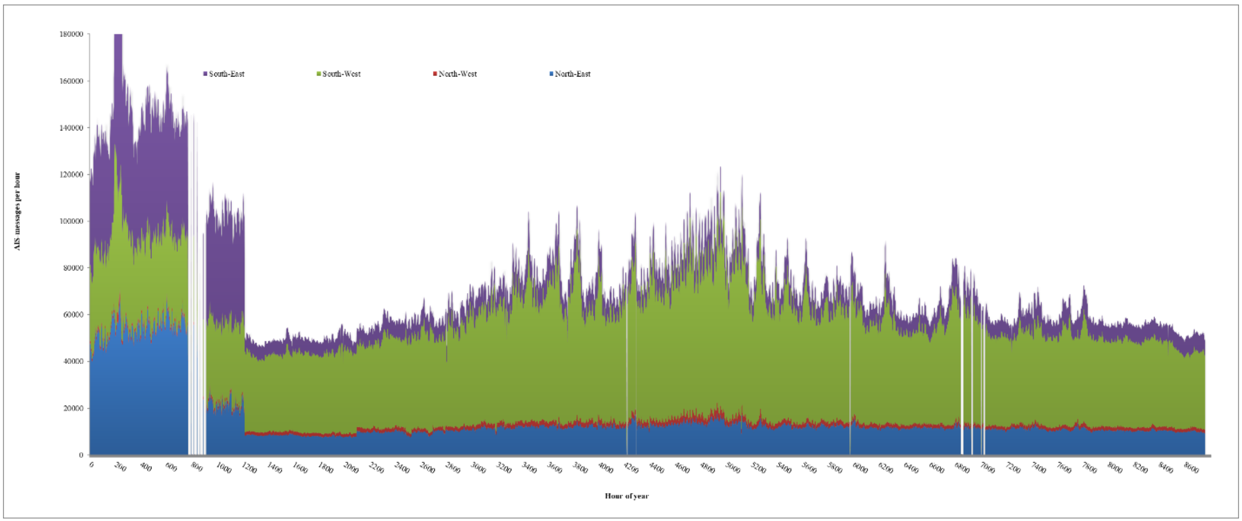

Figure 9 AIS-data hourly coverage in different parts of the modelling region for 2017.

Metadata

Fuel and vessel operational procedures can have a large impact on exhaust emissions. Emission factors for ships are in accordance with the latest literature and are believed to represent a reasonable estimate of the resulting emissions. Marine currents, fouling and sea ice can have a significant impact on emissions, but these effects have not been accounted for in this study.

Some uncertainty in predicted emissions arises from the large number of small vessels for which technical details are unavailable or incomplete. However, the internet contains some basic vessel characteristics even for such small and unknown ships[1] and by using an automated vessel characteristics extraction routine, it has been verified that the group of unknown ships are in fact small vessels and as such do not cause significant margins of error for the modelled annual emission totals. Nevertheless, only a fraction of recreational boating activity can be studied with AIS. It describes the activity of commercial ship traffic well because AIS is mandatory for large vessels.

[1]For example, www.marinetraffic.com and www.vesselfinder.com usually yield the ship type and physical dimensions for vessels that have no IMO-number..