# Emissions from Baltic Sea shipping in 2015

**Authors:** Lasse Johansson, Jukka-Pekka Jalkanen

Finnish Meteorological Institute, Atmospheric Composition Research
P.O Box 503, FI-00101 Helsinki, Finland

## Key message

1. **Total emissions from all vessels in the Baltic Sea in 2015 were 342 kt of $NO_x$, 10 kt of $SO_x$, 10 kt of PM, 23 kt of CO and 15.9 Mt of $CO_2$.** The $CO_2$ amount corresponds to 4970 kilotons of fuel, of which 26% was associated to auxiliary engines. The fuel consumption of inland waterway traffic sending AIS-messages was only 58 kilotons.

2. **The most significant contribution to emissions can be associated with RoPaX vessels, tankers, cargo ships and container ships.** In terms of fuel consumption, the respective shares for these vessel types in the presented order are 1310 (-4.4%), 1090 (+18.5%), 869 (+14.3%) and 759 (+10%) kt of fuel consumed.

3. **The emissions of $NO_x$ and $CO_2$ have increased by 6.3 and 5.6% when compared to year 2014. For CO a decrease of 33% was observed which is largely due to better classification of unknown vessels to proper ship types**. The emissions of $CO_2$ and CO from non-IMO registered vessels were 3.7% and 5.1%.

4. **Overall transport work (vessel type dependent fraction of DWT*km) has increased by +1.8% while the total travelling distance of IMO-registered vessels have decreased by -2.6%**. The transport work of containership segment decreased by -4.8% whereas the transport work of tankers and cargo ships increased by +3.6% and +5.5%. For RoPaX vessels a decrease of -6.8% was observed. The simultaneous increase of transport work and the decrease in travel distance indicates an increase in vessel transport capacity on average.

5. The emissions of particulate matter and sulphur from Baltic Sea shipping have decreased gradually since 2006 because of the tightening $SO_x$ emission regulations of the MARPOL Convention in the Baltic Sea SECA area. From January 1st 2015, only 0.1% sulphur or less was allowed in marine fuels. **This has significantly reduced the emissions of $SO_x$ (-88%) and PM (-36%). Reduction of PM emissions is not as large as with $SO_x$ because most of primary PM emitted in the area constitutes of components which do not contain sulphur.** During this period the number of IMO-registered vessels has decreased by -2.0%.

## Results and assessment

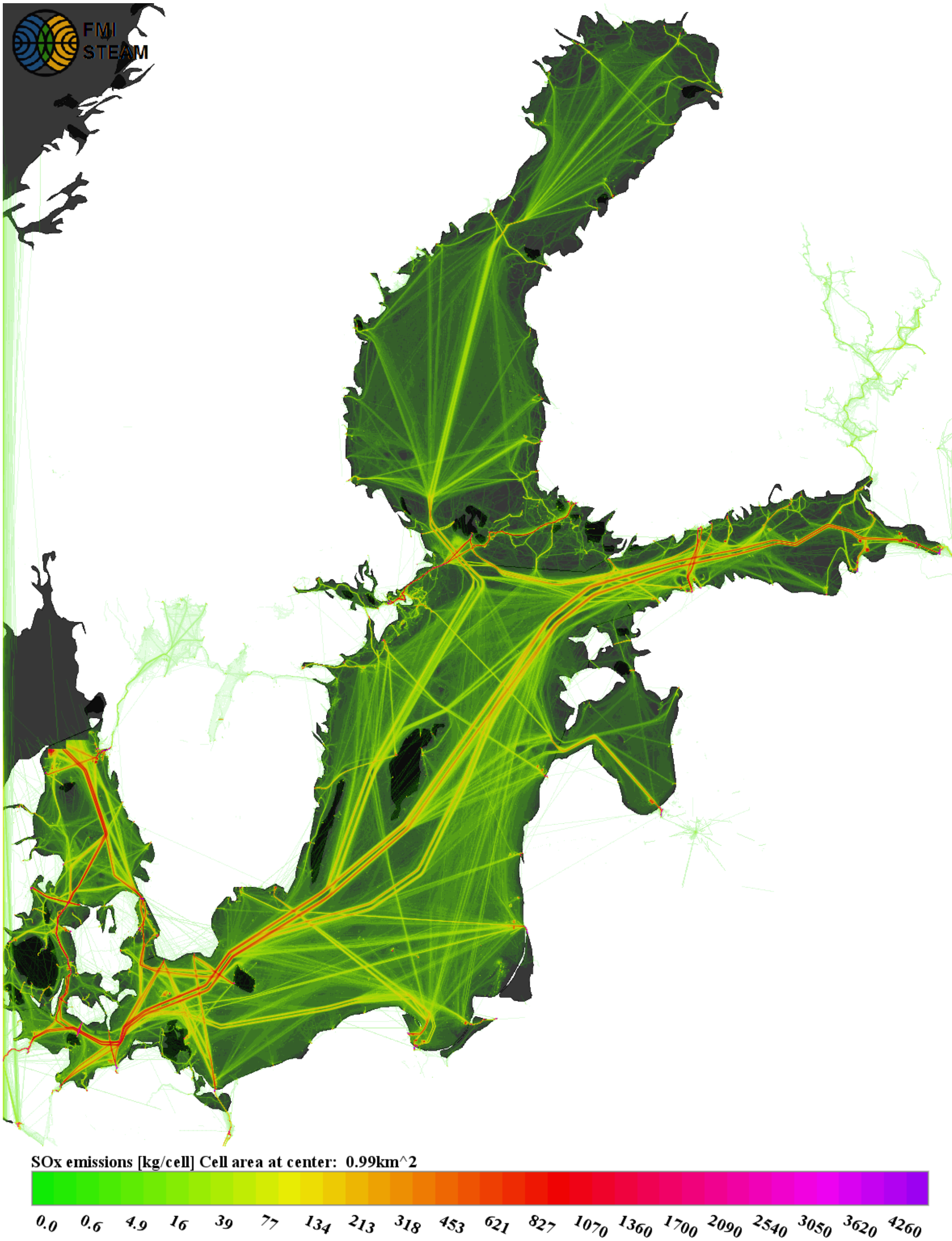



**Figure 1.** The geographical distribution of $SO_x$ emissions from Baltic Sea shipping in 2015. Emissions are reported in kilograms per grid cell.

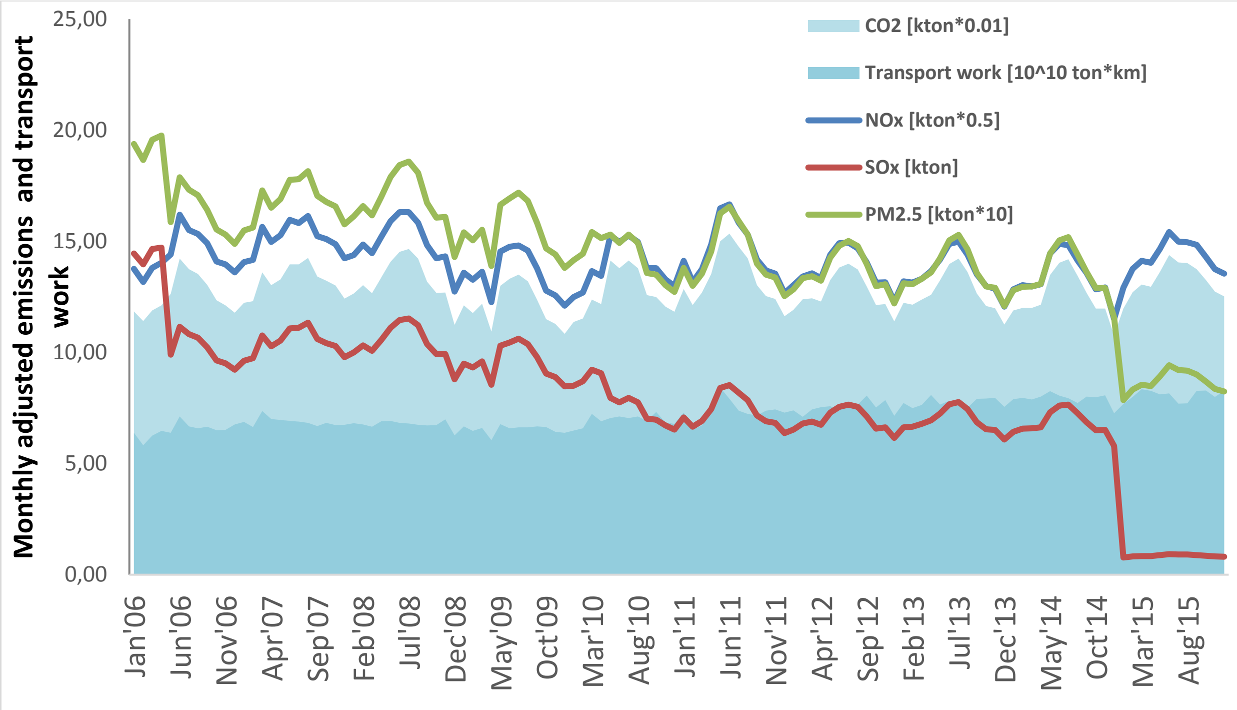



**Figure 2.** Seasonal variation of ship emissions in the Baltic Sea during the period 2006-2015. $CO_2$ and transport work are shown as area plots. All monthly values have been corrected for AIS-coverage and normalized according to the total amount of days in the month. Note, that PM emissions do not contain the associated water.

Figure 2 illustrates the seasonal variation of ship emissions in the Baltic Sea area during the period 2006-2015. $SO_x$ and PM emissions have decreased significantly during this time, especially because of the 2015 fuel sulphur reduction. Overall transport work across the Baltic has experienced a steady yet small growth during 2010 – 2015.

The summary of results for 2015 has been collected to Table 1. In Table 1a, the estimated annual total emissions are shown for different parts of the Baltic Sea and by vessel type. Most of the emissions are produced in the main body of the Baltic Sea although the much smaller areas of Kattegat and the Gulf of Finland constitute a fair share of the total emissions. In Table 1b, the fuel consumption statistics, travel distances, transportation work and the number of ships are shown. The total number of vessels was 21 616 in 2015, of which 9% were unidentified vessels. Over 60% of AIS targets in the Baltic Sea were not IMO-registered.

**Table 1 a-b.** Summary of key results from Baltic Sea shipping in 2015.

| Baltic - 2015 | | $NO_x$ [ton] | $SO_x$ [ton] | $PM_{2.5}$ [ton] | CO [ton] | $CO_2$ [$10^3$ ton] |
|---|---|---|---|---|---|---|
| **All** | | 342 846 | 10 269 | 10 435 | 22 793 | 15 916 |
| | **IMO** | 331 444 | 9 879 | 10 070 | 21 618 | 15 327 |
| **Baltic Sea** | **Baltic Sea** | 192 435 | 5 651 | 5 775 | 12 505 | 8 794 |
| | **Kattegat** | 67 867 | 1 953 | 1 994 | 4 496 | 3 038 |
| | **Gulf of Finland** | 50 678 | 1 523 | 1 560 | 3 454 | 2 370 |
| | **Gulf of Bothnia** | 23 201 | 830 | 831 | 1 636 | 1 289 |
| | **Gulf of Riga** | 5 061 | 178 | 155 | 357 | 239 |
| **Other** | **Other** | 3 626 | 135 | 121 | 346 | 186 |
| **RoPaX** | | 81 867 | 2 694 | 2 723 | 4 759 | 4 179 |
| **Passenger_Cruiser** | | 8 501 | 299 | 307 | 571 | 463 |
| **Passengers_Ferry** | | 1 274 | 44 | 40 | 125 | 69 |
| **Service_ships** | | 2 636 | 82 | 80 | 221 | 128 |
| **Cargo_ships** | | 60 958 | 1 802 | 1 788 | 4 886 | 2 780 |
| **Container_ships** | | 56 971 | 1 564 | 1 634 | 3 683 | 2 428 |
| **Tanker_ships** | | 84 157 | 2 248 | 2 338 | 4 822 | 3 500 |
| **Other_ships** | | 13 180 | 457 | 435 | 1 316 | 700 |
| **Fishing_vessels** | | 2 921 | 104 | 94 | 282 | 156 |
| **Vehicle_Carriers** | | 28 866 | 912 | 934 | 1 896 | 1 420 |
| **Unknown_ships** | | 1 539 | 63 | 63 | 234 | 95 |

| Baltic - 2015 | | Main_Eng, Fuel cons. [$10^3$ ton] | Aux_Eng Fuel cons. [$10^3$ ton] | TRAVEL [$10^3$ km] | Transport work [$10^6$ ton km] | SHIPS |
|---|---|---|---|---|---|---|
| **All** | | 3 675 | 1 298 | 137 427 | 968 634 | 21 616 |
| | **IMO** | 3 590 | 1 200 | 113 285 | 965 744 | 8 404 |
| **Baltic Sea** | **Baltic Sea** | 2 169 | 579 | 78 596 | 570 065 | 0 |
| | **Kattegat** | 660 | 289 | 27 838 | 199 998 | 0 |
| | **Gulf of Finland** | 471 | 270 | 14 159 | 135 237 | 0 |
| | **Gulf of Bothnia** | 308 | 95 | 12 153 | 45 575 | 0 |
| | **Gulf of Riga** | 43 | 32 | 2 576 | 12 351 | 0 |
| **Other** | **Other** | 25 | 34 | 2 109 | 5 417 | 0 |
| **RoPaX** | | 1 104 | 202 | 16 614 | 31 384 | 295 |
| **Passenger_Cruiser** | | 121 | 24 | 1 278 | 0 | 93 |
| **Passengers_Ferry** | | 12 | 9 | 2 390 | 0 | 277 |
| **Service** | | 22 | 18 | 2 815 | 0 | 576 |
| **Cargo** | | 658 | 211 | 43 468 | 316 246 | 4 153 |
| **Container** | | 492 | 266 | 12 719 | 150 812 | 832 |
| **Tanker** | | 747 | 347 | 21 165 | 412 879 | 1 920 |
| **Other** | | 110 | 109 | 20 786 | 0 | 10 185 |
| **Fishing** | | 21 | 27 | 6 705 | 0 | 1 111 |

| | | | | | |
|---|---|---|---|---|---|
| **Vehicle_Carrier** | 384 | 60 | 7 900 | 57 319 | 293 |
| **Unknown** | 4 | 25 | 1 589 | 0 | 1 881 |

There were 8404 AIS targets with a valid IMO number and 13212 targets which transmitted only MMSI information. Searching vessel databases and internet with MMSI codes yielded no data for 1880 targets and these represented 2.8% of AIS data received in the Helcom 2015 dataset. For the remaining 11 332 MMSI targets closest match (physical dimension, installed engine size, design speed) of the STEAM vessel database was used. In the previous annual ship emission reports, targets transmitting only MMSI information and no IMO number, 500 GT vessel with 1000 kW engine was assumed. This may explain the lower CO emissions than in previous reports, because the previous default description for a small vessel was quite large. Using data from similar, closest matching vessels to fill the gaps in ship technical data should provide a more reliable estimate of the vessel fuel consumption and emissions.

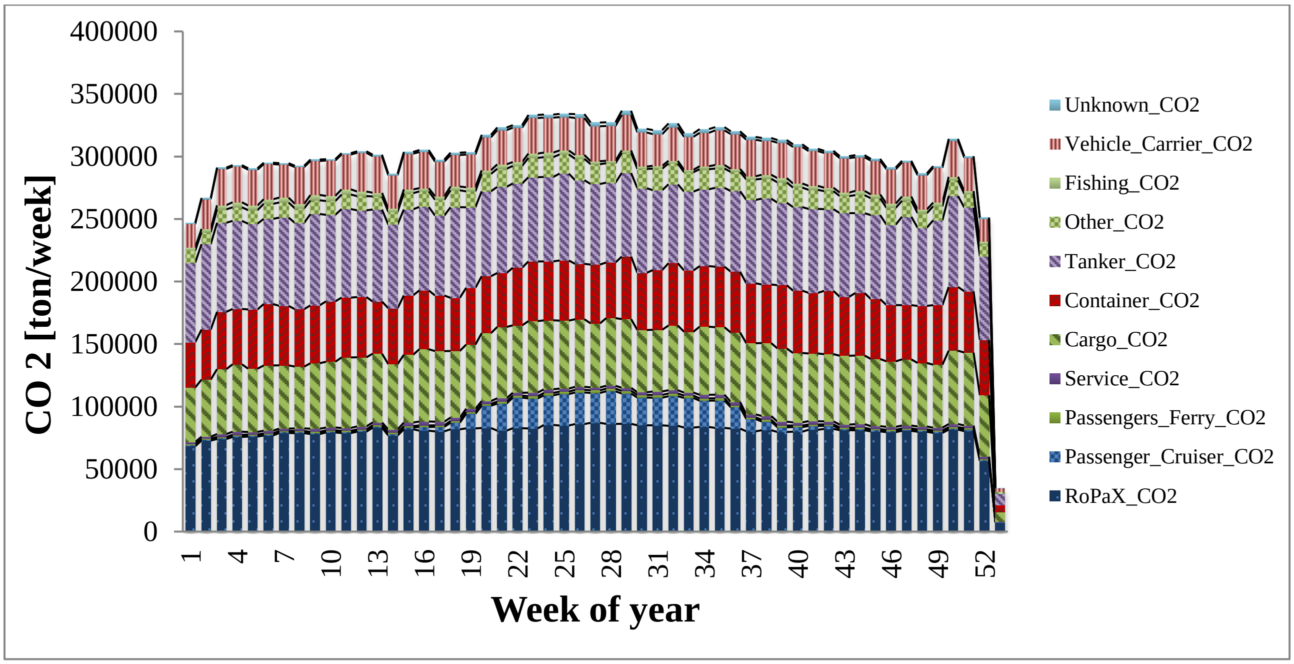



**Figure 3.** $CO_2$ weekly emissions for classified by ship category. Vehicle carriers include RoRo vessels. Category 'Other' includes tugs, dredgers, barges, S&R, ice breakers and law enforcement vessels.

The contribution of RoPaX vessels, tankers, cargo ships and container ships remains steady throughout the year (Figure 3). The most significant seasonal variation can be observed with passenger cruisers, which operate almost exclusively during summer.

In Figure 4 the share of emissions are shown for different size categories. It can be seen from the figure that medium sized vessels (10 000GT – 30 0000GT) contribute almost 55% to the total $CO_2$ emissions while they represent just over 14% of all the commercially operated ships.

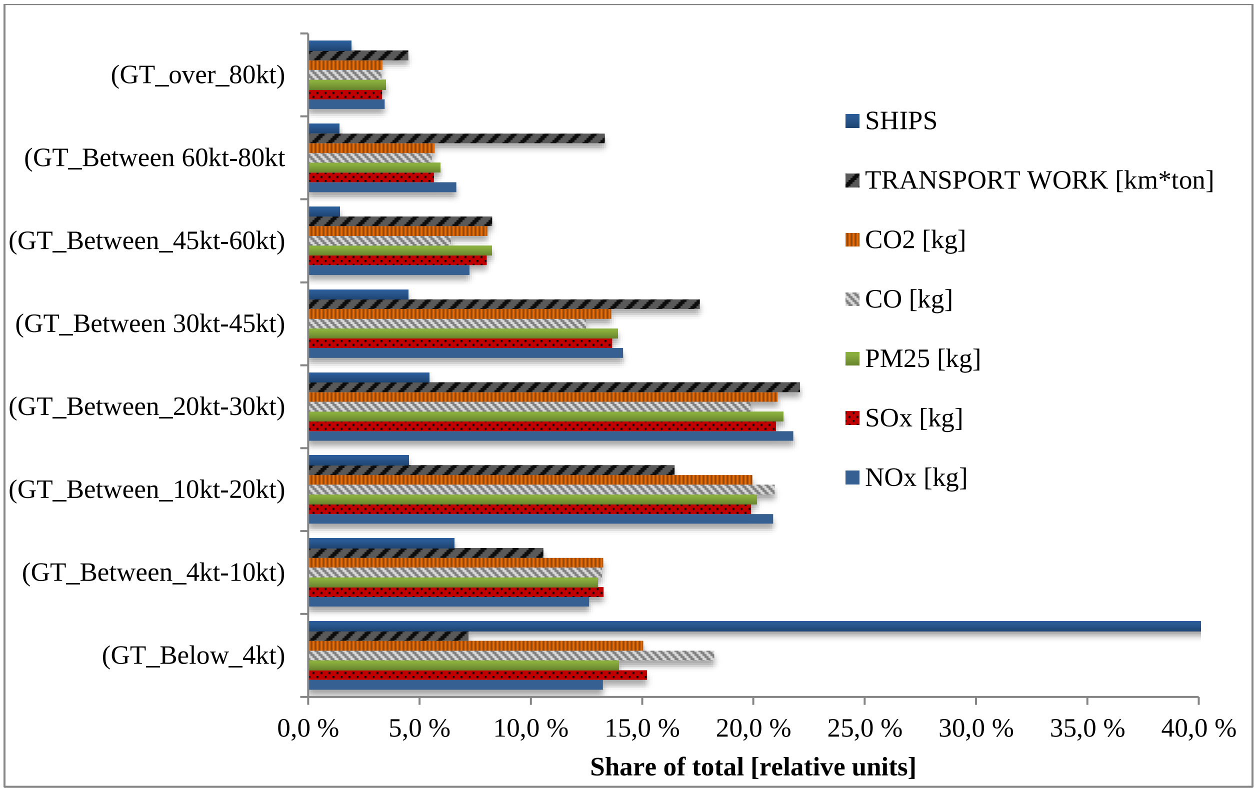



**Figure 1**. Share of emissions, transport work and the number of ships from Baltic Sea total in 2015, classified by ship size category (Gross tonnage, GT).

In Figure 5 the share of emissions are shown for the top 16 flag sates (based on $CO_2$ output). It can be seen from the figure that vessels under the flag of Finland contribute the most of all the flag states in 2015. During the study years 2006 - 2013 Sweden has been the largest contributor and Finland has been the second largest.

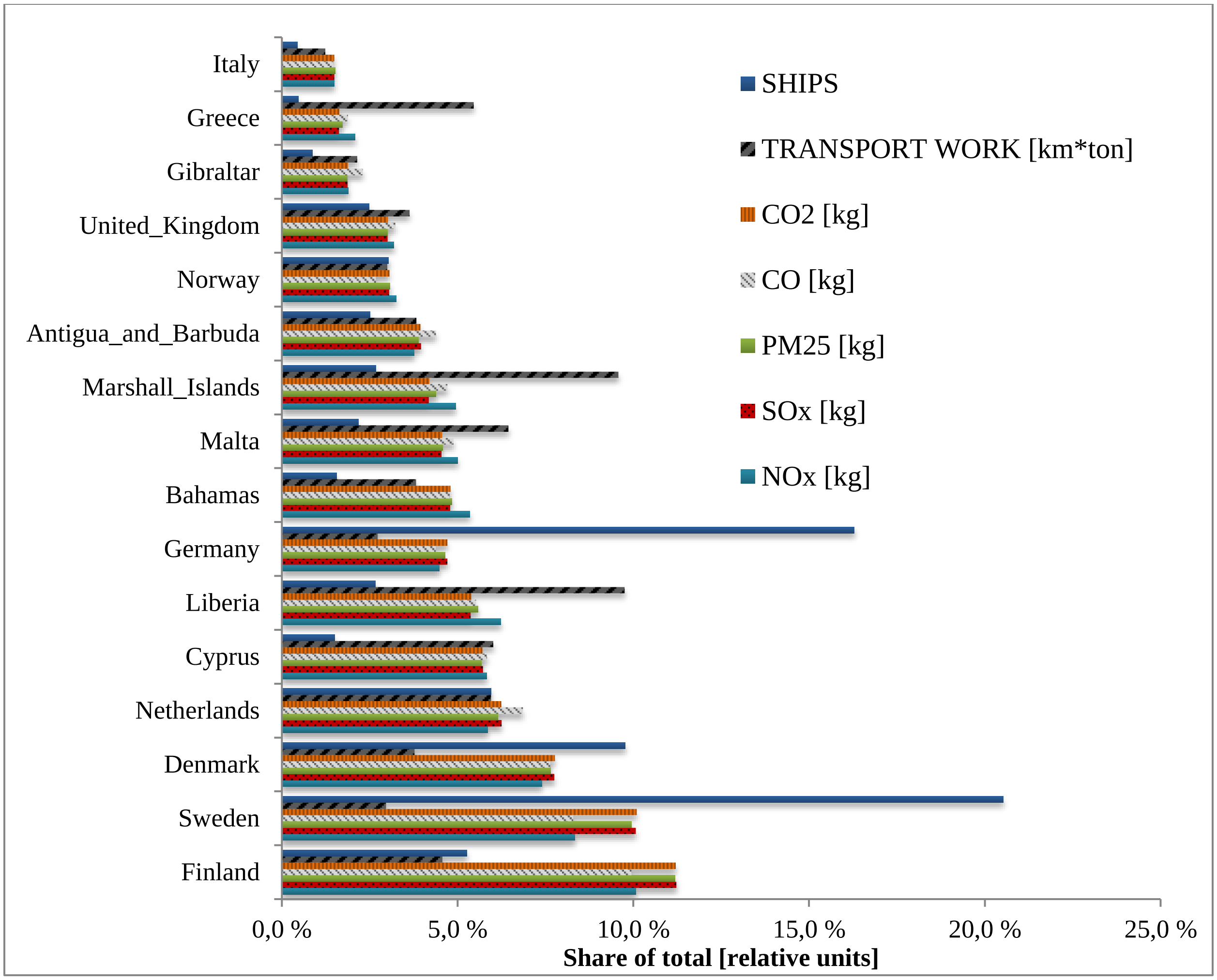



**Figure 2**. Share of emissions, transport work and the number of ships of the Baltic Sea total in 2015, classified by flag state.

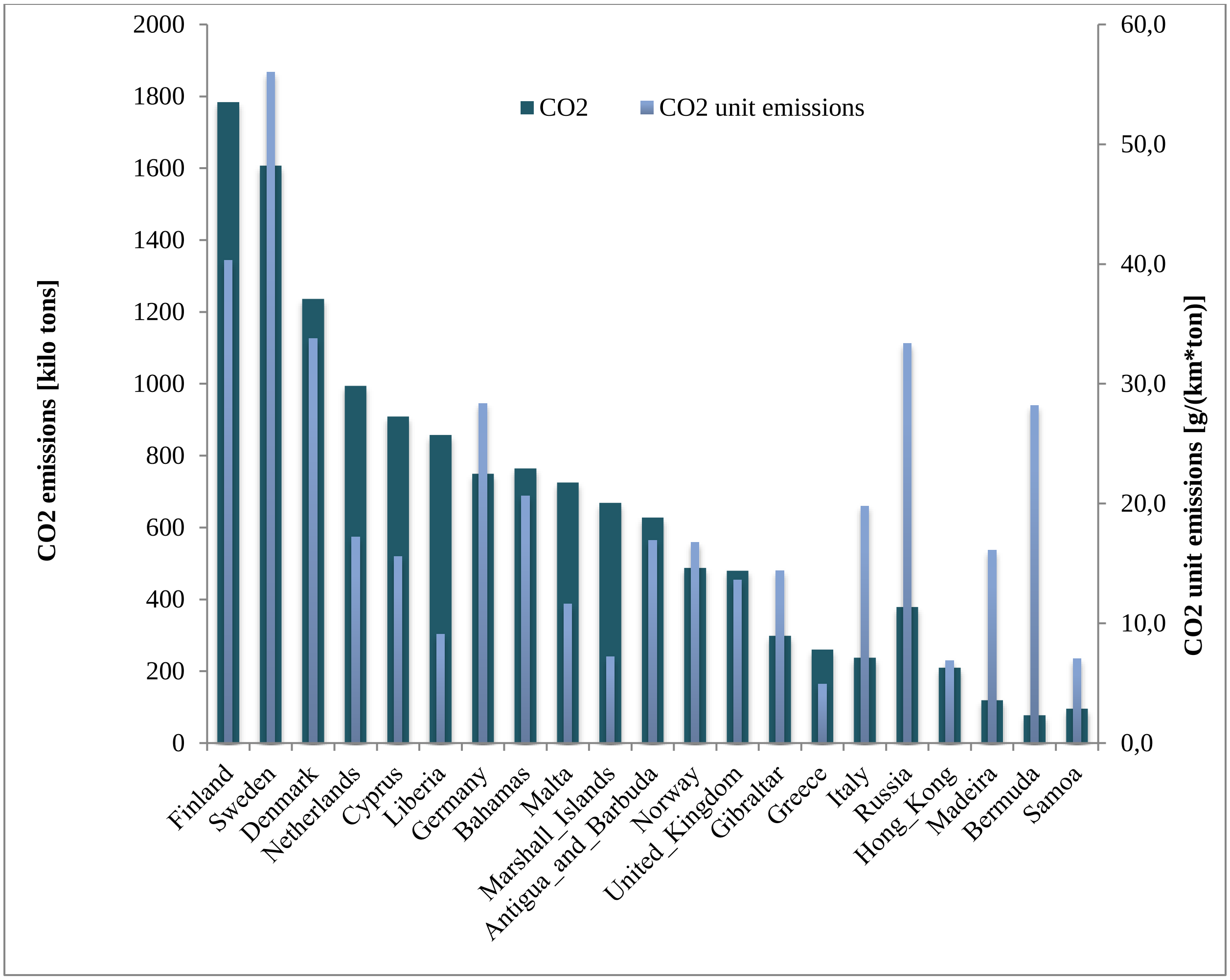



**Figure 3**. Unit emissions of $CO_2$ (in g ton$^{-1}$ km$^{-1}$) and total fuel consumption according to flag state in 2015. The transport work has been calculated as described in the 2$^{nd}$ IMO GHG study (IMO, 2009).

Unit emissions and total fuel consumption were calculated for each flag state (see Figure 6). Cargo oriented fleets (Liberia, Hong Kong, Greece, Marshall Islands) have lowest unit emissions. It should be noted, that passenger carrying capacity has no effect on the unit emission calculation, because only DWT of vessels is considered. In this study, the exclusion of passenger carrying capacity during the unit emissions calculations will favor cargo oriented fleets. The net weight of the cargo transport onboard was evaluated with a method described in the 2$^{nd}$ IMO GHG study (IMO, 2009).

## References

International Maritime Organization, Second IMO GHG Study 2009, London, UK, April 2009; Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W., Yoshida, K.

Jalkanen, J.-P., Brink, A., Kalli, J., Pettersson, H., Kukkonen, J. and Stipa, T., ”A modelling system for the exhaust emissions of marine traffic and its application to the Baltic Sea area”, *Atmospheric Chemistry and Physics*, **9** (2009) 9209-9223.

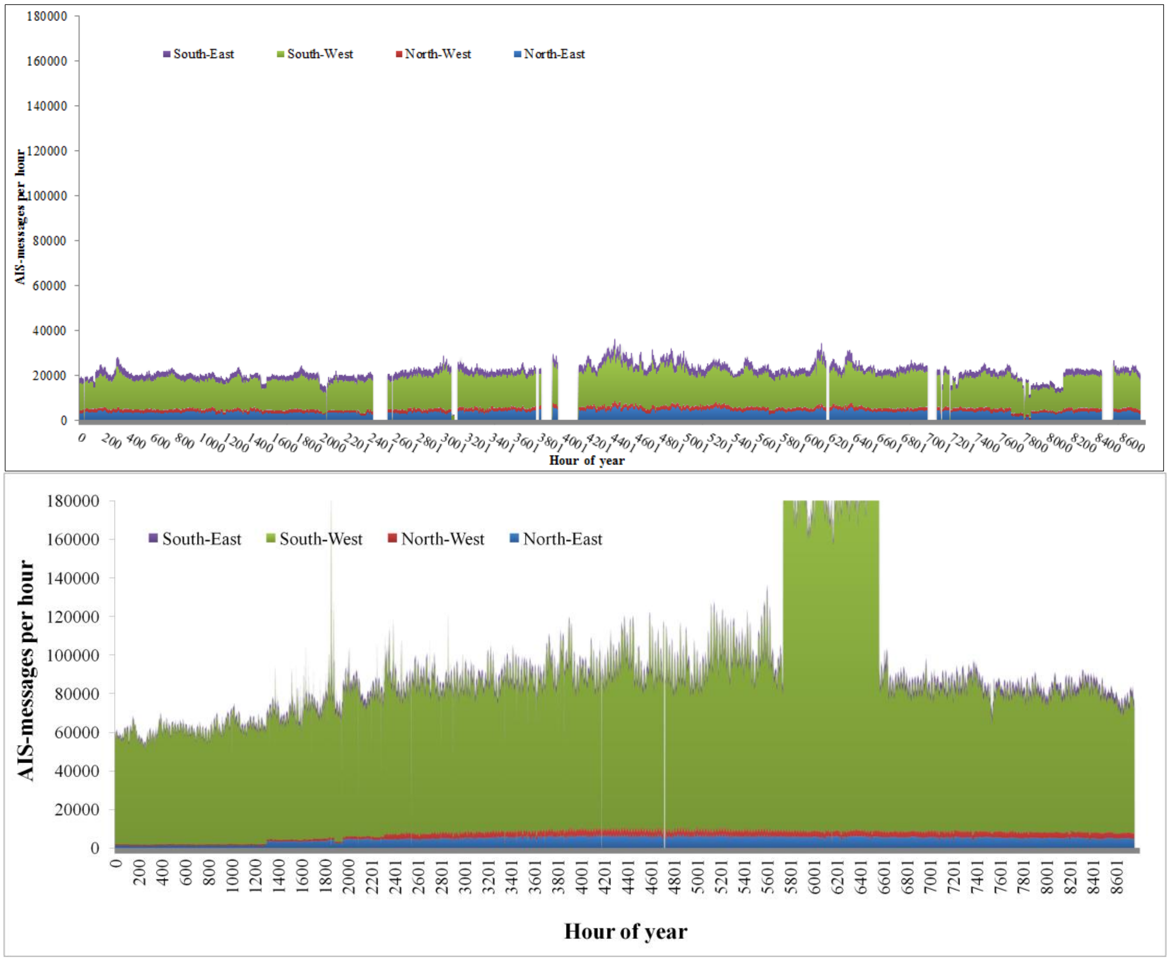
Jalkanen, J.-P., Johansson, L., Kukkonen, J., Brink, A., Kalli, J., and Stipa, T., ”Extension of assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide”, *Atmospheric Chemistry and Physics*, **12** (2012) 2641-2659.

Johansson L., Jalkanen J.-P., Kalli J. and Kukkonen J., "The evolution of shipping emissions and the costs of recent and forthcoming emission regulations in the northern European emission control area", *Atmospheric Chemistry and Physics*, **13** (2013) 11375-11389.

## Data

The emission estimates for the year 2015 are based on over 1.65 billion AIS-messages sent by 21 616 different ships, of which 8 404 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) of Jalkanen et al. (2009, 2012) and further described in Johansson et al. (2013).

For 2015, the temporal coverage was 99.3% without any significant data gaps. Most of the messages originate from South-Western region of the Baltic Sea near the Danish and southern Swedish sea areas (Figure 7). For individual vessels however, data gaps occur regularly but the route segmentation logic of the STEAM model (Johansson et al., 2013) interpolates vessel activities (including berthing activities) between two consecutive AIS-messages in such cases.




**Figures 7a-b.** AIS-data hourly coverage in different parts of the modelling region for 2006 (upper) and 2015 (lower).

## 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. This was indicated by the reduction of number of “Unknown ships” and the increase of “Other ships”. Nevertheless, only a fraction of recreational boating activity can be studied with AIS. According to a

[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.

recent estimate[2], there exists over 250 000 boats in more than 3 000 locations in the Baltic Sea area which are not required to carry AIS onboard. It is likely that the total number of AIS targets observed during the year 2015 represents less than 10% of the total waterborne vessels, but describes the activity of commercial ship traffic very well because AIS is mandatory for large vessels.

**For reference purposes, please cite this Baltic Sea environment fact sheet as follows:**

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[2] Sustainable Shipping and Environment of the Baltic Sea region (SHEBA) project, Deliverable 1.3 “Activity data for the Baltic pleasure boats”.