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Emissions from ships in Faxaflóahafnir 2017

Commissioned by Faxaflóahafnir

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This report has been reviewed and approved in accordance with IVL's audited and approved management system.
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Summary

This study estimates the emissions to air from ships in Faxaflóahafnir 2017. Emissions are presented per four operational modes; *in port basin*, *at anchor*, *manoeuvring* and *at berth*. Further, emissions are allocated to different engine types, ship types, and also to the four harbour areas of Faxaflóahafnir; Akranes harbour, Grundartangi harbour, Old harbour, and Sunda harbour.

For each port call, emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_X), hydrocarbons (HC), particles (PM_{10} and $PM_{2.5}$), and sulphur dioxide (SO_2) are estimated using an emission inventory model specifically developed for port areas. Total emissions in 2017 are presented in the table below.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_X (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)
TOTAL emissions 2017	**43 000**	**540**	**1 700**	**630 000**	**26 000**	**20 000**	**17 000**	**89 000**

Container ships account for a larger share of emissions than other ship types, followed by cruise ships and fishing vessels. Whale watching boats are in frequent traffic to the port with 5375 calls in 2017. Since these in general have relatively small engines, they are estimated to contribute around 2% of the CO_2 emissions.

Like 2016, Sunda harbour is the harbour area that receives the majority of the visiting container and cruise ships. Ships calling Sunda port are responsible for more than half of emissions in Faxaflóahafnir, regardless of type of emission. Sunda harbour has reduced emissions through the use of shore side electricity by ships at berth. However, the positive effect from shore side power was most significant in the Old harbour in 2017.

In a comparison with emissions from ships in the port in 2016, there is an overall increase; CO_2 has increased with 14%, and other emissions increase between 9% and 20% except NO_X, for which the estimated increase is 32%. This increase is likely due to that less visiting ships have been reported to use NO_X abatement techniques on board. The comparison is made with updated emission calculations for 2016 that use the same assumptions as in the calculations for 2017.

Contents

1 Introduction

IVL Swedish Environmental Research Institute has on assignment of Faxaflóahafnir calculated emissions from ships visiting their ports in 2017. Faxaflóahafnir comprises the four ports of Akranes harbour, Grundartangi harbour, and Sunda harbour and Old harbour in Reykjavik. The location of the different ports is shown in Figure 1, which also indicates with red lines the traffic areas covered in the emission inventory.

The inventory includes emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), hydrocarbons (HC), particles (PM_{10} and $PM_{2.5}$), and sulphur dioxide (SO_2). The emission calculations are based on call statistics obtained from the port.

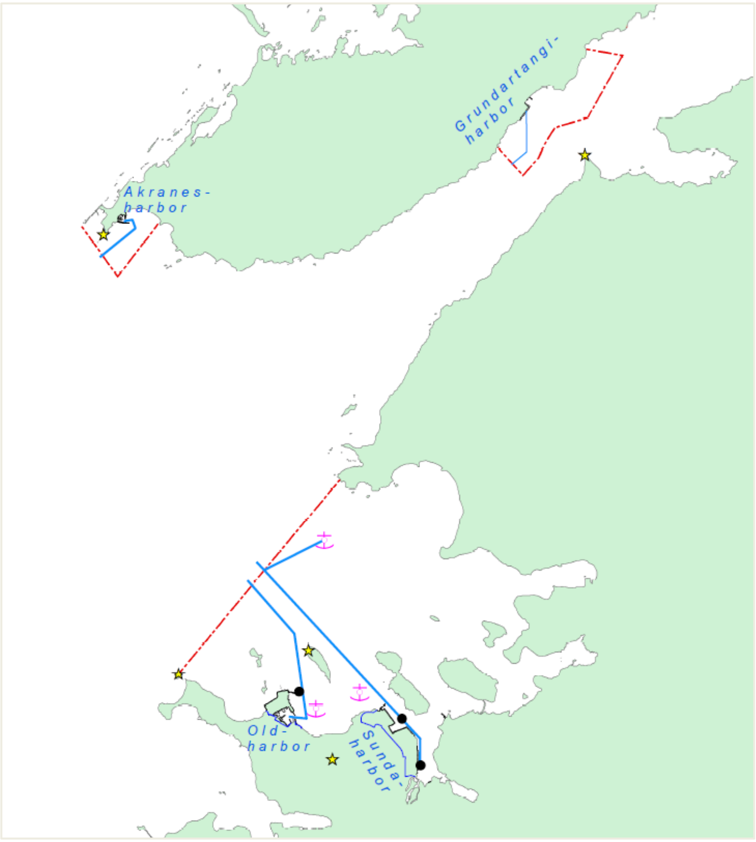


Figure 1. The four ports of Faxaflóahafnir and the areas outside the ports included in the emission inventory.

This report describes the calculation models, the data used, and the results from the calculations. The results are analysed and discussed in relation to results from similar studies for other ports.

2 Ship traffic

The ship traffic to the different harbours in Faxaflóahafnir comprise several different ship types and ship sizes; from large container vessels to small whale watching boats.

In total, the port received 393 larger vessels, making in total 1516 unique port calls. It is common that ships are required to shift berth during their stay in a port. In 2017, there were 866 shifts between berths in Faxaflóahafnir. In addition to these calls, the port has a lot of traffic from whale watching boats.

The ships that are in traffic to and from the port have been categorised into nine ship types, depending on the type of cargo they carry or the service they provide. The categories and their respective number of calls to the different harbours are presented in Table 1.

Table 1. Number of calls from ships and boats to the four ports of Faxaflóahafnir in 2017.

Ship type	Akranes harbour	Grundartangi harbour	Sunda harbour Reykjavik[4]	Old harbour Reykjavik	Total
	Number of calls/visits	Number of calls/visits	Number of calls/visits	Number of calls/visits	Number of calls
Dry bulk carrier	12	20	2	1	35
Container ship[1]	0	11	279	5	295
Cruise ship	1	0	80	49	130
Oil- and chemical tanker[2]	2	1	5	108	116
RoRo vessel/Ferry	0	0	0	6	6
General cargo ship	9	106	174	8	297
CRUISE AND CARGO SHIPS	**24**	**138**	**540**	**177**	**879**
OTHER SHIPS[3]	**0**	**0**	**31**	**118**	**149**
FISHING VESSELS	**20**	**0**	**112**	**356**	**488**
WHALE WATCHING BOATS[5]	**0**	**0**	**0**	**5375**	**5375**
TOTAL	**44**	**138**	**683**	**6026**	**6891**

[1] Also includes reefers

[2] Including bunker vessels

[3]The category "Other ships" include military vessels, research and survey vessels, tugs, yachts and dredgers

[4]Including anchoring at Kollafjörður

[5]Number of assumed berths, see method chapter

For each of the four harbours an area has been identified within which emissions from the ships are calculated. These areas are indicated by red lines in Figure 1. The emissions from ships in these areas are calculated for four different operational modes: *in port basin*, *manoeuvring*, *at berth*, and *at anchor*. Emissions from *in port basin* operations are emissions from the time spent for each ship in transit between the outer boundary of the port area and their assigned berth. *Manoeuvring* operations are estimated to twenty minutes per call, during which the ships are manoeuvred with high precision before and after laying still at quayside – a period which often requires rapid engine load changes that influence emission parameters. During periods *at berth*, the ships are assumed to use auxiliary engines for electricity requirements on board. Several of the ships in Faxaflóahafnir also use shore side electricity when at berth. Statistics on time at berth and shore side power use for individual ship calls have been provided by Faxaflóahafnir. There are four anchoring sites in the traffic areas covered by the inventory. During periods *at anchor*, operation of ship engines is similar to operations *at berth*, although power needs are lower for certain ship types.

The time in the *port basin* is estimated from the distance between a quay and the limits of the traffic area. Further, ship speeds are assumed to be related to ship sizes, and ship size has therefore been used as a proxy to estimate time in the area. All estimates have been provided by Faxaflóahafnir and can be found in Appendix 1.

All movements in the port area are assigned a unique call-ID. During a visit in the port a ship may have more than one registered call-ID if it moves between different berths or from an anchoring site to quay. For each movement between berths, a manoeuvring period is added in the calculations assuming 20 minutes in transfer.

AIS signals for 23 whale watching boats operating in the port area of Faxaflóahafnir were analysed. Whale watching boats were assumed to be berthing if it stayed longer than one hour in the port area.

3 Emission calculation

For each ship call, engine emissions are calculated as a product of emission factors, the utilised engine power and time. For each engine and during each of the four operational modes equation (1) is applied.

$$E = EF * t * P \qquad (1)$$

E is emissions of a substance with the unit gram, *EF* is the emission factor for a substance in g/kWh, *t* is the time in hours, and *P* is the estimated power utilization from the engine in kW.

3.1 Emission factors

All emission factors for marine engines used in this report are presented in Appendices 2 and 3. The main parameters determining emission factors are the fuel used and the engine speed. To give two examples: a heavy fuel with high sulphur content results in significantly higher emission factors for sulphur dioxide and particles than lighter fuel qualities while NO_X emissions depend on engine speed to a large extent with less emissions per unit energy from high speed engines than from slow speed engines.

Emission factors for CO_2, CH_4, N_2O, and HC for main engines and auxiliary engines are from Cooper and Gustavsson (2004). Emission factors for NO_X are assumed to follow the regulatory standards that became effective in 2005 and that apply to all ships keel laid from 2000 (Tier I) and that were further strengthened in 2010 (IMO, 2011). Ships constructed prior to 1990 are not covered by any regulations unless they have undergone significant engine changes, and ships constructed between 1990 and 2000 are only covered if specific criteria on engine size and technical possibilities for emission reductions are met. Information on which ships from before 2000 that fulfil Tier I requirements has not been available, and for all ships from before that year emission factors that are representative for engines that have no NO_X reduction measures are used (Cooper and Gustafsson, 2004). Emission factors for newer ships follow regulatory standards; Tier I levels for ships constructed between 2000 and 2011, and Tier II levels for ships built thereafter (IMO, 2011). In Appendix 2 the details of calculations behind emission factors in the regulations are presented. Emission factors for sulphur dioxide are based on the fuel consumption and the estimated sulphur content of the fuels used. We estimate the sulphur content in heavy fuel oil to be 2.7% on average. This value is from a study from 2007 by US EPA and represents the world average sulphur content in marine heavy fuel oil at that time (USEPA, 2007). Fishing vessels are assumed to use different qualities of fuel, depending mainly on vessel size, varying from 0.001% to 1.7% S. Whale watching boats are assumed to use only marine gasoil with an estimated sulphur content of 0.1%.

The emission factors for particles (PM_{10} och $PM_{2,5}$)[1] are strongly dependent on the sulphur content of the fuel. We use a formula for the relation between fuel sulphur content and PM emission factors. The formula is linear equation representing a fit to values from several emission measurement studies (Winnes and Fridell, 2009). The equation is presented in Appendix 2.

However, for fuel sulphur contents below 0.5%, the formula is not relevant. A recent literature review of emission measurement results shows that little can be said about relationship between fuel sulphur content and particle emissions at low sulphur content, and, further, that a dependence on engine load is uncertain. The emission factors for PM emissions from fuels with low sulphur content that are used in the calculations are presented in Appendix 2. This is an update to the model that will have an effect on the estimate of total PM emissions.

It is common to use oil fired boilers on board ships in order to produce steam and heat. When the main engine is running on high loads the boiler is often replaced by an exhaust gas economiser that uses excess heat from the exhausts for heat and steam production. However, when at berth or operating on low main engine loads, the oil-fired boilers are needed since the exhaust gas heat is too low for meeting the demand of steam and heat on board.

Only few studies report on emission factors from boilers. In this study, we use emission factors from USEPA (1999) reported for boilers in relevant sizes for ship installations. The emission factors used are found in Appendix 2. Emissions of CO_2 and SO_2 from boilers are calculated from expected carbon and sulphur content in the fuel used, assuming use of marine distillate oil with a 0.1% sulphur content and complete combustion. The uncertainties in the calculated emissions from boilers are relatively high due to the lack of reliable emission factors and also due to limited available information on the utilisation of boiler power.

Some ships are assigned individual emission factors. These include ships that connect to shore side electricity at berth, which are assumed to have no emissions at berth except for the time used to connect and disconnect to the power grid. Another category of ships assigned individual emission factors are those registered for the Environmental Ship Index (ESI). The ESI is an index that tells how well ships perform with regard to emissions of NO_X, SO_X and CO_2. There were 61 ships visiting Faxaflóahafnir in 2017 that were matched to the ESI register. The ESI register from the inventory for 2016 has been used, which may cause certain assumptions to be out of date. The effect of this on total emissions is expected to be small. The ships in the ESI register are presented in Appendix 3 together with their estimated emission factors for SO_2 and NO_X.

[1] We use an estimate that 85% of PM10 is made up of PM2.5

The ESI system combines NO_x emission factors for all engines on board via a weighing process to a single value. Our estimate is only based on information on the main engine. The ESI score for SO_2 differentiates between sulphur content in the consumed residual oil and the marine distillate oil. In our calculation we assume that the average values of sulphur content in different fuel qualities and the ratio between usage of different fuel qualities – both given in the ESI listing – are valid also for the traffic in Faxaflóahafnir. Details on these calculations are presented in Appendix 3.

3.2 Engines and fuels

Emissions are estimated from main engines, auxiliary engines and auxiliary boilers separately.

The database *Sea-Web Ship* contains information on all ships with IMO-numbers (IHS, 2017). *Sea-Web Ship* has been used for retrieving information on installed main engine power for an absolute majority of the ships visiting Faxaflóahafnir. For a limited number of ships the installed main engine power has been estimated from ship size and ship type according to statistics developed by IMO (IMO, 2014).

Sea-web Ship also contains information on engine speed for most main engines. If this information is not given in the database, an estimated engine speed based on known engine speeds for similar ship types and ship sizes is calculated.

The installed power in auxiliary engines is not given in the database. Instead, empirical relations from a large number of ships of similar types that relate installed auxiliary engine power to ship size is used (Sjöbris et al., 2005). All auxiliary engines are assumed to be high speed diesel engines.

The installed main engine power for fishing vessels is taken from *SeaWeb*. Auxiliary engine power are estimated as central values in a span of likely installed auxiliary power for ships of different sizes and installed main engine power. A categorization of fishing vessels was provided by HB Grandi for the purpose of this study (HB Grandi, 2017). HB Grandi is a large sea food company based in Reykjavík and owner of ten large fishing vessels. Each category was assigned a typical range of installed main engine- and auxiliary engine power, respectively. We have matched the categories and the installed main engine power of shipping vessels in Faxaflóahafnir stated in the *Sea-web Ship* data base. As a result, fishing vessels are divided into five categories primarily based on installed main engine power. The categories and the central values for installed auxiliary engine power used in the calculations are presented in Table 2.

Table 2. Categories of installed power on fishing vessels, main engines and aux engines

Category No.	Fishing vessel - Main engine power category (min – max, kW)	Fishing vessel - Aux engine power category (min – max, kW)	Aux engine central value (kW)
1	37 – 559	0	0
2	600 - 1035	220 – 600	410
3	1036 - 1762	220 – 600	410
4	1763 – 3699	700 – 900	800
5	3700 - 9000	1500 - 2000	1750

The utilization of power from the engines during the different operational modes is important information for the emission calculations. This information is often relatively uncertain and differs a lot between different ships. For this study generic values first reported by Entec UK (2002) are used. These values are presented in Table 3.

Table 3. Estimated power utilization (as share of installed engine power) at different operational modes (Entec UK Ltd, 2002).

	In port basin	Manoeuvring	At anchor/at berth[1]
Main engine	20%	20%	0%
Auxiliary engine	40%	50%	40%

[1]Cruise ships with diesel electric drives use main engine power at berth, 12% power utilization is assumed corresponding power needs of cruise ships with diesel mechanic drive and aux engines installed

Main engine load of Fishing vessels are assumed to be the same as for the other ship categories. However, the installed auxiliary engine power on certain categories of fishing vessels is to a large extent dimensioned for electricity need to freeze fish or for trawling. From information and values provided by HB Grandi we have made assumptions on utilization of auxiliary engine power as presented in Table 4 (HB Grandi, 2017).

Table 4. Estimated power utilization of auxiliary engines in different categories of fishing vessels.

Category No.	In port basin	Manoeuvring	At berth	Comment
1	0	0	0	No aux engines are installed on these vessels
2	0	50%	21%	Auxiliary engine system dimensioned for trawling. Therefore, lower aux engine load at berth assumed than for other ship types. 21 % is an estimated value.
3	0	50%	40%	These ships often use shaft generators and the engine dimensions and utilization can be assumed to be similar to most ship types.
4	40%	50%	26%	These ships can process and freeze fish on board. Between 17% and 43% of installed aux engine power is needed for freezing. At berth, shore side electricity is not always enough. We assume that they need power for freezing and un-loading (up to 300 kW), 50% of this time. For 50% of the time, during lay-up, 150 kW is assumed to be needed. 26% aux engine utilization is an approximated average for time at berth.
5	40%	50%	23%	These ships can process and freeze fish on board. Between 15% and 40% of installed aux engine power is used at berth. At berth, shore side electricity is not always enough. We assume that they need power for freezing and un-loading (500-600 kW), 50% of this time. For 50% of the time, during lay-up, 300 kW is assumed to be needed. 23% aux engine utilization is an approximated average for time at berth.

For the ships using shore side electricity when at berth, it is assumed that the auxiliary engines are run to cover electricity production for one hour at berth before the ship has been connected to the network and similarly for one hour after disconnecting. For the rest of the reported time at berth it is assumed that the ships only use electricity produced as "green" electricity[2] which do not add any emissions to the calculations. An exception is the category fishing vessels. The need for electricity is

[2] This study contains emissions from the ship from a "tank-to-propeller" perspective. No emissions from green electricity production is thus part of the study.

very varying during *at berth* operations. According to port statistics, many fishing vessels at berth cover parts of their electricity need by connection to the land based grid. However, the land based grid can often not to fulfil the vessels' full power requirements. From the information on supplied amount of shore side electricity (kWh) and estimates of power need on board (kW), we calculate an approximate time that the fishing vessels at berth have their electricity supplied from land. The rest of the time, power from auxiliary engines according to Table 2 and Table 4 are used in the calculations.

Tankers often use electricity from the auxiliary engines to run cargo pumps. In the model, this is accounted for by adding fuel consumption that relates to the carrying capacity of the individual tanker. According to information from a tanker operator the typical fuel consumption for cargo pumps are 3 tonnes/day at off-loading. An off-loading operation for 14000 tonnes oil requires about 15 hours. Based on this information a generic value of 0.13 kg fuel/tonne cargo has been calculated and is used for all tanker ships at off-loading operations. Further, the amount of cargo on the tankers is estimated to 42% of the ships' dead weight tonnage. This is an updated value, compared to the inventory in 2016. The value is based on a study made for Port of Gothenburg in 2017. Thus, for each tanker call, additional fuel consumption (in kg) according to equation (3) is assumed.

$$Fuel\ consumption\ =\ 0.42\ *\ DWT\ *\ 0.13 \qquad (3)$$

The fuel used in main engines during operations *in port basin*, and *manoeuvering* is assumed to be a heavy fuel oil with 2.7% S, while the fuel used in auxiliary engines is assumed to be marine gasoil with 0.1% S. More detailed information on the use of different fuel qualities by fishing vessels has been possible to include in the model after communication with HB Grandi (HB Grandi, 2017). Large fishing vessels are reported by Grandi to use heavy fuel oil with a sulphur content of 1.7% in the main engines, and marine gasoil with 0.1% sulphur in the auxiliary engines, while small fishing vessels are reported to use marine gasoil with 0.1% S, exclusively. All small fishing boats in the HB Grandi fleet use diesel oil with an S-content of 0.001%. The fuel types reported by Grandi are assumed for all fishing vessels of the respective size in the inventory. Further, whale watching boats are assumed to use only marine gasoil.

Large tankers sometimes use steam from oil fired boilers to run their cargo pumps. In this study it is, however, assumed that all cargo pumps use electricity from auxiliary engines. This seems to be the most common arrangement for tankers of the size classes that are common in Faxaflóahafnir; tankers of mall sizes tend to use electricity driven pumps while larger ships use steam driven pumps.

A size dependent generic value on fuel consumption in ship boilers has been calculated for all visiting ships from values from a report from the Port of Los Angeles (2010). Exceptions are made for the category RoRo/ferry, for which values from a study in Gothenburg is used (Winnes and Parsmo, 2016). The values are presented in Table 5.

Table 5. Fuel consumption in oil fired boilers for operational modes *at anchor, in port basin, manoeuvring,* and *at berth*. Fuel consumption is given per thousand gross tonnes and hour.

Ship type	Fuel consumption/ (1000 GT *hour)
Bulk carrier	1.4
Oil- and chemical tanker	4
Container ship	2.9
Cruise ship	4
General cargo ship	0.9
Other ships[1]	4
Reefer	5.4
RoRo/Ferry	2

[1]Including fishing vessels in category 5 (the largest fishing vessels only). No boilers are expected on smaller fishing vessels and whale watching boats.

The fuel used in boilers is assumed to be marine gasoil exclusively.

Results

Table 6 presents the emissions of the different substances per engine type and operational mode. The values are presented with three digits of significance. This is in order to avoid misunderstandings related to rounding of results and we recommend using only two digits of significance in communication of the results. How the total emissions are divided between operational modes varies from one substance to another. The period *at berth* accounts for the largest share of emissions of all substances except SO_2, for which emissions are higher from operations *in port basin*. Similarly, emissions of SO_2 are mainly caused by combustion in main engines, while for other emissions the auxiliary engines are the dominant source. Emissions of SO_2 are directly related to the sulphur content in fuel and since main engines are assumed to run on high sulphur fuel oil to a large extent, the main engine emissions dominate. Further, main engines are almost exclusively used for propulsion. Emissions of particles are also mainly from combustion in main engines. High sulphur content causes more particle emissions than low sulphur fuel as discussed in Section 3.1.

CO_2 emissions are directly related to the fuel consumption. In a comparison between the different operational modes the operations *at berth* can be attributed approximately 80% of the total fuel consumption. The fuel consumption in auxiliary engines is estimated to be more than twice the consumption in the main engines. Emissions of the greenhouse gases CO_2, CH_4 and N_2O together cause emissions of CO_2 equivalents[3] of 43 900 tonnes, a value that is totally dominated by the emissions of CO_2.

[3] The factors used for calculation of CO_2-eqv are 34 for CH_4 and 298 for N_2O (Myhre et al., 2013)

Table 6. Overview of emissions from ships in Faxaflóahafnir 2017.

		CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)
Main engines	In port basin	4 760	74.2	202	80 300	2 920	7 830	6 660	57 600
	At anchor*	17.0	0.190	0.735	292	9.67	5.45	4.64	10.7
	Manoeuvring	927	13.8	39.4	15 200	561	1350	1 150	9 640
	At berth*	4 850	54.2	210	78 700	2 760	1 560	1 320	3 050
Auxiliary engines	In port basin	1 600	23.1	71.7	28 200	1 180	532	452	972
	At anchor*	187	2.72	8.42	3 090	139	62.5	53.1	116
	Manoeuvring	388	5.63	17.4	6 760	287	129	110	229
	At berth*	24 400	354	1 100	412 000	18 100	8 150	6 920	13 500
	Tankers at berth using cargo pumps	139	2.01	6.22	2 120	102	46.2	39.3	87.2
Boilers	In port basin	359	0.835	4.18	327	4.06	32.7	27.8	226
	At anchor*	34.2	0.0796	0.398	31.2	0.388	3.12	2.65	21.5
	Manoeuvring	57.6	0.132	0.659	51.6	0.641	5.16	4.39	35.6
	At berth*	5 680	13.2	66.1	5 180	64.4	518	441	3584
TOTAL (engines and boilers)	Main engines	10 600	142	452	175 000	6 250	10 700	9130	70 300
	Auxiliary engines	26 700	388	1 200	452 200	19 800	8 920	7 580	14 900
	Boilers	6 130	14.3	71.4	5 590	69.4	559	475	3 870
TOTAL (Operational modes)	In port basin	6 720	98.2	278	109 000	4 100	8 400	7 140	58 800
	At anchor*	239	2.98	9.55	3 410	149	71.0	60.4	148
	Manoeuvring	1 370	19.6	57.5	22 000	848	1 480	1 260	9 910
	At berth*	35 100	424	1380	498 000	21 000	10 300	8 730	20 200
TOTAL	**All engines and boiler, all operational modes**	**43 400**	**544**	**1 730**	**632 000**	**26 100**	**20 200**	**17 200**	**89 000**

*Only cruise ships with diesel electric power trains

**Include emissions from ships in ship yard

Faxaflóahafnir provide connections to shore side electricity in Akranes harbour, Old harbour and Sunda harbour, and many ships use shore side power at berth. By assuming that these ships would have used electricity from on board diesel generators if the shore side connections were not available, a measure of "avoided emissions" can be calculated. This is thus the difference between emissions at berth if no ships were to use on shore power and the estimated actual emissions at berth. Approximately 7.5% -10% of emissions from ships at berth are thus estimated to be avoided by the use of shore side electricity except for emissions of sulphur dioxide which is avoided to a lesser extent. The avoided emissions are presented in Table 7 for the three harbour areas. Records on the electricity provided by the port to ships indicate that less emission is avoided; the avoided emissions appear to be overestimated by between 20%-30%. This is probably due to the assumptions made in the model regarding the time connected to shore side electricity and other assumptions on energy requirements for ships at berth.

Table 7. Total avoided emissions by the use of shore side electricity in the port.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)
Akranes Harbour	473	6.86	21.3	5 920	350	158	134	46.3
Old harbour	1 660	24.1	74.8	26 100	1 230	555	472	913
Sunda harbour	425	6.16	19.1	7 200	314	142	120	233
TOTAL	2 560	37.1	115	39 200	1 890	854	726	1 190

The category 'Cruise and cargo ships' cause significantly higher emissions than the other categories of ships and boats and contribute with approximately 70% of the total fuel combustion. This category of ships also accounts for approximately 90 % of the SO_2 emissions. Of the cruise and cargo ships, the main contributing ship type is container ships followed by the cruise ships, regardless of type of emission. Emissions and calls from the different ship types are presented in **Error! Not a valid bookmark self-reference.**. The total emissions in 2016 are accounted for in the bottom row of Table 8. These values are adjusted from the values reported in report U 5817, for alignment of assumptions that influence calculation, between the two years.

The fishing vessels are estimated to produce similar quantities of emissions as the cruise ships. Emissions of hydrocarbons are higher than cruise ship emissions, while other substances are lower. Emissions of SO_2 and particles are however considerable lower from fishing vessels than from cruise ships. Many fishing vessels have high power needs at berth for cooling and off-loading the catch. This causes relatively high emissions from the electricity production in diesel electric generators on board.

Table 8. Emissions and ship calls per ship type in Faxaflóahafnir in 2017.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)	Ship calls
Dry bulk carrier	1 880	23.3	73.2	21 900	1 150	727	618	2360	35
Container ship	13 400	171	541	224 000	8 550	8 110	6 900	38 800	295
Cruise ship	11 400	124	445	163 000	6 140	5 410	4 600	30 000	130
Oil- and chemical tanker**	987	32.3	38.6	13 100	615	445	378	2 380	116
RoRo vessel/Ferry	188	2.55	8.02	2 790	129	70.1	59.6	244	6
General cargo ship	2 720	36.3	116	41 900	1 830	1 370	1 170	7 070	297
CRUISE AND CARGO SHIPS	**30 600**	**389**	**1 220**	**467 000**	**18 400**	**16 100**	**13 700**	**80 800**	**879**
OTHER SHIPS	**1810**	**13.8**	**50.4**	**14 600**	**604**	**379**	**322**	**1150**	**149**
FISHING VESSELS	**10 200**	**131**	**417**	**140 000**	**6 570**	**3 440**	**2 900**	**6 520**	**488**
WHALE WATCHING BOATS	**837**	**9.91**	**36.2**	**11 600**	**504**	**268**	**228**	**526**	**5375**
TOTAL 2017	**43 400**	**544**	**1 720**	**632 000**	**26 100**	**20 200**	**17 200**	**89 000**	**6891**
TOTAL 2016	***38 000***	***460***	***1500***	***480 000***	***23 000***	***17 000***	***15 000***	***82 000***	***7108***

The different harbour areas in the port serve different ship types to some extent. Sunda harbour is the busiest cargo and cruise port and emissions of CO_2, which indicate fuel consumption, are significantly higher in Sunda harbour than in the other harbours. Akranes harbour is the lower extreme with approximately 2600 tonnes of CO_2 emissions during the year. The total emissions from each harbour area are presented in Table 9.

Table 9. Emissions from ships in the different harbour areas of Faxaflóahafnir 2017.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)	Ship calls
Akranes harbour	2 630	32.8	104	28 200	1 630	811	690	821	44
Grundartangi harbour	5 260	67.7	212	79 300	3 380	2 780	2 360	11 000	138
Old harbour	9 930	140	390	136 000	5 970	3 350	2 850	9 820	6026
Sunda harbour	25 600	304	1 020	389 000	15 100	13 300	11 300	67 400	683
TOTAL	**43 400**	**544**	**1 720**	**632 000**	**26 100**	**20 200**	**17 200**	**89 000**	**6891**

Further details on emissions per ship type in the different harbour areas are presented in Table 10 (Akranes harbour),

Table 11 (Grundartangi harbour), Table 12 (Old harbour), and Table 13 (Sunda harbour). For each Table, the total emissions in 2016 are accounted for in the bottom row. These values are adjusted from the values reported in report U 5817, for alignment of assumptions in the calculation, between the two years.

Table 10. Akranes harbour - emissions from different ship types 2017.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)	Ship calls
Dry bulk carrier	173	2.28	7.22	1 940	114	70.6	60.0	218	12
Container ship	-	-	-	-	-	-	-	-	-
Cruise ship	14.5	0.137	0.537	187	6.68	7.16	6.08	45.9	1
Oil- and chemical tanker	16.9	0.214	0.681	234	10.7	6.64	5.65	29.0	2
RoRo vessel/Ferry	-	-	-	-	-	-	-	-	-
General cargo ship	35.6	0.483	1.53	570	24.4	15.3	13.0	64.7	9
CRUISE AND CARGO SHIPS	**240**	**3.11**	**9.97**	**2 930**	**156**	**99.7**	**84.8**	**358**	**24**
OTHER SHIPS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
FISHING VESSELS	**2 390**	**29.7**	**93.9**	**25 300**	**1 470**	**711**	**605**	**463**	**20**
WHALE WATCHING BOATS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
TOTAL 2017	**2 630**	**32.8**	**104**	**28 200**	**1 630**	**811**	**690**	**821**	**44**
TOTAL 2016	***2 100***	***27***	***8.6***	***29 000***	***1 400***	***680***	***580***	***1 100***	***36***

Table 11. Grundartangi harbour – emissions from different ship types 2017.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)	Ship calls
Dry bulk carrier	1 670	20.4	64.2	19 300	1 010	631	536	2020	20
Container ship	2 580	33.5	105	44 200	1 680	1 720	1 460	7 610	11
Cruise ship	-	-	-	-	-	-	-	-	-
Oil- and chemical tanker	2.25	0.0298	0.0940	35.0	1.50	0.813	0.691	2.75	1
RoRo vessel/Ferry	-	-	-	-	-	-	-	-	-
General cargo ship	1 010	13.7	43.0	15 800	694	426	362	1 390	106
CRUISE AND CARGO SHIPS	**5 250**	**67.7**	**212**	**79300**	**3 380**	**2 780**	**2 360**	**11 0001**	**138**
OTHER SHIPS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
FISHING VESSELS	**2.86**	**0.0362**	**0.117**	**32.2**	**1.81**	**0.869**	**0.739**	**0.227**	*
WHALE WATCHING	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

BOATS									
TOTAL 2017	**5 260**	**67.7**	**212**	**79 300**	**3 380**	**2 780**	**2 360**	**11 000**	**138**
TOTAL 2016	***4 200***	***54***	***170***	***59 000***	***2 700***	***2 400***	***2 100***	***9 900***	***129***

*Fishing vessels and chemical tankers only use the port during shifting operations and ship calls are for this reason not accounted for in the table.

Table 12. Old harbour – emissions from different ship types 2017.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)	Ship calls
Dry bulk carrier	8.95	0.127	0.371	155	6.38	10.7	9.11	55.0	1
Container ship	84.6	1.02	3.38	1 220	51.0	54.0	45.9	389	5
Cruise ship	929	12.0	38.5	14 100	602	384	326	1 720	49
Oil- and chemical tanker	9065	31.3	35.4	12 000	566	403	343	2 130	108
RoRo vessel/Ferry	188	2.55	8.02	2 790	129	70.1	59.6	244	6
General cargo ship	67.8	0.872	2.85	1050	44.0	43.7	37.1	305	8
CRUISE AND CARGO SHIPS	**2 180**	**47.8**	**88.6**	**31 300**	**1 400**	**965**	**820**	**4 840**	**177**
OTHER SHIPS	**1 170**	**7.20**	**27.6**	**7 180**	**289**	**209**	**178**	**742**	**118**
FISHING VESSELS	**5 740**	**75.3**	**238**	**85 800**	**3 780**	**1 910**	**1 620**	**3 710**	**356**
WHALE WATCHING BOATS	**837**	**9.90**	**36.2**	**11 600**	**504**	**268**	**228**	**526**	**5375**
TOTAL 2017	**9 930**	**140**	**390**	**136 000**	**5 970**	**3 350**	**2 850**	**9 800**	**6026**
TOTAL 2016	**10 300**	**126**	**405**	**144 000**	**6 230**	**3 390**	**2 880**	**8 790**	***6423***

Table 13. Sunda harbour – emissions from different ship types 2017.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO_2 (kg)	Ship calls
Dry bulk carrier	34.4	0.454	1.44	497	22.9	15.1	12.8	66.5	2
Container ship	10 700	136	433	179 000	6 820	6 330	5 380	30 800	279
Cruise ship	10 500	112	406	148 000	5 530	5 020	4 260	28 200	80
Oil- and chemical tanker	62.1	0.747	2.43	837	37.1	34.6	29.4	218	5
RoRo vessel/Ferry	-	-	-	-	-	-	-	-	-
General cargo ship	1 610	21.2	68.2	24 400	1 070	886	753	5 310	174
CRUISE AND	**22 900**	**271**	**911**	**353 000**	**13 500**	**12 300**	**10 400**	**64 600**	**540**

CARGO SHIPS									
OTHER SHIPS*	**646**	**6.56**	**22.8**	**7420**	**315**	**170**	**144**	**407**	**31**
FISHING VESSELS	**2 080**	**26.4**	**84.6**	**28 500**	**1 320**	**821**	**698**	**2 350**	**112**
WHALE WATCHING BOATS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	-
TOTAL 2017	**25 600**	**304**	**1 020**	**389 000**	**15 100**	**13 300**	**11 300**	**67 400**	**683**
TOTAL 2016	***21 100***	***254***	***843***	***324 000***	***12 700***	***10 700***	***9 130***	***50 400***	***528***

4 Discussion

It is difficult to compare one port to another since the characteristics of ports vary considerably. Differences in ship sizes, logistic requirements, and ship types can all influence emissions; large ships need longer time at berth, small tankers in general cause more emissions at berth than small RoRo vessels, and the fairway channel varies in length in different ports, to give three examples.

A comparison of average values of emissions of CO_2/call in the four port areas show that:

- in Akranes, the average values are stable around 60 tonnes/call between the two years
- in Grundartangi, the average emissions per call has risen slightly from 33 to 38 ton/call
- in Old harbour the average values are 1.6 tonnes /call for both years. This value is considerably lower than in the other areas of the port due to the high share of whale watching boats.
- and that emissions in Sunda are stable around 38 tonnes/call.

The model used includes generic values in many instances. These are often based on averages from a large number of observations or reports, which include variations around the average value. Examples of such generic values are the emission factors, the sulphur content in fuel, and the engine loads at different operational modes. This causes uncertainty in the results. However, in an emission inventory like this with a large number of ships and ship calls, the total results will present a fair view of the actual emissions. If the scope is narrowed to few ships or single ship types, the uncertainty in the result increases. Due to these uncertainties, all values are given with two significant figures. With rounded values there might be totals given in tables that deviate slightly from sums of individual factors.

Emissions from two ship categories rely on other assumptions than the rest. These are the fishing vessels and the whale watching boats, contributing 24% and 2% to total CO_2 emissions, respectively. The information on fishing vessels is considered equally reliable as information on other ship types. A categorisation of the fishing vessels have accounted for large differences between ships within this category. Data on whale watching boats are however less reliable. Whale watching boats are different in character from one another; some of the whale watching boats are merely the size of leisure boats, while others are larger – possibly former fishing vessels. It can be expected that the smallest whale watching boats use more refined fuel than the marine distillates used by larger ships in this study. However, information on installed main engine power has been available for these boats, which makes estimates on emissions during operations *in port basin* and *manoeuvring* relatively good for emissions of CO_2 and SO_2 that are directly related to fuel consumption. Estimates of emissions that have a strong dependency on engine characteristics, such as NO_X, hydrocarbons and particles, are more uncertain since engine types are expected to vary with the size of the vessel. It is probable that emissions of NO_X are somewhat overestimated for the whale watching boats, while hydrocarbons are underestimated. Often the fishing vessels connect to shore side power when at berth, which also reduces uncertainty in these estimates. The whale watching boats always connect to the land based electricity grid when at berth. Still, the total emission estimates from the whale watching boats remain more uncertain than those for other ship types.

Some changes of assumptions have been made to emission calculations for year 2016 (Winnes and Parsmo 2017). This has mainly had an influence on estimates of emissions in the port basin and thus emissions from the main engines. This has resulted in significantly lower total emissions of SO_2 in this year's estimate. Other minor changes to the report for last year include a changed assumption of fuel needed in cruise ship boilers, and updated emission factors for particles. Another adjustment that has influenced emissions from whale watching boats relate to the time these boats spend in the port basin. In order to facilitate comparison and consider potential trends, the emissions from ships in Faxaflóahafnir during 2016 have been recalculated. Total estimated emissions and emissions in different port areas for 2016 are presented in this report. Comparisons show an increase in total emissions; CO_2 has increased with 14%, and other emissions have increased between 9% and 20% except NO_X, for which the estimated increase is 32%. This increase is likely due to that less visiting ships have been reported to use NO_X abatement techniques on board.

The traffic to and from the port was reduced by approximately 3% between 2016 and 2017. However, both container ships and cruise ships had more calls to the port in 2017 than the year before, and since these two ship types contribute significantly to emissions the total emission increase. There were emission increases in all harbour areas except Old harbour in 2017.

References

Cooper, D. & Gustafsson, T. (2004), Methodology for calculating emissions from ships: 1, Update of emission factors, Report series SMED and SMED&SLU Nr 4 2004 (http://www.smed.se/).

Entec UK Ltd. (2002) Quantification of emissions from ships associated with ship movements between ports in the European Community. Northwich, Entec UK Limited.

HB Grandi, 2017, personal communication with Guðmundur Hafsteinsson

IHS, 2017, SeaWeb Ship, available at: http://www.sea-web.com/authenticated/seaweb_subscriber_welcome.aspx

IMO, 2011, MARPOL Consolidated edition 2011, International Maritime Organization, London

IMO, 2014, Third IMO GHG Study 2014; International Maritime Organization (IMO) London, UK, June 2014; Smith, T. W. P.; Jalkanen, J. P.; Anderson, B. A.; Corbett, J. J.; Faber, J.; Hanayama, S.; O'Keeffe, E.; Parker, S.; Johansson, L.; Aldous, L.; Raucci, C.; Traut, M.; Ettinger, S.; Nelissen, D.; Lee, D. S.; Ng, S.; Agrawal, A.; Winebrake, J. J.; Hoen, M.; Chesworth, S.; Pandey,A.

Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang (2013) "Anthropogenic and Natural Radiative Forcing". In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Anthropogenic and Natural Radiative Forcing

Port of Los Angeles, 2010, Inventory of air emissions 2009

Sjöbris A., Gustafsson J och Jivén K., 2005. ARTEMIS Sea transport emission modelling For the European Commission DG Tren, Mariterm AB

USEPA, 1999,. AP42, 5th ed, Vol1 Ch1 External Combustion Sources, sections 1.3 and 1.4.

USEPA, 2007, Global Trade and Fuels Assessment - Future Trends and Effects of Requiring Clean Fuels in the Marine Sector, Prepared for EPA by RTI International Research Triangle Park, EnSys Energy & Systems, Inc. Lexington, and Navigistics Counsulting Boxborough, EPA Contract No. EP-C-05-040

Winnes H. and Parsmo R., 2016, Emissionsinventering av fartygen i Göteborgs hamn 2015, Rapport U5604

Winnes H. and Parsmo R., 2017 Emissions from ships in Faxaflóahafnir 2016, Rapport U5817

Winnes and Fridell, 2009, Particle emissions from ships – dependence on fuel types, Journal of Air and Waste Management

Appendixes:

1. Distances and times between port area border and berths in Faxaflóahafnir
2. Emission factors
3. Environmental Ship Index (ESI)

Appendix 1. Distances and times between port area border and berths in Faxaflóahafnir.

			Estimated time from port area border to at berth position (h)				
Berth number	Name	Distance (NM)	0_10 GRT	10_20 GRT	>20 GRT	Type	Port
110	NORÐURGARÐUR - ISPS	3.20	0.50			Berth	Old harbour
111	NORÐURGARÐUR-111	3.20	0.50			Berth	Old harbour
112	NORÐURGARÐUR-112	3.20	0.50			Berth	Old harbour
113	NORÐURGARÐUR-113	3.20	0.50			Berth	Old harbour
114	NORÐURGARÐUR-114	3.20	0.50			Berth	Old harbour
121	SÍLDARBRYGGJA-121	3.20	0.50			Berth	Old harbour
122	SÍLDARBRYGGJA-122	3.20	0.50			Berth	Old harbour
123	OLÍUBRYGGJA-123	3.20	0.50			Berth	Old harbour
124	OLÍUBRYGGJA-124	3.20	0.50			Berth	Old harbour
131	Grandabryggja-Stubbur	3.20	0.50			Berth	Old harbour
141	GRANDABRYGGJA-141	3.20	0.50			Berth	Old harbour
142	GRANDABRYGGJA-142	3.20	0.50			Berth	Old harbour
143	GRANDABRYGGJA-143	3.20	0.50			Berth	Old harbour
144	GRANDABRYGGJA-144	3.20	0.50			Berth	Old harbour
145	GRANDABRYGGJA-145	3.20	0.50			Berth	Old harbour
151	GRANDABAKKI-151	3.20	0.50			Berth	Old harbour
152	GRANDABAKKI-152	3.20	0.50			Berth	Old harbour
153	Bótarbryggja -153	3.20	0.50			Berth	Old harbour
154	Bótarbryggja -154	3.20	0.50			Berth	Old harbour
155	Bótarbryggja -155	3.20	0.50			Berth	Old harbour
161	VERBÚÐARBRYGGJUR-161	3.20	0.50			Berth	Old harbour
162	VERBÚÐARBRYGGJUR-162	3.20	0.50			Berth	Old harbour
163	VERBÚÐARBRYGGJUR-163	3.20	0.50			Berth	Old harbour
164	VERBÚÐARBRYGGJUR-164	3.20	0.50			Berth	Old harbour
165	VERBÚÐARBRYGGJUR-165	3.20	0.50			Berth	Old harbour
166	VERBÚÐARBRYGGJUR-166	3.20	0.50			Berth	Old harbour
171	EYJARGARÐUR-171	2.50	0.42			Berth	Old harbour
181	DANÍELSSLIPPUR-181	3.20	1.00			Shipyard	Old harbour
182	VESTARI SLIPPUR-182	3.20	1.00			Shipyard	Old harbour
183	STÓRI SLIPPUR-183	3.20	1.00			Shipyard	Old harbour
184	EYSTRI SLIPPUR-184	3.20	1.00			Shipyard	Old harbour
191	EYJARGARÐUR-191	2.50	0.50	1.00		Berth	Old harbour
211	ÆGISGARÐUR-211	3.20	0.50	0.75		Berth	Old harbour
212	ÆGISGARÐUR-212	3.20	0.50	0.75		Berth	Old harbour
213	ÆGISGARÐUR-213	3.20	0.50	0.75		Berth	Old harbour
214	ÆGISGARÐUR-214	3.20	0.50	0.75		Berth	Old harbour
215	ÆGISGARÐUR-215	3.20	0.50	0.75		Berth	Old harbour
216	ÆGISGARÐUR-216	3.20	0.50	0.75		Berth	Old harbour
217	ÆGISGARÐUR-217	3.20	0.50	0.75		Berth	Old harbour
221	GRÓFARBRYGGJA-221	3.20	0.50			Berth	Old harbour

222	GRÓFARBRYGGJA-222	3.20	0.50			Berth	Old harbour
231	MIÐBAKKI-231	3.20	0.50	0.75		Berth	Old harbour
232	MIÐBAKKI-232	3.20	0.50	0.75		Berth	Old harbour
233	MIÐBAKKI-233	3.20	0.50	0.75		Berth	Old harbour
234	MIÐBAKKI-234	3.20	0.50	0.75		Berth	Old harbour
251	FAXAGARÐUR-251	3.20	0.50	0.75		Berth	Old harbour
252	FAXAGARÐUR-252	3.20	0.50	0.75		Berth	Old harbour
253	FAXAGARÐUR-253	3.20	0.50	0.75		Berth	Old harbour
254	FAXAGARÐUR-254	3.20	0.50	0.75		Berth	Old harbour
261	INGÓLFSGARÐUR-261	3.20	0.50			Berth	Old harbour
262	INGÓLFSGARÐUR-262	3.20	0.50			Berth	Old harbour
263	INGÓLFSGARÐUR-263	3.20	0.50			Berth	Old harbour
291	SUÐURBUGT	3.20	0.33			Berth	Old harbour
311	SKARFABAKKI-311	4.00	0.50		1.50	Berth	Sunda harbour
312	SKARFABAKKI-312	4.00	0.75	1.00	1.50	Berth	Sunda harbour
313	SKARFABAKKI-313	4.00	0.75	1.00	1.50	Berth	Sunda harbour
314	SKARFABAKKI-314	4.00	0.75	1.00	1.50	Berth	Sunda harbour
315	SKARFABAKKI-315	4.00	0.75	1.00	1.50	Berth	Sunda harbour
411	KORNGARÐUR-411	4.00	0.75	1.25	1.50	Berth	Sunda harbour
412	KORNGARÐUR-412	4.00	0.75	1.25	1.50	Berth	Sunda harbour
420	SUNDABAKKI - ISPS	4.00	0.75	1.25	1.50	Berth	Sunda harbour
421	SUNDABAKKI-421	4.00	0.75	1.25	1.50	Berth	Sunda harbour
422	SUNDABAKKI-422	4.00	0.75	1.25	1.50	Berth	Sunda harbour
423	SUNDABAKKI-423	4.00	0.75	1.25	1.50	Berth	Sunda harbour
430	KLEPPSBAKKI - ISPS	4.00	0.75	1.25	1.50	Berth	Sunda harbour
431	KLEPPSBAKKI-431	4.00	0.75	1.00	1.50	Berth	Sunda harbour
432	KLEPPSBAKKI-432	4.00	0.75	1.00	1.50	Berth	Sunda harbour
433	KLEPPSBAKKI-433	4.00	0.75	1.00	1.50	Berth	Sunda harbour
434	KLEPPSBAKKI-434	4.00	0.75	1.00	1.50	Berth	Sunda harbour
529	VOGABAKKI-529	5.10	1.00	1.25	1.67	Berth	Sunda harbour
530	VOGABAKKI - ISPS	5.10	1.00	1.25	1.67	Berth	Sunda harbour
531	VOGABAKKI-531	5.10	1.00	1.25	1.67	Berth	Sunda harbour
532	VOGABAKKI-532	5.10	1.00	1.25	1.67	Berth	Sunda harbour
533	VOGABAKKI-533	5.10	1.00	1.25	1.67	Berth	Sunda harbour
534	VOGABAKKI-534	5.10	1.00	1.25	1.67	Berth	Sunda

							harbour
535	VOGABAKKI-535	5.10	1.00	1.25	1.67	Berth	Sunda harbour
610	Ártúnshöfði -610	5.20	1.50			Berth	Sunda harbour
611	Ártúnshöfði -611	5.20	1.50			Berth	Sunda harbour
612	Ártúnshöfði -612	5.20	1.50			Berth	Sunda harbour
711	GRUNDARTANGI-AUSTURKANTUR-711	1.20	0.50	0.75	1.67	Berth	Grundartangi Harbour
721	GRUNDARTANGI-TANGABAKKI	1.20	0.50	1.00	1.67	Berth	Grundartangi Harbour
722	GRUNDARTANGI-TANGABAKKI	1.20	0.50	1.00	1.67	Berth	Grundartangi Harbour
723	GRUNDARTANGI-TANGABAKKI	1.20	0.50	1.00	1.67	Berth	Grundartangi Harbour
724	GRUNDARTANGI-TANGABAKKI	1.20	0.50	1.00	1.67	Berth	Grundartangi Harbour
811	AKRANES-AÐALHAFNARGARÐUR	1.20	0.50	1.00		Berth	Akranes Harbour
812	AKRANES-AÐALHAFNARGARÐUR	1.20	0.50	1.00		Berth	Akranes Harbour
813	AKRANES-AÐALHAFNARGARÐUR	1.20	0.50	1.00		Berth	Akranes Harbour
814	AKRANES-AÐALHAFNARGARÐUR	1.20	0.50	1.12		Berth	Akranes Harbour
821	AKRANES-BÁTABRYGGJA	1.20	0.50			Berth	Akranes Harbour
822	AKRANES-BÁTABRYGGJA	1.20	0.50			Berth	Akranes Harbour
823	AKRANES-BÁTABRYGGJA	1.20	0.50			Berth	Akranes Harbour
824	AKRANES-BÁTABRYGGJA	1.20	0.50			Berth	Akranes Harbour
831	AKRANES-FAXABRYGGJA	1.20	0.50			Berth	Akranes Harbour
832	AKRANES-FAXABRYGGJA	1.20	0.50			Berth	Akranes Harbour
841	AKRANES-FERJUBRYGGJA	1.20	0.50			Berth	Akranes Harbour
861	AKRANES-AÐSTAÐA HAFNSÖGUB.	1.20	0.50			Berth	Akranes Harbour
871	AKRANES-Viðgerðarbryggja	1.50	0.80			Berth	Akranes Harbour
881	AKRANES-Skipalyfta	1.50	0.80			Shipyard	Akranes Harbour
951	KOLLAFJÖRÐUR	2.20	0.50	0.75	0.75	Anchor	Reykjavik
961	Ytri höfn innan Engeyjar	3.00	0.50	0.75	0.75	Anchor	Old harbour
971	Viðeyjarsund	2.70	0.50	0.75	0.75	Anchor	Sunda harbour
972	Grundartangi-Biðsvæði	1.20	0.75	0.75	1.50	Anchor	Grundartangi Harbour
U7B	7-BAUJA					Pilot	Pilot
1001	Whale 1	3.20	0.5	0.5		Berth	Old harbour
1002	Whale 2	6.00	0.9375	0.9375		Berth	Old harbour

Appendix 2. Emission factors

Emission factors (g/kWh) for the main engine in the port basin and during manoeuvring.

Engine type	Fuel type	CO_2	CH_4	N_2O	TIER 0 NO_x	HC
HSD	MD	717	0.008	0.031	9.6	0.408
MSD	MD	717	0.008	0.031	10.6	0.408
SSD	MD	647	0.012	0.031	13.6	0.612
HSD	RO	752	0.008	0.031	10.2	0.408
MSD	RO	752	0.008	0.031	11.2	0.408
SSD	RO	682	0.012	0.031	14.5	0.612

Emission factors (g/kWh) for aux engines in all operational modes.

Engine type	Fuel type	CO_2	CH_4	N_2O	TIER 0 NOX	HC
HSD	MD	690	0.01	0.031	11.8	0.51

Abbreviations used:

SSD – "Slow Speed Diesel" (Engines with revolutions <300 rpm)
MSD – "Medium Speed Diesel" (Engines with revolutions 300-1000 rpm)
HSD – "High Speed Diesel" (Engines with revolutions > 1000 rpm)
MD – Marine distillate oil
RO – Residual oil

NO_x-emission factors for engines on ships constructed between 2001 and 2011 calculated according to IMO's NO_x Tier-I standards and from 2011 and onwards according to IMO's Tier II standards:

Engine speed (RPM)	Emission factor (g/kWh)	
	Tier I	Tier II
<130	17	14.4
130 – 2000	$45*RPM^{(-0.2)}$	$44*RPM^{(-0.23)}$
>2000	9.8	7.7

SO_2 emissions are calculated from fuel consumption and the sulphur content of the fuel. Assumed 0.1 % S in MD, and 2.7 % in RO. Other sulphur contents are used for shipping vessels and whale watching boats according what is stated in the report.

Particle emission factors, at fuels with sulphur content >0.5%:

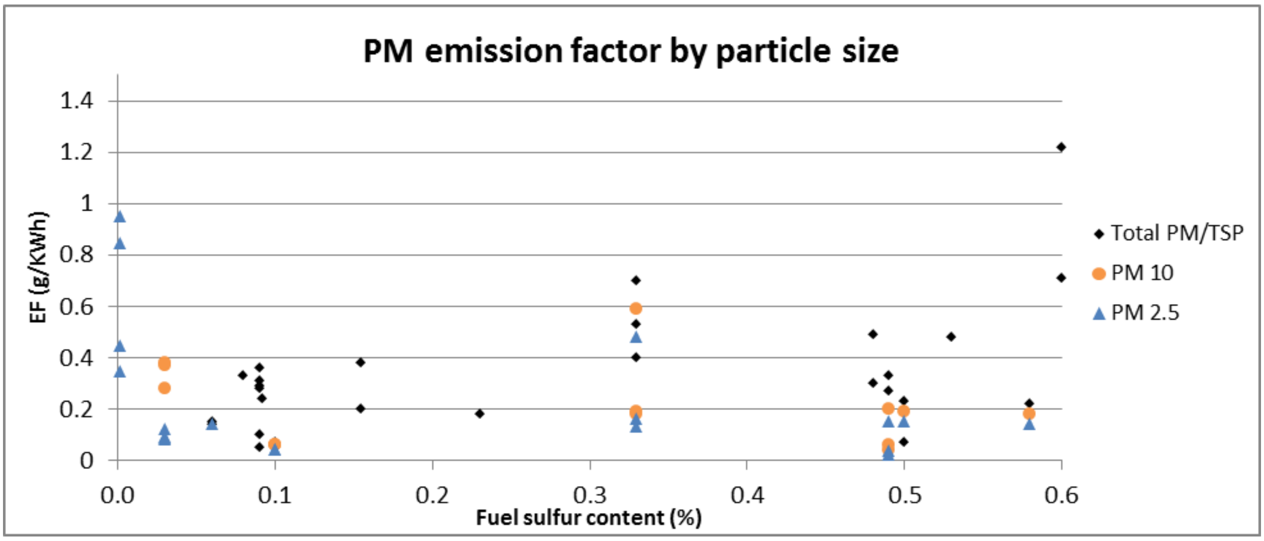
4-stroke engines: $y = 37.624x + 0.2714$

2-stroke engines: $84.509x - 0.2531$

y gives the emission factor for PM10 in g/kWh, *x* is the sulphur content of fuel

Particle emission factors, at fuels with sulphur content <0.5%:

Relation between particle emission factor and sulphur content of fuel from a literature study:



Sources:

Kasper,A et al., 2007. Particulate Emissions from a Low-Speed Marine Diesel Engine. Aerosol Science and Technology, 41(1), pp. 24-32.;

Cooper, D., 2001. Exhaust emissions from high speed passenger ferries. Atmospheric Environment, Volume 35, p. 4189–4200;

Cooper, D., 2003. Exhaust emissions from ships at berth. Atmospheric Environment, Volume 37, p. 3817–3830;

Lack, D.A et al., 2011. Impact of fuel quality regulation and speed reductions on shipping emissions: implications for climate and air quality. Environmental Science & Technology, Volume 45, pp. 9052-9060;

Lack D.A: et al., 2009, Particulate emissions from commercial shipping: Chemical, physical, and optical properties. Journal of Geophysical Research: Atmospheres, 114(D7);

Fridell, E. et al., 2008. Primary particles in ship emissions. Atmospheric Environment, Volume 42, p. 1160–1168;

Agrawal H et al., 2008. In-use gaseous and particulate matter emissions from a modern ocean going container vessel. Atmospheric Environment, Volume 42, p. 5504–5510;

Agrawal, H et al., 2008, Emission Measurements from a Crude Oil Tanker at Sea. Environmental Science & Technology, 42(19), p. 7098–7103;

Winnes H and Fridell, E, 2009. Particle Emissions from Ships: Dependence on Fuel Type. Journal of the Air & Waste Management Association, Volume 59, p. 1391–1398;

Winnes H et al., 2016. On-board measurements of particle. Journal of Engineering for the Maritime Environment, 230(1), p. 45–54; ICCT, 2016. Black Carbon Measurement Methods and Emission Factors from Ships

Moldanová J et al., 2013. Physical and chemical characterisation of PM emissions from two ships operating in European Emission Control Areas. Atmospheric Measurement Techniques, Volume 6, p. 3577–3596.;

Moldanova J., et al., 2009. Characterisation of particulate matter and gaseous emissions from a large ship diesel engine. Atmospheric Environment, Volume 43, p. 2632–2641;

Murphy S.M. et al., 2009. Comprehensive Simultaneous Shipboard and Airborne Characterization of Exhaust from a Modern Container Ship at Sea. Environmental Science & Technology, 43(13), pp. 4626-4640; U.S.

Environmental Protection Agency, 2009. Proposal to Designate an Emission Control Area for Nitrogen Oxides, Sulfur Oxides and Particulate Matter

Zetterdahl, M., 2016. Particle Emissions from Ships

Results:

Sulfur content (%)	PM tot (σ) (g/kWh)
<0.2	0.23 (0.12)
0.4 – 0.6	0.43 (0.33)

The carbon in 1 kg fuel cause 3.179 kg **CO_2** (Cooper and Gustafsson, 2004).

Emission factors for boiler in g/tonne fuel:

Fuel	NO_x	PM	HC	CH_4	N_2O
MD	2900	290	36	7,4	37

Appendix 3. Environmental Ship Index (ESI)

Description of methodology for estimating sulphur content in fuel from ESI score:

According to the Environmental Ship Index (ESI) the ESI score is calculated with the following model:

ESI SO_x=x·30+y·35+z·35

Where:

x: the relative reduction of the average sulphur content of Heavy Fuel Oil (HFO). The sulphur content is greater than 0.50% S but do not exceeding 3.50% S

y: the relative reduction of the average sulphur content of Marine Diesel Oil (MD). The sulphur content is equal or less than 0.50%, but greater than 0.1%

z: the relative reduction of the average sulphur content of MD. The Marine Diesel Oil has a sulphur content equal to or less than 0.10% S

Since Iceland has a 0.1% restriction at berth we assume that the MDO are 0.1 % or lower for ships entering Icelandic waters. We therefore exclude all boats having a lower ESI than 35 since:

$$ESI\ SO_x = x \cdot 30 + y \cdot 35 + z \cdot 35 \rightarrow ESI\ SO_x = 0 \cdot 30 + \frac{0.50\% - 0.1\%}{0.50\% - 0.1\%} \cdot 35 + 0 \cdot 35 = 35$$

Furthermore, for ships having an ESI SOx score between 30 and 65, we assume that the sulphur content in the Heavy Fuel Oil is reduced. The following equation describes how the sulphur content from RO is extracted for ships where 30 < ESI score < 65:

$$\text{S content in HFO} = 3.5\% - \frac{ESI\ SO_x - 35}{30} \cdot 3\ \%$$

If instead ESI score>65:

$$\text{S content in HFO} = 0.05\%$$

$$S\ content\ in\ MDO = 0.1\% - \frac{ESI\ SO_x - 65}{35} \cdot 0.1\%$$

Description of methodology for estimating NOx emission factor from ESI score:

The emission factors for NOx are estimated from the scores given in the ESI register by resolving $EF_{NOX\ rated}$ from equation (2).

$$ESI_{NOX} = \frac{100 * (EF_{NOX\ Tier\ I\ limit} - EF_{NOX\ rated})}{EF_{NOX\ Tier\ I\ limit}} \tag{2}$$

Where ESI_{NOX} is the NOx score calculated by ESI, $EF_{NOX\ Tier\ I\ limit}$ the emission factor corresponding to Tier I-limits for the engine in g/kWh, and $EF_{NOX\ rated}$ is the measured emission factor of the engine in g/kWh.

Calculated sulphur content of fuels and NOx emission factors (should not be disclosed):

Ship name	IMO	S content RO	NOx factor g/kWh
AKUREY	9756327	0.00001	
ARCADIA	9226906	0.0109	9.7
ARION	9177868		11.5
AZURA	9424883	0.0097	12.6
BRUARFOSS	8914568	0.0157	12.6
CELEBRITY ECLIPSE	9404314		12.9
CONMAR HAWK	9244207	0.0181	12.0
CRYSTAL SYMPHONY	9066667		12.9
DELIA	9234317	0.0091	11.5
DETTIFOSS	9086801	0.0200	17.0
ENGEY	9756315	0.0000	
FEHN LUNA	9130212	0.0050	11.5
FRI TIDE	9195676	0.0050	11.3
FRI WAVE	8915627	0.0191	12.0
FURE WEST	9301873		4.4
GODAFOSS	9086796	0.0206	17.0
HELGA MARIA	8709793	0.00001	
HOFRUNGUR III	8704987	0.00001	
JUMBO	8518297	0.0050	13.3
LAGARFOSS	9641314	0.0184	10.2
MEIN SCHIFF 4	9678408	0.0267	8.2
ORFIRISEY	8704975	0.00001	
OTTO N. THORLAKSSON	7811214	0.00001	
PATRONA I	9305178		11.0
PRINSENDAM	8700280		12.8
QUEEN ELIZABETH	9477438	0.0050	12.0
ROTTERDAM	9122552		12.9
SEABOURN QUEST	9483126		11.9
SERENADE OF THE SEAS	9228344		10.1

STAR LEGEND	9008598		11.7
STENHEIM	9261114		13.0
STURLAUGUR H BODVARSSON	8003993	0.00001	
TERNVIND	9425356		10.5
THERNEY	8901511	0.00001	
THESEUS	9199256	0.0087	11.5
UBC CORK	9448279	0.0144	8.3
VENUS	9718296	0.00001	
VIDEY	9756339	0.00001	
VIKINGUR	9718301	0.00001	
WILSON ALGECIRAS	9507350	0.0173	11.2
WILSON ALMERIA	9507362	0.0171	10.4
WILSON AVILES	9313709	0.0103	10.4
WILSON DOVER	9005754	0.0050	11.9
WILSON DUNKIRK	9536521		11.3
WILSON DVINA	9005742	0.0071	11.9
WILSON FARSUND	9491733	0.0115	7.8
WILSON FEDJE	9491757	0.0131	7.8
WILSON FLUSHING	9491745	0.0149	7.8
WILSON GARSTON	9000833	0.0050	12.5
WILSON HARRIER	9064891	0.0161	12.5
WILSON HORSENS	9518426		11.3
WILSON HUELVA	9518414	0.0270	10.8
WILSON LEER	9150482	0.0093	11.5
WILSON MALM	7810210	0.0067	12.7
WILSON MERSIN	7810222	0.0233	12.7
WILSON NANTES	9430973	0.0188	9.4
WILSON NEWCASTLE	9431006	0.0234	7.7
WILSON NORFOLK	9430997	0.0083	9.5
WILSON TEES	9150535		11.5
WILSON TRENT	7926095	0.0108	15.2
WILSON TYNE	7915307	0.0138	15.2

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