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Emissions from ships in Faxaflóahafnir 2018

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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 calculates the emissions to air from ships in Faxaflóahafnir 2018. 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), and sulphur dioxide (SO_2) are calculated using an emission inventory model specifically developed for port areas. Total emissions in 2018 are presented in the table below.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)
TOTAL emissions 2018	**47 000**	**0.58**	**1.9**	**660**	**29**	**20**	**100**

Container ships account for a larger share of emissions than other ship types, closely followed by cruise ships. Each of the two ship types contribute to approximately 30% of the total emissions of CO_2 from the ships visiting Faxaflóahafnir in 2018. The emissions per call by cruise ships are considerably higher than those from other vessels. The fishing vessels constitute the third largest contributing ship type category in the port. Whale watching boats are in frequent traffic to the port with 4520 calls in 2018. Since these in general have relatively small engines, they are calculated to contribute around 2% to the total CO_2 emissions.

Sunda harbour and Old harbour receives significantly more ship calls than Akranes and Grundartangi. 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 the emissions to air in Faxaflóahafnir, regardless the 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 2018.

In a comparison with emissions from ships in the port in 2017, there is an overall increase. The increase can mainly be attributed to more emissions from container ships and cruise ships. In Akranes the trend is the opposite and emissions are lower in 2018 than in 2017. Overall, CO_2 has increased with 7%, and other emissions between 4% and 14%. SO_2 emissions rose significantly compared to CO_2 emissions. This inconsistency is due to fewer ships using fuels with low sulphur content in 2018 than in 2017.

1 Introduction

IVL Swedish Environmental Research Institute has on assignment of Faxaflóahafnir calculated emissions from ships visiting its ports in 2018. Faxaflóahafnir comprises the four ports of Akranes harbour, Grundartangi harbour, and Sunda harbour and Old harbour in Reykjavik. The locations of the different ports are 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), and sulphur dioxide (SO_2). The emission calculations are based on call statistics obtained from the port.

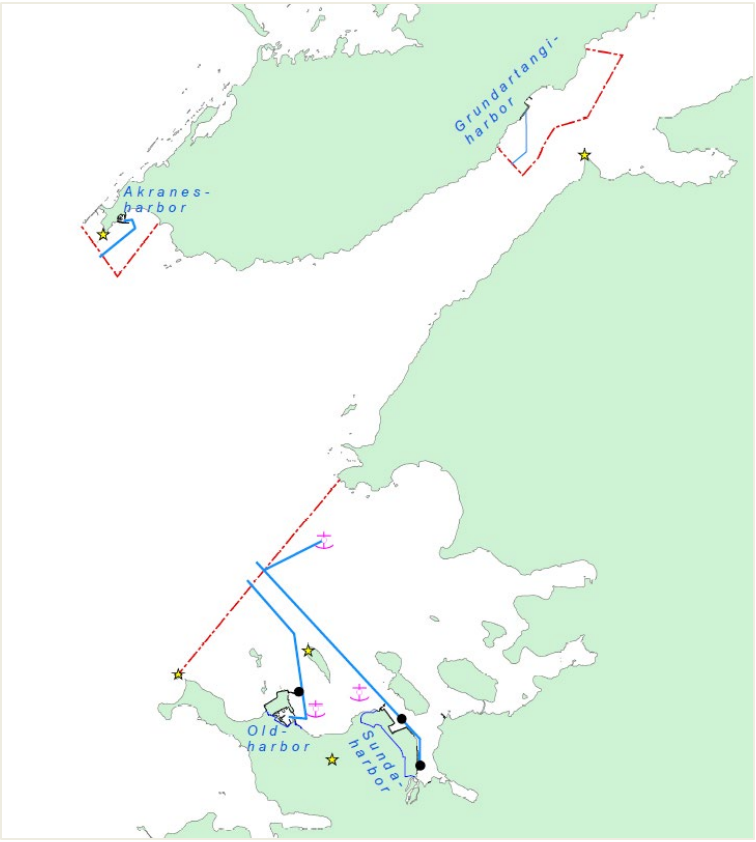

Figure 1. The four ports of Faxaflóahafnir and the areas outside the ports included in the emission inventory.

This report describes the calculation models, the data used, and the results from the calculations. The results are analysed and discussed in relation to emission calculations made from ships calling the port in 2016 and 2017. Some minor modifications have been made to the calculation model from previous years. We therefore present updated emissions for 2016 and 2017 for reasonable comparisons.

2 Ship traffic

In total, this inventory covers 1486 port calls comprising in total 368 larger vessels. The received port call statistics included 1492 calls, of which 6 has been excluded from the calculation due to insufficient data. In addition to these calls, the port received 4520 calls from whale watching boats in 2018. These are all covered by the inventory.

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. 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 ship types are "Dry bulk carriers", "Container ships", "Cruise ships", "Oil- and chemical tankers", "RoRo-vessels/Ferries", "General cargo ships", "Fishing vessels", "Whale watching boats" and "Other ships".

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 operation *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.

Whale watching boats were assumed to be berthing if they 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 the 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, with fuel sulphur content 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) are dependent on the sulphur content of the fuel. For high sulphur fuels we use a formula for the relation between fuel sulphur content and PM emission factors. The formula is a linear equation representing a fit to values from several emission measurement studies. Different equations are used for high-, medium- and slow speed engines. However, for fuel sulphur contents below 0.5%, the formula is less relevant. A literature review of emission measurement results shows no clear 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 are presented in Appendix 2.

It is common to use oil fired boilers on board ships 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 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. The fishing vessels in the HB Grandi fleet are also treated as special cases as these are known to use fuel with very low sulphur content. Another category of ships that are 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 122 ships visiting Faxaflóahafnir in 2018 that were matched to the ESI register. The ESI register that we use for this inventory is valid for 2018. The previously reported emission inventories for Faxaflóahafnir (2016 and 2017) have used the ESI register of 2016. The ships in the ESI register are presented in Appendix 3 together with their estimated emission factors for SO_2 and NO_X.

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 calculated for 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 are 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 powers 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 has in a previous study been provided by HB Grandi (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 1.

Table 1. 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 – 1 035	220 – 600	410
3	1 036 – 1 762	220 – 600	410
4	1 763 – 3 699	700 – 900	800
5	3 700 – 9 000	1 500 – 2 000	1 750

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 2.

Table 2. 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 is 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 3 (HB Grandi, 2017).

Table 3. Estimated power utilization of auxiliary engines in different categories of fishing vessels.

Cate-gory No.	In port basin	Mano-euvring	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[1] which do not add any emissions to the calculations. An exception is the category fishing vessels. The need for electricity is 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 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 1 and Table 3 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 tons/day at off-loading. An off-loading operation for 14000 tons oil requires about 15 hours. Based on this information a generic value of 0.13 kg fuel/ton 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. 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 (2) is assumed.

[1] 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.

$$Fuel\ consumption = 0.42 * DWT * 0.13 \quad (2)$$

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 small sizes tend to use electricity driven pumps while larger ships use steam driven pumps.

The fuel used in main engines during operations *in port basin*, and *manoeuvring* 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.

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 4.

Table 4. 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 carriers	1.4
Oil- and chemical tankers	4
Container ships	2.9
Cruise ships	4
General cargo ships	0.9
Other ships	4
Reefers	5.4
RoRo/Ferries	2

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

4 Results

Table 5 presents the emissions of the different substances per engine type and operational mode.

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 most 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 which is the reason o the relative importance of the emissions from the *in port basin* operational mode. 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 calculated 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[2] of 48 000 tonnes, a value that is totally dominated by the emissions of CO_2.

[2] The factors used for calculation of CO_2-eqv are 30 for CH_4 and 265 for N_2O (IPCC, 2013).

Table 5. Overview of emissions from ships in Faxaflóahafnir 2018.

		CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)
Main Engines	In port basin	5 160	0.0607	0.218	86.1	3.09	8.24	61.2
	At anchor*	0	0	0	0	0	0	0
	Manoeuvring	968	0.0113	0.0410	15.8	0.576	1.40	10.4
	At berth*	5 470	0.0610	0.236	87.8	3.11	1.52	11.2
Auxiliary Engines	In port basin	1 680	0.0244	0.0756	26.9	1.24	0.488	1.01
	At anchor*	231	0.00334	0.0104	3.57	0.171	0.0669	0.142
	Manoeuvring	408	0.00591	0.0183	6.48	0.301	0.118	0.235
	At berth*	27 100	0.392	1.22	424	20.0	7.84	14.7
	Tankers at berth using cargo pumps	143	0.00208	0.00643	2.20	0.106	0.0415	0.0877
Boilers	In port basin	395	0.000919	0.00460	0.360	0.00447	0.0360	0.248
	At anchor*	32.1	0.0000746	0.000373	0.0292	0.000363	0.00292	0.0202
	Manoeuvring	62.1	0.000145	0.000723	0.0566	0.000703	0.00566	0.0390
	At berth*	5 900	0.0137	0.0684	5.36	0.0666	0.536	3.70
TOTAL (Engines	Main engines	11 600	0.133	0.495	190	6.78	11.2	82.7
	Auxiliary engines	30 000	0.428	1.33	463	21.8	8.56	16.1
	Boilers	6 370	0.0148	0.0741	5.81	0.0721	0.581	4.01
TOTAL (Operational)	In port basin	7 200	0.0860	0.298	113	4.34	8.76	62.4
	At anchor*	263	0.00342	0.0107	3.60	0.171	0.0698	0.162
	Manoeuvring	1 400	0.0173	0.0600	22.3	0.878	1.52	10.6
	At berth*	38 600	0.469	1.53	520	23.3	9.95	29.6
TOTAL	**All engines and boilers, all operational modes**	47 500	0.576	1.90	659	28.7	20.3	103

*Only cruise ships with diesel electric power trains

**Include emissions from ships in ship yard

The emissions in total have increased during the last three years. In Table 6 the emissions from 2016 and 2017 are presented and compared to emissions in 2018. The values presented for 2017 and 2016 are slightly modified from the values reported previously in report U 5817 (Winnes and Parsmo 2017) and report U 5953 (Parsmo and Winnes, 2018). These modifications are due to updates in methodology between the years. In order to make the comparison between the years the methodology should be similar in all inventories. The major changes in methodology comprise:

- A new, more automated way of connecting arrival and departure times for whale watching boats. This affects both emissions and number of calls 2017 and 2018 slightly.
- A new emission factor is used for emissions of particles from low sulphur fuels.

- Calculations of shore side electricity and avoided emissions are done without considering electricity delivered for special services as agreed in discussion with Faxaflóahafnir.

Table 6. Emissions from ships visiting Faxaflóahafnir 2016, 2017, and 2018 and number of calls.

Year	CO_2 (ton)	CH_4 (ton)	N_2O (ton)	NO_x (ton)	HC (ton)	PM (ton)	SO_2 (ton)	Ship calls
2018	47 500	0.576	1.90	659	28.7	20.3	103	6006
2017	44 300	0.556	1.76	615	26.7	19.0	90.3	7059
2016	37 900	0.465	1.52	543	23.2	16.1	73.2	7136

The increase in emissions from 2017 to 2018 can mainly be attributed to more emissions from container ships and cruise ships. Emissions from the other ship types does not change significantly between the years. In Figure 2., this is exemplified by presenting the CO_2 emissions from different ship types in 2016, 2017, and 2018.

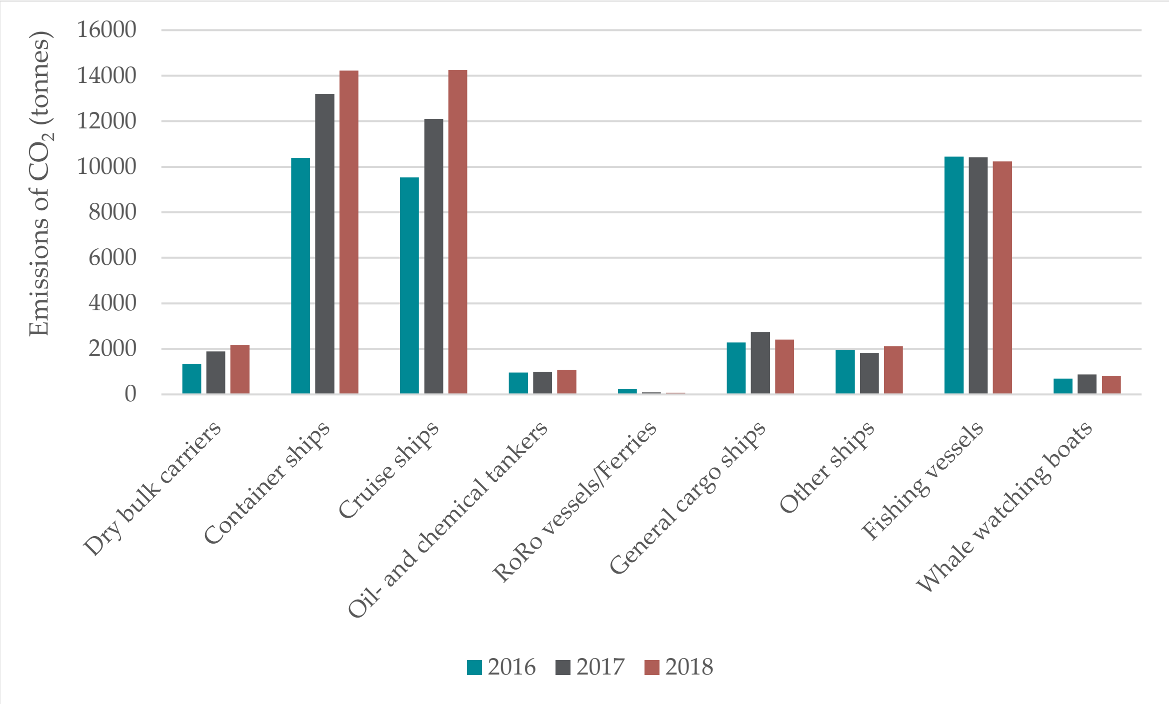

Figure 2. CO_2 emissions from different ship types 2016, 2017 and 2018.

Faxaflóahafnir provides 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 calculated actual emissions at berth. Approximately 2% - 4% of emissions from ships at berth are avoided in this respect. The avoided emissions are presented in Table 7 for the three harbour areas.

Table 7. Total avoided emissions from the use of shore side electricity in the port 2018.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)
Akranes Harbour	56.6	0.000820	0.00254	0.706	0.0418	0.0164	0.000356
Old harbour	1027	0.0149	0.0461	15.9	0.759	0.298	0.559
Sunda harbour	116	0.00168	0.00521	1.64	0.0857	0.0336	0.0327
TOTAL	1199	0.0174	0.0539	18.3	0.886	0.348	0.592

'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, container ships and cruise ships cause the most emissions. Further, container ships have significantly higher impact on total SO_2 emissions than any other ship type. The fishing vessels are the third largest contributor to emissions in the port. 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. Emissions and calls from the different ship types are presented in Table 8 and their contribution to total emissions are illustrated in Figure 3.

Table 8. Emissions and ship calls per ship type in Faxaflóahafnir in 2018.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	2 170	0.0268	0.0844	25.3	1.33	0.715	2.35	33
Container ships	14 400	0.182	0.580	208	9.11	8.29	49.2	306
Cruise ships	14 300	0.158	0.560	204	7.87	6.02	36.5	146
Oil- and chemical tankers**	1 080	0.0130	0.0421	14.0	0.646	0.454	1.83	121
RoRo vessels/Ferries	75.2	0.000961	0.00308	1.10	0.0481	0.0316	0.178	5
General cargo ships	2 400	0.0322	0.102	35.2	1.63	1.08	5.45	273
CRUISE AND CARGO SHIPS	**34 300**	**0.414**	**1.37**	**488**	**20.6**	**16.6**	**95.4**	**884**
OTHER SHIPS	**2 110**	**0.0199**	**0.0687**	**21.8**	**0.931**	**0.455**	**1.32**	**141**
FISHING VESSELS	**10 200**	**0.133**	**0.420**	**138**	**6.632**	**3.02**	**5.57**	**461**
WHALE WATCHING BOATS	**811**	**0.00963**	**0.0350**	**11.2**	**0.490**	**0.226**	**0.509**	**4520**
TOTAL 2018	**47 500**	**0.576**	**1.90**	**659**	**28.7**	**20.3**	**103**	**6006**

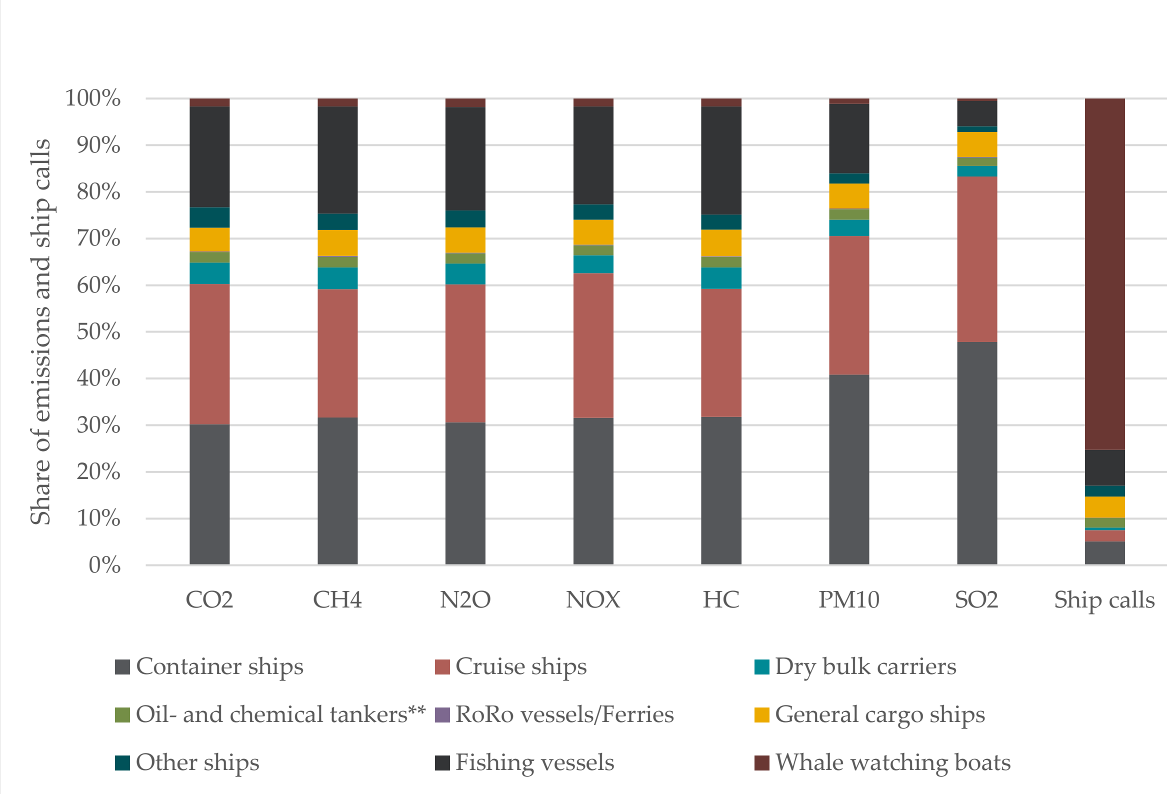

Figure 3. Share of total emissions and ship calls by the ship type categories, 2018.

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 1000 tonnes of CO_2 emissions in 2018. In Akranes emissions dropped with more than 50% between 2017 and 2018. The total emissions from each harbour area are presented in Table 9.

Table 9. Emissions from ships in the different harbour areas of Faxaflóahafnir 2018.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	Ship calls (cargo, & cruise, fishing and "other")	Ship calls (whale watching boats)
Akranes harbour	1 020	0.0131	0.0415	12.2	0.653	0.313	0.523	34	-
Grundartangi harbour	5 420	0.0696	0.219	73.0	3.47	2.61	12.2	157	-
Old harbour	12 700	0.157	0.506	170	7.81	3.75	9.71	667	4520
Sunda harbour	28 400	0.336	1.13	403	16.7	13.6	80.4	628	-
TOTAL	**47 500**	**0.576**	**1.90**	**659**	**28.7**	**20.3**	**103**	**1486**	**4520**

Further details on emissions per ship type in the different harbour areas are presented in Table 10 (Akranes harbour), Table 12 (Grundartangi harbour), Table 14 (Old harbour), and Table 16 (Sunda harbour). The emissions from each harbour area are accounted for in separate tables, Table 11 (Akranes harbour), Table 13 (Grundartangi harbour), Table 15 (Old harbour), and Table 17 (Sunda harbour). These values are adjusted from the values reported in reports in U 5817 (2016) and U 5953 (2017), for alignment of assumptions in the calculation, between the years.

Table 10. Akranes harbour - emissions from different ship types 2018 and the number of calls.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	163	0.00214	0.00679	2.30	0.108	0.0600	0.233	11
Container ships	-	-	-	-	-	-	-	-
Cruise ships	31.2	0.000375	0.00127	0.462	0.0188	0.0149	0.0946	1
Oil- and chemical tankers*	1.91	2.46E-05	7.96E-05	0.0295	0.00124	0.000986	0.00652	(-)
RoRo vessels/Ferries	-	-	-	-	-	-	-	-
General cargo ships	49.5	0.000678	0.00213	0.803	0.0343	0.0177	0.0618	7
CRUISE AND CARGO SHIPS	**245**	**0.00322**	**0.0103**	**3.60**	**0.162**	**0.0936**	**0.396**	**19**
OTHER SHIPS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
FISHING VESSELS	**778**	**0.00986**	**0.0312**	**8.62**	**0.491**	**0.219**	**0.126**	**15**
WHALE WATCHING BOATS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
TOTAL 2018	**1 020**	**0.0131**	**0.0415**	**12.2**	**0.653**	**0.313**	**0.523**	**34**

* One call by a chemical tanker during a shifting operation is not accounted for in the ship call column.

Table 11. Emissions from ships calling Akranes harbour 2016, 2017 and 2018, and the number of calls.

Year	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
2018	1 020	0.0131	0.0415	12.2	0.653	0.313	0.523	34
2017	2 600	0.0328	0.104	28.7	1.63	0.717	0.813	45
2016	2 090	0.0273	0.0860	29.1	1.37	0.601	1.13	32

Table 12. Grundartangi harbour – emissions from different ship types 2018.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	1 950	0.0240	0.0754	22.2	1.18	0.635	2.05	20
Container ships	2 470	0.0321	0.100	36.7	1.60	1.59	8.87	37
Cruise ships	-	-	-	-	-	-	-	-
Oil- and chemical tankers	-	-	-	-	-	-	-	-
RoRo vessels/Ferries	-	-	-	-	-	-	-	-
General cargo ships	1 000	0.0136	0.0428	14.1	0.687	0.387	1.34	100
CRUISE AND CARGO SHIPS	**5 420**	**0.0696**	**0.219**	**73.0**	**3.47**	**2.61**	**12.2**	**157**
OTHER SHIPS	-	-	-	-	-	-	-	-
FISHING VESSELS	-	-	-	-	-	-	-	-
WHALE WATCHING BOATS	-	-	-	-	-	-	-	-
TOTAL 2018	**5 420**	**0.0696**	**0.219**	**73.0**	**3.47**	**2.61**	**12.2**	**157**

Table 13. Emissions from ships calling Grundartangi harbour 2016, 2017 and 2018, and the number of calls.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
2018	5 420	0.0696	0.219	73.0	3.47	2.61	12.2	157
2017	5 260	0.0677	0.212	72.9	3.38	2.61	11.0	188
2016	4 150	0.0541	0.169	59.8	2.71	2.29	9.90	251

Table 14. Old harbour – emissions from different ship types 2018.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	-	-	-	-	-	-	-	-
Container ships	86.7	0.00104	0.00348	1.26	0.0521	0.0580	0.437	6
Cruise ships	1 970	0.0262	0.0830	30.8	1.32	0.670	2.73	62
Oil- and chemical tankers	949	0.0115	0.0370	12.5	0.567	0.394	1.47	112
RoRo vessels/ Ferries	63.2	0.000815	0.00260	0.940	0.0408	0.0244	0.125	4
General cargo ship	21.4	0.000287	0.000916	0.322	0.0145	0.00947	0.0535	5
CRUISE AND CARGO SHIPS	**3 090**	**0.0398**	**0.127**	**45.8**	**1.99**	**1.155**	**4.81**	**189**
OTHER SHIPS	**1 290**	**0.0100**	**0.0361**	**10.4**	**0.443**	**0.244**	**0.809**	**110**
FISHING VESSELS	**7 480**	**0.0975**	**0.308**	**103**	**4.88**	**2.12**	**3.58**	**368**
WHALE WATCHING BOATS	**811**	**0.00963**	**0.0350**	**11.2**	**0.490**	**0.226**	**0.509**	**4520**
TOTAL 2018	**12 700**	**0.157**	**0.506**	**170**	**7.81**	**3.75**	**9.71**	**5187**

Table 15. Emissions from ships calling Old harbour 2016, 2017 and 2018, and the number of calls.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls (cargo, & cruise, fishing and "other")**	**Ship calls (whale watching boats)**
2018	12 700	0.157	0.506	170	7.81	3.75	9.71	776	5635
2017	10 200	0.144	0.401	140	6.14	3.07	9.95	658	5542
2016	10 400	0.126	0.407	143	6.26	3.04	8.82	667	4520

Table 16. Sunda harbour – emissions from different ship types 2018.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	54.4	0.000700	0.00220	0.766	0.0349	0.0197	0.0733	2
Container ships	11 800	0.149	0.477	170	7.46	6.65	39.9	263
Cruise ships	12 300	0.132	0.476	173	6.53	5.34	33.6	83
Oil- and chemical tankers	125	0.00155	0.00502	1.54	0.0774	0.0591	0.353	9
RoRo vessels/Ferries	11.9	0.000146	0.000481	0.165	0.00729	0.00714	0.0530	1
General cargo ships	1 330	0.0176	0.0566	20.0	0.890	0.669	4.00	161
CRUISE AND CARGO SHIPS	**25 600**	**0.301**	**1.02**	**366**	**15.0**	**12.7**	**78.0**	**519**
OTHER SHIPS*	**817**	**0.00982**	**0.0325**	**11.4**	**0.488**	**0.212**	**0.514**	**31**
FISHING VESSELS	**1 970**	**0.0252**	**0.0804**	**26.5**	**1.26**	**0.681**	**1.87**	**78**
WHALE WATCHING BOATS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
TOTAL 2018	**28 400**	**0.336**	**1.13**	**403**	**16.7**	**13.6**	**80.4**	**628**

Table 17. Emissions from ships calling Sunda harbour 2016, 2017 and 2018, and the number of calls.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
2018	28 400	0.336	1.13	403	16.7	13.6	80.4	628
2017	26 200	0.312	1.05	373	15.5	12.6	68.5	626
2016	21 300	0.258	0.855	311	12.8	10.2	53.3	442

The values presented in the tables are given three digits of significance. This is to avoid misunderstandings related to rounding of results and we recommend using only two digits of significance in communication of the results.

5 Discussion

Total emissions from ships visiting Faxaflóahafnir in 2018 increased from 2017. The increase was around 7% for most emitted substances, and higher for sulphur dioxide. The emissions in 2017 and 2018 were both significantly higher than in 2016. The traffic to the port has included around 1500 calls by larger vessels per year in 2016, 2017 and 2018 and the change in emission between the years cannot be directly related to a traffic increase. The calculations suggest the increase in emissions is mainly related to emissions from ships at berth. The calculated total increase of CO_2 emissions 2017 to 2018 is 3200 tonnes and the increase in CO_2 emissions from ships at berth only is

2400 ton. Cruise ships at berth alone contribute to an increase of 2000 tonnes between 2017 and 2018. The average time at berth per ship call has increased for cruise ships and for containerships, the two ship types that causes most emissions in the port.

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 around 60 tonnes/call in 2016 and 2017 but decreases significantly to 30 tonnes/call in 2018;
- in Grundartangi, the average CO_2 emissions per call doubled from 2016 to 2018, 17 tonnes/call in 2016 and 35 tonnes per call in 2018. In 2017 the emissions of CO_2 per call was 28 tonnes;
- in Old harbour the average values are around 2 tonnes /call for all years. This is considerably lower than in the other areas of the port due to frequent visits of whale watching boats;
- and that emissions in Sunda harbour are 48, 42 and 45 for the years 2016, 2017 and 2018, respectively.

These comparisons are most relevant to make for Sunda harbour and Old harbour which each year receives a high number of calls. These harbour areas are less sensitive to single calls that cause very high emissions that may influence the results significantly. No large variations in CO_2 emissions per call have been found over the three years for these two harbour areas.

The traffic, calculated as number of calls to and from the port, was reduced by approximately 15% between 2017 and 2018. This is almost exclusively related to the traffic of whale watching boats. Ship types other than the whale watching boats were reduced by 2%. Minor changes include an increase in number of calls by container and cruise ships and reduced number of calls by fishing vessels. The total emissions are little affected by the traffic of whale watching boats. There were emission increases in all harbour areas except Akranes in 2018.

A notable difference from 2017 to 2018 is the increase in SO_2 emissions which is high relative to the increase in CO_2 emissions. This is a sign of increased sulphur contents in the fuels used by the visiting ships. An explanation for this is that the ESI lists for 2016 and 2017 included many of the visiting containerships. These ships were listed as using fuel with sulphur contents lower than 2.7%, which is used as the generic value on fuel sulphur content of residual oil in our calculations. Although the same ships visit the port in 2018, they are no longer occurring in the ESI list for 2018. Consequently, average fuel sulphur content of the visiting ships is estimated to have increased. Even though this only concerns a handful of ships their frequent visits to Faxaflóahafnir and their large power requirement make them contribute a relatively high share of the total emissions.

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. The use of generic values 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. This makes the model unsuitable for analysis of emissions from individual ships or small groups of ships.

Emissions from two ship categories rely on other assumptions than the rest. These are the fishing vessels and the whale watching boats, contributing 22% 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 has 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 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 since the engine types are not known. Often the fishing vessels connect to shore side power when at berth, which also reduces uncertainty in these results. 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.

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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	1.83	1.83		Berth	Whale
1002	Whale 2	6.00	3.44	3.44		Berth	Whale

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	Ref.
HSD	MD	717	0.008	0.031	9.6	0,4	Cooper and Gustavsson, 2004
MSD	MD	717	0.008	0.031	10.6	0,4	Cooper and Gustavsson, 2004
SSD	MD	647	0.012	0.031	13.6	0,6	Cooper and Gustavsson, 2004
HSD	RO	752	0.008	0.031	10.2	0.4	Cooper and Gustavsson, 2004
MSD	RO	752	0.008	0.031	11.2	0.4	Cooper and Gustavsson, 2004
SSD	RO	682	0.012	0.031	14.5	0.6	Cooper and Gustavsson, 2004

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	Ref.
HSD	MD	690	0.01	0.031	11.8	0.5	Cooper and Gustavsson, 2004

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 destillate oil
RO – Residual oil

The carbon in 1 kg fuel cause 3,179 kg **CO_2** (Cooper och Gustafsson, 2004).

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.

Particle emissions are determined based on the used fuel type and its sulphur content from a statistical analysis of multiple references:

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%:

HSD/MSD/SSD: 0.2 g/kWh

Used references for calculating particle mass emission factors:

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- Zetterdahl, M., 2016. Particle Emissions from Ships

Emission factors for **boilers** in g/tonne fuel:

Fuel	NO_x	PM	HC	CH_4	N_2O
MD	2900	290	36	7.4	37

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

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 sulfur content in the Heavy Fuel Oil is reduced. The following equation describes how the sulfur 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).

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

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):

Name_of_Ship	IMO_No	ShipType	NOx (g/kWh)	Sulfur content RO (%)	Sulfur content MD (%)
ADONIA	9210220	Cruise DE	12.0	0.01	
ARCADIA	9226906	Cruise DE	9.7	0.05	0.0009
ARION	9177868	General cargo	11.5	0.03	
ARKLOW MANOR	9440241	General cargo	12.0	0.02	
ARKLOW MARSH	9440253	General cargo	12.0	0.01	
ARKLOW MEADOW	9440277	General cargo	12.0	0.05	0.0009
ARKLOW MILL	9440265	General cargo	12.0	0.01	
AURORA	9169524	Cruise DE	12.9	0.05	0.0009
AZURA	9424883	Cruise DE	12.6	0.05	0.0010
BALTICA HAV	8215728	General cargo	12.4	0.05	0.0004
BERIT	9156187	General cargo	11.8	0.05	0.0008
COSTA MEDITERRANEA	9237345	Cruise DE	11.3	0.01	
CRYSTAL SYMPHONY	9066667	Cruise DE	12.9	0.05	0.0008
DELIA	9234317	General cargo	11.5	0.03	
EUROPA 2	9616230	Cruise DE	10.5	0.01	
FEDERAL DANUBE	9271511	Bulk carrier	13.9	0.01	
FEHN LUNA	9130212	General cargo	11.5	0.03	
FERRO	9005730	General cargo	13.3	0.03	
FRI BREVIK	9190183	General cargo	12.0	0.05	0.0006
FRI KVAM	9211078	General cargo	12.0	0.05	0.0008
FRI LAKE	9195664	General cargo	11.3	0.05	0.0008
FRI OCEAN	9195690	General cargo	11.3	0.05	0.0005
FRI PORSGRUNN	9196199	General cargo	12.0	0.05	0.0008
FRI SEA	9229166	General cargo	11.3	0.05	0.0007
FRI SKIEN	9148192	General cargo	12.1	0.05	0.0009
FRI TIDE	9195676	General cargo	11.3	0.05	0.0008
FRI WAVE	8915627	General cargo	12.0	0.05	0.0008
FURE WEST	9301873	Chemical tanker	4.4	0.05	0.0005
HESTIA	9177894	General cargo	11.5	0.05	0.0009
JUMBO	8518297	General cargo	13.3	0.05	0.0009
KINE	9145140	General cargo	11.5	0.05	0.0008
KRISTIN D	9163582	General cargo	11.5	0.05	0.0008
MARINUS	9232840	Chemical tanker	10.7	0.02	
MSC MERAVIGLIA	9760512	Cruise DE	10.0	0.05	0.0010
MSC ORCHESTRA	9320099	Cruise DE	12.0	0.05	0.0009
MSC SPLENDIDA	9359806	Cruise DE	12.7	0.01	
NEPTUNUS	9410519	Chemical tanker	10.7	0.02	
NESTOR	9234305	General cargo	11.5	0.05	0.0007

NINA	9156199	General cargo	11.8	0.05	0.0009
NORD SYDNEY	9577886	Bulk carrier	14.2	0.05	0.0008
NORWEGIAN JADE	9304057	Cruise DE	11.1	0.05	0.0009
NORWEGIAN STAR	9195157	Cruise DE	11.8	0.01	
OCCITAN KEY	9302475	Bulk carrier	15.3	0.02	
OCCITAN SKY	9274355	Bulk carrier	11.8	0.05	0.0010
OPDR TANGER	9389306	Container ship	13.0	0.02	
ORIANA	9050137	Cruise DM	13.4	0.01	
ORIENT TRANSIT	9467598	Bulk carrier	14.8	0.02	
PATRONA I	9305178	Chemical tanker	11.0	0.02	
PLATO	8822636	General cargo	13.3	0.05	0.0009
PLUTO	8518340	General cargo	13.3	0.05	0.0009
PORT ALBERNI	9335886	Bulk carrier	16.4	0.05	0.0010
QUEEN ELIZABETH	9477438	Cruise DE	12.0	0.02	
QUEEN VICTORIA	9320556	Cruise DE	10.8	0.05	0.0009
STEN BERGEN	9407988	Chemical tanker	12.1	0.01	
STEN IDUN	9261102	Chemical tanker	13.0	0.01	
STENBERG	9283978	Chemical tanker	13.0	0.01	
STENHEIM	9261114	Chemical tanker	13.0	0.05	0.0009
TERNVIND	9425356	Chemical tanker	10.5	0.01	
THEBE	9199696	General cargo	11.5	0.03	
THESEUS	9199256	General cargo	11.5	0.05	0.0008
TINNO	8908806	General cargo	13.3	0.05	0.0009
UBC CARTAGENA	9448281	Bulk carrier	8.6	0.01	
UBC CORK	9448279	Bulk carrier	8.3	0.02	
WILSON ALGECIRAS	9507350	General cargo	11.2	0.01	
WILSON ALICANTE	9507374	General cargo	10.4	0.02	
WILSON ALMERIA	9507362	General cargo	10.4	0.03	
WILSON AMSTERDAM	9313735	General cargo	11.3	0.01	
WILSON ASTAKOS	9313759	General cargo	10.4	0.01	
WILSON AVILES	9313709	General cargo	10.4	0.02	
WILSON AVONMOUTH	9313747	General cargo	10.4	0.01	
WILSON BERGEN	9557408	General cargo	8.9	0.05	0.0008
WILSON BILBAO	9014705	General cargo	11.5	0.05	0.0008
WILSON BORG	9106924	General cargo	11.5	0.03	
WILSON BRAKE	9150511	General cargo	11.5	0.05	0.0009
WILSON BREST	9126900	General cargo	11.5	0.02	
WILSON CADIZ	9192612	General cargo	12.5	0.01	
WILSON CAEN	9173290	General cargo	12.5	0.02	
WILSON CALAIS	9156101	General cargo	12.5	0.05	0.0009
WILSON CLYDE	9178458	General cargo	12.5	0.02	
WILSON DALE	9462500	General cargo	9.4	0.05	0.0009
WILSON DALVIK	9536064	General cargo	9.4	0.03	
WILSON DOVER	9005754	General cargo	11.9	0.05	0.0008
WILSON DUNDEE	9390159	General cargo	9.2	0.01	
WILSON DVINA	9005742	General cargo	11.9	0.05	0.0009
WILSON GAETA	9171096	General cargo	11.5	0.05	0.0008
WILSON GARSTON	9000833	General cargo	12.5	0.03	
WILSON GDANSK	9056026	General cargo	11.9	0.03	
WILSON GDYNIA	9056064	General cargo	12.0	0.05	0.0009
WILSON GHENT	9150236	General cargo	11.5	0.05	0.0007
WILSON GIJON	9056038	General cargo	11.9	0.03	
WILSON GOOLE	9126687	General cargo	11.5	0.05	0.0009
WILSON GRIMSBY	9056040	General cargo	11.9	0.05	0.0007
WILSON HALMSTAD	9576703	General cargo	9.1	0.03	
WILSON HARRIER	9064891	General cargo	12.5	0.02	

WILSON HELSINKI	9518402	General cargo	11.5	0.03	
WILSON HERON	9116022	General cargo	12.5	0.02	
WILSON HOLLA	9229130	General cargo	12.0	0.01	
WILSON HOOK	9017434	General cargo	12.5	0.01	
WILSON HORSENS	9518426	General cargo	9.0	0.03	
WILSON HUELVA	9518414	General cargo	9.4	0.03	
WILSON HUMBER	9017381	General cargo	12.5	0.02	
WILSON HUSUM	9017379	Bulk carrier	12.5	0.05	0.0010
WILSON LAHN	9198458	General cargo	11.5	0.05	0.0008
WILSON LEER	9150482	General cargo	11.5	0.03	
WILSON MAIN	8913485	General cargo	12.2	0.03	
WILSON MALM	7810210	General cargo	12.7	0.01	
WILSON MERSIN	7810222	General cargo	12.7	0.01	
WILSON NEWPORT	9430985	General cargo	9.5	0.05	0.0009
WILSON NICE	9430959	General cargo	9.9	0.01	
WILSON NORFOLK	9430997	General cargo	9.5	0.02	
WILSON NORTH	9430947	General cargo	10.8	0.01	
WILSON ODRA	9177882	General cargo	11.5	0.05	0.0009
WILSON REEF	7382665	Bulk carrier	12.0	0.01	
WILSON RYE	7382677	Bulk carrier	12.0	0.01	
WILSON SAGA	8918461	General cargo	11.9	0.01	
WILSON SKY	9017393	General cargo	12.0	0.03	
WILSON STADT	8918485	General cargo	12.0	0.01	
WILSON SUND	8918473	General cargo	11.9	0.01	
WILSON TEES	9150535	General cargo	11.5	0.03	
WILSON TRENT	7926095	General cargo	15.2	0.01	
WILSON VARNA	9534274	General cargo	9.9	0.01	
ZEUS	9199684	General cargo	11.5	0.02	

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