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Emissions from ships in Faxaflóahafnir 2016

Commissioned by Faxaflóahafnir

Hulda Winnes, Rasmus Parsmo

Author: Hulda Winnes, Rasmus Parsmo
Commissioned by: Faxaflóahafnir
Photographer: Click and add text
Report number: U 5817

IVL Swedish Environmental Research Institute Ltd.,
P.O Box 210 60, S-100 31 Stockholm, Sweden
Phone +46-(0)10-788 65 00 // www.ivl.se

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 2016. 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 2016 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 2016	**45 000**	**510**	**1 800**	**680 000**	**25 000**	**24 000**	**21 000**	**130 000**

Cruise and cargo ships together account for the largest share of emissions, 62% or more depending on substance, but only 11% of the calls. Fishing vessels, and also whale watching boats, contribute significantly to the total emissions, though considerably less than the cruise and cargo ships. Their contribution to emissions of SO_2 in the port area is however not as significant due to use of low sulphur fuel and shore side electricity. Whale watching boats are different in character compared to the other vessels in the study with typically relatively small engines and frequent traffic to the port. These boats accounted for 5 607 calls of the total 7 108 calls to the port in 2016.

Sunda harbour is the harbour area that receives the majority of the larger cruise ships and a majority of emissions comes from ships calling Sunda. Sunda harbour has reduced emissions from the use of shore side electricity by ships at berth. However, the positive effect from shore side power supply is much more significant in Akranes harbour and Old harbour.

In a comparison with emissions from ships in other ports, CO_2 emissions from ships in Faxaflóahafnir prove well in line with the other. However, emissions of sulphur dioxide can be expected to be higher than for ports within sulphur emission control areas, SECAs, where regulations require significantly lower levels of sulphur in marine fuels than in the rest of the world.

Contents

1 Introduction

IVL Swedish Environmental Research Institute has on assignment of Faxaflóahafnir calculated emissions from ships visiting their ports in 2016. Faxaflóahafnir comprise 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.

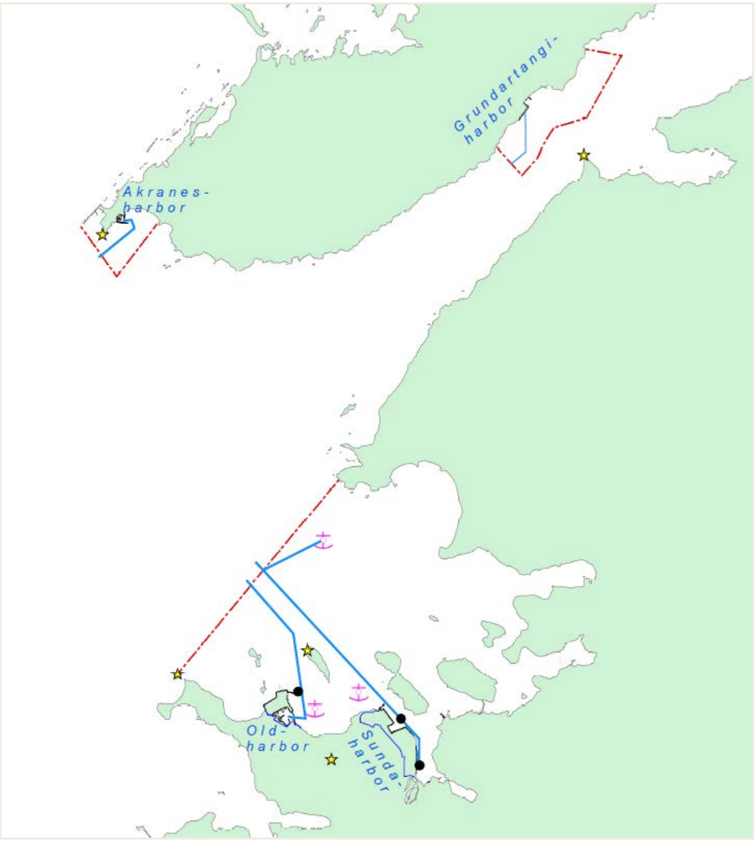

Figure 1. The four ports of Faxaflóahafnir and the areas off port included in the emission inventory.

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 in 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 351 larger vessels, making in total 1 501 unique port calls. It is common that ships are required to shift berth during their stay in a port. In 2016, there were 793 shifts between berths in Faxaflóahafnir. In addition to these calls, the port has a lot of traffic from whale watching boats. According to timetables, the 17 whale watching boats operating from Reykjavik went in and out of the harbour 5 607 times in 2016.

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 2016.

Ship type	Akranes harbour	Grundartangi harbour[4]	Sunda harbour Reykjavik[5]	Old harbour Reykjavik[6]	Total
	Number of calls/visits	Number of calls/visits	Number of calls/visits	Number of calls/visits	Number of calls
Dry bulk carrier	8	18	3		**29**
Container ship[1]		1	233	4	**238**
Cruise ship			62	40	**102**
Oil- and chemical tanker[2]			6	106	**112**
RoRo vessel/Ferry				8	**8**
General cargo ship	6	110	144	3	**263**
CRUISE AND CARGO SHIPS	**14**	**129**	**448**	**161**	**752**
OTHER SHIPS[3]			**30**	**114**	**144**
FISHING VESSELS	**22**		**70**	**513**	**605**
WHALE WATCHING BOATS				**5607**	**5607**
TOTAL	**36**	**129**	**548**	**6395**	**7108**

[1] Also include 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 Grundartangi-Biðsvædi

[5]Including anchoring at Kollafjörður and Viðeyjarsund

[6]Including anchoring Ytri höfn innan Engeyjar

For each of the four harbours an area has been identified within which emissions from ships are calculated. The 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 has 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 energy needs are lower for certain ship types.

The time in the *port basin* is estimated from the distance between a quay and the limit 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.

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.

3.1 Emission factors

All emission factors for marine engines that are 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 has 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.

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 have not been available, and for all ships from before that year emission factors that are representative for engines that do not use any NO_x abatement technology 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 fuel consumption and estimated sulphur content of the fuels used. We assume a sulphur content in heavy fuel oil of 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 1.6%. 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. For *manoeuvring*, we double the emission factors according to recommendations in Cooper and Gustavsson (2004).

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 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 specific 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 specific 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 92 ships visiting Faxaflóahafnir in 2016 that are listed in the ESI register. These 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 estimated from main engines, auxiliary engines and auxiliary boilers separately.

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

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 an absolute majority of installed main engine power on 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 ship main engines. If this information is not given in the database, an estimated 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.

Auxiliary engine power of fishing vessels are estimated as central values in a span of likely installed 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. Each category was assigned a typical range of installed main engine- and auxiliary engine power. We have matched the categories with the installed main engine power of fishing vessels in Faxaflóahafnir as 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 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	560 - 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 aux 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 provided by HB

Grandi we have made assumptions on utilization of auxiliary engine power as presented in Table 4.

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. 20 % 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. 30% 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. 30% 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 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 or loading operations. We assume that the tankers either off-load or load once during each call. Further, the amount of cargo on the tankers 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.

estimated to 95% of the ships' dead weight tonnage. Thus, for each tanker call, additional fuel consumption (in kg) according to equation (3) is assumed.

$$Fuel\ consumption = 0.95 * DWT * 0.13 \quad (3)$$

Fuels used in main engines during operations *in port basin*, and *manoeuvering* is assumed to be a heavy fuel oil with 2.7 % S, while fuel used in auxiliary engines is assumed to be marine distillate oil with 0.1 % S. More detailed information on the use of different fuel qualities of fishing vessels has been possible to include in the model after communication with HB Grandi (HB Grandi, 2017). HB Grandi is a large sea food company based in Reykjavík and owner of ten large fishing vessels. Large fishing vessels are thus assumed to use heavy fuel oil with a sulphur content of 1.6 % in main engines, and marine gasoil with 0.1 % sulphur in aux engines. Small fishing vessels are assumed to use marine gasoil with 0.1 % S, exclusively. All fishing boats in the HB Grandi fleet use diesel oil with an S-content, 0.001%. Further, whale watching boats are assumed to use only marine distillate oil.

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.

A size dependent generic value on fuel consumption in ship boilers have 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	10.1
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.

Fuel used in boilers is assumed to be marine distillate oil exclusively.

Results

Table 6 presents the emissions of the different substances per engine type and operational mode. 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.

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 70% of the total fuel consumption. Fuel consumption in main engines and auxiliary engines are comparable in size, even though main engines are in use considerably less time. Emissions of the climate gases CO_2, CH_4 and N_2O together cause emissions of CO_2 equivalents[3] of approximately 46 000, a value that is totally dominated by the emissions of CO_2.

Table 6. Overview of emissions from ships in Faxaflóahafnir 2016.

		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	10 800	98.3	486	192 000	5 010	12 500	10 700	98 000
	Manoeuvring	724	8.71	31.0	12 200	444	912	775	7 490
	At berth*	3 520	38.9	161	55 500	1 980	1 420	1 200	2 190
Auxiliary engines	In port basin	764	11.1	34.3	13 200	565	314	267	466
	At anchor*	98.2	1.42	4.41	1 620	72.6	38.1	32.4	59.7
	Manoeuvring	360	5.21	16.2	6 300	266	131	111	207
	At berth*	22 400	325	1 010	386 000	16 600	8 270	7 030	12 700
	Tankers at berth using cargo pumps	282	4.08	12.7	4 940	208	126	107	177
Boilers	In port basin	348	0.811	4.10	318	3.94	31.8	27.0	219
	At anchor*	22.5	0.0524	0.268	20.5	0.255	2.05	1.75	14.2
	Manoeuvring	67.7	0.158	0.816	61.8	0.767	6.18	5.25	42.6
	At berth*	5 740	13.4	66.8	5 240	65.0	524	445	3 610
TOTAL (engines and boilers)	Main engines	15 000	146	678	259 000	7 430	14 900	12 600	108 000
	Auxiliary engines	23 900	347	1 075	412 000	17 700	8 880	7 540	13 600
	Boilers	6 180	14.4	72.0	5 640	70.0	564	479	3 890
TOTAL (Operational modes)	In port basin	11 900	110	524	205 000	5 580	12 900	11 000	98 700
	At anchor*	121	1.48	4.68	1 640	72.8	40.2	34.1	73.9
	Manoeuvring	1 150	14.1	48.0	18 500	711	1 050	892	7 740
	At berth*	32 000	381	1 250	451 000	18 800	10 330	8 780	18 700
TOTAL	**All engines and boiler, all operational modes**	**45 000**	**510**	**1 800**	**680 000**	**25 000**	**24 000**	**21 000**	**130 000**

*Only cruise ships with diesel electric power trains

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

Faxaflóahafnir provide connections to shore side electricity in Akranes harbour, Old harbour and Sunda harbour, and many ships use a shore side power supply 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 of emissions at berth if no ships were to use on shore power minus the estimated actual emissions at berth. Approximately 4% - 5 % of emissions from ships at berth are estimated to be avoided by shore side electricity supply except for emissions of sulphur dioxide and particles which are avoided to a lesser extent. The avoided emissions are presented in Table 7 for the three harbour areas.

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	203	2.94	11.6	3 160	150	65.2	55.4	85.7
Old harbour	1 430	20.7	67.5	22 700	1 10	516	438	696
Sunda harbour	205	2.98	11.1	3 400	152	91.9	78.1	129
TOTAL	**1 800**	**27**	**90**	**29 000**	**1 400**	**670**	**570**	**910**

Cruise and cargo ships cause significantly higher emissions than the other categories of ships and boats and contribute approximately 64% of total fuel combustion. This category of ships also accounts for over 90 % of SO_2 emissions. The main contributing ship types are cruise ships and container ships, regardless of type of emission. Emissions and calls from the different ship types are presented in Table 8.

The fishing vessels are the third largest emitter of the studied ship types, comparable with container ships in emitted amounts with exception of emissions of SO_2 and particles. Many fishing vessels have high power needs at berth for cooling and off-loading of 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 2016.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO2 (kg)	Ship calls
Dry bulk carrier	1 440	18.3	57.3	19 900	910	888	754	3 540	**29**
Container ship	9 950	127	402	167 000	6330	6180	5 250	36 700	**238**
Cruise ship	13 700	138	512	176 000	6 730	8 780	7 460	58 400	**102**
Oil- and chemical tanker**	1 180	14.0	47.1	17 900	698	823	699	4 960	**112**
RoRo vessel/Ferry	242	3.12	10.3	3860	157	136	116	540	**8**
General cargo ship	2 510	30.8	109	41 100	1 560	1 690	1 440	9 230	**263**
CRUISE AND CARGO SHIPS	**29 000**	**331**	**1 140**	**426 000**	**16 400**	**18 500**	**15 700**	**113 000**	**752**
OTHER SHIPS	**1 950**	**15.3**	**59.9**	**19 300**	**689**	**576**	**490**	**1 220**	**144**
FISHING VESSELS	**9 920**	**131**	**436**	**155 000**	**6 630**	**3 270**	**2 780**	**7 870**	**605**
WHALE WATCHING BOATS	**4230**	**29.5**	**199**	**76 400**	**1 500**	**1 980**	**1 680**	**2 660**	**5 607**
TOTAL	**45 000**	**510**	**1 800**	**680 000**	**25 000**	**24 000**	**21 000**	**130 000**	**7108**

The different harbour areas in the port serve different ship types to some extent. 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 less than 500 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 2016.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO2 (kg)	Ship calls
Akranes harbour	1 870	26.5	83.3	28 500	1 350	630	540	1 140	36
Grundartangi harbour	3 680	47.2	150	57 600	2 360	1 800	1 530	7 150	129
Old harbour	14 100	148	594	219 000	7 400	5 690	4 830	15 600	6 395
Sunda harbour	25 500	285	998	371 000	14 100	16 200	13 800	101 000	548
TOTAL	**45 000**	**500**	**1 800**	**680 000**	**25 000**	**24 000**	**21 000**	**130 000**	**7 108**

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).

Table 10. Akranes harbour - emissions from different ship types 2016.

	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	101	1.24	4.29	1 130	62.3	54.6	46.4	203	8
Container ship	-	-	-	-	-	-	-	-	-
Cruise ship	-	-	-	-	-	-	-	-	-
Oil- and chemical tanker	-	-	-	-	-	-	-	-	-
RoRo vessel/Ferry	-	-	-	-	-	-	-	-	-
General cargo ship	21.2	0.262	0.920	303	13.2	13.9	11.8	68.5	6
CRUISE AND CARGO SHIPS	123	1.50	5.21	1 430	75.6	68.6	58.3	272	14
OTHER SHIPS	-	-	-	-	-	-	-	-	-
FISHING VESSELS	1740	25.0	78.0	27 100	1 270	562	477	8710	22
WHALE WATCHING BOATS	-	-	-	-	-	-	-	-	-
TOTAL	**1 900**	**26**	**83**	**29 000**	**1 300**	**630**	**540**	**1 100**	**36**

Table 11. Grundartangi harbour – emissions from different ship types 2016.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO2 (kg)	Ship calls
Dry bulk carrier	1 280	16.4	50.5	18 000	812	783	666	3 070	18
Container ship	1 430	18.2	57.3	23 500	904	542	461	2 200	1
Cruise ship	-	-	-	-	-	-	-	-	-
Oil- and chemical tanker	-	-	-	-	-	-	-	-	-
RoRo vessel/Ferry	-	-	-	-	-	-	-	-	-
General cargo ship	969	12.7	41.8	16 200	643	469	399	1 890	110
CRUISE AND CARGO SHIPS	3 680	47.2	150	57 600	2 360	1 800	1 520	7 150	129
OTHER SHIPS	-	-	-	-	-	-	-	-	-
FISHING VESSELS	-	-	-	-	-	-	-	-	-
WHALE WATCHING BOATS	-	-	-	-	-	-	-	-	-
TOTAL	**3 700**	**47**	**150**	**58 000**	**2 400**	**1 800**	**1 500**	**7 200**	**129**

Table 12. Old harbour – emissions from different ship types 2016.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO2 (kg)	Ship calls
Dry bulk carrier	-	-	-	-	-	-	-	-	-
Container ship	19.5	0.232	0.770	281	11.6	13.6	11.5	87.1	4
Cruise ship	1 200	14.7	47.5	17 300	729	657	559	3 130	40
Oil- and chemical tanker	1 100	13.2	43.8	16 800	658	755	641	4 510	106
RoRo vessel/Ferry	242	3.12	10.3	3 860	157	136	116	540	8
General cargo ship	20.3	0.234	0.877	321	11.8	15.4	13.1	90.2	3
CRUISE AND CARGO SHIPS	2 580	31.4	103	38 600	1 570	1 580	1 340	8 360	161
OTHER SHIPS	1 170	7.31	31.1	8 940	302	293	249	736	114
FISHING VESSELS	6 140	80.0	261	95 400	4 030	1 830	1 560	3 800	513
WHALE WATCHING BOATS	4 230	29.5	199	76 400	1500	1 980	1 680	2 660	5607
TOTAL	**14 000**	**150**	**590**	**220 000**	**7 400**	**5 700**	**4 800**	**16 000**	**6 395**

Table 13. Sunda harbour – emissions from different ship types 2016.

	CO_2 (ton)	CH_4 (kg)	N_2O (kg)	NO_x (kg)	HC (kg)	PM_{10} (kg)	$PM_{2.5}$ (kg)	SO2 (kg)	Ship calls
Dry bulk carrier	62.2	0.725	2.47	770	35.9	50	42.5	266	3
Container ship	8 500	108	344	144 000	5 420	5 620	4 780	34 500	233
Cruise ship	12 500	124	465	159 000	6 000	8 120	6 900	55 200	62
Oil- and chemical tanker	78.2	0.819	3.51	1 070	40.6	68.2	58.0	444	6
RoRo vessel/Ferry	-	-	-	-	-	-	-	-	-
General cargo ship	1500	17.6	64.9	24 200	888	1 190	1 010	7 180	144
CRUISE AND CARGO SHIPS	22 700	251	879	329 000	12 400	15 100	12 800	97 600	448
OTHER SHIPS*	781	8.00	28.9	10 300	387	283	241	491	30
FISHING VESSELS	2 040	26.2	89.6	32 100	1 330	871	741	3 200	70
WHALE WATCHING BOATS	-	-	-	-	-	-	-	-	-
TOTAL	**25 000**	**290**	**1 000**	**370 000**	**14 000**	**16 000**	**14 000**	**100 000**	**548**

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. Comparisons with a study of emissions of climate gases from ships in four different ports show that the CO_2 emissions per port call are well in line with those of the other ports; emissions in the harbour areas Old harbour, Sunda harbour, Grundartangi harbour, and Akranes harbour are 2, 46, 29, and 52 tonnes CO_2 per call respectively, which can be compared to Port of Gothenburg, the Port of Long Beach, the Port of Osaka and the Ports of Sydney with 25, 69, 8 and 70 tonnes per call, respectively (Styhre et al., 2016). If instead using CO_2 emissions per ship size as a benchmark value – i.e. comparing total CO_2 emissions per total deadweight tonnes or gross tonnage - emissions from ships in Faxaflóahafnir are well in line with or slightly higher than those estimated for the other four ports, for single ship types. However, emissions of sulphur dioxide can be expected to be higher than for ports within sulphur emission control areas, SECAs, where regulations require significantly lower levels of sulphur in marine fuels than in the rest of the world.

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, it is recommended that values should not be used not be are used with more than two significant figures. In the tables in this report values rounded to three significant figures are sometimes given in order to avoid that totals deviate 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 22% and 11% 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 very 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.

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IVL Swedish Environmental Research Institute Ltd.
P.O. Box 210 60 // S-100 31 Stockholm // Sweden
Phone +46-(0)10-7886500 // www.ivl.se