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Emissions from ships in Faxaflóahafnir 2020

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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

In this study we calculate the emissions to air from ships in Faxaflóahafnir 2020. 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. The results are compared to the emissions calculated for 2016, 2017, 2018, and 2019.

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 2020 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 2020	**42 700**	**0.70**	**1.7**	**577**	**27**	**15**	**31**

Previous years container ships and cruise ships were the two ship categories that accounted for the largest shares of emissions in the port. Each of them usually contributes approximately 30% of the total emissions of CO_2 from the ships visiting Faxaflóahafnir. But in 2020, cruise ships were responsible only for 2% of the total CO_2 emissions, while container ships accounted for the 52%. The average amount of emissions per call by cruise ships are higher than from other vessels.

In 2020, the fishing vessels constituted the second largest contributing ship type category in the port since cruise ships calls during 2020 were few. In 2020, the fishing vessels accounted for approximately 32% of the CO_2 emissions in the port. The frequent traffic to the port of whale watching boats (5 542 calls only in 2019) has also decreased considerably to only 1 773 in 2020. But since these vessels in general have relatively small engines, their contribution to the total CO_2 is calculated to be only around 1.6% for 2019 and 0.8% in 2020.

Sunda harbour and Old harbour receive significantly more ship calls than Akranes and Grundartangi. Sunda harbour is the harbour area that receives most container ships (3 896 in 2020) while Old harbour has received the most amount of visiting cruise ships (7). Ships calling Sunda harbour are responsible for more than half of the emissions to air in Faxaflóahafnir, regardless the type of emission. Ships in Sunda harbour and Old harbour account for approximately 25 000 and 11 600 tonnes of the total CO_2 emissions, respectively.

In a comparison with CO_2 emissions from ships in the port in 2019, there is a net decrease. The substantial difference can mainly be attributed to the stagnating effect of the Covid-19 pandemic during 2020. This breaks the trend of increasing emissions, that has been registered since 2017. Overall, CO_2 emissions from ships and boats in the harbour decreased with 32% from 2019. Year 2020 is therefore not representative as Faxaflóahafnir's typical emissions inventory result. The decreased emissions of other pollutants, beside CO_2, are partially due also to an update of the emission factor used to calculate PM, SO_2 and HC.

1 Introduction

IVL Swedish Environmental Research Institute has on assignment of Faxaflóahafnir calculated emissions from ships visiting its ports in 2020. 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.

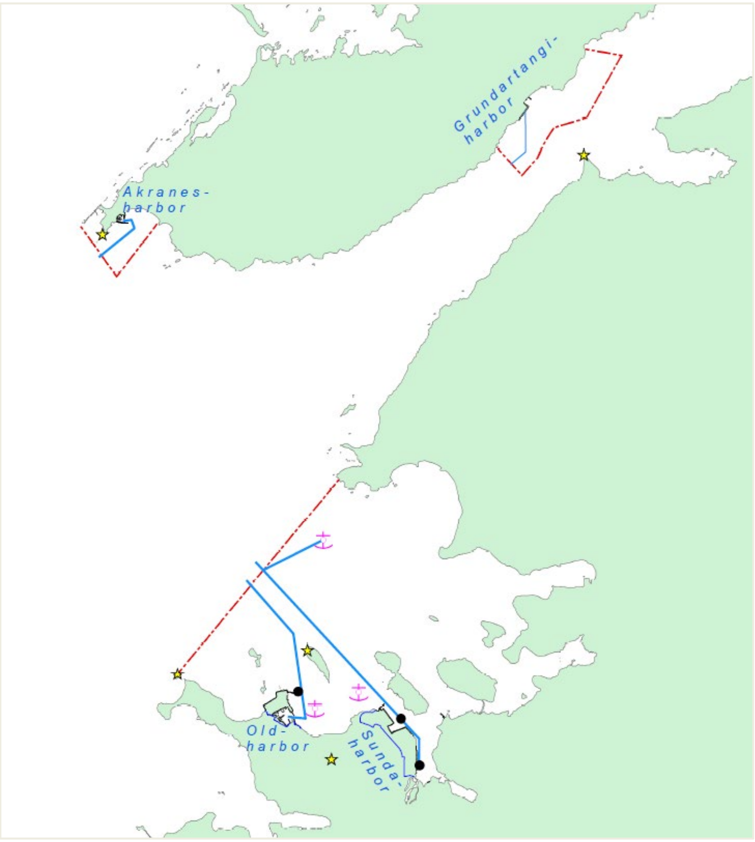

Figure 1. The four ports of Faxaflóahafnir and the areas outside the ports included in the emission inventory.

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, 2017, 2018, and 2019. Due to the new sulphur directive that entered into force in 2020 the emission factors for PM, SO_2, and HC have been updated compared to previous emission inventories. This resulted in a major difference in the results for these emissions, see Chapter 4. Earlier the average sulphur in the fuel used in the port area was assumed to be about 2.7 %, however according to the new regulation ship are only allowed to use fuel with a sulphur content of 0.5 % or using scrubbers.

2 Ship traffic

In total, this inventory covers 2 816 port calls comprising in total 1 043 larger vessels. In addition to these calls, the port received 1 773 calls from whale watching boats in 2020, which is considerably lower compared to 6 138 in 2019. These are all included in the inventory.

The ship traffic to the different harbours in Faxaflóahafnir comprises 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. An exception are cruise ships with diesel electric power trains that provides auxiliary power from the main engines. 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. For parts of our analysis we assign a specific berth to each call. An update to the previous inventories is that we, in such cases, designate the latest berth of visit as the berth of the call. This is a change applied since 2019 and may have a minor effect on the average ratios of emissions per call.

Whale watching boats are 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.

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

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

The emission factors for marine engines used in this report are presented in Appendix 2. 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. Fishing vessels are assumed to use different qualities of fuel, depending mainly on vessel size, with fuel sulphur content varying from 0.001% to 0.5% S. Whale watching boats are assumed to use only marine gasoil with an estimated sulphur content of 0.1%. For the ships using scrubbers we have assumed the reduction to correspond to an average sulphur content of 0.5 %.

The emission factors for particles (PM) are to certain extent dependent on the sulphur content of the fuel. A literature review of emission measurement results shows no clear relationship between fuel sulphur content and particle emissions at low sulphur content (>0.1 %), and, further, that a dependence on engine load is uncertain, we here only make a distinction between PM emission factors for fuels that have an assumed sulphur content of >0.1 %, such as Ultra-Low Sulphur Fuel Oil (ULSFO)/MGO and fuels that have an assumed sulphur content of >0.5 % (such as Very-Low Sulphur Fuel (VLSFO) or ships using scrubbers). 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 25 ships visiting Faxaflóahafnir in 2020 that were matched to the ESI register. The ESI register that we use for this inventory is valid for 2020. The ships in the ESI register are presented in Appendix 3 together with the scores used to calculate their emission factors for 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. 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, 2020). *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. The estimated power requirements for the categories are presented in Table 1.

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 is 3 tonnes/day at off-loading. An off-loading operation for 14 000 tonnes oil requires about 15 hours. Based on this information a generic value of 0.13 kg fuel/tonne cargo has been calculated and is used for all tanker ships at off-loading operations. Further, the amount of cargo on the tankers is estimated to 42% of the ships' dead weight tonnage. The value is based on a study made

[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.

for Port of Gothenburg in 2017. Thus, for each tanker call, additional fuel consumption (in kg) according to equation (2) is assumed.

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

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 VLSFO or heavy fuel oil for ships that have a scrubber installed, 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 assuming a fuel sulphur content of 0.5% 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. Auxiliary engines are the dominant source for all the emissions.

Emissions of SO_2 are directly related to the sulphur content in the fuel except for the ships with scrubbers. Even though most of the fuel is consumed in the auxiliary engines, SO_2 emissions from main engines are relatively higher than from auxiliary engines, since it is assumed that main engines run on high sulphur fuel to a large extent. Further, main engines are almost exclusively used for propulsion which is the reason to the relative importance of the emissions from the *in-port basin* operational mode. An exception are the diesel electric driven cruise ships which use their main engines also *at berth*, but then exclusively with low sulphur fuel or using aftertreatment.

CO_2 emissions are directly related to the fuel consumption and CO_2 emission are therefore a good proxy to use for fuel consumption in the analysis. In a comparison between the different operational modes the operations *at berth* can be attributed approximately 84% of the total fuel consumption. The fuel consumption in auxiliary engines is calculated to be 77% of the total fuel consumed in 2020 by all the three engine types. Emissions of the greenhouse gases CO_2, CH_4 and N_2O together cause emissions of CO_2 equivalents[2] of 43 200 tonnes, a value that is 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 2020.

		CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)
Main Engines	In port basin	2 940	0.178	0.128	57.2	2.07	2.99	9.02
	At anchor*	147	0.00164	0.00635	1.75	0.0836	0.0451	0.0924
	Manoeuvring	524	0.0298	0.0226	9.60	0.353	0.461	1.58
	At berth*	275	0.00306	0.0119	3.30	0.156	0.0843	0.173
Auxiliary Engines	In port basin	1 110	0.0161	0.0500	16.7	0.823	0.36	0.671
	At anchor*	570	0.00826	0.0256	9.39	0.421	0.18	0.359
	Manoeuvring	242	0.00350	0.0109	3.65	0.179	0.0771	0.140
	At berth*	30 900	0.447	1.39	469	22.8	9.84	15.6
	Tankers at berth using cargo pumps	110	0.00159	0.00493	1.19	0.0811	0.0350	0.0691
Boilers	In port basin	197	0.000459	0.00229	0.180	0.00223	0.0180	0.124
	At anchor*	110	0.000257	0.00128	0.101	0.00125	0.0101	0.0694
	Manoeuvring	32	0.000074	0.000371	0.0291	0.000361	0.00291	0.0200
	At berth*	5 600	0.0130	0.065	5.10	0.0633	0.510	3.52
TOTAL (Engines and boilers)	Main engines	3 890	0.213	0.169	71.9	2.67	3.58	10.9
	Auxiliary engines	32 900	0.477	1.478	500	24.3	10.5	16.8
	Boilers	5 930	0.0138	0.069	5.4	0.0672	0.541	3.73
TOTAL (Operational modes)	In port basin	4 250	0.1950	0.180	74.2	2.90	3.36	9.81
	At anchor*	827	0.0102	0.0332	11.2	0.506	0.237	0.520
	Manoeuvring	798	0.0333	0.0338	13.3	0.532	0.541	1.74
	At berth*	36 830	0.465	1.47	479	23.1	10.5	19.3
TOTAL	**All engines and boilers, all operational modes**	42 700	0.703	1.72	577	27.0	14.6	31.4

*Only cruise ships with diesel electric power trains

**Include emissions from ships in ship yard

In Table 6 the emissions from 2016, 2017, 2018, and 2019 are presented together with emissions in 2020. The values presented for previous years in report U 5817 (Winnes and Parsmo 2017), report U 5953 (Parsmo and Winnes, 2018) report U6107 (Parsmo and Winnes 2019), and report U 6261 (Merelli, Parsmo and Winnes 2020) emissions of SO_2 and particles are slightly corrected since 2019 due to methodological change….

Table 6. Emissions from ships visiting Faxaflóahafnir 2016, 2017, 2018, 2019, and 2020 and number of calls.

Year	CO2	CH4	N2O	NOX	HC	PM	SO2	Ship calls
2020	42 700	0.703	1.72	577	27.0	14.6	31.4	2 816
2019	56 300	0.690	2.25	788	33.9	24.3	116	7 136
2018	47 200	0.572	1.89	655	28.5	20.2	95.4	7 059
2017	43 900	0.550	1.74	608	26.4	18.9	89.2	6 006
2016	37 800	0.463	1.51	541	23.1	16.1	70.5	6 955

As shown in Table 6., the decrease in CO_2 emissions is mainly due to a decrease of about 60% of the of port calls in 2020 compared to 2019. There reason that the emissions have not decreased more is that most the ships segments with decreased number of calls are small, and furthermore, a large proportion of these small vessels are whale watching boats.

In Figure 2., this is exemplified by presenting the CO_2 emissions from different ship types in 2016, 2017, 2018, 2019 and 2020. Emission from container ships have substantially increased in 2020. This is because larger ships have visited the harbour. Cruise ships emission underwent a dramatic decrease in 2020 which probably is a consequence of the Covid-19 pandemic. For the same reason, but with lower intensity, also CO_2 emissions from many other ship types have decreased. Fishing vessels seem to have increased their emissions in 2020.

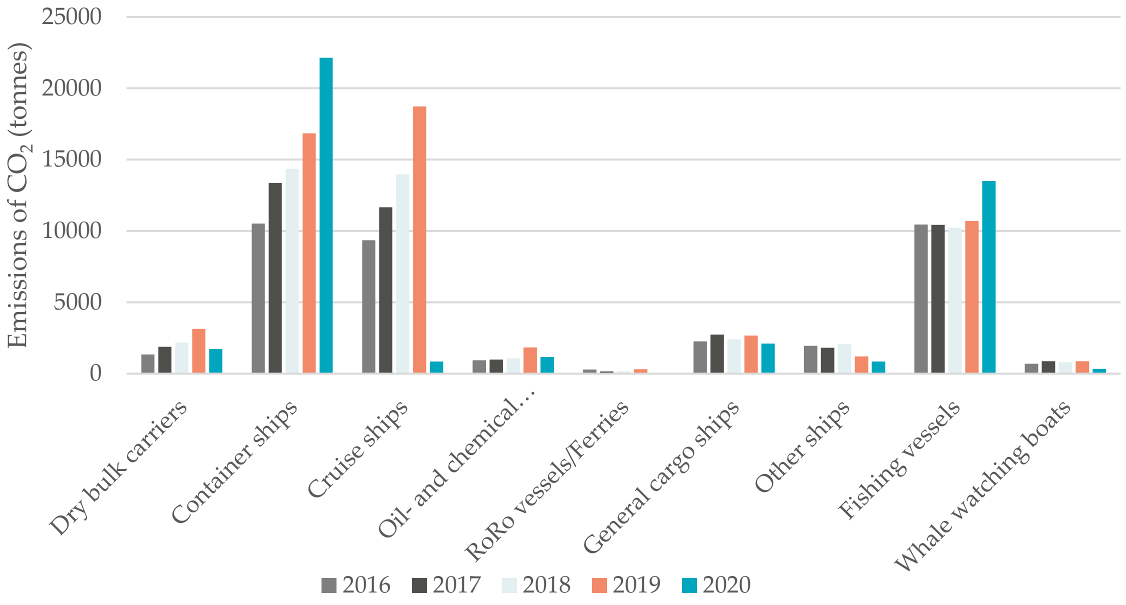

Figure 2. CO_2 emissions from different ship types 2016, 2017, 2018, 2019, and 2020.

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 onboard 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 shore side power and the calculated actual emissions at berth. Approximately 2% of emissions from ships at berth are avoided in this respect. This is the same range as the previous years. 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 2020.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)
Akranes Harbour	0	0	0	0	0	0	0
Old harbour	750	0.0108	0.0336	10.8	0.553	0.238	0.397
Sunda harbour	100	0.0015	0.0047	1.3	0.078	0.034	0.002
TOTAL	**850**	**0.0124**	**0.0383**	**12.2**	**0.630**	**0.272**	**0.400**

Cargo ships cause significantly higher emissions than the other categories of vessels and contribute with approximately 63% of the total fuel combustion in 2020. These categories of ships also account for approximately 77% of the SO_2 emissions. Of the cargo ships, container ships caused the most emissions in 2020. Further, container ships have significantly higher impact on total SO_2 emissions than any other ship type. The fishing vessels are the second largest contributor to emissions in the port in 2020. 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 contributions to total emissions are illustrated in Figure 3.

Table 8. Emissions and ship calls per ship type in Faxaflóahafnir in 2020.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	1 720	0.0211	0.0664	19.5	1.04	0.502	1.23	26
Container ships	22 100	0.286	0.892	314	14.0	8.60	20.4	320
Cruise ships	847	0.00917	0.0327	10.1	0.453	0.239	0.583	7
Oil- and chemical tankers**	1 170	0.174	0.0460	12.6	0.884	0.348	0.939	152
RoRo vessels/Ferries	17	0.000194	0.000694	0.275	0.00763	0.0203	0.0380	1
General cargo ships	2 110	0.0285	0.0902	31.0	1.44	0.692	1.78	192
CRUISE AND CARGO SHIPS	**28 000**	**0.518**	**1.13**	**388**	**17.9**	**10.4**	**25.0**	**698**
OTHER SHIPS	**855**	**0.00647**	**0.0227**	**5.98**	**0.279**	**0.165**	**0.698**	**52**
FISHING VESSELS	**13 500**	**0.174**	**0.549**	**179**	**8.70**	**3.94**	**4.87**	**293**
WHALE WATCHING BOATS	**346**	**0.00411**	**0.0150**	**4.61**	**0.209**	**0.106**	**0.871**	**1 773**
TOTAL 2020	**42 700**	**0.703**	**1.72**	**577**	**27.0**	**14.6**	**31.4**	**2 816**

*The category "Cruise and cargo ships" contains the sum of emissions from the categories "Dry bulk carriers", "Container ships", "Cruise ships", "Oil- and chemical tankers", "RoRo vessels/Ferries", and "General cargo ships".

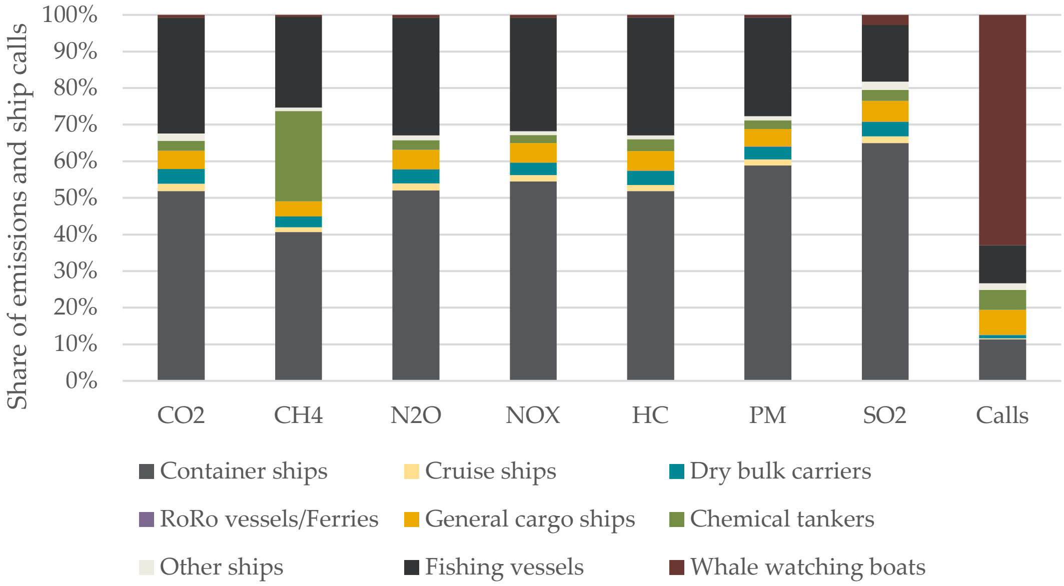

Figure 3. Share of total emissions and ship calls by the ship type categories, 2020.

The different harbour areas in the port serve different ship types to some extent. Sunda harbour is the busiest cargo and cruise port and the 25 600 tonnes emissions of CO_2, which indicate fuel consumption, are significantly higher in Sunda harbour than in the other harbour areas. Akranes harbour is the lower extreme with approximately 166 tonnes of CO_2 emissions in 2020. The total emissions from each harbour area are presented in Table 9.

Table 9. Emissions from ships in the different harbour areas of Faxaflóahafnir 2020.

	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	166	0.00220	0.00697	2.36	0.111	0.0530	0.135	15	0
Grundartangi harbour	5 320	0.0689	0.215	72.8	3.41	1.83	4.78	148	0
Old harbour	11 600	0.303	0.46	151	7.31	3.33	6.32	442	1 773
Sunda harbour*	25 600	0.329	1.02	351	16.2	9.40	20.2	438	0
TOTAL	**42 700**	**0.703**	**1.70**	**577**	**27.0**	**14.6**	**31.4**	**1 043**	**1 773**

*Includes also "Anchorage outside the harbour" and "tugboat on service outside Faxaflóahafnir".

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 total emissions from each harbour area for the last five years are accounted for in separate tables, Table 11 (Akranes harbour), Table 13 (Grundartangi harbour), Table 15 (Old harbour), and Table 17 (Sunda harbour).

Table 10. Akranes harbour - emissions from different ship types 2020 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	119	0.00157	0.00498	1.71	0.0790	0.0377	0.0954	8
Container ships	-	-	-	-	-	-	-	-
Cruise ships	-	-	-	-	-	-	-	-
Oil- and chemical tankers*	-	-	-	-	-	-	-	-
RoRo vessels/Ferries	-	-	-	-	-	-	-	-
General cargo ships	46.6	0.000628	0.00199	0.650	0.0317	0.0153	0.0395	7
CRUISE AND CARGO SHIPS	166	0.00220	0.00697	2.36	0.111	0.053	0.135	**15**
OTHER SHIPS	-	-	-	-	-	-	-	-
FISHING VESSELS	-	-	-	-	-	-	-	-
WHALE WATCHING BOATS	-	-	-	-	-	-	-	-
TOTAL 2020	**166**	**0.00220**	**0.00697**	**2.36**	**0.111**	**0.0530**	**0.135**	**15**

*The category "Cruise and cargo ships" contains the sum of emissions from the categories "Dry bulk carriers", "Container ships", "Cruise ships", "Oil- and chemical tankers", "RoRo vessels/Ferries", and "General cargo ships".

Table 11. Emissions from ships calling Akranes harbour 2016, 2017, 2018, and 2019, 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**
2020	166	0.0022	0.0070	2.4	0.111	0.053	0.135	15
2019	983	0.0214	0.0408	14.3	0.658	0.293	0.770	28
2018	1 020	0.0131	0.0415	12.2	0.653	0.313	0.525	34
2017	2 630	0.0328	0.1040	28.7	1.63	0.717	0.813	44
2016	2 090	0.0273	0.0860	29.1	1.37	0.601	1.129	39

Table 12. Grundartangi harbour – emissions from different ship types 2020.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	1 600	0.0195	0.0614	17.8	0.961	0.464	1.14	18
Container ships	2 870	0.0378	0.117	42.9	1.87	1.09	2.96	45
Cruise ships	-	-	-	-	-	-	-	-
Oil- and chemical tankers	-	-	-	-	-	-	-	-
RoRo vessels/Ferries	-	-	-	-	-	-	-	-
General cargo ships	850	0.0115	0.0364	12.1	0.583	0.276	0.687	85
CRUISE AND CARGO SHIPS	**5 320**	0.0689	0.215	72.8	3.41	1.83	4.78	**148**
OTHER SHIPS	-	-	-	-	-	-	-	-
FISHING VESSELS	-	-	-	-	-	-	-	-
WHALE WATCHING BOATS	-	-	-	-	-	-	-	-
TOTAL 2020	**5 320**	**0.0689**	**0.215**	**72.8**	**3.41**	**1.83**	**4.78**	**148**

*The category "Cruise and cargo ships" contains the sum of emissions from the categories "Dry bulk carriers", "Container ships", "Cruise ships", "Oil- and chemical tankers", "RoRo vessels/Ferries", and "General cargo ships".

Table 13. Emissions from ships calling Grundartangi harbour 2016, 2017, 2018, 2019, and 2020 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**
2020	5 320	0.0689	0.215	72.8	3.41	1.83	4.78	148
2019	4 840	0.0626	0.196	67.8	3.13	2.55	12.4	152
2018	5 420	0.0696	0.219	73.0	3.47	2.61	12.3	179
2017	5 260	0.0677	0.212	72.9	3.38	2.61	11.0	181
2016	4 150	0.0541	0.169	59.8	2.71	2.29	9.90	236

Table 14. Old harbour – emissions from different ship types 2020.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Container ships	205	0.00254	0.00815	2.82	0.126	0.0631	0.174	3
Cruise ships	548	0.00507	0.0200	5.26	0.246	0.145	0.367	6
Oil- and chemical tankers	1 100	0.17300	0.0434	11.8	0.846	0.330	0.889	150
CRUISE AND CARGO SHIPS	1 850	0.181	0.0716	19.9	1.22	0.538	1.43	**159**
OTHER SHIPS	678	0.00460	0.0165	4.19	0.190	0.121	0.541	**43**
FISHING VESSELS	8 770	0.114	0.359	123	5.69	2.562	3.475	**240**
WHALE WATCHING BOATS	346	0.00411	0.0150	4.61	0.209	0.106	0.871	**1 773**
TOTAL 2020	**11 600**	**0.303**	**0.462**	**151**	**7.31**	**3.33**	**6.32**	**2 215**

*The category "Cruise and cargo ships" contains the sum of emissions from the categories "Dry bulk carriers", "Container ships", "Cruise ships", "Oil- and chemical tankers", "RoRo vessels/Ferries", and "General cargo ships".

Table 15. Emissions from ships calling Old harbour 2016, 2017, 2018, 2019, and 2020 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 (cargo, & cruise, fishing and "other")**	**Ship calls (whale watching boats)**
2020	11 600	0.303	0.462	151	7.31	3.33	6.32	442	2 215
2019	14 100	0.176	0.567	192	8.79	4.15	11.0	596	5 542
2018	12 700	0.157	0.506	170	7.81	3.75	9.71	655	5 635
2017	10 200	0.144	0.401	140	6.14	3.07	9.95	673	5 542
2016	10 400	0.126	0.407	143	6.26	3.04	8.82	764	4 520

Table 16. Sunda harbour – emissions from different ship types 2020.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Container ships	19 000	0.245	0.766	268	12.018	7.44	17.2	267
Cruise ships	300	0.00410	0.0127	4.80	0.207	0.0937	0.215	1
Oil- and chemical tankers	68.0	0.000783	0.00252	0.847	0.0382	0.0189	0.0508	2
RoRo vessels/Ferries	17.0	0.000194	0.000694	0.275	0.00763	0.0203	0.0380	1
General cargo ships	1 210	0.0163	0.0517	18.2	0.823	0.400	1.055	100
CRUISE AND CARGO SHIP	20 600	**0.266**	**0.834**	**292**	**13.1**	**7.97**	**18.6**	**371**
OTHER SHIPS*	177	0.00186	0.00617	1.78	0.0894	0.0442	0.157	**14**
FISHING VESSELS	4 740	0.0604	0.191	56.3	3.01	1.38	1.39	**53**
TOTAL 2020	25 600	**0.329**	**1.03**	**351**	**16.2**	**9.39**	**20.1**	**438**

*The category "Cruise and cargo ships" contains the sum of emissions from the categories "Dry bulk carriers", "Container ships", "Cruise ships", "Oil- and chemical tankers", "RoRo vessels/Ferries", and "General cargo ships".

Table 17. Emissions from ships calling Sunda harbour 2016, 2017, 2018,2019, and 2020 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**
2020	25 600	0.329	1.03	351	16.2	9.40	20.2	438
2019	36 500	0.429	1.45	513	21.4	17.3	92.2	637
2018	28 400	0.336	1.13	403	16.7	13.6	72.6	617
2017	26 000	0.308	1.03	370	15.3	12.6	67.5	635
2016	21 300	0.258	0.853	311	12.8	10.2	50.7	461

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

5 Discussion

During 2020 traffic in the port decreased significantly, presumably mainly due to the Covid-19 pandemic. 6 955 port calls resulted in 56 300 tonnes CO_2 in 2019, while 2 816 port calls resulted in 42 700 tonnes CO_2 in 2020. In other terms, a decrease of 60% of the port calls in 2020 resulted in a decrease of 24% of the total CO_2 emitted.

For the emission analysis, none-whale watching vessels are more relevant and within these categories there was an overall decrease between the last two years from 1 413 port calls to 1 043 (approximately 34% decrease).

The increasing trend for visits of both container ships and cruise ships ongoing since 2016 was interrupted in 2020. The number of calls by cruise ships went down from 181 in 2019 to only 7 in 2020, a decrease by 96%. Further, container traffic decreased by 16% from 375 to 315 calls, even though the emission increased. This is explained by increased times at berth for the largest container ships, according to the statistics. Fishing vessels, despite decreasing amount of port calls (292 in 2020 versus 339 in 2019) registered an increase of CO_2 emission of 26%. However, a closer look at the data revealed that two large fishing vessels have been registered at berth for almost one year. It is unlikely that their engines were running with the assumed power demand during the whole period, the actual amount of CO_2 and other pollutants emitted is therefore likely overestimated. However, we used our established methodology because we have not been able to produce specific data on power demands at berth for 2020.

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 some examples.

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

- in Akranes, the average values were around 60 tonnes/call in 2016 and 2017 and decreased to approximately 30 tonnes/call in 2018, remained at a lower level at 35 tonnes of CO_2 per call in 2019, and decreased to the lowest 11 tonnes/call in 2020;
- in Grundartangi, the average CO_2 emissions per call has been approximately on a level of 30 tonnes between 2017 and 2019 and reached 35 tonnes/call in 2020;
- in Old harbour the larger vessels have had a steady increase of emissions the last four years, in 2019 the calculated average CO_2 emissions per call was 22 tonnes, while in 2020 it was calculated being 26 tonnes/call;
- CO_2 emissions per call in Sunda harbour are 46, 41 and 46 for the years 2016, 2017 and 2018, respectively. Average emissions in 2019 had increased significantly to 57 tonnes/call and kept stable in 2020 with 58 tonnes/call. This year, a relative increase in emission per call for container ships (71 tonnes/call in 2020 versus 45 in 2019) is the main reason behind the high value.

These comparisons are most relevant to make for Sunda harbour and Old harbour which each year receives a high number of calls. The "emission per call" ratios in these harbour areas are less sensitive to single calls that may cause very high emissions and that may influence the results significantly.

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. The model therefore 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 in 2020 with 32% and 0.8% 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 and 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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Appendix:

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
451	SUNDABAKKI - 451	4.00	0.75	1.00	1.50	Berth	Sunda harbour
452	SUNDABAKKI - 452	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 maneuvering.

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 (MGO, MDO and ULSFO), and 0.5 % in VLSFO.

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%:

Fuel	FSC (%)	EGCS	Emission factor g/kWh
HFO	2.7	No	1.4
VLSFO	0.5	No	0.43
HFO	2.7	Scrubber	0.98

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

Fuel	NO_x	PM	HC	CH_4	N_2O
MD	2 900	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 NO_x emission factor from ESI score:

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

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

Where ESI_{NOX} is the NO_x 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.

The NO_x scores for the ships in Faxaflóahafnir 2020 that were registered with the ESI are shown in the table (should not be disclosed):

IMO	NOxScore
9229984	12.34
9274551	9.3
9346665	7.16
9371426	4.9
9430947	6.26
9430959	11.67
9430961	4.46
9430985	13.89
9430997	13.89
9431006	12.99
9433456	4.7
9448279	20.62
9448281	18.85
9491745	8.53
9491757	8.53
9507350	0.38
9577628	15.29
9579406	22.45
9617296	12.41
9635248	15.52
9641314	14.21
9711779	20.42
9739836	55.25
9818967	14.95
9822853	23.12

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