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Emissions from ships in Faxaflóahafnir 2022

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Summary

In this study we calculate and present the ship to air emissions for Faxaflóahafnir harbours in 2022. 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 the years 2017, 2018, 2019, 2020 and 2021.

For each port call, emissions of greenhouse gases (*well-to-wheel and tank-to-wheel*), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), particulate matter (PM), and sulphur dioxide (SO_2) are calculated using an emission inventory model specifically developed for port areas. Total emissions in 2022 are presented in the Table 1.

Tabell 1 Result summary of the emissions to air from ships in Faxaflóahafnir 2022

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)
	WTW CO_2e (ton)	TTW CO_2e (ton)	TTW CO_2 (ton)				
Total emissions 2022	60 700	48 800	48 200	570	25	16	46

In 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 30-40% of the total emissions of CO_2 equivalent (CO_2e) from the ships visiting Faxaflóahafnir. In 2022, cruise ships were responsible for 38% of the total CO_2 emissions, while container ships accounted for approximately 30%. The average emissions per call by cruise ships are higher than from other vessels.

In 2022, fishing vessels were the third largest contributing ship type category in the port. In 2022, the fishing vessels accounted for approximately 16% of the CO_2e emissions in the port. The frequent whale watching boat traffic to the port has seen an increase compared to the previous year, reaching 3 959 in 2022 (compared to a high of 5 542 calls in 2019 and low of 1 773 in 2020 during the pandemic). Since these vessels in general have relatively small engines, their contribution to the total CO_2e is calculated to be 1.6% for 2019, 0.8% in 2020, 1.3% in 2021 and 1.7% in 2022.

Sunda harbour and Old harbour receive significantly more ship calls than Akranes and Grundartangi. Sunda harbour received the most container ships (286 in 2022) and the highest number of visiting cruise ships (110). Ships calling at Sunda harbour were responsible for more than half of the emissions to air in Faxaflóahafnir, regardless of the type of emission. Ships in Sunda harbour and Old harbour account for approximately 38 100 and 14 500 tonnes of the total CO_2e emissions, respectively.

In a comparison with CO_2e emissions from ships in the port in 2021, there was a net increase. The difference can mainly be attributed to an increased number of calls and time at berth for cruise ships.

1 Introduction

IVL Swedish Environmental Research Institute has on assignment from Faxaflóahafnir calculated the emissions from ships visiting its harbours in 2022. 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 greenhouse gases (*well-to-wheel* and *tank-to-wheel*) carbon dioxide (CO_2) and carbon dioxide equivalent (CO_2e) which includes the global warming potentials of nitrous oxide (N_2O) and methane (CH_4), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOC), particle matter (PM), and sulphur dioxide (SO_2). The emission calculations are based on call statistics provided by the port.

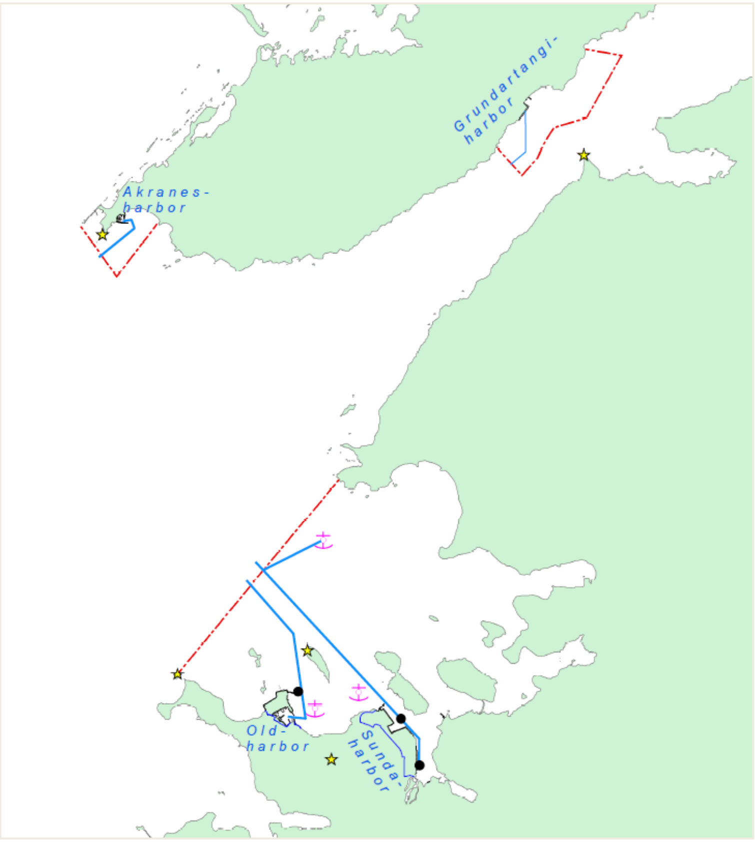

Figure 1. The four ports of Faxaflóahafnir and the areas outside the ports included in the emission inventory.

This report describes the emissions calculation model, the data used, and results. Results for 2022 are analysed and discussed in relation to emission calculations made from ships calling the port in 2017, 2018, 2019, 2020 and 2021. Due to the new sulphur directive that entered into force in 2020, the emission factors for PM, SO_2, and HC have been updated in 2020 compared to previous emission inventories. Before 2020, the average sulphur fuel content used in the port area was assumed to be about 2.7 %, however according to the new regulation, ships are only allowed to use fuel with a sulphur content of maximum 0.5 % or use scrubbers.

2 Ship traffic

In total, this inventory covers 5 394 port calls comprising in total 1 435 larger vessels. In addition to these calls, the port received 3 959 calls from whale watching boats in 2022, which is still considerably lower compared to the 5 542 calls 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. These ships 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, a surrounding 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 calculated from the time each ship spends in transit between the outer boundary of the port area and their assigned berth. *Manoeuvring* operations are assumed as twenty minutes per call, during which the ships are manoeuvred with high precision before and after standing stationary at the quayside – a period which often requires rapid engine load changes that strongly influences emissions. 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, and ship speed, which is assumed to be relative to the size of the vessel. Therefore, ship size has 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 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. If a ship goes between different port areas during the same official port call, the "port call" will be counted on the last port area, while the emissions will be divided between the port areas according to the time spent in each respective area. We have therefore also included a count of ship movements separately which reflects the number of times ships are shifting, shown in Table 2.

Tabell 2. Number of port calls and ship movements registered in 2022 in the different harbours in Faxaflóahafnir. The amount of ship movements in the used data is inferior to the one in the incoming data from port call statistic since for some ship there is no information available.

Harbour	Port calls (cargo, cruise, fishing and "other")	Port calls (whale watching boats)	Ship movements (cargo, cruise, fishing and "other")	
			Used data	Port call statistic indata
Akranes harbour	57	0	72	72
Grundartangi harbour	166	0	295	314
Old harbour	595	3 959	764	803
Sunda harbour*	617	0	958	987
TOTAL	**1 435**	**3 959**	**2 089**	**2 176**

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

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.

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

where E is the emission in grams of a certain substance from an engine in a certain operating mode, EF is the emission factor for a pollutant in g / kWh in a certain operating mode, t is the time in hours when the engine operates in this mode and P is the power output in kW from the engine during this operating mode.

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 taken from Cooper and Gustavsson (2004). Emission factors for NO_x are assumed to follow the regulatory standards that were introduced in 2005, which apply to all ship keels laid from 2000 (Tier I) onwards, and further strengthened in 2011 (IMO, 2011). Ships constructed prior to 1990 are not covered by any regulations unless they have undergone significant engine changes. Ships constructed between 1990 and 2000 are only covered if specific criteria on engine size and technical possibilities for emission reductions are met. Due to lack of data availability, it is not possible to identify which ships from before 2000 fulfil Tier 1 requirements. For these vessels, no NO_x reduction measures are assumed used (Cooper and Gustafsson, 2004).

Emission factors for post-2000 ships follow regulatory standards: Tier I levels for ships constructed between 2000 and 2011, and Tier II levels for ships built after 2011 (IMO, 2011). In Appendix 2 the details of the calculations behind emission factors in the regulations are presented. Emission factors for SO_2 are based on fuel consumption and estimated sulphur content. 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%. Whale watching boats are assumed to use only marine gasoil with an estimated sulphur content of 0.1%. For the ships using scrubbers, a fuel sulphur content of 0.5% is presumed.

The emission factors for particulate matter (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 PM emissions at low sulphur content (>0.1 %), and, further, that a dependence on engine load is uncertain. Here, a distinction between PM emission factors is made 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 onboard 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 to meet heating demands.

Only few studies report emission factors from boilers. In this study, emission factors from USEPA (1999) reported for boilers in relevant sizes for ship installations are used (Appendix 2). Emissions of CO_2 and SO_2 from boilers are calculated from the carbon and sulphur fuel contents, assuming complete combustion and a 0.1% sulphur content for marine distillate oil. 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 indicates a ships emission performance, specifically regarding NO_X, SO_X and CO_2. The ESI register used for this inventory is valid for 2022. 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, 2021). *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 the 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, except for container ships at berth and anchor and product tankers at anchor, for which auxiliary engine powers are determined from specific power demand instead (Appendix 2).

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 powers. The categories and the installed main engine power of shipping vessels in Faxaflóahafnir stated in the *Sea-web Ship* data base have been matched. 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 3.

Tabell 3 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 required for the emission calculations. This information is often relatively uncertain and differs greatly between different ships. For this study, general values first reported by Entec UK (2002) are used. These values are presented in Table 4. However, for container ships at berth and at anchor and product tankers at anchor, the used auxiliary power demand is used (Appendix 2).

Tabell 4 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.

The 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, designed to manage the electricity needs for freezing 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 5 (HB Grandi, 2017).

Tabell 5 Estimated power utilization or power requirements of auxiliary engines in different categories of fishing vessels.

Category No.	In port basin	Manoeuvring	At berth	Comment
1	0	0	0	No auxiliary 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. It is assumed that for 50% of the time these vessels need power for freezing and unloading (up to 300 kW). For 50% of the time, during lay-up, 150 kW is assumed to be needed. 26% auxiliary engine utilization is an approximate average for time at berth.
5	40%	50%	23%	These ships can process and freeze fish on board. Between 15% and 40% of installed auxiliary engine power is used at berth. At berth, shore side electricity is not always enough. It is assumed that for 50% of the time these vessels need power for freezing and unloading (500-600 kW). 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 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

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[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. As a comparison the emissions from the Icelandic electricity was 8.6 g CO_{2e}/kWh_{el} in 2020 while the emission at berth from auxiliary engine was calculated to be about 870 g CO_{2e}/kWh_{el} on average.

may 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. For the rest of the time, power from auxiliary engines according to Table 5 are used in the calculations.

Tankers often use electricity from the auxiliary engines to run cargo pumps. 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 general 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 as 42% of the ships' dead weight tonnage. The value is based on a study made for Port of Gothenburg in 2017. Thus, for each tanker call, additional fuel consumption (in kg) according to equation (2) is assumed.

$$Fuel\ consumption = 0.42 * DWT * 0.13 \tag{2}$$

Large tankers sometimes use steam from oil fired boilers to run their cargo pumps. However here it is 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 smaller sizes tend to use electricity driven pumps while larger ships use steam driven pumps.

The main engines fuel 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 the auxiliary engines is assumed to be marine gasoil with 0.1% sulphur content (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 assumed to use fuel with a sulphur content of 0.5% in the main engines, and marine gasoil with 0.1% sulphur content in the auxiliary engines, while small fishing vessels are reported to use marine gasoil with 0.1% sulphur content, exclusively. All small fishing boats in the HB Grandi fleet use diesel oil with a sulphur 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 6.

Table 6. 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 (0–5 000 TEU)	0,8
Container ships (< 17 000 TEU)	4,2
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.

3.3 Upstream emissions

The greenhouse gas emissions that occur during the production, processing and transport of the fuel are usually called source-to-tank emissions, well-to-tank (WTT). This can be compared with the emissions that occur during combustion, which are usually called tank-to-wheel emissions (TTW). It is extra important to include these upstream emissions when, for example, starting to use biofuels and electricity, as greenhouse gas emissions are not normally calculated for these emissions at the exhaust pipe/propeller (section 3.4). Emissions are instead reported in the production of these fuels, and therefore the WTT emissions are also included in this study. We report this as well-to-wheel / propeller (WTW) which is the sum of WTT and TTW.

The emission factors used here are taken from scientific publications (e.g. Brynolf 2014, Brynolf et al. 2014a) which are in good agreement with, for example, the emission factors for light and heavy fuel oil in the LCA database Sherpa (European average).

To calculate the upstream emissions, first the amount of primary energy found in the unburned fuel is calculated. The energy consumption for main motors and auxiliary machines is calculated using Equation 3.

$$\mathrm{Fuel}_{\mathrm{MJj}} = \mathrm{t} \cdot \mathrm{P} \cdot \mathrm{HV} \cdot \mathrm{SFOC} \qquad (3)$$

Where:

t: is the time in hours when the engine is operating in this mode

P: is the power output in kW from the motor during this operating mode

HV: Heating value is the higher calorific value of the fuel in MJ / kg fuel, see Appendix D for more detailed information.

SFOC: Specific fuel oil consumption is the engines' assumed fuel consumption in kilograms per kWh, i.e. including the assumed engine efficiency, see Appendix 2 for more detailed information.

Fuel consumption for the boilers has been calculated by Equation 4.

$$\mathrm{Fuel}_{\mathrm{MJ}} = \mathrm{FC}_{\mathrm{GT}} \cdot \mathrm{HV} \cdot \mathrm{GT} \cdot \mathrm{t} \qquad (4)$$

where:

FC_{GT}: are standard values for the boilers' fuel consumption

HV: Heating value is the higher calorific value of the fuel in MJ / kg fuel, see Appendix D for more detailed information.

GT: is the ship's gross tonnage.

t: is the time the boilers have been used

3.4 Global warming potential (GWP100)

To assess the emissions of the climate gasses methane (CH_4) and nitrous oxide (N_2O), their total emissions are multiplied by their global warming potential over a 100-year time horizon (GWP100) to produce CO_2 equivalents (CO_2e). The GWP100 for CH_4 is 25 and N_2O for 298 (IPCC, 2013).

4 Results

Table 7 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 higher relative to 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 for the relative importance of emissions during the *in-port basin* operational mode. The diesel electric driven cruise ships are an exception as they use their main engines *at berth* as well, although they use exclusively low sulphur fuel or after-treatment.

CO_2 (TTW) emissions are almost directly related to the fuel consumption and are therefore a good proxy to use for fuel consumption in the analysis. In a comparison between the different operational modes, for 2022, the operations *at berth* can be attributed approximately 79% of the total CO_2 emissions. The CO_2 emissions from the auxiliary engines is calculated to be 47% of the total fuel consumed by all three engine types. Emissions of the greenhouse gases, dominated by CO_2 emissions, reached a value of 60 700 tonnes of CO_2e.

Table 7. Overview of emissions from ships in Faxaflóahafnir 2022.

		Greenhouse gases emissions		**CO_2 (ton)**	**NO_x (ton)**	**NMVOC (ton)**	**PM (ton)**	**SO_2 (ton)**
		CO_{2-e} (ton)	**CO_{2-e} (ton)**					
		Well-To-Propeller (WTW)	***Tank-to-Propeller* (TTW)**					
Main Engines	In port basin	7 200	5 900	5 800	90	3.30	6.1	17.9
	At anchor**	0	0	0	0	0.00	0.0	0.0
	Manoeuvring	1 100	900	900	10	0.50	0.8	2.8
	At berth*	11 300	9 400	9 200	120	4.10	2.4	5.6
Auxiliary Engines	In port basin	2 300	1 800	1 800	20	1.30	0.5	1.1
	At anchor*	700	600	600	10	0.40	0.2	0.4
	Manoeuvring	500	400	400	6	0.30	0.1	0.2
	At berth*	25 400	20 100	19 100	290	25.90	16.9	22.9
	Tankers at berth using cargo pumps	200	100	100	0.8	0.10	0.0	0.1
Boilers	In port basin	900	700	700	0.6	0.01	0.1	0.4
	At anchor**	200	200	200	0.1	0.002	0.0	0.1
	Manoeuvring	100	100	100	0.1	0.00	0.0	0.1
	At berth*	10 800	8 600	8 500	8	0.19	0.8	5.4
TOTAL (Engines and boilers)	Main engines	19 600	16 200	15 900	230	7.8	9.3	26.40
	Auxiliary engines	29 100	23 000	22 700	330	16.8	6.2	13.30
	Boilers	12 000	9 600	9 500	10	0.1	0.7	6.00
TOTAL (Operational modes)	In port basin	10 300	8 400	8 200	120	4.6	6.6	19.4
	At anchor**	900	700	700	10	0.4	0.2	0.5
	Manoeuvring	1 800	1 400	1 400	20	0.8	0.9	3.1
	At berth*	47 700	38 300	37 800	420	19.0	8.4	22.7
TOTAL	**All engines and boilers, all operational modes**	60 700	48 800	48 100	570	25	16	46

*Only cruise ships with diesel electric power trains

**Include emissions from ships in shipyard

In Table 8 the emissions from 2017, 2018, 2019, 2020 and 2021 are presented together with emissions in 2022.

Table 8. Emissions and number of calls from 2017 – 2021 and 2022 for ships visiting Faxaflóahafnir.

Year	Greenhouse gases emissions			N_2O (ton)	NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)						
2017	52 500	42 100	41 600	1.60	560	23	19*	89*	7 059
2018	57 200	45 800	45 300	1.76	610	25	20*	95*	6 006
2019	68 100	54 600	54 000	2.10	730	30	24*	120*	6 955
2020	50 600	40 300	39 800	1.51	500	23	11	30	2 818
2021	43 000	34 400	34 000	1.28	410	18	12	31	3 670
2022	60 700	48 800	48 200	1.80	570	25	16	46	5 394

* Historic values of these emissions were not re-calculated in 2022 since other regulations were in place and other fuel types were used. However, the updated of power demand at berth and anchor don´t effect these figures as much since these emissions are dominated by the fuel combustion in the main engine.

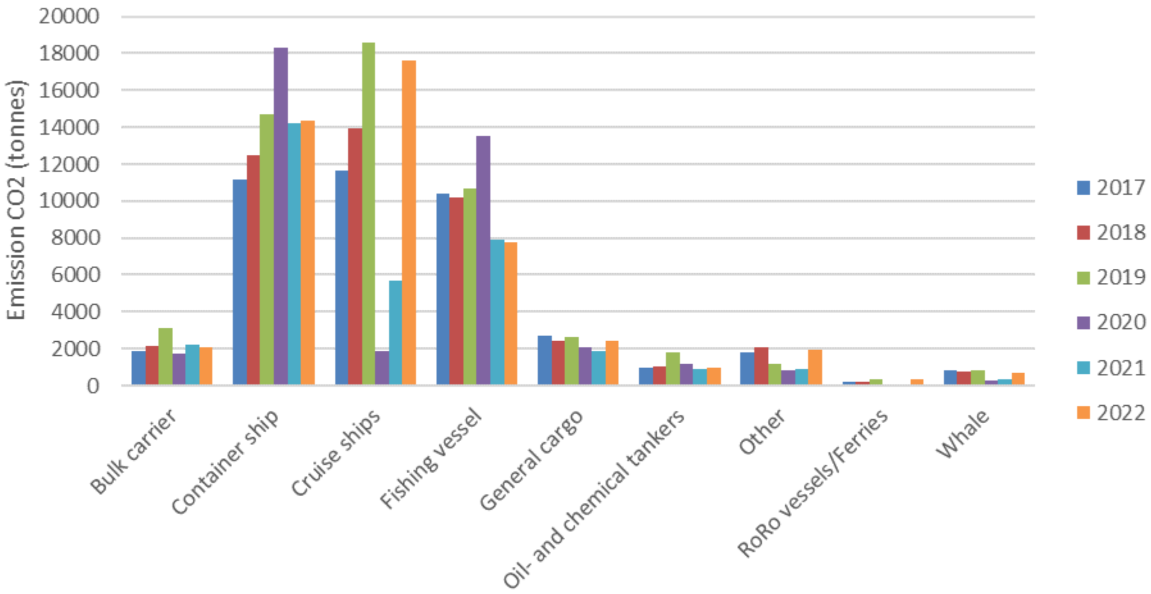

Figure 2, CO_2 emissions are presented for the different ship types in 2017 - 2021 and 2022. Figure 3 illustrates the number of port calls by each ship types for the above-mentioned years. Cruise ships emissions have registered an increase in CO_2 emissions and are back to pre-2020 levels, after having undergone a dramatic decrease in 2020 due to the Covid-19 pandemic. Fishing vessels and container ships appear to have similar emission levels as in 2021. Worth noting is that whale watching boats (not shown in figure 3) registered an increase to around 4 000 port calls in 2022 compared 2 400 to in 2021.

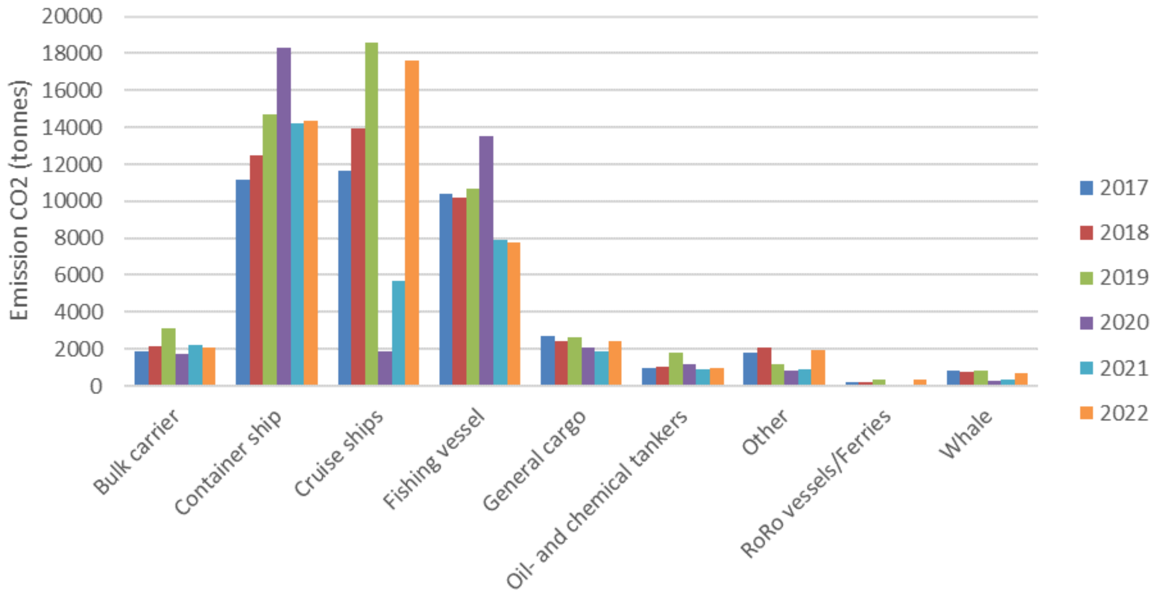

Figure 2. CO_2 emissions from different ship types 2017, 2018, 2019, 2020, 2021 and 2022.

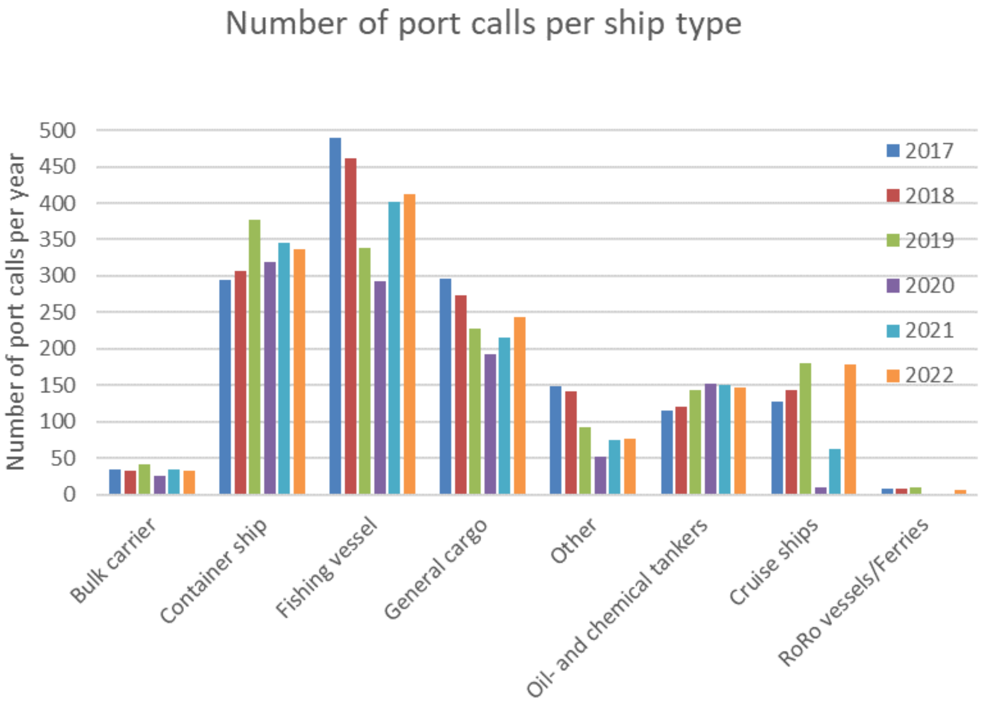

Figure 3 Number of port calls from different ship types 2017 - 2021 and 2022.

Faxaflóahafnir provides connections to shore side electricity in Old harbour and Sunda harbour, and many ships use shore side power at berth. By assuming these ships used electricity from onboard diesel generators if the shore side connections were not available, a measure of “avoided emissions” is estimated. This is the difference between emissions at berth if no ships were to use shore side power and the calculated actual emissions at berth. The avoided emissions are presented in Table 9 for the three harbour areas. The avoided emission estimate is uncertain since some ships reported average or max power demand (kW/h) while some instead report actual energy consumption (kWh), a more precise estimate would be possible if all ships reported the actual energy consumption.

Table 9. Total avoided emissions from the use of shore side electricity in the port 2022.

Harbour	Greenhouse gases emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)				
Akranes harbour	77	61	60	1	0.04	0.02	0.01
Grundartangi harbour	0	0	0	0	0	0	0
Old harbour	2 524	2 001	1 974	30	1.5	0.5	1.2
Sunda harbour	1 079	855	844	13	0.6	0.2	0.4
TOTAL	3 679	2 917	2 877	44	2.1	0.8	1.6

Table 10. Emissions and ship calls per ship type in Faxaflóahafnir in 2022.

	Greenhouse gas emissions			N_2O (ton)	NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)						
Dry bulk carriers	2 660	2 120	2 090	0.1	23	1.3	0.5	1.6	33
Container ships	18 110	14 490	14 340	0.5	170	7.5	6.3	17	337
Cruise ships	21 950	17 920	17 620	0.7	202	7.4	5.9	17	179
Oil- and chemical tankers	1 290	1 020	1 000	0.04	7	0.6	0.2	0.8	147
RoRo vessels/Ferries	300	240	230	0.01	4	0.2	0.1	0.2	6
General cargo ships	3 070	2 440	2 410	0.1	34	1.6	0.7	2.1	243
CRUISE AND CARGO SHIPS*	**47 380**	**38 230**	**37 690**	**1**	**440**	**19**	**14**	**38**	945
OTHER SHIPS	2 480	1 980	1 960	0.1	17	0.8	0.4	1.9	77
FISHING VESSELS	9 870	7 840	7 750	0.3	103	4.9	1.9	4.4	413
WHALE WATCHING BOATS	1000	790	800	0.03	11	0.5	0.2	1.6	3959
TOTAL 2022	**60 700**	**48 800**	**48 200**	**1.8**	**570**	**25**	**16**	**46**	**5 394**

*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”.

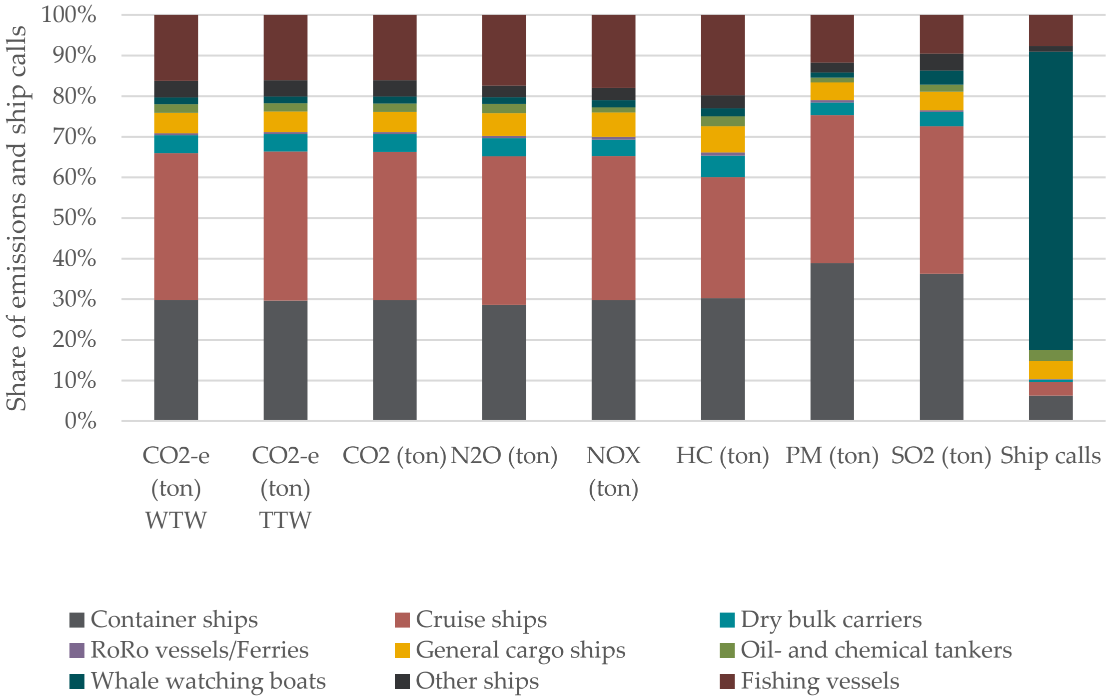

Figure 4. Share of total emissions and ship calls by the ship type categories, 2022.

The different harbour areas in the port serve different ship types to some extent. Sunda harbour is the busiest cargo and cruise port with roughly 38 000 tonnes emissions of CO_2e. Akranes harbour is the least emitting harbour with approximately 900 tonnes of CO_2e emitted in 2022.

Emissions from ships in the different harbour areas

Table 11. Emissions from ships in the different harbour areas of Faxaflóahafnir 2022.

Harbour	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls	Whale watching boat calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)						
Akranes harbour	860	680	680	9.1	0.4	0.2	0.5	57	0
Grundartangi harbour	7 270	5 800	5 730	70	4	1.6	5.4	166	0
Old harbour	14 520	11 600	11 420	140	7	2.8	8.6	595	3959
Sunda harbour*	38 060	30 800	30 360	350	14	11.6	31.2	617	0
TOTAL	**60 700**	**48 900**	**48 200**	**570**	**25**	**16**	**46**	**1 435**	**3 959**

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

Table 11 shows an overview of the emissions in the different harbour areas of Faxaflóahafnir 2022. Further details on emissions per ship type in the different harbour areas are presented in Table 12 (Akranes harbour), Table 14 (Grundartangi harbour), Table 16 (Old harbour), and Table 18 (Sunda harbour). The total emissions from each harbour area for the last six years are accounted for in separate tables, Table 13 (Akranes harbour), Table 15 (Grundartangi harbour), Table 17 (Old harbour), and Table 19 (Sunda harbour).

Akranes harbour

Table 12. Akranes harbour - emissions from different ship types 2022 and the number of calls.

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)					
Dry bulk carriers	185	147	145	2	0.1	0.04	0.1	10
Container ships	0	0	0	0.0	0.0	0.0	0.0	0
Cruise ships	0	0	0	0	0.0	0.0	0.0	0
Oil- and chemical tankers	20	16	16	0.2	0.01	0.004	0.01	1
RoRo vessels/Ferries	0	0	0	0.0	0.0	0.0	0.0	0
General cargo ships	158	126	124	1.9	0.09	0.03	0.09	13
CRUISE AND CARGO SHIPS*	**360**	**289**	**285**	**4**	**0.2**	**0.1**	**0.2**	24
OTHER SHIPS	154	122	121	1.5	0.1	0.03	0.1	0
FISHING VESSELS	343	270	270	3.4	0.2	0.1	0.2	33
WHALE WATCHING BOATS	**0**	0	0	0	0	0	0	0
TOTAL 2022	**857**	**681**	**676**	**9.0**	**0.4**	**0.2**	**0.5**	57

*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 Akranes harbour 2017 – 2021 and 2022, and the number of calls.

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)					
2017	3 400	2 700	2 600	30	1.6	0.6	0.7	44
2018	1 300	1 000	1 000	12	0.7	0.3	0.3	34
2019	1 300	1 000	1 000	14	0.6	0.3	0.6	26
2020	200	200	200	2	0.1	0.05	0.1	15
2021	500	400	400	6	0.3	0.1	0.3	31
2022	900	700	700	9	0.4	0.2	0.5	57

Grundartangi harbour

Table 14. Grundartangi harbour – emissions from different ship types 2022.

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)					
Dry bulk carriers	2 452	1949	1926	21	1.2	0.5	1.4	22
Container ships	3 585	2867	2835	38.7	1.6	0.9	3.2	36
Cruise ships	0	0	0	0	0	0	0	0
Oil- and chemical tankers	0	0	0	0	0	0	0	0
RoRo vessels/Ferries	5	4	4	0.1	0.003	0.001	0.004	1
General cargo ships	1 230	978	965	13.2	0.7	0.3	0.8	107
CRUISE AND CARGO SHIPS*	**7 270**	**5 798**	**5 730**	**73**	**3.5**	**1.6**	**5.4**	166
OTHER SHIPS	0	0	0	0	0	0	0	0
FISHING VESSELS	0	0	0	0	0	0	0	0
WHALE WATCHING BOATS	**0**	0	0	0	0	0	0	0
TOTAL 2022	**7 270**	**5 798**	**5 730**	**72.8**	**3.5**	**1.6**	**5.4**	**166**

*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 Grundartangi harbour 2017 – 2021 and 2022 and the number of calls.

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)					
2017	6 100	4 800	4 800	62	2.8	1.4	4.4	166
2018	6 300	5 000	5 000	63	3.0	1.5	4.6	179
2019	5 600	4 500	4 400	58	2.7	1.3	4.3	153
2020	6 200	4 900	4 900	62	2.9	1.4	4.5	144
2021	6 700	5 400	5 300	70	3.2	1.5	5.3	160
2022	7 300	5 800	5 700	73	3.5	1.6	5.4	166

Old harbour

Table 16. Old harbour – emissions from different ship types 2022.

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)					
Dry bulk carriers	0	0	0	0	0	0	0	0
Container ships	170	130	130	1.7	0.1	0.1	0.2	12
Cruise ships	2 920	2330	2300	27	1.4	0.6	1.7	69
Oil- and chemical tankers	1 210	970	940	6.5	0.6	0.2	0.8	145
RoRo vessels/Ferries	290	230	230	3.6	0.2	0.1	0.2	5
General cargo ships	15	12	12	0.1	0.004	0.003	0.02	5
CRUISE AND CARGO SHIPS*	**4 600**	**3 700**	**3 600**	**39**	**2.2**	**0.9**	**2.9**	236
OTHER SHIPS	1 360	1080	1070	7.4	0.3	0.2	0.8	49
FISHING VESSELS	7 570	6010	5940	80	3.8	1.5	3.2	310
WHALE WATCHING BOATS	**980**	790	780	10	0.5	0.2	1.6	3 959
TOTAL 2022	**14 500**	**11 600**	**11 400**	**140**	**6.8**	**2.8**	**8.6**	4 554

*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 Old harbour 2017 - 2021 and 2022 and the number of calls.

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)					
2017	12 700	10 100	10 000	140	6.0	2.5	8.3	6209
2018	15 900	12 700	12 500	170	7.7	3.1	8.8	5182
2019	17 900	14 200	14 100	190	8.8	3.5	9.9	6138
2020	14 700	11 700	11 500	150	7.1	2.8	6.1	2217
2021	10 800	8 700	8 500	100	5.1	2.1	6.0	2960
2022	14 500	11 600	11 400	140	6.8	2.8	8.6	4554

Sunda harbour

Table 18. Sunda harbour – emissions from different ship types 2022.

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)					
Dry bulk carriers	30	21	20	0.3	0.01	0.01	0.02	1
Container ships	14 360	11 489	11 370	129	5.9	5.4	13	289
Cruise ships	19 030	15 591	15 320	175	6.0	5.3	15	110
Oil- and chemical tankers	50	46	50	0.5	0.03	0.01	0.03	1
RoRo vessels/Ferries	0	0	0	0	0	0	0	0
General cargo ships	1 668	1 329	1 311	19	0.9	0	1.2	118
CRUISE AND CARGO SHIPS*	**35 100**	**28 475**	**28 100**	**324**	**12.8**	**11.1**	**29.5**	**519**
OTHER SHIPS	970	771	760	8	0.4	0.2	0.7	28
FISHING VESSELS	1 960	1 558	1 540	20	0.9	0.4	1.0	70
WHALE WATCHING BOATS	0	0	0	0	0	0	0	0
TOTAL	**38 100**	**30 800**	**30 400**	**350**	**14.1**	**11.6**	**31.2**	**617**

*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 19. Emissions from ships calling Sunda harbour 2017 - 2021 and 2022 and the number of calls.

	Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton)					
2017	30 400	24 500	24 200	330	12.2	8.00	24.4	640
2018	33 700	27 100	26 800	360	13.5	8.90	26.7	611
2019	41 400	33 400	33 000	450	16.6	10.7	32.7	619
2020	29 500	23 500	23 300	280	12.9	7.00	18.9	442
2021	24 900	20 000	19 800	230	9.90	8.10	19.9	519
2022	38 100	30 800	30 400	350	14.1	11.6	31.2	617

The values presented in the tables above are given with maximum three significant figures. 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

In this year's harbour inventory hydrocarbons (HC) have been recalculated as non-methane volatile organic compounds (NMVOC) and methane separately and are reported here. To compare historical data, we have updated previous years emissions for Faxaflóahafnir from 2017-2022 (Table 2). A description of the implemented updates is given below.

In this year's report, hydrocarbons (HC) have been separated into non-methane volatile organic compounds (NMVOC) and methane (CH_4) so that these emissions can be distinguished. Methane is a greenhouse gas and relatively unreactive compound compared to the many individual compounds that comprise NMVOC, which can contribute to formation of particle matter and ozone. Historically CH_4 and NMVOC have not been reported separately in emission inventories as emissions of CH_4 are relatively low during combustion of MGO. However, a small number of ships use LNG and is expected to further increase, CH_4 is therefore also expected to increase due to CH_4 slip from LNG engines. CH_4 slip accounts for nearly all CH_4 emissions from LNG ships. To increase the transparency of the inventory, we have chosen to display NMVOC instead of HC in this year's report. CH_4 emissions are instead included in CO_2-e emissions.

During 2022 traffic in the port increased compared to 2021, however the harbours activity is still not back on pre pandemic levels. The 1 435 port calls (non-whale watching vessels) resulted in around 60 000 tonnes CO_2e in 2023, while 1 187 port calls (non-whale watching vessels) resulted in 42 500 tonnes CO_2e in 2021. In other terms, an increase of 20.9% of the port calls in 2022 resulted in a decrease of 40% of the total CO_2e emitted.

In 2022, the price of LNG was very high relative to oil prices, in part due to Russia's invasion of Ukraine. We have had indications that many LNG ships used MGO instead of LNG to reduce costs. We have no means of getting information on exactly which fuel a ship has used, rather our calculations use statistics on installed ship engine type. However, the effect on for example $CO_{2\text{-e}}$ emission is small, as the number of LNG ships is low.

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 value in 2022 was 12 tonnes/call. Earlier values were around 60 tonnes/call in 2016 and 2017 which decreased to approximately 30 tonnes/call in 2018, remained at a lower level at 35 tonnes of CO_2 per call in 2019, decreased to the lowest 11 tonnes/call in 2020, then increased to 13 tonnes/call in 2021.
- In Grundartangi, the average value in 2022 was 34 tonnes/call. Earlier, 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 and 33 tonnes/call in 2021.
- In Old harbour, the average value in 2022 was 18 tonnes/call (excluding whale watching boats). 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 25 tonnes/call, and 14 tonnes/call in 2021.

- CO_2 emissions per call in Sunda harbour were 37, 42, 53, 52 and 37 for the years 2017, 2018, 2019, 2020 and 2021, respectively. Average emissions in 2022 have increased to 49 tonnes/call, back to previous levels.

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 generalised values in many instances. These are often based on averages from many observations or reports, which include variations around the average value. Examples of such general values are the emission factors, the sulphur content in fuel, and the engine loads at different operational modes. This cause uncertainty in the results. However, in an emission inventory like this with many 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 is therefore unsuitable for analysis of emissions from individual ships or small groups of ships.

Emissions from two ship categories rely on different assumptions compared to the other ship categories. These are the fishing vessels and the whale watching boats, contributing 16,1% and 1,7% to total CO_2 emissions in 2022, 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)
4. Updates of the Emission inventory

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