Emissions from ships in Faxaflóahafnir 2023

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Summary

In this study we calculate and present the ship to air emissions for Faxaflóahafnir harbours in 2023. Emissions are presented for 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 to 2022.

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 2023 are presented in Table 1.

Table 1: Result summary of the emissions to air from ships in Faxaflóahafnir 2023

	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 2023	72 600	58 500	57 700	668	28	17	38

Container and cruise ships have historically been the ship categories which account for the largest shares of emissions in the port, and this year's inventory saw an increase in emissions mainly due to increased traffic from these ship categories. In 2023, cruise ships were responsible for 44% of the total CO_2 emissions and had 38% more ports calls than in 2022. The average emissions per call by cruise ships are higher than those from other vessels, which explains their large share of the emissions. Container ships on the other hand accounted for approximately 29% of CO_2 emissions and had 10% more port calls than last year. Fishing vessels were the third largest contributing ship type category in the port this year, accounting for approximately 15% of the CO_2e emissions in the port. The frequent whale watching boat traffic to the port has increased from 3 959 calls in 2022 to 4 387 calls in 2023 (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 WTW CO_2e is only calculated to be 1.4% for 2023.

Sunda harbour and Old harbour receive significantly more ship calls than Akranes and Grundartangi. Sunda harbour received the most container (331), cruise (166), and general cargo ships (109) in 2023. Ships calling at Sunda harbour were responsible for around 70% of CO_2e emissions to air in Faxaflóahafnir,. Ships in Sunda harbour and Old harbour account for approximately 50 710 and 13 660 tonnes of the total WTW CO_2e emissions, respectively.

1 Introduction

IVL Swedish Environmental Research Institute has on assignment from Faxaflóahafnir calculated the emissions from ships visiting its harbours in 2023. 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.

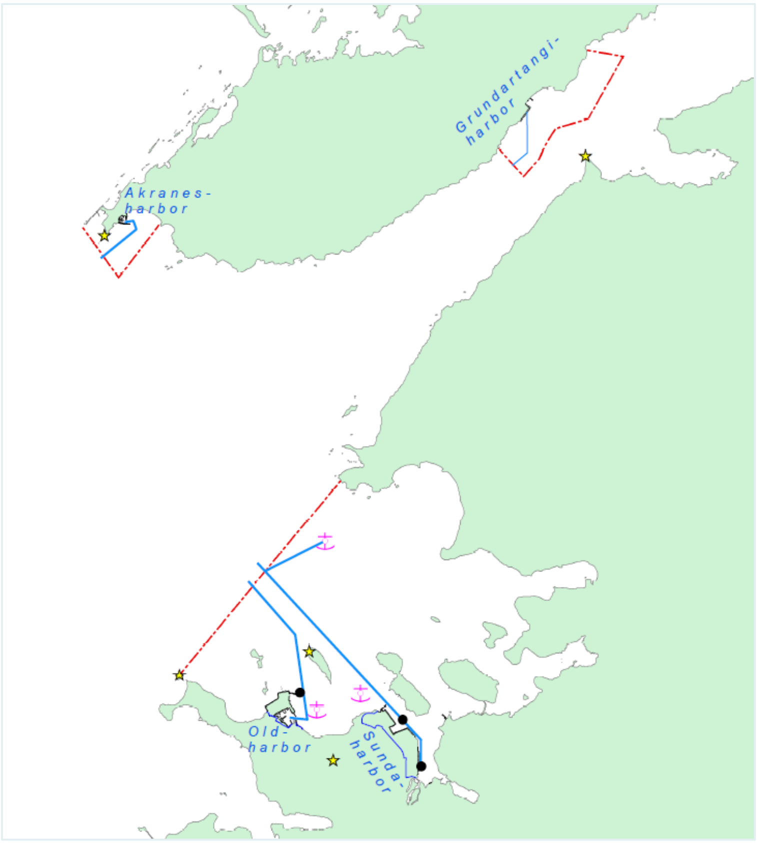

Figure 1. The four ports of Faxaflóahafnir and the areas outside the ports included in the emission inventory.

This report describes the emissions calculation model, the data used, and results. Results for 2023 are analysed and discussed in relation to emission calculations made from ships calling the port in the years 2017 - 2022. The method has been updated to account for the mitigating effects that scrubbers have on emissions to air for PM, NMVOC and SO_2. Also, emission factors for SO_2 have been changed from using the legal limits to using yearly average sulphur contents as reported by IMO.

2 Ship traffic

In total, this inventory covers 5 892 port calls comprising in total 1 504 larger vessels. In addition to these calls, the port received 4 387 calls from whale watching boats in 2023, which is still 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 to be 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. When doing so, the latest berth of visit is chosen 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. These values include the calls themselves.

Table 2: Number of port calls and ship movements registered in 2023 in the different harbours in Faxaflóahafnir. The number of ship movements in the used data are lower than in the data from port call statistics since some ships are omitted, for example due to being military vessels or lacking information.

Harbour	Port calls (cargo, cruise, fishing and "other")	Port calls (whale watching boats)	Ship movements (cargo, cruise, fishing and "other")	
			Used data	Port call statistics data
Akranes harbour	38	0	47	48
Grundartangi harbour	155	0	317	334
Old harbour	615	4 387	767	793
Sunda harbour*	697	0	944	954
TOTAL	**1 505**	**4 387**	**2 075**	**2 129**

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

Whale watching boats are assumed to be berthing if they stay 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.

In this year's harbour inventory, the calculation method has been updated to include the mitigating effect scrubbers have on SO_2, PM, and NMVOC emissions. Scrubbers are assumed to decrease PM emissions by 30.2% and NMVOC emissions by 36.3% (SMED, 2020). For SO_2, the emission factors have been changed from the legal emission limits to the average sulphur contents in fuel provided by IMO (see Appendix 2). SO_2 emissions from ships running on residual oil with scrubbers are assumed to equal SO_2 emissions running on VLSFO. The emissions for the years 2016 – 2022 have been recalculated along with the 2023 emissions to account for this change. This update decreased total PM and NMVOC emissions in 2020-2022 with between 4.6-10.1% and 0.6-1.8% respectively. SO_2 emissions decreased around

0-13% from 2016-2019 and 21-30% from 2020-2022 compared to if the old emission factors were to be used.

Emission factors for CO_2, CH_4, N_2O, and NMVOC 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). NO_X-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).

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, we assume the same SO_2 emission factor as for Very Low Sulphur Fuel Oil (VLSFO).

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 VLSFO). 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. 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 for NO_X are those registered for the Environmental Ship Index (ESI). The ESI is an index that indicates a ships emission performance, specifically regarding NO_X and CO_2. The ESI register used for this inventory is valid for 2023. The ships in the ESI register are presented in Appendix 3 together with 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 also 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, 2022). *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.

Table 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).

Table 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).

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

Category No.	In port basin	Mano-euvring	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 un-loading (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 un-loading (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 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.

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

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

[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.

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 emissions of greenhouse gases that occur during the production, refining, and transportation of fuel are commonly referred to as well-to-tank (WTT) emissions. These emissions can be contrasted with those that occur during combustion, typically known as tank-to-wheel (TTW) emissions. It is particularly important to include these upstream emissions, when using biofuels and electricity. This is because greenhouse gas emissions from these sources are not usually accounted for at the exhaust pipe/propeller. Instead, emissions are reported during the production of these fuels, thus WTT emissions are also included in this study. We refer to the total emissions as well-to-wheel/propeller (WTW), which encompasses both WTT and TTW emissions.

For upstream emissions related to MGO, we have utilized emission factors from JEC, which are the standard factors used within Europe (Prussi et al. 2020). Emission factors presented in other scientific publications are considerably lower, as evidenced by examples such as Brynolf (2014) and Brynolf et al. (2014a) which are well-aligned with those found for light and heavy fuel oils in the LCA database Sherpa (European average). However, there are indications that new standards for upstream emissions for marine fuels will be established in conjunction with the finalization of "Fuel EU Maritime".

To calculate the upstream emissions, first the amount of primary energy found in the unburned fuel is calculated. Then the upstream emissions can be calculated using the upstream emission factors.

The energy consumption for main motors and auxiliary machines is calculated using Equation 3:

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

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

LCV: Lower calorific value of the fuel in MJ / kg fuel (heating value), see Table 7 for details.

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.

$$Fuel_{MJ} = FC_{GT} \cdot LCV \cdot GT \cdot t \quad (4)$$

where:

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

GT: is the ship's gross tonnage

t: is the time the boilers have been used

Table 7: Lower heating value for different fuels.

Fuel type	Lower heating value	Source
MD	43.0	Bengtsson et. al. (2011)
RO	40.4	Bengtsson et. al. (2011)
VLSFO	40.4	Assumed same as RO

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 is 25 for CH_4 and 298 for N_2O (IPCC, 2013).

4 Results

Table 8 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 2023, the operations *at berth* can be attributed approximately 78% of the total CO_2 emissions. The CO_2 emissions from the auxiliary engines is calculated to be 43% of the total fuel consumed by all three engine types. Emissions of the greenhouse gases, dominated by CO_2 emissions, reached a value of 72 600 tonnes of CO_2e.

Table 8: Overview of emissions from ships in Faxaflóahafnir 2023.

		Greenhouse gas emissions			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)
		CO_2e (ton) WTW	CO_2e (ton) TTW	CO_2 (ton) TTW				
		Well-To-Propeller (WTW)	**Tank-to-Propeller (TTW)**					
Main Engines	In port basin	8 300	6 800	6 700	100	3.10	5.5	17.6
	At anchor**	400	300	300	5	0.10	0.1	0.1
	Manoeuvring	1 300	1 000	1 000	20	0.50	0.7	2.4
	At berth*	17 000	14 100	13 800	170	6.00	3.5	5.1
Auxiliary Engines	In port basin	2 200	1 800	1 700	20	1.30	0.5	0.6
	At anchor*	1 000	800	800	10	0.60	0.2	0.3
	Manoeuvring	500	400	400	6	0.30	0.1	0.1
	At berth*	27 700	21 900	21 300	320	21.90	12.0	13.4
	Tankers at berth using cargo pumps	200	100	100	0.9	0.10	<0.05	0.1
Boilers	In port basin	1 000	800	800	0.8	<0.05	0.1	0.3
	At anchor**	300	200	200	0.2	<0.05	<0.05	0.1
	Manoeuvring	100	100	100	0.1	<0.05	<0.05	<0.05
	At berth*	12 600	10 000	9 900	9	0.17	0.8	3.8
TOTAL (Engines and boilers)	Main engines	26 900	22 200	21 800	300	9.7	9.9	25.30
	Auxiliary engines	31 700	25 100	24 800	360	18.3	6.7	8.40
	Boilers	14 000	11 200	11 200	10	0.1	0.9	4.20
TOTAL (Operational modes)	In port basin	11 500	9 400	9 300	130	4.4	6.0	18.6
	At anchor**	1 700	1 400	1 400	20	0.7	0.3	0.5
	Manoeuvring	1 900	1 500	1 500	20	0.8	0.9	2.6
	At berth*	57 400	46 200	45 600	500	22.2	10.2	16.2
TOTAL	**All engines and boilers, all operational modes**	72 500	58 500	57 800	670	28	17	38

*Only cruise ships with diesel electric power trains

**Include emissions from ships in shipyard

In Table 9 the emissions from 2016-2023 are presented together. Results for previous years have been recalculated, which has an effect especially on PM and SO_2 emissions. For SO_2, average values from IMO have been used for years 2016-2022 (see Appendix 2), with 2023 using the 2022 average as it was the latest available data.

Table 9: Emissions and number of calls from 2016 to 2023 for ships visiting Faxaflóahafnir.

Year	Växthusgasutsläpp			N_2O (ton)	NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (TTW)						
2016	45 600	36 500	36 100	1.41	500	20	11	72	7 136
2017	52 500	42 100	41 600	1.60	560	21	12	89	7 059
2018	57 200	45 800	45 300	1.76	610	24	13	93	6 006
2019	68 100	54 600	54 000	2.10	730	29	16	104	6 955
2020	50 600	40 300	39 800	1.51	500	22	11	20	2 818
2021	43 000	34 400	34 000	1.28	410	18	10	24	3 670
2022	60 900	49 000	48 300	1.81	570	24	14	32	5 394
2023	72 600	58 500	57 700	2.16	670	26	16	38	5 892

In Figure 2, CO_2 emissions are presented for the different ship types in 2017 to 2023:

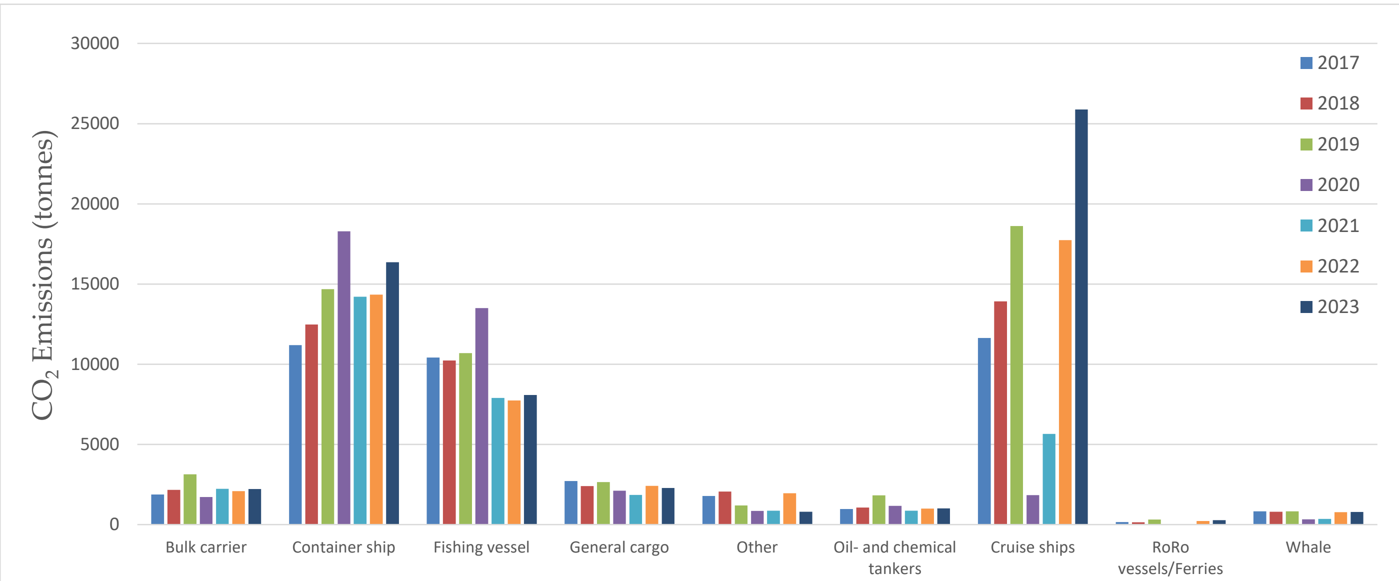

Figure 2: CO2 emissions for different ship types 2017-2023.

Figure 3 illustrates the number of port calls by each ship types for the above-mentioned years. Cruise ships emissions have reached an all-time high due to an 38% increase in port calls. Container ship emissions also went up slightly, while other categories stay around the same level as before. Port calls from whale watching boats increased from around 4 000 in 2022 to around 4 400 in 2023. However, they have no significant impact on the total emissions.

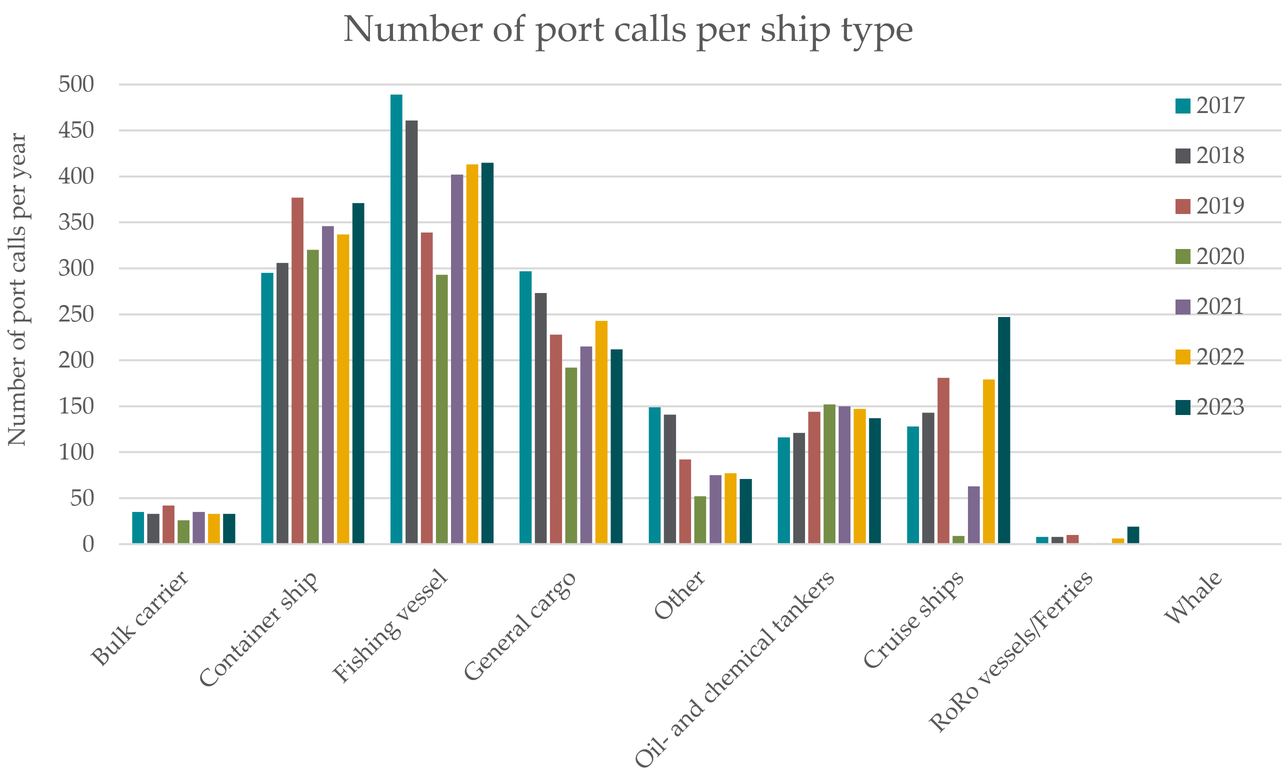

Figure 3: Number of port calls for different ship types 2017 to 2023.

In Figure 4, a calculation of the average CO_2 emission per port call for different ship categories provides an insight into which ships contribute the most toward the total emissions:

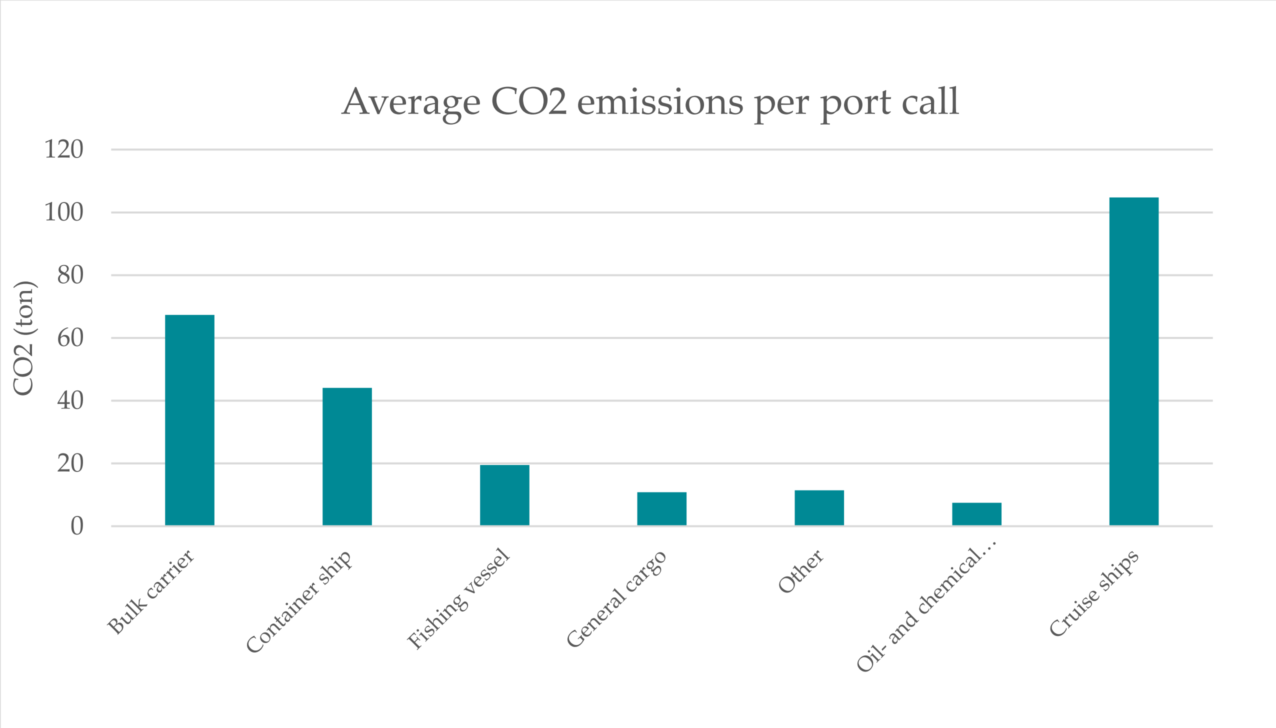

Figure 4: Average CO_2 emissions per port call for different ship categories in 2023.

Faxaflóahafnir provides connections to shore side electricity in Old harbour, Sunda harbour, and Akranes 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 10 for the four 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 10: Total avoided emissions from the use of shore side electricity in the port 2023.

Harbour	Växthusgasutsläpp			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton) TTW				
Akranes harbour	105	83	82	1	0.06	0.02	0.01
Grundartangi harbour	-	-	-	-	-	-	-
Old harbour	1 195	947	935	13	0.7	0.3	0.3
Sunda harbour	733	581	573	8	0.4	0.2	0.1
TOTAL	**2 033**	**1 612**	**1 590**	**23**	**1.2**	**0.4**	**0.4**

Table 11 lists all emissions in 2023 divided by ship type:

Table 11: Emissions and ship calls per ship type in Faxaflóahafnir in 2023.

Ship type	Greenhouse gas emissions			N_2O (ton)	NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 TTW						
Dry bulk carriers	2 830	2 250	2 220	0.1	24	1.4	0.6	1.0	33
Container ships	20 700	16 540	16 360	0.6	190	8.4	5.7	14	371
Cruise ships	32 190	26 290	25 890	1.0	288	10.2	7.9	18	247
Oil- and chemical tankers	1 310	1 040	1 020	0.04	7	0.6	0.2	0.5	137
RoRo vessels/Ferries	360	290	280	0.01	4	0.2	0.1	0.2	19
General cargo ships	2 920	2 320	2 290	0.1	32	1.6	0.6	1.3	212
CRUISE AND CARGO SHIPS*	**60 310**	**48 730**	**48 060**	**2**	**545**	**22**	**15**	**35**	1019
OTHER SHIPS	1 020	820	810	0.0	5	0.3	0.1	0.3	71
FISHING VESSELS	10 290	8 180	8 080	0.3	107	5.1	2	2.4	415
WHALE WATCHING BOATS	1000	800	800	0.03	11	0.5	0.2	0.3	4387
TOTAL 2023	**72 600**	**58 500**	**57 800**	**2.2**	**668**	**28**	**17**	**38**	**5 892**

*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 5 gives a graphical representation of how much different ship types contribute to the total emissions of a certain category:

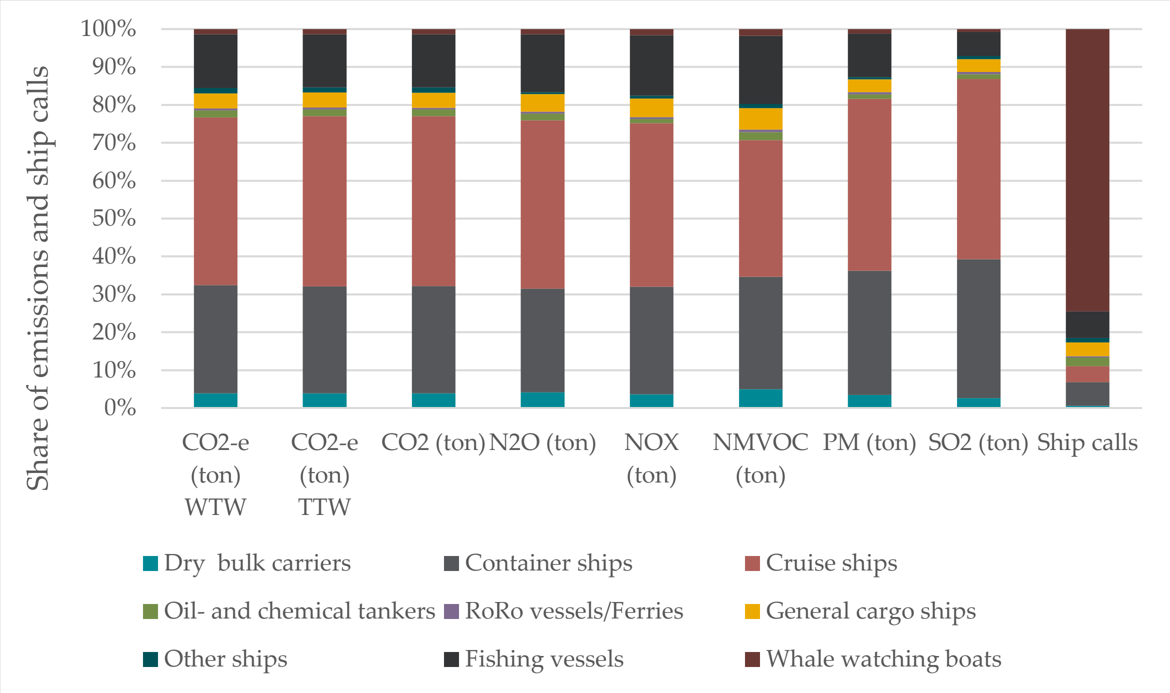

Figure 5. Share of total emissions and ship calls by the ship type categories in 2023.

Emissions from ships in the different harbour areas

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 50 710 tonne emissions of CO_2e. Akranes harbour is the least emitting harbour with approximately 880 tonnes of CO_2e emitted in 2023. Table 12 shows an overview of the emissions in the different harbour areas of Faxaflóahafnir 2023.

Table 12: Emissions from ships in the different harbour areas of Faxaflóahafnir in 2023.

Harbour	Växthusgasutsläpp			NOx	NMVOC (ton)	PM	SO₂	Port calls (cargo, cruise, fishing and "other")	Port calls (whale watching boats)
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (TTW)						
Akranes harbour	880	700	690	8.3	0.4	0.2	0.2	38	0
Grundartangi harbour	7 350	5 860	5 790	71.2	3.5	1.6	3.9	155	0
Old harbour	13 660	10 910	10 770	128.9	6.4	2.7	4.4	615	4387
Sunda harbour*	50 710	41 060	40 490	459.4	17.8	13.0	29.4	697	0
TOTAL	**72 600**	**58 500**	**57 700**	**670**	**28**	**17**	**38**	**1 505**	**4 387**

*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 13 (Akranes harbour), Table 15 (Grundartangi harbour), Table 17 (Old harbour), and Table 19 (Sunda harbour). The total emissions from each harbour area for the last seven years are accounted for in separate tables, Table 14 (Akranes harbour), Table 16 (Grundartangi harbour), Table 18 (Old harbour), and Table 20 (Sunda harbour).

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

Akranes harbour

Table 13. Akranes harbour - emissions from different ship types 2023 and the number of calls.

	Växthusgasutsläpp			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton) TTW					
Dry bulk carriers	184	146	144	2	0.1	0.04	0.1	10
Container ships	-	-	-	-	-	-	-	0
Cruise ships	70	58	57	0.3	<0.05	<0.05	<0.05	1
Oil- and chemical tankers	8	6	6	0.1	<0.05	<0.05	<0.05	1
RoRo vessels/Ferries	-	-	-	-	-	-	-	0
General cargo ships	111	88	87	1.3	0.06	0.02	0.05	11
CRUISE AND CARGO SHIPS*	**370**	**300**	**290**	**4**	**0.2**	**0.1**	**0.1**	23
OTHER SHIPS	-	-	-	-	-	-	-	0
FISHING VESSELS	510	400	400	4.6	0.2	0.1	0.1	15
WHALE WATCHING BOATS	**-**	-	-	-	-	-	-	0
TOTAL 2023	**880**	**700**	**690**	**8.2**	**0.4**	**0.2**	**0.2**	38

*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 14. Emissions from ships calling Akranes harbour 2017 to 2023, and the number of calls.

	Växthusgasutsläpp			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton)					
2017	3 350	2 660	2 630	30	1.6	0.6	0.8	44
2018	1 300	1 040	1 020	12	0.7	0.3	0.5	34
2019	1 250	1 000	980	14	0.6	0.3	0.6	26
2020	210	170	170	2	0.1	0.05	0.1	15
2021	500	400	390	6	0.3	0.1	0.2	31
2022	860	680	680	9.0	0.4	0.2	0.3	57
2023	880	700	690	8.0	0.4	0.2	0.2	38

Grundartangi harbour

Table 15: Grundartangi harbour – emissions from different ship types in 2023.

	Växthusgasutsläpp			NOx (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton) TTW					
Dry bulk carriers	2 541	2 019	1 995	21.1	1.2	0.5	0.9	21
Container ships	3 383	2 705	2 675	34.9	1.5	0.8	2.3	30
Cruise ships	-	-	-	-	-	-	-	0
Oil- and chemical tankers	-	-	-	-	-	-	-	0
RoRo vessels/Ferries	7	6	6	0.1	<0.05	<0.05	<0.06	1
General cargo ships	1 386	1101	1087	14.9	0.7	0.3	0.6	90
CRUISE AND CARGO SHIPS*	**7 320**	**5 830**	**5 760**	**71.0**	**3.5**	**1.6**	**3.8**	142
OTHER SHIPS	32	26	26	0.2	0.01	0.01	0.04	13
FISHING VESSELS	-	-	-	-	-	-	-	0
WHALE WATCHING BOATS	-	-	-	-	-	-	-	0
TOTAL 2023	**7 350**	**5 860**	**5 790**	**71.2**	**3.5**	**1.6**	**3.9**	**155**

*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 16: Emissions from ships calling Grundartangi harbour 2017 to 2023, and the number of calls.

	Växthusgasutsläpp			NOx (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton) TTW					
2017	6 050	4 820	4 770	62	2.8	1.3	11.5	166
2018	6 310	5 030	4 970	63	2.9	1.4	11.2	179
2019	5 630	4 490	4 440	58	2.6	1.3	10.5	153
2020	6 180	4 920	4 870	62	2.9	1.3	3.2	144
2021	6 740	5 370	5 310	70	3.2	1.5	4.2	160
2022	7 270	5 800	5 730	73	3.4	1.6	4.0	166
2023	7 350	5 860	5 790	71	3.5	1.6	3.9	155

Old harbour

Table 17: Old harbour – emissions from different ship types in 2023.

	Växthusgasutsläpp			NOx (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton)					
Dry bulk carriers	-	-	-	-	-	-	-	0
Container ships	231	186	184	2.2	0.1	0.1	0.3	10
Cruise ships	3 717	2987	2950	34	1.7	0.8	1.5	80
Oil- and chemical tankers	1 200	956	934	6.1	0.6	0.2	0.4	132
RoRo vessels/Ferries	281	224	222	3.0	0.1	0.1	0.2	14
General cargo ships	3	2	2	<0.05	<0.05	<0.05	<0.05	2
CRUISE AND CARGO SHIPS*	**5 430**	**4 360**	**4 290**	**45**	**2.5**	**1.1**	**2.3**	238
OTHER SHIPS	706	563	560	2.5	0.1	0.1	0.2	44
FISHING VESSELS	6 540	5195	5132	70	3.3	1.3	1.5	333
WHALE WATCHING BOATS	984	797	786	11	0.5	0.2	0.3	4 387
TOTAL 2023	**13 660**	**10 920**	**10 770**	**130**	**6.4**	**2.7**	**4.4**	5 002

*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 18: Emissions from ships calling Old harbour 2017 to 2023, and the number of calls.

	Växthusgasutsläpp			NOx (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton)					
2017	12 720	10 140	10 020	140	6.0	2.5	9.5	6209
2018	15 890	12 650	12 500	170	7.7	3.1	9.1	5182
2019	17 880	14 240	14 070	190	8.8	3.5	9.6	6138
2020	14 670	11 670	11 530	150	7.1	2.8	3.3	2217
2021	10 830	8 650	8 540	100	5.1	2.1	3.7	2960
2022	14 520	11 570	11 420	140	6.8	2.8	4.5	4554
2023	13 660	10 910	10 770	130	6.4	2.7	4.4	5002

Sunda harbour

Table 19: Sunda harbour – emissions from different ship types in 2023.

	Växthusgasutsläpp			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton)					
Dry bulk carriers	105	83	82	0.9	0.1	<0.05	<0.05	2
Container ships	17 082	13 651	13 504	153	6.8	4.8	11	331
Cruise ships	28 399	23 250	22 878	254	8.5	7.1	16	166
Oil- and chemical tankers	102	82	80	0.9	<0.05	<0.02	<0.05	4
RoRo vessels/Ferries	71	56	56	0.8	<0.05	<0.05	<0.05	4
General cargo ships	1 420	1 131	1 116	16	0.8	0.3	0.7	109
CRUISE AND CARGO SHIPS*	**47 180**	**38 250**	**37 720**	**425**	**16.1**	**12.3**	**28.5**	**616**
OTHER SHIPS	284	227	225	2	0.1	<0.05	0.1	14
FISHING VESSELS	3 246	2 579	2 548	32	1.6	0.6	0.8	67
WHALE WATCHING BOATS	-	-	-	-	-	-	-	0
TOTAL 2023	**50 710**	**41 060**	**40 490**	**460**	17.8	13.0	29.4	697

*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 20: Emissions from ships calling Sunda harbour 2017 to 2023, and the number of calls.

	Växthusgasutsläpp			NO_x (ton)	NMVOC (ton)	PM (ton)	SO_2 (ton)	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2 (ton)					
2017	30 390	24 460	24 180	330	12.0	7.3	67.5	640
2018	33 660	27 100	26 780	360	13.3	8.1	72.6	611
2019	41 420	33 370	32 980	450	16.4	9.8	82.2	619
2020	29 520	23 550	23 290	280	12.8	6.5	13.5	442
2021	24 890	19 980	19 760	230	9.5	6.9	15.8	519
2022	38 210	30 910	30 480	350	13.7	10.1	23.4	617
2023	50 710	41 060	40 490	460	17.8	13.0	29.4	697

5 Discussion

Reason for increase in emissions:

Total emissions increased with 19% since last year, from 60 900 CO_2e in 2022 to 72 600 CO_2e in 2023. This can first and foremost be attributed to the increased traffic from cruise ships (38% more port calls and 43% more time at berth). As shown in Figure 4, cruise ships cause the most CO_2 emissions per port call on average, and an increase in traffic therefore has significant impacts on the result. The second largest factor contributing to the heightened emission level is the increased traffic from container ships which is almost back to the pre-pandemic level of 2019. Container ships also cause relatively high emissions per port call, yet only around half that of cruise ships. Overall, the port saw an increase in traffic compared to 2022, but the amount of port calls is still lower than before the pandemic. Calls from non-whale watching vessels were 1 505 in 2023, compared to 1 435 in 2022. This in an increase of 5%.

Model considerations:

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 and engine loads at different operational modes. This causes 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.

Regarding the calculation of avoided emissions from shore-side electricity use, the method for this calculation remained the same. In this method it is assumed that ships which have the option to connect to shore-side electricity always use it, and that the supplied electricity is green. It is also assumed that the ships run their auxiliary engines one hour before and after connecting at berth. The issue with updating this method is that the information provided on shore-side electricity usage is hard to interpret. For example, ships often report the value "400" which appears to be what the operator pays for if they've used 400 kWh or less in a month. It would be better if the data consistently showed actual power consumption. A separate Excel file was provided this year containing shore-side electricity usage for two container ships berthing at Sunda harbor. This data was of high quality but was not used in the inventory as data on two ships does not warrant a change of the methodology.

Comparison between ports:

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.

Given this information, here is a comparison of average values of emissions of ton CO_2 (Tank-to-propeller) per call in the four port areas from 2017 to 2023:

- In Akranes harbour, the average values for ton CO_2 emissions per port call have been:

2017: 60	2021: 13
2018: 30	2022: 12
2019: 38	2023: 18
2020: 11	

  Due to the total amount of port calls being low for Akranes, the average can fluctuate heavily dependent on the individual ships that call the port.

- In Grundartangi harbour, the average values for ton CO_2 emissions per port call have been:

2017: 29	2021: 33
2018: 28	2022: 34
2019: 29	2023: 37
2020: 34	

  The increase is mainly due to cargo ships staying longer at berth and having slightly higher average CO_2 emissions per port call compared to 2022.

- In Old harbour, the average values for ton CO_2 emissions (excluding whale-watching boats) per port call have been:

2017: 14	2021: 14
2018: 18	2022: 18

2019: 22	2023: 16
2020: 25	

Average emissions in Old harbour saw a slight decrease which can be attributed mainly to fishing vessels reducing their average CO_2 emissions per port call with around 20%, spending less time at berth and at shipyards. Fishing vessels make up around half of the non-whale-watching traffic to Old harbour.

- In Sunda harbour, the average values for ton CO_2 emissions per port call have been:

2017: 38	2021: 38
2018: 44	2022: 49
2019: 53	2023: 58
2020: 53	

Average emissions in Sunda harbour have risen above pre-pandemic levels in 2023. Cruise ship traffic to Sunda harbour increased with 50% from 2022, raising the average significantly.

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.

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