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Emissions from ships in Faxaflóahafnir 2021

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

Table of contents

Summary

In this study we calculate the emissions to air from ships in Faxaflóahafnir 2021. 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 2017, 2018, 2019, and 2020.

For each port call, emissions of greenhouse gases (*well-to-wheel and tank-to-wheel*), nitrogen oxides (NO_X), hydrocarbons (HC), particulate matter (PM), and sulphur dioxide (SO_2) are calculated using an emission inventory model specifically developed for port areas. Total emissions in 2021 are presented in the Table 1.

Tabell 1 Result summary of the emissions to air from ships in Faxaflóahafnir 2021

	Greenhouse gas emissions			NO_X (ton)	HC (ton)	PM (ton)	SO_2 (ton)
	WTW CO_2-e(ton)	TTW CO_2-e (ton)	TTW CO_2 (ton)				
Total emissions 2021	**42 819**	**34 301**	**33 899**	**407**	**19**	**12**	**32**

Previous years container ships and cruise ships were the two ship categories that accounted for the largest shares of emissions in the port. Each of them usually contributes approximately 30% of the total emissions of CO_2 equivalents from the ships visiting Faxaflóahafnir. In 2021, cruise ships were responsible for 16% of the total CO_2 emissions, while container ships accounted for the around 42%. The average amount of emissions per call by cruise ships are higher than from other vessels.

In 2021, the fishing vessels constituted the second largest contributing ship type category in the port since cruise ships calls during 2020 were few. In 2021, the fishing vessels accounted for approximately 23% of the CO_2 equivalents emissions in the port. The frequent traffic to the port of whale watching boats (5 542 calls in 2019, decreased to only 1 773 in 2020) has seen a slight increase compared to the previous year, reaching 2 383 in 2021. But since these vessels in general have relatively small engines, their contribution to the total CO_2 equivalents is calculated to be only around 1.6% for 2019, 0.8% in 2020 and 1.3% in n 2021.

Sunda harbour and Old harbour receive significantly more ship calls than Akranes and Grundartangi. Sunda harbour is the harbour area that receives most container ships (288 in 2021) and the highest amount of visiting cruise ships (34). Ships calling Sunda harbour are responsible for more than half of the emissions to air in Faxaflóahafnir, regardless the type of emission. Ships in Sunda harbour and Old harbour account for approximately 25 000 and 10 500 tonnes of the total CO_2 equivalents emissions, respectively.

In a comparison with CO_2 equivalents emissions from ships in the port in 2020, there was a net decrease. The difference can mainly be attributed to a decrease of time at berth for both container ships and fishing vessels even though the number of calls increased.

In this report the power demand for container ships and product tanker have been slightly updated. Also, the assumed fuel consumption of container ship has been updated based on new data. The historic emission results have therefore also been updated accordingly.

1 Introduction

IVL Swedish Environmental Research Institute has on assignment of Faxaflóahafnir calculated emissions from ships visiting its ports in 2021. 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*), nitrogen oxides (NO_X), hydrocarbons (HC), particles (PM), and sulphur dioxide (SO_2). The emission calculations are based on call statistics obtained from the port.

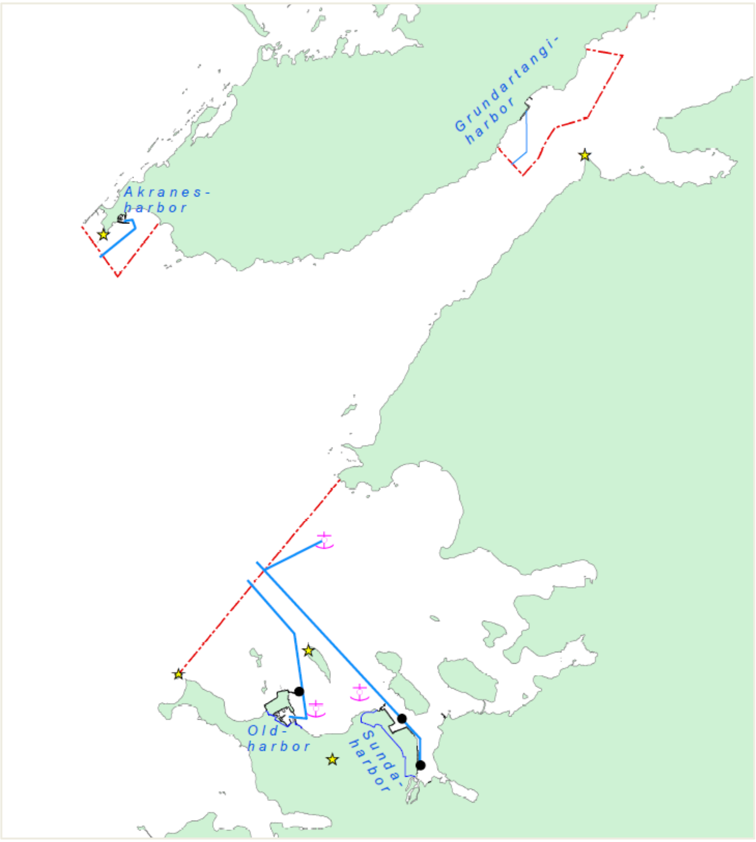

Figure 1. The four ports of Faxaflóahafnir and the areas outside the ports included in the emission inventory.

This report describes the calculation models, the data used, and the results from the calculations. Results for 2021 are analysed and discussed in relation to emission calculations made from ships calling the port in 2017, 2018, 2019 and 2020. 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. Earlier the average sulphur in the fuel used in the port area was assumed to be about 2.7 %, however according to the new regulation ship are only allowed to use fuel with a sulphur content of maximum 0.5 % or using scrubbers.

2 Ship traffic

In total, this inventory covers 3 667 port calls comprising in total 1 284 larger vessels. In addition to these calls, the port received 2 383 calls from whale watching boats in 2021, 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. The ships that are in traffic to and from the port have been categorised into nine ship types, depending on the type of cargo they carry or the service they provide. The ship types are "Dry bulk carriers", "Container ships", "Cruise ships", "Oil- and chemical tankers", "RoRo-vessels/Ferries", "General cargo ships", "Fishing vessels", "Whale watching boats" and "Other ships".

For each of the four harbours an area has been identified within which emissions from the ships are calculated. These areas are indicated by red lines in Figure 1. The emissions from ships in these areas are calculated for four different operational modes: *in port basin*, *manoeuvring*, *at berth*, and *at anchor*. Emissions from *in port basin* operations are emissions from the time spent for each ship in transit between the outer boundary of the port area and their assigned berth. *Manoeuvring* operations are estimated to twenty minutes per call, during which the ships are manoeuvred with high precision before and after laying still at quayside – a period which often requires rapid engine load changes that influence emission parameters. During periods *at berth*, the ships are assumed to use auxiliary engines for electricity requirements on board. An exception are cruise ships with diesel electric power trains that provides auxiliary power from the main engines. Several of the ships in Faxaflóahafnir also use shore side electricity when at berth. Statistics on time at berth and shore side power use for individual ship calls have been provided by Faxaflóahafnir. There are four anchoring sites in the traffic areas covered by the inventory. During periods *at anchor*, operation of ship engines is similar to operation *at berth*, although power needs are lower for certain ship types.

The time in the *port basin* is estimated from the distance between a quay and the limits of the traffic area. Further, ship speeds are assumed to be related to ship sizes, and ship size has therefore been used as a proxy to estimate time in the area. All estimates have been provided by Faxaflóahafnir and can be found in Appendix 1.

All movements in the port area are assigned a unique call-ID. During a visit in the port a ship may have more than one registered call-ID if it moves between different berths or from an anchoring site to quay. For each movement between berths, a manoeuvring period is added in the calculations assuming 20 minutes in transfer. For parts of our analysis, we assign a specific berth to each call. An update to 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 which is shown in Table 2.

Tabell 2. Number of port calls and ship movements registered in 2021 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	28	0	33	33
Grundartangi harbour	163	0	342	343
Old harbour	565	2 383	712	737
Sunda harbour*	528	0	853	868
TOTAL	**1 284**	**2 383**	**1 940**	**1 981**

*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 from Cooper and Gustavsson (2004). Emission factors for NO_x are assumed to follow the regulatory standards that became effective in 2005 and that apply to all ships keels laid from 2000 (Tier I) and that were further strengthened in 2011 (IMO, 2011). Ships constructed prior to 1990 are not covered by any regulations unless they have undergone significant engine changes, and ships constructed between 1990 and 2000 are only covered if specific criteria on engine size and technical possibilities for emission reductions are met. Information on which ships from before 2000 that fulfil Tier I requirements has not been available, and for all ships from before that year emission factors that are representative for engines that have no NO_X reduction measures are used (Cooper and Gustafsson, 2004). Emission factors for newer ships follow regulatory standards: Tier I levels for ships constructed between 2000 and 2011, and Tier II levels for ships built thereafter (IMO, 2011). In Appendix 2 the details of the calculations behind emission factors in the regulations are presented. Emission factors for sulphur dioxide are based on the fuel consumption and the estimated sulphur content of the fuels used. Fishing vessels are assumed to use different qualities of fuel, depending mainly on vessel size, with fuel sulphur content varying from 0.001% to 0.5% S. Whale watching boats are assumed to use only marine gasoil with an estimated sulphur content of 0.1%. For the ships using scrubbers we have assumed the reduction in emissions of SO_2 to correspond to an average sulphur content of 0.5 %.

The emission factors for particles (PM) are to certain extent dependent on the sulphur content of the fuel. A literature review of emission measurement results shows no clear relationship between fuel sulphur content and particle emissions at low sulphur content (>0.1 %), and, further, that a dependence on engine load is uncertain, we here only make a distinction between PM emission factors for fuels that have an assumed sulphur content of >0.1 %, such as Ultra-Low Sulphur Fuel Oil (ULSFO)/MGO and fuels that have an assumed sulphur content of >0.5 % (such as Very-Low Sulphur Fuel (VLSFO) or ships using scrubbers). The emission factors for PM emissions are presented in Appendix 2.

It is common to use oil fired boilers on board ships to produce steam and heat. When the main engine is running on high loads the boiler is often replaced by an exhaust gas economiser that uses excess heat from the exhausts for heat and steam production. However, when at berth or operating on low main engine loads, the oil-fired boilers are needed since the exhaust gas heat is too low for meeting the demand of steam and heat on board.

Only few studies report on emission factors from boilers. In this study, we use emission factors from USEPA (1999) reported for boilers in relevant sizes for ship installations. The emission factors used are found in Appendix 2. Emissions of CO_2 and SO_2 from boilers are calculated from expected carbon and sulphur content in the fuel used, assuming use of marine distillate oil with a 0.1% sulphur content and complete combustion. The uncertainties in the calculated emissions from boilers are relatively high due to the lack of reliable emission factors, and due to limited available information on the utilisation of boiler power.

Some ships are assigned individual emission factors. These include ships that connect to shore side electricity at berth, which are assumed to have no emissions at berth except for the time used to connect and disconnect to the power grid. The fishing vessels in the HB Grandi fleet are also treated as special cases as these are known to use fuel with very low sulphur content. Another category of ships that are assigned individual emission factors are those registered for the Environmental Ship Index (ESI). The ESI is an index that tells how well ships perform with regard to emissions of NO_X, SO_X and CO_2. The ESI register that we use for this inventory is valid for 2021. 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 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). Except for container ships at berth and anchor and product tankers at anchor, which are instead determined from specific power demand, see Appendix 2 All auxiliary engines are assumed to be high speed diesel engines.

The installed main engine power for fishing vessels is taken from *SeaWeb*. Auxiliary engine powers are estimated as central values in a span of likely installed auxiliary power for ships of different sizes and installed main engine power. A categorization of fishing vessels has in a previous study been provided by HB Grandi (HB Grandi, 2017). HB Grandi is a large sea food company based in Reykjavík and owner of ten large fishing vessels. Each category was assigned a typical range of installed main engine- and auxiliary engine power, respectively. We have matched the categories and the installed main engine power of shipping vessels in Faxaflóahafnir stated in the *Sea-web Ship* data base. As a result, fishing vessels are divided into five categories primarily based on installed main engine power. The categories and the central values for installed auxiliary engine power used in the calculations are presented in Table 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 important information for the emission calculations. This information is often relatively uncertain and differs a lot between different ships. For this study generic values first reported by Entec UK (2002) are used. These values are presented in Table 4. However, for container ships at berth and at anchor and product tankers at anchor, the used auxiliary power demand is described in 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

Main engine load of fishing vessels is assumed to be the same as for the other ship categories. However, the installed auxiliary engine power on certain categories of fishing vessels is to a large extent dimensioned for electricity need to freeze fish or for trawling. From information and values provided by HB Grandi we have made assumptions on utilization of auxiliary engine power as presented in Table 5 (HB Grandi, 2017).

Tabell 5 Estimated power utilization of auxiliary engines in different categories of fishing vessels. The estimated power requirements for the categories are presented in Table 3.

Category No.	In port basin	Manoeuvring	At berth	Comment
1	0	0	0	No aux engines are installed on these vessels
2	0	50%	21%	Auxiliary engine system dimensioned for trawling. Therefore, lower aux engine load at berth assumed than for other ship types. 21 % is an estimated value.
3	0	50%	40%	These ships often use shaft generators and the engine dimensions and utilization can be assumed to be similar to most ship types.
4	40%	50%	26%	These ships can process and freeze fish on board. Between 17% and 43% of installed aux engine power is needed for freezing. At berth, shore side electricity is not always enough. We assume that they need power for freezing and un-loading (up to 300 kW), 50% of this time. For 50% of the time, during lay-up, 150 kW is assumed to be needed. 26% aux engine utilization is an approximated average for time at berth.
5	40%	50%	23%	These ships can process and freeze fish on board. Between 15% and 40% of installed aux engine power is used at berth. At berth, shore side electricity is not always enough. We assume that they need power for freezing and un-loading (500-600 kW), 50% of this time. For 50% of the time, during lay-up, 300 kW is assumed to be needed. 23% aux engine utilization is an approximated average for time at berth.

For the ships using shore side electricity when at berth, it is assumed that the auxiliary engines are run to cover electricity production for one hour at berth before the ship has been connected to the network and similarly for one hour after disconnecting. For the rest of the reported time at berth it is assumed that the ships only use electricity produced as "green" electricity[1] which do not add any emissions to the calculations. An exception is the category fishing vessels. The need for electricity is 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

[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.

can often not fulfil the vessels' full power requirements. From the information on supplied amount of shore side electricity (kWh) and estimates of power need on board (kW), we calculate an approximate time that the fishing vessels at berth have their electricity supplied from land. The rest of the time, power from auxiliary engines according to **Error! Reference source not found.** and REF _Ref484172831 \h * MERGEFORMAT **Error! Reference source not found.** are used in the calculations.

Tankers often use electricity from the auxiliary engines to run cargo pumps. In the model, this is accounted for by adding fuel consumption that relates to the carrying capacity of the individual tanker. According to information from a tanker operator the typical fuel consumption for cargo pumps is 3 tonnes/day at off-loading. An off-loading operation for 14 000 tonnes oil requires about 15 hours. Based on this information a generic value of 0.13 kg fuel/tonne cargo has been calculated and is used for all tanker ships at off-loading operations. Further, the amount of cargo on the tankers is estimated to 42% of the ships' dead weight tonnage. The value is based on a study made for Port of Gothenburg in 2017. Thus, for each tanker call, additional fuel consumption (in kg) according to equation (2) is assumed.

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

Large tankers sometimes use steam from oil fired boilers to run their cargo pumps. In this study it is, however, assumed that all cargo pumps use electricity from auxiliary engines. This seems to be the most common arrangement for tankers of the size classes that are common in Faxaflóahafnir; tankers of small sizes tend to use electricity driven pumps while larger ships use steam driven pumps.

The fuel used in main engines during operations *in port basin*, and *manoeuvring* is assumed to be VLSFO or heavy fuel oil for ships that have a scrubber installed, while the fuel used in auxiliary engines is assumed to be marine gasoil with 0.1% S. More detailed information on the use of different fuel qualities by fishing vessels has been possible to include in the model after communication with HB Grandi (HB Grandi, 2017). Large fishing vessels are reported assuming a fuel sulphur content of 0.5% in the main engines, and marine gasoil with 0.1% sulphur in the auxiliary engines, while small fishing vessels are reported to use marine gasoil with 0.1% S, exclusively. All small fishing boats in the HB Grandi fleet use diesel oil with an S-content of 0.001%. The fuel types reported by Grandi are assumed for all fishing vessels of the respective size in the inventory. Further, whale watching boats are assumed to use only marine gasoil.

A size dependent generic value on fuel consumption in ship boilers has been calculated for all visiting ships from values from a report from the Port of Los Angeles (2010). Exceptions are made for the category RoRo/ferry, for which values from a study in Gothenburg is used (Winnes and Parsmo, 2016). The values are presented in Table 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, see 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.

For the vessels, we have used emission factors that have been developed in scientific publications, see for example (Brynolf 2014, Brynolf et al. 2014a). These data are in good agreement with, for example, the emission factors that exist for light and heavy fuel oil in the LCA database Sherpa (European average).

To calculate the upstream emissions, you need to calculate how much primary energy is in the unburned fuel. The energy consumption for main motors and auxiliary machines has been calculated using Equation 3.

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

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.

$$\mathrm{Fuel}_{\mathrm{MJ}} = \mathrm{FC}_{\mathrm{GT}} \cdot \mathrm{HV} \cdot \mathrm{GT} \cdot \mathrm{t} \tag{4}$$

where:

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

t: is the time the boilers have been used

GT: is the ship's gross tonnage.

3.4 Global warming potential (GWP100)

To calculate greenhouse gas emissions, we have converted the emissions of methane (CH_4) and di nitrogen dioxide (N_2O) into carbon dioxide equivalents. In this report, we have used the conversion factors 25 and 298 for CH_4 and N_2O, respectively. These are that represent an emissions GWP with a 100-year perspective[2].

[2] The factors used for calculation of CO_2-eqv are 25 for CH_4 and 298 for N_2O (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 relatively higher than from auxiliary engines, since it is assumed that main engines run on high sulphur fuel to a large extent. Further, main engines are almost exclusively used for propulsion which is the reason to the relative importance of the emissions from the *in-port basin* operational mode. An exception are the diesel electric driven cruise ships which use their main engines also *at berth*, but then exclusively with low sulphur fuel or using aftertreatment.

CO_2 (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 the operations *at berth* can be attributed approximately 75% of the total fuel consumption. The fuel consumption in auxiliary engines is calculated to be 55% of the total fuel consumed in 2021 by all the three engine types. Emissions of the greenhouse gases, dominated by CO_2 emissions, reached a value of 42 800 tonnes of CO_2 equivalents.

Table 7. Overview of emissions from ships in Faxaflóahafnir 2021.

		Greenhouse gases emissions CO_{2-e} (ton)	Greenhouse gases emissions CO_{2-e} (ton)	CO_2 (ton)	NO_x (ton)	HC (ton)	PM (ton)	SO_2 (ton)
		Well-To-Propeller (WTW)	*Tank-to-Propeller* (TTW)					
Main Engines	In port basin	5 100	4 200	4 100	70	3.00	4.7	12.7
	At anchor**	300	300	300	3	0.10	0.1	0.2
	Manoeuvring	800	700	700	10	0.50	0.6	2.1
	At berth*	3 600	3 000	3 000	40	1.20	0.8	1.9
Auxiliary Engines	In port basin	2 000	1 600	1 600	20	1.20	0.4	0.9
	At anchor*	1 100	800	800	10	0.60	0.2	0.5
	Manoeuvring	400	300	300	5	0.20	0.1	0.2
	At berth*	20 600	16 300	15 300	240	23.90	16.7	20.9
	Tankers at berth using cargo pumps	200	100	100	0.7	0.10	0.004	0.1
Boilers	In port basin	600	500	500	0.4	0.01	0.0	0.3
	At anchor**	400	300	300	0.3	0.00	0.0	0.2
	Manoeuvring	100	100	100	0.1	0.00	0.0	0.0
	At berth*	7 700	6 100	6 000	6	0.16	0.6	3.9
TOTAL (Engines and boilers)	Main engines	9 800	8 100	8 000	130	4.8	6.1	16.7
	Auxiliary engines	24 200	19 200	18 900	270	14.0	5.1	10.5
	Boilers	8 800	7 000	7 000	10	0.1	0.5	4.4
TOTAL (Operational modes)	In port basin	7 700	6 200	6 200	90	4.1	5.1	13.9
	At anchor**	1 800	1 400	1 400	20	0.7	0.3	0.9
	Manoeuvring	1 300	1 100	1 100	20	0.7	0.7	2.3
	At berth*	32 000	25 600	25 300	280	13.3	5.6	14.5
TOTAL	**All engines and boilers, all operational modes**	42 800	34 300	34 000	410	19	12	32

*Only cruise ships with diesel electric power trains

**Include emissions from ships in shipyard

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

Table 8. Emissions from ships visiting Faxaflóahafnir 2017, 2018, 2019, 2020 and 2021 and number of calls.

Year	Greenhouse gases emissions			N_2O	NO_x	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2						
2021	42 800	34 300	33 900	1.28	410	19	12	32	3 667
2020	50 600	40 300	39 800	1.51	500	23	11	30	2 818
2019	68 100	54 600	54 000	2.10	730	30	24*	120*	6 955
2018	57 100	45 800	45 200	1.76	610	25	20*	95*	6 006
2017	52 500	42 100	41 600	1.60	560	23	19*	89*	7 059

* Historic values of these emissions were not re-calculated in 2021 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.

In Figure 2, CO_2 emissions are presented for the different ship types in 2017, 2018, 2019, 2020 and 2021. Figure 3 illustrates the number of port calls by each ship types for the above-mentioned years.

Emissions from container ships in 2021 have decreased and come back to values similar to the years previous 2020. Cruise ships emissions, after having undergone a dramatic decrease in 2020, because of the Covid-19 pandemic, have registered an increase in CO_2 emissions which nonetheless remain still low compared to pre-2020 values. Fishing vessels appear to have decreased their emissions in 2021 while increasing the total number of port calls. This is because time at berth has decreased for these ship types, even though, as seen in Figure 3, the number of ship-calls in 2021 has increased.

The other ship types show emission values in line with previous years.

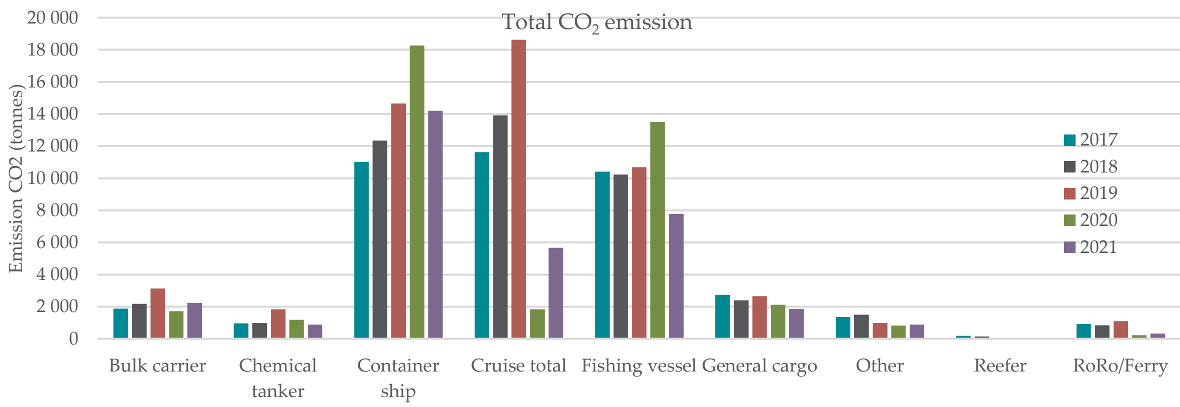

Figure 2. CO_2 emissions from different ship types 2017, 2018, 2019, 2020 and 2021.

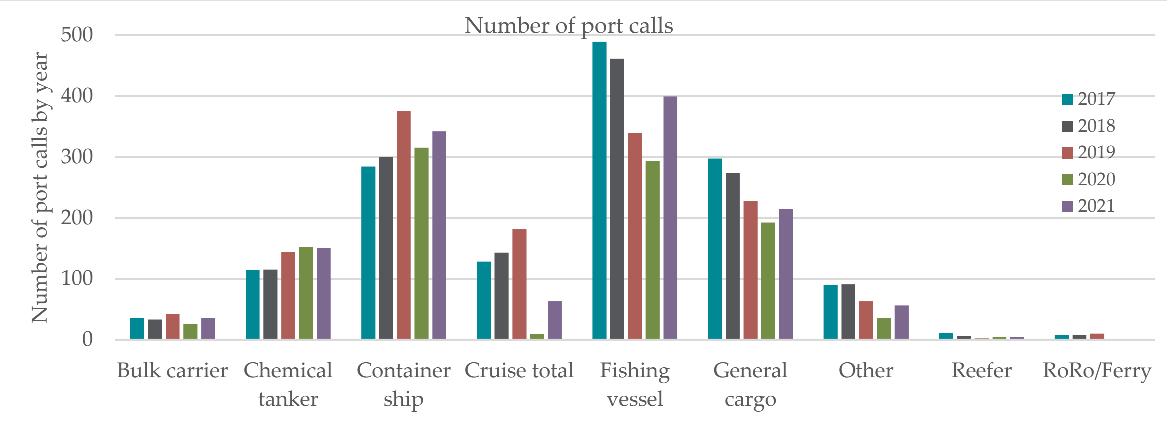

Figure 3 Number of port calls from different ship types 2017, 2018, 2019, 2020 and 2021.

Whale watching boats registered an increase of around 600 port calls in 2021 compared to 2020. Despite this, the total emissions of CO_2 remain similar to 2020 level due to a significant decrease in average CO_2 emissions per port call (minus 900 tonnes CO_2 /port call). Total CO_2 emissions, CO_2 emissions per port call and total port calls from whale watching boat are presented in Figure 4 for the latest five years.

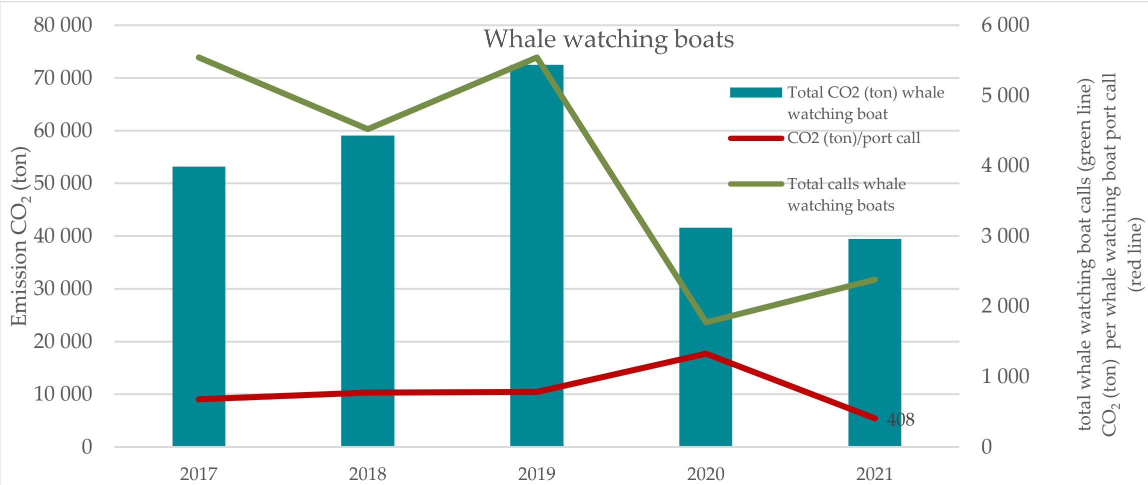

Figure 4 Total CO_2 emissions, CO_2 emissions per port call and total port calls from whale watching boats 2017, 2018, 2019, 2020 and 2021.

Faxaflóahafnir provides connections to shore side electricity in Old harbour and Sunda harbour, and many ships use shore side power at berth. By assuming that these ships would have used electricity from onboard diesel generators if the shore side connections were not available, a measure of "avoided emissions" is estimated. This is thus the difference between emissions at berth if no ships were to use shore side power and the calculated actual emissions at berth. The avoided emissions are presented in Table 9 for the three harbour areas. The estimated emission reduction in Sunda harbour in Table 8 from onshore power is higher than last year. This is because no cruise ships were connected in 2020 while 26 ship were connected in 2021.

Table 9. Total avoided emissions from the use of shore side electricity in the port 2021.

Harbour	Växthusgasutsläpp			NO_x	HC	PM	SO_2
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2				
Akranes harbour	0	0	0	0.0	0.00	0.00	0
Grundartangi harbour	0	0	0	0.0	0.00	0.00	0
Old harbour	963	763	753	10.9	0.56	0.20	0.4
Sunda harbour	135	107	105	1.3	0.08	0.03	0.002
TOTAL	**1 097**	**870**	**858**	**12.3**	**0.63**	**0.23**	**0.4**

Cruise and cargo ships cause significantly higher emissions than the other categories of vessels and contribute with approximately 73% of the total fuel combustion in 2021. These categories of ships also account for approximately 81% of the SO_2 emissions. Of the cargo ships, container ships caused the most emissions in 2021. Further, container ships have significantly higher impact on total SO_2 emissions than any other ship type. The fishing vessels are the second largest contributor to CO_2 emissions in the port in 2021. Many fishing vessels have high power needs at berth for cooling and off-loading the catch. This causes relatively high emissions from the electricity production in diesel electric generators on board. Emissions and calls from the different ship types are presented in Table 10 and their contributions to total emissions are illustrated in

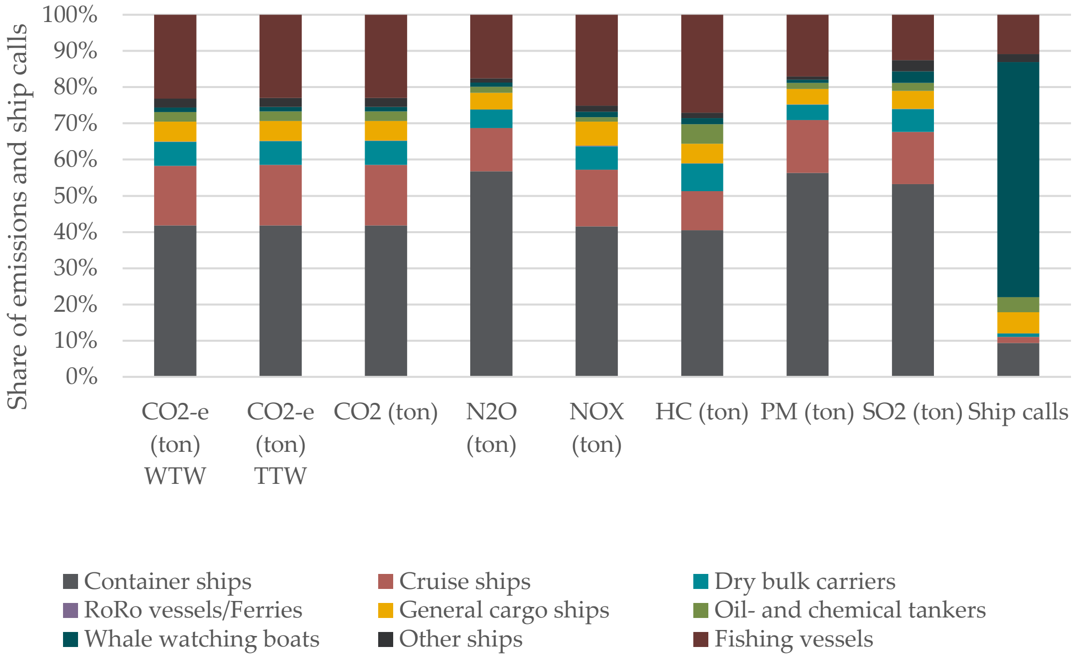

Figure 5.

Table 10. Emissions and ship calls per ship type in Faxaflóahafnir in 2021.

	Växthusgasutsläpp			N_2O	NO_x	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2						
Dry bulk carriers	2 840	2 300	2 200	0.1	26	1.4	0.5	1.6	35
Container ships	17 920	14 300	14 200	0.5	169	7.5	6.6	17	342
Cruise ships	7 000	5 700	5 700	0.2	64	0.7	1.7	4.6	63

Oil- and chemical tankers	1 100	900	900	0.03	5	1	0.2	0.7	150
RoRo vessels/Ferries	46	36.1	35.7	0.001	1	0.2	0.01	0.02	1
General cargo ships	2 400	1 880	1 850	0.1	27	1.3	0.5	1.6	215
CRUISE AND CARGO SHIPS*	**31 306**	**25 100**	**24 900**	**1**	**292**	**12**	**10**	**26**	**806**
OTHER SHIPS	**1 100**	**850**	**840**	**0.02**	**7**	**0.3**	**0.1**	**1**	**79**
FISHING VESSELS	**9 900**	**7 900**	**7 800**	**0.3**	**102**	**4.9**	**2**	**4**	**399**
WHALE WATCHING BOATS	500	400	400	0.02	6	0.3	0.1	1	2383
TOTAL 2021	**42 800**	**34 200**	**33 900**	**1**	**407**	**18**	**12**	**32**	**3 667**

*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".

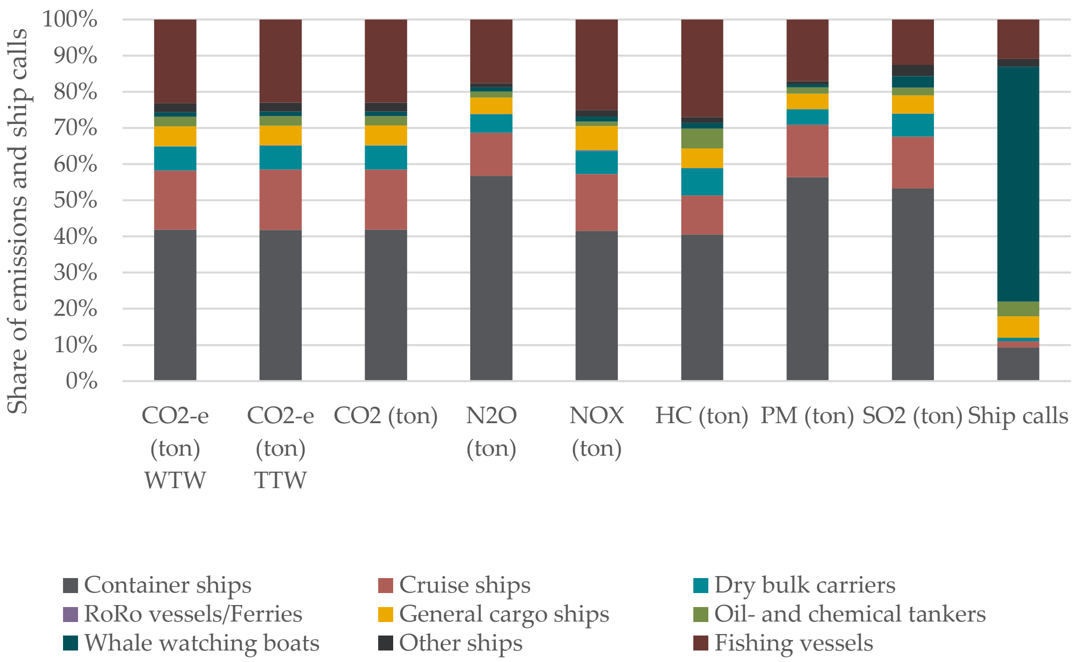

Figure 5. Share of total emissions and ship calls by the ship type categories, 2021.

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 25 000 tonnes emissions of CO_2 equivalents. Akranes harbour is the least emitting harbour with approximately 500 tonnes of CO_2 equivalents emitted in 2021.

Emissions from ships in the different harbour areas

Table 11. Emissions from ships in the different harbour areas of Faxaflóahafnir 2021.

Harbour	Växthusgasutsläpp			NOx	HC	PM	SO_2	Ship calls	Whale watching boat calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2						
Akranes harbour	500	400	400	5.5	0.3	0.1	0.3	28	0
Grundartangi harbour	6 700	5 400	5 300	70	3	1.5	5.3	163	0
Old harbour	10 700	8 600	8 400	100	6	2.1	6.1	565	2 383
Sunda harbour*	24 900	20 000	19 800	230	10	8.1	**20**	528	0
TOTAL	**42 800**	**34 400**	**33 900**	**406**	**19**	**12**	**32**	**1 284**	**2 383**

*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 2021. 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 five 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 2021 and the number of calls.

	Växthusgasutsläpp			NO_x	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2					
Dry bulk carriers	150	120	118	1.6	0.1	0.03	0.1	9
Container ships	0	0	0	-	-	-	-	0
Cruise ships	230	185	182	2.7	0.1	0.05	0.1	5
Oil- and chemical tankers	-	-	-	-	-	-	-	0
RoRo vessels/Ferries	-	-	-	-	-	-	-	0
General cargo ships	70	58	57	0.8	0.04	0.02	0.1	8
CRUISE AND CARGO SHIPS*	**450**	**363**	**357**	**5**	**0**	**0.1**	**0.3**	22
OTHER SHIPS	-	-	-	-	-	-	-	0
FISHING VESSELS	**40**	**35**	**35**	**0.4**	**0.02**	**0.01**	**0.02**	6
WHALE WATCHING BOATS	-	-	-	-	-	-	-	0
TOTAL 2021	**490**	**398**	**392**	**6**	**0.3**	**0.1**	**0.3**	28

*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, 2018, 2019, 2020 and 2021, and the number of calls.

	Växthusgasutsläpp			NO_x	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2					
2021	500	400	400	6	0.3	0.1	0.3	28
2020	200	200	200	2	0.1	0.05	0.1	15
2019	1 300	1 000	1 000	14	0.7	0.3	0.6	27
2018	1 300	1 000	1 000	12	0.7	0.3	0.3	35
2017	3 400	2 700	2 600	30	1.6	0.6	0.7	44

Grundartangi harbour

Table 14. Grundartangi harbour – emissions from different ship types 2021.

	Växthusgasutsläpp			NO_x	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2					
Dry bulk carriers	2 170	1 730	1 710	20	1	0.4	1.0	20
Container ships	3 540	2 830	2 800	39	1.6	0.9	3.0	44
Cruise ships	-	-	-	-	-	-	-	0
Oil- and chemical tankers	-	-	-	-	-	-	-	0
RoRo vessels/Ferries	-	-	-	-	-	-	-	0
General cargo ships	1 010	800	790	11	0.5	0.2	0.7	98
CRUISE AND CARGO SHIPS*	**6 720**	**5 360**	**5 300**	**70**	**3.1**	**1.5**	**4.7**	162
OTHER SHIPS	**7**	**5**	**5**	**0**	**0.003**	**0.001**	**0.01**	1
FISHING VESSELS	-	-	-	-	-	-	-	0
WHALE WATCHING BOATS	-	-	-	-	-	-	-	0
TOTAL 2021	**6 730**	**5 370**	**5 310**	**70**	**3.1**	**1.5**	**4.7**	163

*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, 2018, 2019, 2020 and 2021 and the number of calls.

	Växthusgasutsläpp			NO_x	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2					
2021	6 700	5 400	5 300	70	3.2	1.5	5.3	163
2020	6 200	4 900	4 900	62	2.9	1.4	4.5	141
2019	5 600	4 500	4 400	58	2.7	1.3	4.3	151
2018	6 300	5 000	5 000	63	3.0	1.5	4.6	168
2017	6 100	4 800	4 800	62	2.8	1.4	4.4	160

Old harbour

Table 16. Old harbour – emissions from different ship types 2021.

	Växthusgasutsläpp			NO_x	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2					
Dry bulk carriers	10	8	8	0.2	0.01	0.002	0.01	1
Container ships	190	155	153	2	0.1	0.1	0.3	10
Cruise ships	1 900	1 540	1 530	19	0.9	1.7	1.1	24
Oil- and chemical tankers	1 110	880	860	5	1	0.2	0.7	149
RoRo vessels/Ferries	50	36	35.7	1	0.02	0.1	0.02	1
General cargo ships	0.1	0.1	0.1	0.001	0.00004	0.5	0.0002	1
CRUISE AND CARGO SHIPS*	**3 260**	**2 620**	**2 590**	**27**	**2**	**2.6**	**2.1**	186
OTHER SHIPS	**700**	**590**	**585**	**4**	**0.2**	**0.1**	**1.0**	60
FISHING VESSELS	**6 160**	**4 900**	**4 800**	**100**	**3.1**	**1.2**	**2.5**	319
WHALE WATCHING BOATS	542	440	434	6	0.3	0.1	1.0	2 383
TOTAL 2021	**10 700**	**8 500**	**8 400**	**137**	**5.6**	**4.0**	**6.6**	2 948

*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, 2018, 2019, 2020 and 2021 and the number of calls.

	Växthusgasutsläpp			NO_x	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2					
2021	10 700	8 600	8 400	100	5.5	2.1	6.1	2 948
2020	14 700	11 700	11 500	150	7.3	2.8	6.2	2 216
2019	17 900	14 200	14 100	190	8.8	3.5	10.2	6 138
2018	15 900	12 600	12 500	170	7.7	3.1	8.9	5 176
2017	12 800	10 200	10 100	140	6.1	2.5	8.6	6 204

Sunda harbour

Table 18. Sunda harbour – emissions from different ship types 2021.

	Växthusgasutsläpp			NOx	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2					
Dry bulk carriers	510	404	399	5	0.2	0.1	0.3	5
Container ships	14 200	11 400	11 240	128	5.8	5.7	13.7	288
Cruise ships	4 880	3 990	3 950	9	0.3	0.2	0.6	34
Oil- and chemical tankers	18	17.9	17.5	0.2	0.02	0.004	0.01	1
RoRo vessels/Ferries	-	-	-	-	-	-	-	0
General cargo ships	1 270	1 010	1 000	15	0.7	0	0.9	108
CRUISE AND CARGO SHIPS*	**20 900**	**16 800**	**16 600**	**157**	**7**	**6**	**16**	**436**
OTHER SHIPS	300	251	248	2	0.1	0	0.3	18
FISHING VESSELS	**3 720**	**2 940**	2 900	**36**	**1.8**	**1**	**1.4**	74
WHALE WATCHING BOATS	-	-	-	-	-	-	-	0
TOTAL 2021	**24 900**	**20 000**	**19 800**	**195**	**8.9**	**7.0**	**17.2**	528

*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, 2018, 2019, 2020, and 2021 and the number of calls.

	Växthusgasutsläpp			NOx	HC	PM	SO_2	Ship calls
	CO_2-e (ton) WTW	CO_2-e (ton) TTW	CO_2					
2021	24 900	20 000	19 800	230	9.9	8.1	19.9	528
2020	29 500	23 500	23 300	280	12.9	7.0	18.9	446
2019	41 400	33 400	33 000	450	16.7	10.7	32.7	621
2018	33 700	27 100	26 800	360	13.5	8.9	26.7	627
2017	30 400	24 500	24 200	330	12.2	8.0	24.4	651

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

5 Discussion

During 2021 traffic in the port increased compared to 2020, however the harbours activity is still affected by the Covid-19 pandemic. The 1 284 port calls (non-whale watching vessels) resulted in around 42 300 tonnes CO_2 equivalents in 2021, while 1 045 port calls (non-whale watching vessels) resulted in 50 000 tonnes CO_2 equivalents in 2020. In other terms, an increase of 23% of the port calls in 2021 resulted in a decrease of 18% of the total CO_2 equivalents emitted.

For the emission analysis, non-whale watching vessels are more relevant and within these categories there was an overall decrease between the last two years from 1 773 port calls to 2 838 (approximately 26% increase).

The number of visits of both container ships and cruise ships, that underwent a drastic decrease om 2020, is now almost back to pre-2020 levels. The number of calls by cruise ships, that went down from 181 in 2019 to only 7 in 2020, has seen a slight increase in 2021 with 63 total visiting cruise vessels. Further, container traffic increased from 315 calls to 342 in 2021. Even though the port calls increased, the total CO2 emitted has decreased compared to 2020 due to a lower amount of emission per port call. This is explained by decreased time at berth for container ships and for fishing vessels, according to the statistics. Fishing vessels, despite increasing in amount of port calls (399 in 2021 versus 292 in 2020) registered a decrease in CO_2 emission by 73%.

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 2021 was 14 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, and decreased to the lowest 11 tonnes/call in 2020.
- in Grundartangi, the average value in 2021 was 33 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.
- in Old harbour, the average value in 2021 for was 14 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 calculated being 26 tonnes/call.
- CO_2 emissions per call in Sunda harbour are 37, 42, 53, and 52 and for the years 2017, 2018, 2019 and 2020, respectively. Average emissions in 2021 have decreased significantly to 37 tonnes/call. This year, a relative decrease in emission per call for container ships is the main reason behind the lower value.

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

The model used includes generic values in many instances. These are often based on averages from a large number of observations or reports, which include variations around the average value. Examples of such generic values are the emission factors, the sulphur content in fuel, and the engine loads at different operational modes. The use of generic values causes uncertainty in the results. However, in an emission inventory like this with a large number of ships and ship calls, the total results will present a fair view of the actual emissions. If the scope is narrowed to few ships or single ship types, the uncertainty in the result increases. The model 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 in 2021 with around 23% and 1.3% to total CO_2 emissions, respectively. The information on fishing vessels is considered equally reliable as information on other ship types. A categorisation of the fishing vessels has accounted for large differences between ships within this category. Data on whale watching boats are however less reliable. Whale watching boats are different in character from one another; some of the whale watching boats are merely the size of leisure boats, while others are larger – possibly former fishing vessels. It can be expected that the smallest whale watching boats use more refined fuel than the marine distillates used by larger ships in this study. However, information on installed main engine power has been available for these boats, which makes estimates on emissions during operations *in port basin* and *manoeuvring* relatively good for emissions of CO_2 that are directly related to fuel consumption. Estimates of emissions that have a strong dependency on engine characteristics, such as NO_X, hydrocarbons and particles, are more uncertain since engine types are expected to vary with the size of the vessel and the engine types are not known. Often the fishing vessels connect to shore side power when at berth, which also reduces uncertainty in these results. The whale watching boats always connect to the land-based electricity grid when at berth. Still, the total emission estimates from the whale watching boats remain more uncertain than those for other ship types.

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