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Emissions from ships in Faxaflóahafnir 2019

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Summary

In this study we calculate the emissions to air from ships in Faxaflóahafnir 2019. Emissions are presented per four operational modes; *in port basin*, *at anchor*, *manoeuvring* and *at berth*. Further, emissions are allocated to different engine types, ship types, and also to the four harbour areas of Faxaflóahafnir: Akranes harbour, Grundartangi harbour, Old harbour, and Sunda harbour. The results are compared to the emissions calculated for 2016, 2017, and 2018.

For each port call, emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_X), hydrocarbons (HC), particles (PM), and sulphur dioxide (SO_2) are calculated using an emission inventory model specifically developed for port areas. Total emissions in 2019 are presented in the table below.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_X (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)
TOTAL emissions 2019	**56 000**	**0.69**	**2.2**	**790**	**34**	**24**	**120**

Container ships and cruise ships are the two ship categories that account for the largest shares of emissions in the port. Each of them contributes approximately 30% of the total emissions of CO_2 from the ships visiting Faxaflóahafnir in 2019. The average amount of emissions per call by cruise ships are higher than from other vessels. The fishing vessels constitute the third largest contributing ship type category in the port although the trend is decreasing since 2016. In 2019, the fishing vessels accounted for approximately 19% of the CO_2 emissions in the port. Whale watching boats are in frequent traffic to the port with 5542 calls in 2019. Since these in general have relatively small engines, they are calculated to contribute around 1.6% to the total CO_2 emissions.

Sunda harbour and Old harbour receives significantly more ship calls than Akranes and Grundartangi. Sunda harbour is the harbour area that receives the majority of the visiting container and cruise ships. Ships calling Sunda port 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 34 000 and 14 000 tonnes of the total CO_2 emissions, respectively.

In a comparison with emissions from ships in the port in 2018, there is an overall increase. The increase can mainly be attributed to more emissions from cruise ships and container ships. This is a situation that was also registered for the increase between 2017 and 2018. In Akranes the trend is the opposite and emissions have had a decreasing trend since 2017. Overall, CO_2 emissions from ships and boats in the harbour increased with 16% from last 2018, and other emissions between 16% and 18%.

1 Introduction

IVL Swedish Environmental Research Institute has on assignment of Faxaflóahafnir calculated emissions from ships visiting its ports in 2019. Faxaflóahafnir comprises the four ports of Akranes harbour, Grundartangi harbour, and Sunda harbour and Old harbour in Reykjavik. The locations of the different ports are shown in Figure 1, which also indicates with red lines the traffic areas covered in the emission inventory.

The inventory includes emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_X), hydrocarbons (HC), particles (PM), and sulphur dioxide (SO_2). The emission calculations are based on call statistics obtained from the port.

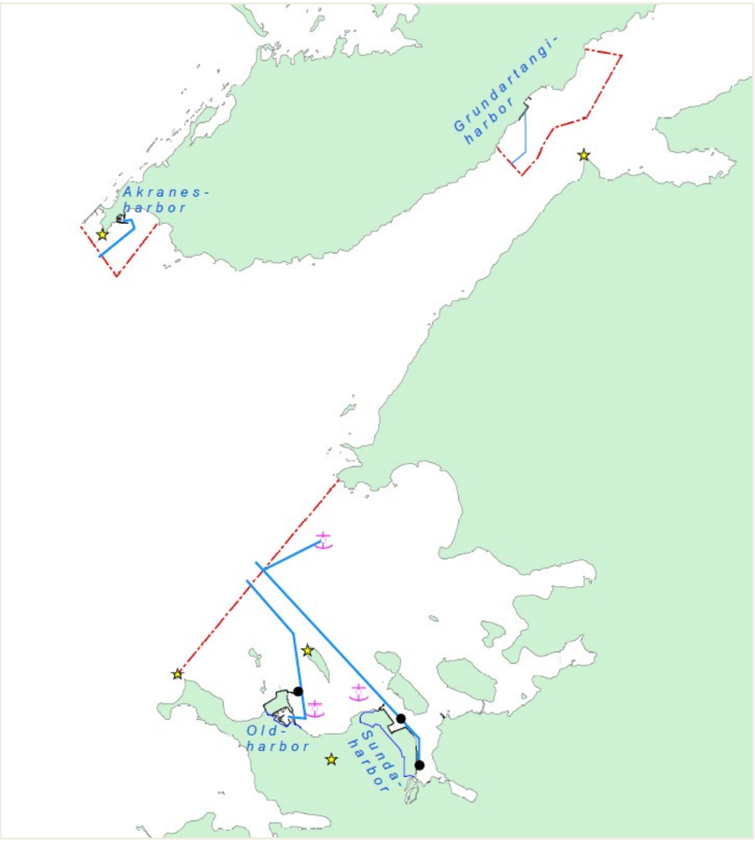

Figure 1. The four ports of Faxaflóahafnir and the areas outside the ports included in the emission inventory.

This report describes the calculation models, the data used, and the results from the calculations. The results are analysed and discussed in relation to emission calculations made from ships calling the port in 2016, 2017, and 2018. Some minor modifications have been made to the calculation model from previous years. We therefore present updated emissions for 2016, 2017, and 2018 for reasonable comparisons.

2 Ship traffic

In total, this inventory covers 1413 port calls comprising in total 362 larger vessels. In addition to these calls, the port received 5542 calls from whale watching boats in 2019. These are all included in the inventory.

The ship traffic to the different harbours in Faxaflóahafnir comprise several different ship types and ship sizes; from large container vessels to small whale watching boats. The ships that are in traffic to and from the port have been categorised into nine ship types, depending on the type of cargo they carry or the service they provide. The ship types are "Dry bulk carriers", "Container ships", "Cruise ships", "Oil- and chemical tankers", "RoRo-vessels/Ferries", "General cargo ships", "Fishing vessels", "Whale watching boats" and "Other ships".

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

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

All movements in the port area are assigned a unique call-ID. During a visit in the port a ship may have more than one registered call-ID if it moves between different berths or from an anchoring site to quay. For each movement between berths, a manoeuvring period is added in the calculations assuming 20 minutes in transfer. For parts of our analysis we assign a specific berth to each call. An update to the previous inventories is that we in such cases designate the latest berth of visit as the berth of the call. This is a change from previous years and may have a minor effect on the average ratios of emissions per call.

Whale watching boats are assumed to be berthing if they stayed longer than one hour in the port area.

3 Emission calculation

For each ship call, engine emissions are calculated as a product of emission factors, the utilised engine power and time. For each engine and during each of the four operational modes equation (1) is applied.

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

E is emissions of a substance with the unit gram, *EF* is the emission factor for a substance in g/kWh, *t* is the time in hours, and *P* is the estimated power utilization from the engine in kW.

3.1 Emission factors

The emission factors for marine engines used in this report are presented in Appendix 2. The main parameters determining emission factors are the fuel used and the engine speed. To give two examples: a heavy fuel with high sulphur content results in significantly higher emission factors for sulphur dioxide and particles than lighter fuel qualities while NO_X emissions depend on engine speed to a large extent with less emissions per unit energy from high speed engines than from slow speed engines.

Emission factors for CO_2, CH_4, N_2O, and HC for main engines and auxiliary engines are from Cooper and Gustavsson (2004). Emission factors for NO_X are assumed to follow the regulatory standards that became effective in 2005 and that apply to all ships keel laid from 2000 (Tier I) and that were further strengthened in 2010 (IMO, 2011). Ships constructed prior to 1990 are not covered by any regulations unless they have undergone significant engine changes, and ships constructed between 1990 and 2000 are only covered if specific criteria on engine size and technical possibilities for emission reductions are met. Information on which ships from before 2000 that fulfil Tier I requirements has not been available, and for all ships from before that year emission factors that are representative for engines that have no NO_X reduction measures are used (Cooper and Gustafsson, 2004). Emission factors for newer ships follow regulatory standards: Tier I levels for ships constructed between 2000 and 2011, and Tier II levels for ships built thereafter (IMO, 2011). In Appendix 2 the details of the calculations behind emission factors in the regulations are presented. Emission factors for sulphur dioxide are based on the fuel consumption and the estimated sulphur content of the fuels used. We estimate the sulphur content in heavy fuel oil to be 2.7% on average. This value is from a study from 2007 by US EPA and represents the world average sulphur content in marine heavy fuel oil at that time (USEPA, 2007). Fishing vessels are assumed to use different qualities of fuel, depending mainly on vessel size, with fuel sulphur content varying from 0.001% to 1.7% S. Whale watching boats are assumed to use only marine gasoil with an estimated sulphur content of 0.1%.

The emission factors for particles (PM) are dependent on the sulphur content of the fuel. For high sulphur fuels we use a formula for the relation between fuel sulphur content and PM emission factors. The formula is a linear equation representing a fit to values from several emission measurement studies. Different equations are used for high-, medium- and slow speed engines. However, for fuel sulphur contents below 0.5%, the formula is less relevant. A literature review of emission measurement results shows no clear relationship between fuel sulphur content and particle emissions at low sulphur content, and, further, that a dependence on engine load is uncertain. The emission factors for PM emissions are presented in Appendix 2.

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

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

Some ships are assigned individual emission factors. These include ships that connect to shore side electricity at berth, which are assumed to have no emissions at berth except for the time used to connect and disconnect to the power grid. The fishing vessels in the HB Grandi fleet are also treated as special cases as these are known to use fuel with very low sulphur content. Another category of ships that are assigned individual emission factors are those registered for the Environmental Ship Index (ESI). The ESI is an index that tells how well ships perform with regard to emissions of NO_X, SO_X and CO_2. There were 103 ships visiting Faxaflóahafnir in 2019 that were matched to the ESI register. The ESI register that we use for this inventory is valid for 2019. The ships in the ESI register are presented in Appendix 3 together with the scores used to calculate their emission factors for SO_2 and NO_X.

The ESI system combines NO_X emission factors for all engines on board via a weighing process to a single value. Our estimate is only based on information on the main engine. The ESI score for SO_2 differentiates between sulphur content in the consumed residual oil and the marine distillate oil. In our calculation we assume that the average values of sulphur content in different fuel qualities and the ratio between usage of different fuel qualities – both given in the ESI listing – are valid also for the traffic in Faxaflóahafnir. Details on these calculations are presented in Appendix 3.

3.2 Engines and fuels

Emissions are calculated for main engines, auxiliary engines and auxiliary boilers separately.

The database *Sea-Web Ship* contains information on all ships with IMO-numbers (IHS, 2019). *Sea-Web Ship* has been used for retrieving information on installed main engine power for an absolute majority of the ships visiting Faxaflóahafnir. For a limited number of ships the installed main engine power has been estimated from ship size and ship type according to statistics developed by IMO (IMO, 2014).

Sea-web Ship also contains information on engine speed for most main engines. If this information is not given in the database, an estimated engine speed based on known engine speeds for similar ship types and ship sizes is calculated.

The installed power in auxiliary engines is not given in the database. Instead, empirical relations from a large number of ships of similar types that relate installed auxiliary engine power to ship size are used (Sjöbris et al., 2005). All auxiliary engines are assumed to be high speed diesel engines.

The installed main engine power for fishing vessels is taken from *SeaWeb*. Auxiliary engine powers are estimated as central values in a span of likely installed auxiliary power for ships of different sizes and installed main engine power. A categorization of fishing vessels has in a previous study been provided by HB Grandi (HB Grandi, 2017). HB Grandi is a large sea food company based in Reykjavík and owner of ten large fishing vessels. Each category was assigned a typical range of installed main engine- and auxiliary engine power, respectively. We have matched the categories and the installed main engine power of shipping vessels in Faxaflóahafnir stated in the *Sea-web Ship* data base. As a result, fishing vessels are divided into five categories primarily based on installed main engine power. The categories and the central values for installed auxiliary engine power used in the calculations are presented in Table 1.

Table 1. Categories of installed power on fishing vessels, main engines and aux engines

Category No.	Fishing vessel - Main engine power category (min – max, kW)	Fishing vessel - Aux engine power category (min – max, kW)	Aux Engine central value (kW)
1	37 – 559	0	0
2	600 – 1 035	220 – 600	410
3	1 036 – 1 762	220 – 600	410
4	1 763 – 3 699	700 – 900	800
5	3 700 – 9 000	1 500 – 2 000	1 750

The utilization of power from the engines during the different operational modes is important information for the emission calculations. This information is often relatively uncertain and differs a lot between different ships. For this study generic values first reported by Entec UK (2002) are used. These values are presented in Table 2.

Table 2. Estimated power utilization (as share of installed engine power) at different operational modes (Entec UK Ltd, 2002).

	In port basin	Manoeuvring	At anchor/at berth[1]
Main Engine	20%	20%	0%
Auxiliary Engine	40%	50%	40%

[1]Cruise ships with diesel electric drives use main engine power at berth, 12% power utilization is assumed corresponding power needs of cruise ships with diesel mechanic drive and aux engines installed

Main engine load of fishing vessels is assumed to be the same as for the other ship categories. However, the installed auxiliary engine power on certain categories of fishing vessels is to a large extent dimensioned for electricity need to freeze fish or for trawling. From information and values provided by HB Grandi we have made assumptions on utilization of auxiliary engine power as presented in Table 3 (HB Grandi, 2017).

Table 3. Estimated power utilization of auxiliary engines in different categories of fishing vessels. The estimated power requirements for the categories are presented in Table 1.

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 very varying during *at berth* operations. According to port statistics, many fishing vessels at berth cover parts of their electricity need by connection to the land-based grid. However, the land-based grid can often not fulfil the vessels' full power requirements. From the information on supplied amount of shore side electricity (kWh) and estimates of power need on board (kW), we calculate an approximate time that the fishing vessels at berth have their electricity supplied from land. The rest of the time, power from auxiliary engines according to Table 1 and Table 3 are used in the calculations.

Tankers often use electricity from the auxiliary engines to run cargo pumps. In the model, this is accounted for by adding fuel consumption that relates to the carrying capacity of the individual tanker. According to information from a tanker operator the typical fuel consumption for cargo pumps are 3 tonnes/day at off-loading. An off-loading operation for 14000 tonnes oil requires about 15 hours. Based on this information a generic value of 0.13 kg fuel/tonne cargo has been calculated and is used for all tanker ships at off-loading 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

[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.

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 a heavy fuel oil with 2.7% S, 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 by Grandi to use heavy fuel oil with a sulphur content of 1.7% in the main engines, and marine gasoil with 0.1% sulphur in the auxiliary engines, while small fishing vessels are reported to use marine gasoil with 0.1% S, exclusively. All small fishing boats in the HB Grandi fleet use diesel oil with an S-content of 0.001%. The fuel types reported by Grandi are assumed for all fishing vessels of the respective size in the inventory. Further, whale watching boats are assumed to use only marine gasoil.

A size dependent generic value on fuel consumption in ship boilers has been calculated for all visiting ships from values from a report from the Port of Los Angeles (2010). Exceptions are made for the category RoRo/ferry, for which values from a study in Gothenburg is used (Winnes and Parsmo, 2016). The values are presented in Table 4.

Table 4. Fuel consumption in oil fired boilers for operational modes *at anchor*, *in port basin*, *manoeuvring*, and *at berth*. Fuel consumption is given per thousand gross tonnes and hour.

Ship type	Fuel consumption/ (1000 GT *hour)
Bulk carriers	1.4
Oil- and chemical tankers	4
Container ships	2.9
Cruise ships	4
General cargo ships	0.9
Other ships	4
Reefers	5.4
RoRo/Ferries	2

The fuel used in boilers is assumed to be marine gasoil exclusively.

4 Results

Table 5 presents the emissions of the different substances per engine type and operational mode.

The period *at berth* accounts for the largest share of emissions of all substances except SO_2, for which emissions are higher from operations *in port basin*. Similarly, emissions of SO_2 are mainly caused by combustion in main engines, while for most other emissions the auxiliary engines are the dominant source. Emissions of SO_2 are directly related to the sulphur content in fuel and since main engines are assumed to run on high sulphur fuel oil to a large extent, the main engine emissions dominate. Further, main engines are almost exclusively used for propulsion which is the reason to the relative importance of the emissions from the *in port basin* operational mode. An exception are the diesel electric driven cruise ships which use their main engines also *at berth*, but then exclusively with low sulphur fuel or using aftertreatment.

CO_2 emissions are directly related to the fuel consumption and results on CO_2 are good proxies to use for fuel consumption in the analysis. In a comparison between the different operational modes the operations *at berth* can be attributed approximately 80% of the total fuel consumption. The fuel consumption in auxiliary engines is calculated to be more than twice the consumption in the main engines. Emissions of the greenhouse gases CO_2, CH_4 and N_2O together cause emissions of CO_2 equivalents[2] of 57 000 tonnes, a value that is totally dominated by the emissions of CO_2.

[2] The factors used for calculation of CO_2-eqv are 30 for CH_4 and 265 for N_2O (IPCC, 2013).

Table 5. Overview of emissions from ships in Faxaflóahafnir 2019.

		CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)
Main Engines	In port basin	5 890	0.0767	0.249	100	3.59	10.0	75.0
	At anchor*	0	0	0	0	0	0	0
	Manoeuvring	10 120	0.0142	0.0432	17.0	0.618	1.59	12.0
	At berth**	7 780	0.0868	0.336	122	4.43	2.17	4.89
Auxiliary Engines	In port basin	1 870	0.0271	0.0840	30.0	1.38	0.542	1.14
	At anchor*	436	0.00632	0.0196	6.75	0.322	0.126	0.269
	Manoeuvring	431	0.00625	0.0194	6.87	0.319	0.125	0.257
	At berth**	31 200	0.452	1.40	494	23.0	9.03	17.8
	Tankers at berth using cargo pumps	218	0.00316	0.00979	3.31	0.161	0.0631	0.133
Boilers	In port basin	478	0.00111	0.00556	0.436	0.00541	0.0436	0.300
	At anchor*	79.6	0.000185	0.000926	0.0726	0.000901	0.00726	0.0501
	Manoeuvring	72.2	0.000168	0.000841	0.0659	0.000818	0.00659	0.0454
	At berth**	6 890	0.0160	0.0801	6.28	0.0780	0.628	4.34
TOTAL (Engines and boilers)	Main engines	14 700	0.178	0.629	240	8.64	13.8	91.9
	Auxiliary engines	34 100	0.495	1.53	541	25.2	9.89	19.6
	Boilers	7 520	0.0175	0.0875	6.86	0.0851	0.686	4.73
TOTAL (Operational modes)	In port basin	8 240	0.105	0.339	131	4.98	10.6	76.5
	At anchor*	515	0.00650	0.0205	6.82	0.323	0.134	0.319
	Manoeuvring	1 520	0.0206	0.0634	23.9	0.938	1.73	12.3
	At berth**	46 100	0.558	1.83	626	27.7	11.9	27.2
TOTAL	**All engines and boilers, all operational modes**	56 300	0.690	2.25	788	33.9	24.3	116

*Only cruise ships with diesel electric power trains

**Include emissions from ships in ship yard

The emissions in total have followed an increasing trend the last three years. In Table 6 the emissions from 2016, 2017, and 2018 are presented together with emissions in 2019. The values presented for previous years in report U 5817 (Winnes and Parsmo 2017), report U 5953 (Parsmo and Winnes, 2018) and report U6107 (Parsmo and Winnes 2019) are slightly corrected for emissions of SO_2. We have adjusted the sulphur dioxide emission factor from cruise ships at berth. The change only concerns cruise ships with diesel electric drives. Previously the model used a too high sulphur content in the calculations, and the emission factor has been adjusted for all previous inventories.

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

Year	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	Ship calls
2019	56 300	0.690	2.25	788	33.9	24.3	116	6 955
2018	47 500	0.576	1.90	659	28.7	20.3	95.4	6 006
2017	44 300	0.556	1.76	615	26.7	19.0	89.2	7 059
2016	37 900	0.465	1.52	543	23.2	16.1	70.5	7 136

The increase in emissions from 2018 to 2019 can mainly be attributed to more emissions from container ships and cruise ships. In Figure 2., this is exemplified by presenting the CO_2 emissions from different ship types in 2016, 2017, 2018, and 2019.

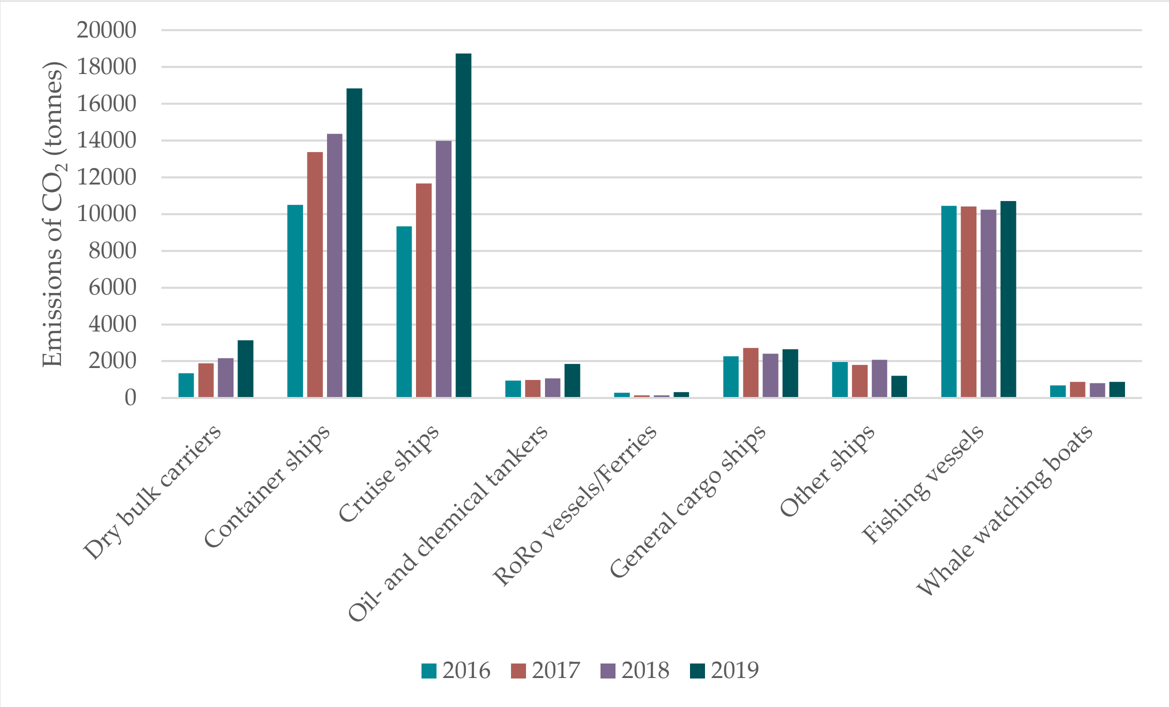

Figure 2. CO_2 emissions from different ship types 2016, 2017, 2018, and 2019.

Faxaflóahafnir provides connections to shore side electricity in Akranes harbour, Old harbour and Sunda harbour, and many ships use shore side power at berth. By assuming that these ships would have used electricity from on board diesel generators if the shore side connections were not available, a measure of “avoided emissions” can be calculated. This is thus the difference between emissions at berth if no ships were to use shore side power and the calculated actual emissions at berth. Approximately 2-4% of emissions from ships at berth are avoided in this respect. This is the same range as the previous year. The avoided emissions are presented in Table 7 for the three harbour areas.

Table 7. Total avoided emissions from the use of shore side electricity in the port 2019.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)
Akranes Harbour	86	0.0012	0.0039	1.3	0.064	0.025	0.031
Old harbour	1 100	0.016	0.051	17	0.83	0.33	0.64
Sunda harbour	67	0.0010	0.0030	1.0	0.050	0.019	0.019
TOTAL	**1 300**	**0.019**	**0.057**	**19**	**0.95**	**0.37**	**0.69**

Cruise ships and cargo ships cause significantly higher emissions than the other categories of ships and boats and contribute with approximately 77% of the total fuel combustion. These categories of ships also account for approximately 90% of the SO_2 emissions. Of the cruise and cargo ships, container ships and cruise ships cause the most emissions. Further, container ships have significantly higher impact on total SO_2 emissions than any other ship type. The fishing vessels are the third largest contributor to emissions in the port. Many fishing vessels have high power needs at berth for cooling and off-loading the catch. This causes relatively high emissions from the electricity production in diesel electric generators on board. Emissions and calls from the different ship types are presented in Table 8 and their contribution to total emissions are illustrated in Figure 3.

Table 8. Emissions and ship calls per ship type in Faxaflóahafnir in 2019.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	3 140	0.0478	0.124	39.1	1.96	1.00	3.06	42
Container ships	16 800	0.214	0.681	247	10.7	10.2	61.0	377
Cruise ships	18 700	0.206	0.734	261	10.2	7.81	37.5	181
Oil- and chemical tankers	1 850	0.022	0.0706	22.7	1.08	0.627	1.79	144
RoRo vessels/Ferries	323	0.00397	0.0128	4.55	0.197	0.139	0.832	10
General cargo ships	2 660	0.0358	0.113	40.1	1.81	1.10	5.20	228
CRUISE AND CARGO SHIPS*	**43 500**	**0.530**	**1.74**	**615**	**26.0**	**20.9**	**109**	**982**
OTHER SHIPS	**1 210**	**0.00922**	**0.0330**	**9.31**	**0.403**	**0.223**	**0.756**	**92**
FISHING VESSELS	**10 700**	**0.140**	**0.442**	**151**	**7.04**	**3.00**	**5.68**	**339**
WHALE WATCHING BOATS	**884**	**0.0105**	**0.0382**	**12.2**	**0.533**	**0.247**	**0.555**	**5 542**
TOTAL 2019	**56 300**	**0.690**	**2.25**	**788**	**33.9**	**24.3**	**116**	**6 955**

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

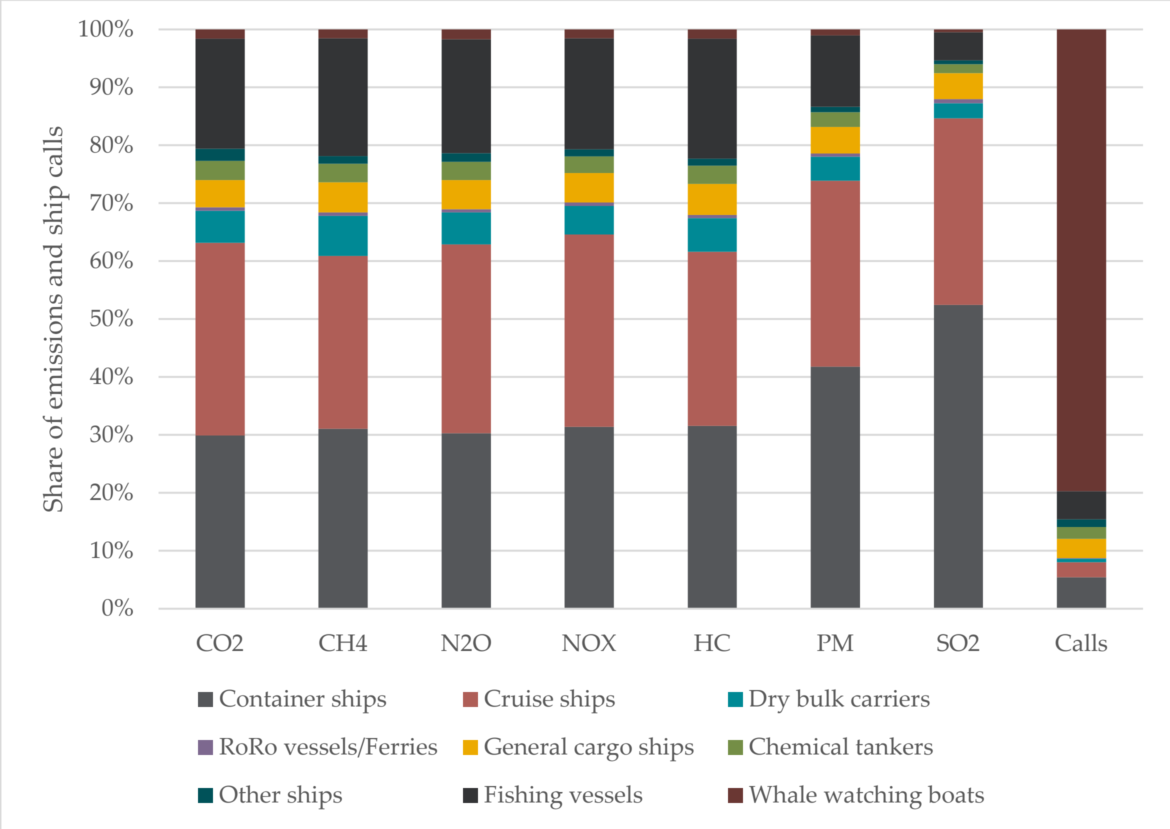

Figure 3. Share of total emissions and ship calls by the ship type categories, 2019.

The different harbour areas in the port serve different ship types to some extent. Sunda harbour is the busiest cargo and cruise port and emissions of CO_2, which indicate fuel consumption, are significantly higher in Sunda harbour than in the other harbour areas. Akranes harbour is the lower extreme with approximately 1000 tonnes of CO_2 emissions in 2019. The total emissions from each harbour area are presented in Table 9.

Table 9. Emissions from ships in the different harbour areas of Faxaflóahafnir 2019.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	Ship calls (cargo, & cruise, fishing and "other")	Ship calls (whale watching boats)
Akranes harbour	983	0.0214	0.0408	14.3	0.658	0.293	0.770	28	-
Grundartangi harbour	4 840	0.0626	0.196	67.8	3.13	2.55	12.4	152	-
Old harbour	14 100	0.176	0.567	192	8.79	4.15	11.0	596	5 542
Sunda harbour*	36 500	0.429	1.45	513	21.4	17.3	92.2	637	-
TOTAL	**56 300**	**0.690**	**2.25**	**788**	**33.9**	**24.3**	**116**	**1 413**	**5 542**

*Includes also "Reykjavik" and "tugboat on service outside Faxaflóahafnir".

Further details on emissions per ship type in the different harbour areas are presented in Table 10 (Akranes harbour), Table 12 (Grundartangi harbour), Table 14 (Old harbour), and Table 16 (Sunda harbour). The total emissions from each harbour area for the last four years are accounted for in separate tables, Table 11 (Akranes harbour), Table 13 (Grundartangi harbour), Table 15 (Old harbour), and Table 17 (Sunda harbour).

Table 10. Akranes harbour - emissions from different ship types 2019 and the number of calls.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	142	0.0103	0.00592	1.95	0.103	0.0515	0.180	11
Container ships	-	-	-	-	-	-	-	-
Cruise ships	22.0	0.000253	0.000878	0.317	0.0126	0.01049	0.0679	6
Oil- and chemical tankers	5.25	6.68E-05	0.000214	0.0788	0.00334	0.00205	0.0108	1
RoRo vessels/Ferries	-	-	-	-	-	-	-	-
General cargo ships	29.7	0.000398	0.00127	0.391	0.0201	0.0125	0.0632	7
CRUISE AND CARGO SHIPS*	**199**	**0.0111**	**0.00828**	**2.73**	**0.139**	**0.0765**	**0.322**	**25**
OTHER SHIPS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
FISHING VESSELS	**784**	**0.0104**	**0.0325**	**11.6**	**0.519**	**0.217**	**0.449**	**3**
WHALE WATCHING BOATS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
TOTAL 2019	**983**	**0.0214**	**0.0408**	**14.3**	**0.658**	**0.293**	**0.770**	**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 11. Emissions from ships calling Akranes harbour 2016, 2017, 2018, and 2019, and the number of calls.

Year	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
2019	983	0.0214	0.0408	14.3	0.658	0.293	0.770	28
2018	1 020	0.0131	0.0415	12.2	0.653	0.313	0.525	34
2017	2 600	0.0328	0.104	28.7	1.63	0.717	0.813	44
2016	2 090	0.0273	0.0860	29.1	1.37	0.601	1.13	39

Table 12. Grundartangi harbour – emissions from different ship types 2019.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	1 460	0.0180	0.0567	17.2	0.891	0.525	1.77	17
Container ships	2 480	0.0324	0.101	37.3	1.62	1.68	9.44	38
Cruise ships	-	-	-	-	-	-	-	-
Oil- and chemical tankers	-	-	-	-	-	-	-	-
RoRo vessels/Ferries	-	-	-	-	-	-	-	-
General cargo ships	897	0.0122	0.0383	13.3	0.614	0.343	1.196	97
CRUISE AND CARGO SHIPS*	**4 840**	**0.0626**	**0.196**	**67.8**	**3.13**	**2.55**	**12.4**	**152**
OTHER SHIPS	-	-	-	-	-	-	-	-
FISHING VESSELS	-	-	-	-	-	-	-	-
WHALE WATCHING BOATS	-	-	-	-	-	-	-	-
TOTAL 2019	**4 840**	**0.0626**	**0.196**	**67.8**	**3.13**	**2.55**	**12.4**	**152**

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

Table 13. Emissions from ships calling Grundartangi harbour 2016, 2017, 2018, and 2019, and the number of calls.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
2019	4 840	0.0626	0.196	67.8	3.13	2.55	12.4	152
2018	5 420	0.0696	0.219	73.0	3.47	2.61	12.3	179
2017	5 260	0.0677	0.212	72.9	3.38	2.61	11.0	181
2016	4 150	0.0541	0.169	59.8	2.71	2.29	9.90	236

Table 14. Old harbour – emissions from different ship types 2019.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls**
Dry bulk carriers	509	0.00695	0.0217	8.14	0.351	0.141	0.328	1
Container ships	174	0.00208	0.00700	2.55	0.104	0.127	1.03	6
Cruise ships	2 210	0.0289	0.0930	33.3	1.46	0.760	3.17	72
Oil- and chemical tankers	1 120	0.0138	0.0442	14.4	0.683	0.437	1.26	134
RoRo vessels/ Ferries	33.9	0.000417	0.00137	0.489	0.0209	0.0200	0.147	4
General cargo ship	7.61	9.46E-05	0.000320	0.118	0.00479	0.00660	0.0560	2
CRUISE AND CARGO SHIPS*	**4 050**	**0.0522**	**0.168**	**59.0**	**2.62**	**1.49**	**5.99**	**219**
OTHER SHIPS	**1 060**	**0.00752**	**0.0274**	**7.34**	**0.320**	**0.186**	**0.661**	**83**
FISHING VESSELS	**8 060**	**0.106**	**0.334**	**114**	**5.32**	**2.22**	**3.76**	**294**
WHALE WATCHING BOATS	**884**	**0.0105**	**0.038**	**12.2**	**0.53**	**0.247**	**0.55**	**5 542**
TOTAL 2019	**14 100**	**0.176**	**0.567**	**192**	**8.8**	**4.15**	**11.0**	**6 138**

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

Table 15. Emissions from ships calling Old harbour 2016, 2017, 2018 and 2019, and the number of calls.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	**Ship calls (cargo, & cruise, fishing and "other")**	**Ship calls (whale watching boats)**
2019	14 100	0.176	0.567	192	8.79	4.15	11.0	596	5 542
2018	12 700	0.157	0.506	170	7.81	3.75	9.71	655	5 635
2017	10 200	0.144	0.401	140	6.14	3.07	9.95	673	5 542
2016	10 400	0.126	0.407	143	6.26	3.04	8.82	764	4 520

Table 16. Sunda harbour – emissions from different ship types 2019.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	Ship calls
Dry bulk carriers	1 020	0.0125	0.0395	11.8	0.615	0.286	0.777	13
Container ships	14 200	0.180	0.573	207	8.99	8.36	50.5	333
Cruise ships	16 500	0.176	0.640	228	8.73	7.04	34.2	103
Oil- and chemical tankers	726	0.00821	0.0263	8.27	0.398	0.188	0.524	9
RoRo vessels/Ferries	289	0.00355	0.0115	4.07	0.176	0.119	0.684	6
General cargo ships	1 720	0.0231	0.0735	26.3	1.17	0.742	3.89	122
CRUISE AND CARGO SHIPS*	**34 400**	**0.404**	**1.36**	**485**	**20.1**	**16.7**	**90.6**	**586**
OTHER SHIPS	**150**	**0.00170**	**0.00563**	**1.96**	**0.0832**	**0.0368**	**0.0947**	**9**
FISHING VESSELS	**1 860**	**0.0240**	**0.0759**	**25.6**	**1.20**	**0.564**	**1.47**	**42**
WHALE WATCHING BOATS	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
TOTAL 2019	**36 500**	**0.429**	**1.45**	**513**	**21.4**	**17.3**	**92.2**	**637**

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

Table 17. Emissions from ships calling Sunda harbour 2016, 2017, 2018 and 2019, and the number of calls.

	CO_2 (tonne)	CH_4 (tonne)	N_2O (tonne)	NO_x (tonne)	HC (tonne)	PM (tonne)	SO_2 (tonne)	Ship calls
2019	36 500	0.429	1.45	513	21.4	17.3	92.2	637
2018	28 400	0.336	1.13	403	16.7	13.6	72.6	617
2017	26 000	0.308	1.03	370	15.3	12.6	67.5	635
2016	21 300	0.258	0.853	311	12.8	10.2	50.7	461

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

5 Discussion

The ship and boat traffic in the port increased between 2018 and 2019. The main reason for the increase is more activity by whale watching boats, which had more than 5500 visits in 2019 and just above 4500 in 2018. For the emission analysis the traffic by larger vessels are more relevant and, in these categories, there were an overall decrease between the years from 1486 to 1413, approximately 5%. Still, the number of calls by cruise ships was 143 in 2018 and 181 in 2019, an increase by 27%. Further, container traffic increased from 306 to 377 calls, an increase by 23%. There has been an increasing trend for visits of both container ships and cruise ships since 2016. Fishing vessels has an opposite trend, and both visits and emissions were less in 2019 than the previous years. In all, however, the changes in emission between the years cannot be directly related to changes in the number of calls.

An increase in emissions of between 16% and 18% was seen for 2019 compared to 2018. Cruise ships and container ships contribute to 78% of this increase. Also bulk carriers and chemical tankers contributed significantly to the increase. Although the number of calls by fishing vessels decreased their emissions increased from 2018. This is explained by increased times at berth for the largest fishing vessels, according to the statistics.

The calculations suggest the increase in emissions is mainly related to emissions from ships at berth. The calculated total increase of CO_2 emissions between 2018 and 2019 is 9090 tonnes and the increase in CO_2 emissions from ships at berth only is 7720 tonnes. Cruise ships at berth alone contribute to an increase of 4090 tonnes CO_2 between 2018 and 2019. The average time at berth per ship call has on the other hand decreased for both cruise ships and containerships.

It is difficult to compare one port to another since the characteristics of ports vary considerably. Differences in ship sizes, logistic requirements, and ship types can all influence emissions; large ships need longer time at berth, small tankers in general cause more emissions at berth than small RoRo vessels, and the fairway channel varies in length in different ports, to give some examples.

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

- in Akranes, the average values were around 60 tonnes/call in 2016 and 2017 and decreased to approximately 30 tonnes/call in 2018, and remained at a lower level at 35 tonnes of CO_2 per call in 2019;
- in Grundartangi, the average CO_2 emissions per call has been approximately on a level of 30 tonnes for the last three years;
- in Old harbour the larger vessels have had a steady increase of emissions the last four years and in 2019 the calculated average CO_2 emissions per call was 22 tonnes;
- CO_2 emissions in Sunda harbour are 46, 41 and 46 for the years 2016, 2017 and 2018, respectively while average emissions in 2019 had increased significantly to 57 tonnes/call. This is due to a relative increase in calls from cruise vessels, which has significantly higher emission per visit than other ship categories.

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 cause very high emissions and that may influence the results significantly. Emissions in both ports were significantly higher in 2019 than in 2018 mainly due to more time spent at berth by visiting ships. In addition to cruise and container ships, the average time at berth also increased for bulk carriers, general cargo ships, and chemical tankers.

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. This makes the model unsuitable for analysis of emissions from individual ships or small groups of ships.

Emissions from two ship categories rely on other assumptions than the rest. These are the fishing vessels and the whale watching boats, contributing 19% and 1.6% 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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