Emissions and Effluents from Cruise Ships in the Bay of La Paz, Mexico From January 2020 to June 2021

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Abstract

Cruise ships introduce polluting emissions into the atmosphere, even when at anchor. Additionally, a growing number of these vessels are retrofitted with Exhaust Gas Cleaning Systems, also known as scrubbers, which discharge washwater effluents into the ocean that are found to have negative impacts for marine life and the entire marine ecosystems. This technology runs as long as any of the ship's engines are on and consuming fuel, as they are meant to reduce Sulfur Oxides from the vessel's exhaust gases in order to comply with a 2020 regulation imposed by the International Maritime Organization (IMO). At different moments during the COVID-19 pandemic, several larger-than-average cruise ships anchored in the Bay of La Paz, Baja California Sur, Mexico, in the Gulf of California, without scheduled calls or passenger-related activities, for several weeks at a time. This study evaluates air emissions and washwater effluents of 10 of those vessels between January 1, 2020, and June 30, 2021. We find that during the study period, the 10 vessels consumed an estimated total of 436,300 metric tons (MT) of fuel, releasing 108,760 MT of carbon dioxide (CO_2), 330 MT of sulfur dioxide (SO_2), and 2,800 MT of nitrogen oxides (NO_x) into the atmosphere. All of the cruise ships have scrubbers installed, and they discharged in aggregate about 8.06 million m^3 of scrubber washwater, equivalent to the capacity of 3,224 Olympic-size swimming pools. We conclude that these vessels emitted significant levels of atmospheric pollutants (including those that are harmful to human health and that contribute significantly to climate change), as well as polluting washwater effluents, while at extended anchorage in the Bay of La Paz waiting for COVID-19 restrictions to be lifted.

List of Figures and Tables

List of Acronyms

AIS: Automatic Identification System
CARB: California Air Resources Board
CO_2: Carbon Dioxide
ECA: Emission Control Area
EERA: Energy and Environmental Research Associates
EF: Pollutant Emission Factors
EGCS: Exhaust Gas Cleaning System
EPA: US Environmental Protection Agency
GHG: Greenhouse Gas
Gt: Gigaton(s)
HFO: Heavy Fuel Oil
ICCT: International Council on Clean Transportation
IMO: International Maritime Organization
IMO 2020: Regulation issued by the International Maritime Organization to limit sulfur content of ships' fuel to 0.5%; entered into force on 1 January 2020.
LNG: Liquefied Natural Gas
LSFO: Low Sulfur Fuel Oil
m^3: Cubic Meter(s)
MARPOL: International Convention for the Prevention of Pollution from Ships
MEPC: IMO's Marine Environment Protection Committee
MGO: Marine Gas Oil
MT: Metric Tons
NO_x: Nitrogen Oxide
OGV: Ocean-Going Vessel
PM: Particulate Matter
SO_x: Sulfur Oxide
VOC: Volatile Organic Compound
WHO: World Health Organization

1 Introduction

1.1 Purpose of the Study

Cruise ships produce emissions to the air and water through their normal vessel operations. Air emissions include combustion emissions from the vessel's main and auxiliary engines and boilers, from polluting and global warming components such as Sulfur Oxide (SO_x), Nitrogen Oxide (NO_x), Carbon Dioxide (CO_2) and Particulate Matter (PM). In cases where installed and operational Exhaust Gas Cleaning Systems (EGCS), also known as scrubbers, are used to remove pollutants from exhaust emissions, thus reducing air emissions, increased washwater effluents are expected. Scrubber washwater is discharged to the marine environment by open-loop scrubbers, and these effluents contain dissolved and suspended exhaust gases and particulates, including acidic compounds, toxic substances, and heavy metals potentially harmful to marine life and marine ecosystems.

During the global COVID-19 pandemic, a number of vessels from different cruise lines traveled to the Bay of La Paz, Baja California Sur, Mexico, in the Gulf of California—while not carrying passengers—for the purpose of waiting at anchor in calm waters until travel restrictions were lifted and passenger operations could resume. During this time, those vessels operated in a warm lay-up mode, with on-board systems active to maintain temperature and humidity controls so that the vessel could be quickly activated in the case that travel and tourism restrictions related to the pandemic were lifted. This meant, however, that the environmental impact of the vessels was also higher, through higher engine loads, emissions, and washwater from installed open-loop scrubbers.

The purpose of this study is to evaluate and quantify the air emissions and washwater effluents of ten vessels known to have waited at anchor at the Bay of La Paz between January 1, 2020, and June 30, 2021.

1.2 Context on air emissions and washwater effluents

1.2.1 IMO 2020

The maritime industry produces about 3% of the world's total CO_2 emissions annually, as well as 15% of SO_x emissions, and 13% of NO_x emissions.[1] In addition, the prevailing fuel oil used in the maritime industry, known as Heavy Fuel Oil (HFO), is highly dangerous for human health when combusted. According to peer-reviewed paper from 2018 published in *Nature*,[2] "*Prior to cleaner ship fuels, ship-related health impacts include ~400,000 premature deaths from lung cancer and cardiovascular disease and ~ 14 million childhood asthma cases annually*". As part of an effort to

[1] https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx
[2] https://www.nature.com/articles/s41467-017-02774-9.pdf

tackle this, in 2008 the International Maritime Organization (IMO) decided to lower the limit of allowable sulfur content in ships fuel oil from 3.5% to 0.5%, starting on January 1st, 2020.[3]

Such regulation (known as IMO 2020) falls under the International Convention for the Prevention of Pollution from Ships—better known as MARPOL,[4] adopted in 1973 and modified by Protocol in 1978—and is expected to improve air quality in coastal regions as well as help tackle the climate crisis. According to the IMO, "*the new limit will mean a 77% drop in overall SO_x emissions from ships, equivalent to an annual reduction of approximately 8.5 million metric tonnes of SO_x. Particulate matter - tiny harmful particles which form when fuel is burnt – will also be reduced*".[5]

The IMO has 174 member countries, and MARPOL is composed by six Annexes tackling different polluting substances. It is important to note that IMO's regulations agreed to under MARPOL are legally binding for signatories. Regarding air pollution, MARPOL Annex VI entered into force years later, in 2005, and seeks to limit the emission of the main air pollutants contained in ships' exhaust gases, including SO_x, NO_x, and PM; prohibits deliberate emissions of ozone-depleting substances; and regulates shipboard incineration as well as the emissions of Volatile Organic Compounds (VOC). Amendments to Annex VI in 2011 also introduced measures to reduce greenhouse gas (GHG) emissions, as well as what are called Emission Control Areas (ECAs), which aim to heavily reduce emissions of air pollutants in designated sea areas through the adoption of special mandatory measures for all vessels. The sulfur limit at ECAs is 0.1% since 2015—even lower than the 0.5% established by IMO 2020 in the rest of the waters.

Per the IMO, there are different avenues to comply with the IMO 2020 regulation on sulfur limits, like using Low Sulfur Fuel Oil (LSFO)—with a sulfur content less than 0.5% m/m—and others: "*Ships may also use different fuels, with low or even zero sulphur - for example, liquefied natural gas, or biofuels. Limiting air pollutants by installing Exhaust Gas Cleaning Systems, also known as scrubbers, is accepted if flag States approve as an alternative means to meet the sulphur limit requirement*".[6]

Exhaust gas cleaning systems, or scrubbers, use an alkaline scrubbing material to neutralize the acidic nature of the exhaust gases of the ships. The avenue to comply with IMO 2020 is up to the owner/operator of the vessel and leaves the possibility open for vessels to continue to burn cheaper, more polluting high-sulfur fuels as long as they scrub the resulting emissions. Scrubbers can reduce sulfur emissions by 98%.[7]

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[3] https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx
[4] MARPOL is recognized as one of the most important international marine environmental conventions.
[5] https://www.imo.org/en/MediaCentre/PressBriefings/Pages/34-IMO-2020-sulphur-limit-.aspx
[6] https://www.imo.org/en/MediaCentre/PressBriefings/Pages/34-IMO-2020-sulphur-limit-.aspx
[7] https://www.sciencedirect.com/science/article/abs/pii/S1361920913001491?via%3Dihub

1.2.2 Exhaust Gas Cleaning Systems, or Scrubbers

There are different types of EGCS, depending on how they operate. *Open-loop* scrubbers, by and large the most common, use seawater, which is alkaline, to neutralize sulfur oxides from the exhaust gases in a chamber before they are released to the atmosphere, and then discharge the used seawater (known as washwater or effluent), back into the ocean. Most open-loop scrubbers discharge washwater back to the ocean without treating it first.

According to research by the International Council on Clean Transportation (ICCT), as of 2020, open-loop scrubbers accounted for 85% of total EGCS installations, as they are less expensive than hybrid and closed-loop systems. Ships equipped with this type of technology will discharge washwater into the ocean more or less continuously as long as the vessel is consuming power—including in port and at berth.

In contrast, *closed-loop* scrubbers add caustic soda to filtering water to neutralize the acidity of the exhaust gases (instead of using seawater), and collect the scrubber sludge on board and store it for disposal on land. Closed-loop systems can operate in zero-discharge mode, where nothing is discharged into the marine environment. *Hybrid* scrubbers can function in open- or closed-loop mode. According to ICCT research, 14% of scrubber installations to date were hybrid systems and only 1% were closed loop.

The IMO established guidelines for EGCS installations, for washwater criterion, as well as for testing and compliance through its Marine Environment Protection Committee (MEPC),[8] in 2015—long before IMO 2020 came into effect. However, vessels are only expected, but not obligated, to monitor chemical and physical parameters of scrubber's washwater, and the 2015 guidelines do not include limits for any heavy metals. More importantly, the MEPC guidelines are meant to act as an initial guidance for ships, as the IMO intends to amend them in the future as more data becomes available. According to the IMO website, "*The (MEPC) Sub-Committee on Pollution Prevention and Response is undertaking a review of the 2015 Guidelines on EGCS*".

As the decision on *how* to comply with IMO 2020 is left up to the vessel owners, shipping and cruise companies can decide on the avenue that best fits their business model. On the one hand, they can invest in adapting ships to run on liquefied natural gas (LNG)—which emits close to zero sulfur emissions—or use biofuels.[9] They can also use the still more expensive LSFOs, including marine gas oil (MGO), which are also IMO-compliant. Lastly, they can continue to burn regular HFO and retrofit vessels with EGCS, in order to ensure emissions are IMO compliant in terms of sulfur limits.

[8] The MEPC is a subsidiary body of the IMO that gets together every nine months to discuss and come to a consensus about the most pressing matters in terms of marine environment protection.
[9] Although biofuels SOx emissions are generally lower than bunker fuels, they can emit criteria pollutants.

1.3 The Rise of Scrubber Adoption in Cruise Ships

The decision on how to comply with IMO 2020 varies among companies and certainly between vessel types. For instance, an ICCT analysis[10] found that bulk carriers, container ships, and oil tankers make around three quarters of the fleet retrofitted with scrubbers, by number of ships. From those, bulk carriers are the most common ship with scrubbers installed, in absolute terms—1,246 ships, or 34% of all outfitted ships. Nonetheless, within each ship category, the study also found that cruise ships installed this technology in the largest share within each type.

According to a 2021 report[11] from the Cruise Lines International Association (CLIA)—one of the industry's leading conglomerates—by the end of 2021, almost 70% of the cruise ship global fleet was retrofitted with EGCS, and 96% of non-liquified natural gas new build ships will be adapted with scrubbers. This is in line with the fact that the world's four largest cruise companies—Carnival Corporation, Royal Caribbean Cruises, Norwegian Cruise Line Holdings, and MSC Cruises—are installing or have installed scrubbers on most of their ships. According to a Miami Herald investigation, as of January 1, 2020, of the 207 cruise ships belonging to these cruise lines collectively, 68% of the vessels were running on HFO and scrubbers, 31% on LSFO, and only 1% on LNG.[12]

Importantly, although cruises represent only 4% of the scrubber-equipped fleet by number of ships, they are responsible for 15% of total discharged washwater (*Figure 1*). Cruise ships are in fact the main contributor to scrubber discharges in ports, as they spend around 25% of their time at berth and, on average, they consume three times more energy per hour spent at port than oil tankers and six times more than container ships. As such, cruises account for 96% of discharges in seven of the 10 ports with the highest total washwater discharges globally.[13]

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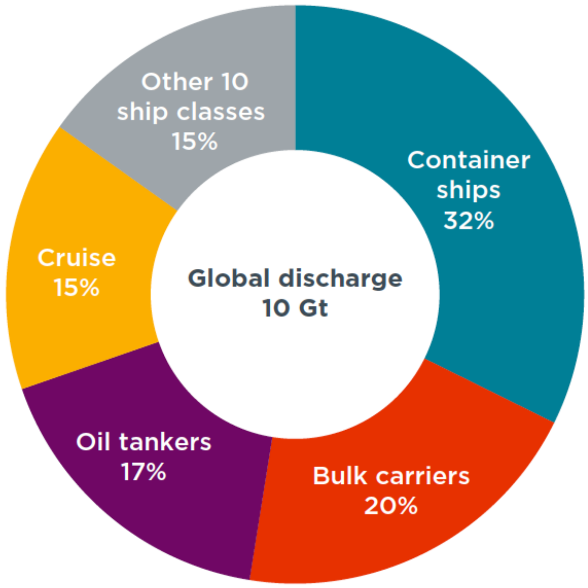
[10] *Global scrubber washwater discharges under IMO's 2020 fuel sulfur limit*, ICCT, 2021.

[11] https://cruising.org/-/media/research-updates/research/2021-state-of-the-cruise-industry_optimized.ashx

[12] *Cruise lines have a solution for a new clean fuel regulation. But is it the greenest option?* Dolven and Harris, Miami Herald, December 2020. https://www.miamiherald.com/news/business/tourism-cruises/article224596880.html

[13] https://theicct.org/sites/default/files/publications/scrubber-discharges-Apr2021.pdf

Figure 1: Scrubber washwater discharges per type of vessel, out of a total of 10 Gigatons (Gt) per year.



Source: *Global scrubber washwater discharges under IMO's 2020 fuel sulfur limit*, ICCT, 2021[14]

2. Study Findings and Discussion

2.1 Studied Vessels

This study focused on the movements and impacts of the 10 cruise ships shown in *Table* 1, from January 1, 2020, through June 30, 2021. All these vessels were known to have stationed at anchor for extended periods of time at the Bay of La Paz, in Baja California Sur, at some point during the COVID-19 pandemic—when most large cruises were grounded. Data shows that, with the exception of one visit by the Westerdam in April 2020 and another by the Koningsdam in June 2020, all visits and anchorages by the vessels studied occurred during or after February 2021. These 10 vessels sailed globally throughout 2020 and 2021, with routes shifting both seasonally and in response to the COVID-19 pandemic restrictions.

[14] https://theicct.org/sites/default/files/publications/scrubber-discharges-Apr2021.pdf

Table 1: Names and companies of the 10 vessels included in this study.

		2020 Scheduled Calls (Jan – Dec)	2021 Scheduled Calls (Jan – Jun)
Holland America	Koningsdam	0	0
	Nieuw Amsterdam	0	0
	Noordam	0	0
	Westerdam	0	0
	Zuiderdam	0	0
Princess Cruises	Emerald Princess	2	0
	Grand Princess	1	0
	Majestic Princess	0	0
	Royal Princess	0	0
	Ruby Princess	0	0

Based on a review of published cruise itineraries, as can be seen in *Table 1*, these vessels were scheduled to call at La Paz three times in 2020, with no scheduled calls in 2021.[15]

2.2 Global Emissions and Effluents from Studied Vessels

During the study period, the 10 vessels in this analysis consumed an estimated total of 436,300 metric tons (MT) of fuel globally, equivalent to around 4.6% of the global cruise fleet.[16] As shown in
Figure 2, these vessels operated globally during this period, although operations were concentrated around Mexico and the Caribbean, Southeast Asia, and Australia and New Zealand. The vessels in this study emitted proportionally higher emissions than the fleet average, as they have greater tonnages than the average cruise vessels. Based on public data, all 10 vessels in this study are outfitted with open-loop scrubbers, which use seawater to neutralize acidic exhaust gases.

[15] https://crew-center.com/la-paz-mexico-cruise-ship-schedule-2020
[16] https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

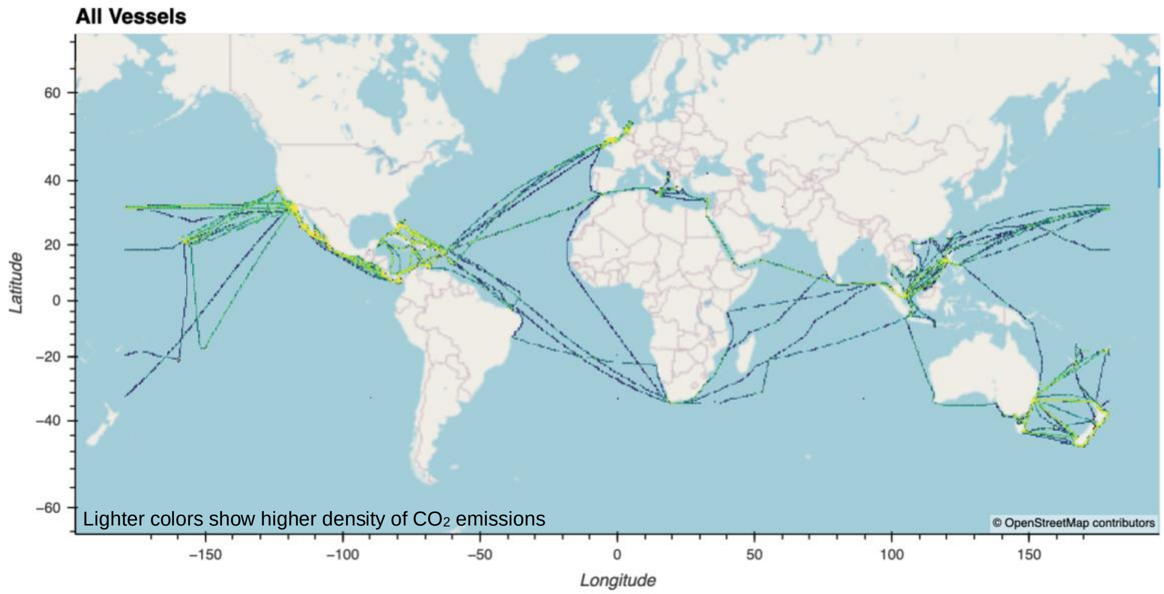


Figure 2. Global heatmap showing positions and density of CO_2 emissions from the 10 cruise ships studied from 1 January 2020 through 30 June 2021.

2.3 Emissions and Effluents in the Bay of La Paz from Studied Vessels

Total emissions and washwater effluents of these cruise ships in the Bay of La Paz are shown in *Table 2* below. In aggregate, the ten vessels that anchored in the Bay during the pandemic released estimated emissions of 108,760 MT of CO_2, 330 MT SO_2, and 2,800 MT NO_x. They also discharged about 8.06 million m^3 of scrubber washwater, equivalent to the capacity of 2.13 million typical septic tanks[17] or 3,224 Olympic-size swimming pools. The data, calculations, and methodology can be consulted in the report's Appendix. It should be noted that all of these emissions and effluents occurred on visits to the bay that were not on the vessel's original itineraries and no calls were scheduled.

When added together, the ten vessels that anchored in the Bay of La Paz visited a combined 45 times, spending nearly 600 days collectively in the Bay. The Koningsdam and the Zuiderdam spent 74.2 and 73.4 days in the Bay, respectively, with NO_x emissions of 340 and 370 MT, and washwater effluents of nearly one million m^3 for each vessel.

The greatest total monthly emissions in the Bay of La Paz from studied vessels occurred in April 2021, during which these anchored ships combined emitted 730 MT of NO_x, 90 MT of SO_2, 35 MT of PM and 2.1 million m^3 of scrubber washwater. The second and third most polluting months were March and June of 2021, respectively. More details are available in the Appendix (*Table 7*).

[17] Septic system for a typical 3 bedroom, 2,500 ft^2 house = 1,000 gal (3.79 m^3).

Table 2. Fuel consumption, emissions and washwater effluents from vessels anchored in the Bay of La Paz between 1 January 2020 and 30 June 2021.

Company	Vessel Name	La Paz Calls	La Paz Time (days)	Fuel (MT)	CO_2 (MT)	NOx (MT)	SO_2 (MT)	PM (MT)	Washwater (m^3)
Holland America	Koningsdam	6	74.2	4,330	13,480	340	40	20	998,510
	Nieuw Amsterdam	3	43.8	2,550	7,950	220	20	10	589,380
	Noordam	5	68.0	3,960	12,350	350	40	10	914,890
	Westerdam	5	57.4	3,340	10,410	290	30	10	771,480
	Zuiderdam	5	73.4	4,280	13,320	370	40	20	986,710
Princess Cruises	Emerald Princess	5	69.4	4,050	12,620	350	40	20	934,360
	Grand Princess	4	57.3	3,340	10,420	310	30	10	771,320
	Majestic Princess	4	53.1	3,090	9,640	50	30	10	713,860
	Royal Princess	4	53.5	3,120	9,720	270	30	10	719,920
	Ruby Princess	4	48.8	2,840	8,850	250	30	10	655,670
	Total	**45**	**598.9**	**34,900**	**108,760**	**2,800**	**330**	**130**	**8,056,100**

After careful review, it is obvious that the visits to the Bay of La Paz by these 10 vessels did not involve any passenger-related or shore-side activities, as vessels were not scheduled to visit the region (*Table 1* - scheduled calls); did not actually call at the cruise terminals; and, they all remained at anchor in the Bay (*Figure 3*). Visits to the Bay of La Paz lasted multiple weeks in many cases (*Figure 4* below), and daily SO_2 emissions activity show them in a state of warm lay-up during the COVID-19 pandemic.[18]

During warm lay-ups, vessels shut down many of the operations associated with cruise passenger entertainment, comfort, and hospitality. Main engines continue to operate as necessary for propulsion of the vessel and maintenance of safe operations. Auxiliary engines are also assumed to remain operational to maintain critical systems, including heating and air conditioning systems on board, even though the vessels are not carrying passengers. Maintaining temperature and humidity systems on board helps avoid issues of mold and condensation that can occur when operating in the marine environment.

[18] https://www.royalcaribbeanblog.com/2020/08/20/what-does-it-mean-when-cruise-ship-goes-cold-lay
https://www.cruiseindustrynews.com/cruise-news/22713-hot-lay-up-to-cost-millions-per-month-per-cruise-ship.html
https://www.forbes.com/sites/douggollan/2020/08/10/where-are-all-the-cruise-ships/?sh=5eb5bb716f6a

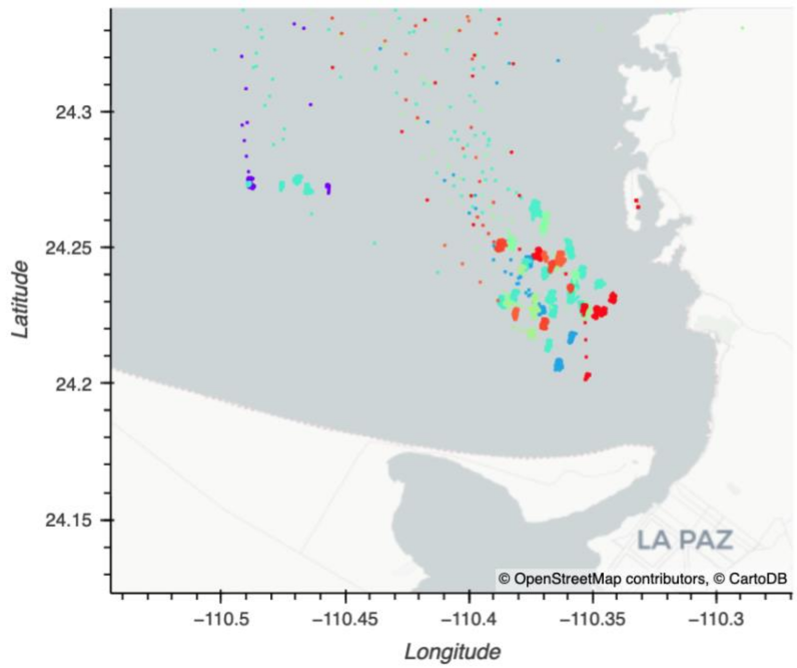
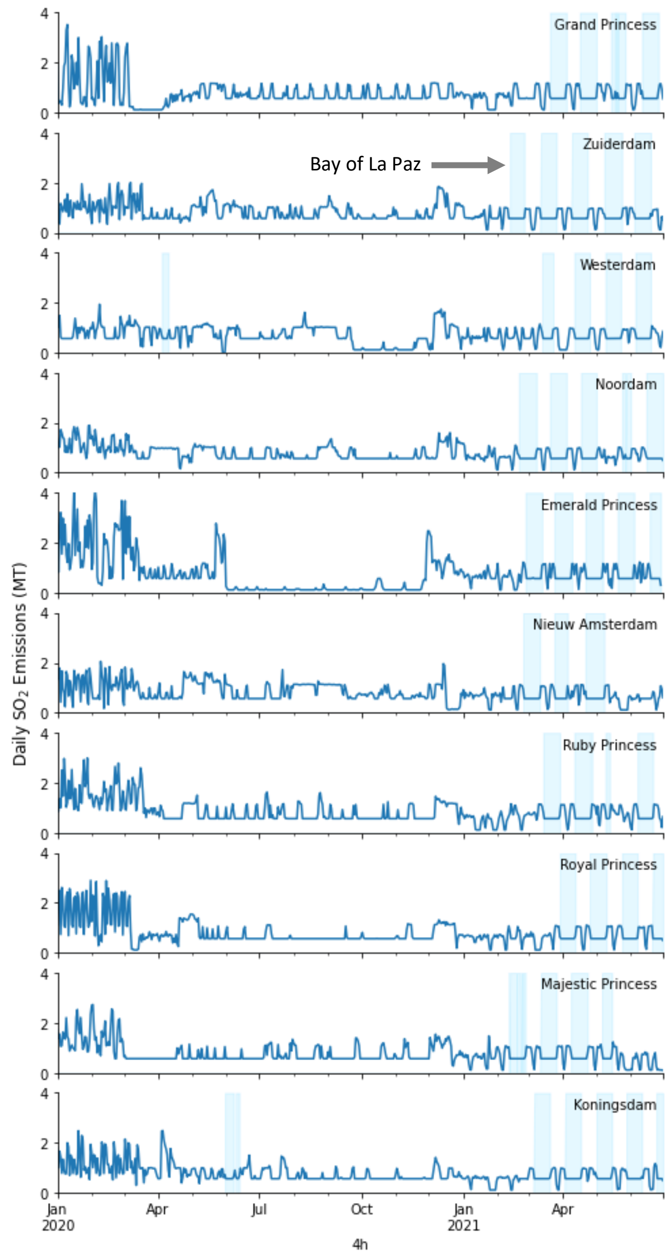


Figure 3. Automatic Identification System (AIS) derived positions for vessels at anchor in the Bay of La Paz. Colors show different vessels.

The COVID-19 pandemic was officially declared by the UN World Health Organization (WHO) on March 11th, 2020. Following the start of the pandemic, as activity restrictions began, vessels entered periods of warm lay-up, where they significantly reduced speeds and engine loads and operated with skeleton crews, showing lower levels of emissions. About one year after the pandemic began, ten of the vessels studied travelled to the Bay of La Paz, in Baja California Sur and sat at anchor in warm lay-up. The periods of time during which these vessels were stationed in the Bay of La Paz are shown by the light blue bars in *Figure 4* below.

Interestingly, however, none of these cruise liners is home-ported in Mexico. In fact, as detailed in Table 3 in the Appendix, five of them are home-ported in Rotterdam, Netherlands; four in Hamilton, Bermuda (a British island territory in the North Atlantic); and one in Vancouver, Canada. This, of course, raises the question of why these vessels parked in the Bay of La Paz, in Mexico, for extended periods of time in warm lay-up, and not in their home ports.

Figure 4: Trend in daily SO_2 emissions, by vessel, from 1 January 2020 through 30 June 2021. Shaded light blue bars show times during which the vessels were anchored in the Bay of La Paz.



3. Environmental Context

3.1 Effects of Scrubber Discharge on the Marine Environment

Public information and analysis on washwater contaminant concentrations is scant. While there are many studies regarding ocean pollution and acidification, there are still many questions regarding the direct and indirect impacts of pollution stemming from scrubber discharge on marine ecosystems. Here, ecologically valuable areas (such as estuaries, bays, coral reefs, etc.) are fragile and require special attention to avoid environmental disturbances that can spark a cascade effect of deterioration that could impact a community's wellbeing down the line.

Scrubbers effectively decrease the sulfur content from ships' exhaust gases, enough to comply with the new IMO-imposed limit. However, this technology uses seawater to decrease SO_x in those gases, and it is then released to the ocean as washwater. This washwater is more acidic than seawater and has also been found to contain polluting heavy metals and other contaminants. Heavy metals present in EGCS effluents include vanadium, nickel, copper, cadmium, mercury and lead—a major concern since these are toxic substances that are ingested and absorbed by living organisms and accumulated through the food chain.

The acidic nature of these effluents lowers the pH of the seawater in areas where vessels discharge. This can threaten multiple marine species since it may affect their ability to maintain an adequate physiological pH balance or assimilate calcium carbonate to form skeletons and shells.

Scientists suspect the acidification of the oceans resulting from increased concentrations of sulfur oxides, metals and Polycyclic Aromatic Hydrocarbons (PAHs) from discharged effluents from vessels can be an important issue moving forward, as it would contribute even further to human-induced climate change. As such, it is something that requires further investigation. Yet, overall, there is ample evidence that these effluents have negative impacts on the marine environment, because they alter the delicate balance of these ecosystems (through changes in temperature, turbidity, pH and other factors), and by directly affecting multiple marine species through its polluting nature.

With a greater number of vessels opting for scrubber technology instead of using low sulfur fuels available and considering that marine ecosystems are already under pressure from pollution and ocean acidification from climate change, these studies have concluded that the discharge of scrubber washwater should be restricted or, at the very least, regulated (particularly within sensitive marine ecosystems and in areas where water circulation is low).

3.2 Air and Water Pollution from the Studied Vessels

Scrubber washwater contains acidic compounds, removed from the exhaust gases, as well as heavy metals and other contaminants. While the specific parameters of contamination in washwater remain uncertain, analysis of multiple studies by the ICCT[19] shows that the median pH of open-loop scrubber systems is 5.63, meaning that washwater discharges from open-loop systems are acidic. Heavy metals present in scrubber washwater include vanadium, nickel, copper, cadmium, mercury and lead.

This analysis shows a clear pattern of vessels visiting the Bay of La Paz for extended periods of time during the COVID-19 pandemic. During these visits, vessels remained at anchor, emitting an estimated 8.06 million m^3 of scrubber washwater. **Open-loop scrubber washwater is acidic and contains heavy metals that can be harmful to the marine environment, a known issue in the Bay of La Paz.[20] Based on the washwater estimates, vessels may have contributed as much as 21.3 kg of PAHs, 1.25 kg of mercury, 93.0 kg of lead, and 1,667.5 kg of vanadium to the marine environment in the Bay of La Paz.[21]**

In total, vessels emitted 2,800 MT of NO_x, most of it from February to June of 2021. To put this in perspective, that amount of NO_x emissions is equivalent to 0.1% of the total U.S. light duty non-diesel vehicle fleet emissions in 2017.[22] Similarly, vessels emitted 330 MT of SO_2, equivalent to 1.6% of the total U.S. light duty non-diesel vehicle SO_2 emissions in 2017.[23] See *Figure 5* below for the aggregate emissions by all 10 vessels, by month.

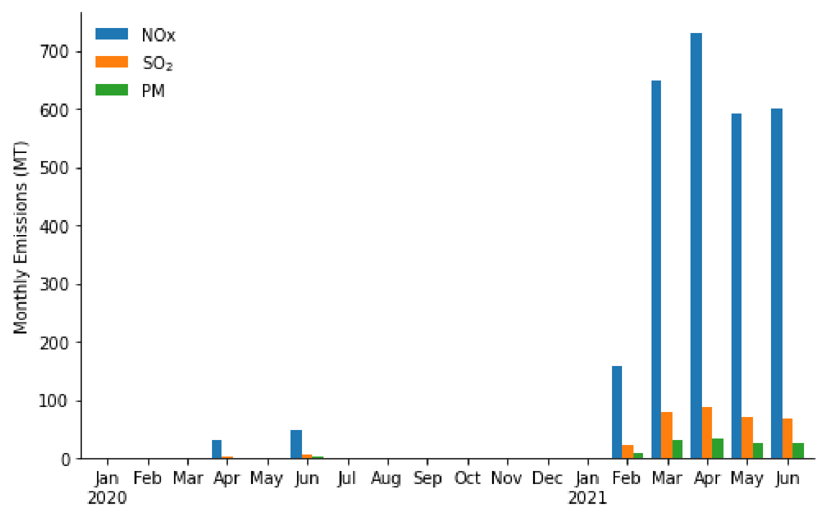


Figure 5. Monthly emissions of NO_x, SO_2 and PM by the 10 vessels studied in the Bay of La Paz from 1 January 2020 through 30 June 2021.

[19] https://theicct.org/wp-content/uploads/2021/06/Air-water-pollution-scrubbers-dec2020.pdf
[20] Pérez-Tribouillier, H., Shumilin, E. and Rodríguez-Figueroa, G.M., 2015. Trace elements in the marine sediments of the La Paz Lagoon, Baja California Peninsula, Mexico: pollution status in 2013. Bulletin of environmental contamination and toxicology, 95(1), pp.61-66.
[21] See Table 9 in report referenced in Footnote 19.
[22] https://gispub.epa.gov/neireport/2017/
[23] Ibid.

4. Conclusions

The IMO passed regulation IMO 2020 to tackle polluting air emissions from the shipping sector, particularly sulfur emissions, by limiting fuel oil's allowable sulfur content. This limit is today set at 0.5%, and as low as 0.1% in emission control areas. As of today, Mexico is not covered by an ECA, and thus the allowable sulfur content limit throughout the country is 0.5%.

Even though a part of the shipping industry is transitioning to cleaner bunker fuel, such as LSFO, including MGO, and LNG, many ships are still powered by heavy fuel-oil and retrofitted with exhaust gas cleaning systems (or scrubbers), to comply with IMO 2020. As such, scrubbers are bound to become more popular in the maritime sector, and particularly within the cruise fleets, as it is still a more economical solution to comply with such regulation. The number of ships retrofitted with scrubbers went up from 243 in 2015 to more than 4,300 in 2020—when IMO 2020 came into effect. Within the cruise ship industry, a 2021 report[24] found that by the end of 2021, almost 70% of the cruise ship global fleet was retrofitted with EGCS, and 96% of non-liquified natural gas new build ships will be adapted with scrubbers.

Open-loop scrubbers use seawater to "clean" exhaust fume contaminants, but as this seawater (with higher concentrations of pollutants, and more acidic) is discharged back into the ocean, this technology is essentially transferring pollution from what would have been air emissions, directly into the marine environment.[25] Washwater effluents contain acidifying compounds as well as heavy metals, PAHs and other toxic substances potentially harmful to marine life, and that can contribute towards ocean acidification and human-induced climate change.

Because of this, some jurisdictions around the world have taken measures to mitigate scrubbers' washwater pollution through regulations of their own. In the Western Hemisphere, eight sites currently ban EGCSs discharges in their waters in some shape or form, and ten if Argentina and Brazil are considered, whose bans are not currently active. A few other sites in the Americas have special criterion for scrubber effluents that include limits on PAH, pH, turbidity, and metals (beyond those established by the IMO EGCS 2015 guidelines), with the goal of ensuring effluents are given the best possible treatment before being discharged at sea.

Until more in-depth research and evidence comes to light as to the long-term consequences of exhaust gas cleaning system effluents on the marine environment (and indirectly, humans), and if or while the IMO acts at the international level, it will remain in the hands of individual jurisdictions to protect their marine environments by implementing local, regional or even nation-wide regulations. La Paz, and Mexico for that matter, has not issued any special regulation tackling either air or marine pollution from shipping; EGCS discharges are allowed.

[24] https://cruising.org/-/media/research-updates/research/2021-state-of-the-cruise-industry_optimized.ashx

[25] Georgeff, E. (2020). A killer whale's tale: Protect critical habitats by addressing scrubber washwater from ships. Available at https://theicct.org/blog/staff/killer-whale-tale-scrubbers-062020

In an effort to understand the potential climate and environmental consequences of cruise ships anchoring in the Bay of La Paz, in the Gulf of California, this study analyzed the movements, and quantified the atmospheric emissions and water effluents, of 10 cruise ships from January 1, 2020 through June 30, 2021 (shown in *Table* 1 of the report). This, as these vessels were all known to have stationed at anchor for extended periods of time at the Bay of La Paz at some point during the COVID-19 pandemic.

During the study period, the 10 vessels in this analysis consumed an estimated total of 436,300 metric tons (MT) of fuel globally, equivalent to around 4.6% of the global cruise fleet. Total emissions and washwater effluents of these cruise ships, specifically in the Bay of La Paz, are shown in *Table 2* of this report. In total, the ten vessels that anchored in the Bay during the pandemic released total estimated emissions of 108,760 MT of CO_2, 330 MT SO_2, and 2,800 MT NO_x. That amount of NO_x emissions are equivalent to 0.1% of the total U.S. light duty non-diesel vehicle fleet emissions in 2017.[26] Similarly, vessels emitted 330 MT of SO_2, equivalent to 1.6% of the total U.S. light duty non-diesel vehicle SO_2 emissions in 2017.

Based on public data, we found that all 10 vessels in this study have been retrofitted with open-loop scrubbers. These ships in aggregate discharged about 8.06 million m^3 of scrubber washwater, equivalent to about 3,224 Olympic-size swimming pools. Open-loop scrubber washwater is acidic and contains heavy metals that can be harmful to the marine environment, a known issue in the Bay of La Paz.[27] Based on the total effluents estimated through this study, these ten vessels may have contributed as much as 21.3 kg of PAHs, 1.25 kg of mercury, 93.0 kg of lead, and 1,667.5 kg of vanadium to the marine environment in the Bay of La Paz.[28]

Upon review of the data, visits to the Bay of La Paz by these 10 vessels did not involve any passenger-related or shore-side activities, as vessels were not scheduled to visit the region (see *Table 1* of this report - scheduled calls); did not actually call at the cruise terminals; and, they all remained at anchor in the Bay (*Figure 3* of this report). Visits to the Bay of La Paz lasted multiple weeks at a time in many cases (*Figure 4*).

These cruise ships visited the Bay of La Paz a total of 45 times during the study period, for non-passenger stays. Combined, they spent nearly 600 days in the Bay of La Paz. During this time, those vessels operated in a warm lay-up mode, with on-board systems active to maintain temperature and humidity controls so that the vessel could be quickly activated in the case that travel and tourism restrictions related to the pandemic were lifted. This meant, however, that the environmental impact of the vessels was also higher, through higher engine loads, emissions, and washwater from installed open-loop scrubbers.

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[26] https://gispub.epa.gov/neireport/2017/

[27] Pérez-Tribouillier, H., Shumilin, E. and Rodríguez-Figueroa, G.M., 2015. Trace elements in the marine sediments of the La Paz Lagoon, Baja California Peninsula, Mexico: pollution status in 2013. Bulletin of environmental contamination and toxicology, 95(1), pp.61-66.

[28] See Table 9 in report referenced in Footnote 17.

This analysis clearly shows that these ten vessels traveled to the Bay of La Paz as cruise ships waited until COVID-19 related restrictions were lifted and anchored there for multiple weeks at a time. Moreover, these cruise ships emitted proportionally higher emissions than the fleet average, as they have greater tonnages than the average cruise vessel. In aggregate, while at extended anchorage in the Bay of La Paz in Mexico, they emitted significant levels of atmospheric pollutants (including those that are harmful to human health and those that contribute to human-induced climate change), as well as polluting washwater effluents that can have multiple negative effects on the marine environment.

Appendix

Inputs and Methodology of the Study

1.1 Vessel Data

EERA gathered vessel characteristics data for the set of 10 cruise ships shown in *Table 3*. These data were gathered from publicly available sources, including cruise line promotional materials, manufacturer websites, and Marine Traffic data. These 10 vessels sailed globally throughout 2020 and 2021, with routes shifting seasonally and in response to the Covid-19 pandemic.

Table 3: Vessel characteristics for the ten vessels included in this study

Vessel Name	IMO	Gross Tonnage	ME Power (kW)	Company	Home Port	Build Year	Max. Speed (knots)
Koningsdam	9692557	99,863	50,400	Holland America	Rotterdam, NL	2014	22
Nieuw Amsterdam	9378450	86,700	64,000	Holland America	Rotterdam, NL	2008	23.9
Noordam	9230115	82,318	51,840	Holland America	Rotterdam, NL	2005	23
Westerdam	9226891	82,348	51,840	Holland America	Rotterdam, NL	2004	24
Zuiderdam	9221279	82,305	51,840	Holland America	Rotterdam, NL	2002	24
Emerald Princess	9333151	113,561	67,000	Princess Cruises	Hamilton, BM	2005	21.5
Grand Princess	9104005	107,517	69,120	Princess Cruises	Hamilton, BM	1998	23
Majestic Princess	9614141	143,700	62,400	Princess Cruises	Vancouver, CA	2017	23
Royal Princess	9584712	142,714	62,400	Princess Cruises	Hamilton, BM	2010	22.9
Ruby Princess	9378462	113,561	67,200	Princess Cruises	Hamilton, BM	2008	23

1.2 AIS Activity Data

AIS positional data were collected for the 10 study vessels from January 1, 2020, through June 30, 2021, from the Marine Cadastre[29] and Marine Traffic. Data were sampled to an average interval of 4 hours between consecutive positions, which allowed for sufficient temporal frequency for analysis of operations.

The distribution of vessel positions in this analysis is shown in *Figure 6* (top). This map shows the global distribution of voyages by these 10 vessels during the period January 1, 2020, through June 30, 2021, with additional insets showing the density of positions on voyages from Southern California along the coast of Baja California, and to Oceania and Asia.

[29] https://marinecadastre.gov/ais/

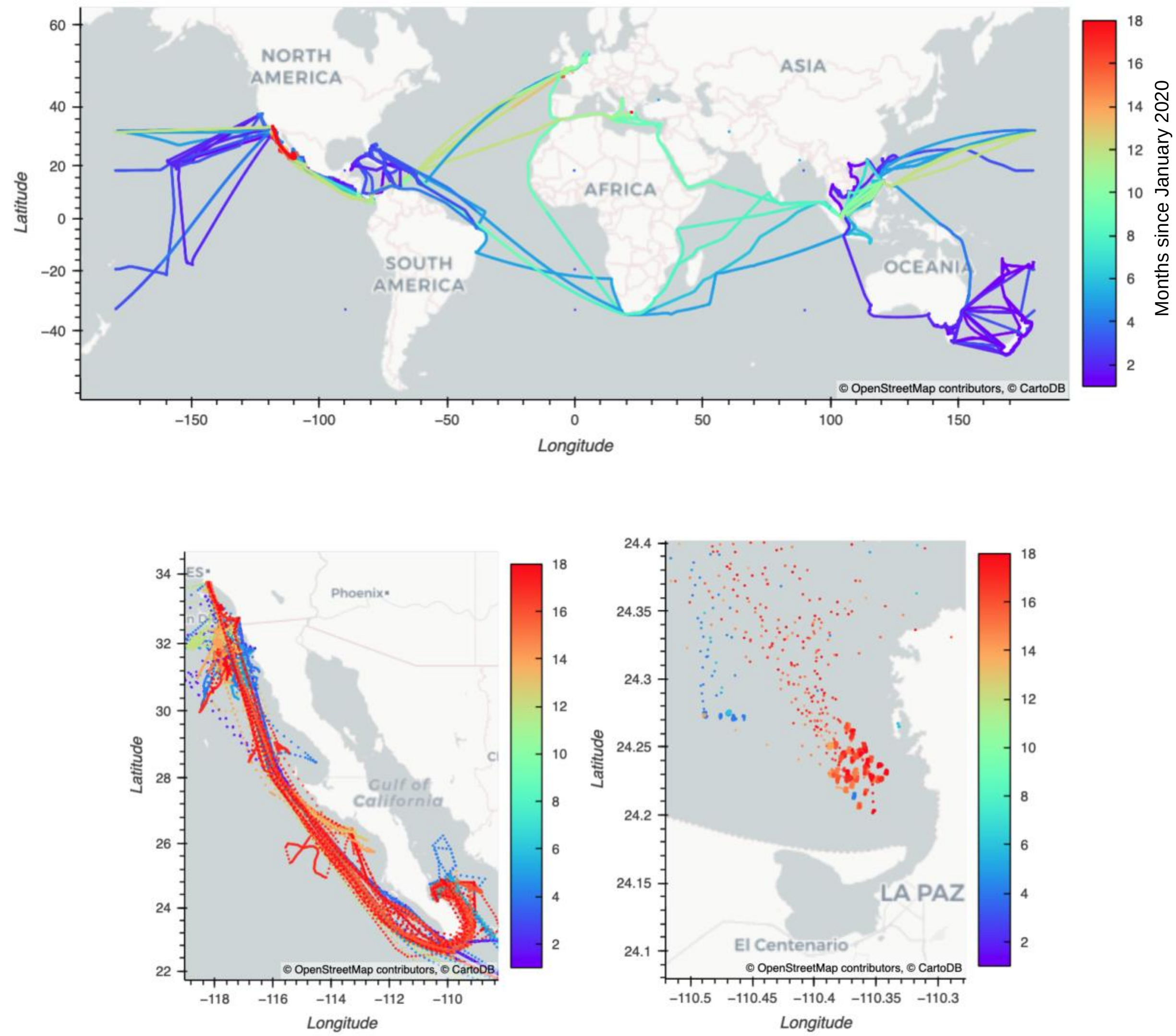

Figure 6: Vessel positions globally (top), around Baja California (bottom left), and in the Bay of La Paz (bottom right) colored by month. Month 1, in violet, corresponds to January 2020 and month 18, in red, to June 2021.

EERA conducted analysis on the temporal distribution of positions. As shown in *Figure 6* above, when observed temporally the distribution of vessel positions shows a concentration in vessel positions from global operations early in the observation period (top panel), shown by colors at the blue end of the rainbow scale, to operations around Baja California (bottom left) later in the observation period, shown by colors at the red end of the rainbow scale, including anchorage in the Bay of La Paz (bottom right).

1.3 Emissions Modeling

Based on the AIS positions observed, EERA estimated engine load, fuel consumption and emissions associated with vessel operations. Positions extracted at an average interval of 4 hours, though due to gaps in AIS coverage some intervals between positions were as high as 91.6 hours. These are outlier positions identified during QA/QC. There were 125 positions where time differences were observed to be greater than 6 hours, in these cases the time interval was assumed to be 4 hours. After cleaning, 4-hour positions were interpolated to 1-hour intervals. This approach allowed to maintain sufficient temporal resolution for detailed analysis.

Vessel main engine power was extracted from a search of publicly available data, and emissions were estimated following EPA guidance[30] based on the vessel speed, according to the modified Propeller Law/Admiralty formula shown below:

$$Power_i = P_{ref} \cdot \left(\frac{V_{obs}}{V_{ref}}\right)^3 \cdot SM$$

Where V_{obs} is the observed vessel speed, and V_{ref} is the maximum vessel speed. P_{ref} is the main engine power and SM is the sea margin, a scaling factor of 1.1 that accounts for marine currents, waves, and weather conditions. Vessel draft was not available in the data provided by Marine Traffic, and thus the fully specified version of the admiralty formula was not applied, and these estimates may be considered an upper bound, as vessels may adjust draft and trim to maximize efficiency while underway.[31]

Emissions (E) of pollutant j, for the time activity delta between positions (t) may then be estimated as follows:

$$E_{i,j,t} \ = \ Power_i \cdot EF_j \cdot Activity_t$$

Where power is described as above, pollutant emission factors (EF) in g/kWh are derived from the EPA guidance, and activity is measured in hours between vessel positions. Auxiliary engine and boiler loads do not typically vary with speed to the extent that main engine loads vary, and so EERA applied auxiliary engine and boiler loads based on EPA guidance. Total emissions were then calculated as the sum of main engine, auxiliary, and boiler emissions.

[30] https://www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance
[31] In the fully specified Admiralty Formula, draft serves to scale the equation, with a scaling factor less than or equal to 1, derived from the ratio of observed draft to design draft, to the power 2/3. As such, a 10% reduction in draft from the design draft, leads to a 6.8% reduction in power requirements.

All vessels studied have open-loop or seawater exhaust gas cleaning systems (EGCS or scrubber) installed. Accordingly, EERA modeled emissions assuming 0.5% S fuels in all areas, in accordance with IMO 2020 regulations, with EGCS activated when the vessel is inside an emission control area. EGCS require energy to operate the system, which is assumed to impose a 3% parasitic load on fuel consumption while the EGCS is operational. Washwater discharge rates are understood to scale linearly with power. Open systems have a washwater rate of around $45 m^3$ of water per MWh of operation, while closed systems discharge 0.1 – 0.3 m^3 per MWh of operation.[32]

EERA applied low load emission factors (see *Table 4* below) based on Table 3.10 in the EPA guidance document to account for non-linearities in emissions of different pollutants at engine loads below 20%. Accounting for low load adjustment is important in this study as 87% of observed positions had engine loads below 20% (*Figure 7*).

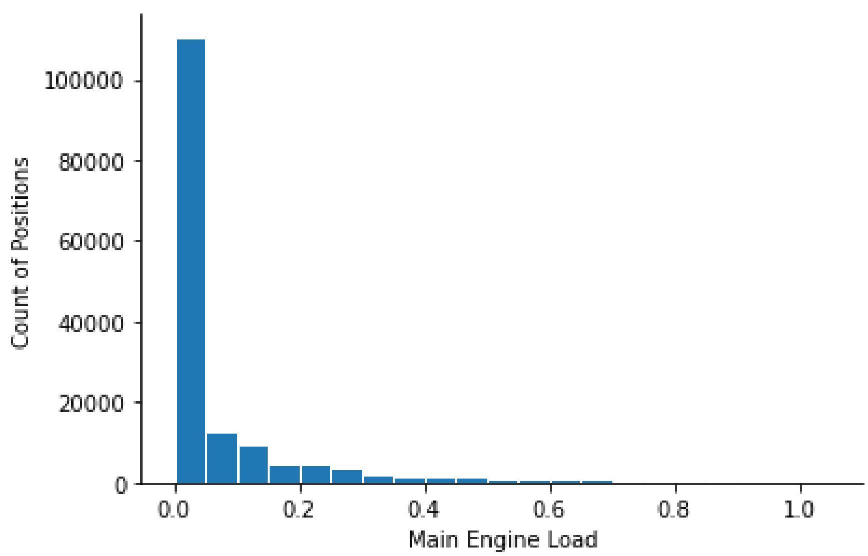

Figure 7: Distribution of main engine loads in the observed dataset

[32] https://www3.epa.gov/npdes/pubs/vgp_exhaust_gas_scrubber.pdf

Table 4: Low load adjustment factors applied per Table 3.10 in the EPA guidance document

Load	nox_ll af	hc_ll af	co_ll af	pm_ll af	co2_ll af	so2_ll af
1%	4.63	21.18	9.68	7.29	3.28	9.54
2%	4.63	21.18	9.68	7.29	3.28	9.54
3%	2.92	11.68	6.46	4.33	2.44	6.38
4%	2.21	7.71	4.86	3.09	2.01	4.79
5%	1.83	5.61	3.89	2.44	1.76	3.85
6%	1.6	4.35	3.25	2.04	1.59	3.21
7%	1.45	3.52	2.79	1.79	1.47	2.76
8%	1.35	2.95	2.45	1.61	1.38	2.42
9%	1.27	2.52	2.18	1.48	1.31	2.16
10%	1.22	2.2	1.96	1.38	1.25	1.95
11%	1.17	1.96	1.79	1.3	1.21	1.78
12%	1.14	1.76	1.64	1.24	1.17	1.63
13%	1.11	1.6	1.52	1.19	1.14	1.51
14%	1.08	1.47	1.41	1.15	1.11	1.41
15%	1.06	1.36	1.32	1.11	1.08	1.32
16%	1.05	1.26	1.24	1.08	1.06	1.24
17%	1.03	1.18	1.17	1.06	1.04	1.17
18%	1.02	1.11	1.11	1.04	1.03	1.11
19%	1.01	1.05	1.05	1.02	1.01	1.05
20%	1	1	1	1	1	1

Hourly fuel consumption as a function of speed follows a non-linear curve, as shown in

Figure *8*. This form fits the functional form of the underlying Admiralty formula, and these curves are in good agreement with the findings from other work performed by EERA, and the findings of the Fourth IMO GHG Study,[33] which show average main engine hourly fuel consumption of 4.1 MT at an average speed of 16.4 kts.[34]

[33] https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

[34] See Table 35 in the Fourth IMO GHG Report. For 150,000+ GT cruise ships, the average days at sea were 236, with a speed over ground of 16.4 kts and average main engine annual consumption of 23.2kT. 23,200/ (236 * 24 hours) = 4.1 metric tons fuel per hour.

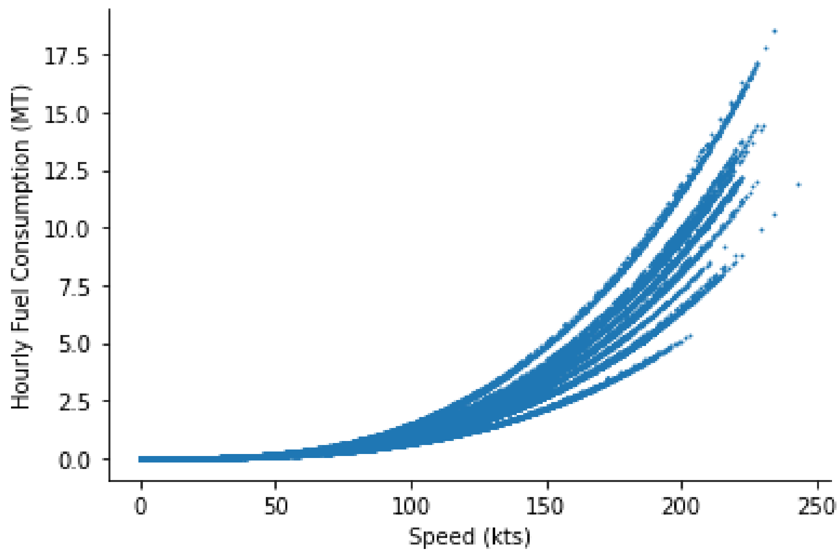

Figure 8: Hourly fuel consumption as a function of observed speed. (AIS data provide speed over ground as multiplied by 10 to avoid storing values as floats in the database).

1.4 Auxiliary Engine and Boiler Loads and Emissions

Auxiliary engine and boiler loads were not available for the vessels studied. Accordingly, EERA followed the approach outlined by the U.S. EPA in their port inventory guidance document,[35] which is aligned with the practice recommended and undertaken in the Fourth IMO GHG Study (See Table 17 in GHG4). EERA applied the estimates of auxiliary and boiler loads by vessel type and size, and operational mode derived from GHG4. Operational mode was determined based on vessel speed and geographical parameters, as shown in *Table 5*. All vessels studied fall under the parameters given in GHG4 for vessels with gross tonnage greater than 60,000 GT.

Table 5: Operation mode parameters and auxiliary and boiler engine loads

Mode	Geography	Speed	Load	Aux + Boiler Load (kW)
Transit	Outside the breakwater	> 3kts	> 20%	11,500
Maneuvering	≤ 10 NM from Port	> 1 kt	≤ 20%	15,480
Hoteling	At berth (< 1 NM from Port)	≤ 1kt	NA	12,450
Anchorage	At anchorage (1 – 10 NM from Port	≤ 3kt	NA	12,600

[35] https://www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance

1.5 EGCS Effluents

Open-loop EGCS draw seawater from the environment and spray it through exhaust gases to capture SOx that may otherwise have been emitted to the atmosphere. The washwater is then discharged back to the marine environment. All EGCS systems in this study are confirmed to be open-loop seawater systems.[36] Per EPA documentation,[37] and aligned with recent studies,[38] EERA assumed a scrubber washwater flow rate of 45 m^3/MWh of operation. Combined main engine plus auxiliary engine and boiler loads were used to estimate total vessel power for each positional record, with washwater flow rates from the EGCS (WW_{EGCS}) estimated using the equation below:

$$WW_{EGCS} = Power_i \times 45\, m^3/MWh$$

Table 6: Percent of global emissions, by vessel, from 1 January 2020 through 30 June 2021

Company	Vessel Name	Fuel (MT)	CO_2 (MT)	NOx (MT)	SO_2 (MT)	PM (MT)	Washwater (m^3)
Holland America	Koningsdam	8.16	8.16	7.85	8.59	8.53	8.17
	Nieuw Amsterdam	8.72	8.75	9.34	9.03	8.94	8.73
	Noordam	7.99	7.99	8.56	8.58	8.54	8.01
	Westerdam	7.75	7.83	8.34	7.69	7.6	7.74
	Zuiderdam	8.45	8.43	9.03	8.85	8.83	8.47
Princess Cruises	Emerald Princess	9.94	9.9	10.44	8.21	8.41	9.89
	Grand Princess	8.68	8.79	9.94	8.42	8.27	8.66
	Majestic Princess	8.07	8.06	1.73	8.39	8.42	8.08
	Royal Princess	8.73	8.7	9.32	8.85	8.92	8.74
	Ruby Princess		8.76	9.38	9.38	9.28	8.76

[36] Personal communication, Bryan Comer.
[37] https://www3.epa.gov/npdes/pubs/vgp_exhaust_gas_scrubber.pdf
[38] https://theicct.org/wp-content/uploads/2021/06/Air-water-pollution-scrubbers-dec2020.pdf

Table 7. Fuel consumption, emissions, and washwater effluents, by month in the Bay of La Paz.

Month Start	Fuel (MT)	CO_2 (MT)	NOx (MT)	SO_2 (MT)	PM (MT)	Washwater (m^3)
1/31/20						
2/29/20						
3/31/20						
4/30/20	360	1,130	30	-	-	83,480
5/31/20	20	60	-	-	-	4,480
6/30/20	630	1,970	50	10	-	146,260
7/31/20						
8/31/20						
9/30/20						
10/31/20						
11/30/20						
12/31/20						
1/31/21						
2/28/21	2,480	7,720	160	20	10	571,580
3/31/21	8,160	25,430	650	80	30	1,883,500
4/30/21	9,070	28,250	730	90	30	2,092,960
5/31/21	7,250	22,590	590	70	30	1,673,000
6/30/21	6,940	21,600	600	70	30	1,600,850