The return of the cruise

How luxury cruises are polluting Europe's cities

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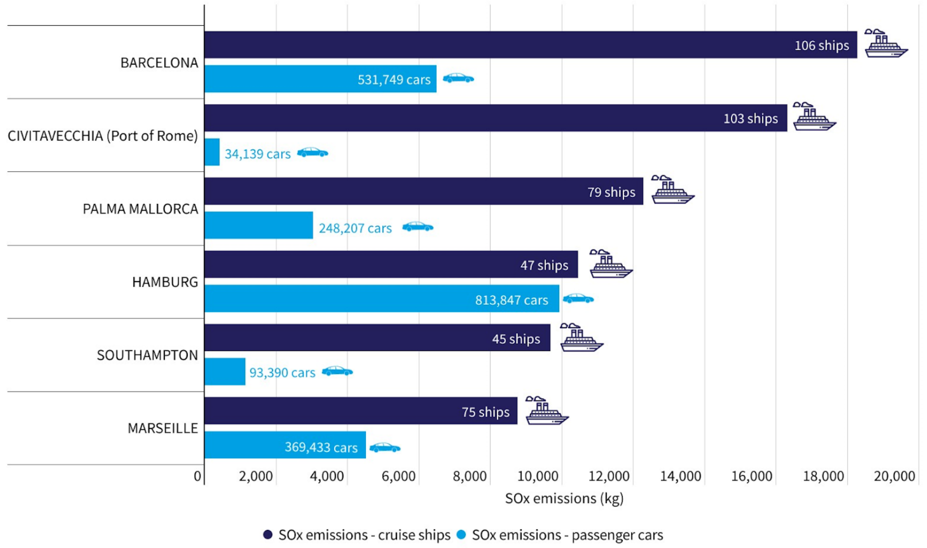
Executive Summary

After a brief hiatus due to COVID-19, luxury cruises are back. In an update to our 2019 study *One Corporation to Pollute Them All,* this new study shows that cruise ship pollution at Europe's busiest ports is back to pre-pandemic levels leaving many cities exposed to air pollution.

Compared to the year 2019, the number of cruise ships, the time they spent around ports and the fuel they consumed all increased by about a quarter (23-24%). This resulted in an increase of 9% in SO_X emissions, 18% in NO_X, and 25% in $PM_{2.5}$ emissions.



Cruise ships polluted more sulphur than all the cars circulating major port cities

Source: Transport & Environment (2023)

More sulphur than 1 billion cars

The analysis shows that despite the introduction of the UN shipping body's sulphur cap in 2020, Europe's 218 cruise ships emitted more sulphur oxides (SO_X) than 1 billion cars in 2022, or 4.4 times more than all the continent's cars.

Barcelona ranks most sulphur polluted port

In terms of cruise-sourced air pollution, Barcelona was Europe's most polluted port last year followed by Civitavecchia, a coastal port northwest of Rome, and the Athenian port of Piraeus. However, it was not just Mediterranean cities that bore the brunt of cruise ship pollution. Hamburg rose from 17^{th} most polluted in 2019 to sixth in 2022. The UK port of Southampton rose to seventh place.

Venice drops from worst to 41st

Yet, it was not all doom and gloom. Venice, Europe's most polluted cruise port in 2019 - and poster child of mass cruise tourism - fell to 41st following a ban on large cruise ships entering the port that was introduced in 2021. This led to an 80% fall in SO_x emissions from cruise ships.

However, that did not stop Italy from surpassing Spain as the most cruise ship polluted country in Europe. While Mediterranean countries made up the top three most polluted, Norway in fourth showed that this is not simply a Mediterranean problem.

One corporation (still) pollutes them all

The most polluting cruise ship operator was MSC Cruises, whose vessels emitted nearly as much sulphur as all the 291 million cars in Europe. When looking at parent companies, as in our original 2019 report, the Carnival Corporation comes on top with the 63 ships under its control emitting 43% more SO_x than all of Europe's cars in 2022.

Disconcerting

Many cruise operators such as MSC Cruises have been investing in fossil gas (LNG) as an alternative to conventional marine fuels. As of now, more than 40% of cruise ships in the order books of global shipyards are slated to be delivered with dual-fuel LNG engines. When running on LNG, these ships will cause less air pollution, but they are more damaging than fuel oils from a climate perspective due to methane slip from their four-stroke engines. Methane is a potent greenhouse gas, over 80 times more climate warming than CO_2 [1]. The cruise ship MS Iona, for example, emitted as much methane as 10,500 cows over a year.

T&E's recommendations:

- Establish more stringent decarbonisation requirements on cruise ships that call at European ports.
- Extend the zero-emission berth mandate for cruise ships to cover stay at anchorage.
- Implement zero-emission operational corridors for the most popular cruise ships trajectories in European waters.
- Extend the Sulphur Emission Control Areas (SECAs) to the rest of all EU and UK waters.
- Develop NO_x operational standards for ships at the EU level.
- Ban the use of scrubbers, especially open-loop ones, in all European waters.
- Cruise companies should discontinue investing in LNG-powered vessels and prioritise zero emission technologies, such as hydrogen fuel-cells, batteries and wind-power.

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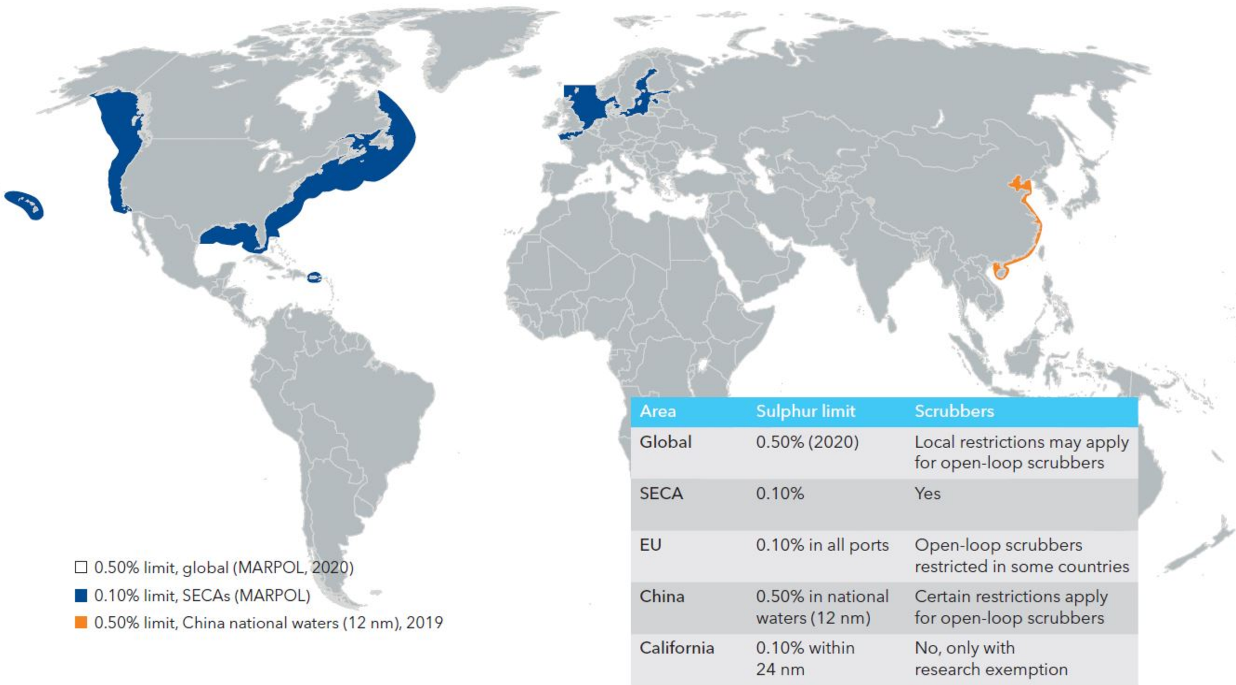
1. Context

The shipping sector plays an important role in the transportation of passengers and goods, and most of the goods used by households and industries today are transported by ship. Despite there being only about 100 thousand vessels in the world, the sector is one of the leading sources of greenhouse gas (GHG) emissions, air and water pollution. The sector still relies almost entirely on fossil fuels of the dirtiest kind, full of toxic substances including sulphur. This is the result of regulatory standards on marine fuels lagging far behind those applicable to other modes of transport. The best marine sulphur standard (0.1% Sulphur (S) | 1000 ppm) for example remains 100 times worse than Europe's sulphur standard for road diesel and petrol (0.001% S | 10 ppm) in place for the past 15 years. This 0.1% standard is only implemented within European ports, in designated sulphur emission control areas (SECAs) in Europe and North America (see Fig. 1) [1], as well as local areas of China, South Korea and Australia [2][3]. Outside these limited areas, the global fuel standard in application since 2020 is at 0.5% (5000 ppm). Until 2020, the sulphur standard in most of the world's oceans and seas was still 3500 higher (3.5% | 35000 ppm) that of European road fuels. Despite the new standard, shipping is estimated to be responsible for more than 250,000 premature deaths per year worldwide from cancer and cardiovascular diseases alone [4] and contributes to roughly 3% of global anthropogenic GHG emissions.



Area	Sulphur limit	Scrubbers
Global	0.50% (2020)	Local restrictions may apply for open-loop scrubbers
SECA	0.10%	Yes
EU	0.10% in all ports	Open-loop scrubbers restricted in some countries
China	0.50% in national waters (12 nm)	Certain restrictions apply for open-loop scrubbers
California	0.10% within 24 nm	No, only with research exemption

Figure 1: Sulphur emission control areas around the world, from [3].

While all ship types have an environmental and climate impact, air pollution from cruise ships is particularly worrying, as we showed in our 2019 study [5]. Although cruise ships represent a small segment of the shipping industry, they tend to operate near coastal areas and remain in port cities throughout the day, during which their engines continue running on dirty fuel and belching air pollutants [6].

The COVID-19 pandemic significantly impacted cruise traffic in 2020 and 2021, many of these ships idling or even getting scrapped. But data from the cruise industry indicates that the sector strongly recovered in 2022 with the number of port calls in the Mediterranean surpassing 2019 levels for example [7]. In this study we examine how cruise ship air pollution and greenhouse gas emissions evolved in 2022, compared to pre-pandemic levels of 2019.

2. Scope of the study and summary of the methodology

This study looks at different air pollutants and greenhouse gas emissions that cruise ships emit as a result of the composition of the fuel they rely on and the combustion process of the engines. The pollutants that are looked at are sulphur oxides (SO_X), nitrogen oxides (NO_X), and fine particles ($PM_{2.5}$). SO_X are chemical compounds that can include sulphur dioxide (SO_2) and/or sulphur trioxide (SO_3), which can provoke cardiovascular and respiratory diseases, and lead to premature death [4]. Similarly, NO_X emissions – which can include nitric oxide (NO) and nitrogen dioxide (NO_2) – can lead to respiratory diseases and are a precursor of ground-level ozone, another health-impacting pollutant. Together, SO_X and NO_X emissions contribute to the acidification of rains which affects the balance of ecological systems, especially plants and animals that are sensitive to acidic waters. Finally, $PM_{2.5}$ emissions are particles made up of fine dust, soot and smoke, that can be inhaled through human lungs.[1]

The study also looks at carbon dioxide (CO_2), black carbon (BC) and methane (CH_4) emissions, three types of greenhouse gases emitted by cruise ships which contribute to global warming. It is well known that the combustion of fossil fuels produces CO_2 emissions. CH_4 emissions are due to the slippage of liquefied natural gas (LNG) for the most part. A smaller part comes from the combustion of fuel oils, which in addition also produces BC.

We analysed cruise ships of more than 5,000 gross tonnage (GT) which stopped at European ports[2] in 2019 and 2022, i.e. 173 and 214 ships respectively. We followed the bottom-up methodology from the Fourth IMO Greenhouse Gas (GHG) study (see p. 40 of [1]) to calculate GHG emissions from ships using automatic identification system (AIS) data and ship technical specifications. We purchased ship technical specifications from IHS Markit and Clarksons' World Fleet Register (WFR) and pre-processed them to fill in the data gaps[8] . We purchased terrestrial and satellite AIS data from Spire. AIS messages are sent by ships at regular intervals during their operation and contain information such as timestamp, position, speed and draught of the vessel. We removed erroneous entries from the AIS data, resampled it at 1-hour intervals and infilled the gaps in the time series for position speed, draught and voyage status (i.e. moored, anchored, cruising or other navigational statuses. We then followed the following steps:

1. Allocation of hourly samples to Exclusive Economic Zones (EEZs) and ECAs in Europe
2. Detection of port stops

[1] PM emissions fall into two size categories: the one with a diameter of 2.5 micrometres or lower ($PM_{2.5}$) which were looked at in this study, and the one with a diameter of 10 micrometres (PM_{10}) which are not part of this study. Ships also emit ultra-fine particles (UFPs) which are not yet regulated and are roughly the size of a virus. These were not included in the study as well.

[2] Ports in a country part of the EU Monitoring, Reporting and Verification System (MRV), excluding outermost regions.

3. Assignment of operational phases
4. Allocation of voyages
5. Calculation of vessel energy consumption and emissions

In estimating emissions, we assumed that cruise ships equipped with dual-fuel LNG engines were running exclusively on LNG since we had no data to determine the precise fuel mix used on board. Other vessels were assumed to run on heavy fuel oil (HFO), very low sulphur fuel oil (VLSFO) or marine gasoil (MGO), complying with the relevant fuel sulphur standards in place on a given year and in a given geographical area. Specifically:

- Ships sailing, anchoring or moored in SECAs are required to use fuel with at most 0.1% sulphur content or rely on exhaust gas cleaning systems (scrubbers) to respect SO_x standards.
- Ships at berth or at anchor within the boundaries of European ports must follow the same rule as above for port stays above two hours.
- Until 1st of January 2020, cruise ships sailing in European EEZ outside SECAs were required to use fuels with a maximum 1.5% sulphur content under the EU Sulphur Directive (2012/33/EU).
- From 1st of January 2020, all ships sailing outside SECAs are required to use residual fuels complying to a maximum 0.5% sulphur content mandated under both EU Sulphur Directive and global MARPOL Annex VI.

We used Clarksons' WFR to identify ships equipped with scrubbers and assumed they were using 2.6% sulphur HFO with scrubbers treatment of exhaust gases when they needed to comply with 0.1% sulphur standards. In ports where the use of open-loop scrubbers is forbidden, we assumed 0.1% MDO/MGO was used instead. We used the ICCT analysis to estimate the decrease or increase in different emission species due to the use of scrubbers [9].

We then aggregated emissions results in two ways:

1. Emissions "around ports" are pollutants emitted by ships within 12 nautical miles (nm) from a given port's main coordinates and at a speed-over-ground (SOG) of less than 3 knots. 12 nm corresponds to the limit of territorial waters whereas 3 knots is the speed observed in AIS below which a ship is considered at anchor or at berth as per the Fourth IMO Greenhouse Gas (GHG) study. Stays at dry docks were naturally excluded.
2. Emissions "in European EEZs" are pollutants emitted by ships within the EEZ of European countries.

Finally, we compared ship pollution to car pollution within port cities or respective countries whose EEZs ships were sailing through. Car numbers were compiled using publicly available sources for cities (see Appendix 2 Table 10) and the European Union Transport Roadmap Model (EUTRM) [10] for each European country. We used EUTRM car emission factors assuming car fleets entirely made of diesel vehicles, which have worse NO_x performance than petrol cars. As the comparisons between cruise ships and cars rely on the ship emissions being divided by those of the passenger cars, the final results are therefore likely to be on the conservative side, i.e. they may well underestimate the comparative extent of air pollution from cruise ships versus cars if we included petrol cars in the equation too.

3. Findings on air pollution

3.1. Air pollution around European port cities (2019 and 2022)

We found that in 2022, 214 cruise ships emitted 509 tonnes of SO_X, 19,125 tonnes of NO_X and 448 tonnes of $PM_{2.5}$ around European ports[3] (see Table 1). Cruise ship activity in Europe clearly keeps increasing with time and so does air pollution, since marine pollutant standards around ports have not improved in many years. Compared to the year 2019, the number of cruise ships, the time they spent around ports and the fuel they consumed all increased by about a quarter (23-24%). This resulted in an increase of 9% in SO_X emissions, 18% in NO_X emissions, and 25% in $PM_{2.5}$ emissions.

Year	Number of cruise ships	Time spent around ports (hours)	Total fuel consumption (t)	Total SO_X (t)	Total NO_X (t)	Total PM2.5 (t)
2019	173	263,624	332,124	465	16,140	360
2022	214	324,387	411,023	509	19,125	448

Table 1: Air pollutant emissions from cruise ships around European ports in 2019 and 2022.

The reason why SO_x and NO_x did not increase as much as fuel consumption is that more ships were using scrubbers or LNG over time. One of the several issues with scrubbers is that using them with 2.6% sulphur HFO to comply with 0.1% sulphur standards increase PM emissions by 61% compared to using 0.1% sulphur MGO. This explains why $PM_{2.5}$ emissions have increased even more than fuel consumption.

What's worse, it appears that despite an increase in cruise ship traffic and emissions, the total number of cruise passengers has decreased. The industry thus polluted more to transport fewer people in 2022 than in 2019. Table 2 shows the number of cruise ship calls and passengers in main European ports in 2019 and 2022, based on official reporting [11] [12] [13] [14] [15] [16]. In these ports, the number of cruise passengers decreased from 18% to 28%, whereas port calls either increased or decreased very slightly. In the Mediterranean region, the number of passengers decreased by 23%, while port calls increased by 7%.

	Number of cruise ship port calls			Number of cruise passengers (in 1,000s)		
	2019	2022	2019 -> 2022 change	2019	2022	2019 -> 2022 change
Barcelona	800	805	+1%	3,138	2,329	-26%

[3] Closer than 12 nm from the port and at a speed of less than 3 knots, as explained in the previous section.

	Number of cruise ship port calls			Number of cruise passengers (in 1,000s)		
	2019	2022	2019 -> 2022 change	2019	2022	2019 -> 2022 change
Civitavecchia, Fiumicino, Gaeta	800	783	-2%	2,652	2,172	-18%
Marseille	497	572	+15%	1,866	1,475	-21%
Piraeus	622	677	+9%	1,098	880	-22%
Mediterranean ports (total)	13,596	14,588	+7%	31,147	24,126	-23%
Baltic sea ports (total)	2,768	2,415	-13%	5,910	4,230	-28%

Table 2: Cruise calls and passengers at main European ports in 2019 and 2022.

INFO BOX 1: Are scrubbers the solution?

IMO and European sulphur limits in ECAs (0.1% | 1000 ppm) and the 2020 global fuel sulphur standard (0.5% | 5000 ppm) have led to a significant uptake of scrubbers by cruise ships. Scrubbers are exhaust gas cleaning systems (EGCSs) that can be fitted on vessels to remove sulphur oxides in the exhaust gases by spraying water in the exhaust pipes [17]. These tools allow cruise ships to comply with stricter sulphur emissions standards while continuing to use cheap sulphur-heavy marine fuels – such as HFO – rather than more expensive distillate-type of fuels such as marine gasoil (MGO), or more desulphurised VLSFO and ultra low sulphur fuel oil (ULSFO).

While using scrubbers has a positive impact on air quality by limiting the amount of sulphur that goes into the air, they come with significant drawbacks from an environmental perspective, often resulting in the release to the oceans of water contaminated with pollutants such as heavy metals, PM, and polyaromatic hydrocarbons (PAH) among other materials present in oil residue.

With open-loop type scrubbers – the most common type [18] – seawater is used to clean the exhaust gases. After being used, the contaminated water is diluted with seawater and discharged back into the sea. Closed-loop type scrubbers, on the other hand, "*reuse most of the water*" and only discharge some part of the water.[4] Discharging contaminated water impacts the chemical composition of ocean water as well as marine life in various ways: the presence of metals can be toxic for marine animals, whereas PM and PAH can also impact the health of marine life [18].

[4] There are also hybrid scrubbers that can work in closed or open loop mode.

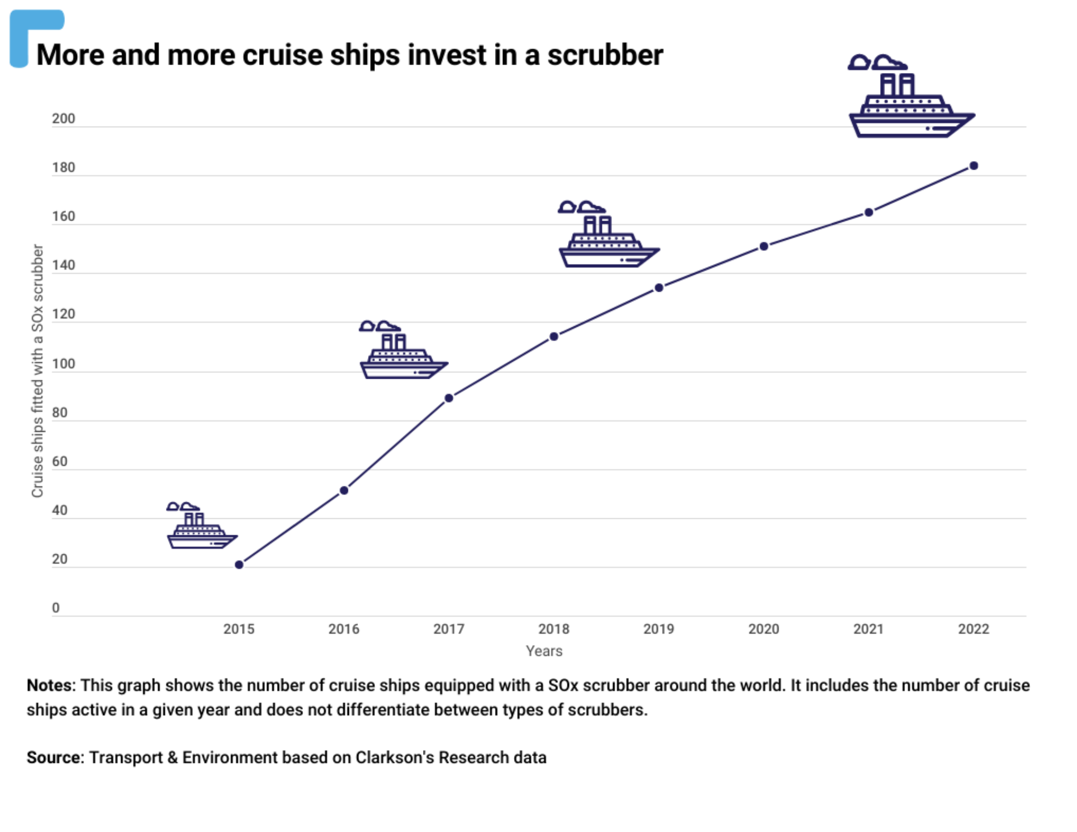


Figure 2: Number of cruise ships equipped with a scrubber globally.

Because of environmental concerns, several jurisdictions in the world set up rules to restrict the use of scrubbers. In the United States, scrubbers cannot be used in the ports and territorial waters of the states of California and Connecticut. In Europe, Portugal banned the use of open-loop scrubbers in all its ports, Spain banned it in the ports of Algeciras, Cartagena, and Huela, while Belgium forbids its use within three nautical miles from its coast.

3.2. Ranking of the most cruise ship-polluted port cities (2022)

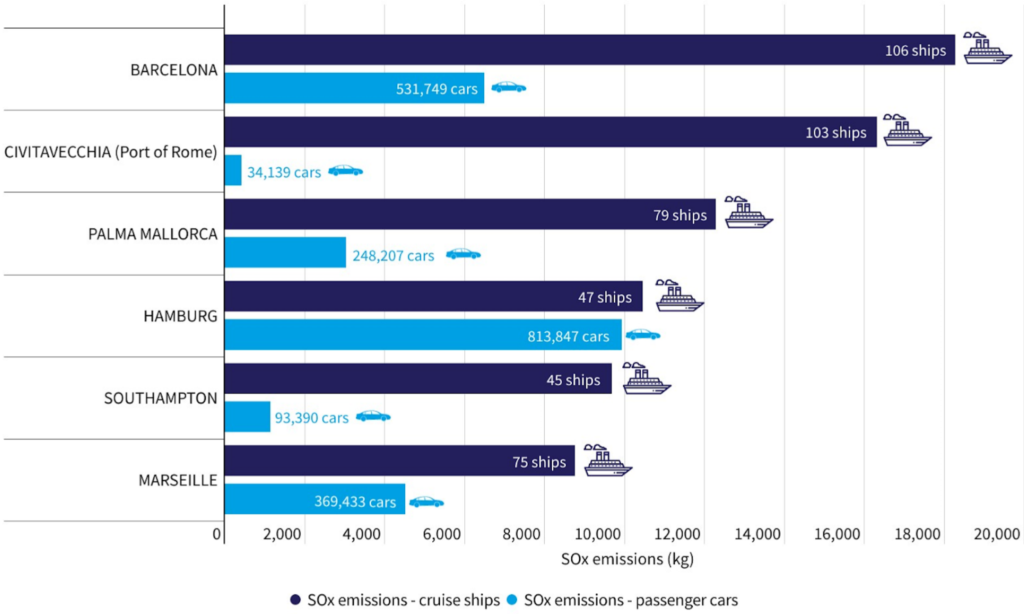
Table 3 ranks the most polluted port cities in Europe based on the amount of SO_x that cruise ships emitted around them in 2022. We compare the SO_x emitted by cruise ships to that of car fleets in each city. Similarly to our 2019 study based on 2017 AIS data [5], cruise SO_x pollution around port cities in 2022 remained many times higher compared to pollution from cars in those cities. This highlights the slow progress to reduce cruise-related pollution in most touristic port cities. NO_x emissions from cruise ships – and $PM_{2.5}$ pollution to a lesser extent – also represent a sizable share of similar pollutants from car fleets. For example, 34% for NO_x and 7% for $PM_{2.5}$ in Barcelona (see Appendix 2 -Table 15). The ranking was and still is dominated by Spanish and Italian cities, followed now by Greek ones, a consequence of the increasing cruise traffic along Greece's coast.

Ranking	Country	Port cities	Number of cruise ships calling at port	Time spent around ports (hours)	SO_x from cruise ships (kg)	Number of registered LDVs in port cities	SO_x from registered LDVs (kg)	Ratio of SO_x from cruise ships and LDVs
1	ESP	Barcelona	106	10,693	18,277	531,749	6,481	2.82
2	ITA	Civitavecchia	103	9,793	16,307	34,139	416	39.19
3	GRC	Piraeus	84	8,776	12,418	-	-	-
4	ESP	Palma Mallorca	79	6,930	12,285	248,207	3,025	4.06
5	PRT	Lisbon	108	5,407	11,132	374,855	4,569	2.44
6	DEU	Hamburg	47	3,993	10,445	813,847	9,919	1.05
7	GBR	Southampton	45	6,690	9,676	93,390	1,138	8.50
8	GRC	Mykonos	56	5,716	9,670	-	-	-
9	GRC	Thira	69	5,771	9,221	-	-	-
10	PRT	Funchal	96	5,275	9,041	-	-	-
11	ITA	Napoli	68	4,860	8,863	551,373	6,720	1.32
12	FRA	Marseille	75	4,744	8,763	369,433	4,503	1.95
13	ITA	Genova	31	3,595	8,546	267,822	3,264	2.62
14	SWE	Stockholm	49	3,433	7,815	358,540	4,370	1.79
15	DEU	Kiel	39	2,690	7,530	87,057	1,061	7.10
16	ITA	Livorno	53	4,192	7,262	87,723	1,069	6.79
17	MLT	Valletta	69	3,467	6,900	313,177	3,817	1.81
18	FRA	Le Havre	40	1,758	6,538	74,649	910	7.19
19	NOR	Port of Bergen	79	5,260	6,433	77,654	946	6.80
20	ESP	Santa Cruz De Tenerife	80	5,138	6,380	119,464	1,456	4.38
21	GRC	Rodhos	50	3,742	6,190		-	-
22	ESP	Malaga	107	3,453	5,743	275,888	3,362	1.71
23	GRC	Corfu (Kerkira)	55	3,573	5,540		-	-
24	DNK	Kobenhavn	70	4,261	5,535	169,654	2,068	2.68
25	EST	Tallinn	45	2,087	5,408	145,426	1,772	3.05
26	DEU	Rostock	30	1,847	5,302	128,424	1,565	3.39
27	ESP	Cadiz	97	3,210	5,195	44,288	540	9.62
28	BEL	Zeebrugge	51	1,698	5,110	56,880	693	7.37
29	ESP	Valencia	73	2,819	4,725	361,390	4,405	1.07
30	HRV	Split	44	2,745	4,559	89,473	1,090	4.18

Table 3: SOX emissions from cruise ships and LDVs in 30 most polluted European port cities by cruise ships in 2022.[5]

[5] Empty cells correspond to cities for which the number of registered cars could not be found.

Cruise ships polluted more sulphur than all the cars circulating major port cities



Source: Transport & Environment (2023)

Figure 3: Comparison between SOX emissions emitted by passenger vehicles circulating in specific cities compared to the SOX emissions emitted by cruise ships that stopped in those cities.

We also analysed 2019 cruise ship emissions around port cities and provided a similar ranking for that year in Appendix 2 Table 17. Some changes in the ranking are particularly noticeable: the most polluted port in 2019, Venice, fell to the 41st place in 2022, as SO_x emissions around the port decreased by 80%. This is due to a ban on cruise ships above 25,000 GT to enter the city's waters from 2021 [19]. As a consequence, the port of Barcelona, which was ranked second in 2019, is now first, although SO_x emissions remained constant. The number of cruise ships that stopped in this city emitted nearly three times more sulphur than all the passenger vehicles registered in Barcelona (see Fig. 3).

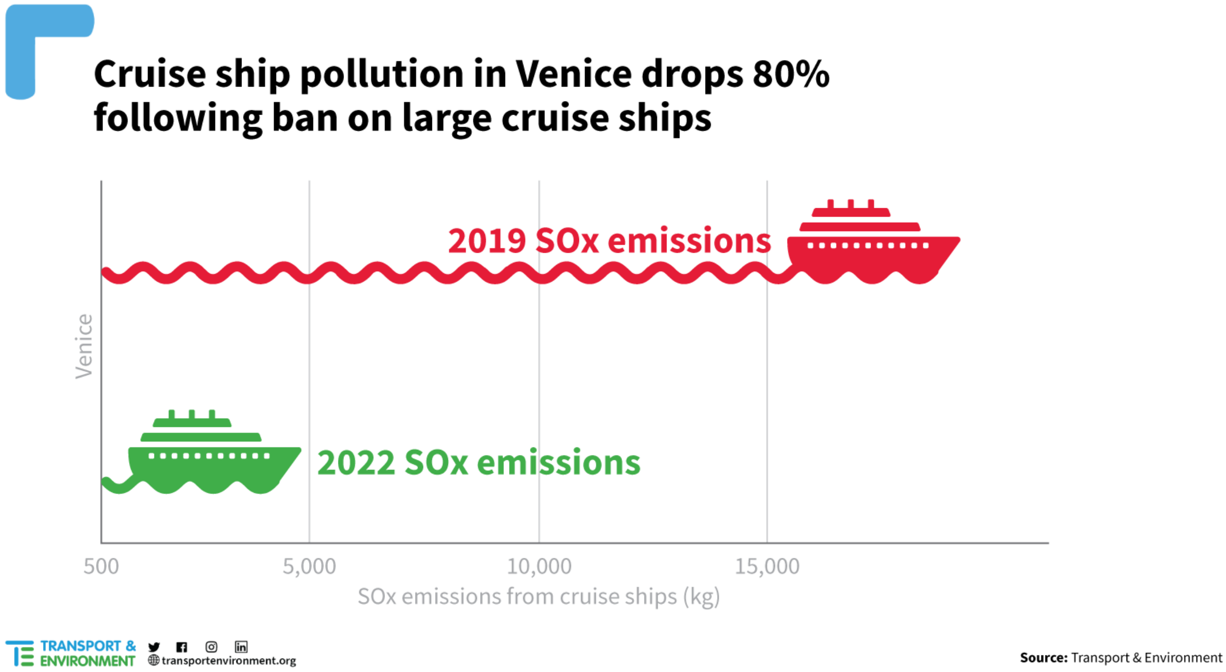
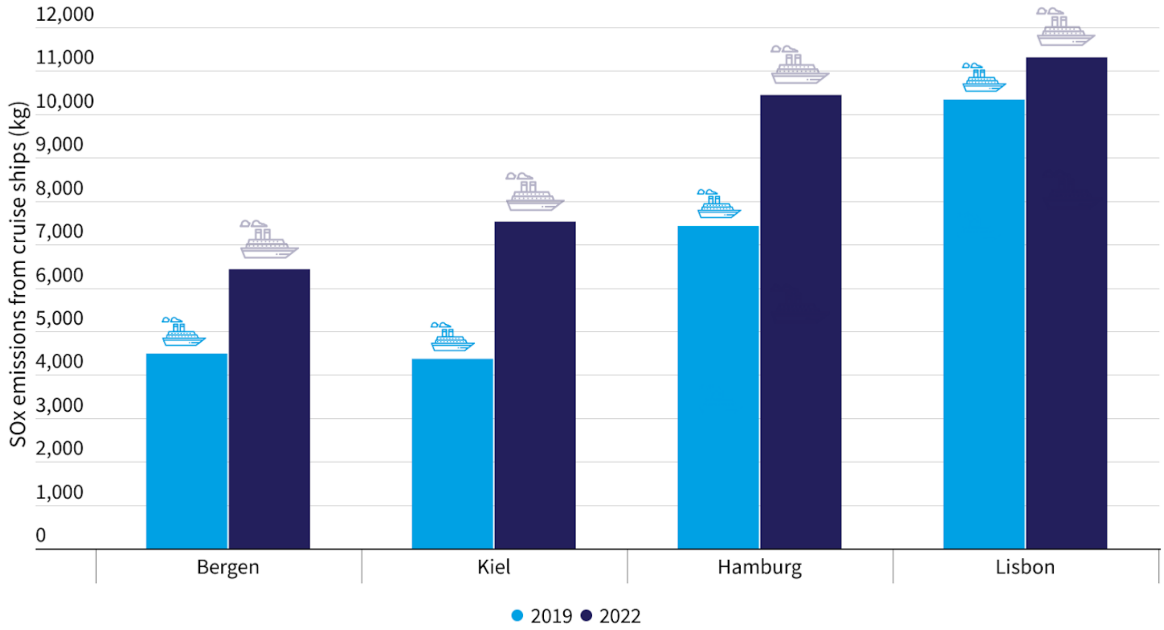


Figure 4: Cruise ships SOx emissions in Venice in 2019 and 2022

In many ports, air pollution increased between 2019 and 2022 following the general trend shown in section 3.1. The port city of Civitavecchia, Italy, is now ranked second most cruise-polluted port in Europe after registering a strong growth between 2019 and 2022 (+60% in SO_x emissions), though 2019 estimates are more uncertain due to poor AIS data quality around this port.[6] In 2022, 103 cruise ships stopped at this port emitting nearly 40 times more sulphur than all the cars in the city (see Fig. 3). As shown in Fig. 5, other port cities where pollution increased noticeably between 2019 and 2022 are Hamburg (+41% in SO_x and 6th place in 2022), Kiel (+71% in SO_x and 15th place in 2022) and Bergen (+43% in SO_x and 19th place in 2022). This shows that the increase in cruise ship traffic in 2022 was not only observed in the Mediterranean.

[6] Only 30% of the hourly samples around Civitavecchia came from AIS messages. The rest, corresponding to gaps in transmission and/or reception of AIS messages, had to be filled in. We noticed the same problem around a few other ports, given in Appendix 2 Table 11. AIS data quality around most other ports was very high, with more than 95% of hourly samples coming from AIS messages.

The ports of Bergen, Kiel, Hamburg and Lisbon were already more polluted in 2022 than before the pandemic



Source: Transport & Environment (2023)

Figure 5: SOX emissions in the ports of Bergen, Kiel, Hamburg and Lisbon in 2019 and 2022.

Other port cities appear to have become less polluted than before the pandemic. This is the case of Ibiza (-47% in SO_x and 46th place in 2022) and Dublin (-89% in SO_x and 152th place in 2022). In Ibiza, the competition for space at the port between ferries and cruise ships may have forced cruise ships to reduce their time at the port and in some cases to no longer stop at this port [20]. In Dublin, the authorities decided to temporarily reduce the number of berths available for cruise ships to provide space for the increased container traffic following Brexit. This measure is not intended to last more than two years and the port is even considering extending its capacity in the long term [21].

Because of the increased uptake in scrubbers and LNG between 2019 and 2022, SO_x emission per unit of fuel burned around a majority of European ports decreased. That is the case for Marseille for example (-28% in SO_x emission per unit of fuel burned), which saw 49 ships equipped with scrubber berth in 2022, compared to 40 in 2019. The increase in the number of ships fueled by LNG was more modest, 3 in 2022 compared to 2 in 2019. However, these ships are some of the biggest vessels in the fleet and thus represent a higher share of the power demand – 16% for Marseille. Combined with a slight decrease in activity, the increased use of scrubbers and LNG around Marseille reduced SO_x emissions by 23% in 2022 versus 2019. While scrubbers and LNG appear to be beneficial for air pollution, they come with drawbacks to climate and water quality which are further explained elsewhere (see info box 2).

3.3. Air pollution in European EEZs (2019 and 2022)

Table 4 shows that the time spent by cruise ships in European EEZs increased similarly to that around ports between 2019 and 2022, i.e. by 23%. The fuel consumed increased less, by 18%, following the increase in distance sailed of 16%. Cruise ships sailed less for each hour spent in European EEZs in 2022. This is likely because some ships were still idle at the beginning of the year as demand had not fully recovered yet after the Covid-related lockdowns.

Year	Number of cruise ships	Time spent in EEZs (hours)	Distance sailed (nm)	Total fuel consumption (kt)	Total SO_x (kt)	Total NO_x (kt)	Total PM2.5 (kt)
2019	173	722,806	6,484,194	2,198	41	128	8
2022	218	887,977	7,514,499	2,591	16	139	7

Table 4: Air pollutant emissions from cruise ships in European EEZs in 2019 and 2022.

SO_x emissions in EEZs decreased by 62% between 2019 and 2022, a consequence of the global 0.5% sulphur cap introduced in 2020. NO_x increased by 8% and $PM_{2.5}$ decreased by 15%. The reduction in PM emissions, which are related to the sulphur content of the fuel, could intuitively be expected to be greater, but as explained above, the increasing use of scrubbers actually worsens $PM_{2.5}$ emissions compared to using MGO with 0.1% sulphur content.

3.4. Ranking of country EEZs

Table 5 ranks the most polluted countries in Europe based on the amount of SO_x that cruise ships emitted in their EEZ in 2022. Despite the introduction of the global 0.5% sulphur fuel standard, 218 cruise ships emitted more than four times more SO_x in European EEZs in 2022 than the 291 million passenger vehicles of those countries.

Italy was the country with the most pollution from cruise ships in 2022. The 3,720 tonnes of SO_x emitted in Italy's EEZ are well above Spain's total of 3,036 tonnes, even though fewer ships spent less time in Italian waters. This can be explained by the fact that bigger and more polluting cruise ships spent more time in Italian waters. Italy and Spain are followed by Greece and Norway, which has the highest sailing time by cruise ships in its waters.

Ranking	Country	Number of cruise ships	Sailing time (hours)	SO_x from cruise ships (t)	Number of registered LDVs in country	SO_x from registered LDVs (t)	Ratio of SO_x from cruise ships and LDVs
1	Italy	152	128,647	3,720	38,039,760	464	8.0
2	Spain	183	136,815	3,036	24,611,551	300	10.1
3	Greece	121	106,223	2,330	4,949,354	60	38.6

Ranking	Country	Number of cruise ships	Sailing time (hours)	SO_x from cruise ships (t)	Number of registered LDVs in country	SO_x from registered LDVs (t)	Ratio of SO_x from cruise ships and LDVs
4	Norway	110	144,792	1,471	2,938,966	36	41.1
5	France	176	62,311	1,320	37,413,447	456	2.9
6	Portugal	170	48,449	1,286	5,325,884	65	19.8
7	Croatia	72	31,282	672	1,568,797	19	35.1
8	United Kingdom	115	67,584	614	36,021,268	439	1.4
9	Iceland	73	24,027	371	270,000	3	112.8
10	Cyprus	60	11,780	255	581,866	7	36.0
11	Ireland	73	7,319	191	2,219,441	27	7.1
12	Germany	98	25,587	86	45,457,533	554	0.2
13	Denmark	103	25,324	84	3,016,223	37	2.3
14	Malta	82	5,737	82	305,579	4	21.9
15	Sweden	83	20,463	61	5,207,522	63	1.0
16	Netherlands	104	16,178	55	8,838,393	108	0.5
17	Estonia	48	5,279	26	846,496	10	2.6
18	Finland	58	6,556	19	2,726,303	33	0.6
19	Belgium	93	3,297	15	5,585,231	68	0.2
20	Latvia	35	3,233	15	682,827	8	1.8
21	Slovenia	41	1,122	7	1,220,346	15	0.5
22	Poland	40	3,217	6	27,743,967	338	0.0
23	Lithuania	29	851	3	2,730,542	33	0.1
	Other countries[7]				32,950,946	402	
	Total	218	887,977	15,744	291,252,242	3,550	4.4

Table 5: SOX emissions from cruise ships and LDVs in European EEZs in 2022.

For simplicity, NO_x and $PM_{2.5}$ are not shown in Table 5, but we provided these results in Appendix 2 (Table 11 and Table 12). In general, the 2022 cruise ships' NO_x emissions represented 12% of the total NO_x emitted by Europe's passenger cars in a year, although there are significant variations. For example, in Iceland and Norway, cruise ships emitted more NO_x than these countries' entire domestic passenger car fleet in a year. In Croatia, Denmark, Cyprus and Greece, cruise vessels were responsible for more NO_x than half the national car fleet.[8]

In absolute terms, the Italian and Spanish coasts are still the most exposed areas to cruise ships' NO_x emissions, with about 27,000 and 22,000 tonnes of NO_x emitted by cruise vessels in these respective countries' EEZ in 2022. Similarly to SO_x, four out of the top five NO_x-exposed European countries are major tourist destinations in Southern Europe. This can be explained by the large amount of time that cruise ships spent along the coasts of Southern European countries.

[7] Austria, Bulgaria, Czech Republic, Hungary, Luxembourg, Romania, Slovakia and Switzerland
[8] Regarding NO_x emissions, we used real-world emission factors for cars, whereas we used legal limits for ships in the absence of real-world factors. This creates a distorted comparative picture between cars and cruise ships, as car's NO_x emissions have been shown to be several times higher than legal limits.

PM emissions from shipping are generally linked to the quality of the fuel used and its sulphur content. The distribution of $PM_{2.5}$ followed a similar pattern to SO_X emissions. When we compared the 2022 $PM_{2.5}$ from cruise ships to $PM_{2.5}$ from the national car fleets, $PM_{2.5}$ from cruise ships accounted for 0.20% to 4.3% $PM_{2.5}$ from the national car fleets in the least exposed countries, but increased to 33% for Greece, 44% for Norway and 110% for Iceland.

3.5. Ranking of the most polluting cruise shipping companies (SO_X emissions)

In Table 18, we present the ranking of the 20 most polluting cruise ships operators based on their SO_X emissions in European EEZs in 2022. We found that the most polluting cruise ship operator was MSC Cruises, whose 19 vessels emitted nearly as much sulphur as 291 million passenger vehicles in Europe. Costa Cruises and the Royal Caribbean Cruises emitted respectively as much as 41% of SO_X emissions from EU vehicles and 36% of SO_X emissions from European passenger cars. When looking at parent companies, Carnival Corporation comes on top, with the 63 ships under its control having emitted 43% more SO_x than the entire European car fleet in 2022. The complete list of operators can be found in Appendix 2 Table 18.

Ranking	Cruise operator	Parent company	# ships	SO_x emissions from cruise ships (t)	Ratio of emissions from cruise ships to all European LDVs[9]
1	MSC Cruises	MSC	19	3,358	95%
2	Costa Cruises	Carnival	11	1,439	41%
3	Royal Caribbean Cruises	Royal Caribbean Group	9	1,295	36%
4	Norwegian Cruise Line	Norwegian Cruise Line Holdings	11	1,189	33%
5	Aida Cruises	Carnival	12	850	24%
6	Princess Cruise Lines Ltd	Carnival	12	809	23%
7	Celebrity Cruises Inc	Royal Caribbean Group	10	790	22%
8	Carnival	Carnival	7	790	22%
9	TUI Cruises GmbH	Royal Caribbean Group/TUI Group (50%/50%)	10	474	13%
10	Fred Olsen Windcarrier AS		3	467	13%
11	Cunard Line Ltd	Carnival	3	456	13%
12	Oceania Cruises Inc	Norwegian Cruise Line Holdings	5	429	12%
13	Holland America Line NV	Carnival	5	387	11%
14	Marella Cruises	TUI Group	4	381	11%
15	Hurtigruten AS		8	335	9%
16	Viking Ocean Cruises Ltd		8	294	8%
17	Saga Cruises Ltd		2	193	5%
18	Silversea Cruises Ltd	Royal Caribbean Group	7	185	5%
19	Regent Seven Seas Cruises Inc	Norwegian Cruise Line Holdings	4	172	5%
20	Carnival Cruise Line	Carnival	6	163	5%

[9] The ratio of emissions from cruise ships to LDVs for NO_X and $PM_{2.5}$ was not added as it is quite low.

Table 6: Ranking of the top 20 cruise ship companies based on SOX emissions in the European EEZ in 2022.

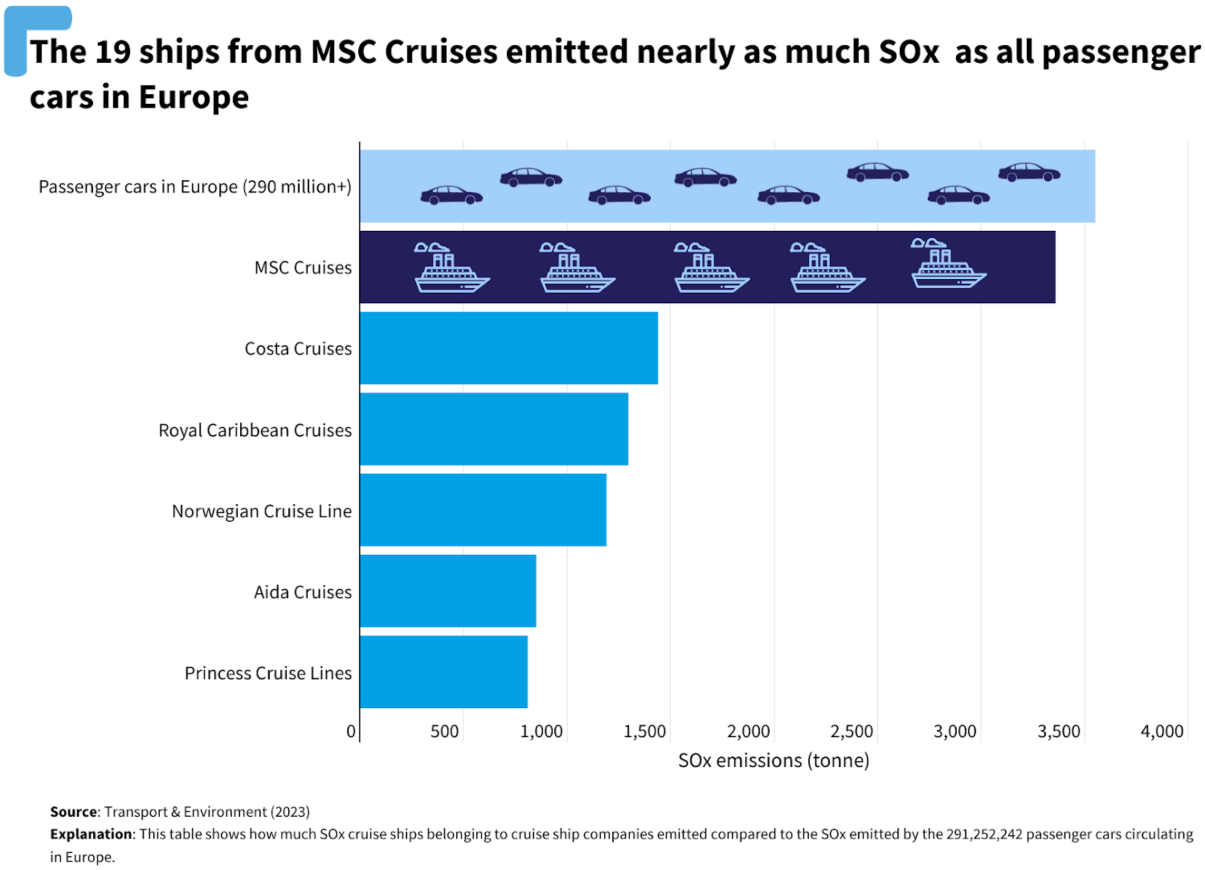


Figure 6: Comparison between SOX emissions from passenger cars and SOX emissions from ships of main cruise operators in 2022

4. Findings on greenhouse gas emissions

In Table 7, we present CO_2, CH_4 and BC emissions by cruise ships in European EEZs in 2019 and 2022. For CH_4 and BC, we show the amounts emitted and the emissions in CO_2 equivalent using 100-year global warming potential (GWP)[10].

Year	Number of cruise ships	Total fuel consumption (t)	Total CO_2 (t)	Total CH_4		Total BC	
				tCH_4	tCO_2eq	tBC	tCO_2eq
2019	173	2,198,023	6,965,227	1,478	44,057	737	663,459

[10] 29.8 for CH_4 [22] and 900 for BC [1].

Year	Number of cruise ships	Total fuel consumption (t)	Total CO_2 (t)	Total CH_4		Total BC	
				tCH_4	tCO_2eq	tBC	tCO_2eq
2022	218	2,591,827	8,126,036	7,804	232,558	859	773,149

Table 7: GHG gas emissions from cruise ships in European EEZs in 2019 and 2022.

We found that all emissions increased between 2019 and 2022. CO_2 emissions increased by nearly 17% to reach 8.1 $MtCO_2$ in 2022 and accounted for the majority of the global warming from cruise ships. These emissions are equivalent to those of 50,000 flights between Paris and New-York.[11]

BC emissions increased similarly to CO_2 (+17%) to reach 859 tonnes in 2022. This may seem like a small amount, but BC, which was historically considered as an air pollutant, is also an extremely potent global warming agent with a GWP of 900 on a 100-year basis [1]. This is because BC is made up of particles from incomplete combustion that absorb sunlight and heat the surrounding areas [23]. Consequently, the 859 tonnes of BC emitted by cruise ships have a similar warming effect as about 773,000 tCO_2 on a 100-year horizon. This is equivalent to 10% of the CO_2 emissions of these ships.

The most worrying trend observed in our results is that methane emissions increased fivefold between 2019 and 2022 to reach 7,804 tonnes. This can be explained by the greater uptake of LNG by cruise ships and the use of highly leaky 4-stroke dual-fuel LNG engines (see info box 2). The reason why cruise ship companies are investing in this type of ships is to decrease their CO_2 emissions by 15-20% as well as air pollutants such as SO_x and PM emissions. But the methane slip from these LNG engines is highly problematic when it comes to climate change. This is due to the fact that CH_4 GWP is 82.5 times that of CO_2 over a period of 20 years and 29.8 times over a 100-year period ([24] - page 1017). This means that the methane emitted by cruise ships in 2022 will have a similar warming effet to 8% of their CO_2 emissions over a 20-year horizon and to 3% of their CO_2 emissions over a 100-year horizon. Worse, CH_4 emissions from cruise ships will further increase given the growing number of LNG-powered cruise vessels entering the fleet each year. As of June 2023, more than 40% of cruise ship order books at the global level are LNG-powered [8].

To provide a point of comparison, we estimate that one of the biggest LNG-powered cruise ship in the fleet, named MS Iona, emitted as much methane in 2022 as 10,500 dairy cows in a year ()[12]. The entire fleet of LNG-powered cruise ships emitted in European EEZs in 2022 as much methane as 62,000 cows.

[11] Using flight emissions from ICAO Carbon Emission calculator: https://applications.icao.int/icec/Home/Index

[12] Assuming that it ran on LNG the whole year and using a factor of 0.126 tCH_4 per cow per year for dairy cattle in Western Europe, from IPCC guidelines for National Greenhouse Gas Inventories [25].

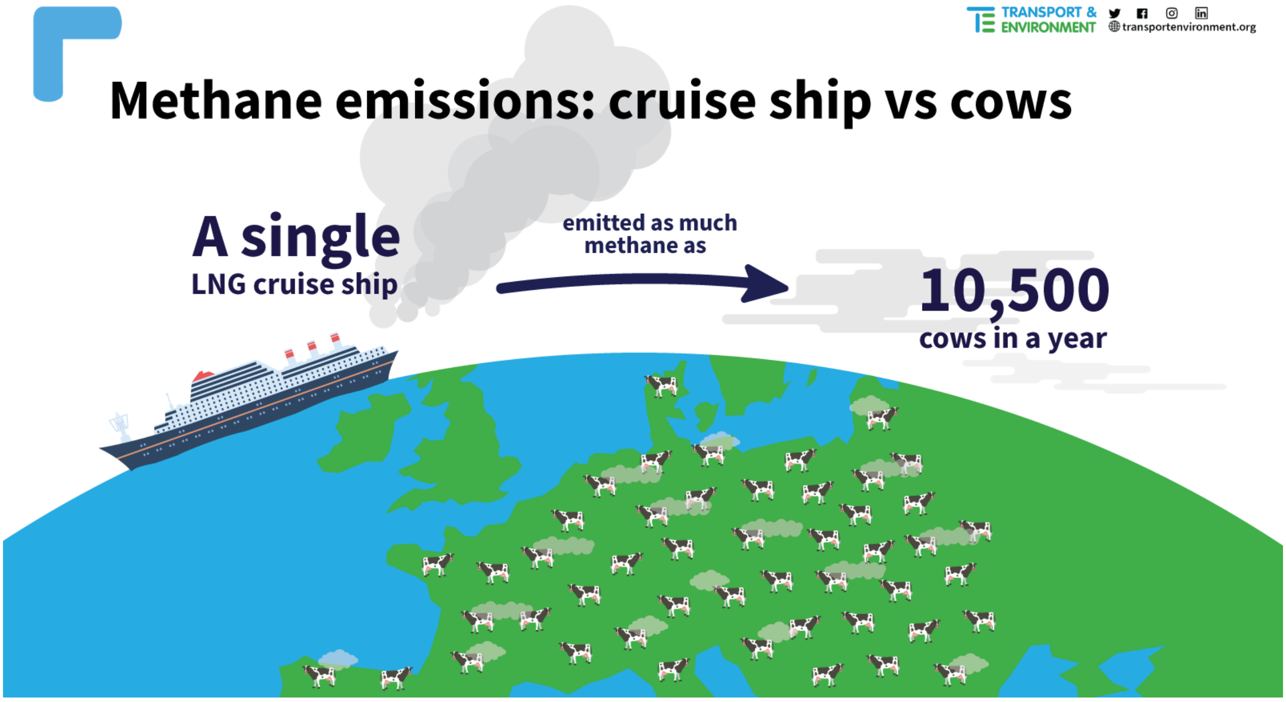


Figure 7: Methane emissions from an LNG-powered cruise ship based on the MS Iona

INFO BOX 2: What is methane slip?

Combustion of LNG normally results in CO_2 emissions. However, because of an incomplete combustion process, methane – which is the main component of LNG – is also released in the air. This is what is referred to as methane slip.

According to the European Commission, four-stroke high pressure dual fuel engines – which is used by nearly all LNG cruise ships – releases on average 3.1% uncombusted LNG into the atmosphere [26]. The 4th IMO GHG Study (2020) estimates put uncombusted methane slip at 3.5% [1]. Those numbers are based on measurements conducted in controlled conditions and must be supplemented by measurements conducted in real-life conditions when the vessels operate at sea. A study conducted on a vessel travelling between Europe and the United States measured that this type of engine releases 8.1% [27] uncombusted methane – a significantly higher number than official standard values – whereas another study supported by the Green Ray project estimates that the methane slip on the four-stroke engine was 2.2%-8% depending on engine load [28].

Methane slips from LNG-powered vessels would remain unchanged even if they used renewable biomethane (a.k.a. bio-LNG) or e-methane (a.k.a. e-LNG), both of which are compatible with existing LNG engines. This means that even if LNG vessels use renewable fuels, methane slips will remain a significant issue affecting climate change.

5. Policy overview: what will change?

New policies agreed at the IMO and EU levels are likely to change the climate and environmental impact of cruise ships over the coming years, although not significantly in the short term.

Firstly, a SECA will be in place from the 1st of May 2025 covering the entire Mediterranean basin. This means that similar to the SECAs already in place in the North and Baltic seas, sulphur limit applicable to marine fuels at sea will further decrease from 0.5% to 0.1%. This will have a positive impact on the air quality across the region, but it could also open the door to false solutions resulting in a greater use of scrubbers and in bigger uptake of LNG, which come with drawbacks from a biodiversity and/or climate perspective.

Secondly, at the EU level, the Fit-for-55 legislative package will drive some changes that will affect cruise ships' climate and environmental performance. These are listed below:

1. The Alternative Fuel Infrastructure Regulation (AFIR) makes it compulsory for most ports to install enough shore-side electricity connecting points to meet the electricity needs of the berthed cruise ships as well as ferries by 2030.[13] The FuelEU Maritime Regulation, additionally, requires cruise ships to connect to these SSE points. This should in theory lead to a decrease of maritime emissions in Europe and result in a significantly better air quality in port areas. This obligation will only apply to cruise ships at berth and not at anchorage, so rules need to be set up to further reduce emissions.
2. The Emissions Trading Scheme (ETS) will include shipping from 2024 onwards which means that cruise ships will have to pay for the climate impact they are responsible for. This might push cruise ships companies to use less polluting fuels and improve the energy efficiency of their vessels by, for example, applying slow steaming, or by installing other energy efficiency technologies, including wind-sails.
3. The FuelEU Maritime Regulation (FuelEU) sets up greenhouse gas intensity targets on consumed marine fuels for ships that become stricter over time, forcing ships – including cruise ships – to opt for more climate friendly fuels. However, in the short term, cruise ships are likely to continue relying mostly on fossil fuels while blending small amounts of biofuels into the fuel. In some cases, biofuels can bring significant greenhouse gas emissions savings, but the limited availability of sustainable feedstock to produce biofuels imply that this will not be a scalable solution [29].

[13] The list of ports affected by this regulation can be found on this webpage.

6. Conclusion and recommendations

While progress is being made from a regulatory perspective, a lot more could be achieved at the EU and IMO levels to tackle both air pollution and climate change caused by cruise ships. Most importantly, the regulations should focus on promoting long-term and scalable solutions that will encourage ships to move away from fossil-based fuels and avoid the use of solutions with downsides such as scrubbers or methane–based fuels.

Recommendation 1: The EU should extend the zero-emission berth mandate for cruise ships to cover anchorage, as well. In practice, cruise vessels would need to either connect to shore-side electricity (SSE), or prove that they are relying on a technology that delivers zero GHG and zero air pollution performance. Such technologies can include fuel cells and large storage batteries.

Recommendation 2: Establish more stringent decarbonisation requirements on cruise ships that call at European ports. For example, a zero-emission operation on a well-to-wake basis could be mandated for all new cruise vessels built after 2030, while existing fleet could be required to reach zero-emission on a well-to-wake basis by 2040. In practice, this can be operationalised through the revision of the FuelEU Maritime regulation by increasing the overall GHG intensity targets set under Article 4.

Recommendation 3: Implement zero-emission corridors for the most popular cruise ships trajectories in European waters.

Recommendation 4: Incentives to LNG uptake in shipping should be discontinued under the European and national regulatory frameworks. This can be achieved by:

- Updating the methane accounting system under the EU ETS and FuelEU Maritime to better reflect real-world methane emissions from shipping. To ensure consistent implementation and avoid cheating, the EU should require ships to install continuous methane monitoring systems onboard the vessels.
- Discontinue LNG infrastructure mandate in European ports under the Alternative Fuels Infrastructure Regulation and replace them with (at least) hydrogen bunkering in cruise terminals.
- Set under FuelEUMaritime a green H2(-based fuels) subtarget of 6% by 2030, significantly increasing in the following periods.

Recommendation 5: SECAs should be extended to the rest of all EU and UK waters.[14] SO_x emissions standards should be lowered to reflect the sulphur content allowed for road transport in the EU (10ppm sulphur standard - 0.001%). In addition, the EU should consider developing its own operational NO_X standard for ships using the architecture of the FuelEU Maritime regulation (e.g. limits on gNO_X/MJ of energy used). Nitrogen ECAs (NECAs) rely on fleet renewal, which can be very ineffective in the short to medium-term.

[14] At the time of writing, there are negotiations at the IMO level to set up a SECA over the Atlantic area.

Recommendation 6: The use of scrubbers, especially open-loop scrubbers, should be banned in all of European waters. This will ensure that cruise ships at the very least move towards distillate-type of fuels with lower sulphur content and prevent cruise ships from potentially polluting the oceans with contaminated water.

Appendix 1 - Detailed methodology

In this Appendix we present a similar but extended version of the methodology in section 2.

We analysed cruise ships which stopped in at least one of the countries part of EU Monitoring, Reporting and Verification System (MRV) in 2019 and 2022. These countries are Belgium, Bulgaria, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden and the United Kingdom (not part of MRV in 2022 but kept in the analysis). We ignored the French outermost regions for simplification. Our previous study on cruise ship air pollution [5] informed us that cruise ships of less than 5000 gross tonnage (GT) represented less than 1% of SO_x emissions around ports. For simplicity, we thus decided to include only ships of more than 5000 GT in this update. For the year 2019, we included all ships qualified as “Passenger ship” under the EU MRV, corresponding to passenger vessels above 5,000 GT that stopped at EU ports to embark or disembark passengers in 2019. For the year 2022, MRV reporting had not yet been published at the time of the analysis and we thus used the list of cruise ships available in IHS Markit Core Ship Database and Clarksons’ World Fleet Register [8]

We followed the bottom-up methodology from the Fourth IMO Greenhouse Gas (GHG) study (see p. 40 of [1]) to calculate GHG emissions from ships using automatic identification system (AIS) data and ship technical specifications. We purchased ship technical specifications from IHS Markit and Clarksons and pre-processed them to fill in the data gaps. We purchased terrestrial and satellite AIS data from Spire. AIS messages are sent by ships at regular intervals during their operation and contain information such as timestamp, position, speed and draught of the vessel. We removed erroneous entries from the AIS data, resampled it at 1-hour intervals and infilled the gaps in the time series for position speed, draught and voyage status (i.e. moored, anchored, cruising or other navigational statuses. We then followed the following steps:

1. Allocation of hourly samples into Exclusive Economic Zones (EEZs) and ECAs in Europe
2. Detection of port stops
3. Assignment of operational phases
4. Allocation of voyages
5. Calculation of vessel energy consumption and emissions.

We calculated emissions of SO_X, NO_X $PM_{2.5}$, CO_2, CH_4 and BC using emission factors from the Fourth IMO GHG study. To further improve our estimations, we used real-world values of cruise ship port CO_2 emissions, reported by ship operators as part of the MRV scheme, to calibrate auxiliary power demand at berths for each of the cruise ships in 2019. Since no MRV data was available for 2022, we used 2021 AIS data and MRV reporting to calibrate auxiliary power demand in 2021 and used it for 2022. This calibration should improve the accuracy of our cruise ship emission estimates compared to using the fleet average values from the IMO Fourth GHG study.

The possibility for ships to connect to shore side electricity (SSE) at ports and thus emit less or not at all could not be modelled at port level, because there is no information about such connection in AIS data and there is no simple way of verifying whether ships connect to shore side electricity when it’s available at port as it is not yet compulsory to do so. However, thanks to the calibration procedure explained previously, a reduction in annual port MRV emissions thanks to SSE will be mirrored by a reduction in the auxiliary emissions at port calculated by our model over the whole year.

In the first part of the year 2022, some cruise ships were still unused as a result of the COVID-19 pandemic. That does not mean that they were not polluting, as most cruise ships cannot be stopped when they are not transporting passengers. We noticed in the AIS data that these ships behaved in various and complex ways but typically stayed for several days at anchor (sometimes far offshore) before going back to a port for short or longer periods. Since most of the equipment (e.g. pools, cinemas, etc.) on the ship was likely unused at that time, the fuel consumption was likely less than that which would be calculated using the methodology from the IMO Fourth GHG study. We thus decided not to count any emissions for ships staying more than 80 consecutive hours at berth and for ships travelling back and forth between anchor and a given port. This should give a conservative view of cruise ship emissions in 2022.

In estimating emissions, we assumed that cruise ships equipped with dual-fuel LNG engines were running exclusively on LNG since we had no data to determine the precise fuel mix used on board. Other vessels were assumed to run on HFO, VLSFO or MGO, complying with the relevant fuel sulphur standards in place on a given year and in a given geographical area. Specifically:

- Ships sailing, anchored or moored in SECAs are required to use fuel with at most 0.1% sulphur content or rely on exhaust gas cleaning systems (scrubbers) to respect SO_X standards.
- Ships at berth or at anchor within the boundaries of European ports must follow the same rule as above for port stays above two hours.
- Until the 1st of January 2020, cruise ships sailing in European EEZ outside SECAs were required to use fuels with a maximum 1.5% sulphur content under the EU Sulphur Directive (2012/33/EU).
- From the 1st of January 2020, all ships sailing outside SECAs are required to use residual fuels complying to a maximum 0.5% sulphur content mandated under both EU Sulphur Directive and global MARPOL Annex VI.

We used Clarksons' WFR to identify ships equipped with scrubbers and assumed they were using 2.6% sulphur HFO with scrubbers treatment of exhaust gases when they needed to comply with 0.1% sulphur standards. In ports where the use of open-loop scrubbers is forbidden, we assumed 0.1% MDO/MGO was used instead. We used the ICCT factors to estimate the decrease or increase in different emission species due to the use of scrubbers, which is presented in Table 8.

SO_x	NO_x	$PM_{2.5}$	CO_2	CH_4	BC (SSD)[15]	BC (MSD)
-52%	0%	+61%	+4%	0%	+81%	+353%

Table 8: Relative emission change after the scrubber using HFO (2.6% S) compared with MGO (0.1% S), from [9].

[15] SSD - slow speed diesel engines, MSD - medium speed diesel engines.

We then aggregated emissions results in two ways:

3. Emissions "around ports" are pollutants emitted by ships within 12 nautical miles (nm) from a given port's main coordinates and at a speed-over-ground (SOG) of less than 3 knots. 12 nm corresponds to the limit of territorial waters whereas 3 knots is the speed observed in AIS below which a ship is considered at anchor or at berth as per the Fourth IMO Greenhouse Gas (GHG) study. Stays at dry docks were naturally excluded.
4. Emissions "in European EEZs" are pollutants emitted by ships within the EEZs of European countries.

Finally, we compared ship pollution to car pollution within port cities or respective countries whose EEZs ships were sailing through. Car numbers were compiled using publicly available sources for cities (see Table 10) and the European Union Transport Roadmap Model (EUTRM) [10] for each European country. We used car emission factors and distribution of cars per Euro category and per country from the EUTRM. The average SO_x, NO_x and $PM_{2.5}$ emissions from European cars in 2022 are given in Table 9. We assumed car fleets entirely made of diesel vehicles, which have worse NO_x performance than petrol cars. As the comparisons between cruise ships and cars rely on the ship emissions being divided by those of the passenger cars, the final results are therefore likely to be on the conservative side, i.e. they may well underestimate the comparative extent of air pollution from cruise ships versus cars if we included petrol cars in the equation too.

SO_x per vehicle per year (kg)	**NO_x per vehicle per year (kg)**	**$PM_{2.5}$ per vehicle per year (kg)**
0.012	3.975	0.482

Table 9: Average SOx, NOx and PM2.5 emissions from European cars in 2022

Port city	**Country**	**Number of registered passenger cars**	**Year**	**Source**
Barcelona	ESP	531,749	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/
Civitavecchia	ITA	34,139	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Ibiza	ESP	89,569	2019	https://www.diariodeibiza.es/pitiuses-balears/2018/02/24/eivissa-soporta-113-vehiculos-motor/971933.html
Palma Mallorca	ESP	248,207	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/
Gibraltar	GIB	17,000	2016	https://www.chronicle.gi/govt-plan-for-cycling-infrastructure-receives-opposition-support-amid-concern-over-rise-in-vehicle-numbers/
Hamburg	DEU	813,847	2022	https://www.statistik-nord.de/fileadmin/Dokumente/Statistische_Berichte/verkehr_umwelt_und_energie/H_I_2_j_HuS/H_I_2_j-17_HH.pdf
Southampton	GBR	93,390	2022	https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables#all-vehicles
Piraeus	GRC			
Mykonos (Mikonos)	GRC			
Thira	GRC			

Port city	Country	Number of registered passenger cars	Year	Source
Napoli	ITA	551,373	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Marseille	FRA	369,433	2022	https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-le-parc-de-vehicules-en-circulation-au-1er-janvier-2022
Genova	ITA	267,822	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Stockholm	SWE	358,540	2022	https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__TK__TK1001__TK1001A/FordonTrafik/
Kiel	DEU	87,057	2022	https://www.kba.de/DE/Statistik/Produktkatalog/produkte/Fahrzeuge/fz3_b_uebersicht.html
Livorno	ITA	87,723	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Malta (Valetta)	MLT	313,177	2022	https://statdb.nso.gov.mt/
Le Havre	FRA	74,649	2022	https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-le-parc-de-vehicules-en-circulation-au-1er-janvier-2022
Port Of Bergen	NOR	77,654	2022	https://www.ssb.no/en/statbank/table/13370/tableViewLayout1/
Santa Cruz De Tenerife	ESP	119,464	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/
Rodhos	GRC			
Malaga	ESP	275,888	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA
Corfu (Kerkira)	GRC			
Kobenhavn	DNK	169,654	2022	https://www-statistikbanken-dk.translate.goog/10220?_x_tr_sl=auto&_x_tr_tl=it&_x_tr_hl=it&_x_tr_pto=wapp
Tallinn	EST	145,426	2020	https://www.tallinn.ee/eng/Yearbooks-and-Statistics
Rostock	DEU	128,424	2022	https://www.kba.de/DE/Statistik/Produktkatalog/produkte/Fahrzeuge/fz3_b_uebersicht.html
Cadiz	ESP	44,288	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/
Zeebrugge	BEL	56,880	2022	https://statbel.fgov.be/fr/themes/mobilite/circulation/parc-de-vehicules#figures
Valencia	ESP	361,390	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA
Split	HRV	89,473	2019	Ministarstvo Unutarnjih Poslova
Dubrovnik	HRV	27,173	2019	Ministarstvo Unutarnjih Poslova
La Spezia	ITA	48,872	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Reykjavik	ISL	79,887	2019	Icelandic Transport Authority
Las Palmas	ESP	182,345	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/
Messina	ITA	146,169	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Akureyri	ISL			https://www.samgongustofa.is/umferd/tolfraedi/onnur-tolfraedi/
Alesund	NOR	29,522	2022	https://www.ssb.no/en/statbank/table/13370/tableViewLayout1/
Cartagena	ESP	115,855	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/
Trieste	ITA	108,872	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Lisbon	PRT	374,855	2017	https://www.dn.pt/sociedade/interior/lisboa-vai-ter-84-mil-lugares-de-estacionamento-pago-8656670.html
Arrecife De Lanzarote	ESP	32,195	2022	https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/
Venezia	ITA	109,289	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Palermo	ITA	395,644	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Bari	ITA	182,131	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Augusta	ITA	22,771	2021	https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html
Stavanger	NOR	49,637	2022	https://www.ssb.no/en/statbank/table/13370/tableViewLayout1/
Funchal	PRT			
Oslo	NOR	193,371	2022	https://www.ssb.no/en/statbank/table/13370/tableViewLayout1/
Amsterdam	NLD	249,771	2022	https://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=37209hvv&D1=0-17&D2=80,241,489,500&D3=15-19&HDR=T&STB=G1,G2&VW=T
Cannes	FRA	40,392	2022	https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-le-parc-de-vehicules-en-circulation-au-1er-janvier-2022

Table 10: Number of passenger cars in European cities.

Appendix 2 - Detailed results

Tables below provide detailed breakdowns of emissions per country and per port city.

Country	Number of cruise ships	Sailing time (hours)	NOx from cruise ships (kg)	Number of registered LDVs	NOx from registered LDVs (kg)	Cruise ships NOx versus LDVs (%)
ITA	152	128,647	26,912,462	38,039,760	137,524,653	20%
ESP	183	136,815	21,709,289	24,611,551	109,251,328	20%
GRC	121	106,223	16,393,076	4,949,354	28,042,497	58%
NOR	110	144,792	15,492,532	2,938,966	12,202,694	127%
FRA	176	62,311	10,782,070	37,413,447	130,550,996	8%
PRT	170	48,449	8,485,762	5,325,884	31,752,197	27%
HRV	72	31,282	4,684,394	1,568,797	7,321,114	64%
GBR	115	67,584	10,517,526	36,021,268	124,850,969	8%
ISL	73	24,027	2,594,137	270,000	1,073,330	242%
CYP	60	11,780	1,902,715	581,866	3,244,967	59%
IRL	73	7,319	1,155,790	2,219,441	5,536,194	21%
DEU	98	25,587	3,186,975	45,457,533	141,966,121	2%
DNK	103	25,324	4,805,800	3,016,223	7,956,357	60%
MLT	82	5,737	785,488	305,579	1,969,183	40%
SWE	83	20,463	3,229,775	5,207,522	17,354,946	19%
NLD	104	16,178	2,813,653	8,838,393	30,934,500	9%
EST	48	5,279	854,961	846,496	2,961,490	29%
FIN	58	6,556	843,667	2,726,303	12,490,522	7%
BEL	93	3,297	465,462	5,585,231	12,989,851	4%
LVA	35	3,233	497,562	682,827	2,422,589	21%
SVN	41	1,122	66,208	1,220,346	4,198,672	2%
POL	40	3,217	314,894	27,743,967	196,726,239	0%
LTU	29	851	86332	2,730,542	7,123,790	1%
AUT				5,245,816	18,079,759	
BGR				2,663,870	15,503,237	
CZE				6,466,981	26,237,711	
HUN				3,838,785	21,853,331	
LUX				456,856	727,462	
ROU				6,640,445	24,102,890	
SVK				2,686,574	7,772,570	
CHE				4,951,619	13,092,242	
TOTAL		**887,977**	**138,760,676**	**291,252,242**	**1,157,814,404**	**12%**

Table 11: NOX emissions from cruise ships and LDVs in European countries in 2022.

Country	Number of cruise ships	Sailing time (hours)	$PM_{2.5}$ from cruise ships (kg)	Number of registered LDVs	$PM_{2.5}$ from registered LDVs (kg)	Cruise ships $PM_{2.5}$ versus LDV (%)
ITA	152	128,647	1,547,627	38,039,760	13,631,444	11.35%
ESP	183	136,815	1,237,081	24,611,551	12,476,140	9.92%
GRC	121	106,223	928,664	4,949,354	2,821,674	32.91%
NOR	110	144,792	667,979	2,938,966	1,532,411	43.59%
FRA	176	62,311	560,175	37,413,447	14,868,297	3.77%
PRT	170	48,449	496,908	5,325,884	4,604,382	10.79%
HRV	72	31,282	269,289	1,568,797	830,797	32.41%
GBR	115	67,584	340,047	36,021,268	14,058,853	2.42%
ISL	73	24,027	142,785	270,000	130,036	109.80%
CYP	60	11,780	99,607	581,866	455,997	21.84%
IRL	73	7,319	63,424	2,219,441	493,924	12.84%
DEU	98	25,587	61,882	45,457,533	15,048,642	0.41%
DNK	103	25,324	115,879	3,016,223	761,714	15.21%
MLT	82	5,737	37,067	305,579	304,782	12.16%
SWE	83	20,463	75,529	5,207,522	2,022,938	3.73%
NLD	104	16,178	65,966	8,838,393	3,241,038	2.04%
EST	48	5,279	13,614	846,496	316,880	4.30%
FIN	58	6,556	18,243	2,726,303	1,382,702	1.32%
BEL	93	3,297	7,851	5,585,231	1,120,946	0.70%
LVA	35	3,233	7,797	682,827	250,832	3.11%
SVN	41	1,122	2,805	1,220,346	456,352	0.61%
POL	40	3,217	7,425	27,743,967	33,408,455	0.02%
LTU	29	851	1409	2,730,542	690,148	0.20%
AUT				5,245,816	2,130,516	
BGR				2,663,870	1,986,146	
CZE				6,466,981	3,687,250	
HUN				3,838,785	2,731,950	
LUX				456,856	53,371	
ROU				6,640,445	2,750,475	
SVK				2,686,574	705,013	
CHE				4,951,619	1,316,815	
TOTAL		887,977	6,777,025	291,252,242	140,270,919	4.80%

Table 12: PM2.5 emissions from cruise ships and LDVs in European countries in 2022

Country	Number of cruise ships	Sailing time (hours)	Cruise ships SOx emissions (kg)	Cruise ships NOx emissions (kg)	Cruise ships PM2.5 emissions (kg)	Cruise ships CO2 emissions (kg)	Cruise ships CH4 emissions (kg)	Cruise ships BC emissions (kg)
ITA	152	128,647	3,719,851	26,912,462	1,547,627	1,569,941,418	1,729,472	159,630
ESP	183	136,815	3,035,591	21,709,289	1,237,081	1,319,680,852	1,837,356	142,961
GRC	121	106,223	2,329,535	16,393,076	928,664	876,206,256	50,637	106,320
NOR	110	144,792	1,470,897	15,492,532	667,979	991,839,514	1,651,385	94,823
FRA	176	62,311	1,319,882	10,782,070	560,175	643,714,993	838,150	68,453
PRT	170	48,449	1,286,121	8,485,762	496,908	486,425,743	475,349	56,383
HRV	72	31,282	671,579	4,684,394	269,289	246,075,559	3,975	29,323
GBR	115	67,584	613,625	10,517,526	340,047	618,993,175	349,302	65,639
ISL	73	24,027	371,178	2,594,137	142,785	148,465,982	61,650	16,833
CYP	60	11,780	255,438	1,902,715	99,607	102,342,644	8,837	13,677
IRL	73	7,319	190,967	1,155,790	63,424	72,037,808	7,126	7,087
DEU	98	25,587	86,134	3,186,975	61,882	190,833,882	192,226	14,935
DNK	103	25,324	83,598	4,805,800	115,879	282,160,509	308,171	28,349
MLT	82	5,737	81,526	785,488	37,067	46,216,885	4,134	4,378
SWE	83	20,463	61,346	3,229,775	75,529	178,818,909	67,783	20,195
NLD	104	16,178	55,224	2,813,653	65,966	171,948,517	188,169	15,258
EST	48	5,279	26,345	854,961	13,614	44,151,736	761	2,887
FIN	58	6,556	18,534	843,667	18,243	45,544,059	816	4,431
BEL	93	3,297	15,312	465,462	7,851	28,127,036	23,680	1,626
LVA	35	3,233	15,223	497,562	7,797	25,353,242	438	1,742
SVN	41	1,122	6,727	66,208	2,805	3,940,792	61	445
POL	40	3,217	6,413	314,894	7,425	17,766,591	1,553	2,309
LTU	29	851	2,840	86,333	1,409	4,773,572	79	347

Table 13: SOX, NOX, PM2.5, CO2, CH4 and BC emissions from cruise ships in European countries in 2022.

Country	Number of cruise ships	Sailing time (hours)	Cruise ships SOx emissions (kg)	Cruise ships NOx emissions (kg)	Cruise ships PM2.5 emissions (kg)	Cruise ships CO2 emissions (kg)	Cruise ships CH4 emissions (kg)	Cruise ships BC emissions (kg)
ITA	131	123,248	10,172,310	24,595,684	1,846,962	1,335,334,029	290,278	138,743
ESP	155	115,446	9,053,500	21,793,865	1,642,426	1,207,099,151	660,449	133,689
GRC	102	90,062	5,976,315	14,624,929	1,066,169	777,751,760	12,160	81,831
FRA	155	50,367	3,561,396	10,076,992	675,618	549,865,164	215,447	58,998
PRT	145	35,498	3,190,356	7,348,658	563,123	390,069,776	186,085	44,703
NOR	96	71,779	2,902,074	11,519,003	620,265	613,640,016	9,941	70,819
HRV	67	26,388	2,401,639	5,678,049	436,450	285,566,386	4,704	28,431
GBR	111	56,213	1,267,756	9,130,319	339,623	502,420,722	14,261	55,692
ISL	70	22,465	942,201	2,227,130	165,399	120,200,732	1,870	13,942
IRL	81	8,725	514,427	1,082,188	79,956	68,604,991	884	6,366
CYP	48	4,607	263,990	602,238	43,489	34,176,543	491	3,664
MLT	65	6,712	225,384	710,931	44,334	41,587,982	629	3,927
DNK	95	21,603	86,078	4,748,388	111,811	256,580,779	13,399	25,468
SWE	78	24,330	83,412	4,061,694	93,198	222,970,631	12,598	22,134
DEU	96	21,808	79,242	3,098,945	62,195	170,519,027	5,307	14,366
NLD	99	14,720	50,931	2,695,259	61,258	146,473,303	4,887	15,157
EST	67	8,321	42,335	1,432,653	25,750	78,634,813	9,582	5,412
FIN	68	10,811	38,954	1,664,507	35,221	94,080,910	34,154	7,968
BEL	92	2,842	13,207	420,276	7,085	23,341,816	368	1,753
SVN	30	1,047	8,911	55,231	2,312	3,595,366	51	226
LVA	45	1,546	7,587	252,750	3,918	12,840,631	251	887
POL	38	2,301	6,441	307,523	6,923	17,101,136	275	1,762
LTU	36	733	2,752	83,684	1,326	4,593,556	74	314
BGR	2	37	1,709	4,230	320	222,908	4	48
ROU	1	25	1,184	3,189	210	171,328	3	19

Table 14: SOX, NOX, PM2.5, CO2, CH4 and BC emissions from cruise ships in European countries in 2019.

Ranking	Port city	Number of cruise ships	Cruise ships SO_x emissions (kg)	Cruise ships NOx emissions (kg)	Cruise ships PM2.5 emissions (kg)	Ratio of SO_x from cruise ships and LDVs	Ratio of NO_x from cruise ships and LDVs	Ratio of PM2.5 from cruise ships and LDVs
1	Barcelona	106	18,277	807,598	19,773	2.82	0.34	0.07
2	Civitavecchia	103	16,307	753,321	18,566	39.19	6.10	1.52
3	Piraeus	84	12,418	464,180	11,323			
4	Palma Mallorca	79	12,285	463,886	10,197	4.06	0.42	0.08
5	Lisbon	108	11,132	278,217	4,766	2.44	0.12	0.01
6	Hamburg	47	10,445	278,031	4,630	1.05	0.11	0.02
7	Southampton	45	9,676	485,212	12,445	8.50	1.50	0.34
8	Mykonos (Mikonos)	56	9,670	360,570	8,269			
9	Thira	69	9,221	370,636	8,859			
10	Funchal	96	9,041	232,553	3,944			
11	Napoli	68	8,863	432,395	10,943	1.32	0.22	0.06
12	Marseille	75	8,763	447,326	11,494	1.95	0.35	0.08
13	Genova	31	8,546	452,751	11,795	2.62	0.47	0.12

Ranking	Port city	Number of cruise ships	Cruise ships SO_x emissions (kg)	Cruise ships NOx emissions (kg)	Cruise ships PM2.5 emissions (kg)	Ratio of SO_x from cruise ships and LDVs	Ratio of NO_x from cruise ships and LDVs	Ratio of PM2.5 from cruise ships and LDVs
14	Stockholm	49	7,815	191,733	3,298	1.79	0.16	0.02
15	Kiel	39	7,530	202,063	3,365	7.10	0.74	0.12
16	Livorno	53	7,262	280,236	6,781	6.79	0.88	0.22
17	Malta (Valetta)	69	6,900	322,545	8,235	1.81	0.16	0.03
18	Le Havre	40	6,538	175,493	2,908	7.19	0.67	0.10
19	Port Of Bergen	79	6,433	239,858	6,039	6.80	0.74	0.15
20	Santa Cruz De Tenerife	80	6,380	267,883	6,457	4.38	0.51	0.11
21	Rodhos	50	6,190	200,379	4,648			
22	Malaga	107	5,743	220,628	5,320	1.71	0.18	0.04
23	Corfu (Kerkira)	55	5,540	240,501	6,036			
24	Kobenhavn	70	5,535	258,970	6,731	2.68	0.58	0.16
25	Tallinn	45	5,408	138,573	2,336	3.05	0.27	0.04
26	Rostock	30	5,302	136,756	2,305	3.39	0.34	0.05
27	Cadiz	97	5,195	197,952	4,671	9.62	1.01	0.21
28	Zeebrugge	51	5,110	137,081	2,279	7.37	1.04	0.20
29	Valencia	73	4,725	205,331	4,978	1.07	0.13	0.03
30	Split	44	4,559	148,970	3,348	4.18	0.36	0.07
31	La Spezia	41	4,545	233,660	5,971	7.63	1.32	0.34
32	Reykjavik	61	4,519	169,156	3,920	4.64	0.53	0.10
33	Las Palmas	75	4,513	189,361	4,559	2.03	0.23	0.05
34	Messina	48	4,369	195,626	4,857	2.45	0.37	0.09
35	Dubrovnik	46	4,198	163,212	4,011	12.68	1.29	0.28
36	Alesund	70	4,172	165,346	3,965	11.59	1.35	0.26
37	Cartagena	73	4,110	105,513	1,781	2.91	0.21	0.03
38	Trieste	26	3,794	183,345	4,649	2.86	0.47	0.12
39	Gibraltar	73	3,693	94,439	1,595			
40	Arrecife De Lanzarote	70	3,681	147,281	3,456	9.38	1.03	0.21
41	Venezia	22	3,661	116,544	2,562	2.75	0.29	0.07
42	Palermo	40	3,584	180,971	4,628	0.74	0.13	0.03
43	Bari	21	3,393	158,944	4,015	1.53	0.24	0.06
44	Augusta	17	3,340	156,044	3,803	12.03	1.90	0.47
45	Stavanger	54	3,180	158,705	4,136	5.26	0.77	0.16
46	Ibiza	22	3,014	156,513	4,002	2.76	0.39	0.09
47	Oslo	53	2,997	140,733	3,631	1.27	0.18	0.04
48	Akureyri	61	2,819	89,572	1,965			
49	Amsterdam	41	2,808	118,346	2,949	0.92	0.14	0.03
50	Cannes	29	2,785	121,421	2,909	5.66	0.86	0.18

Table 15: SOx, NOx and PM2.5 of cruise ships and LDVs in top 50 port cities in 2022.

Ranking	Port city	Number of cruise ships	Cruise ships SOx emissions (kg)	Cruise ships NOx emissions (kg)	Cruise ships PM2.5 emissions (kg)	Cruise ships CO2 emissions (kg)	Cruise ships CH4 emissions (kg)	Cruise ships BC emissions (kg)
1	Barcelona	106	18,277	807,598	19,773	56,801,656	60,070	1,721
2	Civitavecchia	103	16,307	753,321	18,566	54,173,961	76,979	1,650
3	Piraeus	84	12,418	464,180	11,323	32,052,133	985	1,328
4	Palma Mallorca	79	12,285	463,886	10,197	33,690,880	56,413	766
5	Lisbon	108	11,132	278,217	4,766	18,961,727	8,119	459
6	Hamburg	47	10,445	278,031	4,630	17,945,225	9,342	360
7	Southampton	45	9,676	485,212	12,445	32,084,455	14,162	1,492
8	Mykonos (Mikonos)	56	9,670	360,570	8,269	23,382,259	322	698
9	Thira	69	9,221	370,636	8,859	24,100,941	331	761
10	Funchal	96	9,041	232,553	3,944	17,141,931	25,980	453
11	Napoli	68	8,863	432,395	10,943	29,067,420	19,497	948
12	Marseille	75	8,763	447,326	11,494	31,835,200	40,964	919
13	Genova	31	8,546	452,751	11,795	28,580,212	405	824
14	Stockholm	49	7,815	191,733	3,298	12,815,089	172	342
15	Kiel	39	7,530	202,063	3,365	13,931,702	17,809	255
16	Livorno	53	7,262	280,236	6,781	18,929,179	251	784
17	Malta (Valetta)	69	6,900	322,545	8,235	21,077,942	1,934	865
18	Le Havre	40	6,538	175,493	2,908	10,942,727	2,625	240
19	Port Of Bergen	79	6,433	239,858	6,039	18,510,382	13,129	763
20	Santa Cruz De Tenerife	80	6,380	267,883	6,457	19,787,118	29,650	786
21	Rodhos	50	6,190	200,379	4,648	14,176,794	179	569
22	Malaga	107	5,743	220,628	5,320	14,884,209	1,272	540
23	Corfu (Kerkira)	55	5,540	240,501	6,036	15,864,369	215	610
24	Kobenhavn	70	5,535	258,970	6,731	17,806,926	7,625	696
25	Tallinn	45	5,408	138,573	2,336	8,868,870	124	197
26	Rostock	30	5,302	136,756	2,305	8,694,719	122	199
27	Cadiz	97	5,195	197,952	4,671	13,276,804	2,684	470
28	Zeebrugge	51	5,110	137,081	2,279	9,080,151	7,913	178
29	Valencia	73	4,725	205,331	4,978	14,857,249	20,835	400
30	Split	44	4,559	148,970	3,348	10,185,594	133	399
31	La Spezia	41	4,545	233,660	5,971	16,445,512	21,218	436
32	Reykjavik	61	4,519	169,156	3,920	11,514,094	3,803	463
33	Las Palmas	75	4,513	189,361	4,559	14,920,482	31,554	496
34	Messina	48	4,369	195,626	4,857	12,595,624	175	429
35	Dubrovnik	46	4,198	163,212	4,011	11,096,506	146	502
36	Alesund	70	4,172	165,346	3,965	12,142,315	12,380	401
37	Cartagena	73	4,110	105,513	1,781	6,743,583	94	152
38	Trieste	26	3,794	183,345	4,649	11,674,872	164	455
39	Gibraltar	73	3,693	94,439	1,595	6,102,980	612	156
40	Arrecife De Lanzarote	70	3,681	147,281	3,456	11,582,698	24,761	364
41	Venezia	22	3,661	116,544	2,562	7,967,504	104	289

Ranking	Port city	Number of cruise ships	Cruise ships SOx emissions (kg)	Cruise ships NOx emissions (kg)	Cruise ships PM2.5 emissions (kg)	Cruise ships CO2 emissions (kg)	Cruise ships CH4 emissions (kg)	Cruise ships BC emissions (kg)
42	Palermo	40	3,584	180,971	4,628	12,578,150	13,518	375
43	Bari	21	3,393	158,944	4,015	10,207,737	142	316
44	Augusta	17	3,340	156,044	3,803	9,668,734	139	539
45	Stavanger	54	3,180	158,705	4,136	10,775,965	5,814	373
46	Ibiza	22	3,014	156,513	4,002	11,066,517	15,200	284
47	Oslo	53	2,997	140,733	3,631	11,095,782	20,917	396
48	Akureyri	61	2,819	89,572	1,965	6,193,722	1,102	235
49	Amsterdam	41	2,808	118,346	2,949	7,854,142	106	322
50	Cannes	29	2,785	121,421	2,909	7,612,538	109	204

Table 16: SOX, NOx, PM2.5, CO2, CH4 and BC emissions from cruise ships in 50 most polluted European port cities by cruise ships in 2022.

Ranking	Country	Port city	Number of cruise ships calling at port	Time spent around ports (hours)	SOx from cruise ships (kg)	NOx from cruise ships (kg)	PM2.5 from cruise ships (kg)	Cruise ships CO2 emissions (kg)	Cruise ships CH4 emissions (kg)	Cruise ships BC emissions (kg)
1	ITA	Venice	56	8,139	18,603	672,720	14,941	43,115,645	602	1,227
2	ESP	Barcelona	106	10,617	18,343	778,406	18,745	52,242,042	29,810	1,686
3	ESP	Palma Mallorca	75	7,746	16,282	600,667	13,327	40,613,334	30,551	1,026
4	GRC	Piraeus	80	7,969	13,344	434,001	9,509	29,202,792	388	1,070
5	GRC	Thira	66	5,778	12,525	411,492	8,833	27,017,686	368	832
6	GRC	Mykonos (Mikonos)	57	5,552	11,470	387,902	8,540	25,613,713	347	778
7	FRA	Marseille*	68	5,183	11,332	451,150	10,384	29,898,821	17,710	797
8	PRT	Lisbon	101	4,441	10,340	269,189	4,589	17,162,637	241	426
9	ITA	Civitavecchia*	80	6,000	10,178	425,763	10,219	29,079,458	20,599	988
10	SWE	Stockholm	59	4,421	9,540	238,055	4,120	15,759,120	213	441
11	ITA	Genova	37	2,950	9,496	380,884	8,745	23,824,096	340	638
12	ITA	Livorno	60	5,133	9,359	369,708	8,700	23,908,302	331	895
13	ITA	Napoli	68	4,788	8,957	378,068	9,102	24,238,840	338	862
14	GBR	Southampton	41	4,599	8,485	442,109	11,482	28,053,249	395	1,615
15	PRT	Funchal	75	4,463	8,290	218,735	3,715	15,893,660	24,323	419
16	GRC	Corfu (Kerkira)	55	3,198	7,720	283,850	6,323	18,122,676	254	543
17	DEU	Hamburg	38	2,950	7,427	192,175	3,257	12,243,529	172	284
18	DEU	Rostock	39	2,579	6,757	190,922	3,495	12,082,185	171	333
19	MLT	Malta (Valetta)*	61	4,135	6,612	257,266	6,169	17,090,061	230	695
20	EST	Tallinn	65	2,682	6,036	164,980	2,991	10,608,850	148	293
21	ESP	Ibiza	34	2,343	5,723	197,137	4,232	12,554,033	176	312
22	DNK	Kobenhavn	69	3,893	5,715	253,441	6,401	16,661,991	227	715
23	ESP	Santa Cruz De Tenerife	72	3,855	5,545	196,658	4,336	14,745,879	24,192	513
24	IRL	Dublin	58	2,495	5,119	131,649	2,355	8,778,012	118	307

Ranking	Country	Port city	Number of cruise ships calling at port	Time spent around ports (hours)	SOx from cruise ships (kg)	NOx from cruise ships (kg)	PM2.5 from cruise ships (kg)	Cruise ships CO2 emissions (kg)	Cruise ships CH4 emissions (kg)	Cruise ships BC emissions (kg)
25	FRA	Le Havre	45	1,694	4,846	131,861	2,234	8,110,182	118	190
26	GRC	Rodhos	50	2,434	4,645	125,651	2,681	9,214,106	112	387
27	ESP	Cadiz*	86	2,182	4,606	158,139	3,415	10,288,871	1,309	356
28	NOR	Port Of Bergen	80	4,142	4,488	186,851	4,840	13,025,627	167	691
29	ESP	Malaga*	87	2,606	4,473	162,728	3,715	10,737,195	1,091	404
30	ESP	Valencia	57	1,703	4,414	132,676	2,562	8,423,525	285	210
31	DEU	Kiel	24	1,795	4,396	115,344	1,927	7,209,338	103	152
32	BEL	Zeebrugge	51	1,452	4,347	118,074	2,032	7,369,719	106	223
33	ISL	Reykjavik	63	2,954	4,278	152,724	3,600	10,414,165	137	472
34	ESP	Las Palmas	44	3,102	4,149	130,015	2,558	10,391,889	25,633	311
35	HRV	Split	43	1,974	3,754	132,023	2,919	8,570,742	118	290
36	ESP	Arrecife De Lanzarote	49	2,791	3,714	127,660	2,710	10,263,514	25,131	324
37	FIN	Helsinki	62	2,444	3,610	162,312	4,094	10,584,273	145	420
38	NLD	Rotterdam*	29	2,108	3,520	157,065	3,970	10,290,628	140	402
39	HRV	Dubrovnik	41	1,844	3,346	127,050	2,918	8,185,298	114	289
40	GRC	Heraklio (Irakleio)	46	2,062	3,245	92,273	1,977	6,633,902	83	256
41	GBR	London	25	2,090	3,215	86,386	1,784	6,229,114	77	296
42	ITA	Messina	46	1,532	3,160	138,494	3,395	8,878,836	124	310
43	FRA	Cannes	37	1,421	3,140	141,090	3,489	9,006,515	126	268
44	ITA	Palermo	28	1,204	3,119	116,703	2,594	7,334,333	104	187
45	DEU	Bremerhaven	18	2,256	3,035	90,385	1,967	6,315,577	81	220
46	ITA	La Spezia	31	1,774	2,967	132,123	3,114	10,108,797	23,423	233
47	NOR	Stavanger	61	2,052	2,732	127,872	3,297	8,399,799	114	414
48	ITA	Savona	14	1,594	2,720	130,633	3,347	8,612,684	2,504	250
49	ITA	Bari*	16	1,056	2,720	106,289	2,415	6,683,603	95	167
50	ITA	Cagliari	26	837	2,619	83,825	1,695	5,294,699	75	137

Table 17: SOX, NOx, PM2.5, CO2, CH4 and BC emissions from cruise ships in 50 most polluted European port cities by cruise ships in 2019.

*The quality of the AIS data around these ports was poor in 2019 (long time between received messages), emission estimations are thus more uncertain.

Ranking	Cruise operator	Parent company	# ships	SO_x emissions from cruise ships (t)	Ratio of emissions from cruise ships to all European LDVs[16]
1	MSC Cruises	MSC	19	3,358	95%
2	Costa Cruises	Carnival	11	1,439	41%
3	Royal Caribbean Cruises	Royal Caribbean Group	9	1,295	36%
4	Norwegian Cruise Line	Norwegian Cruise Line Holdings	11	1,189	33%
5	Aida Cruises	Carnival	12	850	24%

[16] The ratio of emissions from cruise ships to LDVs for NO_X and $PM_{2.5}$ was not added as it is quite low.

Ranking	Cruise operator	Parent company	# ships	SO_x emissions from cruise ships (t)	Ratio of emissions from cruise ships to all European LDVs[16]
6	Princess Cruise Lines Ltd	Carnival	12	809	23%
7	Celebrity Cruises Inc	Royal Caribbean Group	10	790	22%
8	Carnival	Carnival	7	790	22%
9	TUI Cruises GmbH	Royal Caribbean Group/TUI Group (50%/50%)	10	474	13%
10	Fred Olsen Windcarrier AS		3	467	13%
11	Cunard Line Ltd	Carnival	3	456	13%
12	Oceania Cruises Inc	Norwegian Cruise Line Holdings	5	429	12%
13	Holland America Line NV	Carnival	5	387	11%
14	Marella Cruises	TUI Group	4	381	11%
15	Hurtigruten AS		8	335	9%
16	Viking Ocean Cruises Ltd		8	294	8%
17	Saga Cruises Ltd		2	193	5%
18	Silversea Cruises Ltd	Royal Caribbean Group	7	185	5%
19	Regent Seven Seas Cruises Inc	Norwegian Cruise Line Holdings	4	172	5%
20	Carnival Cruise Line	Carnival	6	163	5%
21	Virgin Voyages		2	155	4%
22	Phoenix Reisen GmbH		3	150	4%
23	Seabourn Cruise Line Ltd	Carnival	5	149	4%
24	PONANT		9	126	4%
25	Columbia Cruise Services Ltd		1	99	3%
26	V Ships Leisure SAM		1	90	3%
27	Celestyal Cruises SA		2	78	2%
28	Magical Cruise Co Ltd		2	62	2%
29	Mano Maritime Ltd		1	56	2%
30	Hapag-Lloyd AG		1	44	1%
31	Azamara Club Cruises		1	33	1%
32	Windstar Cruises MAI LLC		3	29	1%
33	Mystic Cruises SA		4	25	1%
34	Services Transports Cruise		1	18	0%
35	Majestic International Cruises		1	17	0%
36	Swan Hellenic Cruises		1	17	0%
37	Semester at Sea		1	17	0%
38	Carnival Australia	Carnival	1	17	0%
39	Hurtigruten Cruise AS		1	13	0%
40	Plantours & Partner GmbH		1	13	0%
41	Miray Gemicilik Is ve Personel		1	9	0%
42	Windstar Cruises LLC		1	9	0%
43	ROW Management Ltd		1	9	0%
44	Ritz-Carlton Hotel Co		1	8	0%
45	Iceland Pro Cruises ehf		1	8	0%
46	Emerald Cruises		1	7	0%
47	CSSC Carnival Italy Cruise	Carnival	1	6	0%

Ranking	Cruise operator	Parent company	# ships	SO_x emissions from cruise ships (t)	Ratio of emissions from cruise ships to all European LDVs[16]
48	Oceanwide Marine Services BV		1	6	0%
49	Crystal Cruises LLC		1	4	0%
50	Hansa Shipping GmbH & Co KG		1	3	0%
51	Romantic Cruise Doo		1	3	0%
52	Optimum Shipmanagement Service		2	2	0%

Table 18: Ranking of the cruise ship companies based on SOX emissions in the European EEZ in 2022.

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