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 SO₂ emissions, 18% in NOₓ, and 25% in PM₂.₅ emissions.

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 (SO₂) 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 17th 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 SO₂ 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 SO₂ 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 CO₂ [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 NOₓ 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.

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\textsubscript{2}), nitrogen oxides (NO\textsubscript{x}), and fine particles (PM\textsubscript{2.5}). SO\textsubscript{2} are chemical compounds that can include sulphur dioxide (SO\textsubscript{2}) and/or sulphur trioxide (SO\textsubscript{3}), which can provoke cardiovascular and respiratory diseases, and lead to premature death [4]. Similarly, NO\textsubscript{x} emissions – which can include nitric oxide (NO) and nitrogen dioxide (NO\textsubscript{2}) – can lead to respiratory diseases and are a precursor of ground-level ozone, another health-impacting pollutant. Together, SO\textsubscript{2} and NO\textsubscript{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\textsubscript{2.5} emissions are particles made up of fine dust, soot and smoke, that can be inhaled through human lungs.\textsuperscript{1}

The study also looks at carbon dioxide (CO\textsubscript{2}), black carbon (BC) and methane (CH\textsubscript{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\textsubscript{2} emissions. CH\textsubscript{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\textsuperscript{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

\textsuperscript{1} PM emissions fall into two size categories: the one with a diameter of 2.5 micrometres or lower (PM\textsubscript{2.5}) which were looked at in this study, and the one with a diameter of 10 micrometres (PM\textsubscript{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.

\textsuperscript{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 SO₂ 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 NO₂ 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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of cruise ships</th>
<th>Time spent around ports (hours)</th>
<th>Total fuel consumption (t)</th>
<th>Total SO$_x$ (t)</th>
<th>Total NO$_x$ (t)</th>
<th>Total PM$_{2.5}$ (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>173</td>
<td>263,624</td>
<td>332,124</td>
<td>465</td>
<td>16,140</td>
<td>360</td>
</tr>
<tr>
<td>2022</td>
<td>214</td>
<td>324,387</td>
<td>411,023</td>
<td>509</td>
<td>19,125</td>
<td>448</td>
</tr>
</tbody>
</table>

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%.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of cruise ship port calls</th>
<th>Number of cruise passengers (in 1,000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barcelona</td>
<td>800</td>
<td>805</td>
</tr>
</tbody>
</table>

\(^3\) Closer than 12 nm from the port and at a speed of less than 3 knots, as explained in the previous section.
<table>
<thead>
<tr>
<th></th>
<th>Number of cruise ship port calls</th>
<th>Number of cruise passengers (in 1,000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civitavecchia, Fiumicino, Gaeta</td>
<td>800</td>
<td>783</td>
</tr>
<tr>
<td>Marseille</td>
<td>497</td>
<td>572</td>
</tr>
<tr>
<td>Piraeus</td>
<td>622</td>
<td>677</td>
</tr>
<tr>
<td>Mediterranean ports (total)</td>
<td>13,596</td>
<td>14,588</td>
</tr>
<tr>
<td>Baltic sea ports (total)</td>
<td>2,768</td>
<td>2,415</td>
</tr>
</tbody>
</table>

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. 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].

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4 There are also hybrid scrubbers that can work in closed or open loop mode.
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 Huelva, 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\textsubscript{x} that cruise ships emitted around them in 2022. We compare the SO\textsubscript{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\textsubscript{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\textsubscript{x} emissions from cruise ships – and PM\textsubscript{2.5} pollution to a lesser extent – also represent a sizable share of similar pollutants from car fleets. For example, 34% for NO\textsubscript{x} and 7% for PM\textsubscript{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.
<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>Port cities</th>
<th>Number of cruise ships calling at port</th>
<th>Time spent around ports (hours)</th>
<th>SO\textsubscript{x} from cruise ships (kg)</th>
<th>Number of registered LDVs in port cities</th>
<th>SO\textsubscript{x} from registered LDVs (kg)</th>
<th>Ratio of SO\textsubscript{x} from cruise ships and LDVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ESP</td>
<td>Barcelona</td>
<td>106</td>
<td>10,693</td>
<td>18,277</td>
<td>531,749</td>
<td>6,481</td>
<td>2.82</td>
</tr>
<tr>
<td>2</td>
<td>ITA</td>
<td>Civitavecchia</td>
<td>103</td>
<td>9,793</td>
<td>16,307</td>
<td>34,139</td>
<td>416</td>
<td>39.19</td>
</tr>
<tr>
<td>3</td>
<td>GRC</td>
<td>Piraeus</td>
<td>84</td>
<td>8,776</td>
<td>12,418</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>ESP</td>
<td>Palma Mallorca</td>
<td>79</td>
<td>6,930</td>
<td>12,285</td>
<td>248,207</td>
<td>3,025</td>
<td>4.06</td>
</tr>
<tr>
<td>5</td>
<td>PRT</td>
<td>Lisbon</td>
<td>108</td>
<td>5,407</td>
<td>11,132</td>
<td>374,855</td>
<td>4,569</td>
<td>2.44</td>
</tr>
<tr>
<td>6</td>
<td>DEU</td>
<td>Hamburg</td>
<td>47</td>
<td>3,993</td>
<td>10,445</td>
<td>813,847</td>
<td>9,919</td>
<td>1.05</td>
</tr>
<tr>
<td>7</td>
<td>GBR</td>
<td>Southampton</td>
<td>45</td>
<td>6,690</td>
<td>9,676</td>
<td>93,390</td>
<td>1,138</td>
<td>8.50</td>
</tr>
<tr>
<td>8</td>
<td>GRC</td>
<td>Mykonos</td>
<td>56</td>
<td>5,716</td>
<td>9,670</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>GRC</td>
<td>Thira</td>
<td>69</td>
<td>5,771</td>
<td>9,221</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>PRT</td>
<td>Funchal</td>
<td>96</td>
<td>5,275</td>
<td>9,041</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>11</td>
<td>ITA</td>
<td>Napoli</td>
<td>68</td>
<td>4,860</td>
<td>8,863</td>
<td>551,373</td>
<td>6,720</td>
<td>1.32</td>
</tr>
<tr>
<td>12</td>
<td>FRA</td>
<td>Marseille</td>
<td>75</td>
<td>4,744</td>
<td>8,763</td>
<td>369,433</td>
<td>4,503</td>
<td>1.95</td>
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<tr>
<td>13</td>
<td>ITA</td>
<td>Genova</td>
<td>31</td>
<td>3,595</td>
<td>8,546</td>
<td>267,822</td>
<td>3,264</td>
<td>2.62</td>
</tr>
<tr>
<td>14</td>
<td>SWE</td>
<td>Stockholm</td>
<td>49</td>
<td>3,433</td>
<td>7,815</td>
<td>358,540</td>
<td>4,370</td>
<td>1.79</td>
</tr>
<tr>
<td>15</td>
<td>DEU</td>
<td>Kiel</td>
<td>39</td>
<td>2,690</td>
<td>7,530</td>
<td>87,057</td>
<td>1,061</td>
<td>7.10</td>
</tr>
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<td>16</td>
<td>ITA</td>
<td>Livorno</td>
<td>53</td>
<td>4,192</td>
<td>7,262</td>
<td>87,723</td>
<td>1,069</td>
<td>6.79</td>
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<tr>
<td>17</td>
<td>MLT</td>
<td>Valletta</td>
<td>69</td>
<td>3,467</td>
<td>6,900</td>
<td>313,177</td>
<td>3,817</td>
<td>1.81</td>
</tr>
<tr>
<td>18</td>
<td>FRA</td>
<td>Le Havre</td>
<td>40</td>
<td>1,758</td>
<td>6,538</td>
<td>74,649</td>
<td>910</td>
<td>7.19</td>
</tr>
<tr>
<td>19</td>
<td>NOR</td>
<td>Port of Bergen</td>
<td>79</td>
<td>5,260</td>
<td>6,433</td>
<td>77,654</td>
<td>946</td>
<td>6.80</td>
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<tr>
<td>20</td>
<td>ESP</td>
<td>Santa Cruz De Tenerife</td>
<td>80</td>
<td>5,138</td>
<td>6,380</td>
<td>119,464</td>
<td>1,456</td>
<td>4.38</td>
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<td>21</td>
<td>GRC</td>
<td>Rodhos</td>
<td>50</td>
<td>3,742</td>
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<td>-</td>
<td>-</td>
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<td>22</td>
<td>ESP</td>
<td>Malaga</td>
<td>107</td>
<td>3,453</td>
<td>5,743</td>
<td>275,888</td>
<td>3,362</td>
<td>1.71</td>
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<td>23</td>
<td>GRC</td>
<td>Corfu (Kerkira)</td>
<td>55</td>
<td>3,573</td>
<td>5,540</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>24</td>
<td>DNK</td>
<td>Kopenhagen</td>
<td>70</td>
<td>4,261</td>
<td>5,335</td>
<td>169,654</td>
<td>2,068</td>
<td>2.68</td>
</tr>
<tr>
<td>25</td>
<td>EST</td>
<td>Tallinn</td>
<td>45</td>
<td>2,087</td>
<td>5,408</td>
<td>145,426</td>
<td>1,772</td>
<td>3.05</td>
</tr>
<tr>
<td>26</td>
<td>DEU</td>
<td>Rostock</td>
<td>30</td>
<td>1,847</td>
<td>5,302</td>
<td>128,424</td>
<td>1,565</td>
<td>3.39</td>
</tr>
<tr>
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<td>ESP</td>
<td>Cadiz</td>
<td>97</td>
<td>3,210</td>
<td>5,195</td>
<td>44,288</td>
<td>540</td>
<td>9.62</td>
</tr>
<tr>
<td>28</td>
<td>BEL</td>
<td>Zeebrugge</td>
<td>51</td>
<td>1,698</td>
<td>5,110</td>
<td>56,880</td>
<td>693</td>
<td>7.37</td>
</tr>
<tr>
<td>29</td>
<td>ESP</td>
<td>Valencia</td>
<td>73</td>
<td>2,819</td>
<td>4,725</td>
<td>361,390</td>
<td>4,405</td>
<td>1.07</td>
</tr>
<tr>
<td>30</td>
<td>HRV</td>
<td>Split</td>
<td>44</td>
<td>2,745</td>
<td>4,599</td>
<td>89,473</td>
<td>1,090</td>
<td>4.18</td>
</tr>
</tbody>
</table>

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.
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 SOX 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 SOX 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).
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\textsubscript{x} emissions), though 2019 estimates are more uncertain due to poor AIS data quality around this port.\textsuperscript{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\textsubscript{x} and 6th place in 2022), Kiel (+71% in SO\textsubscript{x} and 15th place in 2022) and Bergen (+43% in SO\textsubscript{x} and 19th place in 2022). This shows that the increase in cruise ship traffic in 2022 was not only observed in the Mediterranean.

\textsuperscript{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.

Other port cities appear to have become less polluted than before the pandemic. This is the case of Ibiza (-47% in SO\textsubscript{x} and 46th place in 2022) and Dublin (-89% in SO\textsubscript{x} and 152nd 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\textsubscript{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\textsubscript{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\textsubscript{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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of cruise ships</th>
<th>Time spent in EEZs (hours)</th>
<th>Distance sailed (nm)</th>
<th>Total fuel consumption (kt)</th>
<th>Total SO(_x) (kt)</th>
<th>Total NO(_x) (kt)</th>
<th>Total PM2.5 (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>173</td>
<td>722,806</td>
<td>6,484,194</td>
<td>2,198</td>
<td>41</td>
<td>128</td>
<td>8</td>
</tr>
<tr>
<td>2022</td>
<td>218</td>
<td>887,977</td>
<td>7,514,499</td>
<td>2,591</td>
<td>16</td>
<td>139</td>
<td>7</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>Number of cruise ships</th>
<th>Sailing time (hours)</th>
<th>SO(_x) from cruise ships (t)</th>
<th>Number of registered LDVs in country</th>
<th>SO(_x) from registered LDVs (t)</th>
<th>Ratio of SO(_x) from cruise ships and LDVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Italy</td>
<td>152</td>
<td>128,647</td>
<td>3,720</td>
<td>38,039,760</td>
<td>464</td>
<td>8.0</td>
</tr>
<tr>
<td>2</td>
<td>Spain</td>
<td>183</td>
<td>136,815</td>
<td>3,036</td>
<td>24,611,551</td>
<td>300</td>
<td>10.1</td>
</tr>
<tr>
<td>3</td>
<td>Greece</td>
<td>121</td>
<td>106,223</td>
<td>2,330</td>
<td>4,949,354</td>
<td>60</td>
<td>38.6</td>
</tr>
</tbody>
</table>
In absolute terms, the Italian and Spanish coasts are still the most exposed areas to cruise ships’ NO\textsubscript{x} emissions, with about 27,000 and 22,000 tonnes of NO\textsubscript{x} emitted by cruise vessels in these respective countries’ EEZ in 2022. Similarly to SO\textsubscript{x}, four out of the top five NO\textsubscript{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\textsubscript{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\textsubscript{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.

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

$^3$ 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.

The 19 ships from MSC Cruises emitted nearly as much SOX as all passenger cars in Europe

![Graph comparing SOX emissions from passenger cars and ships](image)

Source: Transport & Environment (2023)
Explanation: This table shows how much SOx cruise ships belonging to cruise ship companies emitted compared to the SOx emitted by the 201,252,242 passenger cars circulating in Europe.

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 CO₂, CH₄ and BC emissions by cruise ships in European EEZs in 2019 and 2022. For CH₄ and BC, we show the amounts emitted and the emissions in CO₂ equivalent using 100-year global warming potential (GWP).

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of cruise ships</th>
<th>Total fuel consumption (t)</th>
<th>Total CO₂ (t)</th>
<th>Total CH₄</th>
<th>Total BC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>tCH₄</td>
<td>tCO₂eq</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>tBC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>tCO₂eq</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>173</td>
<td>2,198,023</td>
<td>6,965,227</td>
<td>1,478</td>
<td>44,057</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>737</td>
<td>663,459</td>
</tr>
</tbody>
</table>

10 29.8 for CH₄ [22] and 900 for BC [1].
We found that all emissions increased between 2019 and 2022. CO₂ emissions increased by nearly 17% to reach 8.1 MtCO₂ 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 CO₂ (+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 tCO₂ on a 100-year horizon. This is equivalent to 10% of the CO₂ 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 CO₂ emissions by 15-20% as well as air pollutants such as SO₂ 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 CH₄ GWP is 82.5 times that of CO₂ 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 effect to 8% of their CO₂ emissions over a 20-year horizon and to 3% of their CO₂ emissions over a 100-year horizon. Worse, CH₄ 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 (Fig. 7)¹². The entire fleet of LNG-powered cruise ships emitted in European EEZs in 2022 as much methane as 62,000 cows.

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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 tCH₄ per cow per year for dairy cattle in Western Europe, from IPCC guidelines for National Greenhouse Gas Inventories [25].
INFO BOX 2: What is methane slip?

Combustion of LNG normally results in CO₂ 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 SO₂ 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 SO₂, NOₓ, PM₁₀, CO₂, CH₄ 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 CO₂ 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 \( \text{SO}_x \) 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.

<table>
<thead>
<tr>
<th>( \text{SO}_x )</th>
<th>( \text{NO}_x )</th>
<th>( \text{PM}_{2.5} )</th>
<th>( \text{CO}_2 )</th>
<th>( \text{CH}_4 )</th>
<th>( \text{BC (SSD)}^{15} )</th>
<th>( \text{BC (MSD)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-52%</td>
<td>0%</td>
<td>+61%</td>
<td>+4%</td>
<td>0%</td>
<td>+81%</td>
<td>+353%</td>
</tr>
</tbody>
</table>

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\textsubscript{x}, NO\textsubscript{x} and PM\textsubscript{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\textsubscript{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.

<table>
<thead>
<tr>
<th>Port city</th>
<th>Country</th>
<th>Number of registered passenger cars</th>
<th>Year</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barcelona</td>
<td>ESP</td>
<td>531,749</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
<tr>
<td>Palma Mallorca</td>
<td>ESP</td>
<td>248,207</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
<tr>
<td>Gibraltar</td>
<td>GIB</td>
<td>17,000</td>
<td>2016</td>
<td><a href="https://www.chronicle.gi/govt-plan-for-cycling-infrastructure-receives-opposition-support-amid-concern-over-rise-in-vehicle-numbers/">https://www.chronicle.gi/govt-plan-for-cycling-infrastructure-receives-opposition-support-amid-concern-over-rise-in-vehicle-numbers/</a></td>
</tr>
<tr>
<td>Hamburg</td>
<td>DEU</td>
<td>813,847</td>
<td>2022</td>
<td><a href="https://www.statistik-nord.de/fileadmin/Dokumente/Statistische_Berichte/verkehr_umwelt_und_energie/H_I_2_i_HuS/H_I_2_i-17_HH.pdf">https://www.statistik-nord.de/fileadmin/Dokumente/Statistische_Berichte/verkehr_umwelt_und_energie/H_I_2_i_HuS/H_I_2_i-17_HH.pdf</a></td>
</tr>
<tr>
<td>Piraeus</td>
<td>GRC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mykonos (Mikonos)</td>
<td>GRC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thira</td>
<td>GRC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9: Average SO\textsubscript{x}, NO\textsubscript{x} and PM\textsubscript{2.5} emissions from European cars in 2022
<table>
<thead>
<tr>
<th>Port</th>
<th>City</th>
<th>Country</th>
<th>Number of registered passenger cars</th>
<th>Year</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiel</td>
<td></td>
<td>DEU</td>
<td>87,057</td>
<td>2022</td>
<td><a href="https://www.kba.de/DE/Statistik/Produktkatalog/produkte/Fahrzeuge/fz3_b_ueber_sicht.html">https://www.kba.de/DE/Statistik/Produktkatalog/produkte/Fahrzeuge/fz3_b_ueber_sicht.html</a></td>
</tr>
<tr>
<td>Malta (Valetta)</td>
<td></td>
<td>MLT</td>
<td>313,177</td>
<td>2022</td>
<td><a href="https://stat.db.nso.gov.mt/">https://stat.db.nso.gov.mt/</a></td>
</tr>
<tr>
<td>Santa Cruz De Tenerife</td>
<td></td>
<td>ESP</td>
<td>119,464</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
<tr>
<td>Rodhos</td>
<td></td>
<td>GRC</td>
<td>275,888</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
<tr>
<td>Corfu (Kerkira)</td>
<td></td>
<td>GRC</td>
<td>169,654</td>
<td>2022</td>
<td><a href="https://www.statistikbanken-dk.translate.goog/10220?_x_tr_sl=auto&amp;_x_tr_tl=it&amp;_x_tr_hl=it&amp;_x_tr_pto=wapp">https://www.statistikbanken-dk.translate.goog/10220?_x_tr_sl=auto&amp;_x_tr_tl=it&amp;_x_tr_hl=it&amp;_x_tr_pto=wapp</a></td>
</tr>
<tr>
<td>Rostock</td>
<td></td>
<td>DEU</td>
<td>128,424</td>
<td>2022</td>
<td><a href="https://www.kba.de/DE/Statistik/Produktkatalog/produkte/Fahrzeuge/fz3_b_ueber_sicht.html">https://www.kba.de/DE/Statistik/Produktkatalog/produkte/Fahrzeuge/fz3_b_ueber_sicht.html</a></td>
</tr>
<tr>
<td>Cadiz</td>
<td></td>
<td>ESP</td>
<td>44,288</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
<tr>
<td>Zeebrugge</td>
<td></td>
<td>BEL</td>
<td>56,880</td>
<td>2022</td>
<td><a href="https://statbel.fgov.be/fr/themes/mobilite/circulation/parc-de-vehicules#figures">https://statbel.fgov.be/fr/themes/mobilite/circulation/parc-de-vehicules#figures</a></td>
</tr>
<tr>
<td>Valencia</td>
<td></td>
<td>ESP</td>
<td>361,390</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
<tr>
<td>Split</td>
<td></td>
<td>HRV</td>
<td>89,473</td>
<td>2019</td>
<td>Ministarstvo Unutarnjih Poslova</td>
</tr>
<tr>
<td>Dubrovnik</td>
<td></td>
<td>HRV</td>
<td>27,173</td>
<td>2019</td>
<td>Ministarstvo Unutarnjih Poslova</td>
</tr>
<tr>
<td>Reykjavik</td>
<td></td>
<td>ISL</td>
<td>79,887</td>
<td>2019</td>
<td>Icelandic Transport Authority</td>
</tr>
<tr>
<td>Las Palmas</td>
<td></td>
<td>ESP</td>
<td>182,345</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
<tr>
<td>Akureyri</td>
<td></td>
<td>ISL</td>
<td>182,131</td>
<td>2022</td>
<td><a href="https://www.samrongustofa.is/umferd/tolfraedi/onnur-tolfraedi/">https://www.samrongustofa.is/umferd/tolfraedi/onnur-tolfraedi/</a></td>
</tr>
<tr>
<td>Cartagena</td>
<td></td>
<td>ESP</td>
<td>115,855</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
<tr>
<td>Arrecife De Lanzarote</td>
<td></td>
<td>ESP</td>
<td>32,195</td>
<td>2022</td>
<td><a href="https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/">https://sedeapl.dgt.gob.es/WEB_IEST_CONSULTA/</a></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of cruise ships</th>
<th>Sailing time (hours)</th>
<th>NOx from cruise ships (kg)</th>
<th>Number of registered LDVs</th>
<th>NOx from registered LDVs (kg)</th>
<th>Cruise ships NOx versus LDVs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITA</td>
<td>152</td>
<td>128,647</td>
<td>26,912,462</td>
<td>38,039,760</td>
<td>137,524,653</td>
<td>20%</td>
</tr>
<tr>
<td>ESP</td>
<td>183</td>
<td>136,815</td>
<td>21,709,289</td>
<td>24,611,551</td>
<td>109,251,328</td>
<td>20%</td>
</tr>
<tr>
<td>GRC</td>
<td>121</td>
<td>106,223</td>
<td>16,393,076</td>
<td>4,949,354</td>
<td>28,042,497</td>
<td>58%</td>
</tr>
<tr>
<td>NOR</td>
<td>110</td>
<td>144,792</td>
<td>15,492,532</td>
<td>2,938,966</td>
<td>12,202,694</td>
<td>127%</td>
</tr>
<tr>
<td>FRA</td>
<td>176</td>
<td>62,311</td>
<td>10,782,070</td>
<td>37,413,447</td>
<td>130,550,996</td>
<td>8%</td>
</tr>
<tr>
<td>PRT</td>
<td>170</td>
<td>48,449</td>
<td>8,485,762</td>
<td>5,325,884</td>
<td>31,752,197</td>
<td>27%</td>
</tr>
<tr>
<td>HRV</td>
<td>72</td>
<td>31,282</td>
<td>4,684,394</td>
<td>1,568,797</td>
<td>7,321,114</td>
<td>64%</td>
</tr>
<tr>
<td>GBR</td>
<td>115</td>
<td>67,584</td>
<td>10,517,526</td>
<td>36,021,268</td>
<td>124,850,969</td>
<td>8%</td>
</tr>
<tr>
<td>ISL</td>
<td>73</td>
<td>24,027</td>
<td>2,594,137</td>
<td>270,000</td>
<td>1,073,330</td>
<td>242%</td>
</tr>
<tr>
<td>CYP</td>
<td>60</td>
<td>11,780</td>
<td>1,902,715</td>
<td>581,866</td>
<td>3,244,967</td>
<td>59%</td>
</tr>
<tr>
<td>IRL</td>
<td>73</td>
<td>7,319</td>
<td>1,155,790</td>
<td>2,219,441</td>
<td>5,536,194</td>
<td>21%</td>
</tr>
<tr>
<td>DEU</td>
<td>98</td>
<td>25,587</td>
<td>3,186,975</td>
<td>45,457,533</td>
<td>141,966,121</td>
<td>2%</td>
</tr>
<tr>
<td>DNK</td>
<td>103</td>
<td>25,324</td>
<td>4,805,800</td>
<td>3,016,223</td>
<td>7,956,357</td>
<td>60%</td>
</tr>
<tr>
<td>MLT</td>
<td>82</td>
<td>5,737</td>
<td>785,488</td>
<td>305,579</td>
<td>1,969,183</td>
<td>40%</td>
</tr>
<tr>
<td>SWE</td>
<td>83</td>
<td>20,463</td>
<td>3,229,775</td>
<td>5,207,522</td>
<td>17,354,946</td>
<td>19%</td>
</tr>
<tr>
<td>NLD</td>
<td>104</td>
<td>16,178</td>
<td>2,813,653</td>
<td>8,383,393</td>
<td>30,934,500</td>
<td>9%</td>
</tr>
<tr>
<td>EST</td>
<td>48</td>
<td>5,279</td>
<td>854,961</td>
<td>846,496</td>
<td>2,961,490</td>
<td>29%</td>
</tr>
<tr>
<td>FIN</td>
<td>58</td>
<td>6,556</td>
<td>843,667</td>
<td>2,726,303</td>
<td>12,490,522</td>
<td>7%</td>
</tr>
<tr>
<td>BEL</td>
<td>93</td>
<td>3,297</td>
<td>465,462</td>
<td>5,585,231</td>
<td>12,989,851</td>
<td>4%</td>
</tr>
<tr>
<td>LVA</td>
<td>35</td>
<td>3,233</td>
<td>497,562</td>
<td>682,827</td>
<td>2,422,589</td>
<td>21%</td>
</tr>
<tr>
<td>SVN</td>
<td>41</td>
<td>1,122</td>
<td>66,208</td>
<td>1,220,346</td>
<td>4,198,672</td>
<td>2%</td>
</tr>
<tr>
<td>POL</td>
<td>40</td>
<td>3,217</td>
<td>314,894</td>
<td>27,743,967</td>
<td>196,726,239</td>
<td>0%</td>
</tr>
<tr>
<td>LTU</td>
<td>29</td>
<td>851</td>
<td>86332</td>
<td>2,730,542</td>
<td>7,123,790</td>
<td>1%</td>
</tr>
<tr>
<td>AUT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5,245,816</td>
<td>18,079,759</td>
</tr>
<tr>
<td>BGR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,663,870</td>
<td>15,503,237</td>
</tr>
<tr>
<td>CZE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6,466,981</td>
<td>26,237,711</td>
</tr>
<tr>
<td>HUN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,838,785</td>
<td>21,853,331</td>
</tr>
<tr>
<td>LUX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>456,856</td>
<td>727,462</td>
</tr>
<tr>
<td>ROU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6,640,445</td>
<td>24,102,890</td>
</tr>
<tr>
<td>SVK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,686,574</td>
<td>7,772,570</td>
</tr>
<tr>
<td>CHE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4,951,619</td>
<td>13,092,242</td>
</tr>
<tr>
<td>TOTAL</td>
<td>887,977</td>
<td>138,760,676</td>
<td>291,252,242</td>
<td>1,157,814,404</td>
<td>12%</td>
<td></td>
</tr>
</tbody>
</table>

Table 11: NOx emissions from cruise ships and LDVs in European countries in 2022.
<table>
<thead>
<tr>
<th>Country</th>
<th>Number of cruise ships</th>
<th>Sailing time (hours)</th>
<th>PM$_{2.5}$ from cruise ships (kg)</th>
<th>Number of registered LDVs</th>
<th>PM$_{2.5}$ from registered LDVs (kg)</th>
<th>Cruise ships PM$_{2.5}$ versus LDV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITA</td>
<td>152</td>
<td>128,647</td>
<td>1,547,627</td>
<td>38,039,760</td>
<td>13,631,444</td>
<td>11.35%</td>
</tr>
<tr>
<td>ESP</td>
<td>183</td>
<td>136,815</td>
<td>1,237,081</td>
<td>24,611,551</td>
<td>12,476,140</td>
<td>9.92%</td>
</tr>
<tr>
<td>GRC</td>
<td>121</td>
<td>106,223</td>
<td>928,664</td>
<td>4,949,354</td>
<td>2,621,674</td>
<td>32.91%</td>
</tr>
<tr>
<td>NOR</td>
<td>110</td>
<td>144,792</td>
<td>667,979</td>
<td>2,938,966</td>
<td>1,532,411</td>
<td>43.59%</td>
</tr>
<tr>
<td>FRA</td>
<td>176</td>
<td>62,311</td>
<td>560,175</td>
<td>37,413,447</td>
<td>14,868,297</td>
<td>3.77%</td>
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<tr>
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<td>170</td>
<td>48,449</td>
<td>496,908</td>
<td>5,325,884</td>
<td>4,604,382</td>
<td>10.79%</td>
</tr>
<tr>
<td>HRV</td>
<td>72</td>
<td>31,282</td>
<td>269,289</td>
<td>1,568,797</td>
<td>830,797</td>
<td>32.41%</td>
</tr>
<tr>
<td>GBR</td>
<td>115</td>
<td>67,584</td>
<td>340,047</td>
<td>36,021,268</td>
<td>14,058,853</td>
<td>2.42%</td>
</tr>
<tr>
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<td>73</td>
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<td>142,785</td>
<td>270,000</td>
<td>130,036</td>
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<td>581,866</td>
<td>455,997</td>
<td>21.84%</td>
</tr>
<tr>
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<td>73</td>
<td>7,319</td>
<td>63,424</td>
<td>2,219,441</td>
<td>493,924</td>
<td>12.84%</td>
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<td>98</td>
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<td>61,882</td>
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<td>15,048,642</td>
<td>0.41%</td>
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<tr>
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<td>846,496</td>
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<td>18,243</td>
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<td>1,382,702</td>
<td>1.32%</td>
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<td></td>
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<td></td>
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<td>53,371</td>
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<td>2,750,475</td>
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<td>705,013</td>
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<td></td>
<td></td>
<td></td>
<td>4,951,619</td>
<td>1,316,815</td>
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<tr>
<td>TOTAL</td>
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<td></td>
<td></td>
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<td>887,977</td>
<td>6,777,025</td>
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Table 12: PM$_{2.5}$ emissions from cruise ships and LDVs in European countries in 2022

A study by Transport & Environment
<table>
<thead>
<tr>
<th>Country</th>
<th>Number of cruise ships</th>
<th>Sailing time (hours)</th>
<th>Cruise ships SOx emissions (kg)</th>
<th>Cruise ships NOx emissions (kg)</th>
<th>Cruise ships PM2.5 emissions (kg)</th>
<th>Cruise ships CO2 emissions (kg)</th>
<th>Cruise ships CH4 emissions (kg)</th>
<th>Cruise ships BC emissions (kg)</th>
</tr>
</thead>
<tbody>
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<td>ITA</td>
<td>152</td>
<td>128,647</td>
<td>3,719,851</td>
<td>26,912,462</td>
<td>1,547,627</td>
<td>1,569,941,418</td>
<td>1,729,472</td>
<td>159,630</td>
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<td>ESP</td>
<td>183</td>
<td>136,815</td>
<td>3,035,591</td>
<td>21,709,289</td>
<td>1,237,081</td>
<td>1,319,680,852</td>
<td>1,837,356</td>
<td>142,961</td>
</tr>
<tr>
<td>GRC</td>
<td>121</td>
<td>106,223</td>
<td>2,329,535</td>
<td>16,393,076</td>
<td>928,664</td>
<td>876,206,256</td>
<td>50,637</td>
<td>106,320</td>
</tr>
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<td>110</td>
<td>144,792</td>
<td>1,470,897</td>
<td>15,492,532</td>
<td>667,979</td>
<td>991,839,514</td>
<td>1,651,385</td>
<td>94,823</td>
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<td>176</td>
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<td>1,319,882</td>
<td>10,782,070</td>
<td>560,175</td>
<td>643,714,993</td>
<td>1,837,356</td>
<td>68,453</td>
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<td>170</td>
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<td>1,286,121</td>
<td>8,485,762</td>
<td>496,908</td>
<td>486,425,743</td>
<td>475,349</td>
<td>56,383</td>
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<td>671,579</td>
<td>4,684,394</td>
<td>269,289</td>
<td>246,075,559</td>
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<td>29,323</td>
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<td>115</td>
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<td>613,625</td>
<td>10,517,526</td>
<td>340,047</td>
<td>618,993,175</td>
<td>349,302</td>
<td>28,349</td>
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<td>73</td>
<td>24,027</td>
<td>371,178</td>
<td>2,594,137</td>
<td>142,785</td>
<td>148,465,982</td>
<td>61,650</td>
<td>16,833</td>
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<td>60</td>
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<td>255,438</td>
<td>1,902,715</td>
<td>99,607</td>
<td>102,342,644</td>
<td>8,837</td>
<td>13,677</td>
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<td>73</td>
<td>7,319</td>
<td>190,967</td>
<td>1,155,790</td>
<td>63,424</td>
<td>72,037,808</td>
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<td>7,087</td>
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<td>98</td>
<td>25,587</td>
<td>86,134</td>
<td>3,186,975</td>
<td>61,882</td>
<td>190,833,882</td>
<td>192,226</td>
<td>14,935</td>
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<td>103</td>
<td>25,324</td>
<td>83,598</td>
<td>4,805,800</td>
<td>115,879</td>
<td>282,160,509</td>
<td>308,171</td>
<td>28,349</td>
</tr>
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<td>82</td>
<td>5,737</td>
<td>81,526</td>
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<td>37,067</td>
<td>46,216,885</td>
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<td>4,378</td>
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<td>20,463</td>
<td>61,346</td>
<td>3,229,775</td>
<td>75,529</td>
<td>178,818,909</td>
<td>67,783</td>
<td>20,195</td>
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<td>55,224</td>
<td>2,813,653</td>
<td>65,966</td>
<td>171,948,517</td>
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<td>15,258</td>
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<td>26,345</td>
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<td>44,151,736</td>
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<td>2,887</td>
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<td>18,534</td>
<td>843,667</td>
<td>18,243</td>
<td>45,544,059</td>
<td>816</td>
<td>4,431</td>
</tr>
<tr>
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<td>3,297</td>
<td>15,312</td>
<td>465,462</td>
<td>7,851</td>
<td>28,127,036</td>
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<td>1,626</td>
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<tr>
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<td>25,353,242</td>
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<td>3,217</td>
<td>6,413</td>
<td>314,894</td>
<td>7,425</td>
<td>17,766,591</td>
<td>1,553</td>
<td>2,309</td>
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Table 13: SOX, NOx, PM2.5, CO2, CH4 and BC emissions from cruise ships in European countries in 2022.
<table>
<thead>
<tr>
<th>Country</th>
<th>Number of cruise ships</th>
<th>Sailing time (hours)</th>
<th>Cruise ships SOx emissions (kg)</th>
<th>Cruise ships NOx emissions (kg)</th>
<th>Cruise ships PM2.5 emissions (kg)</th>
<th>Cruise ships CO2 emissions (kg)</th>
<th>Cruise ships CH4 emissions (kg)</th>
<th>Cruise ships BC emissions (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITA</td>
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<td>138,743</td>
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<td>23,341,816</td>
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</table>

Table 14: SOX, NOX, PM2.5, CO2, CH4 and BC emissions from cruise ships in European countries in 2019.
<table>
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<th>Ranking</th>
<th>Port city</th>
<th>Number of cruise ships</th>
<th>Cruise ships SOx emissions (kg)</th>
<th>Cruise ships NOx emissions (kg)</th>
<th>Cruise ships PM2.5 emissions (kg)</th>
<th>Ratio of SOx from cruise ships and LDVs</th>
<th>Ratio of NOx from cruise ships and LDVs</th>
<th>Ratio of PM2.5 from cruise ships and LDVs</th>
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Table 15: SOx, NOx and PM2.5 of cruise ships and LDVs in top 50 port cities in 2022.
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<td>3,456</td>
<td>11,582,698</td>
<td>24,761</td>
<td>364</td>
</tr>
<tr>
<td>41</td>
<td>Venezia</td>
<td>22</td>
<td>3,661</td>
<td>116,544</td>
<td>2,562</td>
<td>7,967,504</td>
<td>104</td>
<td>289</td>
</tr>
<tr>
<td>Ranking</td>
<td>Port city</td>
<td>Number of cruise ships</td>
<td>Cruise ships SOx emissions (kg)</td>
<td>Cruise ships NOx emissions (kg)</td>
<td>Cruise ships PM2.5 emissions (kg)</td>
<td>Cruise ships CO2 emissions (kg)</td>
<td>Cruise ships CH4 emissions (kg)</td>
<td>Cruise ships BC emissions (kg)</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
<td>------------------------</td>
<td>--------------------------------</td>
<td>--------------------------------</td>
<td>---------------------------------</td>
<td>--------------------------------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>42</td>
<td>Palermo</td>
<td>40</td>
<td>3,584</td>
<td>180,971</td>
<td>4,628</td>
<td>12,578,150</td>
<td>13,518</td>
<td>375</td>
</tr>
<tr>
<td>43</td>
<td>Bari</td>
<td>21</td>
<td>3,393</td>
<td>158,944</td>
<td>4,015</td>
<td>10,207,737</td>
<td>142</td>
<td>316</td>
</tr>
<tr>
<td>44</td>
<td>Augusta</td>
<td>17</td>
<td>3,340</td>
<td>156,044</td>
<td>3,803</td>
<td>9,668,734</td>
<td>139</td>
<td>539</td>
</tr>
<tr>
<td>45</td>
<td>Stavanger</td>
<td>54</td>
<td>3,180</td>
<td>158,705</td>
<td>4,136</td>
<td>10,775,965</td>
<td>5,814</td>
<td>373</td>
</tr>
<tr>
<td>46</td>
<td>Ibiza</td>
<td>22</td>
<td>3,014</td>
<td>156,513</td>
<td>4,002</td>
<td>11,066,517</td>
<td>15,200</td>
<td>284</td>
</tr>
<tr>
<td>47</td>
<td>Oslo</td>
<td>53</td>
<td>2,997</td>
<td>140,733</td>
<td>3,631</td>
<td>11,095,782</td>
<td>20,917</td>
<td>396</td>
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<tr>
<td>48</td>
<td>Akureyri</td>
<td>61</td>
<td>2,619</td>
<td>89,572</td>
<td>1,965</td>
<td>6,193,722</td>
<td>1,102</td>
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<tr>
<td>49</td>
<td>Amsterdam</td>
<td>41</td>
<td>2,808</td>
<td>118,346</td>
<td>2,949</td>
<td>7,854,142</td>
<td>106</td>
<td>322</td>
</tr>
<tr>
<td>50</td>
<td>Cannes</td>
<td>29</td>
<td>2,785</td>
<td>121,421</td>
<td>2,909</td>
<td>7,612,538</td>
<td>109</td>
<td>204</td>
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</table>

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.
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.

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Cruise operator</th>
<th>Parent company</th>
<th># ships</th>
<th>SOx emissions from cruise ships (t)</th>
<th>Ratio of emissions from cruise ships to all European LDVs16</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MSC Cruises</td>
<td>MSC</td>
<td>19</td>
<td>3,358</td>
<td>95%</td>
</tr>
<tr>
<td>2</td>
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<td>Carnival</td>
<td>11</td>
<td>1,439</td>
<td>41%</td>
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<tr>
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<td>Royal Caribbean Cruises</td>
<td>Royal Caribbean Group</td>
<td>9</td>
<td>1,295</td>
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<tr>
<td>4</td>
<td>Norwegian Cruise Line</td>
<td>Norwegian Cruise Line Holdings</td>
<td>11</td>
<td>1,189</td>
<td>33%</td>
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<tr>
<td>5</td>
<td>Aida Cruises</td>
<td>Carnival</td>
<td>12</td>
<td>850</td>
<td>24%</td>
</tr>
</tbody>
</table>

16 The ratio of emissions from cruise ships to LDVs for NOx and PM2.5 was not added as it is quite low.
<table>
<thead>
<tr>
<th>Ranking</th>
<th>Cruise operator</th>
<th>Parent company</th>
<th># ships</th>
<th>SO₂ emissions from cruise ships (t)</th>
<th>Ratio of emissions from cruise ships to all European LDVs&lt;sup&gt;16&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Princess Cruise Lines Ltd</td>
<td>Carnival</td>
<td>12</td>
<td>809</td>
<td>23%</td>
</tr>
<tr>
<td>7</td>
<td>Celebrity Cruises Inc</td>
<td>Royal Caribbean Group</td>
<td>10</td>
<td>790</td>
<td>22%</td>
</tr>
<tr>
<td>8</td>
<td>Carnival</td>
<td>Carnival</td>
<td>7</td>
<td>790</td>
<td>22%</td>
</tr>
<tr>
<td>9</td>
<td>TUI Cruises GmbH</td>
<td>Royal Caribbean Group/TUI Group (50%/50%)</td>
<td>10</td>
<td>474</td>
<td>13%</td>
</tr>
<tr>
<td>10</td>
<td>Fred Olsen Windcarrier AS</td>
<td></td>
<td>3</td>
<td>467</td>
<td>13%</td>
</tr>
<tr>
<td>11</td>
<td>Cunard Line Ltd</td>
<td>Carnival</td>
<td>3</td>
<td>456</td>
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</tr>
<tr>
<td>12</td>
<td>Oceania Cruises Inc</td>
<td>Norwegian Cruise Line Holdings</td>
<td>5</td>
<td>429</td>
<td>12%</td>
</tr>
<tr>
<td>13</td>
<td>Holland America Line NV</td>
<td>Carnival</td>
<td>5</td>
<td>387</td>
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</tr>
<tr>
<td>14</td>
<td>Marella Cruises</td>
<td>TUI Group</td>
<td>4</td>
<td>381</td>
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</tr>
<tr>
<td>15</td>
<td>Hurtigruten AS</td>
<td></td>
<td>8</td>
<td>335</td>
<td>9%</td>
</tr>
<tr>
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<td>Viking Ocean Cruises Ltd</td>
<td></td>
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<td>294</td>
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<tr>
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<td>5%</td>
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<tr>
<td>18</td>
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<td>Regent Seven Seas Cruises Inc</td>
<td>Norwegian Cruise Line Holdings</td>
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<tr>
<td>20</td>
<td>Carnival Cruise Line</td>
<td>Carnival</td>
<td>6</td>
<td>163</td>
<td>5%</td>
</tr>
<tr>
<td>21</td>
<td>Virgin Voyages</td>
<td></td>
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<tr>
<td>22</td>
<td>Phoenix Reisen GmbH</td>
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<td>3</td>
<td>150</td>
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<tr>
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<td>Seabourn Cruise Line Ltd</td>
<td>Carnival</td>
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<td>149</td>
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</tr>
<tr>
<td>24</td>
<td>PONANT</td>
<td></td>
<td>9</td>
<td>126</td>
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</tr>
<tr>
<td>25</td>
<td>Columbia Cruise Services Ltd</td>
<td></td>
<td>1</td>
<td>99</td>
<td>3%</td>
</tr>
<tr>
<td>26</td>
<td>V Ships Leisure SAM</td>
<td></td>
<td>1</td>
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<td>3%</td>
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<tr>
<td>27</td>
<td>Celestyal Cruises SA</td>
<td></td>
<td>2</td>
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<tr>
<td>28</td>
<td>Magical Cruise Co Ltd</td>
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</tr>
<tr>
<td>29</td>
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</tr>
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<td>Azamara Club Cruises</td>
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<tr>
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<tr>
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<tr>
<td>34</td>
<td>Services Transports Cruise</td>
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</tr>
<tr>
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<td>17</td>
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<tr>
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<td>Hurtigruten Cruise AS</td>
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<td>13</td>
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</tr>
<tr>
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<td>Plantours &amp; Partner GmbH</td>
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<td>13</td>
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</tr>
<tr>
<td>41</td>
<td>Miray Gemicilik Is ve Personel</td>
<td></td>
<td>1</td>
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<td>0%</td>
</tr>
<tr>
<td>42</td>
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</tr>
<tr>
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<td>0%</td>
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<tr>
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<td></td>
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</tr>
<tr>
<td>45</td>
<td>Iceland Pro Cruises ehf</td>
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<td>Emerald Cruises</td>
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</tr>
<tr>
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<td>CSSC Carnival Italy Cruise</td>
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<td>1</td>
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<td>0%</td>
</tr>
<tr>
<td>Ranking</td>
<td>Cruise operator</td>
<td>Parent company</td>
<td># ships</td>
<td>SO\textsubscript{X} emissions from cruise ships (t)</td>
<td>Ratio of emissions from cruise ships to all European LDVs\textsuperscript{1a}</td>
</tr>
<tr>
<td>---------</td>
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<td>---------------------------------------</td>
<td>---------</td>
<td>----------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
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<td>Oceanwide Marine Services BV</td>
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<tr>
<td>50</td>
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</tr>
<tr>
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<td>Romantic Cruise Doo</td>
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<td>3</td>
<td>0%</td>
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<tr>
<td>52</td>
<td>Optimum Shipmanagement Service</td>
<td></td>
<td>2</td>
<td>2</td>
<td>0%</td>
</tr>
</tbody>
</table>

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


Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor CINEA can be held responsible for them.