AIR POLLUTION FROM CRUISE SHIPS DURING HOTELLING IN PORTS: A CASE STUDY IN ANCONA HARBOUR, ITALY

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ABSTRACT

Air pollution caused by cruise ships during the hotelling phase in ports represents a significant source of emissions. The hotelling phase refers to the period during which ships remain docked and keep their main and auxiliary engines running to supply power to onboard systems. Numerous studies have shown that this practice significantly contributes to emissions of nitrogen oxides (NO_x), sulphur oxides (SO_x), particulate matter (PM), and carbon dioxide (CO_2), degrading air quality in port areas and surrounding urban zones. Cruise ships, equipped with powerful internal combustion engines, release substantial amounts of pollutants even during hotelling. Emissions of NO_x and SO_x are particularly concerning due to their adverse health effects, associated with respiratory and cardiovascular diseases. Additionally, CO_2 emissions significantly contribute to global greenhouse gas emissions, exacerbating the issue of climate change. The scientific literature has explored various solutions to mitigate these impacts. Among these, the implementation of cold ironing (shore power supply) and the installation of exhaust gas cleaning systems, such as scrubbers, have been identified as effective technologies. However, the adoption of these solutions is uneven globally, influenced by economic and infrastructural factors. In the case study conducted at Ancona Harbour, the analysis focused on a period during the COVID-19 pandemic when a cruise ship carrying COVID-positive passengers was docked in the port for over a month (Central Adriatic Ports Authority, https://porto.ancona.it/). This period was compared with the average pollutant levels of SO_2, NO_x, and PM10 during the same timeframe in 2019. The results showed that during the 2020 hotelling, the average concentrations of NO_x were 63 $\mu g/m^3$, PM10 was 15 $\mu g/m^3$, and SO_2 was 4.5 $\mu g/m^3$. In contrast, during the same period in 2019, the average concentrations were significantly lower: NO_x at 25 $\mu g/m^3$, PM10 at 12 $\mu g/m^3$, and SO_2 at 2.5 $\mu g/m^3$. These findings indicate a substantial increase in pollutant levels during the prolonged hotelling of the cruise ship in 2020, underscoring the environmental impact of such events. The case highlights the critical need for implementing effective emission reduction strategies, particularly in scenarios involving extended docking periods.

Keywords: cruise ship emissions, hotelling, cold ironing, covid, lockdown.

1 INTRODUCTION

Urban ports present a significant challenge in terms of atmospheric pollution due to maritime activities taking place in densely populated areas. Cruise ships are among the main contributors to harmful emissions in ports, significantly increasing the concentration of nitrogen oxides (NO_x), sulphur oxides (SO_x), and fine particulate matter (PM10) [1], [2], substances known for their detrimental effects on both human health and the environment. Numerous studies have highlighted how maritime traffic and port operations are responsible for a substantial portion of atmospheric emissions in port cities, exacerbating existing air quality problems caused by other pollution sources such as road traffic and industrial activities [3]. Specifically, cruise ships emit large amounts of pollutants during the hotelling phase, when they remain docked with auxiliary engines running to power onboard systems, causing significant localised emission peaks [4].

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The issue of emissions due to the hotelling phase has been widely documented. During docking, ships keep their auxiliary engines running to maintain vital systems, such as lighting, air conditioning, and hotel services, requiring fuel consumption that leads to continuous emissions. This phenomenon is particularly relevant in urban ports, where the proximity between the pier and residential areas directly exposes local populations to pollutants [5]. Further studies conducted in different European ports, showed that cruise ships contribute a substantial portion of the total SO_x and PM10 emissions in the urban area, significantly contributing to the exceedance of air quality limits set by European regulations [6], [7].

Another crucial aspect concerns European regulations on marine fuel quality, which have recently undergone significant revisions to improve air quality in port areas. Directive (EU) 2016/802 has set stricter limits on the sulphur content of fuels used by ships, reducing the maximum sulphur content to 0.50% by mass from 2020 for international waters, and further reduced to 0.10% for Emission Control Areas, such as the Mediterranean Sea (Marpol Annex VI, IMO, 2020). This measure has direct implications for the hotelling phase, as ships are required to use low-sulphur fuels while docked, significantly reducing SO_x emissions and helping to improve air quality in port surroundings. However, despite regulatory advancements, emissions from low-sulphur fuels do not eliminate the environmental impact of hotelling, as other pollutants, such as NO_x and particulate matter, continue to be emitted in significant quantities.

The Port of Ancona, located on Italy’s Adriatic coast, serves as a crucial hub for commercial and passenger traffic, acting as a point of connection between Italy and numerous ports in Eastern Europe and the Mediterranean. With a long history as a mercantile port, Ancona has expanded in recent decades to include an increasing number of cruise ships, which now represent a significant component of the local economy. The port is located adjacent to the urban centre, with residential and commercial areas directly surrounding the docks (Fig. 1).

This proximity between the port and the city makes atmospheric pollution from port activities a central concern for the quality of life of Ancona’s population [8]. The port infrastructure includes a network of air quality monitoring stations, with a specific focus on tracking pollutants such as NO_x, SO_2, and PM10, due to their relevance to public health and the obligation to comply with European air quality regulations.

During the lockdown imposed by the COVID-19 pandemic in 2020, global maritime traffic drastically decreased, with many ships remaining docked for extended periods without engaging in the usual loading and unloading operations. This exceptional scenario provided a unique opportunity to assess the impact of cruise ships in prolonged hotelling on atmospheric pollutant concentrations in port areas.

The objective of this study is to analyse how the prolonged docking of a cruise ship in hotelling mode at the Port of Ancona during the COVID-19 lockdown may have affected the air pollutant measurements recorded by an air quality monitoring station located near the port in an elevated position. In particular, the study will focus on the concentrations of NO_x, SO_2, and PM10, three of the most relevant pollutants for urban air quality and linked to naval emissions. The lockdown offered a unique context to isolate the impact of the cruise ship in hotelling mode, as many other industrial and vehicular traffic activities were minimised, allowing for a more accurate attribution of pollutant variations to the ship’s activity. The data collected by the monitoring station during the extended docking period will be analysed and compared with the historical average values of the same pollutants in similar periods of previous year.

Figure 1: (a) Italy in orange, Marche region in yellow and Ancona Harbour is identified with a cruise ship icon; (b) Front view of Ancona Harbour; and (c) Aerial view of port, red pin denotes the position of measuring point.

This study is part of the broader discussion on strategies to reduce the environmental impact of ships in urban ports, with a particular focus on measures that can be implemented to minimise emissions during the hotelling phase, such as shore-side electricity (cold ironing) and the use of cleaner fuels. The results obtained may provide useful insights for local and national policies aimed at mitigating the effects of atmospheric pollution in ports and coastal cities, contributing to promoting more sustainable practices in the maritime sector.

2 METHODS

To evaluate NO_x, SO_2, and PM10 concentrations, data was collected from the Ancona-Cittadella urban monitoring station (ARPAM, https://aria.arpa.marche.it/), located about 1 km from the cruise ship dock. Italy's Phase 1 COVID-19 lockdown began on 9 March 2020, ending on 3 May 2020, followed by Phase 2 from 4 May to 14 June. The cruise ship, which docked on 28 April 2020, remained in 'hotelling' mode until 4 June with auxiliary engines running. Pollutant average concentrations were analysed for two periods: 9 March–27 April (hard lockdown, no cruise ship) and 28 April–4 June (partial lockdown, cruise ship present), compared with the same periods in 2019 (Table 1).

Table 1: Summary table with the characteristics of the periods analysed.

Periods	**Date**	**Pollutants**	**Lockdown**	**Cruise ship hotelling**
Period 1	9 March–27 April	NO_x–SO_2–PM10	Hard	No
Period 2	28 April–4 June	NO_x–SO_2–PM10	Partial	Yes

3 RESULTS

During the COVID-19 lockdown, various sources reported a positive impact on air quality due to the reduction in vehicular traffic and industrial activities. However, there was also an increase in domestic emissions, primarily due to the heightened use of heating systems and electricity as people were forced to stay at home. Several studies confirm this trend. For instance, a report by the European Environment Agency (EEA, https://www.eea.europa.eu/) highlighted that the drop in transport-related emissions was counterbalanced by a rise in emissions from residential heating systems during the lockdown. Furthermore, an analysis by ISPRA (Italian Institute for Environmental Protection and Research, https://www.isprambiente.gov.it/) noted that the demand for heating and energy use at home led to an increase in pollutants such as NO_x, PM10, and SO_2, particularly in urban areas with high population density.

The time series reported in Fig. 2, display the concentrations of PM10, NO_x, and SO_2 pollutants from 9 March to 4 June. A marked increase in concentrations is noted during Period 2 of 2020 compared to the same period in 2019. Preliminary analysis suggests that, on average, pollutant levels in 2020 are higher in both Period 1 and Period 2 (All periods) than those recorded in 2019, except for PM10, which shows a comparable trend.

Analysing the average concentrations of PM10 (Tables 2 and 3), it is immediately evident that the percentage variation in 2020 compared to 2019 is only −2.7%. Upon closer examination, it is noted that 2020 Period 1 shows a reduction of +8.7% compared to 2019 Period 1. Moreover, 2020 Period 2 shows a +28.6% reduction compared to 2020 Period 1. This decrease does not appear to be influenced by cruise ship extended hotelling but seems to be more affected by the reduced use of domestic heating systems, particularly biomass devices, due to the rise in spring temperatures.

Analysing the average concentrations of NO_x (Tables 2 and 3), it becomes immediately evident that the percentage variation in 2020 compared to 2019 is significant, reaching +111.9%. Specifically, the Period 1 in 2020 shows an increase of +104.2% compared to 2019 Period 1, with this upward trend intensifying in 2020 Period 2, which records a +152% rise compared to the same period in 2019. This increase may be attributed to the heightened use of domestic gas heating systems during the lockdown. Unlike PM10, there is no reduction in 2020 Period 2 due to the seasonal temperature rise. Additionally, 2020 Period 2 shows a +28.6% increase compared to 2020 Period 1, which, in this case, could be influenced by cruise ship extended hotelling.

The average concentration data of SO_2 (Tables 2 and 3) indicate a significant percentage increase of +51.9% in 2020 compared to 2019. A more detailed analysis shows that 2020 Period 1 experienced a +33.3% rise compared to 2019 Period 1, with the growth trend further intensifying in 2020 Period 2, showing an +80% increase over the same period in 2019. Additionally, 2020 Period 2 recorded a +12.5% increase compared to 2020 Period 1. This rise could be attributed to cruise ship hotelling. Given that SO_2 is a typical pollutant from combustion in ship engines, which use fuels containing sulphur, even in small percentages, this trend is particularly significant.

4 CONCLUSIONS

This study emphasises the significant impact of cruise ships on air quality, particularly during the hotelling phase, when ships are docked but continue to run their engines to power onboard systems. The data collected at the Port of Ancona during the COVID-19 lockdown demonstrate a clear increase in the concentrations of NO_x, SO_2 when a cruise ship was docked

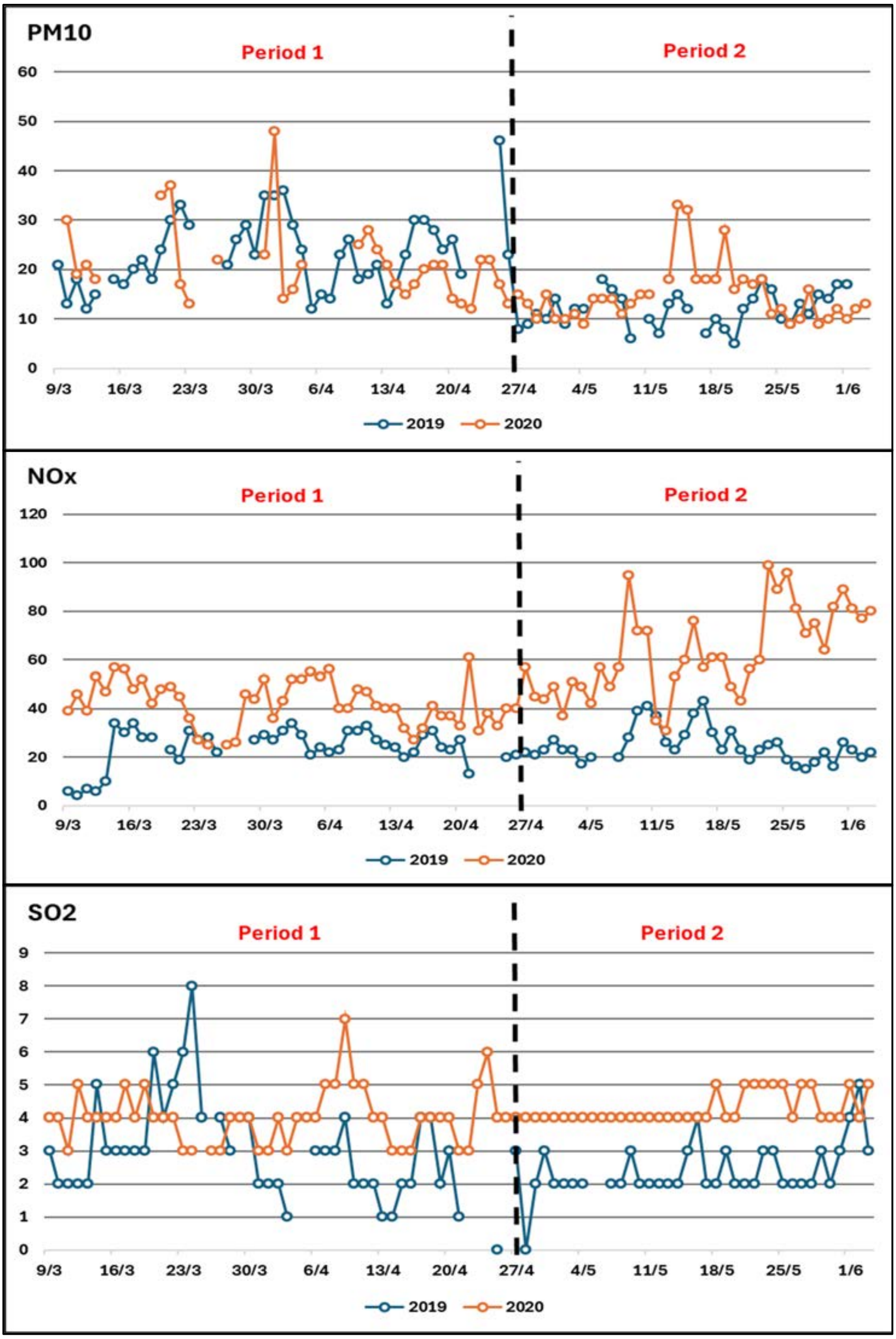

Figure 2: PM10 time series (upper panel); NO_x time series (central panel); SO_2 time series (lower panel).

Table 2: Average concentration (AC) (µg/m^3) for each pollutant in different periods analysed.

	2019			2020		
	AC Period 1	AC Period 2	AC All periods 2019	AC Period 1	AC Period 2	AC All periods 2020
PM10	23	12	18.2	21	15	17.7
NO_x	24	25	24.3	49	63	51.5
SO_2	3	2.5	2.7	4	4.5	4.1

Table 3: Ratio (%) for each pollutant in different periods analysed.

Pollutant	**Ratio %** (2020 Period 1)/ (2019 Period 1)	**Ratio %** (2020 Period 2)/ (2019 Period 2)	**Ratio %** (2020 Period 1)/ (2020 Period 2)	**Ratio %** (ALL periods 2020)/ (ALL periods 2019)
PM10	−8.7	25	−28.6	−2.7
NO_x	104.2	152	28.6	111.9
SO_2	33.3	80	12.5	51.9

for an extended period. This highlights the pressing environmental challenge posed by the hotelling phase, particularly in urban ports, where the proximity to residential areas exacerbates the effects of emissions on local populations.

Cruise ships are equipped with large auxiliary engines that burn fossil fuels contributing significantly to the emission of pollutants such as nitrogen oxides (NO_x), sulphur oxides (SO_2), particulate matter (PM), and carbon dioxide (CO_2). These emissions have well-documented effects on public health, contributing to respiratory and cardiovascular diseases [3]. Furthermore, they contribute to the broader issue of climate change, with CO_2 being a major greenhouse gas [9].

One of the most effective strategies to mitigate emissions during the hotelling phase is the use of cold ironing, also known as shore-side power. This technology allows ships to connect to the local electrical grid while docked, enabling them to shut down their engines entirely. By switching to grid electricity, ships can reduce their emissions of NO_x, SO_2, and CO_2 to near-zero levels while in port, significantly improving local air quality [6].

However, despite its clear environmental benefits, the adoption of cold ironing remains limited due to several factors. First, the cost of retrofitting existing ships with the necessary infrastructure can be prohibitively high. Additionally, ports must invest in significant infrastructure upgrades to provide the necessary electrical power, which can be challenging in regions with limited resources or less stringent environmental regulations [10]. Moreover, the effectiveness of cold ironing depends on the cleanliness of the local electrical grid. In areas where the grid relies heavily on fossil fuels, the overall reduction in emissions may be less significant.

Despite these challenges, the increased awareness of maritime emissions and tightening environmental regulations, particularly in the European Union and Emission Control Areas, are likely to drive broader adoption of cold ironing and similar technologies. The results of this case study underscore the urgency of implementing such measures to reduce the environmental footprint of cruise ships, particularly in urban ports where the health and environmental impacts of emissions are most pronounced. As the global maritime industry moves toward more sustainable practices, cold ironing represents a critical tool in reducing emissions and protecting air quality.

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