Assessment of Ship-based Air Pollutant Emissions in Iskenderun Bay Before and During the COVID-19 Pandemic

Özkan Akar[1*], Vahit Çalışır[2], Aydın Demirci[3] and Emrah Şimşek[4]

[1]Maritime Technologies Vocational School, Iskenderun Technical University, Hatay, Türkiye (*ozkan.akar@iste.edu.tr; https://orcid.org/0000-0002-9547-0966).

[2]Department of Maritime Transportation and Management Engineering, Faculty of Barbaros Hayrettin Naval Architecture and Maritime, Iskenderun Technical University, Hatay, Türkiye (vahit.calisir@iste.edu.tr; https://orcid.org/0000-0001-6575-8988).

[3]Department of Marine Technologies, Faculty of Marine Sciences and Technology, Iskenderun Technical University, Hatay, Türkiye (aydin.demirci@iste.edu.tr; https://orcid.org/0000-0002-7168-9904).

[4]Department of Marine Technologies, Faculty of Marine Sciences and Technology, Iskenderun Technical University, Hatay, Türkiye (emrah.simsek@iste.edu.tr; https://orcid.org/0000-0001-7066-2534).

ABSTRACT

The COVID-19 pandemic, which emerged as a global crisis in early 2020, disrupted many sectors, including maritime transport. Iskenderun Bay, located in southeastern Türkiye, is home to numerous industrial ports and plays a significant role in national and regional logistics. This study examines the impact of the pandemic on ship-based emissions of air pollutants by comparing the annual emission levels for 2019 and 2020. The analysis focuses on five major pollutants: nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon dioxide (CO_2), hydrocarbons (HC), and particulate matter (PM), evaluated by both port location and ship type. Emission data were estimated using vessel traffic information obtained from port authorities and regional maritime institutions. Each vessel's operational parameters, such as engine size and activity modes including cruising, maneuvering, and berthing, were considered. Emission factors consistent with internationally recognized methodologies were applied. Spatial analysis techniques and descriptive statistics were used to highlight temporal and locational variations. The results reveal that while a general decrease in emissions was observed in many ports due to reduced maritime traffic, some locations experienced notable increases. For instance, CO_2 emissions at the EKMAR port increased significantly in 2020, exceeding the highest port-level emission recorded in 2019. On the other hand, SANKO port demonstrated a sharp decline, with reductions in emissions reaching over 95 percent in some pollutant categories. When grouped by ship type, all categories showed reduced emissions in 2020 compared to the previous year, likely due to changes in fuel regulations and reduced global demand for shipping services. These findings suggest that the environmental impacts of global disruptions like pandemics can vary substantially at the regional level. The study provides valuable insights for maritime policymakers and port administrators seeking to develop adaptive strategies for emission control and sustainability planning.

Keywords: Iskenderun Bay, Ship emissions, COVID-19, Port activity, Air pollution, Turkey.

1. INTRODUCTION

Maritime shipping underpins global trade and economic activity but also contributes to air pollution and greenhouse gas (GHG) emissions. Approximately 80-90% of world trade (by weight) moves by sea, highlighting the strategic importance of ocean transport to global supply

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chains (IMO, 2020; UNCTAD, 2022). Türkiye's economy is similarly maritime-oriented: national statistics indicate that roughly 85-90% of Türkiye's import/export tonnage is carried by sea due to the country's extensive coastline on the Mediterranean, Aegean, Black, and Marmara Seas (TÜİK, 2023). However, the growth in sea-borne trade comes with environmental costs. The shipping sector emits large quantities of CO_2 and other pollutants from vessel engines and auxiliary systems. Shipping is estimated to contribute on the order of 2-3% of global anthropogenic CO_2 emissions (IMO, 2020) and is a significant source of nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), and hydrocarbons. These emissions adversely affect air quality and public health in coastal areas (Corbett and Köhler, 2003). International regulations have begun to address this issue - for example, MARPOL Annex VI requires ships to use low-sulfur fuel (reduced to 0.50% sulfur content after 2020) and to improve energy efficiency (IMO, 2017).

The global COVID-19 pandemic in early 2020 caused an unprecedented shock to the maritime sector (Can et al., 2020; Demirci et al., 2020). Following the emergence of SARS-CoV-2 in late 2019, countries worldwide imposed lockdowns, travel restrictions, and port delays to contain the virus (UNCTAD, 2022). These measures led to a sudden contraction in international trade and shipping activity. Vessel calls at ports plummeted, and many scheduled sailings were cancelled, especially in the first half of 2020 (March et al., 2021; UNCTAD, 2022). For example, U.S. container imports declined by about 7% in the first half of 2020 compared to 2019, even though they later rebounded sharply in late 2020 (USITC, 2020). Globally, research shows that over 70% of the world's exclusive economic zones experienced reductions in ship traffic occupancy during the early pandemic (March et al., 2021). This "anthropause" of shipping was shorter lived than in other sectors by 2021, maritime trade and emissions had largely returned to, or even exceeded, pre-pandemic levels (UNCTAD, 2022; Climate Action Tracker, 2023).

The abrupt slowdown in shipping also yielded noticeable environmental effects. With fewer ships operating, emissions of SO_2, NO_x, CO_2 and particulate matter from the maritime sector dropped temporarily. Quantitative studies report reductions in shipping-related emissions in 2020: for instance, one analysis found that global ship CO_2, NO_x, CO, HC and N_2O emissions fell by roughly 7-14%, and SO_2 and $PM_{2.5}$ by as much as 40-80%, compared to a business-as-usual scenario (Yi et al., 2024). Similarly, analyses of transport sectors have documented marked declines in roadside and airborne pollutants during lockdowns. In Europe and Asia, levels of NO_2, PM, and other pollutants dropped sharply under restricted mobility (Sharma et al., 2020; Donzelli et al., 2021). Air quality improvements during 2020 have been

linked to measurable health benefits, such as fewer asthma attacks and respiratory illnesses (Rupani et al., 2020). In Türkiye, studies of the pandemic period found significant decreases in vehicle traffic and urban air pollution metrics (Aygül and Baştuğ, 2020; Yılmaz and Karagözoğlu, 2022). However, most of these studies have focused on city air quality; there have been relatively few analyses of the pandemic's impact on ship-based emissions or port-region air quality.

Iskenderun Bay, located on Türkiye's eastern Mediterranean coast, is a major hub of seaborne trade and heavy industry, and thus a critical case for study (Akar and Demirci, 2025). The bay hosts a dense cluster of ports, terminals, pipelines and floating facilities supporting bulk cargoes (e.g. iron ore, steel, petroleum, LNG) and general cargo (Doymuş, 2021). In total, 28 coastal facilities (including commercial ports and offshore moorings) are active in this region, and large private terminals such as BOTAŞ, İsdemir (steel plant), LimakPort, AssanPort, Tosyalı, and Atakaş handle most of the vessel traffic. In 2019-2020, roughly 10,500 commercial vessel calls were recorded at Iskenderun and nearby ports (Türk Denizcilik Genel Müdürlüğü, 2021). This concentration of maritime activity - together with extensive industrial emission sources - makes the region environmentally sensitive. Because Iskenderun Bay is both strategically important for regional trade and representative of Türkiye's port-industrial complexes, it provides a valuable case to examine how COVID-19 interruptions affected shipping emissions.

Given the gap in the literature on pandemic effects in the maritime sector, this study analyzes ship-sourced emissions in Iskenderun Bay during the COVID-19 period. We compare detailed emission inventories for 2019 (pre-pandemic) and 2020 (pandemic year), using vessel movement data and industry-standard emission factors for NO_x, SO_2, CO_2, particulate matter, and hydrocarbons. Our goal is to quantify the changes in pollutants attributable to altered maritime traffic, thereby shedding light on the short-term environmental impact of the pandemic on a key Turkish port region. The findings will inform policymakers and port authorities seeking sustainable strategies as global trade patterns continue to evolve post-pandemic.

2. MATERIAL AND METHODS

This study investigates the impact of the COVID-19 outbreak on maritime activities in the İskenderun Bay, one of the critical maritime regions of the eastern Mediterranean in Türkiye (Fig 1). The pandemic's effects in Türkiye became significant in 2020, which led to various operational and environmental changes in the maritime transport sector (Gössling, 2020).

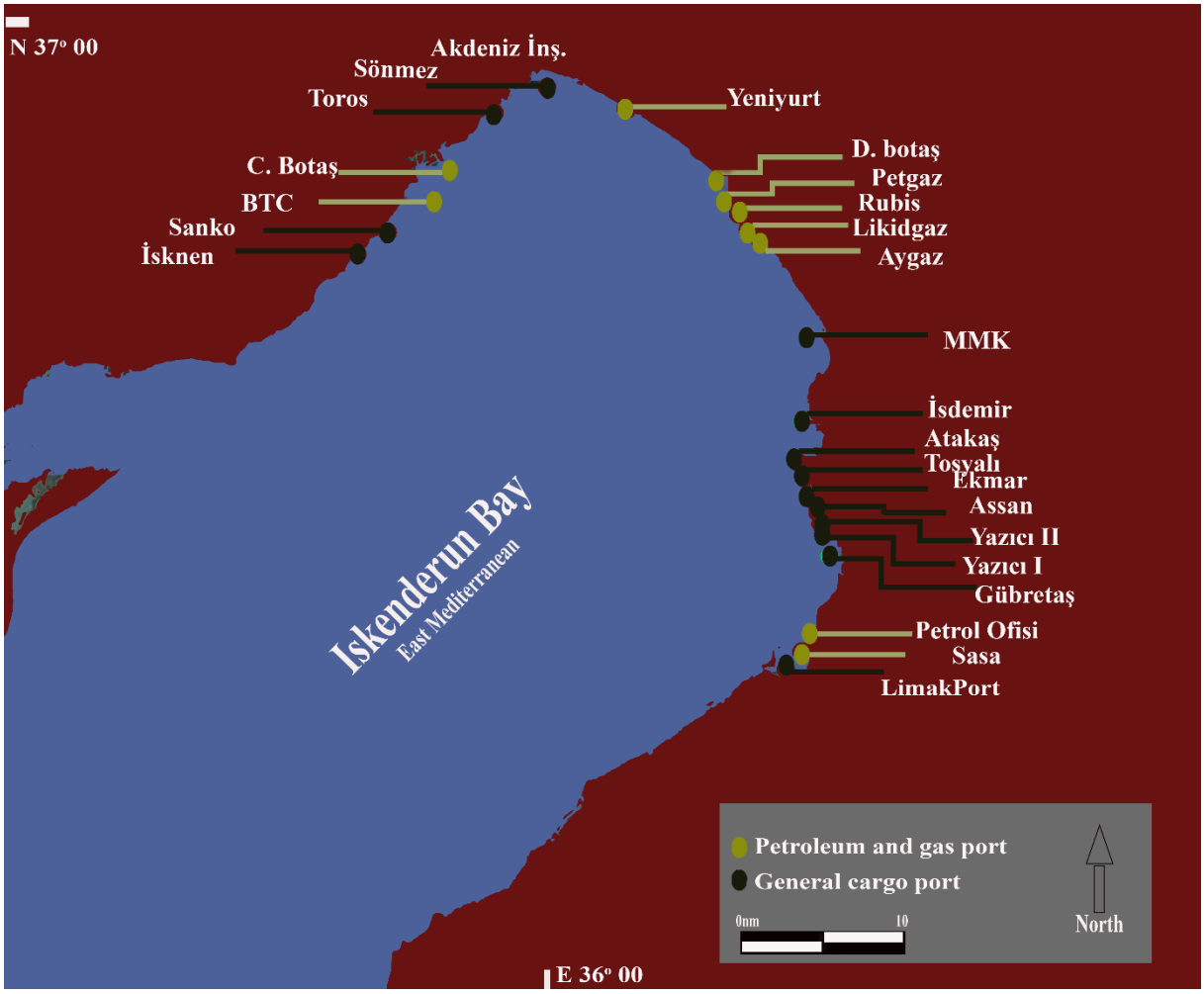


Figure 1. Study area.

The years 2019 and 2020 were selected as the pre-pandemic and pandemic periods, respectively. Emission data from ships calling at ports in İskenderun Bay during these years were analyzed comparatively. The dataset includes calculated or reported emissions of five major air pollutants: nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon dioxide (CO_2), particulate matter (PM), and hydrocarbons (HC). All calculated emissions were converted from grams to tons (t) and are reported consistently on a mass basis throughout the study.

The raw data was obtained from the İskenderun Chamber of Shipping and preprocessed to eliminate missing values, inconsistencies, and outliers. Only ports with georeferenced coordinates were included in spatial analyses. The data was classified by ship type and operational mode, and the annual average emission values for each pollutant in 2019 and 2020 were calculated and compared.

Emission calculations followed internationally accepted bottom-up activity-based methods, particularly the Entec (2002) and EMEP/EEA Tier 3 (Trozzi, 2010) methodologies.

These methods divide ship operations into three main modes: cruising, maneuvering, and hoteling. Emissions were estimated separately for each mode using the formula:

$$E = T \times (P \times LF \times EF)$$

Where, *P* is engine power (kW), *LF* is the load factor, *T* is the activity duration (hours), and *EF* is the emission factor for pollutant *i* (g/kWh).

Each ship's main and auxiliary engines were considered with mode-specific operational parameters and emission factors (Tokuşlu, 2021).

The calculation used emission factors and load assumptions consistent with Turkish regional studies (Demirci and Karagüzel, 2018). For example, cruising mode assumed main engine loads of approximately 80%, while hotelling mode assumed 20-30% for auxiliary engines depending on vessel type. Emission factors varied between engine and fuel types; for example, NO_x values ranged from 8 to 16 g/kWh depending on vessel class and operation mode (Tokuşlu, 2021).

A spatial NO_x emission change map was produced using coordinates of ports. Ports with increased NO_x emissions in 2020 compared to 2019 were marked in red, and those with reductions were shown in blue. Circle sizes represented the magnitude of the change. This enabled a visual interpretation of COVID-19's impact on maritime emission patterns.

3. RESULTS

The average ship-based emission values for ports in İskenderun Bay for the years 2019 and 2020 are presented in tables 1 and 2 (all values are in tons (t)). In these tables, the annual average values of five main pollutants (NO_x, SO_2, CO_2, HC, and PM) are shown for each port. Overall, the results indicate that emission levels in many ports decreased in 2020 compared to 2019. However, increases were observed in some ports in 2020, suggesting that the change in ship activities was not homogeneous across ports.

According to the data, the largest increase in NOx emissions was recorded at EKMAR, rising from 0.0 t in 2019 to 2049.7 t in 2020. LİMAKPORT showed the second-largest increase, from 7.4 t to 196.5 t (+189.1 t), while ASSANPORT increased from 9.9 t to 16.6 t (+6.7 t). In contrast, the largest reduction was observed at SANKO, where NOx emissions decreased from 1126.7 t in 2019 to 9.8 t in 2020 (−1116.9 t). MMK and ATAKAŞ also showed decreases of approximately 25.0 t and 2.0 t, respectively.

Table 1. Average ship-related emissions of ports in Iskenderun Bay in 2019 and 2020 (t).

PORT	***Years/ Emissions***									
	2019	***2020***	***2019***	***2020***	***2019***	***2020***	***2019***	***2020***	***2019***	***2020***
	NO_x		***SO_2***		***CO_2***		***HC***		***PM***	
Akdeniz Gemi İnş.	3.8	NA	2.7	NA	166.7	NA	0.1	NA	0.3	NA
Assanport	9.9	16.6	7.3	10.4	486.4	654.7	0.3	0.6	0.8	1.5
Atakaş	9.3	7.3	6.5	5.2	403.0	321.5	0.3	0.3	0.8	0.6
Aygaz	1.2	0.9	1.1	0.9	68.1	51.4	0.1	0.1	0.1	0.1
B. Ceyhan	1.4	1.4	1.2	1.2	74.8	74.5	0.1	0.1	0.1	0.1
B. Dörtyol	1.1	1.4	1.0	1.2	59.3	73.0	0.1	0.1	0.1	0.1
Btc	1.5	1.1	1.3	1.0	79.0	60.0	0.1	0.1	0.2	0.1
Delta	0.6	1.5	0.5	1.2	29.6	72.6	0.0	0.1	0.1	0.1
Ekmar	0.0	2049.7	0.0	1280.4	0.4	75305.7	0.0	6.8	0.0	184.7
Gübretaş	0.9	0.8	0.8	0.7	47.2	42.2	0.1	0.0	0.1	0.1
İpragaz	1.5	1.3	1.3	1.2	81.2	73.9	0.1	0.1	0.2	0.1
İsdemir	8.2	8.5	5.7	6.0	353.0	368.7	0.3	0.3	0.7	0.7
İsken	12.9	11.4	9.1	8.6	560.5	531.9	0.4	0.4	1.1	0.9
Karayollari	5.0	NA	3.5	NA	217.8	NA	0.2	NA	0.4	NA
Limakport	7.4	196.5	5.2	123.0	331.8	7269.6	0.3	6.5	0.6	17.7
Milangaz	1.1	0.1	1.0	0.1	58.7	4.6	0.1	0.0	0.1	0.0
Mmk	493.9	468.9	309.0	293.3	18186.6	17260.0	16.3	15.5	44.5	42.2
Nato	2.0	0.6	1.8	0.5	107.8	32.8	0.1	0.0	0.2	0.1
P.O.	5.5	5.6	3.8	3.9	232.1	237.1	0.2	0.2	0.5	0.5
Pet Gaz	0.6	6.2	0.6	3.9	33.7	238.7	0.0	0.2	0.1	0.5
Sanko	1126.7	9.8	703.9	6.6	41405.2	413.8	37.1	0.3	101.5	0.8
Sasa	2.2	2.0	1.5	1.4	89.7	83.5	0.1	0.1	0.2	0.2
Sönmez	0.1	11.8	0.1	7.4	4.9	452.6	0.0	0.4	0.0	1.0
Toros	0.2	14.1	0.1	9.1	7.0	533.9	0.0	0.4	0.0	1.1
Tosyali	2.4	34.7	1.7	21.7	97.2	1249.4	0.1	0.9	0.2	2.4
Yazici	6.4	1.2	4.5	0.9	280.6	54.5	0.2	0.0	0.5	0.1
Yeniyurt	1.2	5.0	1.0	3.0	63.0	181.9	0.1	0.1	0.1	0.3

Note: NA = Not Available.

Table 2. Average emission values by ship type in İskenderun Bay for the years 2019 and 2020 (t).

Ship Type	***NO_x***		***SO_2***		***CO_2***		***HC***		***PM***	
	2019	***2020***	***2019***	***2020***	***2019***	***2020***	***2019***	***2020***	***2019***	***2020***
Tanker	1.53	1.30	1.37	0.14	82.73	73.57	0.08	0.07	0.16	0.15
Chemical Tanker	1.41	1.20	1.23	0.13	75.46	66.85	0.07	0.06	0.14	0.12
Bulk Cargo	1.20	1.02	1.05	0.11	63.36	55.23	0.06	0.05	0.13	0.11
Dry Cargo	1.10	0.89	0.96	0.10	58.69	49.78	0.05	0.05	0.12	0.10
Container	1.65	1.31	1.47	0.15	85.28	64.92	0.08	0.06	0.16	0.13
Ro Ro	1.32	1.01	1.17	0.12	70.54	52.78	0.07	0.05	0.15	0.12
Various	1.10	0.93	0.98	0.10	59.33	50.22	0.05	0.04	0.12	0.11

During the COVID-19 pandemic, EKMAR Port experienced a noticeable increase in traffic, as it became a preferred hub for shipping activities. The port's operational efficiency, particularly its ability to provide fast berthing and departure services, made it highly attractive to ship operators seeking to minimize turnaround times. This high-performance handling capacity not only enhanced the port's competitiveness during the crisis but also explains why emission levels in 2020 were significantly higher compared to other regional ports. This value

exceeded the highest port-level emission recorded in 2019 (SANKO Port) by around 82%. MMK Port remained among the top emitters in both years, although its emission levels in 2020 were slightly lower compared to 2019 (CO_2: ~18187 t in 2019 vs. ~17260 t in 2020). LİMAKPORT showed a significant increase in 2020, with its average CO_2 emission reaching approximately 7270 t, about 22 times higher than the previous year.

In general, most ports showed a decrease in average emissions in 2020 compared to 2019. For example, at ports such as AYGAZ, BTC, MİLANGAZ, NATO, GÜBRETAŞ, and İPRAGAZ, a clear decline was observed across all pollutant types. A particularly sharp drop was observed at SANKO Port; its very high average CO_2 emission of 41405.2 t in 2019 fell to 413.8 t in 2020, representing approximately 1% of the 2019 level. This dramatic reduction caused SANKO to lose its top position in 2020. On the other hand, some ports-such as ASSANPORT, B. DÖRTYOL, İSDEMİR, TOSYALI, and LİMAKPORT-experienced an increase in average emissions in 2020. The increases observed at LİMAKPORT and EKMAR were particularly notable, standing out as exceptions to the overall decreasing trend in the region.

The annual average emission values from different ship types in İskenderun Bay for 2019 and 2020 are presented in Table 2. The values are given for five pollutant types (NOx, SO_2, CO_2, HC, and PM), with the averages for both years shown side by side to allow comparison. Table 2 clearly shows that emissions from all ship types decreased in 2020 compared with 2019. This decrease can be attributed to the reduction in maritime traffic caused by the COVID-19 pandemic and the global implementation of low-sulfur fuel regulations in 2020.

The largest proportional reduction was observed in sulfur dioxide (SO_2) emissions. The main reason for this decrease was the new regulation by the International Maritime Organization (IMO), which reduced the sulfur content in marine fuels from 3.5% to 0.5% as of 2020. This policy change was intended to reduce SO_2 emissions by approximately 77%. As seen in the table, SO_2 values in many ship types fell by up to 80% in 2020 compared to 2019. Similarly, reductions were also recorded in carbon dioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM) emissions. For example, the average CO_2 emission of container ships decreased from 85.28 t in 2019 to 64.92 t in 2020, which corresponds to a reduction of around 24%. Likewise, the CO_2 emissions of RO-RO ships decreased from 70.54 t to 52.78 t, representing a reduction of approximately 25%. Although the overall trend was downward, the rate of decrease was more limited in some ship types. This suggests that these types of vessels may have continued to operate at a high level during the

pandemic. It is understood that tankers and bulk cargo ships, which are responsible for transporting essential raw materials, remained largely operational during the COVID-19 period.

In conclusion, the year 2020 was marked by a noticeable decline in ship emissions. This comparison by ship type is important for understanding both the effectiveness of environmental regulations and the impacts of global crises on maritime transport. The findings from the İskenderun Bay case are valuable for guiding sustainable port management and emission control policies.

When the spatial distribution of NO_x (nitrogen oxides) emission differences between 2020 and 2019 at ports in İskenderun Bay was examined, a clear variation was observed among the ports. Each port was represented by a circle on the map; the colors indicated the direction of the change, and the sizes reflected the magnitude of the absolute difference. Red circles represented ports where NO_x emissions increased in 2020, while blue circles indicated ports with a decrease. The size of each circle was proportional to the absolute emission difference in t. To improve readability, port names were displayed with guiding arrows and shifted labels (Fig 2).

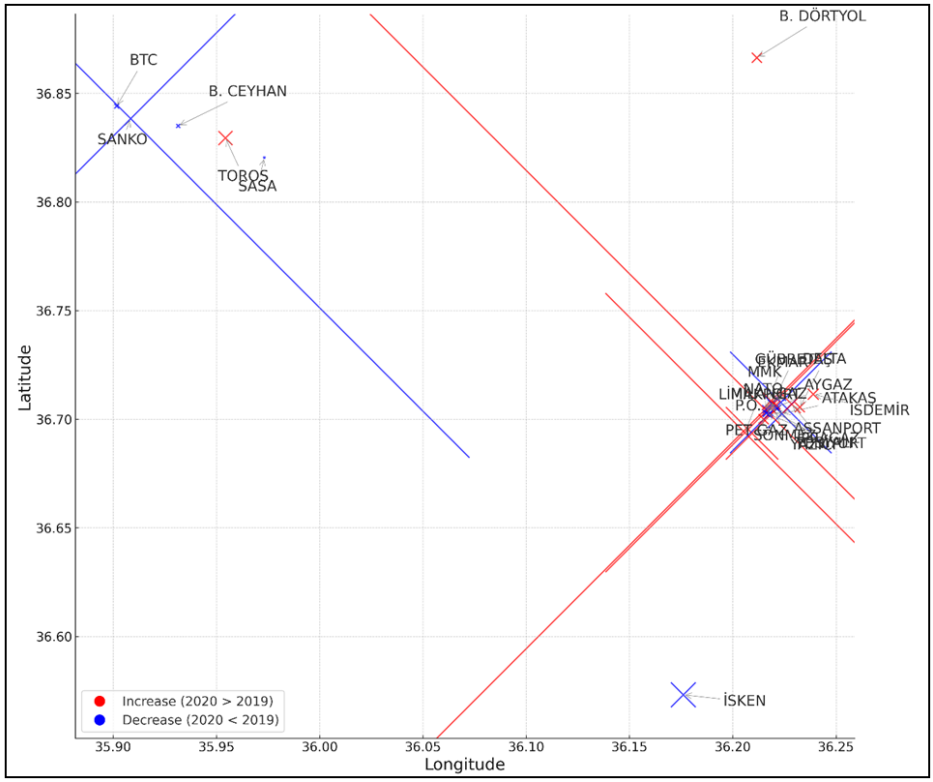


Figure 2. Spatial distribution of NO_x emission differences (2020-2019) across major ports in İskenderun Bay, Türkiye. (Red circles indicate an increase in NO_x emissions in 2020 compared to 2019, while blue circles represent a decrease).

According to the data, the largest increase in NOx emissions was recorded at EKMAR, where emissions increased from 0.0 t in 2019 to 2049.7 t in 2020. LİMAKPORT showed the second-largest increase, rising from 7.4 t to 196.5 t (+189.1 t), while ASSANPORT increased from 9.9 t to 16.6 t (+6.7 t). These ports appeared to have maintained or increased their operations despite the pandemic. In contrast, the largest reduction was observed at SANKO Port, where NOx emissions decreased from 1126.7 t in 2019 to 9.8 t in 2020 (−1116.9 t). Other notable decreases were observed at MMK (−25.0 t) and ATAKAŞ (−2.0 t).

Although the map focused only on NOx emissions, similar patterns were observed for other pollutants. For instance, CO_2 emissions at SANKO Port decreased by 40991.4 t, from 41405.2 t in 2019 to 413.8 t in 2020, while SO_2 emissions decreased by 697.3 t, from 703.9 t to 6.6 t. In contrast, increases in SO_2 and CO_2 emissions were observed at ports such as ASSANPORT and LİMAKPORT, broadly consistent with their NOx trends. These findings indicate that the effects of the pandemic and concurrent environmental regulations, including the low-sulfur fuel requirement implemented in 2020, varied considerably among ports.

4. DISCUSSION

In the literature, the impact of COVID-19 on maritime transport emissions has generally been reported as a reduction. For example, Yi et al. (2024) reported that ship-sourced emissions of NO_x, CO, HC, CO_2, and N_2O decreased by approximately 7-14% in 2020 compared to 2019, while SO_2, $PM_{2.5}$, and black carbon dropped by 41-82%. A significant part of this reduction has been attributed to the IMO (2020) regulation, which globally reduced the sulfur content in marine fuels from 3.5% to 0.5%. Yuan et al. (2024) also reported that SO_2 emissions from shipping were reduced by around 80% as a result of this regulation. However, while global emissions have declined, regional variations have been reported. Yi et al. (2024) found a sharp decline in emissions in Asian routes in February 2020 followed by recovery in May, whereas European and American routes showed a decrease around May and a recovery by August. These findings suggest that emissions are closely related to shipping activity and trade volume. Contrary to the overall global trend, this study revealed substantial port-level heterogeneity in İskenderun Bay. While emissions decreased at many ports, several facilities showed marked increases in one or more pollutants in 2020 compared with 2019. The port activities in İskenderun are of strategic importance from a national perspective, and container and tanker traffic in this region remained strong or even recovered rapidly during the pandemic. This may be explained by increased local traffic or alternative operational modes. While cruise and ferry call in Europe declined sharply during the same period, the number of container ship calls

increased in İskenderun. Therefore, emission increases in İskenderun might be attributed to high traffic volumes rather than the overall national average. Other possible contributing factors include fleet complexity and changes in regional logistics, such as redirected transit traffic or emergency shipments during the pandemic.

In some cases, reductions in port traffic do not directly translate into proportional emission decreases. For instance, Mujal-Colilles et al. (2022) found in Barcelona that despite a 27.9% decrease in port calls from March to June 2020, CO_2 emissions only dropped by 1.8%, and SO_2 and PM showed no significant change, while NOx slightly increased (1.3%). This demonstrates that reduced traffic does not necessarily lead to reduced emissions. Similar trends were observed in the European ferry sector, where ferry calls at EU ports decreased by about 19% in 2020, but ship-level emission changes remained limited (Mannarini et al., 2022). These findings suggest that even in the Black Sea or Mediterranean, local data may diverge from global expectations.

Emission profiles also vary according to ship operating modes: sailing, maneuvering, and hotelling. While sailing ships account for most NO_x and CO_2 emissions, ships at berth contribute less. For example, in the Barcelona study, 75.8% of NO_x emissions came from sailing ships, while only 14.6% came from ships at berth. During the pandemic, auxiliary engines of berthed ships continued to operate at high power for longer durations, which may have balanced out expected reductions. This may also explain the limited decrease in emissions despite reduced ship movement. In İskenderun, similar trends could have occurred if ships spent longer periods waiting near ports.

Fuel type also plays a significant role in emissions. IMO (2020) mandated the use of low-sulfur fuels, resulting in a global decline in SO_2 emissions (Yuan et al., 2024). In Barcelona, increased use of marine gas oil (0.5% S) and LNG led to decreased SO_2 emissions, especially from LNG-powered tankers and passenger ships. These fuels also contribute to lower PM emissions. However, the observed increases in SO_2 and PM emissions in İskenderun may reflect differences in vessel activity levels, operational profiles, fuel characteristics, or longer operating times. Regional differences in fuel use may also explain the variation, as the Eastern Mediterranean and Black Sea regions may not align with global fuel trends.

In summary, while global studies have reported significant emission reductions during the pandemic, local investigations have shown more varied results (Yi et al., 2024; Yuan et al., 2024). In Barcelona, traffic declines did not directly reflect in emissions, and only limited reductions were recorded in Mediterranean ferry emissions (Mujal-Colilles et al., 2022; Mannarini et al., 2022). In areas like the Malta Channel, traffic remained steady, and air quality

changes were minimal (Saliba et al., 2021). For the Black Sea, few studies are available, but heavy ship traffic may have prevented substantial declines. Therefore, the emission changes observed in İskenderun Bay during the pandemic appear to be shaped by local factors such as intense transit traffic, port waiting times, and fuel usage patterns, differing from the global trend.

5. CONCLUSION

This study has shown that the maritime sector in Iskenderun Bay experienced significant shifts in air pollutant emissions during the COVID-19 pandemic. While some ports showed clear reductions in emissions, many others such as EKMAR and LİMAKPORT saw notable increases, especially in NO_x and CO_2 levels. These differences indicate that local factors, including port activity intensity, ship type composition, and changes in trade routes, played a major role in shaping emission outcomes during the pandemic. Although many global regions reported a decline in maritime traffic, the industrial importance of Iskenderun Bay likely contributed to the maintenance or even expansion of shipping activities in certain segments. Furthermore, the emission changes observed suggest that reduced vessel numbers do not always result in proportionally lower emissions. Longer berthing times, increased use of auxiliary engines, and differences in vessel operational profiles may have counteracted expected declines. The findings also reflect the complexity of maritime operations and the need for site-specific assessments when evaluating environmental impacts. This case study emphasizes the importance of localized data collection, real-time monitoring, and adaptive emission management policies, especially under extraordinary global events like pandemics.

6. ACKNOWLEDGEMENTS

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7. CONFLICT OF INTERESTS

The authors declare that they have no conflicts of interest.

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