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Research Article

Role of Port Tugs in Ship-Borne Emissions: An Analysis in Izmit Bay-TURKIYE

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Abstract

Thanks to the awareness created by the concrete effects of global warming and climatic irregularities, concepts such as carbon emissions, polluting gases, internal combustion engines, energy efficiency are gaining more and more importance in our lives globally. In this context, the maritime sector, which provides the transfer of 90% of global trade, has become the center of attention with its ships boasting huge machinery and has also been a subject of exhaust emission studies. The fact that approximately 70% of ship emissions occur in coastal areas requires more scrutiny of ships operating in these areas. Providing docking and departing services for ports, having small hull sizes compared to other ships but featuring big machinery in terms of power output (kW), port tugboats are a serious source of emissions. Although it is not calculated cumulatively, it is an undeniable fact that its effects on the emissions of tugboats in port areas where ship movement is intense. As a first in this literature, the present study aimed to make a 3-month emission inventory of port tugs in Izmit Bay, where Turkey's largest shipping activities take place, and to compare it with emission studies for other ships. In the study period, port tugs' emissions of CO2, NOX, SOX, VOC, PM, CO were calculated to be 7,398.88 tonnes, 121.09 tonnes, 66.43 tonnes, 2.13 tonnes, 4.27 tonnes, and 5.77 tonnes, respectively. This suggests that port tugs have a significant place among ship types in terms of producing exhaust emissions.

Keywords: Ship emissions, port tugs, carbon emissions, Izmit Bay

Introduction

Regardless of a specific route, the seaway, which provides the transfer of large masses and volumes of cargo, today constitutes approximately 90% of the world trade. As of 2020, approximately 120,000 merchant ships are in service worldwide and 40% of these are 25 years old or over (Equasis-Electronic Ship Qualty Shipping İnformation System, 2020). Both their high average age as mentioned in the table, also their significant intensity of use makes them the subject of many researches, and especially make their huge internal combustion engines the subject of exhaust emission studies. In parallel, the trend of combating climate change in the world is to focus on reducing emissions policies. In 2030, it is aimed to reduce human-induced CO2 emissions by 45% compared to 2010 and to reach net zero emissions by 2050 (IPCC, 1996). Perhaps the most important of the measures taken for this purpose is to reduce the sulfur content in ship bunkers to 0.5% by 2020 (IMO, 2020).

For this reason, recently increasing awareness of emissions pollution has led to the emergence of many studies on the subject, and ultimately, governments to sign agreements to take precautions and organizations such as the International Maritime Organization (IMO) to take action by issuing regulations (Bayırhan et al., 2019; Corbett et al., 2007; IMO, 2020; Mersin, 2020; Ülker et al., 2021; UNCTAD, 2020; United Nationals, 2023; United Nations, 1992; Wang and Corbett, 2007; Mersin and Yıldırım, 2021).

The Mediterranean is one of the most useful waterways in the world due to its location and is the region where the most shipping activities are carried out after Southeast Asia. Being surrounded by seas on three sides and geographically situated as a bridge between Asia and Europe, Türkiye has been a useful route and destination for ships. Each year, approximately 40,000 ships pass through the Turkish Straits, which serve as a transit corridor (UAB- Ulaştırma ve Altyapı Bakanlığı, 2022). Some are transitive, that is, they enter from the north and exit from the south or vice versa. The rest stop by Turkish ports (Bayırhan et al., 2019; Tokuşlu, 2019; Ülker et al., 2021).

It is necessary to monitor ship-based exhaust emissions in areas where such intensive shipping activities take place and where a coastal settlement is also present. Although it is not calculated cumulatively, it is an undeniable fact that its effects on the emissions of tugboats in port areas where ship movement is intense. Therefore, in this study, as a first in the literature, the effects of port tugboats on emission pollution are discussed. This study presents the exhaust emissions caused by port tugs in the Izmit Bay area, where the highest number of ship movements takes place among all Turkish ports.

Table-1 Ship age scala(Equasis ,2020), [(1) GT<500 - (2) 500≤GT<25.000 - (3)25.000≤GT<60.000 - (4) GT≥60.000]

Ship age category	**Small(l)**		**Medium(2)**		**Large(3)**		**Very Large(4)**		**Total**	
0-4 years Old	4,072	6.9%	4,476	9.5%	1,976	15.5%	1,483	21.9%	12,007	9.6%
5-14 years Old	13,029	22.2%	16,099	34.2%	7,037	55.3%	3,743	55.2%	39,908	31.9%
15-24 years old	9,723	16.6%	8,697	18.5%	3,137	24.7%	1,381	20.4%	22,938	18.3%
+25 years Old	31,822	54.3%	17,86	37.9%	564	4.4%	172	2.5%	50,418	40.2%
Total	**58,646**	**100%**	**47,132**	**100%**	**17,714**	**100%**	**6,779**	**100%**	**125,271**	**100%**

Izmit Bay

The Gulf of Izmit is an area whose western borders start with the line that connects Pendik Cape (Istanbul) in the north and Deveboynu Cape (Yalova) in the south (Coordinates: 40°52.30' N / 29° 13.57' E [Pendik Cape], 40°48.44' N / 29°08.96' E, 40°39.66' N / 29°08.66' E [Deveboynu Cape]) and which comprises the rest of the Marmara Sea to the east (KEGM, 2016). It is known that Kocaeli province, which borders a large part of the Gulf of Izmit, produced 21.23 million tons of CO_2 in 2017 due to anthropogenic effects, and 18.6% of this amount, ie 4.155.967 tons, was caused by transportation (Atmaca and Sevimoğlu).

According to a report published by the Ministry of Transport, Izmit Bay, which is the industrial centre of the Marmara Region as the country's industrial region, is the most dynamic area among the Turkish ports with a monthly average of 3500 shipping activities (Kocaeli Liman Başkanlığı, 2022).

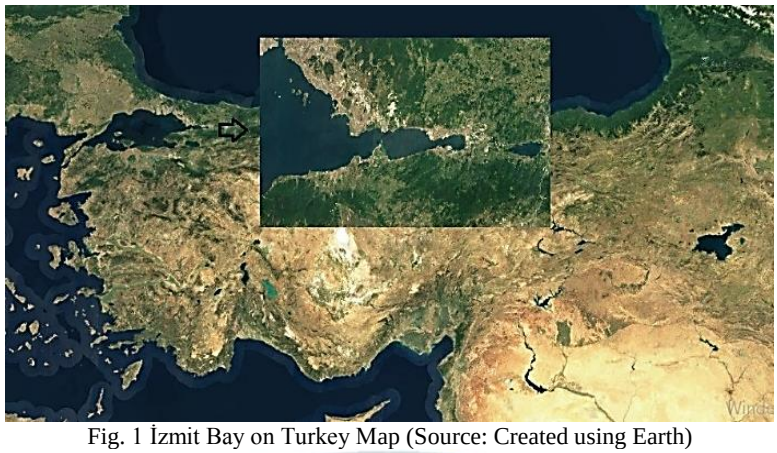

Fig. 1 İzmit Bay on Turkey Map (Source: Created using Earth)

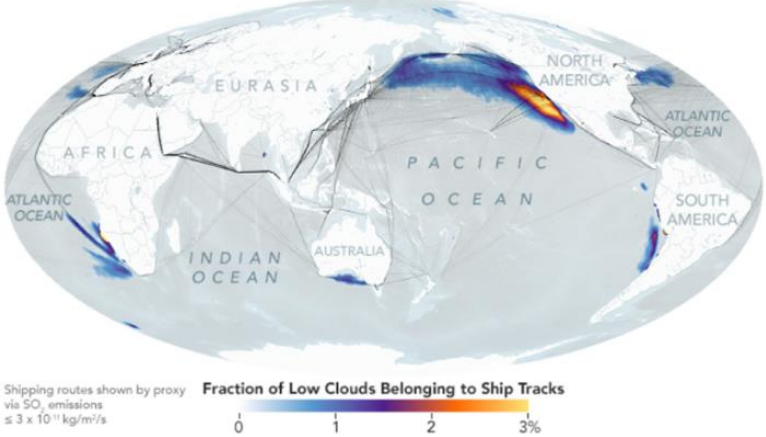

Fig. 2. Ship sourced sulfur oxide emission map (National Aeronautics and Space Administration - NASA, 2022)

Port Tugs

Globally, the vast majority (70%) of ship exhaust emissions occur within 400 km of coastline and port areas. Tugs constitute approximately 16% of the global fleet of ships (Corbett et al., 2007).

According to European port statistics, among emissions from all types of ships, port tugs are responsible for an average of 8-14% of annual air pollution, including 7.7% of SO_2, 19% of CO_2, and 14% of NO_X emissions. These are important air pollution indicators that need to be addressed (European Commission, 2017a).

Port tugs are to ensure safe docking, departing, salvage, fire-fighting operations, mooring, and operation in stormy weather conditions. Therefore, they must have powerful, dynamic, and reliable machinery. High power density diesel engines with frequent and large load changes cause high specific emissions of harmful substances and particles such as CO_2, SO_X, NO_X, PM, VOC, and CO into the atmosphere. Taking measures to

reduce emissions from tug machinery, therefore, is of great importance in and around ports. Various efforts have been made to reduce diesel machinery emissions.

Examples include preference for LNG fuelled engines or hybrid (fuel cell and diesel fuelled) systems in newly built tugs, replacement of diesel engines with dual (LNG and diesel) fuelled engines, use of methanol fuel, use of common rail technology in fuel pump systems, etc (Chen and Lam, 2022; Deniz and Zincir, 2016; Kumar et al., 2018; Lebedevas et al., 2021).

Study Area

The Gulf of Izmit, where monthly 3000 and annually 4000 vessels enter, exit, anchor, or port on average, is the region where the most intensive porting activities take place in Turkish territorial waters. There is an upward trend in ship density over the years (Kocaeli Liman Başkanlığı, 2022). Figure 3 shows the ship movement density in the east-west and north-south directions for 2021. In compliance with international agreements and legislations, the Administration is obliged to purchase tugs as stated in table 2 in order to carry out these vessel activities safely.

Table 2. Port Tug Requirement List (Port Regulations; 2012)

Gross Tonnage	Ship Type	Tug Requirements (Minimum)	Requirement Pulling Force (Minimum)	Definition
2000 – 5000	All Ships	1	16	Min. 16 ton
5001 – 15000	All Ships	2	32	At least 16 tons each
15001 – 30000	All Ships	2	60	At least 30 tons each
30000 – 45000	All Ships	2	75	At least 30 tons each
45000 over	Non Dangerous Good Carrying Ships	2	90	At least 30 tons each
45001 – 75000	LPG, flammable , Explosion and Chemical	3	90	At least 30 tons each
75 000 over	LPG, flammable , Explosion and Chemical	3	120	At least 30 tons each
All Tonnage	LNG Carrying Ships	3	150	At least 30 tons each

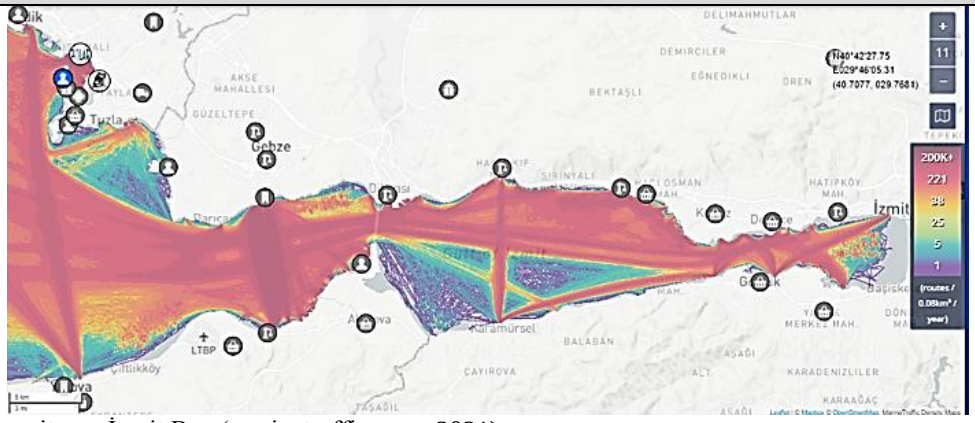

Fig. -3. Ship Density on İzmit Bay (marinetraffic.com, 2021)

Table 3. Ship and Tug Statistics for Months

Months	Ship Movement	Tug Movement
03.2020	3357	2884
04.2020	2879	2352
05.2020	2940	2598
Total	**9176**	**7834**

Ship Movements in Izmit Bay

Except for local traffic and military purposes, all vessels over 20 metres and 100 gross tons were considered as participants in this study, which used the data that were converted into statistics by Izmit Vessel Traffic Services affiliated under the Directorate General of Coastal Safety. The months of March, April, May 2020 were chosen as the time period for the study, as they are the months when the measures related to the COVID-19 pandemic began in the world and in Turkey (Yılmaz and Bayram, 2020). As Table 3 indicates, 9176 ship movements were registered in Izmit Bay between March and May 2020.

Izmit Bay Port Tugs

Izmit Bay contains two shipyards, one in the north and one in the south, and 36 ports including container, liquid and gas transfer terminals and berths serving for various purposes. Six companies for the safe docking provide

towage services and departure activities of ships of various tonnages based on the conditions specified in Table 1. As Table 2 shows, 7834 towage activities were carried out in 9176 ship movements. The average tug service time in Izmit Bay is 45 min = 0.75 h. The average length, width, draft, gross tonnage, towing power capacity, maximum speed, and machinery parameters of the tugs providing towage services in Izmit Bay are given in Table 4.

Table 4. Average Port Tug Particular

Specification	Parameter	Units
Length O. A	28-32	m
Beam O. A	10-12.8	m
Average Draught	4.5-5.5	m
Gross Tonnage	350-49	t
Pulling Capacity	58-70	t
Max. Speed	11-14	Knot
Main Engines	2 x Diesel Engines 2250-2350 kW	
Aux Engines	2 x Diesel Engines 110-125 kW	
Total Power	2420-2600	kW

Pollutants

Because of the chemical reaction in the internal combustion engines of a ship, 450 different pollutants are released (Bilgili and Celebi, 2016). In this study, carbon dioxide (CO_2), nitrogen oxides (NO_X), sulphur oxides (SO_X), particulate matter (PM), volatile organic compounds (VOC), and carbon monoxide (CO) pollutants were calculated.

SO_X

The sulphur in the fuel reacts with oxygen during the combustion process and causes sulphur oxide (SO_X) outputs at a rate of approximately 1%. Sulphur oxide emissions have negative effects on humans and environment. Its effects on humans include damage to the respiratory system. It leads to cardiovascular and lung diseases. The most important effect on the environment is acidification. SO_X emissions resulting from the combustion reaction contribute to acidification, especially by leaking into water resources. Besides, it combines with raindrops in the air and causes acid rain (International Maritime Organization -IMO, 2020). In addition to these effects, SO_X emissions can also reflect harmful solar beams (Sofiev et al., 2018).

CO_2

Carbon dioxide is the most common exhaust gas resulting from combustion. It approximately accounts for 96% of exhaust emissions. Creating a greenhouse gas effect, it is the biggest factor in global warming. Based on the principle of maximum operation with minimum movement, it is tried to be reduced with applications such as energy efficiency and operational efficiency on ships (Aspelund et al., 2006; IMO, 2019).

NO_X

Naturally coming within the air sucked into the machine cylinders to mix with the fuel, nitrogen molecules form nitrogen oxide gases with high temperature. Nitrogen oxides entering the body through the respiratory tract have a negative impact on the lungs (IMO, 2020).

PM

Particulate matter (PM), which is the solid product of ship exhaust emissions, can be found in various sizes such as $PM_{2.5}$ and PM_{10}. It can penetrate and damage internal organs through inhalation (Chu Van et al., 2019; IMO, 2020).

VOC

Volatile organic compounds are a type of emission formed by the fuel evaporating in the fuel tanks of ships. Depending on the intensity and time of exposure, it causes damage to the respiratory tract of people and respiratory deficiencies.

CO

Carbon monoxide gas is formed due to incomplete combustion in ship machinery. It is one of the primary pollutants and can remain in nature for two months. It is dangerous because it has a poisonous effect. It can lead to loss of consciousness and death if inhaled in a closed environment.

Method

Two types of approaches are used to determine ship exhaust emissions. The first is the top-down method, which is based on the amount of fuel consumption and the type of ship. The second is the bottom-up approach that calculates emissions according to the type of ship, engine class and speed, and navigation mode (Entec UK, 2010). ENTEC method belonging to the second approach was used in this study. In the tug emission calculation, the operating time of the main and auxiliary machines and the total maximum output power capacities are multiplied with the load coefficient and emission coefficient according to the operating mode. It is given in the equation below in units.

$$\sum E = t\,[(\sum P_{ME} \times LF_{ME} \times EF_{ME}) + (\sum P_{AE} \times LF_{AE} \times EF_{AE})] \quad \text{(Eq. 1)}$$

$$\sum E = t(h) \times (\sum ME(kW) \times LF_{ME}(\%) \times EF_{ME}(g/kWh)) + (\sum AE(kW) \times LF_{AE}(\%) \times EF_{AE}(g/kWh)) \quad \text{(Eq.2)}$$

$\sum E$ = Total emission(g)
t = Time (hour)
$\sum ME$ = Total main engine power (kW)
LF_{ME} = Main engine load factor (%)
EF_{ME} = Main engine emission factor (g/kWh)
$\sum AE$ = Total auxiliary engine power (kW)
LF_{AE} = Auxiliary engine load factor (%)
EF_{AE} = Auxiliary engine emission factor (g/kWh)

Results

In connection with a total of 9176 ship activities that occurred in Izmit Bay between March and May 2020 (3 months), 7834 port tug activities took place as shown in Table 5. Accordingly, 11.280.260 kWh of energy was consumed and a total of 7.598,65 tonnes of emission output occurred in 3 months.

Table 5. Statistics of movements, energies, and emissions for months

Months	Movement Number	Consumed Energy(kWh)	Total Emission(ton)
March 2020	2884	4.152.960	2.797,36
April 2020	2352	3.386.880	2.281,34
May 2020	2598	3.741.120	2.519,95
Total	**7834**	**11.280.960**	**7.598,65**

As a result of 2884 port towage activities in March 2020, 4,152,960 kWh of energy was consumed and a total of 2,797.36 tons of emissions, including 44.58 tons of NOX, 24.46 tons of SOX, 2,723.82 tons of CO2, 0.78 tons of VOC, 1.57 tons of PM, and 2.13 tons of CO were released, as can be seen in Table 6.

Table -6. March Emissions

March 2020	**2884 Movements**
Emissions Type	**Ton**
NO_X	44,58
SO_X	24,46
CO_2	2.723,82
VOC	0,78
PM	1,57
CO	2,13
Total	**2.797,36**

As a result of 2352, port towage activities in April 2020, 3,386,880 kWh of energy was consumed and, as Table 7 shows, a total of 2,281.34 tons of emissions were released, including 36.35 tons of NOX, 19.94 tons of SOX, 2,221.36 tons of CO2, 0.64 tons of VOC, 1.28 tons of PM, and 1.33 tons of CO.

Table -7. April Emissions

April 2020	**2352 Movements**
Emissions Type	**Ton**
NO_X	36,35
SO_X	19,94
CO_2	2.221,36
VOC	0,64
PM	1,28
CO	1,73
Total	**2.281,34**

With 2598 port towage activities in May 2020, 3,741,120 kWh of energy was consumed and a total of 2,519.95 tonnes of emissions including 40.16 tonnes of NO_X, 22.03 tonnes of SO_X, 2,453.7 tonnes of CO_2, 0.71 tonnes of VOC, 1.42 tonnes of PM, and 1.91 tonnes of CO were released as can be seen in Table 8.

Table -8. May Emissions

May 2020	**2598 Movements**
Emissions Type	**Ton**
NO_X	40,16
SO_X	22,03
CO_2	2.453,7
VOC	0,71
PM	1,42
CO	1,91
Total	**2.519,95**

Table 9 shows ship generated CO2 emissions in the same region. In the doctoral thesis study from which this study is derived, CO_2 emissions were 259,812 tonnes per year and 7,398.88 tonnes per quarter, 254,261 tonnes per year in the study by Kılıç and Deniz, and 134,120.8 tonnes per year in the study by Ekmekçioğlu in Kocaeli Port.

Table 9. Emissions Values from the Present Study and Earlier Studies (Ekmekçioğlu et al., 2020; Kiliç-Deniz, 2009)

Study	Source	Area	Time	Emissions
This study, 2023	Ships	Izmit Bay	1 year (2020)	297.773 ton CO_2
Kılıç ve Deniz, 2007	Ships	İzmit Bay	1 year (2005)	254.261 ton CO2
Ekmekçioğlu,2020	Ships	Kocaeli Port	1 year (09.17-09.18)	134.120,8 ton CO2
This study 2023	Port tug	Izmit Bay	3 months (03-05.2020)	7.398,88 ton CO2

Figure 4 shows the average percentage and type of pollutants in the unit emission amount. Approximately 97% of the pollutant emission mass consists of carbon dioxide (CO_2), 2% nitrogen oxides (NO_X), 1% sulphur oxides (SO_X), 0.8% carbon monoxide (CO), 0.7% particulate matter (PM), and 0.5% volatile organic compounds (VOC). Finally, carbon dioxide (CO_2) is the most produced type of exhaust emission on a mass basis.

The ship-based CO_2 emissions of Izmit Bay in 2019 were divided by 3 months to compare with the tug emissions of the same year, and the result was 64,953 tonnes. Figure 5 shows that port tug emissions constitute 10% among all ship emissions. A similar study commissioned by the European Commission found that port tugs have an average share of 8-14% among all ship emissions (European Commission, 2017b).

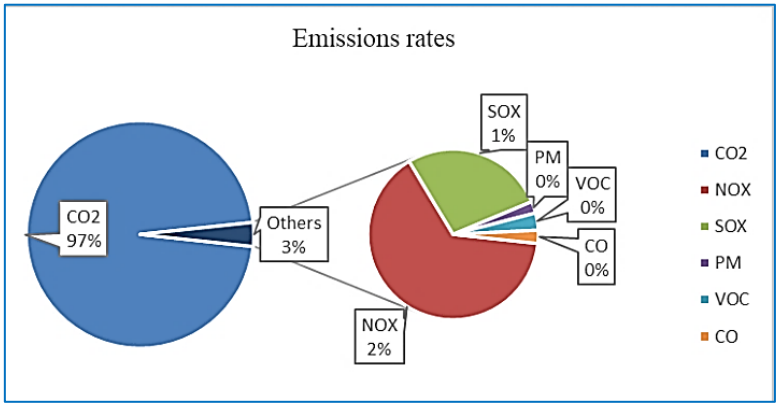

Fig. -4. Ship Emissions Type Ratio (Source: This Study)

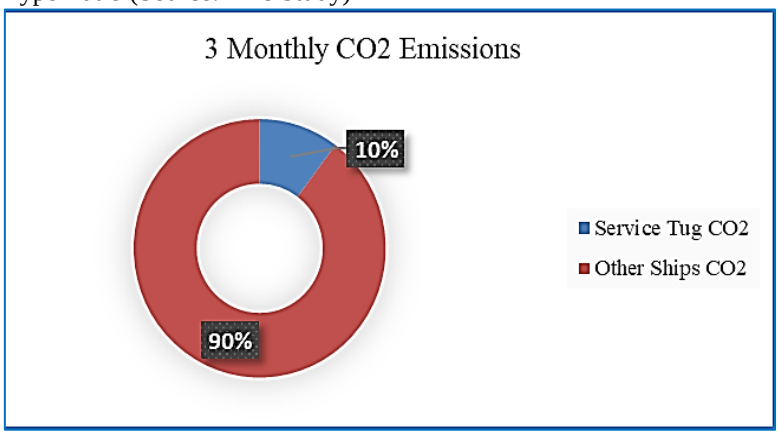

Fig. -5. Emission Rates (Source: This Study)

Discussion and Conclusion

Port tugs, which contain powerful machines that enable ships to perform port operations safely, are one of the serious emission sources for port areas. With this study, as a first in the literature, the emissions of port tugboats in the Gulf of Izmit, where Turkey's largest maritime activities are carried out, were examined. In this research, carbon dioxide (CO_2), nitrogen oxides (NO_X), sulphur oxides (SO_X), particulate matter (PM), volatile organic compounds (VOC), and carbon monoxide (CO) pollutants from port tugs performing a total of 7834 port operations in March, April, and May 2020 in Izmit Bay were studied separately and it was calculated that they produced 7,598.65 tonnes of pollutant emissions in total. A comparison of emission values in similar regions and studies shows that port tug emissions have an average share of 10% among all ship emissions for port areas. The effects of tugboats on emission pollution have not been studied in the literature. For this reason, this study will form a basis for ongoing studies with a much longer time series in terms of terms and periods. Therefore, it is necessary to consider port tugs within the scope of monitoring ship exhaust emissions and taking mitigation measures.

In this context, various measures can be taken to reduce the exhaust emissions of port tugs. Measures such as improvements in fuel content, use of methanol fuel, refinement processes in fuel components, use of dual fuel machines, operational improvements, use of hybrid machine systems, use of fuel cells, and declaration of emission control areas are the main ones (National Aeronautics and Space Administration - NASA, 2022; ISO 8217 Bunker Standart, 2017; Türk Loydu, 2023). Future long-term studies for monitoring ship traffic, which shows an upward trend in the region, and the related port tug movements, will provide projections on port tug emissions.

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