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Analyzing the Shipping Emissions in Port of Ereğli and Examining the Contribution of SO_X Emissions Reduction to the Port Emissions

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ABSTRACT:
As of January 1, 2020, the sulfur content in the fuel will be reduced from 3.5% to 0.50% within the scope of the measures implemented by International Maritime Organization (IMO), and ships will use fuel with this rate of sulfur. With this practice, the harmful effects of SO_X and PM emissions from ships on the environment and people will be reduced. The shipping emissions in the port of Ereğli were evaluated based on ship activity-based methods and total emissions generated from ships were 505 t y^{-1} for SO_X, 70 t y^{-1} for PM, 1.281 t y^{-1} for NO_X, 67.639 t y^{-1} for CO_2, 49 t y^{-1} for VOC for the year of 2019. General cargo and bulk carrier vessels are the main polluters in the port and they are responsible for 95% of all shipping emissions. Shipping emissions are generally produced at cruising mode (83%), followed by hoteling mode (16%). The environmental cost of the shipping emissions for each pollutant has been predicted as $41,5 million and $58.734 per ship call. In this study, it has been observed that with the implementation of SO_X reduction since 2020, PM and SO_X emissions will decrease properly and fall to tolerable levels for human and environmental health in the port of Ereğli.

KEYWORDS: Port of Ereğli, Environmental pollution, Shipping Emissions, Sulphur reduction, Environmental cost.

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Ereğli Limanı'ndaki Gemi Kaynaklı Emisyonların Analizi ve SO_X Emisyonlarının Azaltılmasının Liman Emisyonlarına Katkısının İncelenmesi

ÖZ:

1 Ocak 2020 itibariyle, Uluslararası Denizcilik Örgütü (IMO) tarafından alınan tedbirler kapsamında gemilerin kullandıkları yakıtların kükürt içeriği %3,5'ten %0,5'ye düşürülmüş ve gemiler tarafindan düşük kükürt oranına sahip yakıtlar kullanılmaya başlanmıştır. Bu uygulama ile gemilerden kaynaklanan SO_X ve PM emisyonlarının çevre ve insan sağlığı üzerindeki zararlı etkileri azaltılmış olunacaktır. Bu kapsamda, Ereğli limanını ziyaret eden gemilerin emisyonları 2019 yılı için hesaplanmış ve yıllık toplam emisyon SO_X için 505 ton, PM için 70 ton, NO_X için 1.281 ton, CO_2 için 67.639 ton ve VOC için 49 ton olarak bulunmuştur. Limandaki ana kirletici gemi tipleri, genel kargo ve dökme yük gemileri olup, limandaki tüm gemi kaynaklı emisyonların %95'inden sorumludurlar. Gemi emisyonları en çok seyir modunda (%83), ardından liman modunda (%16) üretilmektedir. Liman bölgesindeki kirletici emisyonların oluşturduğu çevresel maliyetin, toplam 41,5 milyon $ olacağı hesaplanmış ve gemi başına çevresel maliyetin ortalama 58.734 $ olacağı öngörülmüştür. Bu çalışmada, 2020 yılından itibaren uygulamaya giren SO_X azaltımının, Ereğli limanında PM ve SO_X emisyonlarını azaltacağı, insan ve çevre sağlığı için kabul edilebilir seviyelere düşeceği gözlemlenmiştir.

Anahtar Kelimeler: Ereğli Limanı, Çevre Kirliliği, Emisyonlar, Sülfür Azaltımı, Çevresel Maliyet.

INTRODUCTION:

The International Maritime Organization (IMO) has presented new regulations to prevent exhaust gas emissions emitted from vessels and implemented Annex VI to the MARPOL 73/78 Convention. The new regulations cover all vessels navigating at international waters with a tonnage of 400 GRT and larger. There are numerous new practices put into force by IMO under Annex VI. Generally, these practices can be specified as;

a) Emission Control Areas (ECA) and Sulphur Emission Control Areas (SECA) have been created and ship-induced emissions were limited to certain limits for ships navigating these areas.

b) Nitrogen oxides (NO_X) produced from ships are controlled through tiers within the limits set by years (IMO, 2009).

c) Sulfur content in ship fuels should not exceed 0.1% and limits to be applied by years are regulated by rule 14. In Sulphur Emission Control Areas (SECA), ships will use sulfur in fuel according to these limits (IMO, 2008).

The use of marine diesel oil (MDO) in SECA is recommended by IMO. The limits to which SO_X reduction within the scope of MARPOL Annex VI will be implemented over the years are shown in Fig. 1 (IMO, 2009). From 1 January 2012 to 2020, the sulfur content in fuel will be used globally with a maximum rate of 3.50% and from 1 January 2020, the sulfur content in fuel will be 0.50% (IMO, 2008). In the SECA region, ships will gradually reduce the sulfur content in their fuels until 2015 and they will use zero-sulfur fuels starting from 2015. With all these practices, IMO has focused on reducing green gas emissions from shipping for all existing vessels that damage human health and nature, and aims to ensure that new-built ships are energy efficient.

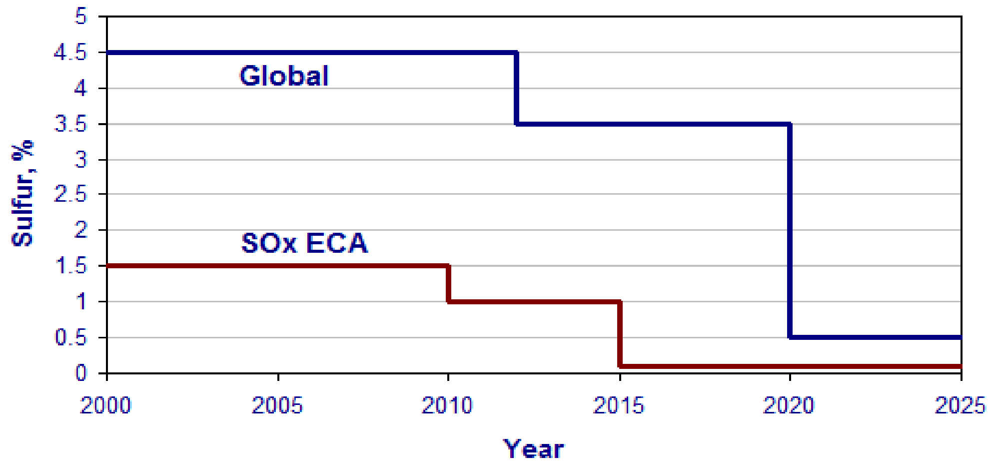

Figure 1. Marpol Annex VI SO_X limits (IMO, 2009)

A considerable amount of literature has examined emissions generated from shipping and port emissions such as; Buhaug et al. (2009); Endresen et al. (2003); Eyring et al. (2009); Corbett et al. (2007); Cohen et al. (2005); Cofala et al. (2007); Wang et al. (2008); Deniz and Kilic (2009); EEA (2013); Viana et al. (2014); Tokuslu (2019); Bayirhan et al. (2019); Mersin et al. (2019); Saracoglu et al. (2013); Lonati et al. (2010); Goldsworthy and Goldsworthy (2015); Popa and Florin (2014); López-Aparicio et al. (2017); Song (2014); Yang (2007), Tokuslu (2020) and these studies have underlined that ship-borne air emissions have negative effects on human health and environment and necessary measures should be taken to reduce their effects.

Although there are many studies on port emissions, there is no research on the Eregli port emissions so far. Port emissions are also one of the main contamination sources in the Eregli district and should be surveyed in this context. In this study, the port emissions generated from ships in the port of Eregli were assessed based on ship activity-based method and as of January 1, 2020, analyses were made according to reducing the sulfur content that can be used in fuel from 3.5% to 0.5%. The aim of this study is to calculate the emissions that will occur in Eregli port before and after the SO_X reduction comes into effect and to examine the effect of SO_X reduction in this context. This study focuces on only port emissions generated from ships and doesn`t engage with other district emisssions (residential heating, road traffic, and industry).

MATERIALS AND METHODS

1. Study Area

The port is located in the Ereğli district center of the city of Zonguldak and is 48 km from the city of Zonguldak. (Fig. 2). The port of Eregli is the gateway to the world from the Black Sea to Turkey (Erdemir, 2020). The port of Ereğli, especially in coal and bulk cargo such as ore is one of Turkey's largest ports. There are three ports in the region such as Erdemir port, municipal port, and military port and the area where the emission estimation is made includes Erdemir port. Only the Erdemir port functions for commercial purposes and hosts commercial ships. Erdemir port is operated by the ERDEMIR (Ereğli Demir ve Çelik Fab.T.A.Ş) (Erdemir, 2020). The port hosts bulk carrier, general cargo, tanker, container, chemicals, ro-ro cargo, and ferries. Its capacity is 13.750.000 tons of bulk dry cargo, 6.250.000 tons of general cargo. The total port area is 750.000 m2, covered porch is 3.000 m2. The port has 8 docks that deliver loading and unloading activities between the vessels and the shore with a total length of 1.670 meters (Erdemir, 2020).

Figure 2. The Port of Ereğli

2. Calculation Method

Port emissions generated from vessels are generally calculated with the up-down approach based on ship activity-based methods. In this study, Entec Uk Limited methodology, which is one of the bottom-up approaches in the literature, was used to evaluate the emissions in the port of Ereğli. The shipping emissions in the port of Eregli can be assessed with equations (1,2,3) as follows;

$$E_{cruising} = D * [[ME * LF_{ME}] + [AE * LF_{AE}]] * EF_{cruising} / V) \quad (1)$$

$$E_{manoeuvring} = T * [[ME * LF_{ME}] + [AE * LF_{AE}]] * EF_{manoeuvring} \quad (2)$$

$$E_{hotelling} = T * AE * LF_{AE} * EF_{hotelling} \quad (3)$$

$E_{cruising,\ maneuvering,\ hotelling}$ is the emissions of pollutants (NO_X, CO_2, VOC, PM, and SO_X) during cruising, maneuvering, and hotelling modes (units: tonne), D is the vessel cruising distance (units: mile), ME is the power of the main engine (units: kW), LF_{ME} is the main engine load factor (units: %), AE is the power of the auxiliary engine (units: kW), LF_{AE} is the auxiliary engine load factor (units: %), EF is the emission factors according to operational modes (cruising, maneuvering, hotelling), V is the speed of the vessel (units: knots) and T is the times of maneuvering and hotelling activities (units: hour).

The information to be used in the methodology such as the type of vessel, tonnage, speed, operation times were attained from the harbor authority. The total cruising distance from the port of Eregli is 20 nm since this distance is the low-speed zone and the pilotage and it was determined according to navigational routes by using the navigational charts of the port. Maneuvering and hotelling mode times were considered in hours (Entec, 2005). The average time for maneuvering for all types of hosted vessels is 1 hour and hotelling times of every vessel's calls were 38 hours for tanker and chemical, 14 hours for the container, 52 hours for general cargo, bulk carrier and 27 hours for other vessels (support vessel, research, multipurpose vessel, cable layer, etc) respectively. Table 1 displays the emission factors of operational modes (Entec, 2002; Entec, 2005; Entec, 2007) for every type of vessel. The SO_2 emissions differ depending on the sulfur content of the fuel consumed. Vessels are assumed to use MDO (Marine Diesel Oil) for main and auxiliary engines in all modes of operation (cruising, maneuvering, and hotelling) in the vicinity of the Iskenderun Gulf since it is hard to find the type of fuel used in operation modes by ships.

Table 1. Emission factors according to the type of vessels (g/kWh) (C: Cruising, M: Maneuvering, H: Hotelling)

Types of	NO_X	SO_X	CO_2	VOC	PM

Vessel	C	M	H	C	M	H	C	M	H	C	M	H	C	M	H
Liquefied Gas	8	8.9	8.8	12.4	12.5	6.9	816	818	795	0.31	0.67	0.6	1.03	1.55	1.2
Chemical	14.6	11.9	11.6	11	12.2	5.7	650	715	698	0.55	1.04	1	1.34	1.6	1.2
Oil	13.3	11.2	11	11.7	12.7	7.8	690	745	730	0.5	1.1	1.1	1.43	1.82	1.5
Bulk Dry	15.9	12.6	11.5	10.6	11.9	1.6	627	698	690	0.59	1.3	0.5	1.61	1.84	0.5
General Cargo	14.5	11.9	11.4	10.9	12.1	1.2	649	715	691	0.54	1.03	0.5	1.28	1.59	0.4
Container	15.5	12.3	11.4	10.8	12	1.4	635	705	690	0.57	1.19	0.5	1.56	1.73	0.5
Ro-Ro Cargo	13.7	11.5	11.3	11.1	12.2	1.3	655	719	692	0.52	1.06	0.5	1.17	1.68	0.5
Passenger	11.9	10.6	11.2	11.8	12.6	1.5	697	747	696	0.46	0.97	0.5	0.81	1.71	0.5

The main and auxiliary engine load factors are used as 80% for LF_{ME}, 30% for LF_{AE} in cruising mode, 20% for LF_{ME}, 50% for LF_{AE} in maneuvering mode, 20% for LF_{ME}, 40% for LF_{AE} in hotelling mode (except tankers), and 20% for LF_{ME}, 60% for LF_{AE} in hotelling mode (for tankers) (Entec, 2005; Entec, 2007). Port calling statistics do not contain the main and auxiliary engine power of vessels. As it is difficult to find the actual engine details and the speed of the ships, the main and auxiliary engine powers and cruising speeds of the ships are accepted as shown in Table 2 (Lavender et al., 2006)

Table 2. Main and auxiliary engine powers of vessels and cruising speeds (Lavender et al., 2006)

Type of Vessel	Speed Factor (knots)	Estimated Main Engine Power kW (total power of all engines)						Estimated Auxiliary Engine Power kW (medium speed)					
		<500 GRT	500-999 GRT	1000-4999 GRT	5000-9999 GRT	10000-49999 GRT	>= 50000 GRT	<500 GRT	500-999 GRT	1000-4999 GRT	5000-9999 GRT	10000-49999 GRT	>= 50000 GRT
Liquified Gas	16	650	700	2250	5350	11600	15200	75	100	125	300	400	1000
Chemical	15	1000	-	2000	5000	10250	-	40	50	165	300	435	-
Tanker	14	600	950	2200	4300	9600	17200	40	50	165	300	435	530
Bulk Carrier	14	550	750	2700	5000	8800	17000	20	40	175	300	380	500
General Cargo	14	550	950	1800	5500	8500	-	20	40	175	300	380	-
Container	20	1000	1750	2950	6000	17200	35000	40	60	160	500	1400	1400
Ro-Ro Cargo	18	1500	1900	4300	7200	11600	12550	100	150	350	1000	2500	4000
Other Vessels	15	900	1200	2400	6200	9900	18700	50	80	200	450	900	1750

3. Vessel Activities

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The vessel activities in the port of Ereğli between 2011 and 2019 is demonstrated in Fig. 3 (TDGCS, 2020). The total amount of vessels staying in the port was the highest (1302 vessel) in 2011 and on average 960 vessels call the port annually.

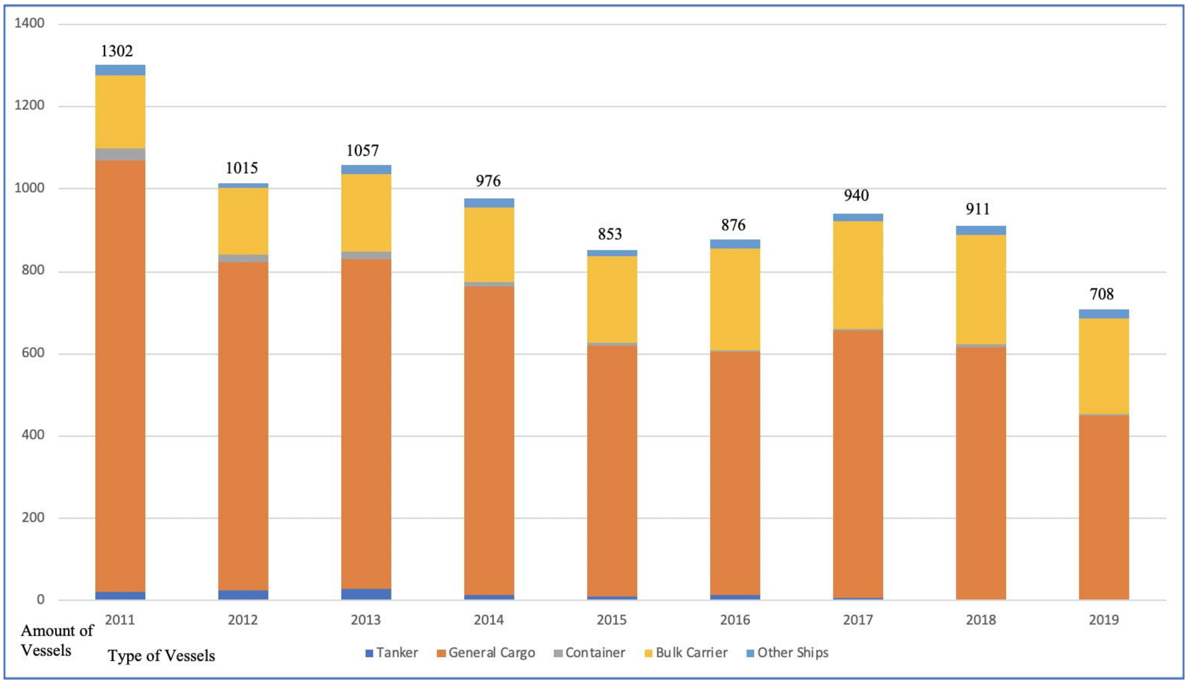


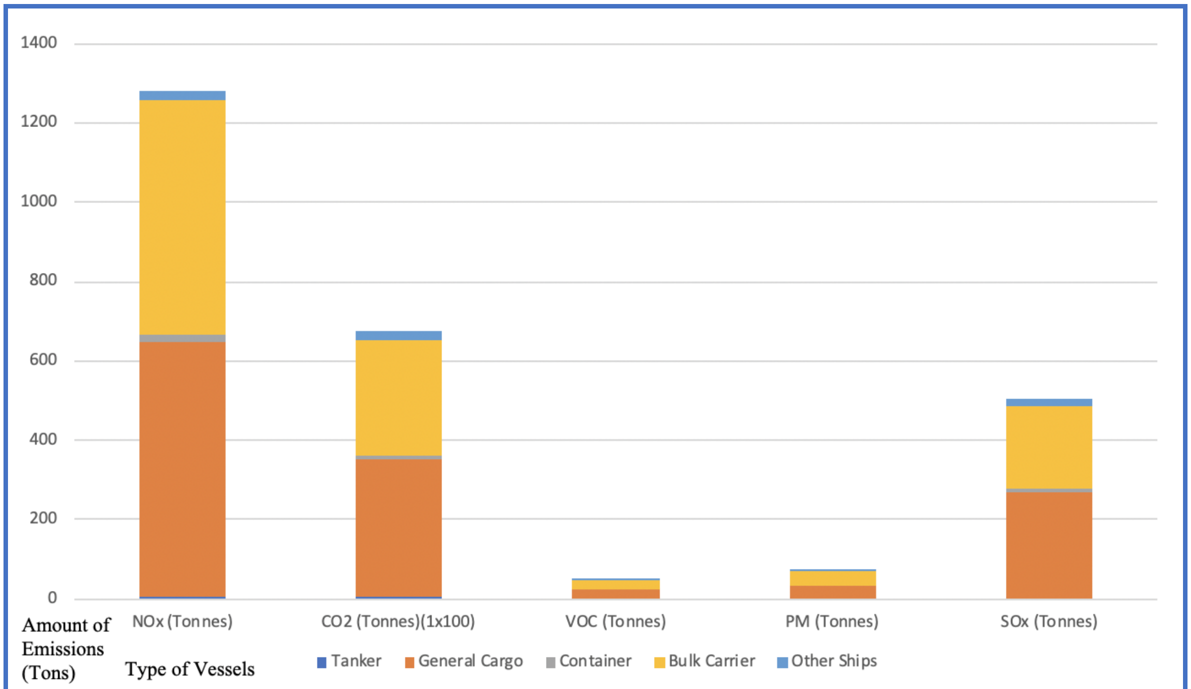
Figure 3. Vessel Activities in the Port of Ereğli

The port generally welcomes five types of vessels such as general cargo (63%), bulk carrier (33%), container (1%), tanker (1%), and other ships (2%) annually. There has been a decrease in the number of vessels visiting the port since 2011. It is believed that the number of vessels visiting the port will decrease further in 2020 and later years.

RESULTS AND DISCUSSION

1. Port Emissions

In this study, port emissions generated from ships during operational modes (cruising, maneuvering, and hotelling) were estimated based on ship activity-based methods. Total port emissions from visiting vessels were assessed as 505 $t\ y^{-1}$ for SO_X, 70 $t\ y^{-1}$ for PM, 1.281 $t\ y^{-1}$ for NO_X, 67.639 $t\ y^{-1}$ for CO_2, 49 $t\ y^{-1}$ for VOC for 2019. Annual emissions according to vessel types is presented in Fig. 4. General cargo and bulk carrier vessels produce the maximum level of emissions in the port and they generate 95% of all the port emissions. Containers, tankers, and other ships such as research, support, multipurpose, and cable layer generate 5% of the remaining emissions. The present findings seem to be consistent with other studies presented by Deniz and Kilic (2009); Popa and Florin (2014); Saracoglu et al. (2013) which found that general cargo is the main emitters in the studied harbors.



Type of Vessels	NOx (Tonnes)	CO2 (Tonnes)	VOC (Tonnes)	PM (Tonnes)	SOx (Tonnes)
Tanker	6	377	0,5	1	3
General Cargo	643	35040	24	33	265
Container	18	898	1	1	8
Bulk Carrier	589	29133	22,5	34	212
Other Ships	25	2191	1	1	17
TOTAL	1281	67639	49	70	505

Figure 4. Annual Releases According to Vessel Types

The cruise mode emissions are higher than the hotelling and maneuvering modes since the vessels cruise 20 miles before approaching the port. Fig. 5 explains the operational modes of emissions. Cruising mode emissions comprise 83% of all emissions, 16% of hotelling mode emissions, and 1% of maneuvering mode emissions.

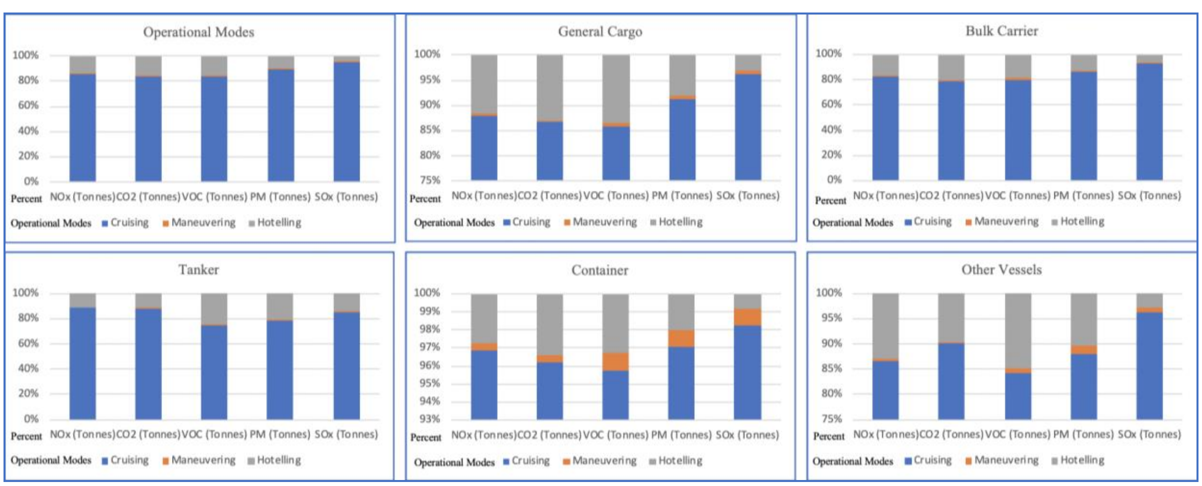


Figure 5. The Operational Modes Emissions

The emission similarity of Ereğli port with other ports is shown in Table 3 and it can be decided that Ereğli port can be considered as a minimal scale harbor on a global scale.

Table 3. Comparision of Port Emissions

Ports	**Study year**	**Hosted Number of Ships**	**NOx (ton y^{-1})**	**CO_2 (ton y^{-1})**	**PM (ton y^{-1})**	**SO_X (ton y^{-1})**	**Source**
Ambarlı Port, Turkey	2005	5.432	845	78.590	36	242	Deniz and Kilic, 2009
The Port of Oslo, Norway	2013	3.004	759	56.289	18	260	Lopez-Aparicio et al., 2015
Izmir Port, Turkey	2007	2.806	1.923	82.753	165	1.405	Saraçoğlu et al., 2013
Port of Oakland, USA	2012	1.916	2.591	133.005	67	289	EIC, 2012
Shanghai Port, China	2003	1.280	397	-	221	56	Yang et al., 2007
Yangshan Port, China	2009	6.518	10.758	578.444	859	1.136	Song, 2014
Las Palmas Port, Spain	2011	3.183	4.237	208.697	338	1.420	Tichavska and Tovar, 2015
The Port of Ereğli, Turkey	2019	708	1.281	67.639	70	505	This Study

2. Environmental Costs

The environmental cost of the port of Ereğli shipping emissions for each pollutant has been assessed for 2019 based on bottom-up approach (Realise, 2004; Bickel, 2006). Total environmental costs were $41,5 million and $58.734 per ship call (Table 4).

Table 4. Environmental costs of the Port of Ereğli

Pollutants	**NO_X**	**CO_2**	**VOC**	**PM**	**SO_X**	**Total Environmental Costs**
Environmental cost (Lee et al., 2010)	4.992 $/ton	26 $/ton	1.390 $/ton	375.888 $/ton	13.960 $/ton	-
The amount of port emissions	1.281 tons	67.639 tons	49 tons	70 tons	505 tons	-
Total environmental costs	6.394.752$	1.758.614$	68.110$	26.312.160$	7.049.800$	41.583.436$

Although the amount of PM emissions indicates the least amount of pollutants, its environmental cost per unit is relatively high compared to the costs of other pollutants. Cleaning the PM pollution from the air comprises most of the environmental cost. Even though CO_2 emissions have the maximum pollution amount, it has the minimum environmental cost compared to other emissions (except VOC). These results can be matched with other environmental costs. Berechman and Tseng (2010) estimated the environmental costs of Kaohsiung port as $123 million per year. Maragkogianni and Papaefthimiou (2015) projected the emissions of cruise vessels staying in Greece seaports such as Piraeus, Santorini, Mykonos, Corfu, and Katakolo as €24.25 million. Song (2014) valued the social cost and eco-efficiency of the Shanghai Yangshan port and they predicted the total social cost as $287 million and eco-efficiency performance was $36,528.

3. SO_X Reduction

The decrease in the number of ships that started in 2011 continues every year. With the implementation of SO_X reduction in 2020, a considerable reduction will be made in SO_X and PM emissions. SO_X and PM emissions have a dangerous influence on people's health and should be monitored regularly. As of 01 January 2020, vessels navigating international cruises with the tonnage of 400 GRT and greater will consume fuels with a reduced rate of sulfur content from 3.5% to 0.5 %. Shipping emission results according to the sulfur reduction are displayed in Fig. 6. PM and SO_X emissions, which have a direct harmful effect on people's health, are decreasing as they should, dropping to tolerable levels, according to new emissions study. There are no differences in other emissions (NO_X, CO_2, and VOC) scores. It is assessed that it is necessary to check whether the ships using the port of Ereğli comply with the SO_X reduction measures as of 2020.

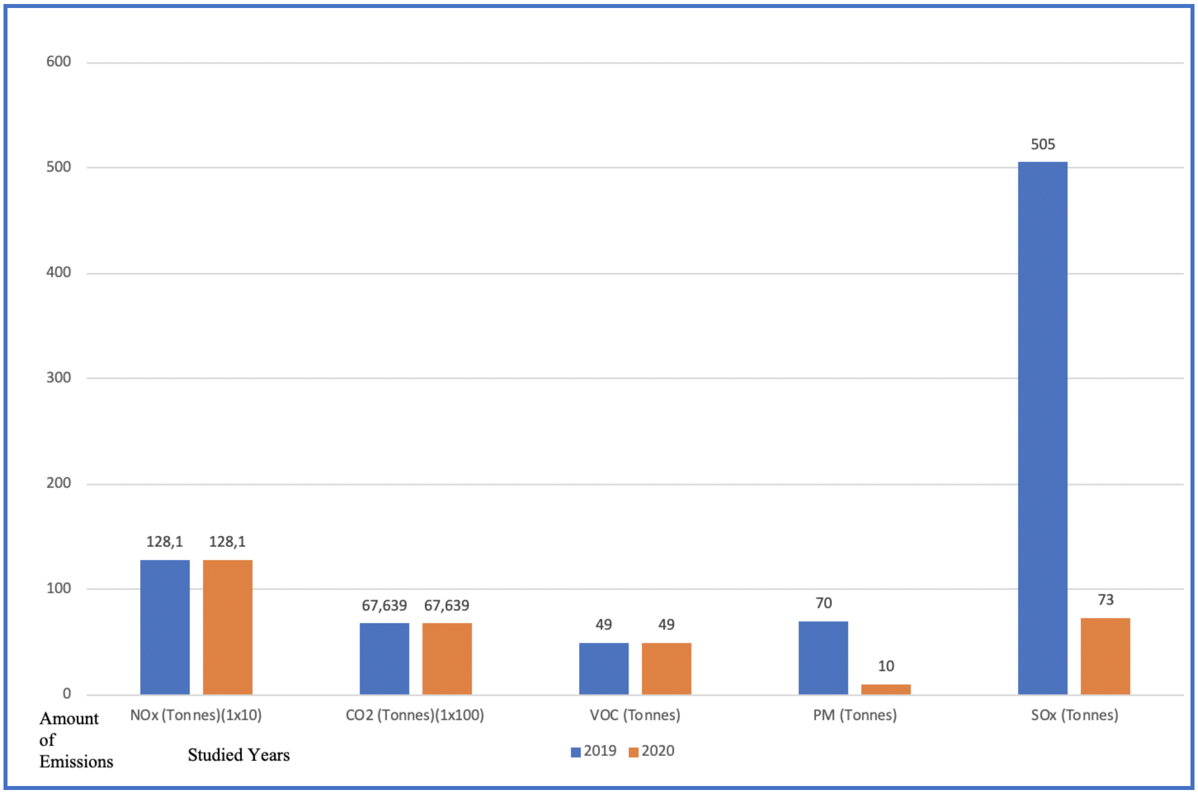


Figure 6. Shipping emission results according to the sulfur reduction

CONCLUSIONS

The shipping emissions in the port of Ereğli were assessed as 505 t y^{-1} for SO_X, 70 t y^{-1} for PM, 1.281 t y^{-1} for NO_X, 67.639 t y^{-1} for CO_2, 49 t y^{-1} for VOC. General cargo and bulk carrier vessels are blameable for 95% of all shipping emissions in the harbor, and container, tanker, tugs, etc track it. Shipping emissions are generally discharged at cruising mode (83%), followed by hotelling mode (16%). Hotelling mode emissions are greater than the maneuvering mode emissions (1%) since hotelling actions are longer than the maneuvering actions. As of January 1, 2020, the sulfur content in fuel will reduce from 3.5% to 0.5%. In this study, the emissions that will occur in the port of Ereğli before and after SO_X reduction takes effect in 2020 were calculated and the rate of SO_X reduction is analyzed. It has been observed that with the implementation of the SO_X reduction, PM and SO_X emissions have been decreased properly and reduced to tolerable levels with the SO_X practices. It is assessed that it is necessary to check whether the ships using the port of Ereğli comply with the SO_X reduction measures as of 2020.

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