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Research Article

Analysing shipping emissions of Turkish ports in the Black Sea and investigating their contributions to Black Sea emissions

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Abstract

The Black Sea is the crossroads for many nations and the economic interests of numerous countries. The ports in the Black Sea are the most important economic activity centres where the Black Sea countries carry out their import and export activities. In this paper, shipping emissions generated from ships visiting the 10 Turkish ports located in the Black Sea were estimated and their ratio in shipping emissions in the Black Sea region was evaluated. Total emissions from ships in the studied ports were estimated as 4.949 t y^{-1} for NO_X, 280.498 t y^{-1} for CO_2, 2.059 t y^{-1} for SO_2, 197 t y^{-1} for VOC, 260 t y^{-1} for PM for 2018 based on ship activity-based method. General cargo and tanker ships were responsible for 92% of the total ship-borne emissions in the region, and chemicals, bulk carrier, passenger/ro-ro cargo, and other ships such as tugs, barge, multi-purpose ships, yachts, warships follow it. Emissions produced from ships were mainly emitted at cruising mode (84%), followed by hotelling mode (15%). The environmental cost of the port emissions for each pollutant was estimated as $61,5 million and $6.164 per ship call. Black Sea shipping emissions were 2,5% of the total international shipping emissions and shipping emissions from Turkish ports constitute 6-7% of PM, 14% of CO_2, 6-14% of SO_2, and 11-20% of NO_X emissions of Black Sea emissions. The Black Sea region should be declared as an emission control area/sulphur emission control area to reduce shipping emissions. This is the first study to estimate Turkish port emissions in the Black Sea.

Keywords: Black Sea, emissions inventory, environmental costs, environmental pollution, shipping emissions

Introduction

The Black Sea, being one of the most important inland seas of the world, has an important place in the maritime trade between East and West since ancient times due to its location between Europe and Asia. It is the crossroads for many nations and the economic interests of numerous countries. The maritime trade worth a level of 113.5 billion dollars in the Black Sea (Helbing, 2014). The ports in the Black Sea are the most important economic activity centres where the Black Sea countries carry out their import and export activities, and these ports are generally container, tanker, and general cargo handling ports. The Turkish ports at the Black Sea mostly offer territorial cargo volumes like copper, coal, fertilizer, construction products, and lumber (Şengonul and Esmer, 2016). After the implementation of the energy project (Baku-Tbilisi-Ceyhan pipeline) and the ancient silk road (Baku-Tbilisi-Kars), the number of ships passing through the Bosphorus to the Black Sea decreased while the number of ships with larger tonnages increased at the same level (Tokuslu, 2019). The number of transit ships passing through the Istanbul Strait to the Black Sea for years was shown in Figure 1 (TDGCS, 2019). Since 2007, there has been a decrease in the number of transit ships crossing the Black Sea.

There are a limited number of studies investigating the emissions in the Black Sea region. These studies are at a global level and the total emission estimation has been made for the Black Sea and other regions (North Sea, Mediterranean, Baltic Sea, and NE Atlantic). These estimations are the most important studies conducted for the Black Sea and other regions so far. The amount of ship emissions in the region does not change with the fact that the Black Sea is an inland sea and there is not much-changed ship movement in the region (Cofala et al. (2007), IIASA (2007), Tokuslu et al. (2020), Tokuslu and Burak (2021).

These global studies are carried out by Cofala et al. (2007), Chiffi et al. (2007), and IIASA (2007). They reached that Black Sea shipping emissions are 2,5% of the total international shipping emissions. Black Sea shipping emissions are shown in Table 1.

Table 1. Black Sea shipping emissions (tons/year)

Year	CO_2	SO_2	NO_X	PM	Source
2000	3.721.000	62.000	86.000	7.000	Cofala et al. (2007)
2005	-	27.000	47.000	-	Chiffi et al. (2007)
2007	3.853.000	65.000	89.000	-	IIASA (2007)

There are also local emission studies for the Black Sea ports, and these studies highlight that emissions generated from ships may negatively affect people's health, cause illness, and disturb the quality of life of people living in the harbour area. Florin and Cosofret (2013) estimated the port emissions for the port of Constanta, Alver et al. (2018) investigated the emissions from shipping in the Samsun Port in Turkey, the effects of emissions from ships visiting the Turkish ports (Zonguldak, Trabzon, Eregli, and Bartın) in the Black Sea have been investigated in detail (Tokuslu, 2020a, 2020b, 2020c, 2020d).

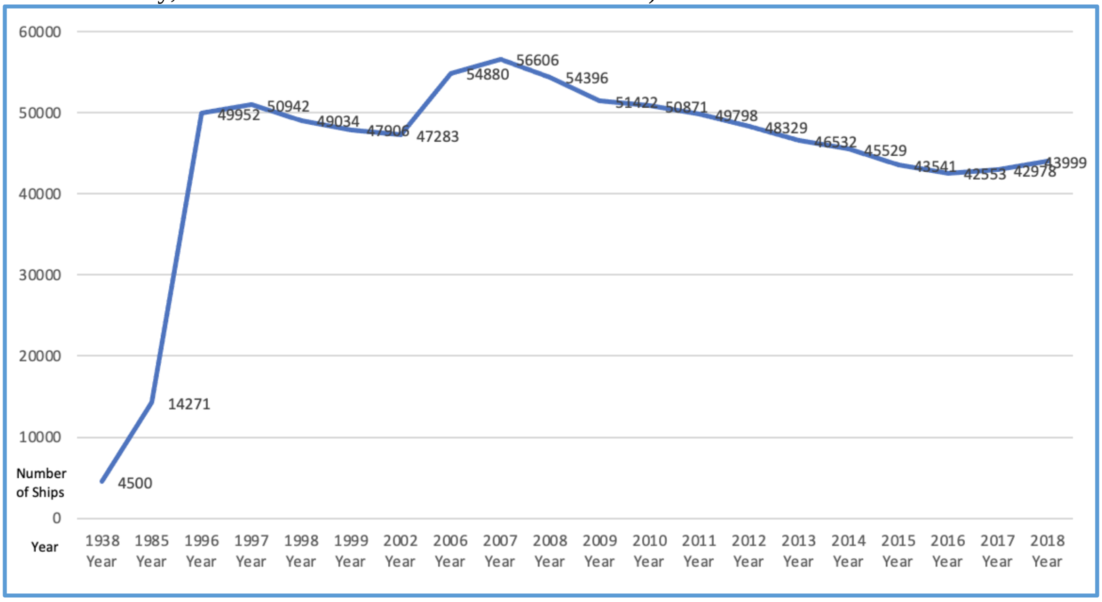

Fig. 1. The number of transit ships passing through the Istanbul Strait to the Black Sea (TDGCS, 2019).

The study aims to analyse shipping emissions generated from ships visiting the 10 Turkish ports located at the Black Sea and to explore their share in international shipping emissions in the region. In this study, 10 Turkish ports (Igneada Port, Sile Port, Amasra Port, Sinop Port, Unye Port, Fatsa Port, Giresun Port, Port of Rize, Hopa Port, and Tirebolu Port) were examined. This study will create a shipping emission inventory for the Turkish ports located in the Black Sea. This study focuses on only port emissions generated from ships and doesn`t involve other emissions (residential heating, road traffic, and industry).

Materials and Methods

Study area

There are 18 Turkish ports located at the Black Sea, and 10 of them (Igneada Port, Sile Port, Amasra Port, Sinop Port, Unye Port, Fatsa Port, Giresun Port, Port of Rize, Hopa Port, and Tirebolu Port) were examined in this study. The rest of the 3 ports (Gerze Port, Kefken Port, and Ordu Port) were disregarded since we couldn't reach the data, these ports have less than 50 ship movements in a year and their quantity will not affect the result of the study. The other 5 of the ports (Samsun port, port of Zonguldak, Trabzon port, port of Bartın and port of Ereğli) were investigated by Tokuslu (2020a, 2020b, 2020c, 2020d, 2021). Maritime trade in the Turkish Black Sea ports generally is carried out with general cargo and tanker ships. Turkish ports are crucial for maritime trade for the Black Sea region and Turkey. The location of the studied ports was shown in Figure 2.

ENTEC methodology

In this study, the Entec methodology (Entec, 2002, 2005), a bottom-up approach widely used in the literature, was chosen to estimate ship emissions on Turkish ports in the Black Sea according to the data we have. The bottom-up approach gives more accurate results in estimating emissions based on data such as engine power, load factor, ship speed, and times during operational (manoeuvring and hotelling) modes.

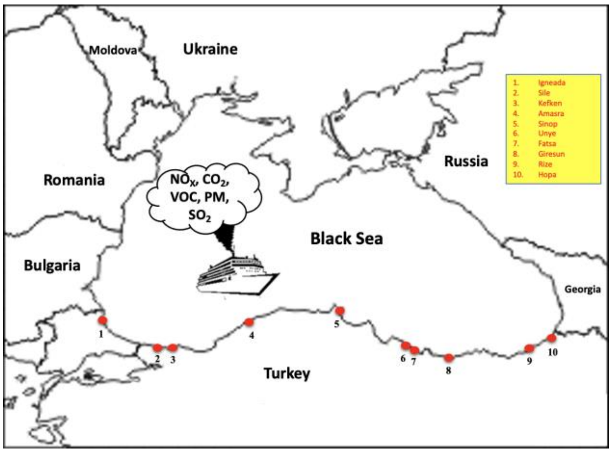

Fig. 2. The location of studied ports

Bottom-up approaches are generally limited to emission inventory analysis studies at the regional and local levels. (Bayirhan et al. 2019; Deniz et al., 2010; Entec, 2007; Kilic and Deniz, 2009; Liu et al., 2014; Ng et al., 2013; Nunes at al., 2017; Song, 2014; Tichavska and Tovar, 2015; Mersin et al., 2019-2020; Tokuslu, 2020b; Tzannatos, 2010; Yau et al., 2012; Ülker et al., 2020; Tokuslu and Burak 2021). The ship estimation equation (1,2,3) in the methodology is stated as;

$$E_{cruising} = D*[[ME * LF_{ME}]+[AE * LF_{AE}]]*EF_{cruising} /V) \quad (Eq1)$$

$$E_{manoeuvring} = T*[[ME*LF_{ME}]+[AE*LF_{AE}]]*EF_{manoeuvring} \quad (Eq2)$$

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

$E_{cruising,\ manoeuvring,\ hotelling}$ are the emissions of pollutants (NO_X, CO_2, VOC, PM, and SO_2) during cruising, manoeuvring, and hotelling modes (units: tonne), D is the 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, manoeuvring, hotelling) (units: g/kWh), V is the speed of vessel (units: knots) and T is the times (units: hours) during manoeuvring and hotelling activities.

Load factor and engine power

Load factors of the main and auxiliary engine were obtained for the operational modes of each ship (cruising, manoeuvring, hoteling) and these values are accepted as 80% for LF_{ME}, 30% for LF_{AE} in cruising mode, 20% for LF_{ME}, 50% for LF_{AE} in manoeuvring 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; 2007). The emission factors for each operational mode were presented in Table 2 (Entec 2002). Port calling data did not contain the power of the main and auxiliary engine of ships.

As it was difficult to find the actual engine details and the speed of the ships, the power of the main and auxiliary engine and cruising speeds of the ships were accepted as shown in Table 3 (Lavender et al. 2006). Lack of detailed data for vessel engines and the fuels are a source of vagueness in this study. For ships whose data we could not access, data of similar ships were used as an example in the calculation. and as a general, ships were assumed to use MDO (Marine Diesel Oil) for main and auxiliary engines in all modes of operation (cruising, manoeuvring, and hotelling).

Table 2. Emission factors (Entec 2002, 2005, 2010)

Ship Types	Emission factors (C-Cruising, M-Manoeuvring, H-Hotelling) (g/kWh)														
	NO_X			SO_2			CO_2			VOC			PM		
	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
Tanker	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

Table 3. Powers of main and auxiliary engine of ships and cruising speeds (Lavender et al. 2006)

Ship Type	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 Dry	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 Ships	15	900	1200	2400	6200	9900	18700	50	80	200	450	900	1750

Data collection and vessel movements

The data in this study including the type of ship, tonnage, position, speed, course, operation mode, and times were obtained from the Fleetmon site (Fleetmon, 2020) and the port authorities. The period covers all the ship movements of Turkish ports located at the Black Sea for the year 2018. The data of 10 Turkish ports (Igneada Port, Sile Port, Amasra Port, Sinop Port, Unye Port, Fatsa Port, Giresun Port, Port of Rize, Hopa Port, and Tirebolu Port) in the Black Sea were involved in the study. The total cruising distance from the ports 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 ports. Times during manoeuvring and hotelling modes were calculated in hours (Entec, 2005). The average time for manoeuvring for all types of hosted ships is 1 hour which implies a total time of ship arrival and departure. Hoteling times were obtained from the port authorities as it was 38 hours for a tanker and chemical, 14 hours for the container, 52 hours for general cargo, bulk carrier, and 27 hours for other ships (research, ro-ro cargo, passenger, etc) respectively.

Small ships less than 400 GT navigating in the ports were not included in the calculation, emission amounts can be neglected since their quantities are not very high. 20-25% of all visiting ships are Turkish flagged vessels, and Malta, Panama, Netherlands, China, Russia, and Liberia follow it respectively. Ship movements in the studied ports between 2011 and 2018 were demonstrated in Figure 3 (TDGCS, 2019).

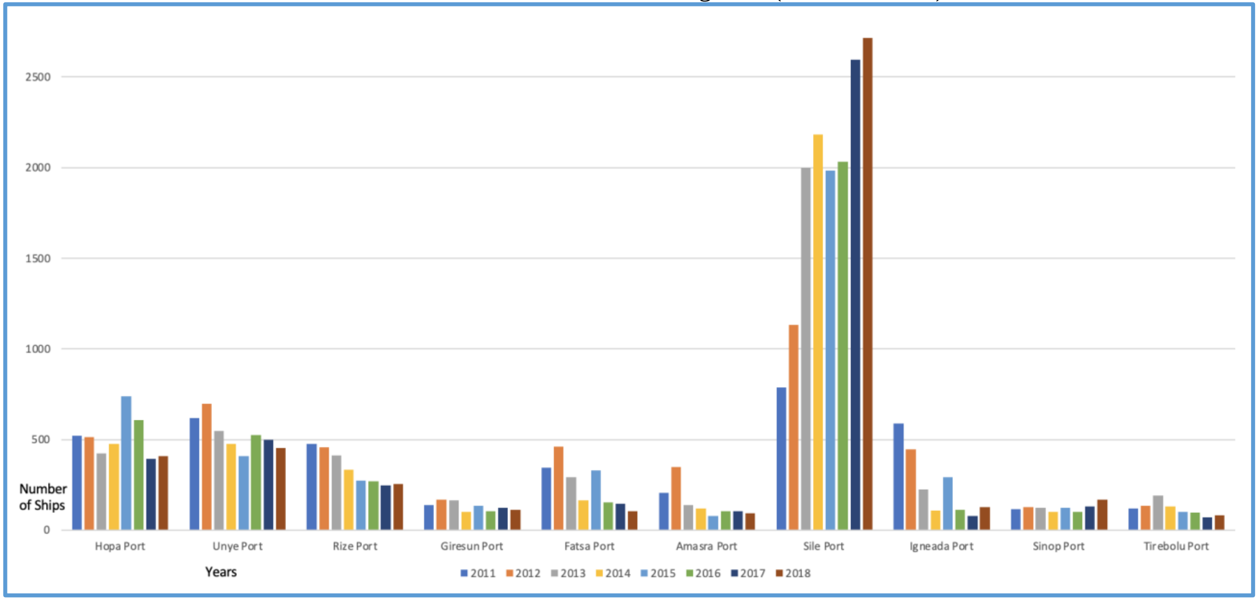

Fig. 3. Ship movements in the studied ports

Shipping traffic in the Turkish ports generally tends to increase. In 2011, 3.919 ships visited the ports, and in 2018, 4520 ships were hosted in the ports, and on average 4322 ships stayed at the ports between the years of 2011-2018. In 2018, six types of ships such as general cargo (88%), bulk carrier (1,7%), tanker (3,7%), chemical (0,5%), passenger/ro-ro cargo (2,4%), and other ships (3,7%) were hosted in the Turkish ports of Black Sea. The distribution of hosted ships in all ports was presented in Figure 4 (TDGCS, 2019). In all ports, it was observed that general cargo ships were having the most port visits and the source of the highest emissions. Tanker ships and other ships (tugs, barge, multi-purpose ships, yachts, warships) followed it respectively.

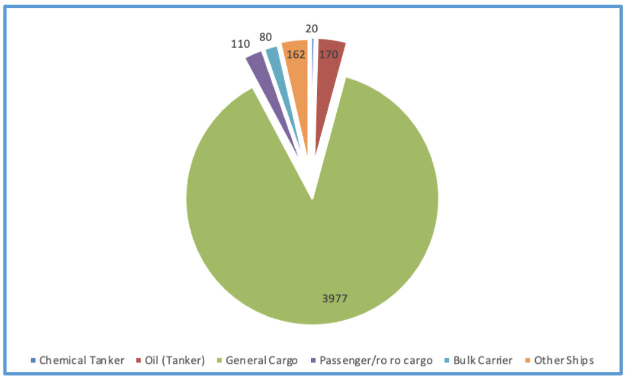

Fig. 4. The distribution of hosted ships in all ports

Results

Emissions

In this study, 10 Turkish ports emissions located in the Black Sea during operational modes (cruising, manoeuvring, and hotelling) were evaluated as 4.949 t y^{-1} for NO_X, 280.498 t y^{-1} for CO_2, 2.059 t y^{-1} for SO_2, 197 t y^{-1} for VOC, 260 t y^{-1} for PM for 2018. Annual shipping emissions of operational modes were illustrated in Table 4. The cruising mode emissions were much more than the manoeuvring and hotelling modes emissions. Cruising mode emissions were responsible for 84% of all port emissions, hotelling mode emissions are 15%, and manoeuvring mode emissions are 1% of it. 4520 ships were analysed during the port visit, including cruising, manoeuvring, and hotelling modes. Usually, hotelling mode emissions are bigger than the manoeuvring mode emissions because ships stay much more in the hotelling mode. When ships use the main engine, emissions of more than 85% and 65%, respectively, occur in cruise and manoeuvring mode, depending on the distance. However, when a ship is at hotelling mode for cargo handling, it turns off the main engine and emissions occur most often during hotelling mode when using the auxiliary engine.

Turkish flagged ships account for 25% of total emissions. General cargo and tanker ships were responsible for 92% of total shipping emissions in the studied ports and produce the highest amounts of emissions (95%). Chemicals, bulk carriers, passenger/ro-ro cargo, and other ships emit the rest of 5% of total emissions. As seen in Figure 4, general cargo and tanker ships were the ships that used the Turkish ports in the Black Sea most frequently. These results tie well with earlier studies (Alver et al., 2018; Kilic and Deniz, 2009; Popa and Florin, 2014; Saraçoglu et al., 2013; Tokuslu, 2020b) that general cargo and tanker ships were the main polluters in the studied ports.

Table 4. Annual shipping emissions of operational modes (ton/year)

	NO_X	%	CO_2	%	VOC	%	PM	%	SO_2	%
Cruising	4094	82	228283	81	153	78	220	85	1910	93
Maneuvering	23	1	1391	1	3	1	4	1	23	1
Hotelling	832	17	50824	18	41	21	36	14	126	6
Total	4949	100	280498	100	197	100	260	100	2059	100

Turkish Ports Emissions

There are main 15 Turkish ports located in the Black Sea, and these are: Igneada Port, Sile Port, Amasra Port, Sinop Port, Unye Port, Fatsa Port, Giresun Port, Port of Rize, Hopa Port, Tirebolu Port, Trabzon Port, Samsun Port, Port of Eregli, Port of Zonguldak, and Port of Bartin. The emission results of these ports were shown in Table 5.

Table 5. Turkish ports emissions (tons/year).

Ports	Ship calls	NOx	CO_2	VOC	PM	SO_2	Source
Igneada Port	127	130	7186	5	7	52	This study
Sile Port	2716	2761	151863	107	139	1097	This study
Amasra Port	92	95	5259	4	5	38	This study
Sinop Port	168	208	15273	8	9	109	This study
Unye Port	455	505	29029	20	26	205	This study
Fatsa Port	106	112	6183	5	6	45	This study
Giresun Port	113	232	14504	11	17	127	This study
Port of Rize	253	269	15232	11	14	111	This study
Hopa Port	407	460	25032	18	24	179	This study
Tirebolu Port	83	177	10937	8	13	96	This study
Port of Zonguldak	615	820	45700	32	44	350	Tokuslu (2020a)
Trabzon Port	679	906	52160	38	54	409	Tokuslu (2020b)
Port of Eregli	708	1281	67639	49	70	505	Tokuslu (2020c)
Port of Bartin	360	551	30347	21	28	230	Tokuslu (2020d)
Samsun Port	3088	903	51129	37	52	411	Tokuslu (2021)
Total Emissions	9970	9410	527473	374	508	3964	This study

Environmental costs

A bottom-up approach was used to calculate the environmental costs of ship emissions in the Turkish ports and the environmental costs of pollutants per tonne have been achieved from the final report of the project ExternE (EC, 2005; Bickel, 2006). The ExternE project made the parameter values of fuel consumption and emission factors in its models.

In this study, these parameter values were used for estimation. The environmental costs were calculated with the formula (Eq. 4) of (EC, 2005; Bickel, 2006) which follows as;

$$C^s = \sum_j E_j^s \times C_j^s \qquad \text{(Eq.4)}$$

where: C^s is the total environmental cost, E_j^s is the total emission volume of pollutant type j, C_j^s is the cost of pollutant type j per tonne. The environmental cost of the studied port emissions for each pollutant has been calculated for 2018 and was $61,5 million and $6.164 per ship call (Table 6).

Table 6. Environmental costs of the Turkish port emissions (in 2018)

Pollutants	*NO_X*	*CO_2*	*VOC*	*PM*	*SO_2*
Environmental cost (EC, 2005; Bickel, 2006)	4.992 $/ton	26 $/ton	1.390 $/ton	375,888 $/ton	13,960 $/ton
The amount of port emissions	9.410 tons	527.473 tons	374 tons	508 tons	3.964 tons
Environmental costs per pollutants	46.974.720$	13.714.298$	519.860$	190.951$	55.337$
Total Environmental costs	61.455.166$				

These results can be matched with other ports' emission costs. Berechman and Tseng (2010) evaluated the environmental costs of Kaohsiung port as $119,2 million per year. Maragkogianni and Papaefthimiou (2015) measured the releases of cruise vessels hosted by Greece ports such as Piraeus, Santorini, Mykonos, Corfu, and Katakolo as €24.25 million. Song (2014) estimated the Shanghai Yangshan port`s social cost and eco-efficiency and the total social cost and eco-efficiency performance was found as $287 million, $36,528 respectively. The environmental cost of the Trabzon port emissions for each pollutant has been assessed as $32 million and $47.039 per ship call (Tokuslu, 2020b).

Contribution of Turkish ports emissions to Black Sea ship emissions

Analysis of ship emissions in the Black Sea has been conducted in limited studies at the global level. These studies mainly were Cofala et al. (2007), Chiffi et al. (2007), and IIASA (2007). Black Sea shipping emissions were shown in Table 1. The contribution of Turkish ports emissions to Black Sea ship emissions was illustrated in Table 7. Shipping emissions from Turkish ports constitute 6-7% of PM, 14% of CO_2, 6-14% of SO_2, and 11-20% of NO_X emissions of Black Sea emissions.

The emission rates generated by the Turkish ports were at a level that couldn`t be neglected. One of the countries that generate the most emissions in the Black Sea was Turkey (Entec, 2005). Considering that 25% of the emissions were caused by Turkish flagged ships, it is considered that it would be beneficial to take measures for Turkish flagged and foreign-flagged ships in reducing port emissions.

Table 7. Contribution of Turkish ports emissions to Black Sea emissions (tons/year)

Year	CO_2	SO_2	NO_X	PM	Source
2000	3.721.000	62.000	86.000	7.000	Cofala et al. (2007)
2005	-	27.000	47.000	-	Chiffi et al. (2007)
2007	3.852.000	65.000	89.000	8.000	IIASA (2007)
2018	527.473	3.964	9.410	508	This study
The ratio of Turkish Ports	**14%**	**6-14%**	**11-20%**	**6-7%**	This study

Discussion and Conclusion

The air emissions generated from ships visiting the 10 Turkish ports located in the Black Sea were calculated based on ship activity-based method for the first time and total emissions were estimated as 4.949 t y^{-1} for NO_X, 280.498 t y^{-1} for CO_2, 2.059 t y^{-1} for SO_2, 197 t y^{-1} for VOC, 260 t y^{-1} for PM. General cargo and tanker ships were accountable for the 92% exhaust gas emissions in the studied ports, and chemicals, bulk carrier, passenger/ro-ro cargo, and other ships such as tugs, barge, multi-purpose ships, yachts, warships follow it.

A significant part of the ship-sourced air emissions was generated during the cruise mode of the vessels (84%). Cruising mode emissions were followed by hotelling mode emissions (15%). Hotelling mode emissions are more than the manoeuvring mode emissions (1%) since harbour handling activities were longer than the manoeuvring activities. The environmental cost of the port emissions for each pollutant was estimated as $61,5 million and $6.164 per ship call. Black Sea shipping emissions were 2,5% of the total international shipping emissions and shipping emissions from Turkish ports constitute 6-7% of PM, 14% of CO2, 6-14% of SO_2, and 11-20% of NO_X emissions of Black Sea emissions. The emission rates generated by the Turkish ports were at a level that shouldn`t be disregarded.

Turkish flagged ships accounted for 25% of total emissions. National-flagged ships should be encouraged to use scrubbers and selective catalytic reduction which are effective in lessening emissions. The Black Sea region should be declared as an emission control area/sulphur emission control area to reduce shipping emissions. The extent to which air pollution is reduced in the areas declared as emission control area/sulphur emission control area has been demonstrated by scientific studies.

This is the first study to estimate Turkish port emissions in the Black Sea. This study made some notable contributions to literature about port emissions in the Black Sea region.

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