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"Gheorghe Asachi" Technical University of Iasi, Romania

ASSESSMENT OF ENVIRONMENTAL COSTS OF SHIP EMISSIONS: CASE STUDY ON THE SAMSUN PORT

Aydin Tokuslu

Multinational Maritime Security Center of Excellence, 34330, Besiktas, Istanbul, Turkey
E-mail: aydintokuslu78@gmail.com; Phone: +90 5066905844

Abstract

The Samsun port is one of the biggest in the Black Sea and serves as an international sea trade gateway with neighbour countries. In this study, exhaust gas emissions from ships during cruising, manoeuvring, and hoteling in the Samsun port were calculated based on ship activity-based methods including ship call information. Total exhaust gas emissions from ships in the port were calculated as 51.129 t y^{-1} for CO_2, 903 t y^{-1} for NO_X, 411 t y^{-1} for SO_2, 37 t y^{-1} for VOC, 52 t y^{-1} for PM for the year of 2018. General cargo, ro-ro cargo, and tanker ships are the main polluters at the port, and these ships produce almost 91% of all emissions in the port. Exhaust gas emissions during cruising mode were 86% of total emissions, and 3% for manoeuvring, and 11% for the hotelling. Ship emissions have negative effects on human health and it has been anticipated that the emissions (SO_2, NO_X, PM) generated from the ships calling to the Samsun port will endanger around 64.000-150.000 people living within 1-2 km range from the harbour area annually. All forms of emissions close to the port and district should be examined regularly and measures to reduce exhaust gas emissions in the port area should be considered. The environmental cost of the port is estimated to be over $31 million and $10.095 per ship call in 2018. This study has concretely demonstrated for the first time that maritime emissions affect how many people in the port city. This study will help to create ship emission inventory for the Black Sea region.

Key words: emission, harbour, pollution effects, Samsun, ships

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1. Introduction

International maritime trade is becoming more and more popular every day as it is the cheapest and greenest way of transportation. The shipping sector increased its capacity every year and reached an annual growth rate of 4 percent in five years and became 10.7 billion tons sector annually (UNCTAD, 2018). To meet this demand, the number of ships increased as well and the shipping merchant fleet reached 94171 ships. Maritime merchant fleet generally cruises close to shore and emissions generated from ships are concentrated in port areas, straits, canals, inland seas, and gulfs (NRDC, 2004). While maritime trade proposes a relatively low greenhouse gas alternative for the carrying of goods (Buhaug et al., 2009), its effects on human health cannot be underestimated. Emission impacts from shipping on people health and environment have been investigated globally and regionally (Bayirhan et al., 2019; Buhaug et al., 2009; Cofala et al., 2007; Cohen et al., 2005; Corbett et al., 2007; Deniz and Kilic, 2009; EEA, 2013; Endresen et al., 2003; Eyring et al., 2009; Mersin, 2020; NRDC, 2004; Nunes et al., 2017; Tokuslu, 2019; Tokuslu et al., 2020; Viana et al., 2014; Wang et al., 2008) and they reached a consensus that ship emissions are the main source of city air pollution in harbour cities which have health and environmental impacts even if they are discharged within 400 km of shorelines. When discharging happens close to the coastline, its impacts are getting greater as well. Ports are strong sources of air pollutions that can endanger the air quality of people living in harbour cities during cruising, manoeuvring, hotelling modes. The main pollution sources from ships in port areas are nitrogen oxides, sulphur oxides, and particulate matter which can have a significant impact on human health. Port exhaust gas emissions should be analysed in this context. The relationships between maritime emissions and deaths were found (Corbett et al., 2007; Deniz and Kilic, 2009; Eyring et al., 2009) and around 60.000 cardiopulmonary, respiratory deaths and 20.000–104.000 premature deaths annually are connected with maritime emissions (PM, NO_X, SO_X). Samsun port is located on the north coast of Turkey in the Black Sea. The port is the biggest in the Black Sea and serves as an international sea trade gateway with neighbour countries such as Georgia, Russia, Ukraine, Romania, and Bulgaria. The port is very close to the city centre and its` emissions harmful effects on people`s health and environment should be examined as well.

A large and growing body of literature has investigated port emissions recently. These studies show the importance of shipborne emissions and their impacts on the environment and human health. The Izmir Port emissions using the ship activity-based methodology were examined (Saraçoğlu et al., 2013) and they found that ships making port visits in the port are having serious hazardous impacts on the Izmir city and its surroundings. Ship emission inventory based on automatic identification system (AIS) data in the Bohai Rim region in China was created (Chen et al., 2018). Ship engine exhaust emissions in 34 Australian ports were calculated by using a model (Goldsworthy and Goldsworthy, 2015) and they suggested that estimations of ship emissions within a 300 km radius of major capital cities do not have a non-negligible percentage of air pollutants. The port emissions (CO_2, CH_4, N_2O, PM_{10}, $PM_{2.5}$, NO_X, SO_X, CO, and HC) in the Yangshan port of Shanghai were estimated (Song, 2014) and the port of Constanta was analysed (Popa and Nicolae, 2014). A comprehensive emissions inventory for the port of Oslo for current and future scenarios, including compliance with environmental legislation were developed (López-Aparicio et al., 2015). The emissions of VOC associated with ship-loading operations of petroleum products in refineries were analysed, the diffusion of such pollutants for a case-study by using a proper dispersion modelling was presented and the impact of VOC concentration dispersion on human health due to the ship loadings may be considered acceptable (Milazzo et al., 2017). The effects of emissions from ships visiting the Turkish ports (Trabzon, Eregli, and Zonguldak) in the Black Sea on environmental and human health have been investigated in detail (Tokuslu, 2020a, 2020b, 2020c).

Overall, these studies highlight the need for analysing and assessing the port emissions closely which would have serious impacts on people`s health and environment and future emissions should be taken into consideration as well in this context. This study, therefore, set out a case study to assess the shipping emissions and the effect of these emissions impact on local air quality in the port of Samsun.

2. Material and methods

2.1. Study area

The city of Samsun, located on the northern coast of Turkey, comprises of several ports (Samsun port, Samsun industrial port, Yesilyurt port, Toros port) in the Black Sea (Fig. 1). In this study, vessel movements in the Samsun port were examined and its emissions were analysed. The port is one of the biggest ports in the Black Sea and plays a significant role in the Black Sea countries' economies. The port is a multipurpose port and provides services for general cargo, container, ro-ro cargo, chemical, tanker and, passenger ships with 250.000 TEU all year round and acts as the international gateway of sea trade with neighbour ports such as Georgia's port of Batumi, Poti, and Sukhumi; Russian's ports of Sochi, Tuapse, Novorossiysk, Azov Sea's ports of Azov, Taganrog, Jdanov, Yalta, Berdyansk, Genichesk; Ukraine's ports of Nikolayev, Odesa, Đlichevsk; Romania's port of Constanta and Bulgaria's port of Varna (TISC, 2019) and have connections with Istanbul and all other world ports.

The Samsun port has a railway and road connection with Black Sea countries which makes it unique in the region. The port has been strategically transformed into a world-class logistics centre on the main sea trade routes and over the years in the Black Sea and Mediterranean region and is located on the central route of the Caucasus and Central Asia.

Fig. 1. The location of the Samsun Port (TISC, 2019)

2.2. Calculation method

In most recent studies, ship emissions are calculated in two approaches which are "bottom-up" and "top-down". In this study, the bottom-up approach was used to estimate the emissions in Samsun port according to obtained data. The Entec Uk Limited methodology (Entec, 2010) was chosen to reach the real estimations of ship pollution which are used commonly in literature. The emissions generated from ships in the Samsun Port were analysed with the formula (Eqs. 1-3) of Entec Uk Limited methodology which follows as:

$$E_{cruising} = D \times [[ME \times ME_{LF}] \oplus [AE \times AE_{LF}]] \times EF_{cruising} \div V \tag{1}$$

$$E_{manoeuvring} = T \times [[ME \times ME_{LF}] \oplus [AE \times AE_{LF}]] \times EF_{manoeuvring} \tag{2}$$

$$E_{hotelling} = T \times AE \times AE_{LF} \times EF_{hotelling} \tag{3}$$

where: *D* is the distance a ship travels (units: mile); ME is the main engine power (units: kW); ME_{LF} is the load factor of the main engine (units: %); *AE* is the auxiliary engine power (units: kW); AE_{LF} is the load factor of the auxiliary engine (units: %); *EF* is the emission factor (cruising, manoeuvring, and hoteling) (units: g/kWh); *V* is the speed of ship (units: knot/hour) and *T* is the time spent at manoeuvring and hotelling (units: hour).

The data of the type of ship, tonnage value, speed, operation times were provided by port authorities. Ship speeds were obtained from the harbour authority and speed values were used (Entec, 2010) when it was not achievable to get the genuine speeds of ships. Port calling statistics do not contain the main and auxiliary engine power of ships. As it is difficult to find the actual engine details and the speed of the ships, the main and auxiliary engine powers are accepted as demonstrated by Lavender et al. (2006).

2.3. Load factors and operational modes

Load factors of the main and auxiliary engine were obtained for the operational modes of each ship (cruising, manoeuvring, hotelling) 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, 2010).

Total cruising distance for calculation is 20 nm from the Turkish coastline 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 Turkey. Times during manoeuvring and hoteling modes were calculated in hours and all data is obtained from the harbour authorities. The average time for manoeuvring for all types of visiting ships is 1 hour and hoteling times of every ship's calls were 19 hours for a tanker (oil), chemical ships, 15 hours for ro-ro cargo and container, 32 hours for general cargo, and 14 hours for passenger ships respectively. Table 1 lists the emission factors according to operational modes (Entec, 2005, 2010).

2.4. Ship movements

The ship movements and the type of ships making port visits in Samsun port between 2010 and 2018 were presented in Fig. 2 (TDGCS, 2019). The total number of ships calling at the port was the highest (3088 ship) in 2018 and on average 2600 ships visit the port annually. Generally, the port welcomes six types of ships such as chemical, tanker, general cargo, container, passenger, and ro-ro cargo annually and general cargo (53%), ro-ro cargo (23%) ships have the maximum number of ships calls every year. The vast majority of ships calling the Samsun Port use marine diesel oil both in their main engines and auxiliary engines (generators), but some of them use heavy fuel oil in their main engines. In manoeuvring, mostly marine diesel oil is used as fuel to increase manoeuvrability. Since marine diesel oil fuel is cleaner fuel compared to heavy fuel oil fuel, it emits less exhaust gas emission due to combustion.

3. Results and discussion

3.1. Emissions

In this study, exhaust gas emissions from ships during cruising, manoeuvring, and hotelling were calculated based on the bottom-up approach. Total exhaust gas emissions from ships were calculated as 51.129 t y^{-1} for CO_2, 903 t y^{-1} for NO_X, 411 t y^{-1} for SO_2, 37 t y^{-1} for VOC, 52 t y^{-1} for PM for the year of 2018. The highest levels of ship emissions were generated from general cargo and ro-ro cargo ships, and general cargo, ro-ro cargo, and tanker ships are the main polluters at the port, and these ships produce almost 91% of all emissions in the port. General cargo ships emit half of the total emissions in the port. These results tie well with previous studies wherein reported (Deniz and Kilic, 2009; Popa and Nicolae, 2014; Saraçoğlu et al., 2013) that general cargo, container, and tanker ships are the main pollutants. When compared to the emission of operation modes, cruising mode emissions were higher than manoeuvring and hotelling modes owing to 20 nm navigating distance. Hotelling mode emissions are also much more than manoeuvring mode emissions because of unloading times. Exhaust gas emissions according to ship operational modes (cruising, manoeuvring, hoteling) are illustrated in Fig. 3.

Exhaust gas emissions during cruising mode were 86% of total emissions, and 3% for manoeuvring, and 11% for the hoteling. Ship emissions in Samsun port are compared with other ports are shown in Table 2.

Table 1. Emission factors according to the type of ships (Entec, 2005, 2010)

Ship Types	***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
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
Fish Catching	12.6	11.2	11.3	11.4	12.3	1	678	730	692	0.47	0.85	0.4	0.83	1.48	0.4

C - Cruising, M - Manoeuvring, H - Hoteling

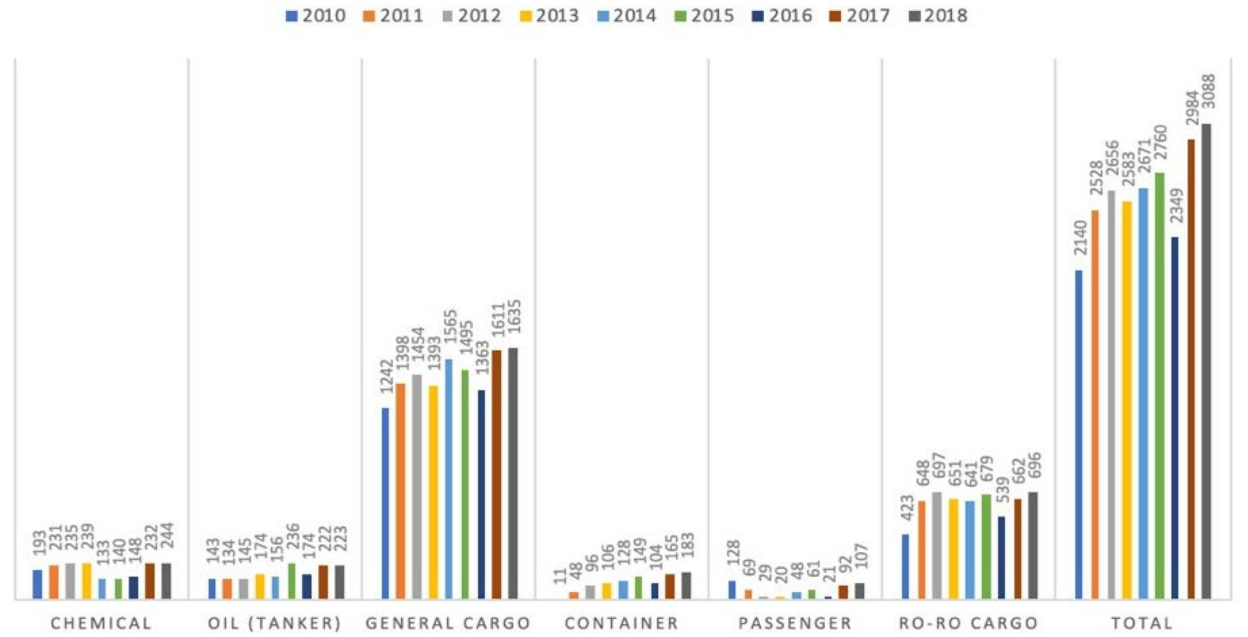


Fig. 2. Ship movements in the Samsun Port between 2010 and 2018 (TDGCS, 2019)

These basic findings are consistent with previous findings (Deniz and Kilic, 2009; Nicolae and Cosofret, 2013; Saraçoğlu et al., 2013) that the Samsun port can be considered as small volume port in the global scale.

3.2. Emission effects on population

Shipping emissions during cruising, manoeuvring, and hotelling modes are considered to affect city air quality. So, in this section, while not giving a clear result, the shipping emissions impacts on human health are tried to assess. The SO_X, NO_X, PM emissions generated from ships are selected to examine the density of annual shipping emissions in the port and to assess the most probable affected population.

Emission effects on the population were calculated according to a numerical distribution model since we could not reach the health statistics in the district. Accordingly, it was learned about the human population likely to be affected by emissions. The Ministry of Environment and Urbanization prepared a clean air action plan for the Samsun city for years of 2014-1019 (SCCAAP, 2015).

It indicated the sources of pollutants in the city such as domestic heating, road traffic, and industry. When compared shipping emission results with these findings (Fig. 4), it can be concluded that main source of pollution in the city comes from road traffic (3.120-ton), and domestic heating follows as the second polluter with the amounts of 2.076-ton, and industry (1.640-ton) and port emissions (1.366-ton) follows respectively.

Samsun city population is 1.295.927 and has 17 districts. The ilkadim district is the biggest district of the city hosting 25% (325.666 people) of the total city population. For the ilkadim district, port emissions are the main pollutant from the other emission resources (domestic heating, road traffic, and industry). This district also has 50 neighbourhood and hosts the Samsun port as well. When examined the distance of the ilkadim districts` neighbourhoods to the Samsun port, we see that 48 neighbourhoods (about 99% of district population) stays within the 6 km radius from the port area and this means that shipping emissions can have hazardous impacts on people health within this range. Except for the harbour zone, there isn`t any inhabited zone near the harbour in the 1-km range. We divided the district`s neighbourhoods into five zones according to distance from the port area starting from 1 km to 6 km with 1 km intervals.

Fig. 5 shows us the ilkadim districts` neighbourhoods and the affected zones from port emissions and it presents us that 98% of the district population living within the 5 km radius which equals 320.708 people are under the threat of shipping emissions.

Table 2. Comparison of port emissions on the different ports

Ports	***Study year***	***Hosted Ships***	***NOx (ton y^{-1})***	***CO_2 (ton y^{-1})***	***PM (ton y^{-1})***	***SO_2 (ton y^{-1})***	***Source***
Ambarli Port, Turkey	2005	5432	845	78.590	36	242	Deniz and Kilic (2009)
The Port of Oslo, Norway	2013	3004	759	56.289	18	260	Lopez-Aparicio et al. (2015)
Izmir Port, Turkey	2007	2806	1.923	82.753	165	1.405	Saraçoğlu et al. (2013)
Civitavecchia Port, Italy	2016	3000	940	-	-	98	Gobbi et al. (2016)
Shanghai Port, China	2003	1280	397	-	221	56	Yang et al. (2007)
Yangshan Port, China	2009	6518	10.758	578.444	859	1.136	Song (2014)
Melbourne, Australia	2010	3065	4.375	247.618	478	3.940	Goldsworthy and Goldsworthy (2015)
Dampier, Australia	2010	3821	3.131	201.753	343	2.869	
Brisbane, Australia	2010	2271	3.140	197.155	362	3.045	
Las Palmas Port, Spain	2011	3183	4.237	208.697	338	1.420	Tichavska and Tovar (2015)
Samsun Port, Turkey	2018	3088	903	51.129	52	411	This Study

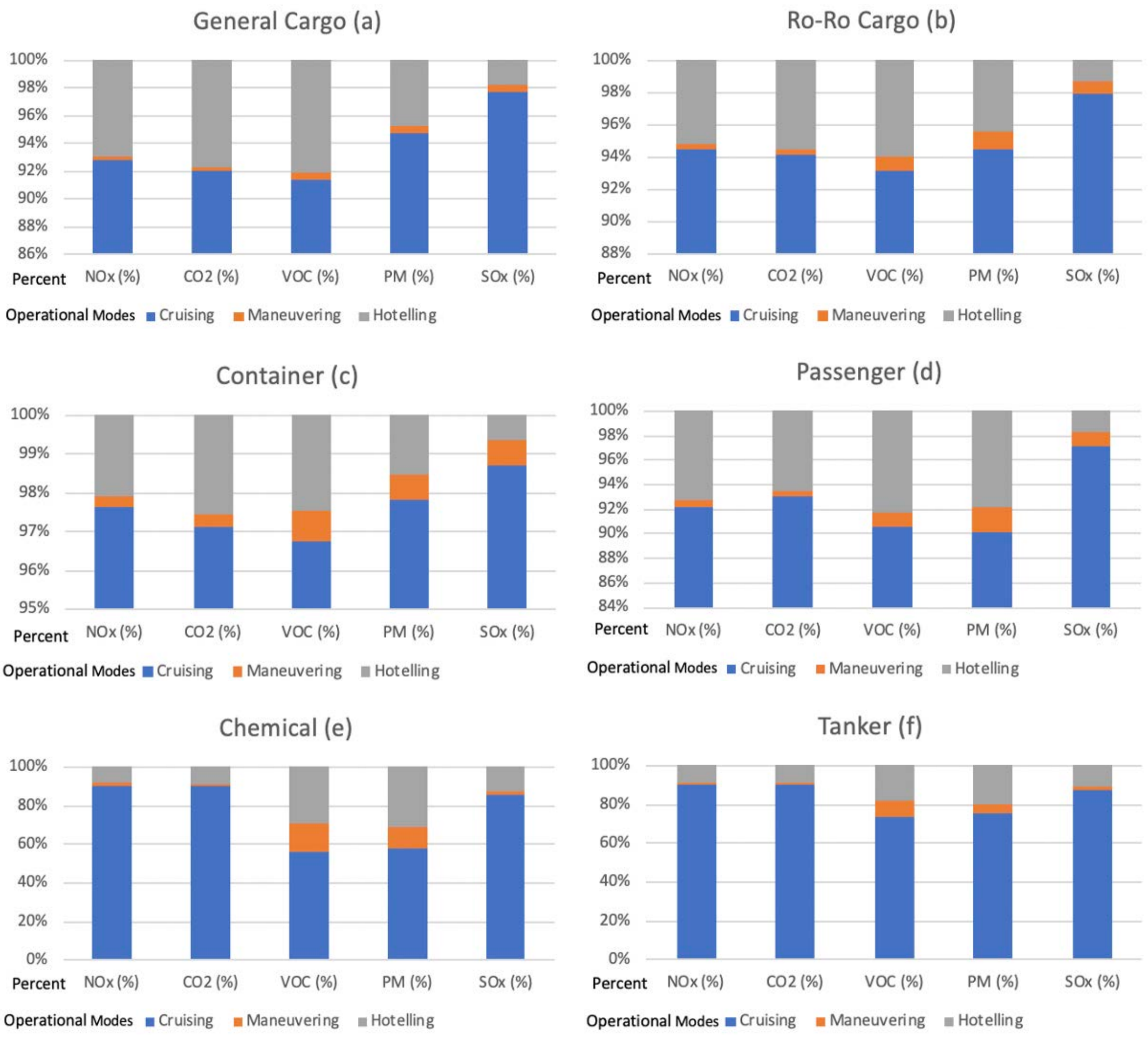


Fig. 3. Exhaust gas emissions according to ship operational modes: (a) general cargo, (b) ro-ro cargo, (c) container, (d) passenger, (e) chemical and (f) tanker

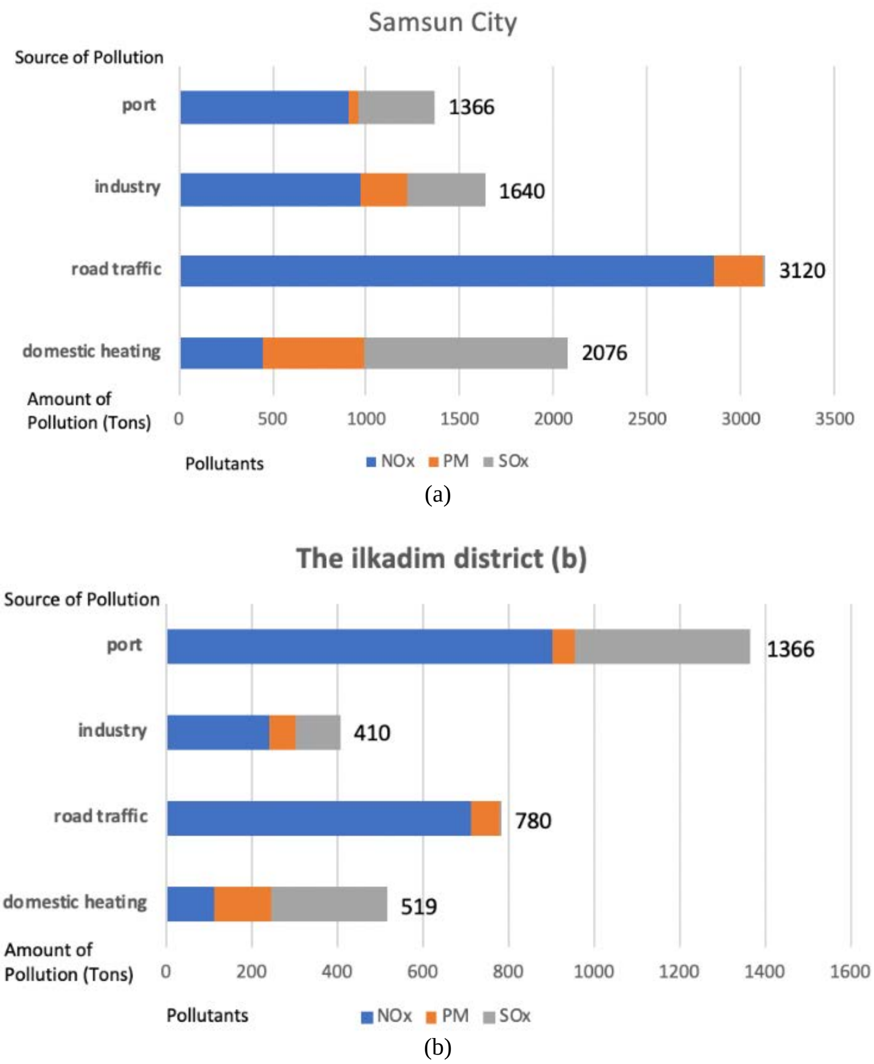


Fig. 4. Sources of emissions in the region: (a) the Samsun city, (b) the ilkadim district (SCCAAP, 2015)

When the radius narrowed to 1 km from the harbour, a minimum of 64,431 people which are about 20% of the total district population, will face harmful emission levels. When taken into consideration a 2 km radius from the port, 154,098 people (47% of the total population) will be under exhaust gas emission impact. In the Samsun port within 1-2 km range from the harbour area, 64,000-150,000 people will feel maritime harmful emissions (SO_2, NO_X, PM) effects including other emission resources (domestic heating, road traffic, and industry). The findings of the current study are consistent with those (Corbett et al., 2007; Deniz and Kilic, 2009; Eyring et al., 2009) and suggest that port emissions will have a relationship with mortality and diseases such as asthma, cardiovascular, respiratory. This study proposes that all forms of emissions close to the port and district should be examined regularly and measures to reduce exhaust gas emissions in the port area should be considered. Sulphur oxide content reduction from 3.5 to 1.0% in the fuel will be implemented starting from January 1, 2020, globally. This significant practice should be implemented in the port area and this implementation will also help to reduce the shipping emissions in the harbour.

3.3. Environmental costs

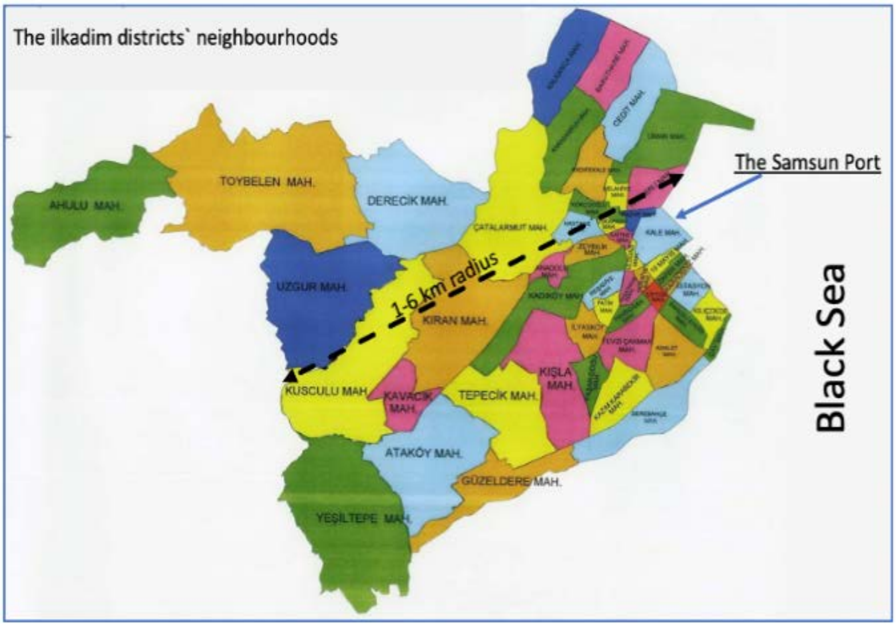
A bottom-up approach was used to estimate the environmental costs of ship emissions in the Samsun Port according to data we have and the environmental costs of pollutants per tonne have been obtained from the final report of the project ExternE (Bickel, 2006; EC, 2005). The ExternE project made the parameter 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;

$$C^s = \sum_j E_j^s \times C_j^s \quad (4)$$

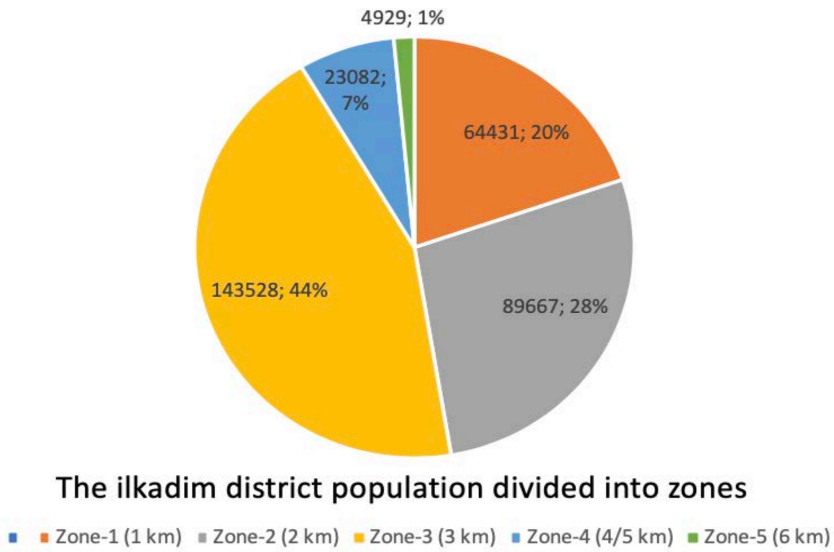
where: C^s is the total environmental cost, E_j^s is the total emission volume of pollutant type j, C_j^s is the cost of pollutant type j per tonne. The environmental cost of the Samsun port emissions for each pollutant has been calculated for 2018 and was $31 million and $10,095 per ship call (Table 3).

Table 3. Environmental costs of the Samsun port emissions (in 2018)

Pollutants	***NO_X***	***CO_2***	***VOC***	***PM***	***SO_2***
Environmental cost (Bickel, 2006; EC, 2005)	4,992 $/ton	26 $/ton	1,390 $/ton	375,888 $/ton	13,960 $/ton
The amount of port emissions	903 tons	51,129 tons	37 tons	52 tons	411 tons
Environmental costs per pollutants	4,507,776$	1,329,354$	51,430$	19,546,176$	5,737,560$
Total Environmental costs	31,172,296$				



(a)



(b)

Fig. 5. Affected zones from the emissions: (a) the ilkadim district, (b) the affected zones

This assessment can be matched with other ports' emission costs. The costs of Kaohsiung port emissions were discovered (Berechman and Tseng, 2010) and it was $119.2 million. The Piraeus port emissions environmental costs were estimated (Tzannatos, 2010) and it was €16.5 million or €10.4 million per cruise passenger. The environmental cost of the Trabzon port emissions for each pollutant has been estimated as $32 million and $47,039 per ship call (Tokuslu, 2020b).

3.4. Sources of ambiguities of the study

Ambiguities in the estimation of port emissions in this study may come from the below issues. All these issues may arise a change of up to ± 35% in the calculation of the SO_2, NO_X, and PM emissions when the below issues are involved in the estimation.

a. Small ships navigating in the port area were not integrated into the estimation, these emissions can be disregarded since their quantities are not very high.

b. Lack of data for ship engines. The data of a ship in the same type and tonnage was used as an example.

c. Lack of data about the types and contents of the fuels. In this regard, the standards used in the world average and literature were taken into consideration.

d. The impacts of current, wave, and wind couldn`t be taken into account since there was not enough data.

4. Conclusions

The findings of this study can be understood as exhaust gas emissions from ships in the Samsun Port were calculated as 51,129 t y^{-1} for CO_2, 903 t y^{-1} for NO_X, 411 t y^{-1} for SO_2, 37 t y^{-1} for VOC, 52 t y^{-1} for PM and whole environmental costs were $31 million and $10,095 per ship call for the year of 2018. All these estimated emissions are discharged only in the Samsun port. Ships causing the most air pollution are chemical, tanker, general cargo, container, passenger, and ro-ro cargo and these ships produce almost 91% of all emissions in the port.

Most of the exhaust gas emissions are discharged during cruising mode and hoteling mode. Hotelling mode emissions are much more than manoeuvring mode emissions, hoteling mode emissions should be observed near the harbour area regularly and also measures such as cold ironing method, the selective catalytic reduction can be used to lessen emissions in the port area. The emissions generated from the ships calling to the Samsun port will endanger around 64,000-150,000 people living within 1-2 km range from the harbour area including other emissions (domestic heating, road traffic, and industry).

All forms of emissions near the port and district should be examined regularly and measures to reduce exhaust gas emissions in the port area should be taken immediately. This study has concretely demonstrated for the first time, that maritime emissions affect how many people in the region of the port area. Correlations between the pollutants (NO_X, SO_2, PM) concentrations and meteorological parameters should be surveyed to assess the effects on human health and the environment as well.

The findings of this study have several important implications for future practice. This study will help to create ship emission inventory in the Black Sea region.

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