IJEPEM

International Journal of Environmental Pollution and Environmental Modelling,
Vol. 3(2): 49-55 (2020)
(Original Paper)

Estimating Exhaust Gas Emissions from Ships on Port of Zonguldak

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Received 12.01.2020; Accepted 02.06.2020

Abstract: In this study, the ship-borne air emissions in the port of Zonguldak were examined based on ship activity-based methods and total emissions generated from ships were estimated as 820 t y^{-1} for NO_X, 45.700 t y^{-1} for CO_2, 350 t y^{-1} for SO_X, 32 t y^{-1} for VOC, 44 t y^{-1} for PM for the year of 2019. General cargo and ro-ro cargo ships are the main polluters in the port and emissions generated from the at-sea mode are higher than the port and maneuvering modes. There are five neighborhoods within 2km from the port of Zonguldak which are at risk of shipping emissions. At least 46,255 people will be exposed to dangerous shipping emissions such as NO_X, SO_X, PM along with other emissions within 2 km of the port area. The environmental cost of the port emissions for each contaminant has been estimated as $27 million and $43.586 per ship call. All types of emissions in the port region should be observed regularly and measures to decrease the emissions should be implemented.
Keywords: Zonguldak, Environmental Pollution, Port, Emissions, Environmental Costs

INTRODUCTION

International maritime trade increased its capacity by 2.6% in 2019, and its capacity is expected to increase with an average growth rate of 3.5% between 2019-2024 (UNCTAD [1]). Global port traffic will increase at the same rate in this context. This increase will also significantly affect port emissions from international maritime transport. Shipping emissions are increasingly recognized as a serious, worldwide public health concern. Surveys such as conducted by Corbett et al. [2], Eyring et al. [3], Deniz and Kilic [4] have shown that there is a close relationship between air pollution (PM, NO_X, and SO_X) and deaths from the respiratory tract, asthma, bronchitis, chronic obstructive pulmonary disease (COPD). Port emissions play an important role in affecting the air quality of the port cities which can have a direct environmental impact on the coastal regions (Saxe and Larsen [5], Corbett et al. [2]). Several studies investigating port emissions have been carried out by Saracoglu et al. [6], Lonati et al. [7], Goldsworthy and Goldsworthy [8], Popa and Florin [9], Deniz and Kilic [4], López-Aparicio et al. [10], Song [11], Yang [12] that as these emissions lead to illnesses, they are responsible for reducing the quality of life of people living near the port area.

The port of Zonguldak, located at the center of the city of Zonguldak on the Black Sea coast, is a center for coal mining and the iron–steel industry in the region. The population of the port city has been experiencing health problems for a long time due to emissions from this industry. Numerous studies have attempted to explain these emission-related health problems and focused on air quality in the Zonguldak region such as Zeydan and Yildirim [13], Akyüz and Çabuk [14,15,16], Tagil and Mentese [17], Yildirim and Bayramoglu [18]. Zeydan and Yildirim [13] calculated the maximum contaminant concentrations in the studied area and air quality is estimated as “dangerous” for SO_2; "unhealthy", "bad" and "dangerous" for NO_X; It has also been determined as "good", "medium" and "sensitive" for PM_{10}. Akyüz and Çabuk [14,15,16] found that coal combustion and vehicle emissions were the major pollutant sources for both $PM_{2.5}$ and $PM_{2.5–10}$ in the region and significant seasonal variations of particle and gas-phase PAH concentrations were observed with higher levels during the cold period. Tagil and Mentese [17] researched the relationship between air pollution (PM_{10} and SO_2) and respiratory patients and a statistically significant positive correlation was observed between PM_{10} and SO_2 concentration and asthma, bronchitis, chronic obstructive pulmonary disease (COPD) diseases in the city.

No study to date has examined ship exhaust gas emissions in the port of Zonguldak. Port emissions are also one of the main pollution sources in the Zonguldak city and should be examined in this context. To fill this gap, the main purpose of this study is to estimate ship-borne air emissions and environmental costs of the port of Zonguldak and create port emission inventory in the region. This study will help us to understand how effective the ship emission in total emissions.

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METHODOLOGY

Study Area

The port is located at the center of the city of Zonguldak and port serves as a gateway for coal mining and the iron–steel industry in the region (Figure 1). The port is operated by the Turkish Stone Coal Institution. The port, which has been at the forefront with coal transportation since its establishment until the beginning of 2000, has gained a port identity where ro-ro transportation is at the forefront as a result of rapid structural and physical changes in recent years. With this development, ro-ro ships are one of the most hosted ship types in the port of Zonguldak. The main parts of the harbors are docks and piers, which provide the connection of the ships with the shore and where loading and unloading are made. There are four piers in the port: cargo pier, coal loading pier, ro-ro pier, and passenger pier.

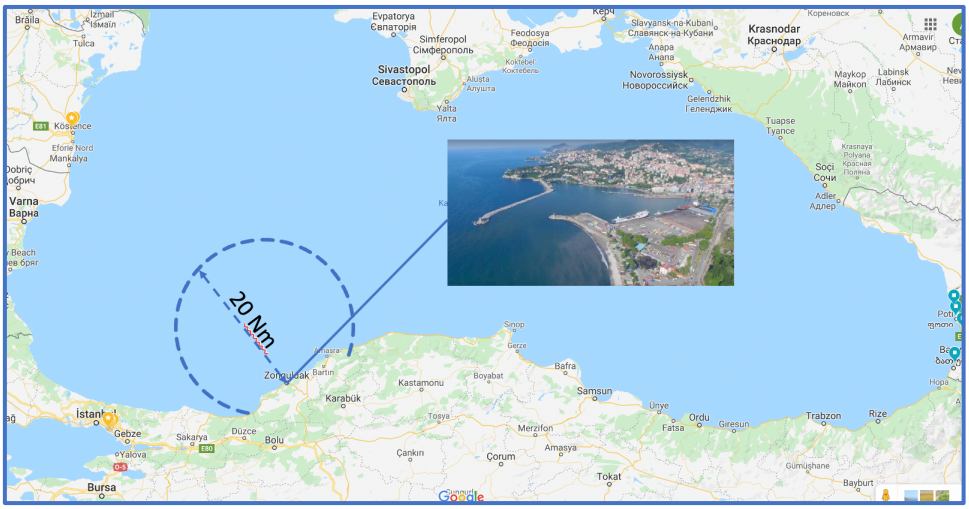

Figure 1. The Port of Zonguldak (Turkish Stone Coal Institution [19])

Calculation Method

Ship originated port emissions are estimated basically in two approaches which are “bottom-up” and “up-down”. In this study, the up-down approach was used to assess the emissions in the port of Zonguldak. Entec Uk Limited developed a methodology to calculate ship exhaust gas emissions. This methodology is used frequently in literature for emission assessments. The ship emissions in the port of Zonguldak were evaluated with equation 1 of Entec Uk Limited Methodology which follows as;

$$E_{at\ sea} = D * [[ME * ME\ LF\ ] + [AE * AE\ LF\ ]\ ] * EF_{at\text{-}sea} / V) \quad \text{(Equation 1)}$$

$$E_{manoeuvring} = T * [[\ ME * ME\ LF\ ] + [AE * AE\ LF\ ]\ ] * EF_{manoeuvring}$$

$$E_{port} = T * AE * AE\ LF * EF_{port}$$

D is the ship cruising distance, ME is the power of the main engine, ME LF is the main engine load factor, AE is the power of the auxiliary engine, AE LF is the auxiliary engine load factor, EF is the emission factors according to operational modes (at-sea, maneuvering, port), V is the shipping speed and T is the times of maneuvering and port activities.

The data in this study consists of ship type, gross tonnage, speed, operation times and they were obtained from the port authority. The total cruising distance from the port of Zonguldak is 20 nm. Times during maneuvering and port modes were calculated in hours (Entec [20]). The average time for maneuvering for all types of visiting ships is 1 hour and port times of every ship's calls were 38 hours for oil (tanker), 15 hours for ro-ro cargo, 14 hours for the container, 52 hours for general cargo, and 27 hours for other ships (research, passenger, etc) respectively. Table 1 shows the emission factors of operational modes (Entec [20,21,22]).

Table 1. Emission Factors According to the Type of Ships

Ship Types	NO_X			SO_X			CO_2			VOC			PM		
	A	M	P	A	M	P	A	M	P	A	M	P	A	M	P
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

A: At-sea, M: Maneuvering, P: Port

The main engine load factors were %80 for the cruise, %20 for maneuvering, %20 for hotelling and auxiliary engine load factors were %30 for the cruise, %40 for maneuvering, %50 for hotelling (EMEP/EEA [23,24]). Figure 2 shows the ship activities in the port between 2011 and 2019 (TDGCS [25]). The total sum of ships visiting the port was the highest (838 ship) in 2013 and on average 670 ships call the port yearly. The port hosts six types of ships such as ro-ro cargo (41%), tanker (1%), general cargo (45%), container (5%), bulk carrier (4%), and other ships (4%) yearly.

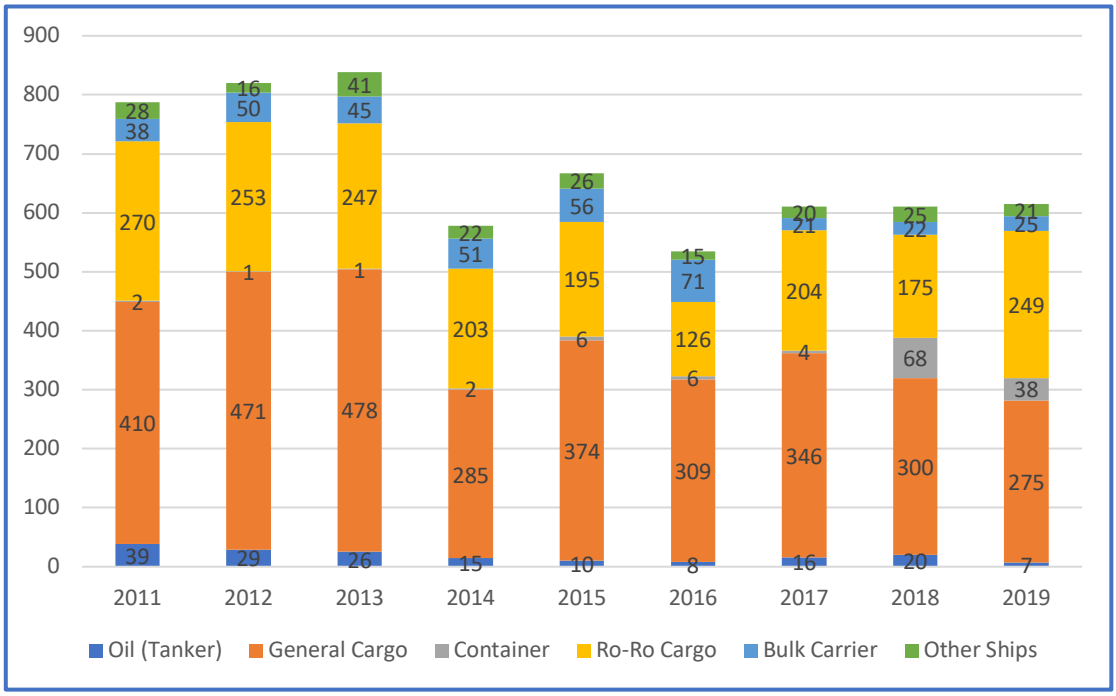

Figure 2. Ship Activities in the Port of Zonguldak

RESULTS AND DISCUSSION

Port Emissions

In this study, exhaust gas emissions from ships during at-sea, maneuvering, and port were calculated based on the up-down approach. Total emissions generated from ships were estimated as

45.700 t y^{-1} for CO_2, 820 t y^{-1} for NO_X, 350 t y^{-1} for SO_X, 32 t y^{-1} for VOC, 44 t y^{-1} for PM for 2019. Annual emissions according to ship types is presented in Table 2.

Table 2. Annual Emissions According to Ship Types

Ship Type	NO_X	CO_2	VOC	PM	SO_X	Total
Oil (Tanker)	15	931	1	1	8	956
General Cargo	279	15.327	11	14	111	15.742
Container	117	5.799	4	7	48	5.975
Ro-Ro Cargo	339	19.552	13	18	154	20.076
Bulk Carrier	51	2.574	2	3	17	2.647
Other Ships	19	1.517	1	1	12	1.550
Total	820	45.700	32	44	350	46.946

General cargo and ro-ro cargo ships emit the highest level of emissions in the port and they create 76% of all the ship emissions. Containers, bulk carriers, tankers, and other ships produce 24% of the rest emissions. Our findings confirm the results presented by Deniz and Kilic [4], Popa and Florin [9], Saracoglu et al. [6] that general cargo are the main polluters in the ports. Emissions generated from the at-sea mode are higher than the port and maneuvering modes. Figure 3 illustrates the emission rates of operational modes. At-sea mode emissions account for 84% of all emissions, 15% of port mode emissions and 1% of maneuvering mode emissions.

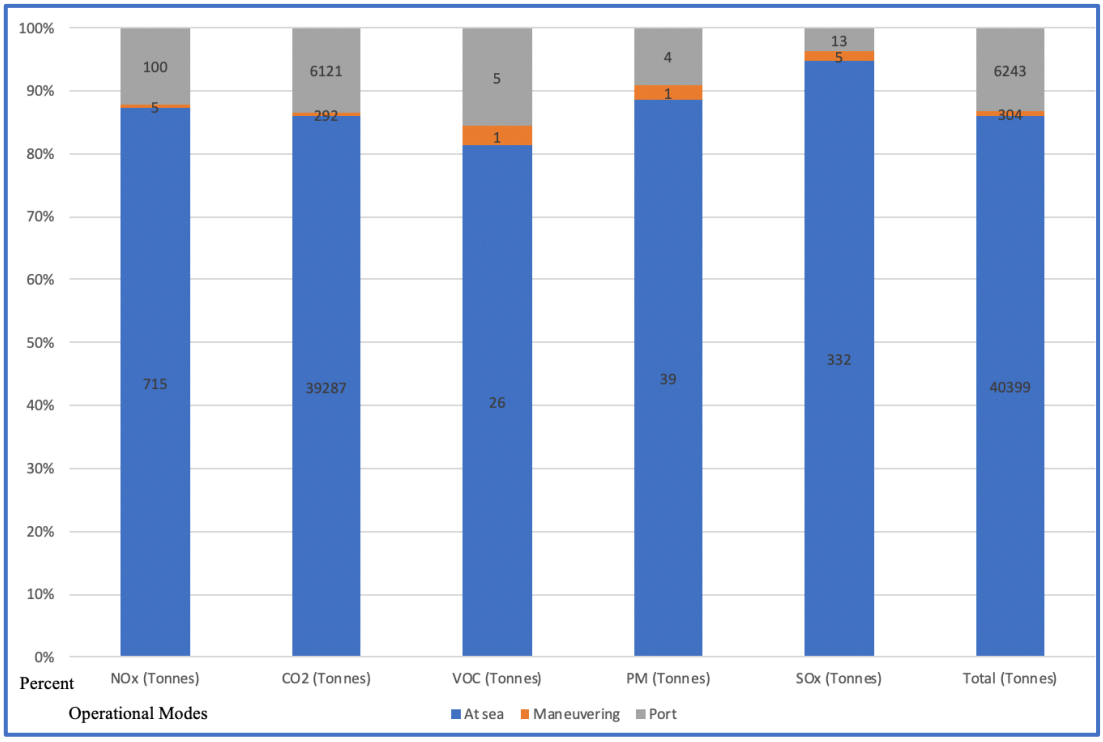

Figure 3. The Emission Rates of Operational Modes

The port of Zonguldak emissions comparison with other ports is presented in Table 3 and it can be concluded that the port of Zonguldak can be accepted as a minor scale port in the global context.

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
Ambarli Port, Turkey	2005	5.432	845	78.590	36	242	Deniz and Kilic [4]
The Port of Oslo, Norway	2013	3.004	759	56.289	18	260	Lopez-Aparicio et al. [10]
Izmir Port, Turkey	2007	2.806	1.923	82.753	165	1.405	Saraçoğlu et al. [6]
Port of Oakland, USA	2012	1.916	2.591	133.005	67	289	EIC [26]
Shanghai Port, China	2003	1.280	397	-	221	56	Yang et al. [12]
Yangshan Port, China	2009	6.518	10.758	578.444	859	1.136	Song [11]
Las Palmas Port, Spain	2011	3.183	4.237	208.697	338	1.420	Tichavska and Tovar [27]
The Port of Zonguldak	2019	615	820	45.700	44	350	This Study

Emission Impacts on People

Zonguldak city population is 596.053 and has 8 districts. The Merkez district is the second biggest district of the city hosting the port of Zonguldak with a population of 123.997 people. For the Merkez district, port exhaust gas emissions are one of the main contaminants with other emissions such as residential heating, road traffic, and industry (Zeydan [28]). The district also has 38 neighborhood. There are five neighborhoods within 2km from the port of Zonguldak which are at risk of shipping emissions. These neighborhoods are called Yayla, Mesrutiyet, Mithatpasa, Terakki, and Bahcelievler, and the neighborhoods` population is 46.255. In the port of Zonguldak within 2 km range from the port region, a minimum of 46.255 people will face dangerous shipping emission releases such as SO_X, NO_X, PM with other emissions. This finding corroborates the studies of Corbett et al. [2], Eyring et al. [3], Deniz and Kilic [4], Zeydan and Yildirim [13], Tagil and Mentese [17], Yildirim and Bayramoglu [18] who suggested that there is a strong relationship between air pollution and diseases such as asthma, bronchitis, chronic obstructive pulmonary disease (COPD). All types of emissions in the port region should be observed regularly and measures to decrease the emissions should be implemented.

Environmental Costs

The environmental cost of the port of Zonguldak emissions for each contaminant has been estimated for 2019 and was $27 million and $43.586 per ship call (Table 4). These findings can be compared with other environmental costs. Berechman and Tseng [29] calculated the environmental costs of Kaohsiung port as $123 million per year. Maragkogianni and Papaefthimiou [30] estimated the emissions of cruise ships visiting Greece ports such as Piraeus, Santorini, Mykonos, Corfu and Katakolo as €24.25 million. Song [11] assessed the social cost and eco-efficiency of the Shanghai Yangshan port and they valued the total social cost as $287 million and eco-efficiency performance was $36,528.

Table 4. Environmental Costs of the Port of Zonguldak

Pollutants	NO_X	CO_2	VOC	PM	SO_X	Total Environmental Costs
Environmental cost (Lee et al. [31])	4.992 $/ton	26 $/ton	1.390 $/ton	375.888 $/ton	13.960 $/ton	-
The amount of port emissions	820 tons	45.700 tons	32 tons	44 tons	350 tons	-
Total environmental costs	4.093.440$	1.188.200$	44.480$	16.539.072$	4.886.000$	26.805.192$

CONCLUSIONS

The ship-borne air emissions in the port of Zonguldak were estimated as 820 t y^{-1} for NO_X, 45.700 t y^{-1} for CO_2, 350 t y^{-1} for SO_X, 32 t y^{-1} for VOC, 44 t y^{-1} for PM. General cargo and ro-ro cargo ships

are responsible for the 76% air emissions in the port, and container, bulk carrier, tanker, tugs follow it. Exhaust gas emissions are mostly released at sea mode (86%), followed by port mode (13%). Port mode emissions are more than the maneuvering mode (1%) since port activities are longer than the maneuvering activities. Port mode emissions should be monitored and measures such as cold ironing, selective catalytic reduction to reduce it should be applied. In the port of Zonguldak within 2 km range from the harbor region, a minimum of 46.255 people will be endangered hazardous ship-borne air emissions such as SO_X, NO_X, PM including residential heating, road traffic, and industrial emissions. All types of emissions in the port region should be observed regularly and measures to decrease the emissions should be implemented. The present study made several noteworthy contributions to literature about shipping emissions in the Black Sea region and this study confirms other emissions in the region. Further studies need to be done to investigate the relationship between meteorological parameters and emissions (SO_X, NO_X, PM).

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