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Estimating of shipping emissions in the Samsun Port from 2010 to 2015

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ABSTRACT

Turkey has an important role in maritime transport because it is surrounded on three sides by the sea and is strategically located between Asia and Europe. Therefore, air pollution due to ships is an important issue for Turkey. This study was carried out in Samsun, which is an important port on the Black Sea coast. Between 2010 and 2015, emissions of nitrogen oxides (NO_2), sulphur dioxide (SO_2), hydrocarbons (HC) and particulate matter less than 10 μm size (PM_{10}) from six different ship types were calculated for different operating modes. The estimated values for NOx, SO_2, HC and PM_{10} were 728 tons, 574 tons, 32 tons and 64 tons, respectively. The highest emission values were generated by general cargo ships. The highest percentage of total pollutants (71.6% for NOx, 65.9% for SO_2, 54.9% for HC and 62.9% for PM_{10}) were generated in cruising mode by Ro-Ro (Roll-on/Roll-off) ships. Additionally, the maneuvering emissions were from 12.6% to 42.4% and the hoteling emissions were from 6.0% to 51.1% in total for all pollutants. In Ro-Ro ships, 80% of the total emissions are generated while the main engine is operational.

1. Introduction

Of the volume of world transport ninety percent is carried by sea. Shipping activities have a remarkable impact on air quality. It is estimated that there 450 different pollutant species to air due to the internal combustion processes in ship engines (Bilgili and Çelebi, 2016). The most important emissions are carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NOx), oxides of sulfur (SOx), volatile organic compounds (VOCs) and particulate matter (PM). These emissions can lead to asthma, respiratory and cardiovascular diseases, lung cancer and premature deaths (NRDC, 2004). Approximately 230 million people are directly exposed to these shipping emissions in the top 100 world ports (Merk, 2014). Corbett et al. (2007)'s study showed that shipping-related PM emissions are responsible for approximately 60,000 cardiopulmonary and lung cancer deaths annually, with most deaths occurring near coastlines in Europe, East Asia, and South Asia. Oeder et al. (2015) aimed at to provide a molecular link between the chemical and physical characteristics of ship emission particles and the cellular responses. They exposed human lung cells under realistic in vitro conditions to exhaust fumes from a ship engine running on either common heavy fuel oil (HFO) or cleaner-burning diesel fuel (DF). They found that the combustion particles from the clean shipping fuel DF influenced several essential pathways of lung cell metabolism more strongly than particles from the unrefined fuel HFO and recommend a reduction of carbonaceous soot in the ship emissions by implementation of filtration devices.

Shipping industries are facing challenges to reduce ship emissions. The International Maritime Organization (IMO) is regulating ship pollution through its International Convention on the Prevention of Pollution from Ships (MARPOL Convention). MARPOL Annex VI regulation relates the Sulphur oxides and particulate matter. The Sulphur content of any fuel oil used on board ship reduced from 4.5% w/w to 3.5% w/w effective 1 January 2012 and to 0.50% effective 1 January 2020 (Cullinane and Bergqvist, 2014; Ye and Feng, 2017). Due to the regulations, emissions of SO_x have been successfully reduced since the 1980s, and over the first decade of the 21st century, total SOx emissions have fallen by 54% in the EU (EEA, 2011; Viana et al., 2014). But Buccolieri et al. (2016) reported that while the implementation of the regulations positively affected the ship related concentrations of SO_2 in the port area, PM_{10} and NO_x reduction was minor for the year 2012 and no reduction for the year of 2020. Nevertheless, Merk (2014) estimates that most shipping emissions in ports will grow four fold up to 2050. It is not clearly known what the impact of current ship emissions will be on the ambient air levels of other pollutants, especially on primary and secondary aerosols.

Ship emissions can be transferred across long distances from sea to

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land or from the port atmosphere to surrounding urban land. The world's fleet stays at port during 55% of time, 25% of it is close to the coast and approximately 80% is close to land (ICCT, 2007). Nearly 70% of ship emissions occur within 400 km of land (Endresen et al., 2003; Eyring et al., 2010). Some studies found that the ships in ports can contribute around 55 to 77% of total emissions near the ports (Hulskotte and Gon, 2010; Cullinane and Cullinane, 2013). In European coastal areas, shipping emissions contribute 1.7% to the ambient air PM_{10} levels, 1.14% of $PM_{2.5}$, and at least 11% of PM_1 (Viana et al., 2014). Pey et al. (2013) reported that harbor emissions accounted for 31% of the average PM_{10} mass over the Western Mediterranean metropolis of Barcelona. In the urban areas of Barcelona, the contributions from the port were estimated to be from 9 to 12% and from 11 to 15% for PM_{10} and $PM_{2.5}$, respectively (Pérez et al., 2016). Also, the primary contribution of in-port ship emissions to $PM_{2.5}$ was estimated to be 2.8%, and the average relative contribution of ship traffic was reported to be 7.4% (± 0.5%) for $PM_{2.5}$ in the harbor–industrial area of Brindisi, Italy (Cesari et al., 2014; Donateo et al., 2014).

In a study performed in three major port cities of Denmark (Copenhagen, Elsinore and Koge) PM_{10}, SO_2 and NO_x emissions were investigated with an air quality dispersion model, and the contribution of marine traffic to urban air quality in these harbors was estimated by modeling. PM_{10} emissions resulting from the sea traffic in Copenhagen were 15%, which compares to 8% PM_{10} emissions resulting from road traffic in the same city (Saxe and Larsen, 2004).

Table 1 summarized the results of studies about ship emissions (using activity based methodology) in the world and Turkey. Emissions are seen to be higher in studies of all ship types and modes at international ports (Chen et al., 2016; Nunes et al., 2017). However, it is seen that only passenger or container ships have lower on the hoteling and maneuvering mode emissions at the ports (Maragkogianni and Papaefthimiou, 2015; Cullinane et al., 2016). Merk (2014) reported that global shipping emissions of CO_2, NOx, SOx and PM_{10} in ports were found to be 18, 0.4, 0.2 and 0.03 million tons in 2011, respectively. Around 85% of emissions came from container ships and tankers. In Corbett's study, it is stated that international trade ships contribute 30% of the global amount of NOx and 9% of SOx (Corbett et al., 1999). It is confirmed that 17% of these emissions are in the Turkish straits, 30% is from vessels in transit across the Sea of Marmara, 48% is from ships berthed at ports in the Sea of Marmara, and 5% is from ships transiting the Sea of Marmara (Deniz and Durmusoğlu, 2008).

The port of Samsun is the largest port in the Black Sea region of Turkey. In this study, the contribution of air pollutants to the air quality of the city is assessed by implementing the 2010 to 2015 annual emission inventory of the ships coming to the port of Samsun.

2. Methodology

Samsun is the major port for Turkey in the Black Sea area. It is one that connects the railway to the Black Sea. The hinterland of the port includes Batumi, Poti and Suchumi in Georgia; Soçi, Tuapse, Novorossiysk, Azov, Taganrog, Jdanov, Yalta, Berdyansk and Geniçesk in Russia; Mis. Kız-Oğul, Feodosiya, Yalta, Todor, Sevastopol, Yevpatorskiy in the Crimea; Nikolayev, Odessa and İliçhevski in the Ukraine; Konstanta in Romania and the port of Varna in Bulgaria. The port of Samsun is the access port of Anatolia. The port area is 445,000 m^2 in total, and 350,000 m^2 of this area is used as a storage and port service area. The port has the capacity to accommodate approximately 2200 ships per year. Shipping traffic in the port of Samsun is increasing gradually every year. The number of general cargo ships is 55% of the total number of ships, followed by Ro-Ro ships at 25%. The number of port calls registered by Samsun Port Authority in 2015 was 2510, 8 million tons of cargo was handled, and 120000 passengers passed through the port.

Fig. 1 shows the location of Samsun, and the cruising and maneuvering activity lines. The area where the emission calculation is made includes Samsun Main Port, Samsun Industrial Port, Yeşilyurt Port and Toros Port (Fig. 1-b). The ship routes given in Fig. 1-c were determined by the Samsun Port Authority as the safest routes to be followed by the ships according to the depths of the sea. The distances for each activity of ships in all ports are given in Table 2. X is the point where each ship starts to cruise in the Samsun port with the guide captain. B and G are points where the cruise ends and the maneuver begins. C, D, E and F are the areas of Samsun Industrial, Samsun, Yeşilyurt, Toros Ports respectively.

In-port ship emissions are produced by the ships' engines (main and auxiliary) when they are cruising, maneuvering in and out of port and staying at berth. Ship exhaust emission inventories can be estimated by applying a fuel-based or an activity-based methodology (Maragkogianni et al., 2016; Nunes et al., 2017). The activity-based method requires detailed data from movements and ship operations (actual speeds, operation times, travel distance, among others). In this study, ship emissions were calculated by the ship activity-based method to estimate the main air pollutants (SO_2, NO_x, HC and PM_{10}), which involves the application of emission factors for each ship activity (cruising, maneuvering and hoteling).

Ship fleet information acquired from ship records is reported in Table 3. Except for ship speed (V), data were obtained from Samsun Port Authority between 2010 and 2015. Cruising speed of the ships indicated in Table 2 are design speed of each ships obtained from the literature (Entec, 2005; Kilic and Deniz, 2010). Gross Tonnage values were taken from the Atlantis database of the Ministry of Transport,

Table 1
Summary of the main results of studies on ship emission inventory in the world and Turkey.

Region/Ports	References	Year	Pollutants (x10^3 tons/year)			
			NO_x	SO_2	PM_{10}	HC
Greece/Piraeus, Santorini, Mykonos, Corfu and Katakolo Ports	Maragkogianni and Papaefthimiou (2015)	2013	1.8	0.7	0.09[a]	ND[b]
Greece/18-ports	Papaefthimiou et al. (2016)	2013	2.4	0.9	0.01	ND
Portugal/4-Ports	Nunes et al. (2017)	2014	29.5	13.7	1.5	1.2
Spain/Las Palmas Port	Tichavska and Tovar (2015)	2011	4.2	1.4	0.3	ND
India/JN-New Bombay Port	Joseph et al. (2009)	2006	0.3	0.3	0.03	ND
China/Shanghai Yangshan Port	Song (2014)	2009	10.7	5.6	0.8	0.5
China/Tianjin Port	Chen et al. (2016)	2014	41.3	29.3	4.0	1.7
Korea/Busan Port	Song and Shon (2014)	2009	8.7	8.2	ND	0.6
Taiwan/Kaohsiung, Keelung, and Taichung Ports	Cullinane et al. (2016)	2012	1.1	1.1	0.09	0.03
Turkey/İzmit Gulf	Kılıc and Deniz (2010)	2005	5.3	4.3	0.5	0.2
Turkey/Ambarlı Port	Deniz and Kılıç (2009)	2009	0.8	0.2	0.03	ND
Turkey/İzmir Port	Saraçoğlu et al. (2013)	2007	1.9	1.4	0.13	0.16
Turkey/Çandarlı Port	Deniz et al. (2010)	2007	0.6	0.6	0.03	0.05

[a] $PM_{2.5}$ emissions.
[b] ND: Not Determined