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

Aydın TOKUSLU

Chief in Editor
Prof. Dr. Cem Gazioğlu

Co-Editors
Prof. Dr. Dursun Zafer Şeker, Prof. Dr. Şinasi Kaya,
Prof. Dr. Ayşegül Tank and Assist. Prof. Dr. Volkan Demir

Editorial Committee (September 2022)

Assoc. Prof. Dr. Abdullah Aksu (TR), Assoc. Prof. Dr. Uğur Algancı (TR),
Prof. Dr. Levent Bat (TR), Prof. Dr. Paul Bates (UK), İrşad Bayrhan (TR), Prof. Dr. Bülent Bayram (TR), Prof. Dr. Luis M. Botana (ES), Prof. Dr. Nuray Çağlar (TR), Prof. Dr. Sukanta Dash (IN), Dr. Soofia T. Elias (UK), Prof. Dr. A. Evren Erginal (TR), Assoc. Prof. Dr. Cüneyt Erenoğlu (TR), Dr. Dieter Fritsch (DE), Prof. Dr. Manik Kalubarme (IN), Dr. Hakan Kaya (TR), Assist. Prof. Dr. Serkan Kükre (TR), Assoc. Prof. Dr. Maged Marghany (MY), Prof. Dr. Micheal Meadows (ZA), Assoc. Prof. Dr. Masafumi Nakagawa (JP), Prof. Dr. Burcu Özoys, Prof. Dr. Hasan Özdemir (TR), Prof. Dr. Chyssy Potsiou (GR), Prof. Dr. Erol Sari (TR), Prof. Dr. Maria Paradiso (IT), Prof. Dr. Petros Patias (GR), Prof. Dr. Barış Salıhoğlu (TR), Assist. Prof. Dr. Başak Savun-Hekimoğlu (TR), Prof. Dr. Elif Sertel, (TR), Prof. Dr. Füsun Balık Şahin (TR), Dr. Duygu Ülker (TR), Prof. Dr. Seyfettin Taş (TR), Assoc. Prof. Dr. Ömer Suat Taşkın (TR), Assist. Prof. Dr. Tuba Ünsal (TR), Assist. Prof. Dr. Sibel Zeki (TR)

Abstracting and Indexing: TR DIZIN, DOAJ, Index Copernicus, OAJI, Scientific Indexing Services, International Scientific Indexing, Journal Factor, Google Scholar, Ulrich's Periodicals Directory, WorldCat, DRJI, ResearchBib, SOBIAD
Analysing shipping emissions of Turkish ports in the Black Sea and investigating their contributions to Black Sea emissions

Aydin Tokusu

PhD. Istanbul University, Institute of Marine Sciences and Management 34134 VEFA Fatih Istanbul

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 calculated. 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 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 (Tokusu, 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), Tokusu et al. (2020), Tokusu 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 Bartin) 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 Bartin and port of Eregli) 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.

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 et al., 2017; Song, 2014; Tichavská and Tovar, 2015; Mersin et al., 2019-2020; Tokuslu, 2020; 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:

\[ E_{\text{cruising}} = D \times \left[ ME \times LF_{\text{ME}} + \left( AE \times LF_{\text{AE}} \right) \times EF_{\text{cruising}} \right] / V \] (Eq1)

\[ E_{\text{manoeuvring}} = T \times \left[ ME \times LF_{\text{ME}} + \left( AE \times LF_{\text{AE}} \right) \times EF_{\text{manoeuvring}} \right] \] (Eq2)

\[ E_{\text{hotelling}} = T \times AE \times LF_{\text{AE}} \times EF_{\text{hotelling}} \] (Eq3)

\( E_{\text{cruising, manoeuvring, hotelling}} \) are the emissions of pollutants (NO\textsubscript{X}, CO\textsubscript{2}, VOC, PM, and SO\textsubscript{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, 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; 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       | NO₂ | SO₂ | CO₂  | VOC | PM  |
|------------------|-----|-----|------|-----|-----|
|                  | C   | M   | H    | C   | M   |
| 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  | 657 | 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 |   |<500 GRT | 500-999 GRT | 1000-4999 GRT | 5000-9999 GRT |   |<500 GRT | 500-999 GRT | 1000-4999 GRT | 5000-9999 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    |
| Bulk Dry        | 14                   | 550      | 750         | 2700            | 5000          | 8800    | 17000   | 20     | 40    | 175   | 300   | 380    |
| 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   |
| Ro-Ro Cargo     | 18                   | 1500     | 1900        | 4300            | 7200          | 11600   | 12550   | 100    | 150   | 350   | 1000  | 2500   |
| Other Ships     | 15                   | 900      | 1200        | 2400            | 6200          | 9900    | 18700   | 50     | 80    | 200   | 450   | 900    |

### 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, Sila Port, Amasra Port, Sinop Port, Ünye 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. Hotelling 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 NOₓ, 280,498 t y⁻¹ for CO₂, 2.059 t y⁻¹ for SO₂, 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)**

| Mode       | NOₓ  | CO₂  | VOC  | PM  | SO₂  |  %  |
|------------|------|------|------|-----|------|-----|
| Cruising   | 4949 | 82   | 228283 | 81 | 153 | 78 |
| Manoeuvring| 23   | 1    | 1391  | 1  | 3   | 4   |
| Hotelling  | 832  | 17   | 50824 | 18 | 41  | 21  |
| Total      | 4949 | 100  | 280498 | 100| 197 | 100 |

17
Turkish Ports Emissions

There are main 15 Turkish ports located in the Black Sea, and these are: İgneada Port, Sile Port, Amsara Port, Sinop Table 5. Turkish ports emissions (tons/year).

| Ports       | Ship calls | NOx  | CO₂   | VOC | PM | SO₂ | Source  |
|-------------|------------|------|-------|-----|-----|-----|---------|
| İgneada Port| 127        | 130  | 7186  | 5   | 7   | 52  | This study |
| Sile Port   | 2716       | 2761 | 151863| 107 | 139 | 1097| This study |
| Amsara Port | 92         | 95   | 5259  | 4   | 5   | 38  | This study |
| Sinop Port  | 168        | 208  | 15273 | 8   | 9   | 109 | This study |
| Ünye 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;

\[ C^v = \sum_j E_j^v \times C_j \]  

(Eq.4)

where: \( C^v \) is the total environmental cost, \( E_j^v \) is the total emission volume of pollutant type \( j \), \( C_j \) 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 | NOx  | CO₂   | VOC | PM | SO₂ |
|------------|------|-------|-----|-----|-----|
| Environmental cost (EC, 2005; Bickel, 2006) | $4.992 | $26 | $1.399 | $375.888 | $13.900 |
| The amount of port emissions | 9.410 tons | 527.433 tons | 174 tons | 508 tons | 1,964 tons |
| Environmental costs per pollutant | 46.974.720$ | 13.714.289$ | 519.860$ | 190.951$ | 55.337$ |
| Total Environmental costs | $61.455.160 |

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 $228 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 CO₂, 6-14% of SO₂, and 11-20% of NOₓ 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 to Black Sea emissions (tons/year)

| Year | CO₂  | SO₂  | NOₓ  | 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

| Year | CO₂  | SO₂  | NOₓ  | 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              |

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 NOₓ, 280,498 t y⁻¹ for CO₂, 2,059 t y⁻¹ for SO₂, 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 SO₂, and 11-20% of NOₓ 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.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The author wishes to express his sincere thanks to the editor of the International Journal of Environment and Geoinformatics (IJEGEO) for the support.

References

Alver, F., Sarac, B.A. and Sahin, U.A. (2018). Estimating of shipping emissions in the Samsun Port from 2010-2015. Atmospheric Pollution Research 9 (2018) 822-828. https://doi.org/10.1016/j.apr.2018.02.003
Bayriran, I., Mersin, K., Tokuşlu, A. and Gazioğlu, C. (2019). Modelling of Ship Originated Exhaust Gas Emissions in the Istanbul Strait. International Journal of Environment and Geoinformatics (IJEGEO),6(3): 238-243, doi.org/10.30897/ijegeo.641397.
Berechman, J. and Tseng, P.H. (2010). Estimating the environmental costs of port related emissions: The case of Kaohsiung. Transportation Research Part D 17 (2012) 35–38. doi:10.1016/j.trd.2011.09.009.
Bickel, P. (2006). Developing Harmonised European Approaches for Transport Costing and Project Assessment. Deliverable 5: Proposal for Harmonised Guidelines. EU-funded project (contract no. FP6-2002-SSP-1/502481), Germany.
Chiffi, F., Schrooten, E., De Vlieger, I. (2007). EXTREMIS - Exploring non road Transport Emissions in Europe Final Report. Institute for Prospective Technological Studies, DG-IRC, Seville, Spain.
Cofala, J., Amann, M., Heyes, C., Wagner, F., Klimont, Z., Posch, M., Schöpp, W., Tarasson, L., Jonson, J.E., Whall, C., Stavrakaki, A. (2007). Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive Service Contract No 070501/2005/419589/MAR/C1, European Commission, International Institute for Applied Systems Analysis, Laxenburg, Austria.
Deniz, C., Kilic, A. and Civkaroglu, G. (2010). Estimation of shipping emissions in Candarli Gulf, Turkey. Environ Monit Assess (2010) 171:219–228, DOI 10.1007/s10661-009-1273-2.
Entec (2002). Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, European Commission, Final Report, Northwich, UK.
Entec (2005). European Commission, Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments, Task I-Preliminary Assignment of Ship Emissions to European Countries, Final Report.
Entec (2007). Ship Emissions Inventory Mediterranean Sea, Final Report for Concawe.
European Communities (EC) (2005). Externalities of Energy Methodology 2005 Update, Office for official publications of the European Communities, web page: http://europa.eu.int, (Accessed 23 October 2020)
Fleetmon (2020). Vessel Movements, [online] https://www.fleetmon.com/ (Accessed 15 September 2020)

Florin, N. and Cossofret, D. (2013). Method for qualitative and quantitative determination of exhaust emissions from shipping and port activities in the Romanian Black Sea maritime area, Contract Research SPMD 157/2012, “Mircea cel Bătrân” Naval Academy, Constanța.

Helbing, J. (2014). Increasing ports capacity in Turkey and the Black Sea region – will the container throughput continue to rise too? 3rd Black Sea Ports and Shipping, 3-4 September 2014, Istanbul.

International Institute for Applied Systems Analysis (IIASA)(2007). Analysis of policy measures to reduce ship emissions in the context of the revision of the national emissions ceilings directive. IIASA Contract No. 06-107; 2007. Laxenburg, Austria.

Kilic, A. and Deniz, V. (2009). Inventory of Shipping Emissions in Izmit Gulf, Turkey. Environmental Progress & Sustainable Energy, Volume 29, Issue 2, (2009) https://doi.org/10.1002/ep.10365.

Lavender, K., Reynolds, G., Webster, A. (2006). Emission inventory guidebook (p. 9). UK: Lloyds Register of Shipping.

Liu, T.K., Sheu, H.Y., Tsai, J.Y. (2014). Sulfur dioxide emission estimates from merchant vessels in a Port area and related control strategies. Aerosol Air Qual. Res. 14, 413-421. http://dx.doi.org/10.4209/aqr.2013.02.0061.

Maragkogianni, A. and Papaefthimiou, S. (2015). Evaluating the social cost of cruise ships air emissions in major ports of Greece. Transportation Research Part D 36 (2015) 10-17. http://dx.doi.org/10.1016/j.trd.2015.02.014

Mersin, K., Bayrurhan, I., Gazioğlu, C. (2019). Review of CO2 Emission and Reducing Methods in Maritime Transportation. Thermal Sciences, 1-8.

Mersin, K., Bayrurhan, I., Gazioğlu, C. (2020). Analysis of the Effects of CO2 Emissions Sourced by Commercial Marine Fleet by using Energy Efficiency Design Index. Thermal Science, 24(1):187-197.

Ng, S.K.W., Loh, C., Lin, C., Booth, V., Chan, J.W.M., Yip, A.C.K., Li, Y., Lau, A.K.H. (2013). Policy change driven by an AIS-assisted marine emission inventory in Hong Kong and the Pearl River Delta. Atmos. Environ. 76, 102-112.

Nunes, R.A.O., Alvim-Ferraz, M.C.M., Martins, F.G., Sousa, S.I.V. (2017). Assessment of shipping emissions on four ports of Portugal. Environmental Pollution, 231 (2017), 1370-1379, http://dx.doi.org/10.1016/j.envpol.2017.08.112.

Popa, C., Filorin, N. (2014). Shipping Air Pollution Assessment. Study Case on Constanța Port, 14th International Multidisciplinary Scientific GeoConference SGEM 2014.

Saraçoglu, H., Deniz, C., Kilic, A. (2013). An investigation on the effects of ship sourced emissions in Izmir port, Turkey. Sci. World J. http://dx.doi.org/10.1155/2013/218324.

Şengonul, G., Esmer, S. (2016). Container transportation at the Black Sea: an evaluation of the ports in Turkey. Journal of Black Studies, Vol: 49: 131-140.

Song, S. (2014). Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port. Atmos. Environ. 82, (2014), pp. 288-297. http://dx.doi.org/10.1016/j.atmosenv.2013.10.006.

Tchavatska, M. and Tovar, B. (2015). Port-city exhaust emission model: An application to cruise and ferry operations in Las Palmas Port. Transportation Research Part A 78 (2015) 347–360. http://dx.doi.org/10.1016/j.tra.2015.05.021.

Tokuslu, A. (2019). Analysis of ship-borne air emissions in the Istanbul Strait and presenting its effects. PhD thesis, Istanbul University, Istanbul, Turkey.

Tokuslu, A. (2020a). Estimating Exhaust Gas Emissions from Ships on Port of Zonguldak. International Journal of Environmental Pollution and Environmental Modelling, Vol. 3(2): 49-55.

Tokuslu, A. (2020b). Assessing the Environmental Costs of Port Emissions: The Case of Trabzon Port. J. Int. Environmental Application & Science, Vol. 15(2): 127-134.

Tokuslu, A. (2020d). Creating an Inventory of Ship Emissions of the Port of Bartın and Calculating the Environmental Cost of Port Emissions. Ulusal Çevre Bilimleri Araştırma Dergisi, 3(4): 208-218.

Tokuslu, A. (2021). Assessment of Environmental Costs of Ship Emissions; Study Case on the Samsun Port. Environmental Engineering and Management Journal, 20(5), 317-325.

Tokuslu, A. and Burak, S. (2021). Examination of exhaust gas emissions of transit ships in the Istanbul Strait. Academic Platform Journal of Engineering and Science, 9 (1): 59-67. Doi: 10.21541/apjes.705918

Tokuslu, A., (2020c). Analyzing the Shipping Emissions in Port of Ereğli and Examining the Contribution of SOx Emissions Reduction to the Port Emissions. Journal of Environmental and Natural Studies, Vol. 2(1): 23-33.

Tokuslu, A., Bayrurhan, I. and Gazioglu, C. (2020). Investigation the Effect of SOx Emission Reduction on Transit Ships Emissions as of January 1, 2020. Thermal Science, 24, 149-155, https://doi.org/10.2298/TSCI20S1149T

Turkish Directorate General of Coastal Safety (TDGCS) (2019). Port Statistics, web page: https://atlantis.udhb.gov.tr/istatistik/istatistik_gemi.aspx. (Accessed 11 October 2020)

Tzanntazos, E. (2010). Ship emissions and their externalities for the port of Piraeus Greece. Atmos. Environ. 44 400-407. http://dx.doi.org/10.1016/j.atmosenv.2009.10.024.

Ülker, D., Bayrurhan, I., Mersin, K., Gazioglu, C. (2020). A comparative CO2 emissions analysis and mitigation strategies of short-sea shipping and road transport in the Marmara Region, Carbon Management, 11(6): doi:10.1080/17583004.2020.1852835.

Yau, P.S., Lee, S.C., Corbett, J.J., Wang, C.F., Cheng, Y., Ho, K.F. (2012). Estimation of exhaust emission from ocean-going vessels in Hong Kong. Sci. Total Environ. 431, 299-306.