Research Article

An Investigation on the Effects of Ship Sourced Emissions in Izmir Port, Turkey

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Maritime transportation is a major source of climate change and air pollution. Shipping emissions cause severe impacts on health and environment. These effects of emissions are emerged especially in territorial waters, inland seas, canals, straits, bays, and port regions. In this paper, exhaust gas emissions from ships in Izmir Port, which is one of the main ports in Turkey, are calculated by the ship activity-based methodology. Total emissions from ships in the port is estimated as 1923 ton y⁻¹ for NOₓ, 1405 ton y⁻¹ for SO₂, 82753 ton y⁻¹ for CO₂, ton y⁻¹ for HC, and 165 ton y⁻¹ for PM in the year 2007. These emissions are classified regarding operation modes and types of ships. The results are compared with the other studies including amounts of exhaust pollutants generated by ships. According to the findings, it is clear that the ships calling the Izmir Port are important air polluting causes of the Izmir city and its surroundings.

1. Introduction

The most important impacts of air pollution are climate change, reduction of ozone layer thickness, acid rains, and the corruption of air quality. One of the most significant air pollution sources are ship-generated emissions. Maritime transportation is the major transportation mode as in that the international marine transport of goods is responsible for roughly 90% of world trade by volume [1]. Similarly, more than 80% of world trade is carried by sea in terms of weight [2]. The world maritime fleet has grown in parallel with the seaborne trade registered under the flags of over 150 nations [3].

Over the past decades, growing international trade resulted in a corresponding growth in the tonnage of merchandise carried by ships [4]. The merchant shipping industry and the development of the world economy are closely related [5]. Maritime transportation is considered to be the most energy efficient cargo transportation mode, which has the potential to make a significant contribution to the efficiency of the transport system.

The growing number of shipping movements and the related release of air pollutants have drawn attention onto this emission source. Shipping activities are one of major air pollution sources as the ships that have high powered main engines often use heavy fuels. More than 95% of the world’s shipping fleet is powered by diesel engines [6].

Since the shipping emissions have not been controlled tightly, there some difficulties to achieve progress in improving environmental performance. Because their air pollutant emissions remain comparatively unregulated, ships are now among the world’s most polluting combustion sources per ton of fuel consumed [7]. The bunker oil used in ocean going ships has been estimated to produce over 100 times compared to on-road diesel per unit volume [8]. Ship emissions have remarkable global, regional, and local adverse impacts on the air quality on sea and land. The most important pollutants emitted from ships are nitrogen oxide (NOₓ), sulfur dioxide (SO₂), carbon dioxide (CO₂), hydrocarbons (HC), and particulate matter (PM). Shipping emissions are easily transferred long distances in the atmosphere from the sea the land and between the continents [9]. Also, the effects of shipping emissions can increase in the domestic seas, narrow channels, straits, guls, and port areas specially including dense maritime traffic, sensitive ecosystems and the presence of populations. The health effects of air pollution at ports may
include asthma, other respiratory diseases, cardiovascular disease, lung cancer, and premature death [10].

Significant progress in estimating international ship emissions has been made in the past decade. Furthermore several global, regional, and local inventory studies have been performed. The emissions of NO\textsubscript{x}, SO\textsubscript{2}, PM, and GHG’s (Green House Gases) from global shipping are increased from 585 to 1096 million tons between 1990–2007 [11]. The CO\textsubscript{2} emissions from international shipping are estimated at 943.5 million tons for the year 2007 [12]. According to a report by TRT (2007), CO\textsubscript{2} emissions from global shipping are about 1 billion tons for the year 2006 [13]. International shipping is responsible for 3% of global CO\textsubscript{2} emissions (II). Based on the fuel consumption, the annual CO\textsubscript{2}, NO\textsubscript{x} and SO\textsubscript{2} emissions from ship corresponds to about 2%, 1%, and 4% of the global anthropogenic emissions, respectively [14].

The port areas are the most recognizable receptors of pollutants emitted from ships. The emissions from ships may threaten the air quality while berthing or maneuvering and in coastal communities while transiting along the coast. Approximately 80% of the world fleet are either harbored (55% of the time) or near a coast (25% of the time) [1]. This means that ships spend about 20% of the time far from land [7].

There are many local studies about estimating the shipping emissions in gulfs and port regions in the literature. It was estimated that the shipping emissions were approximately 1.725 Mt NO\textsubscript{x}, 1.246 Mt SO\textsubscript{2}, 0.147 Mt CO, and 0.035 Mt HC in the Mediterranean Sea and the Black Sea regions based on ship movements [15]. The International Institute for Applied Systems Analysis (IIASA) estimated that the shipping emissions of CO\textsubscript{2}, NO\textsubscript{x}, SO\textsubscript{2}, and HC were 77.140 Mt, 1.818 Mt, 1.278, and 0.062 Mt, respectively, in the Mediterranean Sea [16]. The shipping emissions in the Black Sea were estimated at 3.85 Mt of CO\textsubscript{2}, 0.089 Mt for NO\textsubscript{x}, 0.065 for SO\textsubscript{2} [16]. Deniz and Durmuşoğlu carried out to define as 0.11 Mt for NO\textsubscript{x}, 0.087 Mt of SO\textsubscript{2} in the Sea of Marmara [17]. Minjiang et al. carried out to characterize the air pollutants in Shanghai Port and identify the contribution from ship traffic emission [18]. Tzannatos, estimated the shipping emissions and externalities for Port of Piraeus [19]. The shipping emissions were estimated by Saxe and Larsen (2004) for three Danish ports, Kılıç and Deniz (2010) for Izmit Gulf-Turkey, Deniz and Kılıç (2010) for Ambarlı Port, Deniz and Kılıç (2010) for Candarlı Gulf [20–22].

In this study, the shipping emissions are calculated based on the real shipping activities and engine power information for Izmir Port-Turkey as a major export port region of the country. The annual emissions from ships are calculated as 1923 t\textsuperscript{-1} for NO\textsubscript{x}, 1405 t\textsuperscript{-1} for SO\textsubscript{2}, 82753 t\textsuperscript{-1} for CO\textsubscript{2}, 74 t\textsuperscript{-1} for HC, and 165 t\textsuperscript{-1} for PM.

2. Location and Time of Study

The Izmir Port, one of the important export ports in Turkey, plays a vital function for the Aegean Region’s industrial and agricultural experts. Izmir port is the biggest container terminal and has a great logistic importance for the Turkish economy. Also, it is a trading center because of an increment on the port capacity in the years. The study region is illustrated in Figure 1.

It is the only container handling terminal in this region and has 559.661 TEU and 9.652.714 ton cargo handling capacity per year. In addition, the port has the capacity to accommodate 3.640 ships per year. The port is also one of the largest passenger port in Turkey because Izmir is a tourism center and because of the surrounding historical places to visit.

In 2007, 2803 vessel arrivals, 12 million tons of cargo being handled, and 300.000 passengers pass through the port. The port is also connected with state railway and highway network. In 2008, 11 million tons cargo was handled at Izmir Port; therefore, this amount corresponded to %37 of all cargos handled at other Turkish ports.

Ship fleet information acquired from unique ship records is indicated in Table 1. The number of General Cargo ships consists of 60% of all vessels which followed by Container ships with 30%. Since some vessels call at port more than once and berthing time characteristics of the port depend on port productivity of each ship call, berthing time statistics were calculated based on each ship calls where the other particulars reflects the unique ship characteristics. As a result, the significant number of container ships call in Izmir port constitutes 56% of all ships, while general cargo ships make up 35% of all calls. Statistics based on ships calling into Izmir port were evaluated in the year 2007.

3. Methodology

Ship emissions were calculated by the ship activity-based method which involves the application of emission factors for each ship-activity (cruising, maneuvering, and hotelling). The emission factors are critically important to determine representative values of ship emissions for the ship’s engines during that activity. Furthermore, emission factors depend on speed of the ship and the fuel type.

Ship activity-based method was used to estimate the ship emissions in Izmir port. This method is clarified by flow charts and illustrated in Figure 2. The ship activity-based methodology was applied to the ships calling the Izmir Port to estimating the amounts of the main ship exhaust pollutants (NO\textsubscript{x}, SO\textsubscript{2}, CO\textsubscript{2}, HC, and PM) while cruising, maneuvering and hotelling. Ship emissions depend on the time passed in
| Number of ships | GRT | Max  | Min  | Average | Median | Std Dev. | GRT | Max  | Min  | Average | Median | Std Dev. | GRT | Max  | Min  | Average | Median | Std Dev. |
|----------------|-----|------|------|---------|--------|----------|-----|------|------|---------|--------|----------|-----|------|------|---------|--------|----------|
| Chemical       | 3   | 5998 | 4358 | 5115    | 4989   | 827      | 6564| 1560 | 4008 | 3900    | 2504   |          | 580 | 210  | 444  | 542     | 204    |          |
|                | 4   | 330  | 300  | 310     | 300    | 17       | 91  | 30   | 65   | 69      | 25     |          |     |      |      |         |        |          |
| Container      | 260 | 75590| 959  | 19055   | 14821  | 14601    | 68470| 550  | 13592| 10130   | 11960  |          | 960 | 65   | 254  | 127     | 217    |          |
|                | 1567| 120  | 1    | 21      | 19     | 11       | 376 | 3    | 39   | 28      | 37     |          |     |      |      |         |        |          |
| General cargo  | 502 | 11417| 2889 | 52014   | 22080  | 46874    | 72000| 1200 | 25517| 10294   | 26239  |          | 750 | 78   | 538  | 500     | 258    |          |
|                | 976 | 61   | 4    | 10      | 8      | 8        |     |      |      |         |        |          |     |      |      |         |        |          |
| Passenger      | 19  | 60942| 37710| 47168   | 51714  | 8751     | 60942| 37710| 47168| 51714   | 8751   |          | 113 | 100  | 111  | 112     | 3      |          |
|                | 141 | 36   | 3    | 13      | 13     | 6        |     |      |      |         |        |          |     |      |      |         |        |          |
| Ro-Ro          | 16  | 25487| 6650 | 13955   | 11450  | 6474     | 60942| 37710| 47168| 51714   | 8751   |          | 950 | 102  | 235  | 140     | 213    |          |
|                | 81  | 113  | 19   | 43      | 41     | 21       |     |      |      |         |        |          |     |      |      |         |        |          |
| Tanker         | 30  | 11417| 393  | 11169   | 4968   | 15712    | 72000| 170  | 6911 | 3150    | 9962   |          | 1200| 65   | 427  | 450     | 279    |          |
|                | 34  | 376  | 1    | 27      | 20     | 25       |     |      |      |         |        |          |     |      |      |         |        |          |
| All Ships      | 830 | 11417| 393  | 11169   | 4968   | 15712    | 72000| 170  | 6911 | 3150    | 9962   |          | 1200| 65   | 427  | 450     | 279    |          |
|                | 2803| 376  | 1    | 27      | 20     | 25       |     |      |      |         |        |          |     |      |      |         |        |          |

The exhaust gas emissions were calculated for 2803 ships called Izmir Port in 2007. The emissions produced during the ship's cruising, maneuvering, and hotelling were estimated through the application of the following expressions [23]:

\[
E_{\text{Cruising}}(g) = \frac{D}{V\left[ME \cdot LF_{ME} \cdot EF_1 + AE \cdot LF_{AE} \cdot EF_1\right]},
\]

\[
E_{\text{Maneuvering}}(g) = T_{\text{Maneuvering}}\left(ME \cdot LF_{ME} \cdot EF_2 + AE \cdot LF_{AE} \cdot EF_2\right),
\]

\[
E_{\text{Hotelling}}(g) = T_{\text{Hotelling}}\left(AE \cdot LF_{AE} \cdot EF_3\right),
\]

(1)

where \(ME\) is a main engine power (kW), \(AE\) is a generator power (kW), \(V\) is a ship average speed between cruising and maneuvering (km/h), \(D\) is a distance between cruising and maneuvering (km), \(LF_{ME}\) is a load factor of main engine.
The features of the ships calling Izmir Port

The times passed in the ship activities

The times passed in cruising, maneuvering, and hotelling

The powers of the ships' main engines and generators (kW)

The amount of emissions

Ship emissions for every ship activity (ton/year)

Total emissions (ton/year)

**Figure 2:** The flow chart for the used ship activity-based method.

**Table 2:** Load factors of main engine and generators according to operational modes.

| Operational mode | Main engine load | Generator load |
|------------------|------------------|----------------|
| Cruising         | %40              | %30            |
| Maneuvering      | %40              | %50            |
| Hotelling        | %20              | %40            |

at cruising, maneuvering and hotelling (%), \( LF_{AE} \) is a load factor of generator at cruising, maneuvering and hotelling (%), \( EF_1 \) is an emission factors for cruising mode (g/kWh), \( T_{Man} \) is an average time spent during maneuvering (h), \( EF_2 \) is emission factors for maneuvering mode (g/kWh), \( T_{Hotelling} \) is an average time spent at berth (h), and \( EF_3 \) is an emission factors for hotelling (g/kWh).

The load factors of the main engine and auxiliary engines for cruising, maneuvering and hotelling modes are illustrated in Table 2.

Total cruising distance in the gulf is 128.8 km. The cruising times of ships were determined based on the ship's default service speed at 80% MCR. Since the main engine load is assumed as %40, the half of the service speed of the vessels is used. Ships default service speeds are shown in Table 3 [24]. The cruising ship emissions were calculated for each ship's one main engine and two numbers of generators. At cruising mode, main engine loads were assumed as 40% instead of 80% because of the structure of the gulf. Also, for the ship's safety, at cruising mode, it is estimated that the ships operate two generators synchronized.

Maneuvering emissions are calculated for each ship's one main engine and two parallel generators. During maneuvering, main engine load decreases so load factor in this mode declines to 40% [23]. The average time for maneuvering is a total 2 hours including arrival and departure, obtained by Under Secretariat for Maritime Affairs [25].

It is assumed that the main engine is stopped and one generator is running while loading and unloading the cargo at berthing. Main Engine (ME) load is assumed as 20% and percentage of main engine operation time is assumed as 5%. There is one generator running which load factor is 40% at hotelling phase. The emission factors are shown in Table 4 [23, 24]. The berthing time for each ship calls were obtained from Under secretariat for Maritime Affairs [25].

The data used to estimate ship exhaust emissions as main engine powers, generator powers and ships duration time in the berth, are the actual values for the ships calling the Izmir Port. Since the engine power, engine load, and engine running hours are the key factors to estimate the emissions, using the exact values of these data gives more accurate results.

The significant data of main engine and generator powers of the ships called Izmir Port are explored at Lloyds Register ship data bank [24]. ME powers of ships are compared to the default values of literature which are classified by ship type and ships gross tonnage (Figure 3) [26]. It is obvious that, linear function could be more appropriate instead of stair function especially above and higher than 50 thousand gross tonnages of container ships and 10 thousand gross tonnages of general cargo ships.

**Table 3:** Average ship speed of the ships called Izmir Port.

| Ship type         | Ship speed (km/h) |
|-------------------|-------------------|
| Chemical tanker   | 27.78             |
| Container         | 37.04             |
| General cargo     | 25.93             |
| Passenger         | 37.04             |
| RO-RO             | 33.34             |
| Tanker            | 25.93             |

4. Results and Discussion

In this study, the exhaust emissions are calculated with the activity-based emission model for the Izmir Port, which is the most important container port in Turkey. It is determined that ships calling into Izmir Port are a major source of air pollutants in the city of Izmir. Also, it is stated that ship emissions may lead to critical effects upon human health because Izmir port is within the city of Izmir, which has the third highest population of Turkey.

As seen from Figure 4, the amounts of emissions during ship operations were 1923 t·y⁻¹ for \( NO_x \), 1405 t·y⁻¹ for \( SO_2 \), 82753 t·y⁻¹ for \( CO_2 \), 74 t·y⁻¹ for HC, and 165 t·y⁻¹ for PM. Approximately 26000 tons of fuel were consumed in the gulf by the ships. The emissions during cruising mode were higher than maneuvering and hotelling emissions due to longer distances, also the main engine and one generator were operated at the maximum load. Ship emissions released...
during hotelling, maneuvering, and cruising modes are illustrated in Figure 4. The exhaust gas pollutants generated from ships during cruising were 66.8% of the total amounts in operational modes. Moreover, while maneuvering emissions were 18.1% and during hotelling 15.1% of all amounts.

Also exhaust gas emissions according to ship types are specified in Figure 5. The highest levels of exhaust gas emissions were generated from container ships. General cargo and cruise ships also emit large amounts of exhaust gas as seen in the dataset.

The percentage of NO\textsubscript{x} emissions is shown in Table 5. Container ships constitute 66% of all NO\textsubscript{x} emissions at all operating modes and 74% of all NO\textsubscript{x} emissions generated by ME by ships at cruising modes. Each cell contains two percentage ratios; the first one indicates the emission amount ratio of ship type whilst and the second shows the engine and operating mode ratio of a certain ship type. The multiplication of these values of each cell gives the overall ratio of specified engines at operation modes of a given ship type. For instance, at hotelling mode auxiliary generators of general cargo ships generates 5.76% (0.32 × 0.18) of all NO\textsubscript{x} emissions.

Within the city of Izmir, the air pollutant-emitting sources may be divided into land- and ship-based sources.
Table 5: NO\textsubscript{x} percentage according to ship type and operation mode.

| Ships           | Percentage of NO\textsubscript{x} | ME | AE | ME | AE | ME | AE | Total |
|-----------------|-----------------------------------|----|----|----|----|----|----|-------|
|                 | Cruising                          |    |    |    |    |    |    |       |
| Chemical tanker | 0-72                              | 0-9| 0-7| 0-3| 0-7| 0-2| 0-7| 0-100 |
| Container       | 67-75                             | 59-4| 72-8| 64-2| 69-4| 58-7| 66-100 |
| General cargo   | 11-60                             | 29-10| 10-6| 23-3| 15-5| 32-18| 14-100 |
| Passenger       | 19-85                             | 5-1 | 14-6| 6-1 | 14-4| 7-3 | 16-100 |
| Ro-Ro           | 3-74                              | 5-7 | 3-9 | 5-3 | 2-2 | 2-5 | 3-100 |
| Tanker          | 1-67                              | 1-9 | 1-8 | 1-2 | 1-4 | 1-10| 1-100 |
| All ships       | 100-74                            | 100-4| 100-8| 100-2| 100-4| 100-8| 100-100|

Figure 4: Total exhaust emissions during ship operational modes.

Table 6: Land-based emissions in (t y\textsuperscript{-1}).

| Air pollutant sources | NO\textsubscript{x} | SO\textsubscript{2} | CO\textsubscript{2} | HC | PM | FC |
|-----------------------|---------------------|---------------------|---------------------|----|----|----|
| Domestic heating      | 1.124               | 5.693               | 11.159              |    |    |    |
| Traffic               | 19.418              | 1.862               | 1.351               |    |    |    |
| Industry              | 1273                | 866                 | 30857               | 49.2| 115.9| 16010|
| Shipping              | 1.923               | 1.405               | 165                 |    |    |    |

Land-based sources for an air pollutant is domestic heating, traffic, and industry for Izmir city. Land-based emissions are compared to annual shipping emissions in Izmir Port in the Table 6.

The land-based sources of air pollutants within Izmir city was found as 23,173 t of NO\textsubscript{x}, 13,094 t of SO\textsubscript{2} and 16,451 t of PM [27].

The shipping emissions in Izmir Port are compared with other specific ports in in Table 7. SO\textsubscript{2} emissions from ships calling at Izmir Port have the most amounts because of the higher content of sulfur in marine fuels.

The NO\textsubscript{x} and SO\textsubscript{2} emissions from ships in Izmir port are more than those of other ports except Oakland Port.

Furthermore, ship emissions are compared between Izmir Port and other Turkish Ports in the Table 8. The amount of exhaust gas emissions from ships calling into Izmir Port is the second highest amount except ships calling into Izmit Gulf.

5. Conclusion

Ship emissions are a significant source of air pollution in cities and have a direct effect on the human population. In this study, the estimation of exhaust gas emissions (NO\textsubscript{x}, SO\textsubscript{2}, CO\textsubscript{2}, HC, and PM) from ships in Izmir Port is calculated on the shipping activity based bottom up approach for the first time. The annual emission rates are calculated as 1923 ton y\textsuperscript{-1} for NO\textsubscript{x}, 1405 ton y\textsuperscript{-1} for SO\textsubscript{2}, 82753 ton y\textsuperscript{-1} for CO\textsubscript{2}, 10.0 ton y\textsuperscript{-1} for HC, and 165 ton y\textsuperscript{-1} for PM.

The emissions generated from ships calling into Izmir port might have critical health effects on people living close to Izmir which has the third highest population of Turkey. Some precautions can take to decrease the ship emissions in
Table 7: Comparison of shipping emissions on the different ports (t y⁻¹).

| Port           | Ships call | NO₂ | SO₂ | HC  | PM   | Source |
|----------------|------------|-----|-----|-----|------|--------|
| Aberdeen       | —          | 376 | 52  | —   | 14   | [28]   |
| Copenhagen     | —          | 743 | 162 | —   | 13   | [20]   |
| Oakland        | 1.916      | 2.484| 1.413| —  | 219.5| [29]   |
| JN-New Bombay  | 2.900      | 397 | 56  | —   | 221  | [30]   |
| Port Arthur    | —          | 1716| 833 | —   | 133  | [31]   |
| Izmir          | 2.806      | 1.923| 1.405| 74 | 165  | In this study |

Table 8: Shipping emissions at Turkish ports (t y⁻¹).

| Turkish ports | Ships call | NO₂ | SO₂ | CO₂ | PM | Source |
|---------------|------------|-----|-----|-----|----|--------|
| Izmit Gulf    | 11.645     | 5.356| 4.305| 254.261| 232| [21]   |
| Ambarlı Port  | 5.432      | 845 | 242 | 78.590| 36 | [22]   |
| Çandarlı Gulf | 7.520      | 632 | 574 | 33.848| 32 | [6]    |
| Izmir Port    | 2.806      | 1.923| 1.405| 82.753| 165| This study |

the port. Most of the emissions are released during cruising and hotelling of ships. The cold ironing method could be used for electrical energy demands of the ships to cut off hotelling emissions. All emissions near the port should be monitored regularly.

This paper presents the first ship emission inventory to estimate the ship emissions for Izmir port. Consequently, the ships calling the Izmir Port are important air polluting sources of the Izmir city and its surroundings. The result will help next studies to compare and observe the ship emission inventories for Izmir port. As a conclusion, collected data and results can be used in estimating ship exhaust emissions studies for Izmir.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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