International Journal of e-Navigation and Maritime Economy 18 (2022) 001–009

e-Navi

Available online at http://www.e-navi.kr/
e-Navigation Journal

Original article

Estimation of air pollution from container transportation of Daesan Port in Korea

Hai Dang Bui[a], Gunwoo Lee[b], Hwayoung Kim[c]

[a] Department of Maritime Transportation, Mokpo National Maritime University, Korea, buihaidang.neu@gmail.com

[b] Department of Transportation and Logistics Engineering, Hanyang University, Korea, gunwoo@hanyang.ac.kr

[c] Division of Maritime Transportation, Mokpo National Maritime University, Korea, hwayoung@mmu.ac.kr, Corresponding Author

Abstract

To reduce the air pollution from maritime activities, which is proven to have severe impacts on the worldwide environment and human health, many international regulations have been established. Therefore, an effective political strategy and a complete inventory of emissions are needed to control atmospheric ship pollution and comply with these international standards. The purpose of this study is to calculate the amount of emission in three operating modes (cruising, maneuvering, and hoteling) for some main pollutants emitted from container ships and trucks operating in Daesan port in Korea based on bottom-up methodology. The results showed that the volume of air pollution of about 6,500 tons from container ships and 1,455 tons from container trucks were emitted in Daesan port area. Also, a total of 4 billion won (about 3.6 billion won from container ships, and about 400 million won from container trucks) was estimated.

Keywords: Air emissions, container ship, container truck, bottom-up methodology

https://doi.org/10.52820/j.enavi.2022.18.001

1. Introduction

In recent decades, the world has seen a considerable increase in air emissions, contributing to global environmental issues, namely through climate change, reduction of ozone layer thickness, and acid rain. With approximately ninety percent of world trade by volume carried by sea, shipping activities have a remarkable impact on air quality. The most important pollutants produced by ships on international routes and in-port are nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter (PM), and hydrocarbon (HC). While the first two pollutants are considered culprits of the formation of acid rain, the latter leads to severe impacts on human health. Although in-port emissions are not significantly contributing to the overall emissions from shipping, it cannot be denied that it has a direct effect on human health and air quality in coastal areas because ports attract shipping traffic and inevitably constitute sources of concentrated ship exhaust emissions.

Recently, to reduce pollution from ocean-going vessels, several international regulations have been conducted. By 2020, the International Maritime Organization (IMO) has enforced a regulation to strengthen the sulfur content of fuel oil from 3.5% to 0.5% for international sailing ships passing all seas around the world (IMO, 2020). The Energy Efficiency Design Index (EEDI) for new ships aims at promoting the use of more energy-efficient (less polluting) equipment and engines. Since 1 January 2013, new ship design needs to meet the reference level for their ship type (IMO, 2011). In Korea, the government has made significant efforts to improve national air quality through 10-year comprehensive plans. From September 2020, a new marine fuel standard, SOx Emission Control Area (ECA) regulation, will enter into force. Initially, the 0.10% sulfur limit will be applied to vessels at anchorage or berth in the ECAs, which cover Korea’s five main ports: Busan, Incheon, Yeosu - Gwangyang, Ulsan, and Pyeongtaek - Dangjin. From January 2022 onward, the scope will be expanded to include all vessels entering the ECAs (Lloyd’s Register, 2020). To comply with those standards, shipping companies should prepare various countermeasures such as limiting engine output, installing energy-saving devices, and using eco-friendly alternative fuels to meet greenhouse gas regulations on existing ships. Besides, to understand the quantitative impact of ship emissions on air quality and to implement effective control measures for ship emissions, a detailed analysis of the emission characteristics and the development of a high-resolution emission inventory for ship sources are needed (Trozzi, 2010).

The mainstream methods to prepare ship emission inventory can be broadly categorized into two main approaches: top-down approach (fuel-based) and bottom-up approach (activity-based). In the top-down approach, exhausted ship emissions are estimated from analyzed statistically marine fuel sales and fuel-related emission factors (Nunes et al., 2017). For example, Tzannatos (2011) calculated the emission of the main pollutants from the shipping activity within the Greek seas in 2008 by using fuel sales statistics. The fuel consumption and exhaust gas emissions NOx, CO, CO2, VOC, PM exhausted from coastal passenger ships transit ships in busy Turkish Straits were assessed by Kesgin and Vardar (2001). Lee (2018) estimated emissions resulting from the hoteling of large vessels in 2011 and 2012 using the top-down approach. However, this approach did not reflect the real movements of ships.

Unlike the top-down method, the bottom-up methodology, which is now employed by more studies, requires detailed information about ship specifications (e.g., ship type, engine characteristics, fuel type) and ship operational records (e.g., travel distances, speed, ship tracking, activity time). Also, this method requires a higher level of input parameters such as detailed ship technical data (e.g., ship types, engine characteristics, and design information). It is widely agreed that the bottom-up approach is generally more accurate than the former because it requires detailed and exhaustive inputs (Coello et al., 2015). Tzannatos (2010) calculated the emission of the main pollutants from cruise ships for the Port of Piraeus in Greece, between 2008 and 2009, using an in-port ship activity-based methodology. McArthur and Osland (2013) have estimated emissions by vessel type for ships hoteling, and assess monetary values for the emissions from ships at berth. In Asia, many studies have been conducted to estimate the emissions inventory. A comprehensive in-port ship emission inventory was estimated in the Yangshan port of Shanghai with a sophisticated activity-based methodology, supported by the ship-by-ship and real-time data from the modern automatic identification system (Song, 2014). In Hong Kong, non-GHG emission inventories and policy changes to control and regulate marine emissions were discussed (Ng et al., 2013). Lee et al. (2020) also performed a similar analysis for the Port of Incheon in South Korea. They estimated non-greenhouse gas emissions inventory (CO, NOx, SOx, PM, VOC, and NH3) by different vessel movement phases by ship type.

After reviewing the literature, we find that a limited number of existing studies on estimations of in-port ship emissions have been conducted in Korea. It cannot be denied that some studies already analyzed them but mostly focused on Incheon (Chang et al., 2013; Khan et al., 2018; Lee et al., 2020) and Busan port (Lee & Lee, 2016; Shin & Cheong, 2011; Woo & Im, 2021), which was insufficient to contribute to a total emission inventory in Korea, which helps to provide an overview and build a long-term strategy to improve the air quality for the country. On the other hand, the volume of atmospheric emissions from other means of transportation in port area, which was also considered as a major pollution source, was not taken into account in those previous studies. Therefore, in this study, the contribution of air pollutants to the port area is assessed by implementing the 2017 emission inventory of container ships and trucks in Daesan port. This paper aims to review the methodology for assessing emissions and calculate the volume of NOx, SO2, HC, PM, and CO2 from the container pier in Daesan port.

The rest of the paper is developed as follows. First, the methodology and data source used in this study to estimate emissions are briefly described in Section 2, followed by the results and discussions from the case study of Daesan port in Section 3. Finally, the last section presents the main conclusions from the work and makes suggestions for improvements and further research on the topic in the future.

2. Methodology

2.1. Port introduction

Daesan port is located 339km away from Longan Port in China, which is the focal point of logistics in central Korea along the Yellow Sea coast that offers great accessibility to China. Daesan port has been operating a total of 31 berths including a container berth, supporting a logistics function of its petrochemical complex in the rear area.

Table 1: Number of ships and cargo volume in Daesan port

Year	2017	2018	2019	2020	2021
Ship number (ships)	3,312 (304)	3,181 (256)	3,080 (264)	2,809 (266)	2,785 (189)
Total cargo volume (10^6 tons)	90.3	92.6	93.1	84.5	87.7
Container volume (10^3 TEUs)	110.2	90.8	73.9	120.6	74.6

Table 1 presented the number of ships and cargo throughput in Daesan Port from 2017 to 2021. Those figures above showed an unstable trend recently. In 2021, 2,785 ships entered and departed from the port, of which 189 were container ships. The total amount of cargo handled in 2021 was 87.7 million tons, in which crude oil and petroleum products account for a large portion of the trade volume. After a downfall in 3 consecutive years, containers reached 120.6 thousand TEUs in 2020 and decreased again to 74.6 thousand TEUs because of the covid-19 pandemic. However, based on the total national volume in 2021, Daesan port still ranked 6th in total cargo throughput and 3rd in oil cargo throughput.

2.2. Data source

Ship exhaust emission inventories can be estimated by applying a fuel-based (top-down) or an activity-based (bottom-up) approach. While the former, used when it is not possible to obtain refined data traffic information, is based on the combination of data on marine fuel sales and fuel-related emission factors, the latter, considered more accurate and elaborate, collects data on detailed information on ship specifications to estimate shipping emissions (Nunes et al., 2017). Besides, the activity-based method requires detailed data from movements and ship operations (actual speeds, operation times, and travel distance, among others).

In this study, ship emissions were calculated by the ship activity-based method (method 1) to estimate the main air pollutants (NOx, SO2, PM10, HC, CO2), which involves the application of emission factors for each ship activity. In the port area, a ship is operated in three general modes. The cruising mode is typically defined as vessel movements at the design speed when the propulsion engines are operating at high loads. Maneuvering refers to the slow speed movement of the ship between the port's breakwater and point of berth, whereas berthing refers to the dockside mooring of the ship. In-port ship emissions are produced by the ships' engines (main and auxiliary) when they are cruising, maneuvering, and hoteling. The equation used to calculate emissions through the activity-based method is expressed as (Kim & Dang, 2020):

$$E_{cruising} = (D/V).(ME.LF_{ME}.EF_1 + AE.LF_{AE}.EF_1)$$

$$E_{maneuvering} = T_{maneuvering}.(ME.LF_{ME}.EF_2 + AE.LF_{AE}.EF_2)$$

$$E_{hoteling} = T_{hoteling}.(AE.LF_{AE}.EF_3)$$

Where ME denotes the main engine power (kW), AE denotes the auxiliary engine power (kW), V denotes the ship's speed (knots), D denotes the distance of cruising (nm), T denotes the time of maneuvering, hoteling (h), LFME denotes the load factor of main engine, LFAE denotes load factor of auxiliary engine, EF1, EF2, EF3 denote the emission factor (g/kWh) in cruising, maneuvering, and hoteling, respectively.

Besides, the exhaust gas from container ship results was also compared along with the fuel-based method (method 2) which was suggested by Thanh Le et al. (2019):

$$F_1=0.0070T_{ijk}S_{ijk}^3+15.9194T_{ijk}+\epsilon$$

in which: T_{ijk} denotes the voyage time (in days) of vessel k to travel from port i to port j, S_{ijk} denotes the average sailing speed of vessel k to travel from port i to port j (knots).

Figure 1: Route of container ships in Daesan port

The ship data was collected in Daesan Port in 2017, which focused only on in and out container ships (1,000TEU ~ 1,850TEU) operating on the routes from Jangan Seo P/S to Daesan Port Container Pier 2, 3, 4, as shown in figure 1. Through the AIS information analysis of the container ship, it was confirmed that the speed was reduced for a while to pick up the pilot at Jangan Seo P/S, and then moved to point 2 at the speed of 10 knots. In this study, sections 1-2 were defined as cruising at 6.3 miles, and sections 2-3 were defined as maneuvering and hoteling when berthing.

To calculate the air pollutants emitted from the vessel, the number of ships, the output of the main engine and generator, the vessel berthing time, the vessel speed, and the distance were calculated using the data of the vessel that entered the Daesan Port container pier. The data on main engine (ME) and auxiliary engine (AE) power was collected by surveying a set of container ships that actually entered the port, which classified into 7 main groups: A (928 TEU, ME: 6,178kW, AE: 736kW x 3 sets), B (1,860 TEU, ME: 18,058kW, AE: 990kW x 3 sets), C (1,103 TEU, ME: 7,300kW, AE: 660kW x 3 sets), D (1,891 TEU, ME: 13,860kW, AE: 900kW x 3 sets), E (1,022 TEU, ME: 11,436kW, AE: 660kW x 3 sets), F (954 TEU, ME: 7,860kW, AE: 650kW x 3 sets), G (1,060 TEU, ME: 9,988kW, AE: 700kW x 3 sets). Generally, in 2017, there were 609 container ships entered the port, and the average gross tonnage was estimated at 11,810 tons, the average main engine power was 9,382kW, the average auxiliary engine was 818kW, the average berthing time was 13 hours, the average speed was 10 knots (18.5km/h), and the average traveling distance was 11km.

LFME and LFAE are load factors for the main engine and the auxiliary engine when cruising, maneuvering, and hoteling (%). Load factor values were provided by consulting the port guide captain who enables the vessels to securely approach at the Daesan port. According to the information, average main and auxiliary engine load factors were obtained for the operation mode of each ship (cruising, maneuvering, hoteling) and these values are presented in Table 2.

Table 2: Load factors of main and auxiliary engines

Operational Mode	ME load	AE load
Cruising	40%	40% (2 sets)
Maneuvering	40%	50% (2 sets)
Hoteling	0%	40%

Source: interview result from port guide captain

Emission factors are used to relate the emitted quantity of a certain pollutant with the energy spent by the ship's engines during a certain activity. The values used in this study were taken from other studies (Limited, 2005). Emission factors for the different pollutants were assigned according to operational modes (cruising, maneuvering, and hoteling), illustrated in Table 3.

Table 3: Emission factors for container ship (g/kWh)

Pollutant	Cruising	Maneuvering	Hoteling
NO_x	17.3	13.8	13.5
SO_2	10.8	12.0	12.3
CO_2	635	705	720
HC	0.57	1.19	0.5
PM_{10}	1.56	1.73	0.9

Source: ENTEC UK Limited, "Preliminary assignment of ship estimations to European countries", Final Report, 2005

In order to calculate the volume of air emissions (CO, VOC, NOX, PM10, PM2.5, and CO2) from container trucks entering and exiting Daesan port, the emission coefficient formula suggested by the National Academy of Environmental Sciences (National Air Pollutant Emission Calculation Method Handbook) was applied. The suggested model to estimate the volume of emissions from each pollutant was expressed as $\alpha \times V\beta$, in which V denotes the average speed, α and β denote the coefficients. The detailed formula was listed in Table 4. In the case of CO2, because it was not considered an air pollutant defined by the National Institute of Environmental Research, its own emission formula was not provided. Therefore, the emission coefficient formula for CO2 suggested in the Railroad Investment Evaluation Manual was used.

Table 4: Emission coefficient formula of container truck

Pollutant	Year built	Formula
CO	Before 1995	$30.402xV^{-0.4685}$
	1996 ~ 1997	$18.101xV^{-0.3454}$
	1998 ~ 2002	$28.399xV^{-0.5999}$
	After 2003	$52.136xV^{-0.8618}$
VOC	Before 1995	$15.750xV^{-0.582}$
	1996 ~ 1997	$10.301xV^{-0.5856}$
	1998 ~ 2002	$10.031xV^{-0.5828}$
	After 2003	$3.788xV^{-0.5425}$
NO_x	Before 1995	$117.490xV^{-0.365}$
	1996 ~ 1997	$94.319xV^{-0.4061}$
	1998 ~ 2002	$85.301xV^{-0.4023}$
	After 2003	$107.500xV^{-0.5679}$
PM_{10}	Before 1995	$7.621xV^{-0.4183}$
	1996 ~ 1997	$6.026xV^{-0.4627}$
	1998 ~ 2002	$4.873xV^{-0.4382}$
	After 2003	$3.754xV^{-0.4055}$
$PM_{2.5}$	Before 1995	$7.012xV^{-0.4183}$
	1996 ~ 1997	$5.544xV^{-0.4627}$
	1998 ~ 2002	$4.483xV^{-0.4382}$
	After 2003	$3.454xV^{-0.4055}$

Source: National Air Pollutant Emission Calculation Method Handbook

Because the emissions from container trucks depend on their age, the actual database on the vehicle age is required. However, since it was difficult to obtain the data, the age distribution of trucks nationwide is applied through the vehicle registration statistics of the Ministry of Land, Infrastructure, and Transport to calculate the exhaust gas, which is shown in Figure 2. As can be seen in the graph, most trucks registered were built after 2003.

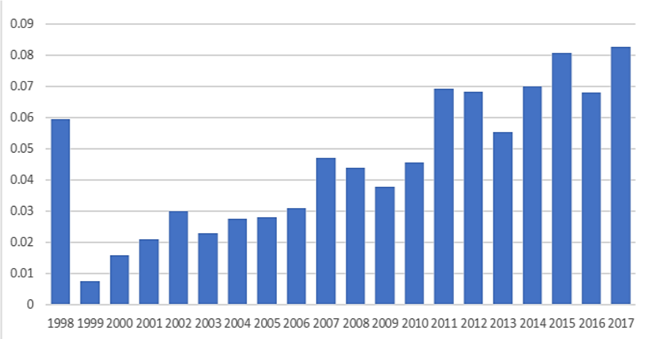
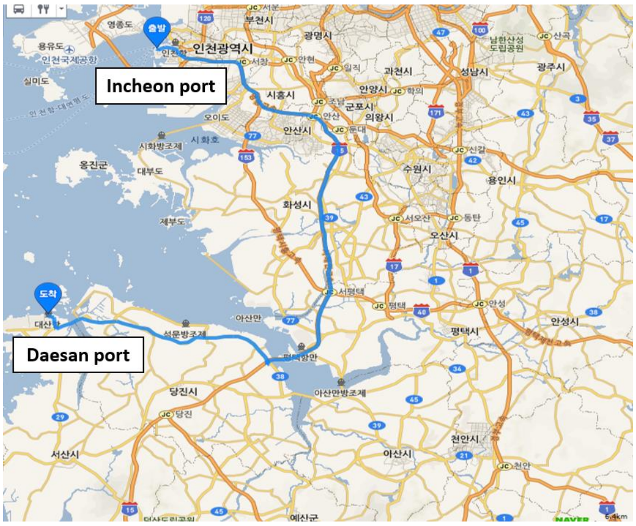


Figure 2: Distribution of truck age

Source: Ministry of Land, Infrastructure and Transport

There are 6 main routes of container trucks operating in Daesan port, which are presented in Figure 3 below.



(Route 1): Daesan port → Yeongdong Expressway → Siheung Expressway → Dangjin Buksaeng-ro → Chorak 2-ro → Incheon port

(Route 2): Daesan port → Chungui-ro → Munhyeon-ro → Jinbeol-ro → Won-ro → Taean

(Route 3): Daesan port → Daejuk 1-ro → Samgilpo 1-ro → Daehoman-ro → Danjin

(Route 4): Daesan port → Daehoman-ro → Seohaean Expressway → Chungseo-ro → Boryong

(Route 5): Daesan port →Seohaean Expressway → Dangjin Buksansae-ro → Chorak 2-ro → Pyeongtaek port

(Route 6): Daesan port → KCC → Daejuk intersection → Dokgot intersection → Seosan

Figure 3: Main routes of container truck operating in Daesan port

The detailed information on travel distance, travel time, average speed, and frequency of entry and exit were also shown in Table 5. While route 1 and route 4 registered the longest traveling distance and time, route 6 was the busiest route in 2017 with more than 33 thousand of trucks. The average speed in all routes was calculated at from 30.9 km/h to 43.5 km/h.

Table 5: Information on main routes of container trucks operating in Daesan port

Route	Distance (km)	Time (minutes)		
		Off-peak hour	Peak hour	Average
1	125	110	180	145
2	58	70	90	80
3	14	20	25	22.5
4	105	120	180	150
5	61	70	100	85
6	9	15	20	17.5

Table 5: Information on main routes of container trucks operating in Daesan port (cont.)

Route	Number of truck entry/exit (2017)	Speed (km/h)		
		Off-peak hour	Peak hour	Average
1	191	49.7	38.7	43.5
2	11,182	49.7	38.7	43.5
3	11,971	42.0	33.6	37.3
4	1,114	52.5	35.0	42.0
5	616	52.3	36.6	43.1
6	33,064	36.0	27.0	30.9

3. Result

The results of emission inventory from a container ship at Daesan port area in 2017 calculated by adapting the methodologies above in 3 operating modes (Cruising – C, Maneuvering – M, Hoteling – H) are now presented in table 6.

Table 6: Ships exhaust emission at Daesan port

Unit: tons/year

	C	M	H	Total	
				Method 1	Method 2*
NO_x	58.3	40.6	37.9	136.8	101.8
SO_2	36.4	35.3	34.6	106.3	51.1
HC	1.9	3.5	1.4	6.8	11.3
PM_{10}	5.3	5.1	2.5	12.9	7.5
CO_2	2140	2072	2024	6,236.7	4,573.3

Remark: * calculated based on emission factor for bunker fuel oil and regression equation by Thanh Le et al. (2019)

The total amount of emitted in-port ship emissions was about 6,500 tons. Specifically, 137 tons of NOx, 106 tons of SO2, 7 tons of HC, 13 tons of PM10, and 6,237 tons of CO2 were calculated by method 1 using the bottom-up method. Compared with the results estimated from method 2, the emission volume was relatively smaller at only 4,745 tons. This can be explained by method 2 was built to mainly estimate the fuel consumption rate on the open sea route, not inside the port area.

Table 7 presents the volume of air emission from container ships in Daesan port, using the data on the number of ships entering and departing in the period from 2011 to 2017. The overall trend is increasing with an average increase percentage of 10.9%/year.

Table 7: Ships exhaust emission at Daesan port

Year	Emission volume (Unit: tons/year)
2011	3,488.3
2012	4,114.4
2013	3,885.8
2014	4,998.8
2015	6,429.9
2016	6,658.5
2017	6,499.5

Economically, to understand the severity of damage to the coastal area near the port of Daesan, the environmental costs should be estimated. Based on the previous study by Lee (2016). The cost per unit was suggested as follows: NOx was 10,196 KRW/ton, SO2 was 11,452 KRW/ton, HC was 9,849 KRW/ton, PM was 33,289 KRW/ton and CO2 was 79 KRW/ton. In 2017, the total cost from container ship emissions in Daesan port was estimated at nearly 3.6 billion KRW, which was 2.6% compared to the 136.9 billion KRW for Busan Port (container ship) estimated by Lee (2016) in 2012.

Besides, in the extent of this study, an estimation of air pollution emitted from container trucks entering and exiting Daesan port was also calculated. The results were presented in Table 8.

Table 8: Container truck air pollution emissions

Route	**Pollutant** (Unit: kg/year)		
	CO_2	**CO**	**VOC**
1	25,350.6	47.6	12.4
2	688,640.7	1,475.3	372.0
3	188,854.2	429.0	104.7
4	125,814.4	273.3	68.4
5	40,032.6	86.1	21.7
6	363,281.5	878.7	205.9
Total	**1,431,974.0**	**3,190.0**	**785.1**

Table 8: Container truck air pollution emissions (cont.)

Route	**Pollutant** (Unit: kg/year)		
	NO_x	**PM_{10}**	**$PM_{2.5}$**
1	294.7	7.7	7.1
2	8,781.0	231.1	212.6
3	2,464.3	65.0	59.8
4	1,613.8	42.5	39.1
5	511.3	13.5	12.4
6	4,833.0	127.8	117.6
Total	**18,498.1**	**487.6**	**448.6**

In 2017, the total volume of air emissions from container trucks in and out of Daesan port was estimated at 1,455.4 tons. CO_2 accounted for the largest proportion, of which 1,432 tons were released into the air, followed by NOx with 18.5 tons, CO with 3.2 tons, and VOC, PM10, and PM2.5 with less than 1 ton. Among 6 routes, Daesan port - Taean route generated the most amount of air emissions.

When considering the economic damage from emissions, the environmental cost of container trucks in 2017 was also estimated. The cost unit was adapted from the study suggested in Transportation facility investment evaluation guidelines (6th revision), in which CO_2 was 45 KRW/ton, CO was 163 KRW/ton, VOC was 2,398 KRW/ton, NOx was 16,294 KRW/ton and PM2.5 was 43,044 KRW/ton. The total cost of air pollution generated by container trucks entering and leaving Daesan Port is approximately 390 million won/year.

4. Conclusion

Due to the increase in container throughput and the number of container ship arrivals and departures recently in Daesan port, this study aimed to estimate the ship emissions based on the activity-based methodology during 2017. According to the results, about 6,500 tons of air pollution from container ships were emitted, in which NOx was 136 tons, SO_2 was 106 tons, HC was 6.8 tons, PM was 12.9 tons and CO_2 was 6,236 tons. Also, it was found that the annual average increase in air emissions was about 11%. Besides, container trucks operating in Daesan port area released 1,455 tons into the air, in which NOx was 18.5 tons, VOC was 0.79 tons, CO was 3.19 tons, PM10 was 0.49 tons, PM2.5 was 0.45 tons, and CO_2 was 1,432 tons.

On the other hand, when converting into environmental costs, a total of 4 billion won (about 3.6 billion won from container ships, and about 400 million won from container trucks) was estimated. In the case of environmental costs from container ships, it accounted for a very small portion at 2.6% of Busan Port. Among the 6 main routes mentioned in this study, Daesan port - Taean route generated the most amount of air emissions.

In the future, it is important to study emissions from all Korean ports, which will allow making a total assessment of atmospheric emissions from ships in the Korean coastal area. Besides, the accuracy of this emission inventory is dependent on the input data used and the assumptions made, such as ship speed, ship specification (ME, AE), loading factor, and emission factor. Further work is needed to improve the outcomes of this study and minimize the scale of uncertainties. Improves could be achieved with the use of higher-resolution input data, such as the Automatic Identification System data (AIS) or the actual power of ME, AE, and the precise value of LF and EF.

References

Chang, Y. T., Song, Y., & Roh, Y. (2013). Assessing greenhouse gas emissions from port vessel operations at the Port of Incheon. Transportation Research Part D: Transport and Environment,25,1–4. https://doi.org/10.1016/J.TRD.2013.06.008

Coello, J., Williams, I., Hudson, D. A., & Kemp, S. (2015). An AIS-based approach to calculate atmospheric emissions from the UK fishing fleet. Atmospheric Environment, 114, 1–7. https://doi.org/10.1016/J.ATMOSENV.2015.05.011

IMO. (2011). Energy Efficiency Measures. http://www.imo.org/en/OurWork/Environment/Pages/Technical-and-Operational-Measures.aspx

IMO. (2020). IMO 2020 – cutting sulphur oxide emissions. https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx

Kesgin, U., & Vardar, N. (2001). A study on exhaust gas emissions from ships in Turkish Straits. Atmospheric Environment,35(10),1863–1870. https://doi.org/10.1016/S1352-2310(00)00487-8

Khan, S., Chang, Y.-T., & Lee, S. (2018). Assessment of greenhouse gas emissions from ships operation at the Port of Incheon using AIS. Journal of Korea Port Economic Association, 34(1), 65–80.

Kim, H., & Dang, B. H. (2020). Estimation of Ship Emission based on Data of Ship's In and Out of Port. Journal of Korean Institute of Intelligent Systems, 30(6), 453–458. https://doi.org/10.5391/jkiis.2020.30.6.453

Lee, H., Park, D., Choo, S., & Pham, H. T. (2020). Estimation of the non-greenhouse gas emissions inventory from ships in the port of incheon. Sustainability (Switzerland), 12(19). https://doi.org/10.3390/su12198231

Lee, M.-W., & Lee, H. (2016). Estimation of Ship Emissions and Environmental Costs : focusing on Port of Busan. In

Journal of Korea Port Economic Association (Vol. 32, Issue 4).

Lee, M.-W., & Lee, H.-S. (2018). A study on atmospheric dispersion pattern of ship emissions – Focusing on Port of Busan. 한국항만경제학회지, 34(1), 35–49. https://doi.org/10.38121/KPEA.2018.03.34.1.35

Lloyd's Register. (2020). South Korea - Designation of SOx Emission Control Areas (SECA) and Speed Reduction Program. https://info.lr.org/l/12702/2020-05-06/8z5p3n

McArthur, D. P., & Osland, L. (2013). Ships in a city harbour: An economic valuation of atmospheric emissions. Transportation Research Part D: Transport and Environment, 21, 47–52. https://doi.org/10.1016/j.trd.2013.02.004

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. Atmospheric Environment, 76, 102–112. https://doi.org/10.1016/J.ATMOSENV.2012.07.070

Nunes, R. A. O., Alvim-Ferraz, M. C. M., Martins, F. G., & Sousa, S. I. V. (2017). The activity-based methodology to assess ship emissions - A review. Environmental Pollution, 231, 87–103. https://doi.org/10.1016/J.ENVPOL.2017.07.099

Shin, K., & Cheong, J. P. (2011). Estimating transportation-related greenhouse gas emissions in the Port of Busan, S. Korea. Asian Journal of Atmospheric Environment, 5(1), 41–46. https://doi.org/10.5572/AJAE.2011.5.1.041

Song, S. (2014). Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port. Atmospheric Environment,82,288–297. https://doi.org/10.1016/j.atmosenv.2013.10.006

Thanh Le, L., Lee, G., Kim, H., & Woo, S.-H. (2019). Voyage-based statistical fuel consumption models of ocean-going container ships in Korea Voyage-based statistical fuel consumption models of ocean-going container ships in Korea. Maritime Policy & Management. https://doi.org/10.1080/03088839.2019.1684591

Trozzi, C. (2010). Emission estimate methodology for maritime navigation.

Tzannatos, E. (2010). Ship emissions and their externalities for the port of Piraeus - Greece. Atmospheric Environment, 44(3), 400–407. https://doi.org/10.1016/J.ATMOSENV.2009.10.024

Tzannatos, E. (2011). Ship generated exhaust emissions and their externalities for Greece. 2.

Woo, D., & Im, N. (2021). Spatial Analysis of the Ship Gas Emission Inventory in the Port of Busan Using Bottom-Up Approach Based on AIS Data. Journal of Marine Science and Engineering 2021, Vol. 9, Page 1457, 9(12), 1457. https://doi.org/10.3390/JMSE9121457

Received **31 May 2022**

Revised **21 June 2022**

Accepted **23 June 2022**