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AIS를 활용한 인천항 선박의 온실가스 배출량 추정*

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Assessment of greenhouse gas emissions from ships operation at the Port of Incheon using AIS

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Abstract

This paper attempts to estimate GHG emissions, primarily CO_2 ship emissions, at the port of Incheon in October 2014. This study employed a bottom-up approach based on Automatic Identification System (AIS) data to estimate the total amount of fuel consumption and the total amount of CO_2 emission produced as a result of fuel combustion. Using a sample of 330 ships operating at the port of Incheon in Korea, the total amount of CO_2 gases emitted from ships in October 2014 were estimated to be 164693.06 tons, with estimated total fuel consumption of 51953.64 tons. General cargo ships were most common type of ships, but they were less polluting compared to passenger ships. The detailed emission estimates by ship type revealed that passenger ships were the most polluting ships (81409.6 tons of emissions), followed by tugboats (37248.4 tons), cargo ships (32154.6 tons), ships used for other activities (9039.1 tons), chemical tankers (4027.06 tons), and fishing ships (814.048 tons), respectively.

Key words: AIS, GHG, Ship CO_2 Emission, Incheon Port, Bottom-up Approach

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Ⅰ. Introduction

Many studies have been conducted to measure ships exhaust emissions and to quantify their contribution to overall atmospheric pollution and resulting climate change or global warming. The findings suggested that due to increasing maritime traffic, ship exhaust emissions have become a significant source of atmospheric pollution. Emissions from maritime traffic contribute a very small portion of the total atmospheric pollution compared to that of rail and other means of land and air transportation though.

The shipping industry has become a key component of the global trade and world' s economy. More than 80% of global trade is carried by sea. Ship transportation is generally considered as an environmentally friendly mean of transportation. However, the relative share of emissions from shipping has increased during the past years due to rapid technological advancement compared to land and air transportation and other industries. The ships are enlarged with more load carrying capacity. On the other hand, there is an increasing concern of climate change and global warming at societal, corporate and governmental levels. One of the biggest challenges for governments both at national and international level is to reduce or limit the emissions of greenhouse gases (GHG), mainly CO_2.

Several studies suggest that ship emissions have become major source of air pollution for cities adjacent to main ports and these emissions have negative effects on local residents causing acid rains and degrading air quality and leading to severe health problems such as cardio and respiratory diseases in common. However on a larger scale, according to recent report issued by United Nation Office for Disaster Risk Reduction (UNISDR) titled "The Human Cost of Weather Related Disasters" reveals that on average 335 weather-related disasters were recorded per year between 2005 -14, an increase of 14% which is almost double compared to the level recorded during 1985-95. 87 million homes were damaged or destroyed over the period of the survey. The report also highlights that 2.3 billion people were affected by floods and killing 157,000; While storms affected 330 million people and killed 242,000, drought affected 1.1 million people and killing 22,000 people; While 94 million were affected by extreme temperature killing 164,000 people and similarly 8 million were affected and 20,000 were killed by land sliding and wildfire. These all weather related disasters were a result of global warming and associated with high CO_2 emissions.

The objective of this study is to measure GHG particularly CO_2 emissions from ships at the port of Incheon.

The paper is structured as follows. Section 2 overviews the literature on estimation of ships emissions. Section 3 describes data and methodology adopted in the study. Section 4 discusses the empirical results. Finally the paper concludes suggesting areas for further research.

II. Literature Review

Various studies on GHG emissions from ships operation were undertaken in different ports of the world.

Ugur Kesgin and Nurten Vardar (2001) conducted a study on exhaust gas emissions from ships in Turkish Straits, namely Bosphorus and Canakkale in Istanbul. In this paper, the general characteristics, the main engine systems, the fuel types, cruising times and speeds of all ships were taken into account for calculating fuel consumption. The results show that the transit ships caused more than half the total amount of emissions from ships on the Bosphorus, as calculated NOx emissions on the Bosphorus were 2720 t from domestic passenger ships and 4357 t from transit ships.

J. Isakson et al. (2001) measured ship emissions and their effects in the harbor of Goteborg in Sweden using multivariate analysis. From 250 ship plumes annual emissions of SO_2 and NO_2 were estimated to be 220 and 115 kg $km^{-2}yr^{-1}$. Environmentally Heavy Metal Pollutants were positively correlated with Nitrous oxide emissions from ships.

D.A. Cooper (2003) investigated exhaust emissions from six ships at berth and during their usual operations, such as hoteling, unloading and loading activities. The results indicate significant changes between different engines among different ships, as well as for the same type of engines used on board. Also emissions from boiler use and possible main engine warm up before departure were less compared to those smaller auxiliary engines. Furthermore, the results obtained for the three passenger ferries suggested that empirically derived, emission formulae using dead weight tonnage can be accurate for harbour emission inventories.

H. Saxe and T. Larsen (2004) conducted a study using operational meteorological air quality model to calculate the urban dispersion of air pollutants emitted from ships in three sea ports of Denmark, namely Copenhagen, Elsinore and Koge. The ships in both Copenhagen and Elsinore harbour's contributed considerably less to urban pollution with SO_2 after the implementation of expected regulations on sulphur content in bunker fuels. However, PM10 emissions from ships in Copenhagen potentially led to health problem for residents living or working close to the harbour (0.2-0.4% EC's limit). On the other hand due to low activity in the Koge harbour the resulting impact on urban air quality was insignificant.

Satish Vutukuru and Donald Dabdub (2008) performed a study for modeling the effects of ocean going ships emission on ozone and coastal air quality of Southern California. The PM concentrations were measured using UCICIT model for the year 2002 and simulated forecast was generated till 2020. The results revealed that controlling ships emissions reduced air pollution and forecasted impact areas were along the coast and as well as inland locations.

S. B. Dalsøren et al. (2009) took into account ships' different specifications along its global port arrival and departure based on data set of 32000 merchant ships and about 2 million global ship observations. The fuel consumption methodology was used to make global emission inventories for a wide range of pollutants distributed geographically. Furthermore, a global Chemical Transport Model (CTM) was used to calculate the environmental impacts of the emissions. The results show that ship emissions were also major source of pollution for world' s ocean to surface concentration of nitrogen dioxide and sulphur dioxide and these emissions had severe impact on ozone in some regions. Emissions were concentrated at large over coastal zones. The container ships traffic was the largest emitter by ship type and made most impacts, followed by bulk ships and tank ships.

Cengiz Deniz and Alper Kilic (2009) examined exhaust gas emissions from ships in one of the main ports in Marmara Sea , Ambarlı port, Turkey, for the base year of 2005. The study estimated total emissions consisting of different pollutants from ships in the port area and a model program was used to estimate the dispersions of those emissions, with the real topographic and meteorological conditions. The results suggested that emissions contributed 100 μgm^{-3} NOx and 55 μgm^{-3} SO_2 to ambient air concentrations in range of 2 km from the port. This highlights the possibility of affecting people around 60000 estimated to be living within that range due to combination of different sources.

Warren B. Fitzgerald et al. (2011) assessed GHG from New Zealand' s international maritime transport of goods, mainly their import and export. The results differed between activity based and fuel based methodologies in measuring a single country's emissions.

Ernestos Tzannatos (2010) conducted a study using fuel based methodology to assess exhaust emissions for 25 years for both international and domestic shipping within Greek Sea' s and also monetized their externalities for 2008. The result finding suggest annual average increase rate of 2.85% from ships emissions which were estimated to be 12.9MT with externalities of 3.1€ billion Euros.

Ernestos Tzannatos (2010) carried out a similar study to estimate ships exhaust emissions and quantify externalities using activity based approach at the port of Piraeus for 2008-09. The annual emissions of pollutants reached up to 2600 tons, whereas the externalities were up to 51 million Euros during the study period.

Volker Matthias et al. (2010) assessed the impact of emissions in Northern Sea' s coastal areas, using a three dimensional Eulerian chemistry transport model for 2000. Germany and Denmark were more affected in the region due to pollutants from ships emissions. Furthermore, SO_2 was condirably reduced due to implementation of sulphu emission control area (SECA).

Veronika Eyring et al. (2010) examined the impact of ship emissions on atmosphere and climate. The emissions spaning within range of 400km affected air quality and mostly coastal population. The results also indicate that decreasing sulphur emissions would result in decrease in their negative radiative forcing at regional level as well.

Apollonia Miola and Biagio Ciuffo1 (2011) analyzed several studies on grounds of different approaches and different data sources that were used, for the purpose of modeling. The finding reveals that estimation of emission based on fuel statistics leads to underestimation, and also there is a degree of uncertainty among the results due to different methodologies and different data sources were used, so further investigation was required using a detailed bottom-up approach.

This study also emphasized on use AIS data and also presented a systematic approach for using different data sources for both domestic as well as international shipping to obtain accurate results.

D. Contini (2011) measured the impact of ships traffic on atmospheric levels and resulting particulate matters (PM) and polycyclic aromatic hydrocarbons (PAHs) at harbour of Venice, using high temporal resolutions along with data on wind direction and information on ships passages. The results show PM levels contributed from 1 to 8% while the PAH's contribution was up to 10% in gaseous state.

Gara Villalba and Eskinder Demisse Gemechu (2011) estimated GHG from ships emissions at the port of Barcelona including both land and sea based emissions for 2008. The results shows 331MT of CO_2 Equivalent emissions, 50% of which were assigned to ships movement at sea while remaining half were ascribed to land based emissions. The highest emitters were auto car carriers based on cargo handled.

Joseph Berechman and Po-Hsing Tseng (2012) conducted a study using bottom-up approach to measure environmental cost arising from ships emission in the port of Kaohsiung, Taiwan, for 2010. The main polluters were tankers, container ships and bulk carrier followed by trucks and the environmental cost for both ships and trucks were over 123$ million dollars annually.

P.S. Yau et al. (2012) measured exhaust emissions from ocean going ships in Hong Kong, by performing activity based approach and using AIS data for 2007. Showing total emissions of 37150t the regions close to East Lamma channel and container port were identified as highest emission locations using spatial allocation.

Clara Schembari et al. (2012) conducted a study based on instruction of European Union, requiring them to estimate air pollution in Mediterranean harbour's for 2010. It measured the effect after the implementation of Sulphur Emission Control Areas (SECA), in which ships were directed to use fuel having sulphur content less than 0.1%. The study found 66% reductions in SO_2 emissions on daily basis for the 3 harbours except Barcelona harbour.

Ching-Chih Chang and Chih-Min Wan (2012) estimated emissions to analyze the effectiveness of green port policies and appraised different strategies for Kaohsiung harbor in Taiwan used for reducing pollutants. The studies suggested a strategy of decreasing ship speed to 12knots, in order to reduce fuel consumption and their resulting emissions. Also using land based power for ship for their onboard activities could reduce CO_2 by 57 % whereas PM up to 39%.

Halil SaraçoLlu et al. (2013) used ships activity based method to investigate ships exhaust emissions for the port of Izmir, Turkey. The ships calling Izmir port were the main source of air pollution in the area which could possibly affect the local population.

Chang et al. (2013) measured GHG emissions from ships operations using bottom up approach based on individual ship characteristics and using the data on ships processed by Incheon Port for 2012. The emissions were 5 times higher compared to the emission results obtained through top down approach. The key polluting ships were identified as international car ferries followed by full container ships and the key polluting activities were passing through lock gates and approaching the dock which together accounted for 96% of the total emissions.

Minjiang Zhao et al. (2013) conducted a study to identify air pollutants due to marine traffic and their characteristics for the Port of Shanghai. On average hourly SO_2 and NO_2 concentrations in Shanghai Port were 29.4 and 63.7㎍m^{-3} respectively, and average daily concentrations of TSP and $PM_{2.5}$ were 114.39 and 62.60 ㎍m^{-3}. Furthermore ship traffic had a significant contribution to atmospheric levels of fine particles.

P.S. Yau et al. (2013) investigated the contribution of ships emissions that resulted in fine particulate in community surrounding at the port of Hong Kong for the period of Aug 2009 to Mar 2010. Samples of PM were selected from both residential as well as from the port area and PMF analysis was used to identify eight potential sources. The proportion of ships emissions to $PM_{2.5}$ was 7.6㎍m^{-3} which accounted for 25% compared to average total of 30.5㎍m^{-3}.

Sang Keun Song and Zang Ho Shon (2014) used activity based method to analyze exhaust emissions from ships at Busan port for the period of 2006-09, and also forecasted emissions for the year 2020 and 2050. The findings revealed that majority of emissions were related to container ships and were observed near port area. The forecasted emissions were estimated to be 6 times higher compared to that of base year 2009.

Fan Zhang et al. (2014) carried out a study to identify and measure emissions from ships at Bohai Rim, using air mass analysis together with temporal distribution. The fine particles concentration during spring season was more compared to that of winter.

Chang et al. (2014) conducted a detailed study using bottom up approach to measure noxious gasses from ships operation at the port of Incheon. International car ferries and full container ships were high polluter and the majority of the emissions were observed during the cruise phase. However, the study only addressed measuring noxious gases, but not the CO_2 emissions, which are major contributor to the global warming and climate change.

Jonathan Coello et al. (2015) measured atmospheric emissions resulting from a group of fishing ships in UK, using both AIS activity and fuel based methodologies. The AIS activity based emission results were significantly high while the fuel based emission results were much lower.

In short, very limited studies have been carried out in this field, using various methodologies and data sources. Reviewing the literature reveals that the use of top-down approach (based on fuel statistics) leads to underestimation of emissions while bottom-up is more appropriate methodology resulting in accurate estimation of emissions.

Most studies were focused on domestic ports, because the pollutants have more negative impact on nearby residents compared to those in open seas. Moreover, few studies were undertaken to formulate policies and strategies to reduce noxious gasses emission as well as other GHG such as CO_2 that is main source of global warming.

This research has originality and contributions to the literature in that using bottom up approach based on the AIS data at the Port of

Incheon as previous studies employed mostly top-down approach or non-AIS based bottom-up approach. Summary of comparisons among existing works can be seen in Appendix.

Ⅲ. Data Description and Methodology

Different methodologies and data sources can be used to estimate fuel consumption and their resulting emissions as outlined previously in literature review. This study employed AIS data and the sample consisted of 330 ships out of total 602 ships which operated at the port of Incheon during the period of October, 2014. The data was collected in cooperation with the Incheon Port Authority and the Korea Maritime Institute. In total 272 ships were excluded due to missing data, in which 3 were hazard goods ship and 4 were pilot boats and other 263 were excluded due to the lack of information on gross tonnage; engine load factor; its design and operating speed. Some ships with gross tonnage less than 300 (GT) were not equipped with AIS system so had to be excluded. The IMO' s International Convention for the Safety of Life at Sea, requires international voyaging ships with gross tonnage of 300 or more tons to have an AIS system, and for all passengers ships it is mandatory regardless of size.

AIS is a technical system that makes it possible to monitor ships from other ships, and from shore based stations. AIS-equipped ships continuously transmit a short message containing information of position, course over ground (COG), speed over ground (SOG), heading, etc.

This study used AIS- based bottom up approach taking into consideration the type of ship along with its specification. The detailed date, time stamp information and speed on ground (operating speed) obtained from AIS data for each ship were thoroughly investigated and were used to calculate exact time spent (hours) and the distance[1)] covered (NM) by individual ship.

The Date and Time information was provided in the form of a UNIX date (14 digits) rather than the more familiar YYYY/MM/DD HH:MM:SS format. Firstly it was converted into "YYYY-MM-DD HH:MM:SS" format and later on calculated the difference between two time stamps/or intervals (rt= t2-t1) and expressed it into seconds and later on converted into hours to be used for calculating distance by multiplying speed (nm) by time in hours.

First of all, we had to estimate the total amount of fuel consumed by each ship during its motion of each activity or stage. Corbett et al. (2009) estimated a ship' s fuel consumption for a given navigation distance by considering the amount of fuel required for main and auxiliary engines on a daily basis. Fuel consumption by the main engine follows the cubic law of the design and operational speed. Chang and Wang (2012) and Chang et al. (2013) both employed the same methodology to estimate GHG emissions at Kaohsiung harbor and port of Incheon, respectively. However, the two previous papers did not use AIS data, which enables us to estimate the emissions more accurately. The data on main engine power; auxiliary engine power; fuel

1) D (distance in nautical miles) = Speed (knots) x Time (hours)

consumption rate; load factor; ship design speed were obtained from previous study of Chang et al. (2013) which is listed in Table 1. That covers most of the ships operated at the port of Incheon. This approach holds the idea of capturing fuel consumptions of the engines (main and auxiliary) between location points in a leg.

Table 1. Data on Engine Operating Speed and Design Speed

	Ships Type	Gross T	MCR	Operating Speed (NM/h)	Design Speed(km/h)
1	LNG	93,765	0.88	20.3	42.9
2	LNG	4,693	0.88	15.0	31.7
3	Tug	4,480	0.85	16.2	35.3
4	Passenger	21,005	0.85	18.0	39.2
5	Chemical Tanker	1,174	0.88	12.0	25.3
6	Tug	1,174	0.88	12.0	25.3
7	Chemical Tanker	4,693	0.88	15.0	31.7
8	General Cargo	1,174	0.88	112.0	25.3
9	Refrigerated Cargo	3,886	0.85	19.0	41.4
10	Bulk Dry	1,174	0.88	12.0	25.3
11	Bullk Dry	28,707	0.88	14.8	31.2
12	Chemical Tanker	4,693	0.88	15.0	31.7
13	Container	4,450	0.90	15.6	32.1
14	Bulk Dry	4,450	0.90	15.6	32.1
15	Passenger	10,067	0.90	14.7	30.1
16	Other Fishing	4,480	0.85	16.2	35.3
17	Chemical Tanker	51,793	0.90	14.0	28.8
18	Gerneral Cargo	4,450	0.90	15.6	32.1
19	Ro-Ro	50,938	0.85	22.0	47.9
20	Chemical Tanker	4,693	0.88	15.0	31.7
21	Other Activities	1,898	0.88	11.0	23.2
22	Container	25,800	0.90	21.0	43.2

The fuel consumption by a ship at each stage of its port movement is denoted as:

$$F_{ijk} = [MF_k \cdot (\frac{S_{1k}}{S_{0k}})^3 + AF_k] \cdot \frac{d_{ij}}{24 s_{1k}} \quad \text{Eq}^{2)}.(1)$$

Whereas,

F_{ijk} = is the amount of fuel consumed by ship k moving from point i to j;

MF_k = is the daily fuel consumption by the main engine;

AF_k= the daily fuel consumption by the auxiliary engine;

S_{1k} = the ship's operating speed[3)] (nm/h);

S_{0k} = is the ship's design speed (nm/h) and

d_{ij}=is the distance from i to j.

Secondly, after measuring the fuel consumptions, the next step was measuring GHG using conversion factors. Normally CO_2 emissions are measured based on fuel combustion. For the purpose of simplicity, it was assumed that all the ships were using bunker fuel, although different type of fuel could be used considering the type of ship, (in general, the bunker fuel is widely used and contains 86.4% of carbon per unit weight). In addition, the ratio of CO_2 to carbon is known to be 44/12.

Therefore, CO_2 emissions from fuel combustion can be estimated as follows:

2) All the equations are adopted from Chang, Y., Song, Y., & Roh, Y. (2013), Assessing greenhouse gas emissions from port ship operations at the Port of Incheon. *Transportation Research Part D,* 25, pp.1-4.

3)Operating Speed was already given for each ship at each date-time stamp and denoted by "speed on Ground". Only values for designed speed were obtained from the table 1.

$$CO_2 = (0.8645)\cdot(\frac{44}{12})\cdot\Sigma_{i,j,k}F_{ijk} = 3.17 * \Sigma_{i,j,k}F_{ijk}$$

Eq.(2)

$$CO_2 = 3.17\cdot\Sigma_{i,j,k}[MF_k\cdot(\frac{S_{1k}}{S_{0k}})^3 + AF_k]\cdot\frac{d_{ij}}{24s_{1k}}$$

Eq(3)

IV. Empirical Results

The total amount of fuel consumed by all the ships (330) from the movement of its arrival to departure was estimated to be 51953.6 tons. The ship call figures in Table 2 show that the general cargo ships used the port of Incheon most frequently, followed by chemical tankers; tug ships; passenger ships and fishing ships respectively. Furthermore, the AIS data stamp information and additional parameters such as information on speed on ground "operating speed of the ships" indicated that 21 ships were stationary while 309 were moving during the period of study.

Table 2. Ships Status and ship Calls

S /No.	Ships Type	Moving	Stop	ship Calls
1	Cargo Ships	149	11	160
2	Fishing ships	9	2	11
3	Other ships	56	5	61
4	Passenger Ships	23	0	23
5	Chemical Tankers	43	0	43
6	Tug Boats	29	3	32
		309	21	330

The major portion of fuel was consumed by Passenger Ships (25681.2 tons), followed by Tugboats (11750.3 tons); Cargo Ships (10143.4 tons); Other ship's (2851.4 tons); Chemical tankers (1270.3 tons) and Fishing ships with 256.7 tons, respectively (see Table 3 and Figure 2).

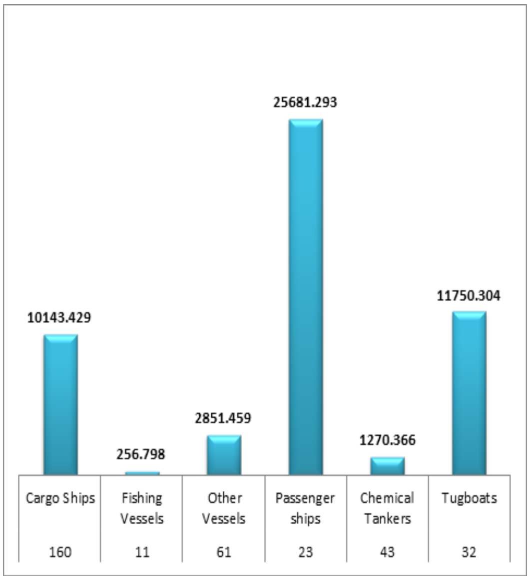
It should be noted that the Passenger ships consumed greatest amount of fuel due to their main engine power compared to that of other ships. On the other hand, the cargo ships outnumbered passenger ships.

Table 3. Estimation of the fuel consumption by ship type

unit : ton

S/ No.	No. of Ships	Ship Type	Fuel Consumption	Average Per Unit
1	160	Cargo Ships	10143.429	63.396
2	11	Fishing ships	256.798	23.345
3	61	Other ships	2851.459	46.745
4	23	Passenger ships	25681.293	1116.578
5	43	Chemical Tankers	1270.366	29.543
6	32	Tugboats	11750.304	367.197
	330	Total Fuel Consumption	51953.649	

Figure 2. Fuel Consumption by ship type



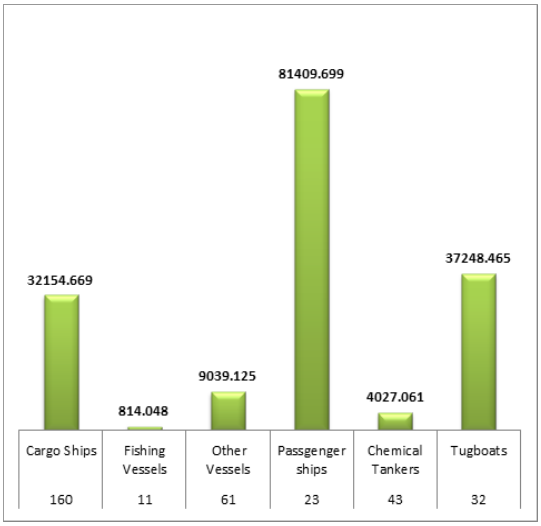
As for CO_2 emissions by ship type most CO_2 was emitted by Passenger Ships (81409.6tons), followed by Tugboats (37248.4tons); Cargo Ships (32154.6tons); Other ships (9039.1tons); Chemical Tankers (4027.06 tons) and Fishing ships (814.04 tons), respectively (see Table 4 and Fig 3).

Table 4. Estimation of CO_2 Emission by Ship type

unit : ton

S/No.	No. of Ships	Ship Type	CO_2 Emission	Average Per Unit
1	160	Cargo Ships	32154.669	200.967
2	11	Fishing ships	814.048	74.004
3	61	Other ships	9039.125	148.182
4	23	Passenger ships	81409.699	3539.552
5	43	Chemical Tankers	4027.061	93.653
6	32	Tugboats	37248.465	1164.015
	330	Total CO_2 Emissions	164693.067	

Figure 3. CO_2 Emissions by Ship Type



V. Conclusion and Recommendations for Further Research

This study was conducted to estimate GHG emissions, mainly CO_2 emissions from ships at the port of Incheon for the period of Oct, 2014. The final sample AIS data consisted of 330 ships and AIS-based bottom up approach was employed to estimate the total amount of fuel consumed and its resulting CO_2 emissions. The detailed date time stamp information and speed on ground (operating speed) obtained from AIS data for each ship were thoroughly investigated and were used to calculate exact time spent (hour) and the distance covered (NM) by individual ship. The total amount CO_2 emitted from ships were estimated to be 164693.06 tons with estimated total fuel consumption of 51953.64 tons for the period of study. The figures show that Cargo Ships make more frequent use of port facilities but is less polluting compared to Passenger Ships. During the period of study 21 ships were reported to be stationary and did not move at all while 309 were moving. The passenger ships were most polluting ships, followed in order by tugboats; Cargo Ships; ships used for other activities; chemical tankers and fishing ships, respectively.

Several studies have been conducted in this field to measure ships exhaust emissions and to quantify their contribution to overall atmospheric pollution and resulting climate change or global warming in general. They were conducted to enhance awareness of global warming and also to enable international organizations and government bodies to meet the growing environmental challenges for lowering the effects of global warming. However, the strategies and policies should be formulated based on authentic reports and studies, as there is still a high degree of uncertainty due to lacking information or access to reliable data sources (commercial databases) and also the type of methodology being used. Though AIS-based bottom approach is more accurate in estimating GHGs emissions, it does have a limitation.

This study could use only 330 ships excluding 272 ships due to missing data, which is one limitation. Future study should find a more proper way to mitigate this common issue of missing data pertinent to AIS studies. Estimation of the amount of GHG and some other pollutants is just the initial step, and further research work is required in this field ensuing GHG studies. Investigating the movement of the emissions and their impact on human population can be one of future research topics including monetization of these impacts. This level of comprehensive integrating works requires researchers to develop new models and collect vast amounts of data on emissions, dispersions and impacts on human society. This work should be perhaps one of overarching study for policy formulations in the future.

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References

2012 greenhouse gas conversion factors for company reporting, https://www.gov.uk/government/publications/2012-greenhouse-gas-conversion- factors-for-company-reporting (access at November 3, 2015).

AIS for Ships in the future, http://www.sjofartsverket.se/upload/1486/a171_2.pdf (access at November 29, 2015).

Berechman, J. and Tseng, P. (2012), Estimating the environmental costs of port related emissions: The case of Kaohsiung, *Transportation Research Part D: Transport and Environment,* 17, 35-38.

Business.un.org, https://business.un.org/en/entities/13 (access at November 16, 2015).

Chang, C. and Wang, C. (2012), Evaluating the effects of green port policy: Case study of Kaohsiung harbor in Taiwan, *Transportation Research Part D: Transport and Environment*, 17, 185-189.

Chang, Y., Roh, Y. and Park, H. (2014), Assessing noxious gases of ship operations in a potential Emission Control Area, *Transportation Research Part D: Transport and Environment*, 28, 91-97.

Chang, Y., Song, Y. and Roh, Y. (2013), Assessing greenhouse gas emissions from port ship operations at the Port of Incheon, *Transportation Research Part D: Transport and Environment*, 25, 1-4.

Coello, J., Williams, I., Hudson, D. and Kemp, S. (2015), An AIS-based approach to calculate atmospheric emissions from the UK fishing fleet, *Atmospheric Environment*, 114, 1-7.

Contini, D., Gambaro, A., Belosi, F., De Pieri, S., Cairns, W. R. L., Donateo, A., Zanotto, E. and Citron, M. (2011), The direct influence of ship traffic on atmospheric PM2.5, PM10 and PAH in Venice, *Journal of Environmental Management*, 92(9), 2119-2129.

Cooper, D. (2003), Exhaust emissions from ships at berth, *Atmospheric Environment*, 37, 3817-3830.

Dalsøren, S., Eide, M., Endresen, Ø, Mjelde, A., Gravir, G. and Isaksen, I. (2009), Update on emissions and environmental impacts from the international fleet of ships: the contribution from major ship types and ports, *Atmospheric Chemistry and Physics*, 9(6), 2171-2194.

Deniz, C. and Kilic, A. (2009), Estimation and assessment of shipping emissions in the region of Ambarlı Port, Turkey, *Environmental progress & Sustainable Energy*, 29(1), 107-115.

Eyring, V., Isaksen, I., Berntsen, T., Collins, W., Corbett, J., Endresen, O., Grainger. R. G., Moldanova, J. Schlager, H. and Stevenson, D. S. (2010), Transport impacts on atmosphere and climate: Shipping, *Atmospheric Environment*, 44(37), 4735-4771.

Fitzgerald, W., Howitt, O. and Smith, I. (2011), Greenhouse gas emissions from the international maritime transport of New Zealand's imports and exports, *Energy Policy,* 39(3), 1521-1531.

Greenhouse Gas Protocl, http://ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values.pdf (access at November 7, 2015).

Incheon Port Authority, Inner Port of Incheon, http://service.icpa.or.kr/ images/eng/cyber/innerPort.jpg (access at June 2, 2015)

Isakson, J., Persson, T. and Lindgren, E. (2001), Identification and assessment of ship emissions and their effects in the harbour of Göteborg, Sweden, *Atmospheric Environment,* 35(21), 3659-3666.

Kesgin, U. and Vardar, N. (2001), A study on exhaust gas emissions from ships in Turkish Straits, *Atmospheric Environment*, 35(10), 1863-1870.

Matthias, V., Bewersdorff, I., Aulinger, A. and Quante, M. (2010), The contribution of ship emissions to air pollution in the North Sea regions, *Environmental Pollution,* 158(6), 2241-2250.

Miola, A. and Ciuffo, B. (2011), Estimating air emissions from ships: Meta-analysis of modelling approaches and available data sources, *Atmospheric Environment*, 45(13), 2242-2251.

Port of Incheon, http://www.worldportsource.com/ports/review/KOR_Port_of_Incheon_1483.php (access at November 23, 2015).

Review of Marine Transport, http://unctad.org/en/PublicationsLibrary/rmt2012_en.pdf (access at November 14, 2015).

Saraçoğlu, H., Deniz, C. and K i l i ç, A. (2013), An Investigation on the Effects of Ship Sourced Emissions in Izmir Port, Turkey, *The Scientific World Journal,* 2013, 1-8.

Saxe, H. and Larsen, T. (2004), Air pollution from ships in three Danish ports, *Atmospheric Environment,* 38(24), 4057-4067.

Schembari, C., Cavalli, F., Cuccia, E., Hjorth, J., Calzolai, G., Pérez, N., Pey, J. Prati, P. and Raes, F. (2012), Impact of a European directive on ship emissions on air quality in Mediterranean harbours, *Atmospheric Environment*, 61, 661-669.

Seatrade Maritime News, http://www.seatrade-maritime.com/news/asia/incheon-new-port-starts-operation-with-8000-teu-capacity.html (access at November 23, 2015).

Song, S. and Shon, Z. (2014), Current and future emission estimates of exhaust gases and particles from shipping at the largest port in Korea, *Environmental Science and Pollution Research*, 21(10), 6612-6622.

Speed, time, and distance; learn how to calculate the missing variable, http://www.schoolofsailing.net/speed-time -and-distance.html (access at November 30, 2015).

The Human Cost of Weather Related Disasters, http://reliefweb.int/sites/reliefweb.int/files/resources/COP21_WeatherDisastersReport_2015_FINAL.pdf (access at November 29, 2015).

Tzannatos, E. (2010), Ship emissions and their externalities for the port of Piraeus – Greece, *Atmospheric Environment*, 44(3), 400-407.

Tzannatos, E. (2010). Ship emissions and their externalities for Greece. Atmospheric Environment, 44, 2194-2202.

UN Report, http://www.un.org/apps/news/story.asp?NewsID=52627#.VmVNg3YrLcd (access at November 23, 2015).

Villalba, G. and Gemechu, E. (2011), Estimating GHG emissions of marine ports—the case of Barcelona, *Energy Policy*, 39(3), 1363-1368.

Vutukuru, S. and Dabdub, D. (2008), Modeling the effects of ship emissions on coastal air quality: A case study of southern California, *Atmospheric Environment*, 42(16), 3751-3764.

Yau, P., Lee, S., Cheng, Y., Huang, Y., Lai, S. and Xu, X. (2013), Contribution of ship emissions to the fine particulate in the community near an international port in Hong Kong, *Atmospheric Research,* 124(28), 61-72.

Yau, P., Lee, S., Corbett, J., Wang, C., Cheng, Y. and Ho, K. (2012), Estimation of exhaust emission from ocean-going ships in Hong Kong, *Science of The Total Environment*, 431, 299-306.

Zhang, F., Chen, Y., Tian, C., Wang, X., Huang, G., Fang, Y. and Zong, Z. (2014), Identification and quantification of shipping emissions in Bohai Rim, *China, Science of The Total Environment*, 497-498, 570-577.

Zhao, M., Zhang, Y., Ma, W., Fu, Q., Yang, X., Li, C., Zhou, B., Yu, Q. and Chen, L. (2013), Characteristics and ship traffic source identification of air pollutants in China's largest port, *Atmospheric Environment*, 64, 277-286.

AIS를 활용한 인천항 선박의 온실가스 배출량 추정

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국문요약

본 연구는 2014년 10월 동안 인천항만에 기항하는 선박들의 온실가스 배출량을 추정하고자 시도되었다. 온실가스 배출량 추정을 위하여 AIS 데이터를 토대로 한 Bottom-up 방식을 활용하였으며 연료소비총량과 연료소비의 결과로서 발생한 이산화탄소 총량을 함께 분석하였다. 배출량 추정은 선박의 종류를 토대로 추정되었으며 각각 개별 선박의 날짜-시간 스템프 사이에서 그들의 움직임에 따라 계산되었다. 인천항에서 운항되는 최종 330 척(AIS-데이터)의 선박 샘플의 결과에 따르면 선박들의 총 이산화탄소 배출량은 164693.06 톤으로 추정되었으며, 연구기간동안 이들 선박의 총 연료소비량은 51953.64 톤에 이르는 것으로 나타났다. 선박의 종류에 따른 구체적 분석 결과를 살펴보면, 여객선이 배출량 81409.6톤으로 가장 오염이 심한 선박으로 나타났으며, 그 뒤를 이어 예인선 (37248.4톤), 화물선 (32154.6톤), 다른 활동에 사용된 선박 (9039.1톤), 화학 탱커 (4027.06톤) 그리고 어선 (814.048톤) 순으로 확인되었다.

주제어: AIS, 온실가스, 선박 CO_2 배출, 인천항, Bottom-up 방식

Appendix

Existing works on emission research

Research work	Methodology	Emission estimation
Ugur Kesgin and Nurten Vardar (2001)	Calculating fuel consumption	NOx
J. Isakson et al. (2001)	Multivariate analysis	SO_2 and NOx
D.A. Cooper (2003)	Equipment	NOx, CO, HC, CO_2 and O_2
H. Saxe and T. Larsen (2004)	Operational meteorological air quality model	SO_2 and PM10
Satish Vutukuru and Donald Dabdub (2008)	UCICIT model	Ozone and PM
S. B. Dalsøren et al. (2009)	Calculating fuel consumption	Nitrogen dioxide and sulphur dioxide
Cengiz Deniz and Alper Kilic (2009)	Simulate dispersions	SO_2 and NOx
Warren B. Fitzgerald et al. (2011)	Activity based and fuel based methodologies	GHG
Ernestos Tzannatos (2010)	Calculating fuel consumption	SO_2 and CO_2
Volker Matthias et al. (2010)	Three dimensional Eulerian chemistry transport model	SO_2
Veronika Eyring et al. (2010)	Emissions spaning	SO_2
D. Contini (2011)	High temporal resolutions	PM and PAHs
Joseph Berechman and Po-Hsing Tseng (2012)	Bottom-up approach	Environmental cost
P.S. Yau et al. (2012)	Activity based approach	SO_2
Halil SaraçoLlu et al. (2013)	Activity based approach	Exhaust emissions
Chang et al. (2013)	Bottom-up approach	GHG
Sang Keun Song and Zang Ho Shon (2014)	Activity based approach	Exhaust emissions
Chang et al. (2014)	Bottom-up approach	PM, SO_2 and NOx
Jonathan Coello et al. (2015)	Bottom-up approach	PM, SO_2 and NOx