Estimating socio-economic impact from ship emissions at the Port of Incheon

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ABSTRACT
Ports create harmful effects on their adjacent population because ships discharge noxious gases like SO$_X$, NO$_X$, and particulate matter (PM). To tackle this problem, some ports started to control emission through regulations such as Emission Control Areas (ECA) and Reduced Speed Zone (RSZ). This paper estimates the social cost of ship emission and eco-efficiency at the Port of Incheon (POI). We further examine how the ECA and RSZ designation can reduce the social cost. The estimation is based on the activity-based approach, where ship type, engine, and movement are used to measure fuel consumption and then emission. Results suggest that the social cost of ship emission at the POI amounts to $90,805,478. The eco-efficiency of the POI, compared to the one at the Port of Las Palmas in another study, is substantially better. Under RSZ, the corresponding emission abatement values are $4,485,308, $2,642,009 and $21,932,435 from SO$_2$, NO$_X$ and PM reduction, respectively. If 1.0% and 0.1% sulfur fuel are used complying with rules of the ECA, the social cost savings amount to $8,174,947 and $12,868,842 from SO$_2$ reduction.

1. Introduction

Ports play a critical role as an interface between land and maritime transportation. Shipping industry has developed significantly due to containerization, developing intermodal networks, shipping alliance, and increasing vessel size (Bae et al. 2013, Yap and Lam 2006). The resulting reduction in shipping costs led to surge in maritime traffic and international trade (Blonigen and Wilson 2013, Hummels 2007). This could not have been accommodated without corresponding advancement in and support from port operations. In addition, ports generate positive industrial chain effect and value added in regional economy (Chang et al. 2014b). This is why many governments consider ports as strategic nodes and intend to support ports in their jurisdiction to be hubs, and tremendous government subsidies are given to ports.

Still, ports generate harmful effects on their adjacent population because ships discharge many noxious gases like SO$_X$, NO$_X$, and particulate matter (PM). These gases can be dangerous to human, increasing respiratory and cardiovascular diseases. For example, Wang and Corbett (2007) found that PM emission from ships worldwide caused 60,000 death each year. Similarly, Tian et al. (2013) estimated that nickel contained in PM$_{10}$ has increased emergency hospital visits for cardiovascular diseases by 1.25% in Hong Kong.

Realizing this problem, policy-makers devised regulations to tackle this problem. The International Maritime Organization (IMO), for instance, designated Emission Control Areas (ECA) in Baltic Sea, North Sea, and North America. Ships in ECAs should use fuel with less sulfur contents or equip scrubbers to filter sulfur in the fuel automatically. In North America, some ports introduced Reduced Speed Zone (RSZ), e.g., the Port of Los Angeles/Long Beach since 2001, the Port of New York/New Jersey since 2009. By requiring ship speed below 12 and

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15 knots at these ports, ships consume less fuel and consequently less emission. Literature supports that ECA and RSZ could reduce emissions substantially (Chang et al. 2013, Wang and Corbett 2007).

Numerous studies estimated emission from ships in a port level, as reviewed in the next section. The significance of these papers lies on that measuring emission inventory and its associated social cost are vital to monitor pollution and serve as useful guidance for emission control legislation (Hammingh et al. 2007, Wang and Corbett 2007, Watanabe 2004). Relevant papers employed in this area have mostly used a bottom-up approach to improve estimation accuracy, where emission in an individual ship level is aggregated to obtain total emissions. To this end, they used ship movement, engine type, and fuel type data. Lately, some researchers went further to examine the social cost of ship emissions and measure ecological indicators like port revenue or vessel calls per emission (Marakogianni and Papaefthimiou 2015, Song 2014, Tichavksa and Tovar 2015). These papers, however, only focused on European ports not Asian ports. Asian governments in a potential ECA may be more interested in how emission regulations such as ECA or RSZ can decrease social cost.

Against this backdrop, this paper estimates the social cost and eco-efficiency of ship emissions at a potential ECA, the Port of Incheon. This paper further examines how introducing ECA or RSZ can reduce the social cost or enhance eco-efficiency in the POI. This study extends Chang et al. (2014a), who estimated emissions in the POI by ship and activity type but did not measure social cost and eco-efficiency. Our main contribution to literature is twofold. First, we calculate the social cost and eco-efficiency of ship emissions in a port level through the bottom-up approach, which were conducted by few studies. Second, this paper assesses benefits of the ECA and RSZ in terms of the emission social cost, which none of existing studies did.

The rest of sections are organized as follows. Section 2 surveys the literature on shipping emission inventory. Section 3 explains methodology to obtain the social cost and eco-efficiency and describes data collection process. Section 4 reports emission estimates, and section 5 concludes.

2. Literature review

Studies that measured emission inventory can be divided into two categories. The first adopts top-down approach (also called fuel-based approach). The method measures emissions using macro-level fuel consumption data. For example, Tzannatos (2010a) examined emissions at Greek ports from both domestic and international shipping. Due to multiple years of port data, they used fuel sales statistics to estimate the emissions. Recently, more studies employed the bottom-up approach. Unlike the top-down method, the bottom-up one requires detailed ship characteristics, engine type, and ship movement data to capture fuel consumption and then emission level. Tzannatos (2010b) measured noxious gases emitted from passenger and cruise ships at the Port of Piraeus, Greece. The method requires shipping movements to be divided into several phases, e.g. maneuvering or at berth, to incorporate difference in fuel consumption and engine usage by phase. Another interesting application of this method is by Liao et al. (2010). They addressed a very specific policy question, ‘what would be the emission reduction benefit by repositioning the current transshipment port to the one closer to major cities in Taiwan?’ Overall reduction was notable under repositioning because it reduced trucking emission significantly. This study, however, overlooked the health damage inflicted to nearby population. Similarly, Park et al. (2007) estimated the emission reduction benefit of the Alameda Corridor, a railway connecting Port of Los Angeles and Port of Long Beach.

Chang et al. (2013) also performed a similar analysis for the Port of Incheon in South Korea. They estimated carbon emissions by different vessel movement phase, e.g., approaching to dock, maneuvering, and hoteling, and further by ship type. In an extension of the previous paper, Chang et al. (2014a) analyzed NOx, SOx and PM15 emissions at the same port. Their main research question this time was not the emission inventory itself but estimating emission reduction potential from such policies as the ECA and RSZ. The findings are surprising: the RSZ could reduce overall emission by 67% and the ECA 93%. Different from the studies thus far, Geerings and Van Duin (2011) measured emissions in port terminals. Cargo movement and land-side emissions from equipment were calculated. Moreover, a counterfactual analysis of replacing low quality fuel with bio-diesel and electrical power is another interesting aspect of the study. These studies, however, only center on emission inventory per se. More important analysis should be to quantify the impact of vessel emission on society that includes human health impact.

An increasing number of studies estimated social cost from emission as well as emission inventory. Song (2014) used a ship movement data at Yangshan Port in China to estimate its social cost and eco-efficiency. To this end, he averaged the social cost estimates of pollutants from several studies. Berechman and Tseng (2012) calculated emissions at the Port of Kaoshiung, Taiwan. Diverse ship types, such as bulk, container, and general cargo ships, were examined. When estimating the social cost of total emission, they used BeTa database that calculates the emission cost factor (i.e., the social cost per emission) in numerous region. McArthur and Osland (2013) investigated ships at berth in Port of Bergen, Norway. They mostly followed the line of previous studies except that they collected the emission cost factor from several sources, including BeTa, and CAFE. Tichavksa and Tovar (2015) did more sophisticated analysis on the Port of Las Palmas (PLP) using ‘Automatic Identification System (AIS)’ data. The AIS data enabled them to locate ship movement by minute and distance, undeniably providing most elaborate emission estimates. The cost factor, on the
other hand, was taken from previous studies.

Reviewing existing studies, we find that the literature has several gaps. First, the social cost and eco-efficiency of ship emission is less studied. Even though some studies already analyzed them, these mostly focus on European ports. Second, more critically, none of the existing studies to the authors’ knowledge examined benefits of the ECA and RSZ through measuring the social cost of emission.

3. Theoretical model

3.1 Methodology

While we mostly adopted emission inventory results in Chang et al. (2014a), this section briefly summarizes their methodology to help readers’ understanding. Following Chang and Wang (2012), the amount of fuel consumption is measured by

$$F_{\text{trip}, k} = \begin{cases} \frac{M_{EF} s_{k}}{s_{k}} + AF_{k} t_{\text{trip}} & \text{if } \text{trip} \in \{\text{cruising, maneuvering}\} \\ AF_{k} t_{\text{trip}} & \text{if } \text{trip} = \text{hoteling} \end{cases}$$

where $F_{\text{trip}, k}$ is the amount of fuel consumed by vessel $k$ for each phase of $\text{trip} \in \{\text{cruising, maneuvering, hoteling}\}$, $M_{EF}$ average daily fuel consumption of a vessel’s main engine, $AF_{k}$ average daily fuel consumption of a vessel’s auxiliary engine, $s_{k}$ the design speed of vessel $k$, $S_{k}$ its operating speed, and $t_{\text{trip}}$ the duration of a ship travel (days).

Next, total emissions can be obtained by multiplying fuel consumption and emission factor, and then summating emissions at each trip type.

$$E_{\text{kgf}} = \sum_{\text{trip}} (F_{\text{kgf}, \text{trip}} EF_{\text{kgf}, \text{trip}})$$

where $E_{\text{kgf}}$ is emissions throughout a complete trip of vessel $k$ (tons), $F_{\text{kgf}, \text{trip}}$ amount of fuel consumed by vessel $k$, $EF_{\text{kgf}, \text{trip}}$ emission factor. Subscript $p$ is the pollutant type (PM, SO$_2$, NOx), $f$ the fuel type (bunker fuel, marine diesel oil/marine gas oil, gasoline), and $g$ the engine type (e.g., slow-, medium-, and high-speed diesel, gas turbine, steam turbine). See Chang et al. (2014a) for detailed data descriptions on fuel type, engine type, and emission factor.

Next, we estimated the social cost of noxious gas emission $SC_{\text{kgf}}$ by

$$SC_{\text{kgf}} = E_{\text{kgf}} v_{p}$$

where $v_{p}$ is the cost inflicted by pollutant type $p$ per ton. Then eco-efficiency is calculated through

$$Eco_{\text{indicator}} = \frac{E_{\text{kgf}}}{\text{indicator}}$$

where $\text{indicator}$ means divergent measures on port output such as the number of passengers, the number of vessels, and port revenue.

3.2 Social cost factor and eco-efficiency data

Most studies refer to the Clean Air for Europe (CAFE) (Holland et al. 2005, Amann et al. 2005), the New Energy Externalities Development for Sustainability (NEEDS) (Preiss and Klotz 2007) and the Benefits Table (BeTa) databases to obtain the social cost factor of emission. These sources, however, are based on European region and therefore can differ significantly from the actual cost factor in the POI region. As an alternative, we employ results by Lee et al. (2010), who estimated the external cost of emission in Taiwan. This can be justified for two reasons. First, Taiwan is close to Korea, which shares similar geographical characteristics. Second, previous studies, e.g., Preiss and Klotz (2008) and Dragović et al. (2015), used cost factors in other regions that share similar GDP per capita level. In our case, Taiwan and Korea have similar per capita GDP, $22,044 and $27,633, respectively (International Monetary Fund, 2016).

Table 1 summarizes employed external cost factors. SO$_2$, NO$_x$ and PM$_{10}$ cause social cost $13,960, $4,992 and $375,888 per ton respectively. Unfortunately, the factor was not available for PM$_{2.5}$ from Lee et al. (2010). Thus, BeTa
was used to calculate it: $594,042. In a ton basis, the most harmful noxious gas is PM$_{2.5}$, causing $594,042$ external cost per ton.

To calculate eco-efficiency, the revenue of the POI was obtained from its annual report. The ship emission data were available only from January to October in 2012 while port revenue covered the whole year. Hence, we approximated the revenue between January to October by multiplying the ship movement ratio to the annual revenue in 2012, where the ratio is the number of ships between January and October divided by the total number of ships entered.

**Table 1.** External cost factor by emissions

| Noxious gas type | External cost factor ($/ton) |
|------------------|-----------------------------|
| SO$_2$           | 13,960                      |
| NO$_X$           | 4,992                       |
| PM$_{2.5}$       | 594,042                     |
| PM$_{10}$        | 375,888                     |

Source: Lee et al. (2010)

4. Results

4.1 Total external cost

Table 2 shows external costs by ship activity stage and pollutants. Total external cost of Port of Incheon from January to October 2012 is $90,805,478. The most harmful pollutant in terms of social cost is the PM$_{2.5}$ causing 42,414,627$ or 42% of total social cost. The most environmentally costly phase is ‘Passing thorough lock gate’ causing 52,142,427$accounting for 57% of total cost. Figure 1 shows external costs by vessel movement.

The external costs by ship and pollutant type are listed in Table 3. International car ferry, full-container vessel, car carrier and general cargo vessel are the largest damage infectors with social costs $30,343,305, $16,933,369, $12,243,705 and $9,339,728, respectively. Specifically, car carrier and international car ferry are the most expensive emitters, which is consistent with Chang et al. (2014a). This means that vessels that carry automobiles should be the main target of emission control. Figure 2 illustrates external costs by vessel type.

**Table 2.** External cost by vessel movement and pollutant (unit: $)

| Pollutant | Anchorage | Maneuvering to lock gate | Passing thorough lock gate | Approaching to dock | Docking | Total       |
|-----------|-----------|--------------------------|---------------------------|---------------------|---------|-------------|
| SO$_2$    | 3,634     | 426,402                  | 7,932,118                 | 5,360,649           | 90,895  | 13,813,699 |
| NO$_X$    | 2,036     | 238,880                  | 4,443,753                 | 3,003,157           | 50,922  | 7,738,748  |
| PM$_{2.5}$| 11,158    | 1,309,257                | 24,355,376                | 16,459,743          | 279,092 | 42,414,627 |
| PM$_{10}$ | 7,061     | 828,450                  | 15,411,179                | 10,415,115          | 176,599 | 26,838,403 |
| Total     | 23,889    | 2,802,989                | 52,142,427                | 35,238,664          | 597,509 | 90,805,478 |

**Figure 1.** External cost estimates by vessel movement (unit: $1,000)
Table 3. External costs by ship type

| Pollutant | LNG carrier | LPG carrier | Towing tug ship | International car ferry | Fuel supplies ship | Other tug ship | Other chemical tanker |
|-----------|-------------|-------------|-----------------|-------------------------|------------------|----------------|-----------------------|
| SO₂       | 282,182     | 177,403     | 363,180         | 4,615,947               | 69,084           | 283,291       | 12,681                |
| NOₓ       | 158,085     | 99,385      | 203,462         | 2,585,958               | 38,702           | 158,706       | 7,104                 |
| PM₂₅      | 866,432     | 544,710     | 1,115,135       | 14,173,135              | 212,120          | 869,837       | 38,935                |
| PM₁₀      | 548,246     | 344,673     | 705,616         | 8,968,246               | 134,221          | 550,401       | 24,637                |
| Total     | 1,854,944   | 1,166,171   | 2,387,393       | 30,343,305              | 454,127          | 1,862,235     | 83,357                |

Figure 2. External cost by ship type (unit: $1000)

4.2 Eco-efficiency

Eco-efficiency was obtained by using the ratio of social costs to port performance indices, i.e., the number of passenger, ship call, and revenue. This gives useful insights on emission from ships at the POI, providing measures of environmental and economic performance. To evaluate the performance of the POI, we compare its eco-efficiency to the Port of Las Palmas (PLP) (Tichavská and Tovar 2015). The eco-efficiencies of the POI and PLP are reported in Table 4 and 5, respectively.

Overall, the eco-efficiency of the POI is better than that of PLP. Inspecting external cost per passenger, one can see that the figures are much lower for the POI by half to four times relative to the PLP. For instance, every passenger carried at the POI, the social cost associated with SO₂ emission at the port is 8.3, which is four times lower than the one at the PLP. The difference is even more drastic for external cost per ton of cargo: from as low as 5.86 times (SO₂) to as high as 24.7 times (NOₓ). The similar argument holds for the external cost per ship call. The highest difference is observed for NOₓ emission (12.41 times) and the lowest one for PM₂₅ (3.33 times). Lastly, external cost of SO₂ per port revenue is significantly higher for the PLP than the POI.

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Table 4. Eco-efficiency at the POI

| Pollutant | Total external cost ($) | External cost per passenger ($/Pax) | External cost per ton of cargo ($/1,000 tons) | External cost per ship call ($/call) | External cost per port revenue ($/1,000$) |
|-----------|------------------------|------------------------------------|-----------------------------------------------|-------------------------------------|------------------------------------------|
| SO\(_2\)  | 13,813,699.2           | 8.3                                | 140.7                                         | 998.9                               | 24.8                                     |
| NO\(_x\)  | 7,738,748.2            | 4.4                                | 78.8                                          | 559.6                               | 139.4                                    |
| PM\(_{2.5}\) | 42,414,627.2           | 25.5                               | 431.9                                         | 3067.1                              | 764.1                                    |
| PM\(_{10}\) | 26,838,403.2           | 16.1                               | 273.3                                         | 1940.7                              | 483.5                                    |
| Total     | 90,805,477.8           | 54.6                               | 924.9                                         | 6566.4                              | 163.0                                    |

Table 5. Eco-efficiency at the PLP

| Pollutant | Total external cost ($) | External cost per passenger ($/Pax) | External cost per ton of cargo ($/1,000 tons) | External cost per ship call ($/call) | External cost per port revenue ($/1,000$) |
|-----------|------------------------|------------------------------------|-----------------------------------------------|-------------------------------------|------------------------------------------|
| SO\(_2\)  | 83,151,625.0           | 25.3                               | 2,119.2                                       | 9,109.9                             | 1,680.4                                  |
| NO\(_x\)  | 63,357,311.0           | 13.0                               | 1,928.1                                       | 6,941.5                             | 1,280.3                                  |
| PM\(_{2.5}\) | 93,391,745.0           | 25.5                               | 2,527.9                                       | 10,231.2                            | 1,887.3                                  |
| Total     | 239,900,681.0          | 73.0                               | 6,114.1                                       | 26,283.0                            | 4,848.1                                  |

4.3 Effects of the ECA and RSZ

Lastly, benefits of ECA and RSZ are examined. Note that we only report results of SO\(_2\) for the ECA, for the policy only regulates SO\(_2\) and the effect of the ECA on other pollutant type is not clear yet (Chang et al., 2014a). In Table 6, introducing RSZ can reduce approximately a third of total emissions. Even more drastic cut in emission is observable if the POI initiates ECA: 59% and 93% of SO\(_2\) emission reduction when the sulfur content per fuel is 1.0 and 0.1%, respectively. Using these estimates, the social benefits of RSZ and ECA at the POI are listed in Table 6. Under RSZ, the corresponding emission abatement values are $4,485,308, $2,642,009 and $21,932,435 from SO\(_2\), NO\(_x\) and PM reduction, respectively. If 1.0% and 0.1% sulfur fuel are used due to the ECA, the social cost savings amount to $8,174,947 and $12,868,842 from SO\(_2\) reduction.

Table 6. External cost and reduction percentage under various scenarios

| Pollutant | Status quo ($) | RSZ ($) | RSZ (%) | ECA 1.0% ($) | ECA 1.0% (%) | ECA 0.1% ($) | ECA 0.1% (%) |
|-----------|----------------|---------|---------|--------------|--------------|--------------|--------------|
| SO\(_2\)  | 13,813,699     | 9,328,391 | 32.47   | 5,638,752    | 59.18        | 944,857      | 93.16        |
| NO\(_x\)  | 7,738,748      | 5,096,739 | 34.14   | –            | –            | –            | –            |
| PM\(_{2.5/10}\) | 69,253,030  | 47,320,030 | 31.67   | –            | –            | –            | –            |

5. Conclusion

This paper measured the social cost and eco-efficiency of vessel emissions at the POI. To this end, we used emission data in Chang et al. (2014a), whose analysis adopted an activity-based approach incorporating ship engine, vessel type, and ship movement data. Findings suggest that the total social cost of ship emission at the POI amounts to $90,805,478. The eco-efficiency of the POI, compared to the one of the Port of Las Palmas in another study, is substantially better. For instance, external cost per ton of cargo including all pollutant types is lowered by eight times, external cost per ship call four times and external cost per $1000 revenue three times. Under RSZ, the corresponding emission abatement values are $4,485,308, $2,642,009 and $21,932,435 from SO\(_2\), NO\(_x\) and PM reduction. If 1.0% and 0.1% sulfur fuel are used due to the ECA, the social cost savings amount to $8,174,947 and $12,868,842 from SO\(_2\) reduction.

The method employed in this study may be applied to other Korean ports. For example, according to Korea Ministry of Oceans and Fisheries, container traffic at the Port of Busan and Gwangyang is greater than that of Incheon. Estimating social cost and eco-efficiency at these ports may help policy makers to measure benefits of introducing ECA and RSZ in the nearby area. Moreover, the tool can be used to assess emission from airplanes. Interested readers may refer to Kim et al. (2010).

This paper has room for improvement. First, using more sophisticated data from AIS can yield more accurate estimates. Second, one may employ the emission cost factor fine-tuned for an analyzed port (in our case, the region surrounding POI). Lastly, even though eco-efficiency suggests that the POI is much more environmentally efficient than the PLP, one need to caution that including other external factors is necessary. An example is life-cycle emission of port operation. Port operation involves constructing berth, positioning cranes, and also inland-side terminal operations. Neglecting emissions from these sources can possibly result in biased estimates of emission from ships.
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References

Amann, M., Bertok, I., Cofala, J., Gyarfas, F., Heyes, C., Klimont, Z., Win inex, W., 2005. Baseline scenarios for the clean air for Europe (CAFE) programme. Final report 79.

Bae, M.J., Chew, E.P., Lee, L.H., Zhang, A., 2013. Container transshipment and port competition. Maritime Policy & Management 40, 479-494.

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

Blonigen, B.A., Wilson W.W., 2013. The growth and patterns of international trade. Maritime Policy & Management 40, 618-635.

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

Chang, Y.T., Shin, S.H., Lee, P.T.W., 2014b. Economic impact of port sectors on South African economy: An input–output analysis. Transport Policy 35, 333-340.

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.

Chang, C.C., Wang, C.M., 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.

Dragović, B., Tzannatos, E., Tselentis, V., Meštrović, R., Škurić, M., 2015. Ship emissions and their externalities in cruise ports. Transportation Research Part D: Transport and Environment, http://dx.doi.org/10.1016/j.trd.2015.11.007.

Geerlings, H., Van Duin, R., 2011. A new method for assessing CO\textsubscript{2}-emissions from container terminals: a promising approach applied in Rotterdam. Journal of Cleaner Production 19, 657-666.

Hammingh, P., Aben, J.M.M., Blom, W.F., Jimmink, B.A., de Vries, W.J., Visser, M., Hammingh, P., 2007. Effectiveness of international emission control measures for North Sea shipping on Dutch air quality. MNP Report, 500092004.

Holland, M.I.K.E., Hunt, A., Hurley, Navrud, S., Watkiss, P., 2005. Methodology for the cost-benefit analysis for CAFE: volume 1: overview of methodology. AEA Technology Environment. Available at: http://ec.europa.eu/environment/archives/air/cafe/activities/chm. Accessed: February 24, 2017.

Hummels, D., 2007. Transportation costs and international trade in the second era of globalization. The Journal of Economic Perspectives 21, 131-154.

Kim, M.J., Hong, S.J., Ha, H.K., 2010. An estimation of gas emissions in Korea’s air transport industry. Journal of International Trade and Logistics 8, 117-140.

Lee, P.T.W., Hu, K.C., Chen, T., 2010. External costs of domestic container transportation: Short-sea shipping versus trucking in Taiwan. Transport Reviews 30, 315-335.

Liao, C.H., Tseng, P.H., Cullinane, K., Lu, C.S., 2010. The impact of an emerging port on the carbon dioxide emissions of inland container transport: An empirical study of Taipei port. Energy Policy 38, 5251-5257.

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.

Maragkogianni, A., Papaefthimiou, S., 2015. Evaluating the social cost of cruise ships air emissions in major ports of Greece. Transportation Research Part D: Transport and Environment 36, 10-17.

Park, M., Regan, A., Yang, C.H., 2007. Emissions impacts of a modal shift: a case study of the Southern California ports region. Journal of International Logistics and Trade 5, 67-81.

Preiss, P., Klotz, V., 2008. Description of updated and extended draft tools for the detailed site-dependent assessment of external costs, EcoSense Web V1. 3. Available at: http://www.needs-project.org/RS1b/NEEDS_RS1b_TP74pdf. Accessed: February 27, 2017.

Song, S., 2014. Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port. Atmospheric Environment 82, 288-297.

Tian, L., Ho, K.F., Louie, P.K., Qiu, H., Pun, V.C., Kan, H., Wong, T.W., 2013. Shipping emissions associated with increased cardiovascular hospitalizations. Atmospheric Environment 74, 320-325.

Tichavskas, M., Tovar, B., 2015. Environmental cost and eco-efficiency from vessel emissions in Las Palmas Port. Transportation Research Part E: Logistics and Transportation Review 83, 126-140.

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

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

Wang, C., Corbett, J.J., 2007. The costs and benefits of reducing SO\textsubscript{2} emissions from ships in the US West Coastal waters. Transportation Research Part D: Transport and Environment 12, 577-588.

Watanabe, Y., 2004. Evaluation of carbon dioxide emissions from container ports. Journal of International Logistics and Trade 2, 85-93.

Yap, W.Y., Lam, J.S., 2006. Competition dynamics between container ports in East Asia. Transportation Research Part A: Policy and Practice 40, 35-51.