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Article

Estimation of Pollutant Emissions and Environmental Costs Caused by Ships at Port: A Case Study of Busan Port

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Abstract: To reduce air pollutants, the International Maritime Organisation and port authorities use ship emissions regulations, such as MARPOL Annex VI and green port policies. To measure the effectiveness of these air emissions regulatory policies, accurate calculations of pollutant emissions and estimations of the social environmental costs of emissions are important. However, Busan Port still suffers from a lack of research on continuous monitoring and easy access to data-based emission calculation methods and estimation of the social environmental costs. Therefore, the purpose of this study is to present quantitative emission calculations based on an open source and social environmental cost estimation method. To this end, the discharge of pollutants (NOx, SO_2, CO_2, VOC, PM2.5, and PM10) from ships in Busan Port was calculated using Port-MIS open data from 2015–2019. Subsequently, when the original study on estimating the social and environmental impact of air pollution from ships in Busan Port was difficult, the international benefit transfer method (an economic valuation method) was applied to estimate the social environmental costs. Our results can provide a basis for verifying the effectiveness of Busan Port's air quality improvement policy in the future.

Keywords: ship pollutant emissions; global sulphur limit; emissions estimation; social environmental cost; international benefit transfer method

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1. Introduction

Regulations on emissions from ships, which are rapidly increasing simultaneously with the shipping volume, have emerged as a significant problem with respect to global air pollution control problem [1–5]. Particularly, air quality management issues, which can adversely affect the health of communities and residents, have been recognised as top environmental management issues, unlike in the past, for ports at which these ships have their final destinations [3,6–11].

First, the International Maritime Organisation (IMO) has increased the emissions regulations for the major air pollutants emitted by ship, such as Sulphur Oxides (SOx), Nitrous Oxides (NOx), and Particulate Matter (PM), based on the adoption of the air pollution regulations proposed in the MARPOL Annex VI in 1997 [12,13]. The IMO has also set the target of a 50% reduction in Greenhouse Gas (GHG) emissions by 2050, as well as air pollutants, owing to vessels centred on the Marine Environment Protection Committee (MEPC) since 2016. The IMO has further implemented a number of compulsory measures, such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). In 2019, the IMO approved the mandatory fuel oil Data Collection System (DCS) for international sailing vessels over 5000 Gross Tonnage (GT) to develop a quantitative monitoring system for ship emissions and a more efficient IMO GHG reduction strategy [14].

Second, for the ports where these ships originate, the port authority of each country has enacted a "green port policy" or "eco-port policy" to manage air pollutants from ships, port unloading equipment, and port trucks. For example, the San Pedro Bay Port Clean Air Action Plan (CAAP) was enacted in 2006 by the ports of Los Angeles (LA) and Long Beach (LB) [3,15,16].

However, for the IMO or the decision-makers at each port authority, assessing the efficiency of the air pollutant and GHG emissions reduction strategies is necessary, as well as assessments of the environmental impact of ship emissions [17,18]. Therefore, the Intergovernmental Panel on Climate Change (IPCC) developed methodology guidelines for national greenhouse gas inventories (2006 IPCC guidelines), which provide a methodology for estimating emissions from ships [19].

Busan Port (Figure 1), the world's sixth largest container port and Korea's largest port [20], established and implemented a comprehensive plan to build a green port in 2011. However, the Busan Port green port policy focuses only on CO_2 reduction initiatives, not air pollutants; the port air quality improvement effect is insufficient due to a lack of legal grounds for forced regulation by the port authority and a lack of finance to implement the planned initiatives [21,22].

For this reason, Busan Port Authority (BPA) has been implementing incentive-based policies to induce ships to voluntarily reduce air pollution, rather than imposing laws. Therefore, as direct emission reduction measures for ships that contributed the most air pollutant emissions in Busan Port as of 2019 (94.79% of the total emissions) [23], the Environmental Ship Index (ESI) rewards scheme and a Vessel Speed Reduction (VSR) program were implemented in 2014 and 2019, respectively. However, participation in the VSR program is low at 35.6% in 2020 [24–26]. In addition, Alternative Maritime Power (AMP), which can reduce NOx, SOx, and PM emissions from ships at berth by approximately 88–92% [27], has been installed and operated since 2018, but the usage of AMP is relatively low in Busan Port (2.78% in 2019, 0.96% in 2020, and 1.19% in June 2021) [27–29].

Nonetheless, BPA and the Ministry of Oceans and Fisheries (MOF) plan to expand the participation of VSR and install a total of 62 AMPs by 2030 to improve the air quality in Busan Port. Given the insufficient budget, doubts are currently raised regarding the smooth implementation of this plan [29–31].

As a result, there has been a recent increase in the interest of Korean citizens in worsening health conditions caused by fine dust; the main cause of air pollutants, including fine dust in port cities, such as Busan and Incheon, has emerged as a major social issue [30,32].

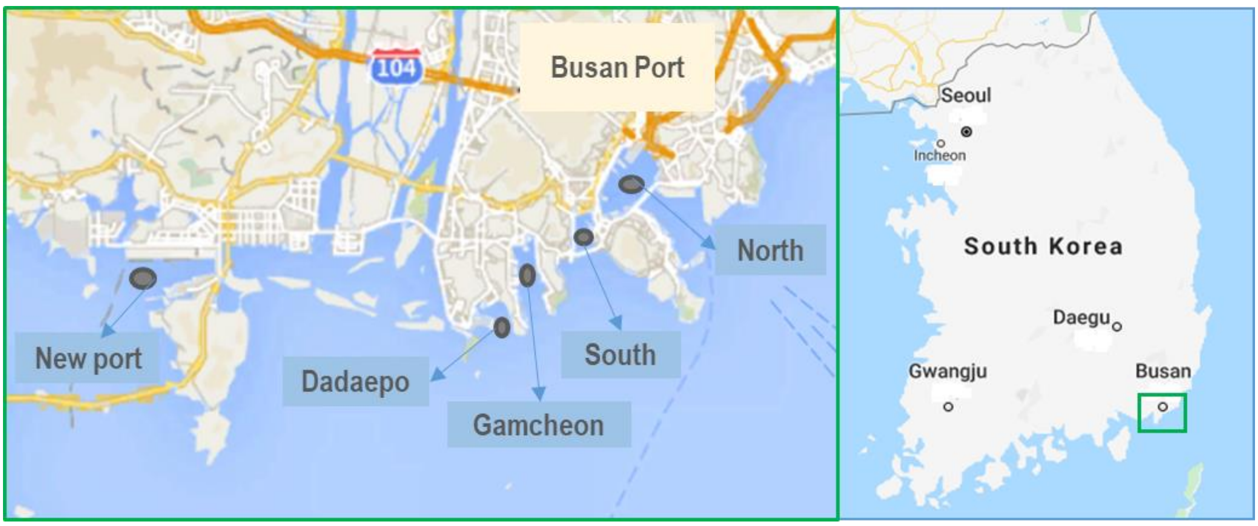

Figure 1. Geographical location of Busan Port, consisting of five harbours (New, Dadaepo, Gamcheon, South, and North) along the Korean Peninsula.

Accordingly, the Korean government has established two policies: "Comprehensive measures for fine dust on port vessels" (January 2018) and "Measures to reduce fine dust in the port sector" (June 2019). The government further implemented the Special Act on the Improvement of Air Quality in Port Area (hereinafter referred to as "Air Quality Special Act") in April 2019 to protect the health of local residents and the environment through port air quality improvements [33]. According to this law, the Korean government established a master plan for improving the air quality of similar areas from 2021 to 2025, aiming to reduce air pollutants, such as NOx, SOx, Volatile Organic Compounds (VOCs), and dust (including PMs), at ports [30,32].

Therefore, unlike the previous green port policy, the enactment of the Air Quality Special Act provided a legal basis for reducing air pollution at ports, including port ships. However, there is still a shortage of air pollutant emission estimation systems at ports and in vessels for the efficient implementation of these government policies and master plans. In other words, unlike the LA/LB ports in the United States and advanced ports in Europe, domestic ports, including Busan, do not have a proper monitoring system to continuously and quantitatively measure emissions caused by ships. Although there are several studies that estimate air pollution emissions, such as at Busan Port, the results differ by study and the statistics used are not unified or up-to-date [21,22,30,34].

For example, prior studies by Chang et al. (2013) [35] as well as Lee and Lee (2016) [34] are meaningful in that they calculated air pollutant emissions using ship data from Korean ports. However, information on the power output and load factor of auxiliary engines used to calculate ship emissions depends on the data provided by shipping companies rather than open data, such that port authorities encounter difficulties in easily accessing these data in real time. Several studies have proposed the calculation of emissions from ship activity based on Automatic Identification System (AIS) data [36,37]. However, in the case of coastal sailing ships without AIS, it is difficult to calculate quantitative data-based emissions. Therefore, an open data-based quantitative ship pollutant emissions calculation system is ideal for more efficient and continuous air pollution control of vessels at ports.

The Busan Port Authority also lacks a survey on the Social Environmental Costs (SEC), an indicator of the economic and environmental impact in the community due to ship and port air pollution emissions. Only two domestic air pollution-related studies have been conducted on the SEC in this port [34,38]. However, KMI (2016) [38] used outdated and unrelated national and international economic valuation results without understanding the environmental valuation methodology. In addition, Lee and Lee (2016) [34] estimated social costs without scientific evidence for ship air pollution and human health risks.

Therefore, the purpose of this study is to establish accessible open data-based ship emissions calculations and estimate the SEC for more efficient port air pollution reduction policies. We first present an open data-based calculation method using the Port Management Information System (Port-MIS) to calculate air pollution emissions at Busan Port [39,40]. Second, based on the calculated results, we estimate the SEC of air pollution emitted from ships at Busan Port in accordance with the international Benefit Transfer Method (BTM), an economic valuation method, with updated scientific results regarding the impact of ship emissions and social environmental damages [41].

Section 2 describes the methodology for calculating the emissions and social costs of pollutants emitted from ships during port at Busan Port. Section 3 provides the emissions calculation results for the pollutants using open data and describes the differences between this study, based on the estimation of the social costs, and other studies. Finally, Section 4 summarises the key findings obtained in this study, as well as presents the limitations of this study and future research directions.

2. Methods

2.1. Korean Port Management Information System (Port-MIS)

According to Article 89 of the Harbour Act (Establishment and Operation of Integrated Harbour Logistics Information Network), since 2008, the Korean government has operated the Port Management Information System (Port-MIS) at 28 trade ports nationwide, which manages port operations and civil complaints, such as ship entry, use of port facilities, control matters, cargo transfers, revenue collection, and departure reports [39]. The Ministry of Oceans and Fisheries also established a web-based Port-MIS platform in April 2010, which provides online services to manage port operations and civil complaints [38,40].

Port-MIS ship entry and departure services provide open data that can be used to calculate ship emissions, such as ship entry numbers, GT, registered tons, entry and departure time, ship type, etc. Ship entry information for a certain period for statistical analysis is provided with a service that allows data downloads corresponding with the period selected by the user in an Excel file format. Figure 2 illustrates a service example provided by the Port-MIS web-based platform.

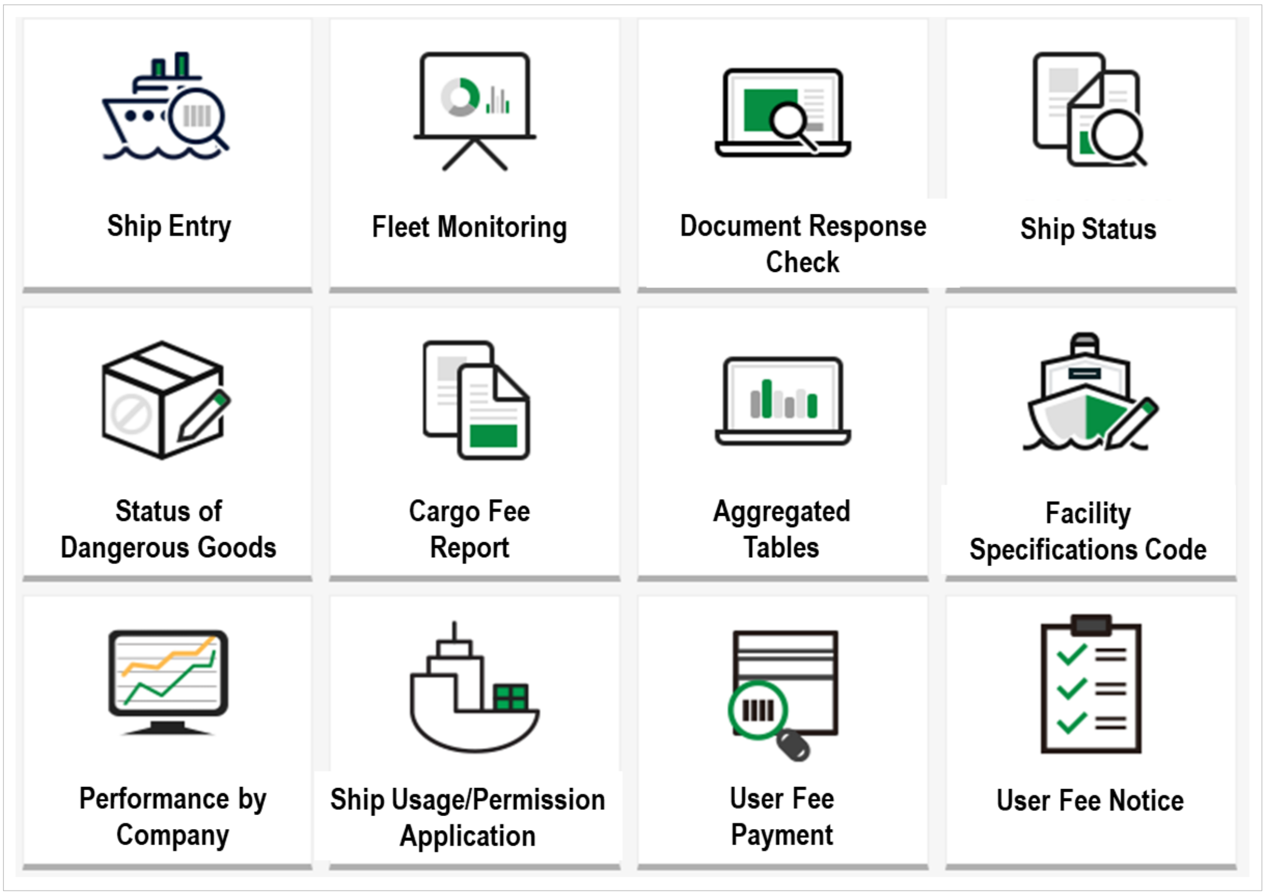

Figure 2. Port-MIS (Port Management Information System) web-based service platform [40].

This study used open data provided by Port-MIS, including data on any ships entering or leaving Busan Port from 2015–2019, to calculate pollutant emissions from ships during hoteling. Figure 3 shows an open data sample in Excel format for the Busan Port ship entry and departure service delivery data from Port-MIS.

Port	Call sign	Ship name	Entry no.		Ver.	In/Out port	In/Outbound	GT	Entry time	Departure time	...	Ship type	...
Busan	088***	***	2010	001	Final	Inport	Inbound	299	2010-01-01 01:25	2010-01-01 02:05	...	Tug boat	...
Busan	DS***	***	2010	001	Final	Inport	Inbound	1,974	2010-01-01 02:00	2010-01-01 13:52	...	Chemical tanker	...
Busan	V3***	7***	2010	001	Final	Inport	Inbound	499	2010-01-01 02:05	2010-01-01 23:50	...	Tanker	...
Busan	080***	***2***	2010	001	Final	Outport	Inbound	212	2010-01-01 02:20	2010-01-01 02:40	...	Tug boat	...
Busan	071***	2***	2010	001	Final	Inport	Inbound	499	2010-01-01 02:55	2010-01-01 16:45	...	Tanker	...
Busan	080***	***2***	2010	002	Final	Outport	Inbound	212	2010-01-01 03:05	2010-01-10 07:15	...	Tug boat	...
Busan	030***	***	2010	001	Final	Inport	Inbound	699	2010-01-01 05:00	2010-01-02 16:25	...	Tanker	...
Busan	001***	***	2010	001	Final	Inport	Inbound	197	2010-01-01 05:10	2010-01-04 11:25	...	Tanker	...
Busan	010***	***7***	2010	001	Final	Inport	Inbound	966	2010-01-01 05:50	2010-01-03 19:30	...	Others	...
Busan	934***	77***	2010	001	Final	Outport	Inbound	148	2010-01-01 06:00	2010-01-05 03:55	...	Tanker	...

Figure 3. Port-MIS (Port Management Information System) ship entry and departure service delivery data example for Busan Port [40].

2.2. Ship Emissions Estimation

The methodology presented in the 2006 IPCC guidelines—Volume 2: Energy's Mobile Consumption of Water-Borne Navigation (including ships) applies to the calculation of emissions from domestic and international ships during hoteling at Busan Port from 2015–2019 [19]. The 2006 IPCC guidelines refer to the 2019 joint European Monitoring and Evaluation Programme/European Environment Agency (EEMP/EEA) air pollution emission inventory guidebook (2019 EEMP/EEA guidebook) as a detailed methodology for estimating ship emissions based on the engine and ship type as well as ship movement data [19,42]. The 2019 EEMP/EEA guidebook presents three methodological tiers for estimating emissions from ships. The Tier 1 method is based on the amount of fuel consumed and the Emissions Factors (EFs) for pollutants. The Tier 2 method requires fuel consumption by fuel type, pollutant EFs, and fuel type (bunker fuel oil, Marine Diesel Oil (MDO)/Marine Gas Oil (MGO), and gasoline). In addition to the Tier 2 methodology, Tier 3 requires ship movement (hoteling, manoeuvring, and cruising) mode data. In this study, the emissions estimation algorithm for Tier 3 was applied as follows [42]:

$$E_{i,\ Trip} = \sum_{p} T_p \sum\nolimits_e \left(P_e \times LF_e \times EF_{e,i,j,m,p}\right) \tag{1}$$

where $E_{i,\ Trip}$ is the emission of pollutant i over a complete trip [kg], p denotes the different phases of a trip (cruising, manoeuvring or hoteling), T is time [hours], e is the engine category (main or auxiliary), P is the engine nominal power [kW], LF is the engine load factor [%], $EF_{i,m}$ is the fuel consumption-specific emission factor of pollutant i, j is the engine type (slow, medium or high-speed diesel; gas/steam turbine for large ships; and diesel/2 stroke/4 stroke gasoline for small vessels) using fuel type m [kg/ton] that is the bunker fuel oil, MDO, MGO, and gasoline.

The EFs for ships using MDO/MGO were used for ship emissions analysis of the principal pollutants since the fuel used by hoteling ships at port changes from bunker fuel oil to MDO before entering the harbour limits based on MARPOL Annex VI regulations [12,43]. The MGO and MDO fuel oil EFs for the ship hoteling phase were applied, as listed in Table 1, and the auxiliary engine load factor for the hoteling phase was applied, as listed in Table 2 [44]. Furthermore, the fuel consumption of auxiliary engines during berth was 60% for tankers and 40% for non-tankers, as compared with the fuel consumption during navigation (Table 3) [42,45].

Table 1. Auxiliary engine emissions factors for pollutants by fuel type during hoteling [g/kWh].

Fuel Type [1]	Pollutants				
	NOx [2]	SO_2	CO_2	VOC	PM [3]
MGO	13.0	0.9	690	0.4	0.3
MDO	13.0	6.5	690	0.4	0.4

[1] Busan Port was designated as an Emissions Control Area (ECA) on 1 September 2020 [46]. [2] NOx fleet average [44]. [3] PM2.5 and PM10 are equivalent to 90 and 95% of the total PM, respectively [44]. Source: Auxiliary emissions factors for "at sea (cruising)", "manoeuvring", and "at berth (hoteling)" in 2007 [44].

Table 2. Installed main engine power as a function of the gross tonnage (GT), vessel ratio of the auxiliary engine (AE) to the main engine (ME), and fuel type by ship type.

Ship Type	ME Fuel	AE Fuel	2010 World Fleet		
			ME Power [kW]	AE Ave. Number	AE/ME [%]
Liquid bulk ships	MDO	MGO	$14.755 \times GT^{0.6082}$	1.5	30
Dry bulk carriers	MDO	MGO	$35.912 \times GT^{0.5276}$	1.5	30
Container	MDO	MDO	$2.9165 \times GT^{0.8719}$	2	25
General cargo	MDO	MGO	$5.56482 \times GT^{0.7425}$	1.5	23
Ro–Ro cargo	MDO	MDO	$164.578 \times GT^{0.4350}$	1.5	24
Passenger	MDO	MDO	$9.55078 \times GT^{0.7570}$	2	16
Fishing	MGO	MGO	$9.75891 \times GT^{0.7527}$	1	39
Other	MGO	MGO	$59.0490 \times GT^{0.5485}$	1	35
Tugs	MGO	MGO	$54.2171 \times GT^{0.6420}$	1	10

Source: EEMP/EEA air pollutant emission inventory guidebook, 2019; IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories [42].

Table 3. Load assumption of MCR for hoteling [%].

Ship Activity	% Load of MCR for ME Operation	% of Electric Power from Shaft Generators	% Load of MCR for AE Operation
Hoteling	20	0	40 (60 for tankers)

Source: Assumption regarding engine operation for different activities [44].

In this study, we utilised the berthing and departure time, ship type, and GT information provided by the Port-MIS ship entry service, as well as the auxiliary engine output, load factor, and fuel type information according to the ship activity phase from Lloyds Marine Intelligence Unit (MIU) data. In addition, the Tier 3 approach was applied to calculate the emissions from domestic and international ships during hoteling at Busan Port from 2015–2019 [42,44,47].

2.3. Environmental Cost Estimation

The SEC of ship emissions can be defined as the monetary value (cost) of environmental damage to society, but not compensated by polluters (ships) [48–51]. Generally, air pollutants (e.g., NOx and PM) emitted from ships entering a port affect human health, such as complications with bronchitis, respiratory disease, and cardiovascular disease. Increased concentrations of ozone and acidic air pollutants cause a variety of environmental damage, including a decrease in crop yield, pollution or corrosion, damage to materials and building surfaces, and a decrease in biodiversity [38,49–52].

Carbon dioxide emissions, known as a leading greenhouse gas, lead to global warming and climate change (temperature rise), which have significant and irreversible effects on ecosystems, human health, and society [10,53]. Therefore, the representative external costs of CO_2 emissions from ships, such as sea level rise, biodiversity loss, water management problems, rapid climate change, crop damage, and global warming, have adverse effects. As a result, the indirect utility ($V(p, m, q)$) of the general public, be it the maximum level of utility given prices, income, and environmental services, which is not related to port and maritime transportation activity, decreases due to air quality degradation ($q^0 > q^1$) as a result of air pollution caused by air pollutant emissions:

$$V(p,\ q^0, \mathrm{m} + \mathrm{WTA}) = V(p,\ q^1, \mathrm{m}) \quad (2)$$

where p is a vector of market goods prices, q is air quality, m is income, and WTA is the willingness to accept.

Here, the monetary value for the welfare loss due to the emissions of air pollutants from ships can be obtained using the Compensating Surplus (CS) and Equivalent Surplus (ES), which are the minimum Willingness to Accept (WTA) values as compensation for air quality degradation (q^1) and the maximum Willingness to Pay (WTP) values for air pollution not to occur, respectively [54–56].

Given that air quality is generally an environmental public good, environmental valuation methods can be used to estimate its total economic value. In this study, BTM was adopted to measure the economic value (or environmental cost) of a ship's emission damage to society, as a direct quality environmental valuation study, such as a Contingent Valuation Method (CVM), is too costly and time-consuming owing to a long and expensive survey-based economic valuation approach with a pre- and post-test process.

BTM is a method that estimates the economic value of an environmental good or service at a current policy site using available information and economic value estimation results (e.g., the environmental cost of air pollution) from studies conducted at different sites in the same or different countries [41,54,57,58]. BTMs largely include value transfer (e.g., unit value transfer and adjusted unit value transfer), which apply the estimated values from existing studies. In addition, there is a value function transfer that applies these value functions since the estimated values in existing CVMs are obtained as functions of several socio-economic factors.

Following the methodology in Ready and Navrud (2006) [41], this study employed an adjusted unit value transfer, which estimates the economic value by simply adjusting different income and purchasing power levels between study and policy sites with a Purchasing Power Parity (PPP)-adjusted exchange rate [59,60]. However, using a BTM when the similarity between the existing study site and the newly estimated policy site in terms of various factors, such as changes in the environmental quality, location, and population characteristics, yields estimation results that are more reliable. Therefore, finding detail-oriented primary research on domestic or overseas sites using a reasonable Economic Valuation Method (EVM) is important for the SEC estimation of air pollution emitted from ships at Busan Port [57,61–63].

2.4. SEC Estimation

Since the 1980s, large-scale long-term projects have been undertaken to estimate the social costs of air pollution from energy consumption and transportation (particularly road, rail, and inland shipping) based on bottom-up and Impact Pathway Approaches (IPA) [64–66]. In other words, to estimate the social costs of air pollution from ships, we must (1) measure the amount of air pollutants emitted from ships in a region, (2) measure the concentration of air pollutants in that region after air diffusion, (3) estimate the impacts, and (4) estimate the economic monetary value.

If the social cost factors for air pollution are estimated, the bottom-up approach applies the EFs for each type of vessel, the operational performance data for the vessel, and the total social cost of national maritime transport [5,67]. Accordingly, representative projects for estimating the social costs of air pollution in Europe have been carried out by European countries, such as the BeTa project (2002) (Benefits Table Database: Estimates of the Marginal Environmental Costs of Air Pollution in Europe), CAFE project (2005) (Clean Air for Europe), HEATCO project (2006) (Developing Harmonised European Approaches for Transport Costing), and NEEDS project (2008) (New Energy Externalities Developments for Environmental Stressors in Europe) [68–71].

As previously discussed, applying the BTM to this study requires an analysis of existing domestic and foreign research results that estimate the SEC of air pollution similar to the current situation at Busan Port, Korea. Lee and Lee (2016) [34] and KMI (2016) [38] are the main studies that have been conducted on air pollution at Busan Port, Korea. However, both studies have limitations with respect to the accuracy of their estimation results (Table 4). Lee and Lee (2016) [34] applied social cost estimation findings to air pollution from national and international land transportation without applying the EVM to the environmental cost estimation [72–75]. KMI (2016) [38] used the survey-based Conjoint Analysis Method (CVM) of EVMs, but the statistics included aviation, railways, construction equipment, and agricultural machinery in addition to air pollutant estimations from ship emissions. In addition, there is an error associated with estimating the failure to present scientific causality data on the increase in the emissions concentration from ships entering Busan Port and health deterioration (i.e., early death, lung cancer, asthma, and cardiovascular disease rates).

Table 4. Studies on estimating the environmental cost of ship emissions in Korea.

Paper	Study Area	Data	Air Pollution Emission	Economic Valuation Method (EVM)	Study Type
KMI (2016)	Busan and Incheon region, Korea	Survey data in 2016	Impact of all air pollutants on human health (not restricted to ships)	Conjoint Analysis	Primary Study
Lee and Lee (2016)	Busan Port, Korea	2011–2012	CO, CO_2, SO_2, NOx, PM, HC, VOC	BTM, but not specified in study	Secondary Study

The following analysis was conducted to estimate the environmental costs for ship-emitting air pollutants conducted overseas. Several recent studies have conducted comprehensive reviews and meta-analyses of studies that estimated the social costs of air pollutants emitted from ships or ports. For example, Tichavska and Tovar (2017) [66] recently reviewed a total of 10 international studies that estimated the social cost of air pollutants emitted from ships at ports. Gren et al. (2020) [64] reviewed 28 international studies that estimated the environmental costs of air pollutants emitted from ships between 2002 and 2019.

However, most of these studies are secondary, i.e., studies that are based on the results of the BeTa, CAFE, HEATCO, and NEEDS [68–71] projects conducted in European countries; the results were estimated to fit the conditions of each study. Among the four projects in Europe, the social costs of air pollution caused by ships, rather than by other land transportation methods, were estimated in the BeTa and NEEDS projects. The BeTa [68] project first estimated the social costs of air pollution from ship emissions in 15 European countries and five European water bodies (Eastern Atlantic, Baltic Sea, English Channel, Northern Mediterranean, and North Sea) based on air pollution levels in 1998. Therefore, the BeTa project estimated the Marginal External Costs (MECs) for the air pollutants NOx, SO_2, VOCs, and PM2.5 from ships by dividing them into urban, rural, and offshore areas (at sea). However, the MECs of NOx and VOCs for urban areas had no direct estimation results. Therefore, the estimated values were used in the rural region; excluding ecosystems and cultural heritage effects limited the estimation of environmental costs [68].

The NEEDS [71] project also estimated the social costs of the air pollution from ship emissions (VOCs, NOx, SO_2, PM2.5, and PM10) in 25 European countries, 14 non-European countries, and five European water bodies (Baltic Sea, Black Sea, Mediterranean Sea, North Sea, and the rest of the North-East Atlantic).

Particularly, the NEEDS project updated its results in 2014 [67] and 2019 [5] with updated features. In other words, the estimates of the social costs of air pollution from ship emissions will depend on the input data used in the specific study: Ship traffic and operating performance data. The results of a value estimation study on social costs can be largely dependent on the development of the science at the IPA methodology stage, as well as the measurement of air pollutant emissions, changes in concentrations accumulated after dispersion in air, and the resulting impact on human health, buildings, and ecosystems, etc. [5]. Therefore, since the 2019 version of the NEEDS project is a result of updating the 2007 findings based on state-of-the-art scientific data and information (Table 5), we used them as a fundamental primary study for the application of BTM to estimate the social costs in this study as a Base Case. Among the annual average Environmental Costs (ECs) in the five European water bodies, as estimated in Table 5, the EC of the North Sea was applied, consisting of ports with similar port traffic to Busan Port.

Table 5. Estimation of annual average social environmental cost [1] for air pollution from ships in European sea areas [EUR_{2016}/ton].

Sea Area	VOC	NOx	SO_2	PM2.5	PM10
Atlantic Sea	400	3500	3800	7200	4100
Baltic Sea	1000	6900	7900	18,300	10,400
Black Sea	200	11,100	7800	30,000	17,100
Mediterranean	500	9200	3000	24,600	14,000
North Sea	2300	10,500	10,700	34,400	19,700

[1] Air pollution impacts include health effects, crop loss, biodiversity loss, and material damage. Source: Handbook on the external costs of transport, version 2019 (No. 18.4 K83. 131) [51].

However, although it includes the latest findings, as the SEC for the North Sea estimated by the NEEDS project is a social cost due to air pollutants emitted from ships operating in coastal waters, the application of this SEC to ships facing Busan Port estimated in this study may be an underestimated result. To date, the only study to estimate the environmental cost of the community due to the emissions of air pollution from ports is the BeTa project, which estimates direct MEC for PM2.5 and SO_2 considering the population density of port cities [17,66,68]. Therefore, when estimating the SEC due to air pollutants from ships at Busan Port, two additional SEC estimation results were applied, as shown in Table 6, as an alternative to the Base Case.

Table 6. Estimated social and environmental costs for air pollution from ships used in this study [EUR_{2000}/ton].

Sea Area	VOC	NOx	SO_2	PM2.5	PM10 [2]	Remarks
Base Case (North Sea from NEEDS project) [1]	1713	7968	7819	25,617	14,670	Ship emissions at sea (offshore)
SEC Case 1 (Urban from BeTa project)	2100	4200	90,000	495,000	283,474	Population Factors = 15
SEC Case 2 (North Sea from BeTa project)	2600	3100	4300	9600	5498	Ship emissions at sea (offshore)

[1] Note: The estimates of the Base Case have been transformed from EUR_{2016} (provided in Table 5) to EUR_{2000}.
[2] Note: PM10 was estimated by applying the ratio of PM2.5 and PM10 estimated in the NEEDS project. Source: Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe [68].

SEC Case 1 was estimated by applying a population factor of 15 for the population of Busan in 2019 (3,466,563 people) [76] to the urban estimate (EUR 33,000 and 6000/ton for PM2.5 and SO_2, respectively) (in the BeTa project, urban MECs for PM2.5 and SO_2 were estimated based on a port city population of 100,000 and then proportional to the population, i.e., population factors 5, 7.5, and 15 for populations of 500,000, 1,000,000, and several millions, respectively [68]) from the BeTa project [68]. The SECs of VOC, NOx, SO_2, and PM2.5 were EUR 2100, 4200, 90,000, and 495,000/ton, respectively. However, the estimated value of SEC Case 2 for PM2.5, which would incur human health effects, was approximately 19.3 times the value of the Base Case (EUR 25,617/ton). In addition, as this was the result of deviating from the range of SEC of PM2.5 presented in Gren et al. (2020) [64], which includes the most recent meta-analysis, its application at this point may have been overestimated.

SEC Case 2 applied the results of the BeTa project, which estimated the MECs for the North Sea area, which is almost the same sea area as in the Base Case. Comparing the estimated SEC values of the Base Case (EUR 43,177/ton) and SEC Case 2 (EUR 19,600/ton), excluding PM10, it can be seen that the estimated values in the Base Case in the present study increased by approximately 2.2 times and, compared with the other pollutants, the marginal external cost of VOC (EUR_{2000}/ton) decreased by approximately 66%. Therefore, as mentioned earlier, a comparative analysis of the Base Case and SEC Case 2 can provide a meaningful result illustrating how the estimated social environmental costs due to ship air pollution change according to the latest scientific data and methodology, change in human and social impact, and change in the human perception of air pollution.

The following are the social cost estimates for CO_2, a representative GHG that has global impacts, such as climate change. However, as the social cost estimation for GHGs (CO_2) is a global issue, the results of this estimation vary depending on the study. For example, Song (2014) [18], estimated the social cost of air pollution at the Shanghai–Yangshan ports in China based on four different studies; the social costs ranged from USD 15 to 42/ton. Furthermore, Wang et al. (2019) [77] conducted a meta-analysis based on several studies to estimate the social cost of carbon emissions, showing that the social cost ranged from USD −13.36 to 2386.91/tCO_2. Therefore, as listed in Table 7, the social impact of CO_2 emissions from ships was first used as the upper limit of the updated 2019 results in the NEEDS project [51], i.e., an average of EUR 100/ton (price in 2016).

Table 7. Social environmental cost estimates of CO_2 emissions from ships.

Study Site	EC of CO_2
EU-28 countries	EUR 100/ton in 2016
USA	USD 42/ton in 2020 (in 2007)

Source: Valuing climate damages [50].

As an alternative to the EUR 100/tCO_2 value presented in Europe, we included estimates of the social costs for CO_2 emissions at the government level since 2008 based on Executive Orders in the United States. In other words, the US government developed and studied a methodology for estimating the social costs of CO_2 within the context of the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) in 2010. Furthermore, IWG (2016) [78] estimated the social costs of CO_2 emissions by 2020 at USD 42/tCO_2 (in 2007).

As the estimated social costs in Tables 6 and 7 were calculated in EUR from 2000 and 2016, respectively, they should be translated into Korean values by applying the international BTM. Generally, if the same individual wishes to have the same actual WTP for air pollution reduction in two countries with different exchange rates, it is possible for the actual price to be identical to the actual income. Therefore, it should be calibrated by applying the PPP, i.e., not simply using the exchange rate correction of the two countries. The CPI, which is the consumer price index, should then be applied to translate the value of the current country's policy site [41]. In other words, to transfer the EC estimated in 2000 or 2016 (t = 2) from the study country (i = b), such as in Equation (3), to the 2019 value (t = 1) for the policy country (i = a).

$$EC_{i=a}^{t=1} = EC_{i=b}^{t=2} \times \frac{PPP_{i=a}^{t=2}}{PPP_{i=b}^{t=2}} \times \frac{CPI_{i=a}^{t=1}}{CPI_{i=a}^{t=2}} \quad (3)$$

where EC is the environmental cost, PPP is the purchasing power parity, CPI is the consumer price index, i is the country ($i = a,b$), and t is time (t = 1,2).

3. Estimation of Ship Emissions and Environmental Cost at Busan Port

3.1. Port-MIS Ship Entry Data from 2015–2019

Busan Port consists of five harbours (New, Dadaepo, Gamcheon, South, and North) along the Korean peninsula, as shown in Figure 1. Table 8 lists the number of domestic and international ships entering Busan Port from 2015–2019. The main ship type is a container ship, accounting for approximately 30% of all incoming ships. The next largest proportion of ships is liquid bulk ships, accounting for approximately 27% of all inbound vessels; container and liquid bulk ships accounted for approximately 57% of all inbound vessels at Busan Port. The second largest percentage of ships after container and liquid bulk ships is represented by tugs, general cargo ships, and passenger ships, with the number of inbound and outbound vessels gradually decreasing since 2016.

Table 8. Ship entry number [1] by ship type at Busan Port from 2015–2019 [num].

Ship Type	Year					
	2015	2016	2017	2018	2019	2015–2019 (% by Ship Type)
Liquid bulk ships	12,801	13,558	12,802	12,509	13,040	64,710 (26.4%)
Dry bulk carriers	1506	1612	1516	1335	1729	7698 (3.1%)
Container	15,091	15,324	15,516	15,223	14,720	75,874 (31.0%)
General cargo	6224	6344	6099	5682	5388	29,737 (12.1%)
Ro–Ro cargo	317	363	313	205	205	1403 (0.6%)
Passenger	3248	3636	3767	3910	3288	17,849 (7.3%)
Fishing	1123	1165	1400	1342	1389	6419 (2.6%)
Other	1038	1048	1095	904	935	5020 (2.1%)
Tugs	8280	7819	7254	6369	6435	36,157 (14.8%)
Sum	49,628	50,869	49,762	47,479	47,129	244,867

[1] Some non-existing data for the departure time were excluded (excluding 227 vessels from the raw data). Source: Port-MIS ship entry and departure services: Ministry of Oceans and Fisheries [47].

Table 9 lists the volume of ships entering Busan Port from 2015–2019. The results of shipping by ship type were as follows: Container ships, dry bulk carriers, passenger ships, liquid bulk ships, and Ro–Ro cargo ships; the overall volume of ships using Busan Port increases annually. Container ships account for the largest entry number and volume of shipping entering Busan Port. The number of ships using Busan Port decreases annually, whereas the volume of shipping increases annually, indicating that ships are becoming larger.

Table 9. Entry ship gross tonnage (GT) statistics [1] by ship type at Busan Port from 2015–2019 [GT].

Ship Type	Year				
	2015	2016	2017	2018	2019
Liquid bulk ships	15,459,190	16,138,568	16,308,114	19,289,104	23,909,309
Dry bulk carriers	28,065,888	33,988,474	33,667,341	29,663,711	36,304,420.34
Container	502,993,471	515,447,303	537,537,814	556,552,624	555,320,490
General cargo	34,235,272	33,616,413	31,756,653	29,934,034	28,217,042
Ro–Ro cargo	12,621,833	16,756,854.2	14,593,470	9,646,058	9,012,494
Passenger	23,852,279	39,652,707	26,268,168	23,577,180	25,023,793
Fishing	1,292,181	1,483,812	1,799,833	1,682,768	1,755,471
Other	2,677,187	2,133,649	1,607,409	1,962,064.72	1,867,217.55
Tugs	1,049,521	978,447	781,481	710,408	667,735.55
Sum	622,246,822	660,196,227.2	664,320,283	673,017,951.72	682,077,972.44

[1] Some non-existing data for the departure time were excluded (excluding 227 vessels from the raw data). Source: Port-MIS ship entry and departure services: Ministry of Oceans and Fisheries [47].

3.2. Ship Pollutant Emissions during Hoteling at Busan Port

To analyse the emissions from ships during hoteling at Busan Port (2015–2019), Port-MIS ship entry and departure times, ship types, and GT data were used to calculate ship emissions [40,44].

The combustion of fuel oil in an internal combustion marine engine produces ship emissions. The principal pollutants from internal combustion engines are carbon monoxide

(CO), VOCs, NOx, and PM, derived from soot mainly related to engine technology, and carbon dioxide (CO_2), SOx, heavy metals, and PM, which originate from fuel speciation [42]. EEMP/EEA (2019) [42] showed that SOx and NOx emissions from national shipping account for a significant portion of the total national emissions (SOx and NOx contribution from national shipping to total emissions: 80 and 30%, respectively). Table 10 shows the emission calculation results used in Equation (1) for each ship type at Busan Port in 2019 (based on the exhaust gas pollutant), while Table 11 lists the annual emissions of the major pollutants (Refer to Appendix A for 2015–2018 results). Emission levels were highest in 2016, and lowest in 2017, and increased again in 2019. Based on the calculated emissions for the major sources of ship pollutants, NOx accounted for the largest percentage of pollutants, at approximately 1.83% (1,335,401.78 kg/yr), followed by SO_2 at 0.68% (496,519.27 kg/yr), VOC at 0.06% (41,089.29 kg/yr), and PM10 and PM2.5 at 0.05% (PM10: 36,130.85 kg/yr; PM2.5: 34,299.22 kg/yr). CO_2 (anthropogenic carbon dioxide), which is not a pollutant, but an atmospheric greenhouse gas emitted by ships, was approximately 97.33% (70,879,017.63 kg/yr) of the annual average emissions by ships, i.e., the highest of all emissions, including pollutants. Figure 4 shows the rate of ship emissions of the major pollutants at Busan Port from 2015–2019 during hoteling.

Table 10. Ship pollutant emissions by ship type at Busan Port in 2019 (ship activity phase: Hoteling) [kg].

Ship Type	Pollutants					
	NOx	SO_2	CO_2	VOC	PM2.5	PM10
Liquid bulk ships	101,426.53	7021.84	5,383,408.12	3120.82	2106.55	2223.58
Dry bulk carriers	34,823.42	2410.85	1,848,319.90	1071.49	723.26	763.44
Container	942,372.10	471,186.05	50,018,211.42	28,996.06	26,096.46	27,546.26
General cargo	77,918.78	5394.38	4,135,689.32	2397.50	1618.31	1708.22
Ro–Ro cargo	7983.66	3991.83	423,747.94	245.65	221.09	233.37
Passenger	23,630.97	11,815.48	1,254,259.12	727.11	654.40	690.75
Fishing	108,944.00	7542.28	5,782,412.51	3352.12	2262.68	2388.39
Other	48,805.21	3378.82	2,590,430.43	1501.70	1013.65	1069.96
Tugs	16,102.75	1114.81	854,684.36	495.47	334.44	353.02
Sum	1,362,007.42	513,856.33	72,291,163.12	41,907.92	35,030.83	36,976.99

Table 11. Annual trend in ship pollutant emissions at Busan Port from 2015–2019 (ship activity phase: Hoteling) [kg].

Year	Pollutants						Annual Emissions
	NOx	SO_2	CO_2	VOC	PM2.5	PM10	
2015	1,321,308.81	472,625.89	70,131,006.09	40,655.66	33,568.20	35,433.10	72,034,597.75
2016	1,379,034.32	512,996.47	73,194,898.60	42,431.83	35,351.70	37,315.69	75,202,028.61
2017	1,294,310.87	480,544.03	68,698,038.32	39,824.95	33,164.77	35,007.26	70,580,890.19
2018	1,320,347.49	502,573.62	70,079,981.99	40,626.08	34,030.61	35,921.20	72,013,480.99
2019	1,362,007.42	513,856.33	72,291,163.12	41,907.92	35,030.83	36,976.99	74,280,942.62
(Yearly mean)	(1,335,401.78)	(496,519.27)	(70,879,017.63)	(41,089.29)	(34,229.22)	(36,130.85)	(72,822,388.03)
Sum by pollutant (%)	6,677,008.91 (1.83%)	2,482,596.34 (0.68%)	354,395,088.13 (97.33%)	205,446.43 (0.06%)	171,146.12 (0.05%)	180,654.24 (0.05%)	364,111,940.16

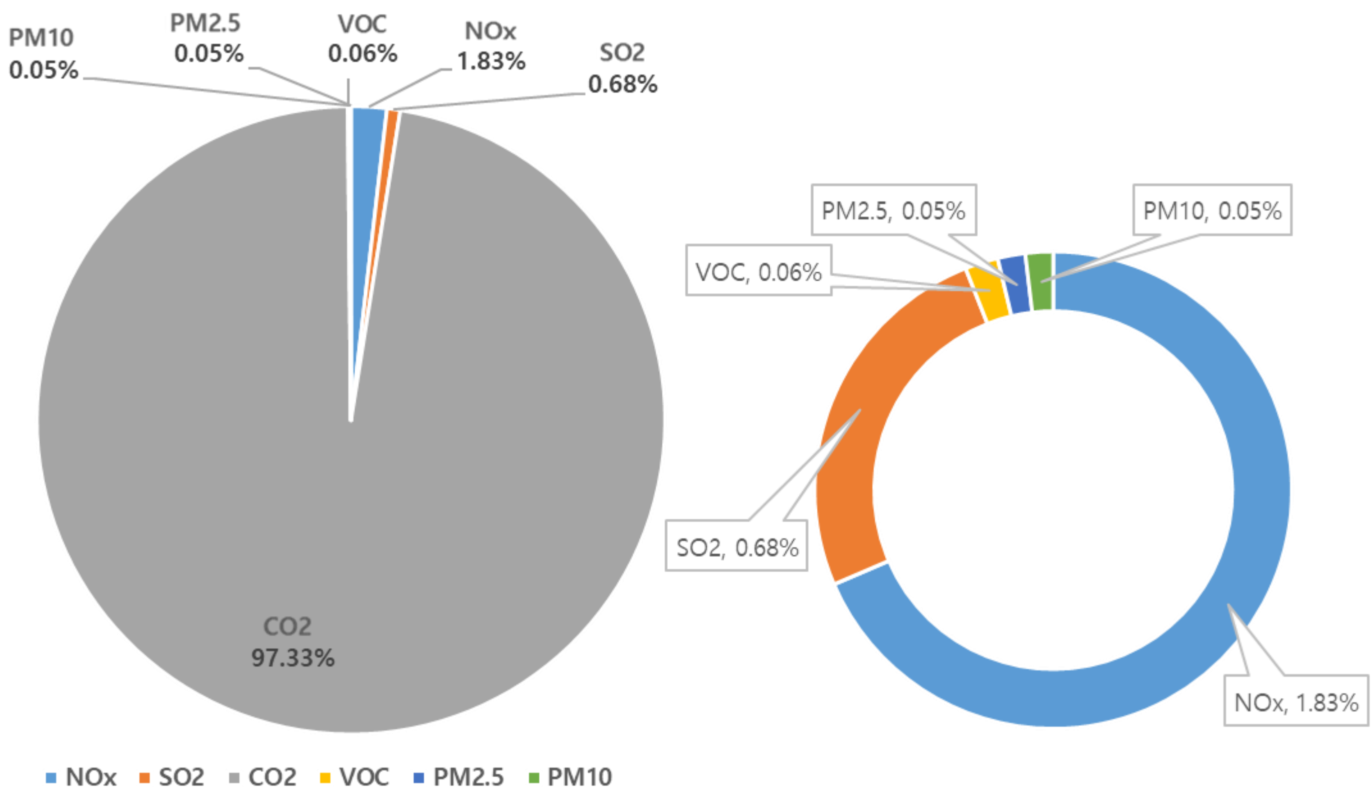

Figure 4. Ship emissions rate of the major pollutants at Busan Port from 2015–2019 during hoteling.

The results for the emissions by ship type showed that container ships, characterised by the highest port entry and maximum shipping volume at Busan Port, had the highest emissions, followed by liquid bulk ships, indicating high pollutant emissions proportional to the ship entry number and shipping volume. In addition, the annual emissions calculation results for the pollutants from ships have increased annually over the past 3 years (2017–2019), but emissions of SOx and ship pollutants should continue to decline in the future owing to the global sulphur limit regulations of 0.5% implemented in 2020 [13].

3.3. Environmental Cost by Ship Emissions at Busan Port

According to the IPA methodology described in Section 2.4, the annual emissions were estimated by the open data-based calculation method using the Port-MIS of Busan Port (Table 11). Subsequently, the marginal social environmental costs of ships air pollution were estimated by adopting the international BTM in Table 12. Finally, the total social costs of air pollutant (including CO_2) emissions from Busan Port were estimated by multiplying the estimated amount of air pollution by the marginal social environmental costs (Table 13).

Table 12. Estimated marginal social environmental cost of air pollution from ships using the international BTM [USD_{2019} 1000/ton].

Air Pollutants	NMVOC	NOx	SO_2	PM2.5	PM10	CO_2	
						EU-28	USA
Base Case	2.48	11.55	11.33	37.13	21.26	0.11	0.04
SEC Case 1	2.44	4.88	104.61	575.34	329.48	0.11	0.04
SEC Case 2	3.02	3.60	5.00	11.16	6.39	0.11	0.04

Table 13. Estimated social environmental cost of ship pollutant emissions at Busan Port [USD million].

Year	Cases	Pollutants							Total	Total
		NOx	SO_2	CO_2_EU [1]	CO_2_US	VOC	PM2.5	PM10	(EU)	(USA)
2015	Base Case	14.35	5.04	7.12	2.59	0.09	1.17	0.71	28.49	23.95
	SEC Case 1	6.07	46.51	7.12	2.59	0.09	18.17	10.98	88.94	84.40
	SEC Case 2	4.48	2.22	7.12	2.59	0.12	0.35	0.21	14.50	9.97
2016	Base Case	14.69	5.36	7.28	2.64	0.10	1.21	0.73	29.37	24.73
	SEC Case 1	6.21	49.48	7.28	2.64	0.10	18.75	11.34	93.16	88.52
	SEC Case 2	4.58	2.36	7.28	2.64	0.12	0.36	0.22	14.93	10.29
2017	Base Case	15.85	5.78	7.86	2.85	0.10	1.31	0.79	31.69	26.68
	SEC Case 1	6.70	53.31	7.86	2.85	0.10	20.23	12.23	100.44	95.43
	SEC Case 2	4.95	2.55	7.86	2.85	0.13	0.39	0.24	16.11	11.10
2018	Base Case	15.74	5.88	7.81	2.84	0.10	1.30	0.79	31.63	26.66
	SEC Case 1	6.66	54.28	7.81	2.84	0.10	20.22	12.22	101.29	96.31
	SEC Case 2	4.91	2.59	7.81	2.84	0.13	0.39	0.24	16.07	11.10
2019	Base Case	15.73	5.82	7.80	2.83	0.10	1.30	0.79	31.55	26.58
	SEC Case 1	6.65	53.75	7.80	2.83	0.10	20.15	12.18	100.64	95.68
	SEC Case 2	4.91	2.57	7.80	2.83	0.13	0.39	0.24	16.03	11.06

[1] Note: The CO_2_EU case is the Base Case for the estimation.

First, as of 2019, the total social costs of air pollutants emitted from 47,129 ships at Busan Port were USD 26.58 to 31.55 million for the Base Case, USD 95.68 to 100.64 million for SEC Case 1, and USD 11.06 to 16.03 million for SEC Case 2. Second, for a CO_2 Base Case, the social environmental costs of the CO_2 (GHG) emissions and ship pollutant emissions obtained by calculating the sum of the values for all the emissions except CO_2 were USD 7.80 million (24.7%) and 23.74 million (75.3%) for the Base Case, USD 7.80 million (7.8%) and 92.84 million (92.2%) for SEC Case 1, and USD 7.80 million (48.7%) and 8.23 million (51.3%) for SEC Case 2, respectively.

Third, for the Base Case in 2019, the social costs of emissions were USD 15.73 million for NOx, USD 7.80 million for CO_2, USD 5.82 million for SO_2, USD 2.09 million for PM (including PM2.5 and PM10), and USD 0.10 million for VOCs, respectively. However, when applying the US estimates of the social costs of CO_2, out of the total social costs of USD 26.58 million, SO_2 ranked second, higher than the social costs of CO_2 at USD 2.83 million (10.7%).

Finally, although it is difficult to directly compare the estimated air pollutant emissions from ships in a specific year and estimate social costs due to the different social cost estimation methods, we compared the results of two existing Korean studies with the social costs of ship emissions at Busan Port in Table 14. The estimated environmental costs of KMI (2016) [38] as well as Lee and Lee (2016) [34] were USD 30.16 million and 1055.02, respectively. Therefore, we estimated to these values to be 95.6 and 3344.4% compared with the 2019 Base Case social costs of USD 31.55 million, and 30.0 and 1048.3% compared with the 2019 SEC Case 1 social costs of USD 100.64 million, respectively.

Table 14. Comparative analysis with existing research results estimating the social costs of air pollution emitted from hoteling ships at Busan Port.

Research	Year	Yearly Social Environmental Cost	Remarks
KMI (2016)	2019	USD 30.16	Estimating economic benefits of reducing health damage caused by air pollution from ship emissions by 10%
Lee and Lee (2016)	2011	USD 1055.02	Estimating environmental costs of ship-emitting air pollutants: NOx, SO_2, CO, CO_2, PM, HC, and VOC
Base Case SEC Case 1 SEC Case 2	2019	USD 31.55 USD 100.64 USD 16.03	Estimating environmental costs of ship emission pollutants during hoteling at Busan Port using Port-MIS open data

4. Discussion and Conclusions

Reinforcement of international and domestic regulations on air pollutant emissions from ships and conflict with the local community due to the deterioration of air quality in the port area are a pre-requisite to maintain the status of Busan Port as an international hub port, which currently ranks 6th in the world's container ports. Busan Port established and implemented a green port policy in 2011, including measures to reduce air pollutants from ships focused on CO_2 emissions [22]. However, compared with EU ports and the ports of LA and LB, the policy implementation performance is poor.

In this study, we calculated pollutant emissions using the Port-MIS open data resource, a top-down method for calculating air pollutant emissions from ships in Busan Port. Then, in the absence of a well-estimated SEC of Busan Port using the bottom-up approach, we estimated the overall external costs of Busan Port using the international BTM based mainly on European projects (BeTa and NEEDS projects), which originally estimated the factors of SECs [66,79]. The study results can be utilised as a baseline to implement efficient policies to improve the air quality at Busan Port in the future.

First, we presented a quantitative open data-based emission calculation system by applying actual data, such as berthing time, ship type, and gross tonnage data of ships entering Busan Port for 5 years from 2015–2019 using open data from the Port-MIS web platform, operated by the MOF. As the quantitative open data-based ship emission calculation system during hoteling can be applied equally to other Korean ports, it can be used as a basis for preparing regulations on pollutants discharged from ships in the port. In addition, this study provided an emission inventory system in port that can continuously analyse the level of port air pollution discharged from ships using official and open data provided by state agencies.

Second, to calculate the pollutant emissions from ships during hoteling at Busan Port, we used the latest auxiliary engine EFs for pollutants by fuel type, as presented in the 2019 EEMP/EEA guidebook and Entec 2010. The Tier 3 method, as reported in the 2019 (2019 EEMP/EEA guidebook), was applied to estimate the emissions of major pollutants (NOx, SO_2, VOC, PM2.5, and PM10) and atmospheric GHGs (CO_2) emitted from hotspots at Busan Port from 2015–2019. Based on the emissions estimation results, the average annual emissions of atmospheric CO_2 were highest at 97.33% (70,878,030.27 kg/yr) of the total emissions (72,822,388.03 kg/yr). According to the estimations of the pollutant emissions, the average annual emissions of NOx, SO_2, VOC, PM2.5, and PM10 were 1,335,401.78 (1.83%), 496,519.27 (0.68%), 41,089.29 (0.06%), 36,130.8 (0.05%), and 34,299.22 kg/yr (0.05%), respectively. However, there is a limit to the current research; the quality of the fuel oil used by Busan Port vessels cannot be reflected owing to inaccurate EF value information, which is the representative value.

Third, as monetised negative economic, social, and environmental impacts using economic valuation methods, the estimation of SECs is not only very difficult but also requires a large amount of time and money due to the existing uncertainties in obtaining scientific data that can reveal an exact causal relationship between ship emissions and negative effects [51,66,79]. Therefore, in a situation where reliable research on the estimation of SECs for ship air pollution in Busan Port is very lacking, this study estimated the latest SECs of Busan Port by applying the international BTM, a recognised economic valuation method.

Unlike the study by Lee and Lee (2016) [34], we used reliable and up-to-date data sources, such as the NEEDS project [51] as the Base Case and the BeTa project [68] as SEC Cases 1 and 2, for SEC estimation in Busan Port by applying a Purchasing Power Parity (PPP)-adjusted exchange rate to adjust different income and purchasing power levels between European and Busan ports [41,59,60]. The total SECs of exhaust gas pollutants from ship emissions during hoteling at Busan Port in 2019, as a Base Case analysis, were estimated at USD 31.55 million, not including the manoeuvring process in port.

As the Base Case was estimated based on the external costs (NEEDS project results from 2019) of ship emissions from ships navigating in the North Sea, the SECs for ship emissions during hoteling at Busan Port may be underestimated. However, this study confirmed that the costs in the Base Case were almost twice as high as those in SEC Case 2 (USD 16.03 million), which was estimated based on older research results (BeTa project results from 2002) for the same North sea areas. Therefore, this result illustrates to what extent the estimated results of SECs depend on the scientific information and methodologies used, and on changes in the human perception of environmental damages from ship emissions.

To reflect the concern that the estimate of ship SECs while berthing in Busan Port was underestimated in the Base Case, this study estimated the SECs of SEC Case 1, as an upper bound estimate, at USD 100.64 million by applying urban results from the BeTa project that estimated the marginal costs of air pollution of ships in the port. In addition, we found that the Base Case estimate as a lower bound and the SEC Case 1 estimate as an upper bound of the SECs of Busan Port were 33.4 and 10.5 times less, respectively, than the estimates of Lee and Lee (2016) [34] (USD 1055.02 million). In light of these results, the SEC values from Lee and Lee (2016) [34] could be overestimated compared with the actual SECs of ship emissions at Busan Port. Therefore, considerable caution should be taken, as the distorted and incomplete estimation results might cause conflicts between the port and local communities.

Finally, in 2019, the largest pollutant source in Busan Port based on ship emissions was CO_2 (97.33% of total emissions). However, in terms of social environmental costs, the ranking of effects by emission pollutants is different. Therefore, based on the EU SEC estimate (USD 7.80 million), the ratio of the SECs of atmospheric CO_2 ranged from 7.8% in SEC Case 1 to 24.7% in the Base Case. The social cost estimation results for exhaust gas pollutants from ship emissions at Busan Port showed that the SECs in the Base Case for NOx, SO_2, PM2.5 (including PM10), and VOC were USD 15.73 million (49.9%), USD 5.82 million (18.5%), USD 2.09 million (6.6%), and USD 0.10 million (0.3%), respectively. Therefore, in the Base Case, the pollutants with the most serious SECs were NOx (USD 15.73 million, 49.9%), CO_2, and SO_2 (USD 5.82 million, 18.5%) in that order, whereas in SEC Case 1, SO_2 (USD 53.75 million, 53.4%), PM2.5 including PM10 (USD 32.34 million, 32.1%), and CO_2 were the most serious, in that order. These results are expected to aid port authorities in prioritising the introduction of efficient reduction policies for each air pollutant emitted by ships at Busan Port.

In summary, as mentioned earlier, our SEC estimates using the international BTM may be inaccurate owing to the underestimated results. In addition, the emission range of air pollutants from ships entering the port, in other words, the range of social environmental damage, should include damages from ships emissions not only during berthing at port, but also during manoeuvring in the coastal areas and within port areas, but we could not carry that out. However, although it is not a direct estimate of the social costs of Busan Port using a bottom-up approach, these results can be meaningful when compared with recent scientific research on the economic damage to society due to ship air pollution in Korea.

With the application of the 2020 global sulphur limits of 0.5%, the efforts of flag states, such as the Emission Control Areas (ECAs) designation, to improve the air environment and reduce air pollutant emissions from ships are expected to continue, as well as regulations from international organisations on the use of low-sulphur oil by ships and shipping companies. Since 1 September 2020, the Korean government has designated five major ports, i.e., Busan Port, Incheon Port, Yeosu, Gwangyang Port, Ulsan Port, and Pyeongtaek-Dangjin Port, as ECAs and applied regulations on sulphur oxides at <0.1%.

In future studies, it plans to establish a continuous monitoring system by securing actual fuel usage data and applying direct ship data to verify the effectiveness of reducing exhaust gas pollutants, while addressing some of the limitations of the present study. In addition, another study will be conducted that considers a life-cycle assessment of air pollutants in Busan Port.

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Appendix A

Tables A1–A4 list the emissions calculation results for each ship type at Busan Port in 2015–2018 during hoteling.

Table A1. Ship pollutant emissions by ship type at Busan Port in 2015 (ship activity phase: Hoteling) [kg].

Ship Type	Pollutants					
	NOx	SO_2	CO_2	VOC	PM2.5	PM10
Liquid bulk ships	103,332.04	7153.76	5,484,546.76	3179.45	2146.13	2265.36
Dry bulk carriers	31,081.65	2151.81	1,649,718.23	956.36	645.54	681.41
Container	840,867.64	420,433.82	44,630,666.92	25,872.85	23,285.57	24,579.21
General cargo	95,556.73	6615.47	5,071,856.99	2940.21	1984.64	2094.90
Ro–Ro cargo	14,457.90	7228.95	767,380.99	444.86	400.37	422.62
Passenger	29,488.50	14,744.25	1,565,158.81	907.34	816.60	861.97
Fishing	97,471.30	6748.01	5,173,476.57	2999.12	2024.40	2136.87
Other	83,777.16	5799.96	4,446,633.95	2577.76	1739.99	1836.65
Tugs	25,275.90	1749.87	1,341,566.87	777.72	524.96	554.13
Sum	1,321,308.81	472,625.89	70,131,006.09	40,655.66	33,568.20	35,433.10

Table A2. Ship pollutant emissions by ship type at Busan Port in 2016 (ship activity phase: Hoteling) [kg].

Ship Type	Pollutants					
	NOx	SO_2	CO_2	VOC	PM2.5	PM10
Liquid bulk ships	127,041.46	8795.18	6,742,970.06	3908.97	2638.55	2785.14
Dry bulk carriers	29,435.59	2037.85	1,562,350.48	905.71	611.35	645.32
Container	918,555.96	459,277.98	48,754,124.11	28,263.26	25,436.93	26,850.10
General cargo	93,570.25	6477.94	4,966,420.95	2879.08	1943.38	2051.35
Ro–Ro cargo	20,607.28	10,303.64	1,093,771.15	634.07	570.66	602.37

Table A2. *Cont.*

Ship Type	Pollutants					
	NOx	SO_2	CO_2	VOC	PM2.5	PM10
Passenger	30,090.89	15,045.45	1,597,132.08	925.87	833.29	879.58
Fishing	86,882.86	6014.97	4,611,474.65	2673.32	1804.49	1904.74
Other	46,815.23	3241.05	2,484,808.53	1440.47	972.32	1026.33
Tugs	26,034.79	1802.41	1,381,846.60	801.07	540.72	570.76
Sum	1,379,034.32	512,996.47	73,194,898.60	42,431.83	35,351.70	37,315.69

Table A3. Ship pollutant emissions by ship type at Busan Port in 2017 (ship activity phase: Hoteling) [kg].

Ship Type	Pollutants					
	NOx	SO_2	CO_2	VOC	PM2.5	PM10
Liquid bulk ships	92,283.77	6388.88	4,898,138.78	2839.50	1916.66	2023.14
Dry bulk carriers	32,255.84	2233.10	1,712,040.86	992.49	669.93	707.15
Container	869,822.05	434,911.02	46,167,477.84	26,763.76	24,087.38	25,425.57
General cargo	89,713.53	6210.94	4,761,718.16	2760.42	1863.28	1966.80
Ro–Ro cargo	17,179.44	8589.72	911,831.76	528.60	475.74	502.17
Passenger	20,532.90	10,266.45	1,089,823.10	631.78	568.60	600.19
Fishing	94,843.86	6566.11	5,034,020.10	2918.27	1969.83	2079.27
Other	52,561.51	3638.87	2,789,803.39	1617.28	1091.66	1152.31
Tugs	25,117.97	1738.94	1,333,184.32	772.86	521.68	550.66
Sum	1,294,310.87	480,544.03	68,698,038.32	39,824.95	33,164.77	35,007.26

Table A4. Ship pollutant emissions by ship type at Busan Port in 2018 (ship activity phase: Hoteling) [kg].

Ship Type	Pollutants					
	NOx	SO_2	CO_2	VOC	PM2.5	PM10
Liquid bulk ships	104,328.54	7222.75	5,537,437.89	3210.11	2166.82	2287.20
Dry bulk carriers	35,590.40	2463.95	1,889,029.13	1095.09	739.19	780.25
Container	924,449.25	462,224.62	49,066,921.67	28,444.59	25,600.13	27,022.36
General cargo	73,668.52	5100.13	3,910,098.13	2266.72	1530.04	1615.04
Ro–Ro cargo	8596.90	4298.45	456,296.80	264.52	238.07	251.29
Passenger	21,443.92	10,721.96	1,138,177.23	659.81	593.83	626.82
Fishing	90,299.15	6251.48	4,792,801.14	2778.44	1875.44	1979.64
Other	43,139.49	2986.58	2,289,711.39	1327.37	895.97	945.75
Tugs	18,831.32	1303.71	999,508.60	579.43	391.11	412.84
Sum	1,320,347.49	502,573.62	70,079,981.99	40,626.08	34,030.61	35,921.20

References

1. Buhaug, Ø.; Corbett, J.J.; Endresen, O.; Eyring, V.; Faber, J.; Hanayama, S.; Yoshida, K. *Second IMO Greenhouse Gas Study*; International Maritime Organization: London, UK, 2009. Available online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/SecondIMOGHGStudy2009.pdf (accessed on 21 August 2021).
2. Franc, P.; Sutto, L. Impact analysis on shipping lines and European ports of a cap- and-trade system on CO_2 emissions in maritime transport. *Marit. Policy Manag.* **2014**, *41*, 61–78. [CrossRef]
3. Hossain, T.; Adams, M.; Walker, T.R. Role of sustainability in global seaports. *Ocean Coast. Manag.* **2021**, *202*, 105435. [CrossRef]
4. Rahim, M.M.; Islam, T.; Kuruppu, S. Regulating global shipping corporations' accountability for reducing greenhouse gas emissions in the seas. *Mar. Policy* **2016**, *69*, 159–170. [CrossRef]
5. Van, T.C.; Ramirez, J.; Rainey, T.; Ristovski, Z.; Brown, R.J. Global impacts of recent IMO regulations on marine fuel oil refining processes and ship emissions. *Transp. Res. Part D Transp. Environ.* **2019**, *70*, 123–134. [CrossRef]
6. Darbra Roman, R.M.; Wooldridge, C.; Puig Duran, M. ESPO Environmental Report 2020-EcoPortsinsights 2020. 2020. Available online: https://www.espo.be/media/Environmental%20Report-WEB-FINAL.pdf (accessed on 1 March 2022).
7. Gobbi, G.P.; Di Liberto, L.; Barnaba, F. Impact of port emissions on EU-regulated and non-regulated air quality indicators: The case of Civitavecchia (Italy). *Sci. Total Environ.* **2019**, *719*, 134984. [CrossRef]

8. Hossain, T.; Adams, M.; Walker, T.R. Sustainability initiatives in Canadian ports. *Mar. Policy* **2019**, *106*, 103519. [CrossRef]
9. Liu, H.; Fu, M.; Jin, X.; Shang, Y.; Shindell, D.; Faluvegi, G.; Shindell, C. Health and climate impacts of ocean-going vessels in East Asia. *Nat. Clim. Chang.* **2016**, *6*, 1037–1041. [CrossRef]
10. Schnurr, R.E.; Walker, T.R. Marine Transportation and Energy Use. In *Reference Module in Earth Systems and Environmental Sciences*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 1–9. [CrossRef]
11. Walker, T.R.; Adebambo, O.; Del Aguila Feijoo, M.C.; Elhaimer, E.; Hossain, T.; Edwards, S.J.; Morrison, C.E.; Romo, J.; Sharma, N.; Taylor, S.; et al. Environmental Effects of Marine Transportation. In *World Seas: An Environmental Evaluation*, 2nd ed.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 505–530, ISBN 978-0-12-805052-1.
12. IMO. Resolution MEPC 176(58), Revised MARPOL Annex VI. International Maritime Organization. 2008. Available online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/176(58).pdf (accessed on 21 August 2021).
13. IMO. Resolution MEPC 280(70), Effective Date of Implementation of the Fuel oil Standard in Regulation 14.1.3 of MARPOL Annex VI. International Maritime Organization. 2016. Available online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/280(70).pdf (accessed on 21 August 2021).
14. Chircop, A. The IMO Initial Strategy for the Reduction of GHGs from International Shipping: A Commentary. *Int. J. Mar. Coast. Law* **2019**, *34*, 482–512. [CrossRef]
15. USEPA. Case Study of the San Pedro Bay Ports' Clean Air Action Plans 2006–2018: Best Practices and Lessons Learned, EPA-420-R-21-011. 2021. Available online: https://www.epa.gov/ports-initiative/san-pedro-bay-ports-clean-air-action-plan-best-practices-and-lessons-learned (accessed on 20 June 2021).
16. USEPA/CARB/SCAQMD. San Pedro Bay Ports Clean Air Action Plan (CAAP), US Environmental Protection Agency (USEPA)/California Air Resources Board (CARB)/South Coast Air Quality Management (SCAQMD). 2006. Available online: https://kentico.portoflosangeles.org/getmedia/4a54591c-83f2-4b60-acee-8473d6e8dc14/CAAP_Overview_Final_2 (accessed on 20 June 2021).
17. Nunes, R.; Alvim-Ferraz, M.; Martins, F.; Sousa, S. Environmental and social valuation of shipping emissions on four ports of Portugal. *J. Environ. Manag.* **2019**, *235*, 62–69. [CrossRef]
18. Song, S. Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port. *Atmos. Environ.* **2014**, *82*, 288–297. [CrossRef]
19. IPCC. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2—Energy, Ch.3. Intergovernmental Panel on Climate Change. 2006. Available online: https://www.ipcc-nggip.iges.or.jp/public/2006gl/ (accessed on 21 August 2021).
20. Statista. The Largest Container Ports Worldwide in 2019. 2019. Available online: https://www.statista.com/statistics/264171/turnover-volume-of-the-largest-container-ports-worldwide/ (accessed on 20 June 2021).
21. Ahn, Y.S.; Yuk, G.H.; Kim, D.K.; Lee, H.Y. *A Study on Improvement Measures for Air Pollutants Management System and Policy in Korean Ports*; Korea Maritime Institute: Busan, Korea, 2019; p. 224. Available online: https://www.kmi.re.kr/web/board/view.do?rbsIdx=286&page=2&idx=36976 (accessed on 21 August 2021).
22. Kim, T.-G.; Kim, H.-S. Study on establishing Green Port Policy in Korea to meet Ports' Characteristics: Development of Ulsan Green Port Policy by using AHP. *J. Korean Navig. Port Res.* **2014**, *38*, 549–559. [CrossRef]
23. BPA. Press Release: Port PM2.5 Will Be Reduced by 70% by 2050 to Create Cleaner Air Quality. Busan Port Authority. 2020. Available online: https://www.busanpa.com/kor/Board.do?mode=view&idx=26602&mCode=MN1445 (accessed on 21 August 2021).
24. BPA. Press Release: Promoting the Installation of Air Pollution Monitoring Stations in 5 Places in the North Port of Busan Port. Busan Port Authority. 2017. Available online: https://www.busanpa.com/kor/Board.do?mode=view&idx=19064&mCode=MN1445 (accessed on 21 August 2021).
25. BPA. Press Release: Active Promotion of Busan Port Green Port Comprehensive Measures to Reduce Fine Dust. Busan Port Authority. 2018. Available online: https://www.busanpa.com/kor/Board.do?mode=view&idx=20838&mCode=MN1445 (accessed on 21 August 2021).
26. An, J.; Lee, K.; Park, H. Effects of a Vessel Speed Reduction Program on Air Quality in Port Areas: Focusing on the Big Three Ports in South Korea. *J. Mar. Sci. Eng.* **2021**, *9*, 407. [CrossRef]
27. Kim, K.; Roh, G.; Chun, K. Analysis of the Emission Benefits of Using Alternative Maritime Power (AMP) for Ships. *J. Korean Soc. Mar. Environ. Saf.* **2019**, *25*, 381–394. [CrossRef]
28. MOF. Press Release: Signed an Agreement for a Pilot Project for AMP Facilities to Reduce Fine Dust in Ports. Ministry of Oceans and Fisheries. Available online: https://www.mof.go.kr/article/view.do?articleKey=26595&boardKey=10&menuKey=376&currentPageNo=1 (accessed on 21 August 2021).
29. Song, H.S. Ministry of Oceans and Fisheries Gives up Business after Pointing out 'Low AMP Usage Rate'? This Year's Budget Zero. Busan Ilbo. 2021. Available online: http://www.busan.com/view/busan/view.php?code=2021102109013930899 (accessed on 10 November 2021).
30. MOF. *1st Comprehensive Plan for Port Air Quality (2021~2025)*; Ministry of Oceans and Fisheries: Sejong, Korea, 2021; p. 48. Available online: https://www.mof.go.kr/en/page.do?menuIdx=1627 (accessed on 21 August 2021).
31. MOF. Press Release: Construction of Onshore Power Supply Facilities (AMP) in 248 Berths by 2030, Ministry of Oceans and Fisheries. 2019. Available online: https://www.mof.go.kr/article/view.do?articleKey=28066&boardKey=10&menuKey=971&currentPageNo=1 (accessed on 21 August 2021).

32. MOF. *3rd Master Plan for Marine and Fisheries Development (2021~2030)*; Report No. 11-1192000-001395-14; Ministry of Oceans and Fisheries: Sejong, Korea, 2021; p. 192. Available online: https://www.mof.go.kr/en/page.do?menuIdx=1626 (accessed on 21 August 2021).
33. KMGL. Special Act on the Improvement of Air Quality in Port Areas, Korean Ministry of Government Legislation. 2019. Available online: https://www.law.go.kr/LSW/eng/engLsSc.do?menuId=2\T1\textsectionion=lawNm&query=port+air+quality&x=0&y=0#liBgcolor1 (accessed on 21 August 2021).
34. Lee, M.W.; Lee, H.S. Estimation of ship emissions and environmental costs: Focusing on port of Busan. *J. Korea Port Econ. Assoc.* **2016**, *32*, 15–28. Available online: https://www.koreascience.or.kr/article/JAKO201617447410339.pdf (accessed on 21 August 2021).
35. Chang, Y.-T.; Song, Y.; Roh, Y. Assessing greenhouse gas emissions from port vessel operations at the Port of Incheon. *Transp. Res. Part D Transp. Environ.* **2013**, *25*, 1–4. [CrossRef]
36. Tichavska, M.; Tovar, B. Port-city exhaust emission model: An application to cruise and ferry operations in Las Palmas Port. *Transp. Res. Part A Policy Pract.* **2015**, *78*, 347–360. [CrossRef]
37. Tichavska, M.; Tovar, B.; Gritsenko, D.; Johansson, L.; Jalkanen, J.-P. Air emissions from ships in port: Does regulation make a difference? *Transp. Policy* **2019**, *75*, 128–140. [CrossRef]
38. KMI. *A Study on the Systematic Management of Air Pollutants from Ships in Korea*; Basic Research No. 2016.-09; Korea Maritime Institute: Seoul, Korea, 2016; p. 202.
39. KMGL. Harbour Act, Article 89. Korean Ministry of Government Legislation. 2008. Available online: https://elaw.klri.re.kr/kor_service/lawView.do?hseq=46264&lang=ENG (accessed on 21 August 2021).
40. MOF. Port-MIS, Ministry of Oceans and Fisheries. 2010. Available online: https://new.portmis.go.kr/portmis/websquare/websquare.jsp?w2xPath=/portmis/w2/main/intro.xml (accessed on 20 June 2021).
41. Ready, R.; Navrud, S. International benefit transfer: Methods and validity tests. *Ecol. Econ.* **2006**, *60*, 429–434. [CrossRef]
42. EMEP/EEA. EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019: Technical Guidance to Prepare National Emission Inventories, Part B: Technical Chapters, 1.A Combustion, 1.A.3.d Navigation (Shipping). The Joint European Monitoring and Evaluation Programme/European Environment Agency. 2019. Available online: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (accessed on 21 August 2021).
43. IMO. International Convention for the Prevention of Pollution from Ships (MARPOL), Annex VI. Consideration and Adoption of the Protocol of 1997 to Amend the MARPOL 1973 as Modified by the Protocol of 1978, MP/CONF.3/34. International Maritime Organization. 1997. Available online: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx (accessed on 21 August 2021).
44. Entec. UK Ship Emissions Inventory, Final Report. Entec. 2010. Available online: https://uk-air.defra.gov.uk/assets/documents/reports/cat15/1012131459_21897_Final_Report_291110.pdf (accessed on 21 August 2021).
45. Trozzi, C.; Vaccaro, R. Methodologies for estimating air pollutant emissions from ships. In Proceedings of the 2nd Environment & Transport Conference (including 15th Transport and Air Pollution conference), Reims, France, 12–14 June 1997.
46. MOF. South Korea Implements 0.10% Sulphur Limit on Vessels at Anchorage or Mooring in Its Five Major ports, Ministry of Oceans and Fisheries. 2020. Available online: https://www.mof.go.kr/en/board.do?menuIdx=1491&bbsIdx=30636 (accessed on 20 June 2021).
47. MOF. Port-MIS Ship Entry and Departure, Ministry of Oceans and Fisheries. 2020. Available online: https://new.portmis.go.kr/portmis/websquare/websquare.jsp?w2xPath=/portmis/w2/main/intro.xml, (accessed on 20 June 2021).
48. Balsdon, E.l.; Kolstad, C.D. *Environmental Economics*; Oxford University Press: Oxford, UK, 1999.
49. Maibach, M.; Schreyer, C.; Sutter, D.; Van Essen, H.P.; Boon, B.H.; Smokers, R.; Bak, M. *Handbook on Estimation of External Costs in the Transport Sector*; Ce Delft: Oude Delft, The Netherlands, 2008; p. 336.
50. NASEM. *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*; National Academies of Sciences, Engineering, and Medicine; National Academies Press: Washington, DC, USA, 2017.
51. Essen, H.; van Wijngaarden, L.; Schroten, A.; Sutter, D.; Bieler, C.; Maffii, S.; El Beyrouty, K. *Handbook on the External Costs of Transport*; Ver. 2019, No. 18.4 K83.131; European Commission: Brussels, Belgium, 2019.
52. Walker, T.R. Green Marine: An environmental program to establish sustainability in marine transportation. *Mar. Pollut. Bull.* **2016**, *105*, 199–207. [CrossRef]
53. Masson-Delmotte, V.; Zhai, P.; Pörtner, H.O.; Roberts, D.; Skea, J.; Shukla, P.R.; Waterfield, T. Global Warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of, 1.5 °C. 2018. pp. 1–9. Available online: https://www.ipcc.ch/sr15/ (accessed on 21 August 2021).
54. Freeman, A.M.; Herriges, J.A.; Kling, C.L. *The Measurement of Environmental and Resource Values: Theory and Methods*; Resources for the Future: Washington, DC, USA, 2003. Available online: http://econdse.org/wp-content/uploads/2016/07/Freeman-Herriges-Kling-2014.pdf (accessed on 21 August 2021).
55. Haab, T.C.; McConnell, K.E. *Valuing Environmental and Natural Resources: The Econometrics of Non-Market Valuation*; Edward Elgar Publishing: Cheltenham, UK, 2002.
56. Perman, R.; Ma, Y.; McGilvray, J.; Common, M. *Natural Resource and Environmental Economics*; Pearson Education: London, UK, 2003.

57. Bergstrom, J.C.; Civita, P. Status of Benefits Transfer in the United States and Canada: Reply. *Can. J. Agric. Econ. Can. d'Agroecon.* **2001**, *49*, 263. [CrossRef]
58. Peterson, L.G. *A Primer on Nonmarket Valuation (Vol. 3)*; Champ, P.A., Boyle, K.J., Brown, T.C., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2003.
59. Gibson, M.; Carnovale, M. The effects of road pricing on driver behavior and air pollution. *J. Urban Econ.* **2015**, *89*, 62–73. [CrossRef]
60. Nurmi, V.; Ahtiainen, H. Distributional Weights in Environmental Valuation and Cost-benefit Analysis: Theory and Practice. *Ecol. Econ.* **2018**, *150*, 217–228. [CrossRef]
61. Desvousges, W.H.; Naughton, M.C.; Parsons, G.R. Benefit transfer: Conceptual problems in estimating water quality benefits using existing studies. *Water Resour. Res.* **1992**, *28*, 675–683. [CrossRef]
62. Piper, S.; Martin, W.E. Evaluating the accuracy of the benefit transfer method: A rural water supply application in the USA. *J. Environ. Manag.* **2001**, *63*, 223–235. [CrossRef]
63. Rosenberger, R.S.; Loomis, J.B. Panel Stratification in Meta-Analysis of Economic Studies: An Investigation of Its Effects in the Recreation Valuation Literature. *J. Agric. Appl. Econ.* **2000**, *32*, 459–470. [CrossRef]
64. Gren, I.-M.; Brutemark, A.; Jägerbrand, A.K.; Svedén, J.B. Costs of air pollutants from shipping: A meta-regression analysis. *Transp. Rev.* **2020**, *40*, 411–428. [CrossRef]
65. Tichavska, M.; Tovar, B. Environmental cost and eco-efficiency from vessel emissions in Las Palmas Port. *Transp. Res. Part E Logist. Transp. Rev.* **2015**, *83*, 126–140. [CrossRef]
66. Tichavska, M.; Tovar, B. External costs from vessel emissions at port: A review of the methodological and empirical state of the art. *Transp. Rev.* **2017**, *37*, 383–402. [CrossRef]
67. MOVE, D. *Update of the Handbook on External Costs of Transport*; RICADO-AEA Report for the European Commission: London, UK, 2014.
68. Holland, M.; Watkiss, P. Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe. 2002. Available online: http://ec.europa.eu/environment/enveco/air/pdf/betaec02aforprinting.pdf (accessed on 21 August 2021).
69. Amann, M.; Bertok, I.; Cabala, R.; Cofala, J.; Heyes, C.; Gyarfas, F.; Wagner, F. A Final Set of Scenarios for the Clean Air for Europe (CAFE) Programme (CAFE Scenario Analysis Report Nr. 6). International Institute for Applied Systems Analysis (IIASA). 2005. Available online: https://www.researchgate.net/publication/237572697_A_final_set_of_scenarios_for_the_Clean_Air_For_Europe_CAFE_programme (accessed on 21 August 2021).
70. Bickel, P.; Friedrich, R.; Burgess, A.; Fagiani, P.; Hunt, A.; Jong, G.D.; Tavasszy, L. HEATCO—Developing Harmonised European Approaches for Transport Costing and Project Assessment. IER University of Stuttgart. 2006. Available online: http://www.kbsz.hu/dokumentumok/20070411_0.2-HEATCO_D5.pdf (accessed on 21 August 2021).
71. Preiss, P.; Klotz, V. Description of Updated and Extended Draft Tools for the Detailed Site-Dependent Assessment of External Costs. Technical Paper No. 7.4-RS1b of NEEDS Project. 2007. Available online: https://www.semanticscholar.org/paper/Technical-Paper-n-%C2%B0-7-.-4-RS-1-b-%E2%80%9C-Description-of-%E2%80%9D-Preiss-Klotz/b65899629b71962c36f0ffadac0c9ff71c55f157 (accessed on 5 April 2022).
72. IPCC. IPCC Second Assessment. A Report of the Intergovernmental Panel on Climate Change, WMO-UNEP. 1995. Available online: https://www.ipcc.ch/site/assets/uploads/2018/05/2nd-assessment-en-1.pdf (accessed on 21 August 2021).
73. KEI. *Guidelines for Pre-Feasibility Study of Road and Railway Projects (5th Phase)*; Korea Environment Institute: Sejong, Korea, 2002; pp. 240–254.
74. Lee, K.J.; Choi, K. Social Cost Comparison of Air-Quality based on Various Traffic Assignment Frameworks. *J. Korean Soc. Civ. Eng.* **2013**, *33*, 1087–1094. [CrossRef]
75. Tol, R. The Economic Effects of Climate Change. *J. Econ. Perspect.* **2009**, *23*, 29–51. [CrossRef]
76. KOSIS. Overall Household and Population Overview in Busan, Korean Statistical Information Service. 2021. Available online: https://kosis.kr/statHtml/statHtml.do?orgId=202&tblId=DT_B1 (accessed on 10 November 2021).
77. Wang, P.; Deng, X.; Zhou, H.; Yu, S. Estimates of the social cost of carbon: A review based on meta-analysis. *J. Clean. Prod.* **2018**, *209*, 1494–1507. [CrossRef]
78. IWG. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*; Technical Support Document; Interagency Working Group (IWG) on Social Cost of Carbon, United States Government: Washington, DC, USA, 2016. Available online: http://www.commerce.wa.gov/wp-content/uploads/2019/05/Social-Cost-CO2-Aug-16.pdf (accessed on 21 August 2021).
79. Tovar, B.; Tichavska, M. Environmental cost and eco-efficiency from vessel emissions under diverse SOx regulatory frameworks: A special focus on passenger port hubs. *Transp. Res. Part D Transp. Environ.* **2019**, *69*, 1–12. [CrossRef]