Journal of
Marine Science and Engineering

MDPI

Article

Ship Air Pollution Estimation by AIS Data: Case Port of Klaipeda

Paulius Rapalis [1,*], Giedrius Šilas [2] and Justas Žaglinskis [3]

[1] Marine Research Institute, Klaipėda University, Herkaus Manto Str. 84, 92294 Klaipeda, Lithuania
[2] Faculty of Marine Technologies and Natural Sciences, Klaipėda University, 92294 Klaipeda, Lithuania
[3] Lithuanian Maritime Academy, I. Kanto 7, 92123 Klaipeda, Lithuania
* Correspondence: paulius.rapalis@ku.lt

Abstract: Ships operating on fossil fuel release pollutant emissions into the atmosphere. Released pollutants have a negative effect on the environment and human health, especially in port cities. For this reason, it is very important to properly evaluate these emissions so they can be managed. The current and most common methodologies for shipping pollution evaluation are used for whole port areas or larger terminals over a long period of time and are not analyzed in terms of detailed activity, which may lead to underestimations in certain areas. This study aims to evaluate emissions from ships in port by combining ships' technical, AIS and EMEP data that allow us to evaluate emissions in port, not as a singular area source but enables individual ship emissions evaluation at any given point in time. To achieve this emission calculation, an algorithm was compiled by using EMEP/EEA Tier 3 methodology. The developed method presents a way to evaluate emissions in a detailed manner not only for groups of ships but also for individual ships if that is required. This method also lets us analyze shipping emissions' intensity throughout all port territory and identify the most excessive pollution sources. However, the method adds additional work for researchers because of the huge data arrays required for complex calculations.

Keywords: port emissions; emission factor; air pollution; AIS data; Klaipeda port; maritime transport; emission from ships

Citation: Rapalis, P.; Šilas, G.; Žaglinskis, J. Ship Air Pollution Estimation by AIS Data: Case Port of Klaipeda. *J. Mar. Sci. Eng.* **2022**, *10*, 1950. https://doi.org/10.3390/jmse10121950

Academic Editors: Rosemary Norman and Tie Li

Received: 27 October 2022
Accepted: 2 December 2022
Published: 8 December 2022

1. Introduction

Almost 70% of ship emissions are 400 km from land. The pollutants emitted in the port make up only a small amount of shipping-related global emissions. However, they may have a major impact on the environment of coastal regions [1–5]. The main air pollutants from ships are exhaust gas, including sulfur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM), and non-methane volatile organic compounds (NMVOC). These play an important role in air quality, weather, climate change and human health [6–10]. Several studies prove the relationship between human health and contaminants such as particulate matter and nitrogen oxides (NO_2 and NO) in the environments of urban areas, both in the case of short-term and long-term effects. These effects include premature deaths, cerebrovascular diseases, infant mortality, pulmonary diseases as a long-term effect and hospital admissions, cardiovascular diseases, and workday loss as a short-term effect [11–13]. Studies also show that pollutants from ships lead to approximately 8% of the total annual mortality from particulate matter and that most deaths occur near the coast in Europe, East Asia and South Asia [3]. Solid particles are of great concern regarding adverse effects on human health, visibility and climate change [14,15]. Although shipping is considered to be one of the ways of energy-saving transportation of goods [16,17], ships release 1.2–1.6 $\times$ 10^9 kg particulate matter each year [18]. In recent years, more and more attention has been paid to port cities' air quality. There are two ways to evaluate air quality changes in the city due to the influence of shipping: (1) direct measurement experiments to detect air pollutants; (2) the use of air quality models [11].

One of the major problems in properly evaluating the effects of emissions on air quality is the assessment of the emissions themselves [11]. Evaluation of pollutants from ships is quite a difficult task, both in direct measurements and by evaluating statistical methods without direct measurements. Most often, ship emissions, especially in ports, are determined by calculation. Here calculations are made either based on fuel consumption (fuel-based) or ship activity (activity-based) [17,19–22]. Using AIS (automatic identification system) can more accurately evaluate the position of ships and operations. As a result, the statistical models based on the activity of the ship are increasingly used [23–31].

Most statistical methods of pollution evaluation require emissions coefficients. These coefficients can be selected using databases and scientific articles and then calculated [32–34]. Assessing the emissions of PM is no exception. Information on the composition of particulate matter, depending on the engine load and sulfur content in fuel, is used to assess the emission factor for particulate emission factor [8]. With all the available capabilities, in many cases, ports are treated as either a singular or somewhat segmented emissions source. This is usually undertaken to reduce the amount of data and simplify the evaluation [35–38]. For example, this was performed in the Abrutyte et al. [35] study, where attempts were made to associate ship emissions evaluated with statistical methods with experimental measurements, but the port was only divided into five sectors. Later these foundations were also used for urban pollution assessments [36]. In both works, the port was seen as having several equal emission sources. However, some terminals can have significantly greater activity and cause higher hotelling emissions, as was shown in earlier work [39]. Moreover, even a ship's passing in the port creates a significant increase in concentration in the ship's sailing area [40]. There are cases where port stevedoring is very constant, and it was shown by Gan et al. [41] that evaluation at a monthly frequency per terminal is sufficient to obtain representative results. The use of AIS data in the evaluation of port emissions, in turn, greatly increases the volume of work for researchers but significantly improves results. Chen et al. [23] and Yang et al. [42] showed that detailed evaluation is important for the proper assessment of the sources of port emissions and the disclosure of more intensive activities' sources. Chen et al. [23] and Paulauskas et al. [43] also draw attention to the importance of the detailed evaluation of ship emissions and the potential for reducing emissions, which in other cases, could be lost. Moreover, as Huan et al. [44] state, AIS-based models can be prepared for automatic operation and, in the future, perform accounting automatically.

At the same time, increasing attention is given to the green port concept, sustainable development in ports [45–47] and co-development with port cities [48]. This includes the increasingly active transition to climate and nature neutrality, and it is very important for seaports to plan development while improving the state of the environment, rational use of natural resources and implementing smart technologies [45,49]. Since shipping emissions are a major source of pollution in ports, it is necessary to seek better ways of monitoring, evaluating and controlling measure implementation [49].

Based on the literature review of other authors and considering the dynamic activity of emission sources in ports, the authors believe that there is a lack of research where a detailed evaluation of port emissions for individual ships is performed. This study aims to fill this gap by evaluating emissions from ships in port by combining ships' technical data (IHS Fairplay), automatic identification systems (AIS) and European Environment Agency (EEA) data. Combining these data allows us to evaluate ships' emissions in port, not as a singular point of the source but as a way to evaluate individual ship emissions at any given point in time.

2. Materials and Methods

2.1. Study Area

Klaipeda port is the only Lithuanian seaport in the southeast of the Baltic Sea, located in the mouth of the Curonian Lagoon (55°43′ N, 21°07′ E) [50]. It is one of the leading ports of the Baltic Sea, with intermodal communication capabilities and integration into the TEN-

T rail corridor. Two main railway lines of this corridor connect the port with neighboring states and Lithuanian domestic territory. It is also the northernmost non-freezing deep-sea harbor on the eastern coast of the Baltic Sea [51].

According to the data, stevedoring carried out in Klaipeda port (Figure 1) in 2021 reached 45.62 million tons. In addition to stevedoring in Klaipeda port, there is also a sufficiently intense movement of cruise ships. Based on the data provided by the port authorities from 2014 to 2019, 56 cruise ships visited the port on average [52].

Given that water in the port of Klaipeda does not freeze during the winter and due to the large stewing and ship flow in the port, it is very important to accurately evaluate the pollution caused by shipping and the propagation of pollutants in the territory of Klaipeda city.

Figure 1. Klaipeda port. Orthophoto map Layer Data: Google Maps.

2.2. Emissions Evaluation Model

2.2.1. Estimation Model

The European Environment Agency co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (EMEP/EEA) Tier 3 air pollution assessment methodology was used [53]. Emissions were calculated according to the algorithm (Figure 2). Pollution was evaluated according to the technical parameters and movement of the ship (operation performed). As shown in Figure 2, the algorithm uses three sets of data: IHS Fairplay data, AIS data and EMEP data. AIS data were sorted to include only ships that are in the port area and included ship position coordinates, speed and IMO number for identification. The IHS Fairplay data block–database of ship technical information included ship type, gross tonnage, main engine type, number of engines and engine power used for ships' technical data, while the AIS data block provided ship activity information. The EMEP data block, consisting of data on load factor, main auxiliary engines ratio, emission factors and SFOC values, was used to obtain emission factors and main and auxiliary engine ratio. In the AIS data block, ship speed was used to determine ship operation (maneuvering, hotelling) and select appropriate engine load factors. The auxiliary and main engine ratio acquired from the EMEP data block was used for the main and auxiliary engines' power determination. The emissions factors from the EMEP data block, the time and load factor from the AIS data block and the main and auxiliary engines' power from the IHS Fairplay data block were used directly in emissions calculations.

The engine type (gas turbine, high-speed diesel, medium-speed diesel, slow-speed diesel, steam turbine) and the fuel used were evaluated for the selection of emissions factors. The IMO number was used to determine the technical parameters of the ship from the IHS Fairplay database. The position of the ship in the port and its speed were determined by using the AIS system data. The ship's operation (maneuvering, hotelling) was evaluated by using the vessel speed—when the ship's speed is >0 m/s, it is assumed to be a maneuvering operation; if the speed is equal to 0, then it is hotelling. Calculations were performed on both the auxiliary and main engines by evaluating the same operations. For better accuracy, only ships whose data were constant were evaluated. A filter that removed data if the difference between the data lines in the AIS data array was more than 4 min 15 s was used.

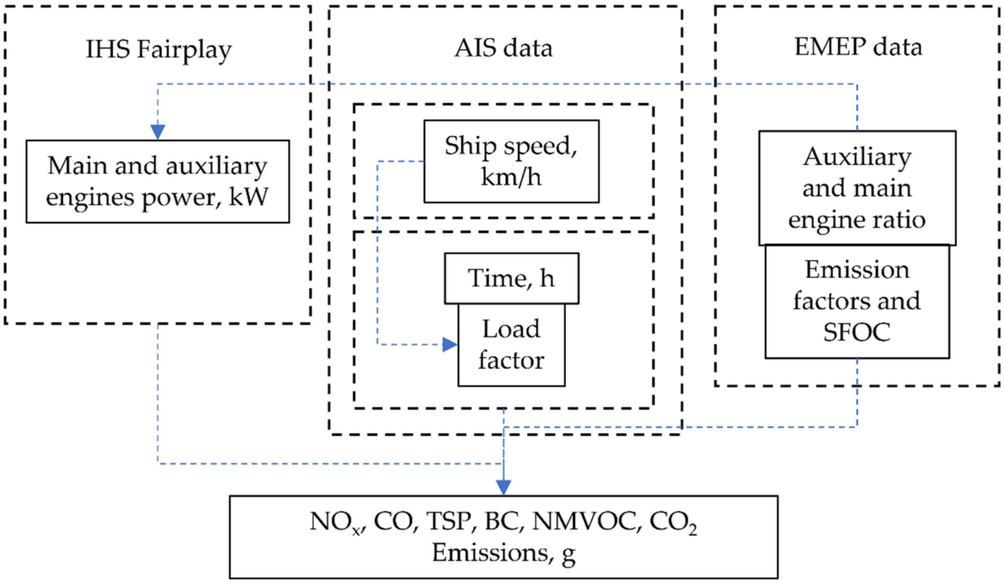

Figure 2. Algorithm for the calculation of emissions.

The load factor (LF) parameter for the main (ME) and auxiliary engines (AE) is selected according to EMEP methodology for each operation separately. Maneuvering operation for auxiliary engines LF = 50% and main engines–20%. The value of the LF for hotelling operations depends on the type of ship. For all ships, except tankers, the LF value for auxiliary engines is 40%, while the LF value for tankers is 60%. Based on the modified EMEP equations, energy consumption, fuel and CO_2 emissions for ships berthed at the quay were evaluated. Calculation of fuel was also undertaken on the basis of EMEP tier III specific fuel consumption values and adopted to every ship in port. CO_2 was calculated by evaluating the consumed fuel based on EMEP-specific fuel oil consumption values, then applying the typical fuel carbon content of 87% and evaluating the CO_2 emission under the assumption that all carbon is burned to CO_2. Modified EMEP equation:

For energy at berth:

$$e_H = \sum_p T_P \sum (P_e \times LF_e) \tag{1}$$

For CO_2 emissions:

$$E_{CO_2} = \sum_p T_P \sum \left(P_e \times LF_e \times SFOC_{e,j,p} \times \frac{12}{44} \times 0.87 \right) \tag{2}$$

e_H–Energy used by ships during hotelling;
E_{CO2} = emission of CO_2 over a complete trip (kg);
$SFOC$ = Specific fuel oil consumption (kg/kWh);
LF = engine load factor, (%);
P = engine nominal power, (kW);
T = time (hours);
e = engine category (main, auxiliary);
j = engine type (slow-, medium-, and high-speed diesel, gas turbine and steam turbine);
p = the different phase of trip (cruise, hotelling, maneuvering);

2.2.2. Data Processing

According to ship AIS data, emissions were evaluated in the position of each ship throughout the port. Later the emissions were summed up for each hour of port activity and each quay of the port by summing up emissions for ships standing at the quay and passing the quay.

3. Results

3.1. Emissions from Different Types of Ships

Klaipeda port consists of 22 different terminals, and various companies are operating inside the port territory. Because of these reasons, the variety of ships coming to Klaipeda port is quite large. By dividing ships into 11 groups (Figure 3), most of all emissions (according to NO_x) are made up of three groups of ships, including Ro-Ro (26%), container ships (24%) and bulk cargo ships (21%).

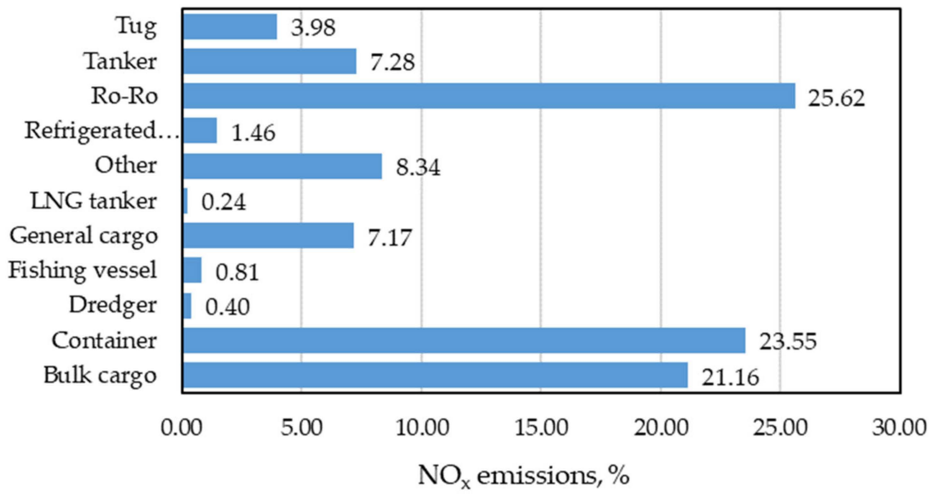

Figure 3. Emissions of ships entering the port of Klaipeda (%) by their type.

After those three main groups, there is a ship group labeled Other, which consists of different auxiliary, repair and other uses for vessels (8%), followed by tankers, general cargo ships (7%), tugs (4%) and other groups that appear in the chart. The further distribution is between refrigerated cargo ships, fishing and LNG vessels (Table 1).

Table 1. Average sizes of all emissions according to ship types.

Ship Type	NO_x, t	CO, t	NMVOC, t	TSP, t	BC, t	CO_2 *, t	Energy, kWh *
LNG tanker	0.57	0.06	0.02	0.01	0.0008	18.73	30,264
Dreger	0.96	0.13	0.08	0.03	0.001	61.33	85,823
Fishing vessel	1.97	0.19	0.08	0.04	0.002	108.09	171,889
Refrigerated Cargo Ship	3.54	0.33	0.15	0.07	0.004	170.31	272,263
Tug	9.66	1.66	0.85	0.27	0.019	372.97	524,570
General cargo	17.42	1.90	0.92	0.40	0.023	898.33	1,375,904
Tanker	17.67	1.63	0.67	0.35	0.019	884.38	1,424,448
Other	20.25	2.26	1.23	0.48	0.026	1307.66	1,933,306
Bulk cargo	51.38	4.21	1.81	0.97	0.054	2321.38	3,747,557
Container	57.18	5.12	2.09	1.11	0.067	2284.59	3,691,608
Ro-Ro	62.22	6.39	2.49	1.30	0.081	2374.02	3,836,118

* Energy and CO_2 calculated for hotelling phase only.

The size of the emissions in the port depends on the intensity of the shipping, and if there are no significant differences in activity in the port, the result will be quite representative when assessing the emissions per year [37]. However, in ports with many different terminals and inconsistent operation intensity, the average assessment of emissions and energy consumption may not properly reflect the effects on air quality. After evaluating average emissions for a day in Klaipeda port from 25 November 2020 to 9 January 2021, according to our data, the result was 5.28 tons of NO_x. Compared to earlier studies, our results were very close to the Elle study [36]. This was performed in 2020 and was much higher than that of Abrutyte et al. [35] (Table 2). The difference between Abrutyte et al.

and other studies can be attributed to much older data dealing with lower ship traffic. The average and maximum sizes of all emissions are given in Table 2. The difference between medium and maximum emissions consisted of 255 to 278%, depending on the pollutant.

Table 2. Average and maximum emissions in Klaipeda port.

Pollutant	Average	Max.	Min.	Average [35]	Average [36]
Nitrogen oxides (NO_x), t/d	5.28	7.64	2.74	2.59	5.06
Total suspended particles (TSP), t/d	0.52	0.74	0.29	-	0.3
Non-methane volatile organic compounds (NMVOC), t/d	0.22	0.32	0.12	-	0.311
Black carbon (BC), t/d	0.064	0.0095	0.0033	-	-
Carbon dioxide (CO_2), t/d	235	341	125	-	-
Energy, kWh	371,603	545,076	197,517	-	-

3.2. Ship Exhaust Emissions and Energy Use in Port

The energy and distribution of ship generators in the port in the period from 25 November 2020 to 9 January 2021 is uniformly distributed. At the minimum amount of energy at 197,518 kWh, the maximum consumption for 545,076 kWh per day and 340 t CO_2 per day, respectively (Figure 4).

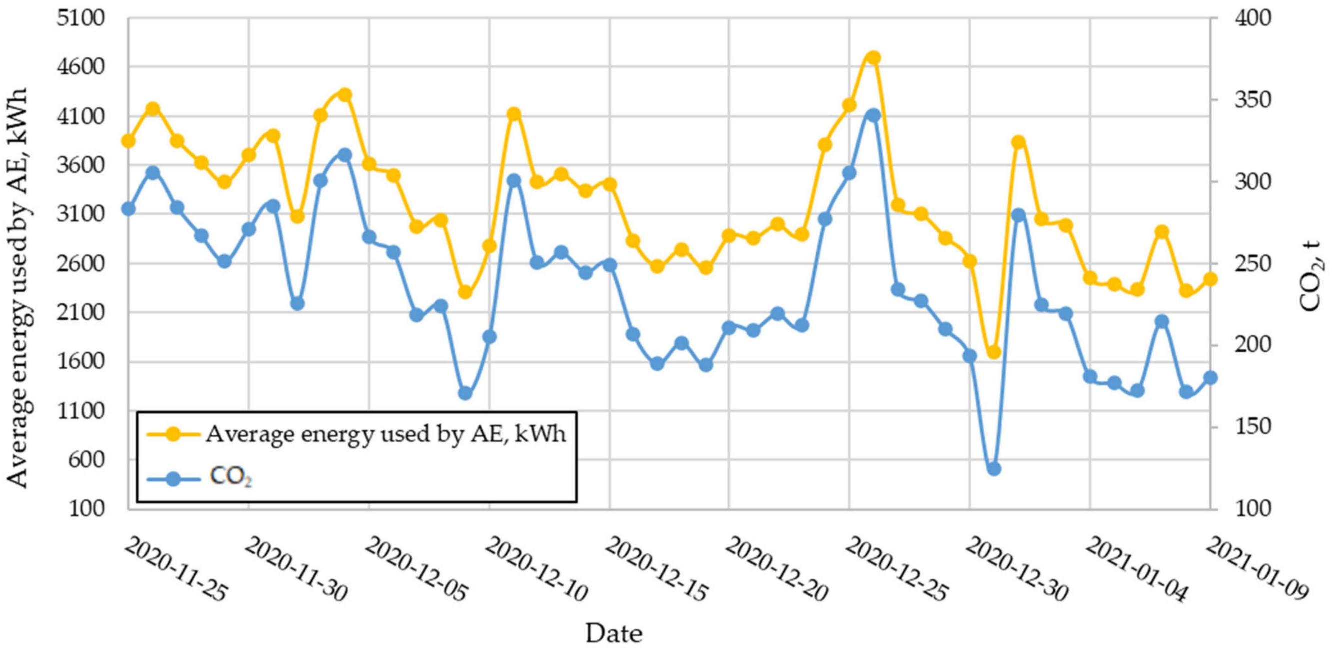

Figure 4. Ship generators produced energy and distribution in port and CO_2 emissions for each day.

Much national and local legislation limits the average concentration of the pollutants per day or even for an hour (NO_x–1 h; SO_2–24 h; PM10–24 h) [54]. When evaluating the effects on the port city, the daily indicators are no less important than the long period of average/total emissions. The graphs showing the emissions change are given in Figures 5 and 6.

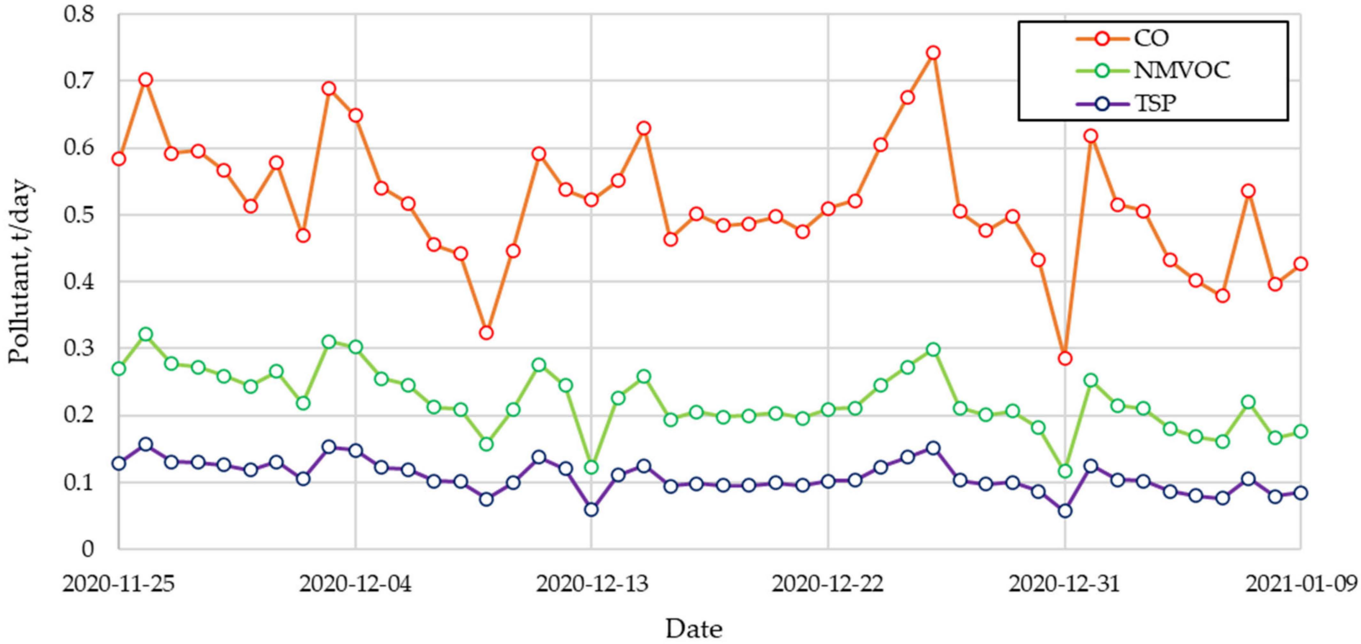

Figure 5. Summed CO, NMVOC and TSP emissions for each individual day.

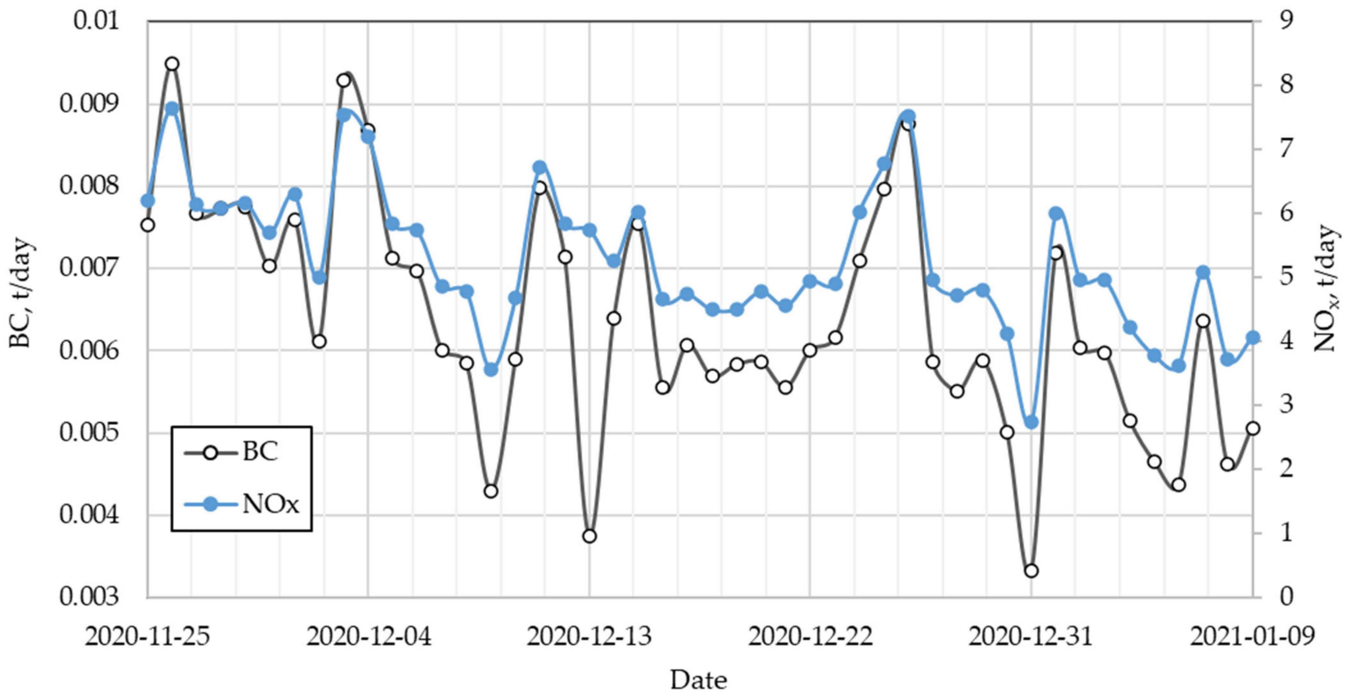

Figure 6. Summed black carbon (BC) and NO_x emissions for each individual day.

The dispersion of emissions also depends on the distribution intensity of emissions in the port terminals. By distributing emissions along the Klaipeda port quays, it was determined that on the quays 1; 54–57; 127 and 128 terminals where tankers (quay 1) were loaded/unloaded, in the quays 127–128 general cargo and Ro-Ro ships were loaded/unloaded, emissions were higher. The emission distribution in time by the quays, which tend to have the largest emissions, was up to 1.24 and 1.07 tons per day, respectively. Comparing these numbers with average NO_x emissions in port (5.28 t NO_x/day), we can see that 20% of the pollutant emission on separate days can be emitted in one place (Figures 7 and 8).

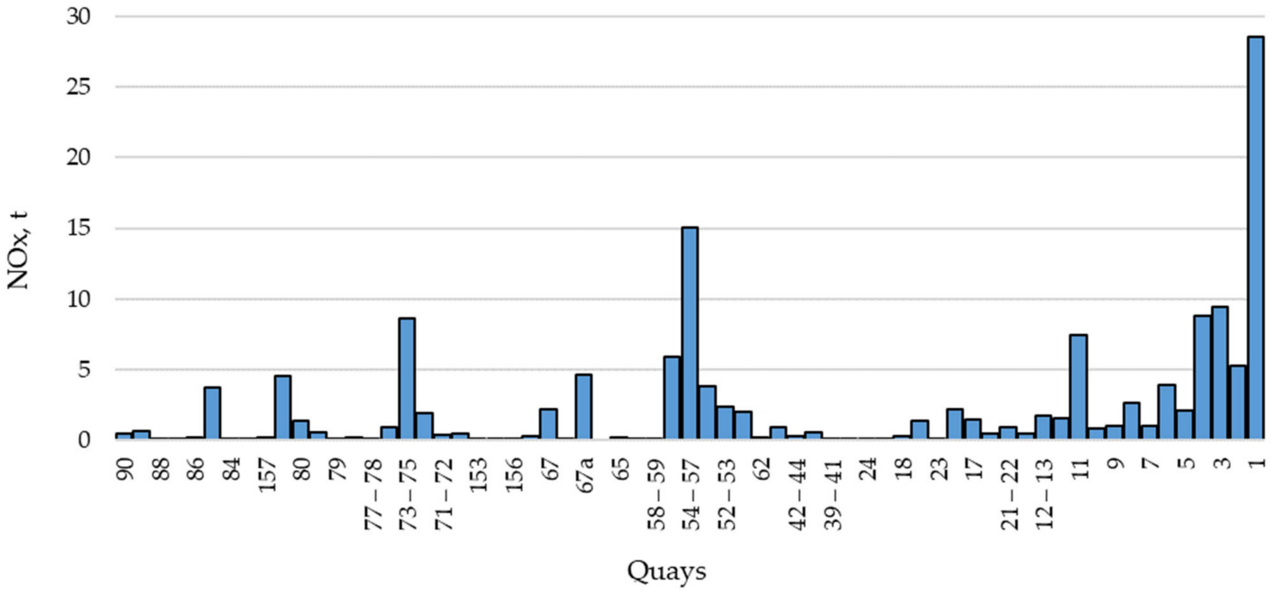

Figure 7. Distribution of emissions in port quays 1–90.

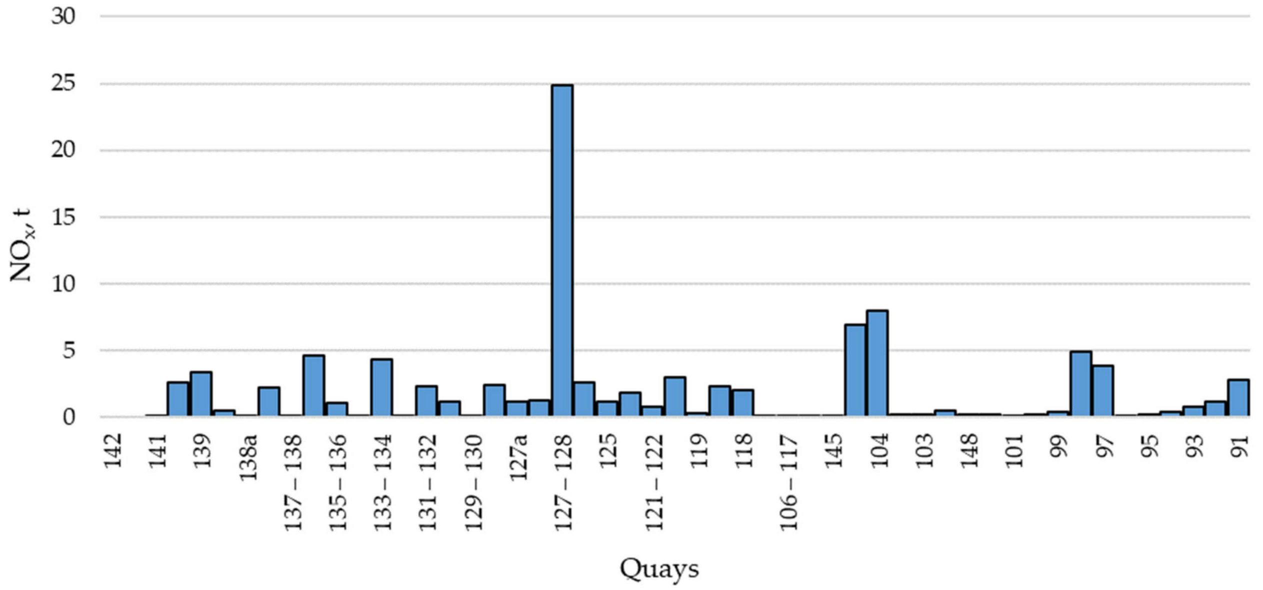

Figure 8. Distribution of emissions in port quays 91–142.

The maximum emissions for quays 127–128 (55.658357; 21.155559) were 1.24 t/day, and for quay No. 1 (55.726619; 21.093111)—1.18 t/day NO_x (Figure 9). It may be noted that although the average emission from the ships in the port was ~5.28 t/day, in the right circumstances, 20% of all emissions from ship emissions may be concentrated on one or another port quay. This is of great importance to the evaluation of the effect of the port and the dissemination of emissions, and the planning of the air pollutant monitoring stations.

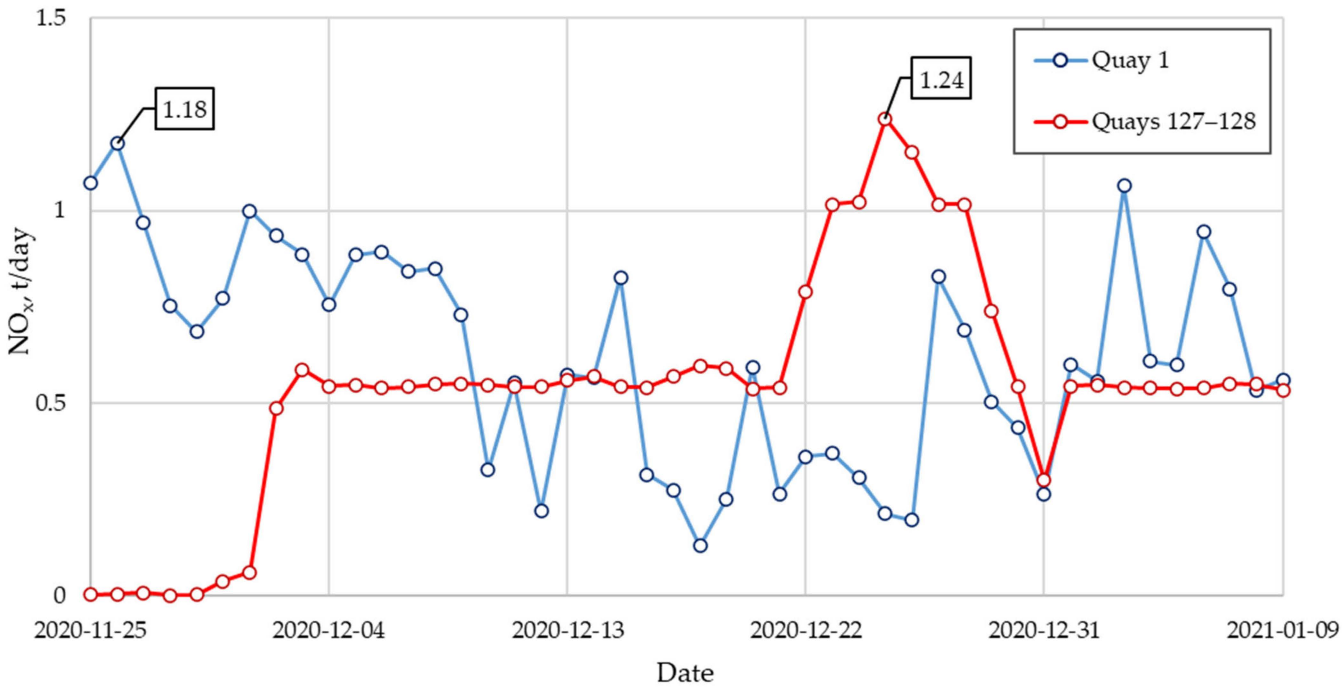

Figure 9. Distribution of NOx emissions on the quays 1 and 127–128.

4. Discussion

This study investigated the shipping emission distribution and emitting duration in Klaipeda port as well as CO_2 emission and power used at the quay. With the rising need for ports to become green and sustainable, difficult goals have to be achieved to ensure CO_2 neutrality and clean air standards. It is, however, noted that there is a lack of evaluations that would target the pollutant emissions, energy consumption and CO_2 emissions in the same study providing a clear view of potential pollutants and CO_2 emission reduction. Using Klaipeda port as an example, we see that three locations in the port were found to have significantly larger emissions due to more vessel traffic and vessel technical characteristics. It was found that although the average emission from the ships in the port was ~5.28 t/day, in the right circumstances, 20% of all ship emissions may be concentrated in one quay. This type of peak emission can be, although temporary, a significant source of pollution to the surrounding residential areas. As was shown by Abrutyte et al. [35] measurement and modelling results, close to or higher than allowed limit concentrations of NOx may occur when emission from high activity terminals is added to other sources, while a 10% increase over background concentration from a single vessel plume was reported by Asier Zubiaga [55] and a 10 μg/m^3 increase in NOx from by Smailys [56]. To avoid exceeding pollutant limitations, locations, where such peak emissions can occur, should be the primary target for monitoring and emission abatement measures, such as cold ironing implementation.

The average daily energy consumption and CO_2 emissions at the quay in the analyzed period were between 500–5000 kWh and 120–350 tons of CO_2, respectively, for a single quay. Although this estimation has limitations due to a lack of data on the exact power and load of auxiliary engines, it provides a good insight into potential energy consumption and estimates of achievable CO_2 reduction for the whole port or by quay basis.

5. Conclusions

The proposed method uses AIS data to create detailed emission estimations with greater insight into their distribution in port areas for a better understanding of the effects on neighboring populated areas.

Average emissions of NO_x 5.28 t/day, TSP 0.52 t/day, NMVOC 0.22 t/day, BC 0.064 t/day, CO_2 235 t/day were estimated based on AIS data in Klaipeda port during the period of 25 November 2020 to 9 January 2021. The difference between the maximum and average emissions was 37.8%. The greatest part of total emissions was undertaken by Ro-Ro and container cargo vessels.

The emission estimation showed that although the average emissions from ships in port are similar to studies undertaken by other researchers, the detailed estimate shows that some locations in port may have significantly higher emissions than other areas.

Adapting the same methodology to evaluate the power used by diesel generators at quays provided insight into quays where most power is used and what average and peak consumption of power is by ships in port, presenting a potential goal for CO_2, another pollutant reduction estimation.

Method limitation: The proposed methodology allows the detailed estimation of air pollutants and CO_2 emissions as well as power used at a quay and provides valuable insights into emission hot points and reduction potentials. However, the methods share EMEP/EEA limitations in terms of load factor and auxiliary engine power estimation.

Author Contributions: Conceptualization, P.R.; methodology, P.R. and G.Š.; software, P.R.; validation, P.R.; formal analysis, P.R. and G.Š.; investigation, P.R. and G.Š.; resources, P.R.; data curation, P.R. and G.Š.; writing—original draft preparation, P.R. and G.Š.; writing—review and editing, G.Š. and J.Ž.; visualization, P.R., G.Š. and J.Ž.; supervision, P.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

AE	auxiliary engine
AIS	automatic identification system
BC	black carbon
CO_2	carbon dioxide
EEA	European Environment Agency
EMEP/EEA	European Environment Agency co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe
LF	load factor
ME	main engine
NMVOC	non-methane volatile organic compounds
NO_x	nitrogen oxides
PM	particulate matter
SFOC	specific fuel oil consumption
SO_x	sulfur oxides
TSP	total suspended particles

References

1. Mamoudou, I.; Zhang, F.; Chen, Q.; Wang, P.; Chen, Y. Characteristics of PM2.5 from ship emissions and their impacts on the ambient air: A case study in Yangshan Harbor, Shanghai. *Sci. Total Environ.* **2018**, *640–641*, 207–216. [CrossRef] [PubMed]
2. Merico, E.; Donateo, A.; Gambaro, A.; Cesari, D.; Gregoris, E.; Barbaro, E.; Dinoi, A.; Giovanelli, G.; Masieri, S.; Contini, D. Influence of in-port ships emissions to gaseous atmospheric pollutants and to particulate matter of different sizes in a Mediterranean harbour in Italy. *Atmos. Environ.* **2016**, *139*, 1–10. [CrossRef]

3. Wen, J.; Wang, X.; Zhang, Y.; Zhu, H.; Chen, Q.; Tian, Y.; Shi, X.; Shi, G.; Feng, Y. PM2.5 source profiles and relative heavy metal risk of ship emissions: Source samples from diverse ships, engines, and navigation processes. *Atmos. Environ.* **2018**, *191*, 55–63. [CrossRef]
4. Ma, Z.; Yang, Y.; Sun, P.; Xing, H.; Duan, S.; Qu, H.; Zou, Y. Analysis of Marine Diesel Engine Emission Characteristics of Different Power Ranges in China. *Atmosphere* **2021**, *12*, 1108. [CrossRef]
5. Kim, Y.; Moon, N.; Chung, Y.; Seo, J. Impact of IMO Sulfur Regulations on Air Quality in Busan, Republic of Korea. *Atmosphere* **2022**, *13*, 1631. [CrossRef]
6. Gibson, M.D.; Kundu, S.; Satish, M. Dispersion model evaluation of PM2.5, NOx and SO_2 from point and major line sources in Nova Scotia, Canada using AERMOD Gaussian plume air dispersion model. *Atmos. Pollut. Res.* **2013**, *4*, 157–167. [CrossRef]
7. Mao, J.; Zhang, Y.; Yu, F.; Chen, J.; Sun, J.; Wang, S.; Zou, Z.; Zhou, J.; Yu, Q.; Ma, W.; et al. Simulating the impacts of ship emissions on coastal air quality: Importance of a high-resolution emission inventory relative to cruise- and land-based observations. *Sci. Total Environ.* **2020**, *728*, 138454. [CrossRef]
8. Toscano, D.; Murena, F. Atmospheric ship emissions in ports: A review. Correlation with data of ship traffic. *Atmos. Environ. X* **2019**, *4*, 100050. [CrossRef]
9. Zhao, J.; Zhang, Y.; Wang, T.; Sun, L.; Yang, Z.; Lin, Y.; Chen, Y.; Mao, H. Characterization of PM2.5-bound polycyclic aromatic hydrocarbons and their derivatives (nitro-and oxy-PAHs) emissions from two ship engines under different operating conditions. *Chemosphere* **2019**, *225*, 43–52. [CrossRef]
10. Li, Y.; Zhang, Y.; Cheng, J.; Zheng, C.; Li, M.; Xu, H.; Wang, R.; Chen, D.; Wang, X.; Fu, X.; et al. Comparative Analysis, Use Recommendations, and Application Cases of Methods for Develop Ship Emission Inventories. *Atmosphere* **2022**, *13*, 1224. [CrossRef]
11. Toscano, D.; Murena, F.; Quaranta, F.; Mocerino, L. Assessment of the impact of ship emissions on air quality based on a complete annual emission inventory using AIS data for the port of Naples. *Ocean Eng.* **2021**, *232*, 109166. [CrossRef]
12. Firląg, S.; Rogulski, M.; Badyda, A. The Influence of Marine Traffic on Particulate Matter (PM) Levels in the Region of Danish Straits, North and Baltic Seas. *Sustainability* **2018**, *10*, 4231. [CrossRef]
13. *World Health Organization (WHO): Health Risks of Air Pollution in Europe—HRAPIE Project, Recommendations for Concentration–Response Functions for Cost–Benefit Analysis of Particulate Matter, Ozone and Nitrogen Dioxide*; WHO Regional Office for Europe: Copenhagen, Denmark, 2013.
14. Xu, L.; Jiao, L.; Hong, Z.; Zhang, Y.; Du, W.; Wu, X.; Chen, Y.; Deng, J.; Hong, Y.; Chen, J. Source identification of PM2.5 at a port and an adjacent urban site in a coastal city of China: Impact of ship emissions and port activities. *Sci. Total Environ.* **2018**, *634*, 1205–1213. [CrossRef] [PubMed]
15. Gagic, R.; Skuric, M.; Djukanovic, G.; Nikolic, D. Establishing Correlation between Cruise Ship Activities and Ambient PM Concentrations in the Kotor Bay Area Using a Low-Cost Sensor Network. *Atmosphere* **2022**, *13*, 1819. [CrossRef]
16. Mousavi, A.; Sowlat, M.H.; Hasheminassab, S.; Pikelnaya, O.; Polidori, A.; Ban-Weiss, G.; Sioutas, C. Impact of particulate matter (PM) emissions from ships, locomotives, and freeways in the communities near the ports of Los Angeles (POLA) and Long Beach (POLB) on the air quality in the Los Angeles county. *Atmos. Environ.* **2018**, *195*, 159–169. [CrossRef]
17. Sun, X.; Tian, Z.; Malekian, R.; Li, Z. Estimation of Vessel Emissions Inventory in Qingdao Port Based on Big data Analysis. *Symmetry* **2018**, *10*, 452. [CrossRef]
18. Ledoux, F.; Roche, C.; Cazier, F.; Beaugard, C.; Courcot, D. Influence of ship emissions on NOx, SO2, O3 and PM concentrations in a North-Sea harbor in France. *J. Environ. Sci.* **2018**, *71*, 56–66. [CrossRef]
19. Alver, F.; Saraç, B.A.; Alver Şahin, Ü. Estimating of shipping emissions in the Samsun Port from 2010 to 2015. *Atmos. Pollut. Res.* **2018**, *9*, 822–828. [CrossRef]
20. Lonati, G.; Cernuschi, S.; Sidi, S. Air quality impact assessment of at-berth ship emissions: Case-study for the project of a new freight port. *Sci. Total Environ.* **2010**, *409*, 192–200. [CrossRef]
21. El-Taybany, A.; Moustafa, M.M.; Mansour, M.; Tawfik, A.A. Quantification of the exhaust emissions from seagoing ships in Suez Canal waterway. *Alex. Eng. J.* **2019**, *58*, 19–25. [CrossRef]
22. Bacalja, B.; Krčum, M.; Slišković, M. A line ship emissions while manoeuvring and hotelling—A case study of port split. *J. Mar. Sci. Eng.* **2020**, *8*, 953. [CrossRef]
23. Chen, S.; Meng, Q.; Jia, P.; Kuang, H. An operational-mode-based method for estimating ship emissions in port waters. *Transp. Res. Part Transp. Environ.* **2021**, *101*, 103080. [CrossRef]
24. Schwarzkopf, D.A.; Petrik, R.; Matthias, V.; Quante, M.; Majamäki, E.; Jalkanen, J.-P. A ship emission modeling system with scenario capabilities. *Atmos. Environ. X* **2021**, *12*, 100132. [CrossRef]
25. Shi, K.; Weng, J.; Li, G. Exploring the effectiveness of ECA policies in reducing pollutant emissions from merchant ships in Shanghai port waters. *Mar. Pollut. Bull.* **2020**, *155*, 111164. [CrossRef]
26. Weng, J.; Shi, K.; Gan, X.; Li, G.; Huang, Z. Ship emission estimation with high spatial-temporal resolution in the Yangtze River estuary using AIS data. *J. Clean. Prod.* **2020**, *248*, 119297. [CrossRef]
27. Yang, L.; Zhang, Q.; Zhang, Y.; Lv, Z.; Wang, Y.; Wu, L.; Feng, X.; Mao, H. An AIS-based emission inventory and the impact on air quality in Tianjin port based on localized emission factors. *Sci. Total Environ.* **2021**, *783*, 146869. [CrossRef]
28. You, Y.; Lee, J.C. Activity-based evaluation of ship pollutant emissions considering ship maneuver according to transportation plan. *Int. J. Nav. Archit. Ocean Eng.* **2022**, *14*, 100427. [CrossRef]

29. Hong, H.; Jeon, H.; Youn, C.; Kim, H. Incorporation of Shipping Activity Data in Recurrent Neural Networks and Long Short-Term Memory Models to Improve Air Quality Predictions around Busan Port. *Atmosphere* **2021**, *12*, 1172. [CrossRef]
30. Garbatov, Y.; Georgiev, P. Air Pollution and Economic Impact from Ships Operating in the Port of Varna. *Atmosphere* **2022**, *13*, 1526. [CrossRef]
31. Fuentes García, G.; Sosa Echeverría, R.; Baldasano Recio, J.M.; Kahl, J.D.W.; Granados Hernández, E.; Alarcón Jímenez, A.L.; Antonio Durán, R.E. Atmospheric Emissions in Ports Due to Maritime Traffic in Mexico. *J. Mar. Sci. Eng.* **2021**, *9*, 1186. [CrossRef]
32. Goldsworthy, L.; Goldsworthy, B. Modelling of ship engine exhaust emissions in ports and extensive coastal waters based on terrestrial AIS data—An Australian case study. *Environ. Model. Softw.* **2015**, *63*, 45–60. [CrossRef]
33. Ng, S.K.W.; Loh, C.; Lin, C.; Booth, V.; Chan, J.W.M.; Yip, A.C.K.; Li, Y.; Lau, A.K.H. Policy change driven by an AIS-assisted marine emission inventory in Hong Kong and the Pearl River Delta. *Atmos. Environ.* **2013**, *76*, 102–112. [CrossRef]
34. Qiao, B.; He, W.; Tian, Y.; Liu, Y.; Cai, O.; Li, Y. Ship emission reduction effect evaluation of air pollution control countermeasures. *Transp. Res. Procedia* **2017**, *25*, 3606–3618. [CrossRef]
35. Abrutytė, E.; Žukauskaitė, A.; Mickevičienė, R.; Zabukas, V.; Paulauskienė, T. Evaluation of NOx emission and dispersion from marine ships in Klaipeda sea port. *J. Environ. Eng. Landsc. Manag.* **2014**, *22*, 264–273. [CrossRef]
36. Report. Klaipėdos Miesto Savivaldybė. *Klaipėdos Miesto Savivaldybės Aplinkos oro Kokybės Valdymo Programa 2020–2023 m. Vilnius. UAB "Estonian, Latvian & Lithuanian Environment"*. 2020. Available online: https://www.klaipeda.lt/data/public/uploads/2020/09/klaipeda-okvp-elle20200911.pdf (accessed on 15 August 2022).
37. Madjidian, J.; Björk, S.; Nilsson, A.; Halén, T. Clean Baltic Sea Shipping CLEANSHIP. 2013, 1. Available online: https://www.researchgate.net/profile/Josefin-Madjidian/publication/291338320_Clean_Baltic_Sea_Shipping/links/56a0adf508aee4d26ad71907/Clean-Baltic-Sea-Shipping.pdf (accessed on 15 August 2022).
38. Xiao, G.; Wang, T.; Chen, X.; Zhou, L. Evaluation of Ship Pollutant Emissions in the Ports of Los Angeles and Long Beach. *J. Mar. Sci. Eng.* **2022**, *10*, 1206. [CrossRef]
39. Rapalis, P.; Daukšys, V. Oro taršos iš įvairių laivų tipų pasiskirstymas Klaipėdos uoste ir taršos mažinimo galimybių apžvalga. *Technol. Mokslo Darb. Vakarų Liet. Konf. Medžiaga* **2012**, *8*, 75–79.
40. Smailys, V.; Rapalis, P.; Strazdauskien, R. Air Pollution by NOx from Ships Passing Klaipeda Port Channel. *Transp. Means* **2013**, *2013*, 97–100.
41. Gan, L.; Che, W.; Zhou, M.; Zhou, C.; Zheng, Y.; Zhang, L.; Rangel-Buitrago, N.; Song, L. Ship exhaust emission estimation and analysis using Automatic Identification System data: The west area of Shenzhen port, China, as a case study. *Ocean Coast. Manag.* **2022**, *226*, 106245. [CrossRef]
42. Yang, L.; Zhang, Q.; Lv, Z.; Zhang, Y.; Yang, Z.; Fu, F.; Lv, J.; Wu, L.; Mao, H. Efficiency of DECA on ship emission and urban air quality: A case study of China port. *J. Clean. Prod.* **2022**, *362*, 132556. [CrossRef]
43. Paulauskas, V.; Filina-Dawidowicz, L.; Paulauskas, D. The Method to Decrease Emissions from Ships in Port Areas. *Sustainability* **2020**, *12*, 4374. [CrossRef]
44. Huang, L.; Wen, Y.; Zhang, Y.; Zhou, C.; Zhang, F.; Yang, T. Dynamic calculation of ship exhaust emissions based on real-time AIS data. *Transp. Res. Part Transp. Environ.* **2020**, *80*, 102277. [CrossRef]
45. Jugović, A.; Sirotić, M.; Poletan Jugović, T. Identification of Pivotal Factors Influencing the Establishment of Green Port Governance Models: A Bibliometric Analysis, Content Analysis, and DPSIR Framework. *J. Mar. Sci. Eng.* **2022**, *10*, 1701. [CrossRef]
46. Lam, J.S.L.; Li, K.X. Green port marketing for sustainable growth and development. *Transp. Policy* **2019**, *84*, 73–81. [CrossRef]
47. Report. VĮ Klaipėdos Valstybinio Jūrų uosto Direkcija. *Klaipėdos Valstybinio Jūrų uosto Žaliojo uosto Koncepcija*. Vilnius. VĮ Klaipėdos Valstybinio Jūrų uosto Direkcija. 2022. Available online: https://governance.lt/vvi/klaipedos-valstybinio-juru-uosto-direkcija/ (accessed on 15 August 2022).
48. Xiao, Z.; Lam, J.S.L. A systems framework for the sustainable development of a Port City: A case study of Singapore's policies. *Res. Transp. Bus. Manag.* **2017**, *22*, 255–262. [CrossRef]
49. Twrdy, E.; Zanne, M. Improvement of the sustainability of ports logistics by the development of innovative green infrastructure solutions. *Transp. Res. Procedia* **2020**, *45*, 539–546. [CrossRef]
50. Klaipėdos Uosto Planas. Available online: http://www.uostas.info/images/stories/pages/uostas/uostoplanas/Klaipedos_uosto_planas_2018.pdf (accessed on 24 November 2022).
51. Liebuvienė, J.; Čižiūnienė, K. Comparative Analysis of Ports on the Eastern Baltic Sea Coast. *Logistics* **2021**, *6*, 1. [CrossRef]
52. Port of Klaipeda: Port Statistics | Portofklaipeda.lt. Available online: https://portofklaipeda.lt/en/port-2/about-the-port-of-klaipeda/statistics/ (accessed on 29 August 2022).
53. European Environment Agency. *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019: Technical Guidance to Prepare National Emission Inventories*; Publications Office, LU: Luxembourg, 2019.
54. Aplinkos Apsaugos Agentūra: Oro Užterštumo Normos. Available online: https://oras.old.gamta.lt/cms/index?rubricId=260ccbe8-5401-4f3b-adb1-b4ab1b9aa2b5 (accessed on 15 August 2022).
55. Zubiaga, A.; Madsen, S.; Khawaja, H.; Boiger, G. Atmospheric Contamination of Coastal Cities by the Exhaust Emissions of Docked Marine Vessels: The Case of Tromsø. *Environments* **2021**, *8*, 88. [CrossRef]
56. Smailys, V.; Strazdauskiene, R.; Bereisiene, K. Evaluation of a Possibility to Identify Port Pollutants Trace in Klaipeda City Air Pollution Monitoring Stations. *Environ. Res. Eng. Manag.* **2009**, *4*, 66–75.