Estimating Shipping Emissions – A Case Study for Cargo Port of Zadar, Croatia

V. Knežević, Z. Pavin & J. Čulin
University of Zadar, Zadar, Croatia

ABSTRACT: Reducing air pollutant emissions and energy consumption, as a necessary step to make ports more sustainable, is one of the crucial tasks and challenges of port management. Some of the port strategies to meet the term "green port" usually include reducing fuel consumption from vessels and vehicles in ports. This paper estimates the emission inventory of maritime traffic for the cargo Port of Zadar. For this research, emissions from cargo ships are estimated in the period from January 01. 2018 until October 01. 2019. The "bottom-up" methodology has been applied for estimating emissions, which includes detailed data on the ship's characteristics (engine power, the load factor, fuel type, the emission factor) and time spent cruising and hotelling. The emissions from cargo ships have been estimated for three ship's activities: cruising in the reduced speed zone, hotelling (time spent at berth), and maneuvering. The emission results (tons/year) refer to the pollutants such as nitrogen oxides (NOx), sulphur oxides (SOx), particulate matter (PM), volatile organic compounds (VOC), and carbon dioxide (CO_2) which represents greenhouse gases. Estimating emission inventory is the first step for planning effective port air quality control. Some recommendations for reducing emissions in port areas are emphasized in this paper.

1 INTRODUCTION

Degradation of air quality and climate change are perceived as the two biggest environmental concerns for Europeans, due to the negative effects on human health, productivity, and property. To reduce emissions of greenhouse gases and air pollutants holistic solutions are needed and efforts must be made at local, regional, national, and global levels [5]. A distinct combination of geographic, bathymetric, orographic, climatic characteristics, and significant anthropogenic pressures makes the Adriatic Sea highly sensitive to pollution, and efforts to promote the environmental sustainability of human activities that affect it have been taken by the Croatian government [13].

Historically, the focus of the prevention measures has been on activities that occur at sea, where the majority of airborne emissions occur, as can be seen in Figure 1 for greenhouse gases (GHG) emissions [10]. However, efforts to make maritime transport less polluting must include ports. The port emissions can significantly contribute to air quality degradation of urban areas [23]. Ships, as the single largest source of port-related pollution, may pose an important health risk in certain port cities. Namely, emissions of SO2 can be larger than those of road traffic, and emissions of PM and NOx can be comparable with those of road traffic and lead to negative health effects like asthma, cardiovascular diseases, lung cancer, premature mortality, and morbidity [1]. Furthermore, the "green ports", an answer to demands of environmentalists, consumers, and government for more

environmentally sustainable movement of goods and people, need to reduce GHG emissions. Moreover, many measures for reducing GHG emissions also reduce emissions of air pollutants and noise [22].
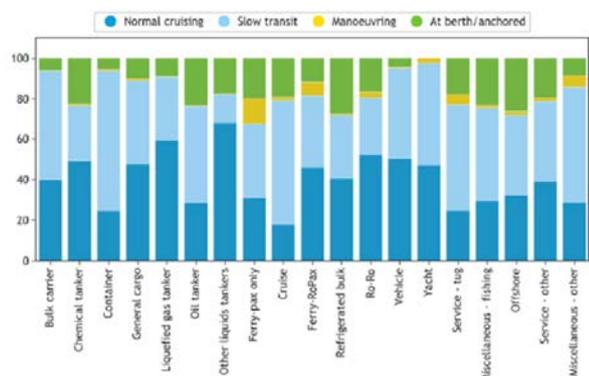

Figure 1. International GHG emissions (in CO2e) by operational phase in 2018, according to the voyage-based allocation of emissions [(3)3]

To develop measures to reduce emissions in the ports it is necessary to estimate emissions from visiting ships [22]. For that basic step, many data are required: vessel parameter data, activity data, operational data, and geographical domain data [8]. A plethora of studies has been conducted to investigate various aspects of ship emissions in ports, including emission inventories for numerous ports [1, 17, 23]. On the national level, it is necessary to develop the National Ships Emissions Inventory. Emission inventories for several Croatian ports have been published so far. Radonja et.al. [18] estimated quantities of CO2, NOx, SOx and PM emitted at the port of Rijeka in 2017, while Stazić et al. [21] published emissions inventory of the port of Split done for the same pollutants and year. The emission inventory of marine traffic in the port of Šibenik in 2018, which included CO2, NOx, SOx, PM, and VOCs has been estimated by Pastorčić et al. [15].

2 AREA OF RESEARCH AND PORT DATA

The emission trends analyzed in this paper are based on the emission inventory of the cargo Port of Zadar in two time periods, the first being the period from January to December 2018 and the second being the period from January to October 2019. The year 2020 wasn't analyzed in this paper due to the effect of the COVID-19 pandemic has had on shipping and was thus concluded that the 2020 trend wouldn't be relevant in comparison with the usual trends. The Zadar cargo port marine traffic has been generated in Table 1 according to the data provided by Port of Zadar Authority and Luka Zadar d.d. [11].

Table 1. Marine cargo traffic in the cargo Port of Zadar for 2018 and 2019 year

Period	January 01-December 31. 2018		January 01-October 01. 2019	
Type of vessel	Number of vessels	Number of arrivals	Number of vessels	Number of arrivals
General cargo	5	5	13	14
Bulk carrier	5	39	6	30
Tankers	19	20	9	23
Reefer	0	0	4	5

Figure 2. Cargo Port of Zadar: 1 – terminal for liquid cargo, 2 – oil platform supply terminal, 3 – terminal for bulk carriers, 4 – terminal for general cargo, 5 and 6 – terminal for general cargo and cement

The liquid cargo terminal is comprised of a 60 m coastline (mooring up to 190 m in length), draft of 10.3 m to 12 m and the potentiality to moor ships up to 40,000 DWT. The terminal also consists of tanks for petroleum products with the capacity of 60,000 m³, tanks for chemicals with the capacity of 15,000 m³, 16 pipelines, and a floating protective barrier with a length of 300 m. The oil platform supply terminal is comprised of a 180 m coastline, a draft of 4.8 m to 7.1 m, closed warehouses and workshops, an open storage area of 20,000 m² and a 9 m long ramp.

The bulk freight loading/unloading terminal is comprised of a 140 m coastline, a 12 m draft with the potentiality to moor ships up to 80,000 DWT. The capacity of the terminal is 500,000 tons annually with an unloading capacity of 500 tons/hour. The terminal's construction provides a possibility to simultaneously load wagons on two railway tracks. The terminal also houses a grain silo with the capacity of 38,000 m3 and closed storage with the capacity of 30,000 m3. The first general cargo loading/unloading terminal is comprised of a 135 m coastline, a draft of 7 m to 11.4 m, and the potentiality to moor ships up to 10.000 DWT.

The second general cargo loading/unloading terminal is comprised of a 150 m coastline, a draft of 8.7 m to 10.2 m with the potentiality to moor ships up to 20,000 DWT. The terminal uses a 24 m long RO-RO ramp, an open storage area of 150,000 m2 and a closed warehouse with an area of 34.000 m2. The terminal also uses an industrial railway track with the capacity of servicing 140 wagons per day. The cement loading/unloading terminal has an annual capacity of 80,000 tons with the potentiality of unloading ships from both general cargo piers, weighing max. up to 50 tons and distribution to trucks.

The distance a ship travels from the start of the pilotage until its end at the port is defined as the "Reduce speed zone". The pilotage starts at the island of Grujica and finishes at the Zadar port breakwater, comprising a pilotage route of 35.245 Nm (64.588 km) (Figure 3). The estimated maximum safe speed for cargo ships in a reduced speed zone is 9 knots [24].
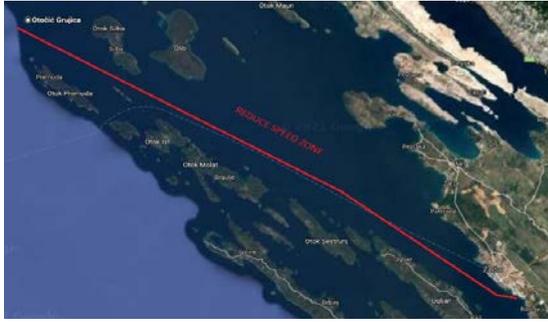
Figure 3. Reduce speed zone – pilotage of ships (Grujica-Zadar)

3 METHODOLOGY

The applied method for estimating emissions from maritime traffic in this paper is the so-called "bottom-up" method. To estimate the quantity of each pollutant emitted this method uses comprehensive data such as the type and power of the main and auxiliary engine, used fuel, engine load factor, emission factor, and ship's voyage data. The guidelines for emission inventories [3, 6, 10, 24] are mostly estimating emissions of NOx, SOx, PM, VOC, HC pollutants, and CO2 as a greenhouse gas. However, the latest edition of the IMO study [10] emphasized the increase of methane (CH4) emissions and black carbon emission, which is not a greenhouse gas but a component of soot, emitted by the incomplete combustion in engines and it is also harmful to the atmosphere.

There are few different approaches for developing a port emission inventory and they can sometimes vary in terms of the research area, time, and available resources. The usual difference is between the highly detailed inventories which are typical for the geographically larger ports with numerous ship calls and the mid-tier approach which is often used for smaller ports. In the detailed port inventories, the emissions from the land-based activities are also included. However, this approach is mainly used for container terminals or ports with cargo handling equipment, locomotives, and heavy-duty vehicles [16].

This methodology estimates the total emissions from the ship's voyage by summing the emissions from all the ship's activities. One particular trip is divided into three activities: cruising at sea, maneuvering, and hotelling (at berth). For a single trip emission can be calculated as:

$$E_T = E_C + E_M + E_H$$

The emissions from a ship in navigation are expressed with the following equation [6]:

$$E_C = \frac{D}{v} \cdot \left[\left(ME \cdot LF_{ME} \cdot EF \right) + \left(AE \cdot LF_{AE} \cdot EF \right) \right]$$

For each ship calling in a port or during maneuvering, the emissions for at berth and maneuvering activities has been calculated as follows [6]:

$$E_H = E_M = T \cdot \left[\left(ME \cdot LF_{ME} \cdot EF \right) + \left(AE \cdot LF_{AE} \cdot EF \right) \right]$$

where:
E – emission (T-trip, C-cruising, M-manoeuvring, H-hotelling) [g]
D – distance travelled (km)
v – average ship's speed (km/h)
ME – installed main engine power (kW)
LFME – main engine load factor (%)
AE – installed auxiliary engine power (kW)
LFAE – auxiliary engine load factor (%)
EF – emission factor, depending on the fuel type and ship's speed (g/kWh)
t – hotelling and manoeuvring time (h)

3.1 Time activities

For more accurate estimation it is necessary to determine the average time of each ship's activity. Each activity is associated with a different engine load that has a unique emission factor. The cruising time (in hours) refers to the slow steaming of the ship in a reduced speed zone. Time is calculated in equation (2) as the ratio of the trip's length (km) and average speed of cargo ships in a reduced speed zone, which is estimated to 9 knots (16.67 km/h) [24].

The maneuvering activity is related to the area between the breakwater and the dock. According to the data obtained from the Port of Zadar authority, the maneuvering time for bulk carriers, general cargo ships, and reefers is 1 hour, while for tankers is 2 hours due to placing additional safety breakwaters.

The hotelling time implies the time ship spent at berth (anchorage). Most of the guidelines for the port emission inventories are estimating the hotelling time according to the type of ship. This approach is useful only for the ports with a large number of ships that call throughout the year or in the case when the information about hotelling time is uncertain. Based on the data obtained from the Port of Zadar [11], the total time at berth for each cargo ship is determined.

3.2 Fuel type and emission factors

The type of fuel used in main and auxiliary engines is highly important when estimating exhaust gases emissions. The exhaust emissions depend on the sulphur and carbon content in the fuel. The sulphur content in fuel is defined by EU directive 2016/802 [7] which requires the use of low sulphur fuel (0.1%) in all EU ports and the inland waters. This paper assumes that ships use marine gas oil with a low sulphur content that does not exceed 0.1% by mass.

The emission factors are commonly used for estimating shipping emissions and they depend on the type of engine, fuel used, the ship's activity, and a load factor of main and auxiliary engines. The main engine emission factors are presented in Table 2 for slow speed (SSD) and medium speed (MSD) diesel engines.

Table 2. ME emission factors (g/kWh) 'at sea', 'while maneuvering, 'at berth' [3]

Engine type/ fuel type	NOx pre-2000 engine	NOx post-2000 engine	SO2	CO2	VOC	PM
	At sea					
SSD/MGO	17.0	14.1	0.7	588	0.6	0.3
MSD/MGO	13.2	11.0	0.8	645	0.5	0.3
	Manoeuvring / at berth					
SSD/MGO	13.6	11.3	0.8	647	1.8	0.9
MSD/MGO	10.6	8.8	0.9	710	1.5	0.9

The NOx emission factors are determined according to the IMO NOx Technical Code [14] because engines installed on the ship before 01 January 2000 need to meet the required NOx emission limit. From overall cargo ships arrived at the port in 2018, the 8 ships have engines installed before 2000, and in 2019 the 13 ships. The auxiliary engine emission factors are presented in Table 3, and they are equal for all three ship's activities.

Table 3. AE emission factors (g/kWh) 'at sea', 'while maneuvering, 'at berth' [3]

Engine type/ fuel type	NOx pre-2000 engine	NOx post-2000 engine	SO2	CO2	VOC	PM
M/H SD/MGO	17.0	14.1	0.7	88	0.4	0.3
M/H SD/MDO	17.0	14.1	5.6	588	0.4	0.4
M/H SD/RO	14.7	12.2	12.3	722	0.4	0.8

3.3 Engine particulars and load factors

For a more precise calculation of emissions, it is necessary to obtain the data of main and auxiliary engine power (kW) and load factor for each cargo ship. The data on the main and auxiliary engines have been obtained from available ship particulars and database [20]. The engine specifications from each ship have shown that all cargo ships are mechanically driven by two-stroke or four-stroke diesel engines.

The load factor of the main and auxiliary engine is a percentage of the load in relation to the maximum continuous rating (MCR). It depends on the actual speed of the ship and different activities. The load factor of the main engines, according to the literature [3] is 80% while cruising, 20% during maneuvering and for hotelling activity, it is assumed that main engines are not running, except in the case of tanker ships where the load factor is 20% due to usage of transfer pumps. The auxiliary engine load factors depend on the type of the ship and activity. The highest load factors are during maneuvering activity due to the usage of bow thrusters which increase electrical energy supply. Moreover, it is assumed that auxiliary engines are running at all the time, except during hotelling if cold ironing is provided in port (not in this case). The used auxiliary engine load factors for each type of cargo ship and activity are presented in Table 4.

Table 4. Auxiliary engine load factors for cargo ships [24]

Vessel type	Cruise	Reduce speed zone	Manoeuvre	At berth
General cargo	0.17	0.27	0.45	0.22
Bulk carrier	0.17	0.27	0.45	0.22
Container ship	0.13	0.25	0.50	0.17
Tanker	0.13	0.27	0.45	0.67
Reefer	0.20	0.34	0.67	0.34

4 RESULTS

The total annual emissions in 2018 are 48.52 t for NOx, 2.45 t for SOx, 1.40 t for PM, 2.57 t for VOC, and in 2019 is 39.04 t for NOx, 1.90 t for SOx, 1.14 t for PM, and 2.14 t for VOC (Figure 4). The emission results in Figures 4 and 5 have been displayed for each pollutant and ship's activity. For 2019 the total annual emissions results are: 39.04 t for NOx, 1.90 t for SOx, 2.14 t for VOC, 1.14 t for PM (Figure 5).
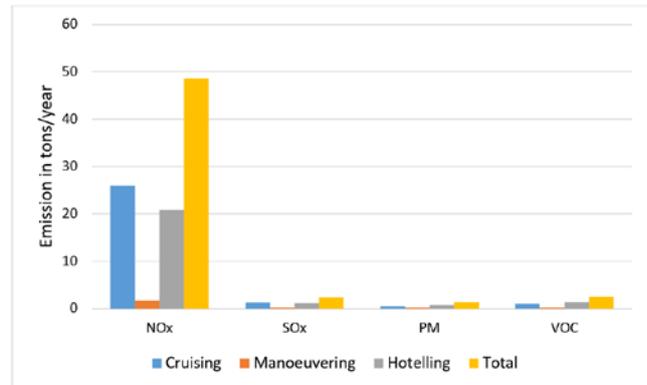

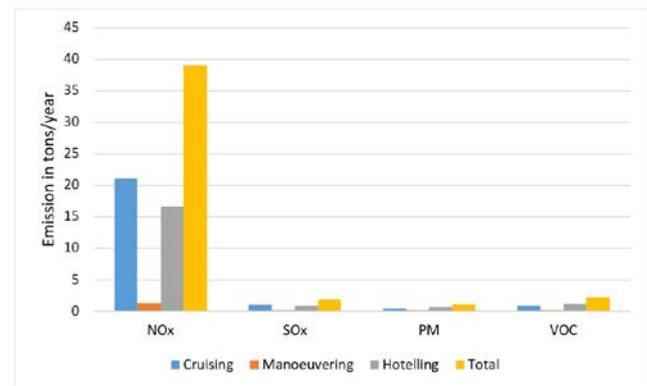Figure 4. Cargo ship emissions in 2018 for each activity

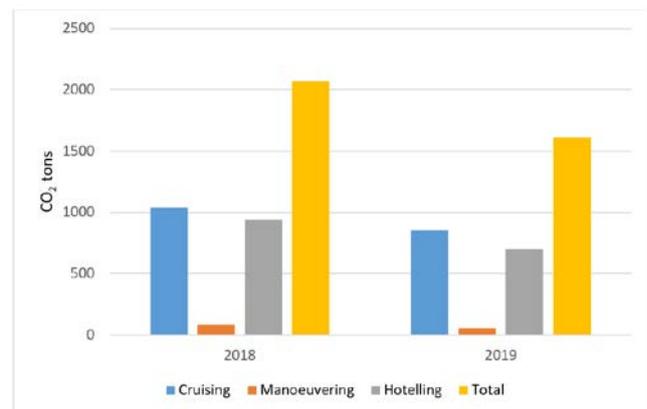Figure 5. Cargo ship emissions in 2019 for each activity

Figure 6. Total CO2 emission for 2018 and 2019

The CO2 emissions of cargo traffic for 2018 and 2019 are shown in Figure 6. Cargo ships emitted 2069.18 tons of CO2 in 2018 and 1612.23 tons in 2019. Obviously, the lowest amount of emission is during maneuvering activity due to the short time and low main engine load factors. The highest quantity of CO2 is emitted during cruising due to high load factors

and installed power of the main engines. The auxiliary engines are responsible for the emissions during hotelling activity and with longer time spent at berth, they are almost as emissions during cruising (2018- cruising 1040.86 t, maneuvering 942.69 t and in 2019 – cruising 854.13 t, maneuvering 701.40 t).

5 DISCUSSION

The results show that most of the emission is generated during cruising activity and a notable part is the result of hotelling activity. The emissions during hotelling and maneuvering have a more significant impact on the port area climate and human health. Most of the emissions in port are from auxiliary engines, due to increased ship's electricity demands. The electricity demand depends on the type of cargo ship, for example, tankers are using electricity for transfer cargo pumps and general cargo ships for loading/unloading the cargo.

In Figure 6 the emissions are divided according to the type of cargo ship. The majority of emissions are produced by tankers (70%) and general cargo ships are responsible for 20%. The main reason why tankers have the highest emissions is due to large installed power (kW), especially of the two-stroke low-speed main engine. The bulk carriers had more port calls than tankers in 2018 and 2019, however, their main engines are mostly high-speed four-stroke engines. Also, the auxiliary engine load factor (at berth) for tanker ships is higher than the rest of the cargo ships.
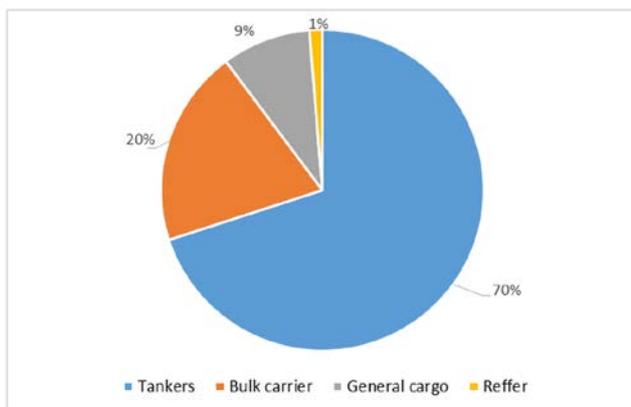

Figure 7. Overall CO2 emissions for a different type of cargo ships (2018 and 2019)

To achieve the term "green port" the port authorities must find the solution for reducing pollution from ships while at berth, moreover, the ship-owners must adapt to the sustainable energy-efficient plan of each port. The emission reduction in port depends on many factors such as port size, number of port calls, type of port, financial condition, and local infrastructure. Few recommended measures for reducing emissions in the port:
− Cold ironing (On-shore power supply)
  The meaning of "cold ironing" term is when shore-side electric power is provided to ships while at berth, allowing them to shut down the auxiliary engines. This measure can significantly reduce emissions in port, however, it depends on the source of electric energy. The ideal scenario is when the port power grid is supplied through renewable energy sources. For ports in the EU where air quality is above normal and with a high level of noise the EU recommendation 2006/339/EC [4] for shore-side electricity is provided. Few examples of large ports in Europe [9, 19] that are using cold ironing are the ports of Gothenburg, Antwerp, Stockholm, Bergen.
− Alternative fuels
  The most efficient method for reducing emissions without installing any technologies on the ship is to change fuel from marine diesel oil to cleaner fuels. The existing alternative fuels for the shipping industry are LNG (Liquefied Natural Gas), LPG (Liquefied Petroleum Gas), NH3 (Ammonia), CH3OH (Methanol), H2 (Hydrogen), HVO (Hydrotreated Vegetable Oil) [2]. When compared with conventional diesel oil, alternative fuels can significantly reduce SOx, NOx, and PM emissions because they primarily depend on fuel used. However, the main difficulties for operating with alternative fuels are in economical aspects such as energy cost, capital cost, and availability. For most of the alternative fuels, current availability is insufficient to cover the energy consumption for the shipping industry and most ports are lacking the necessary infrastructure and bunkering stations.
− Slow steaming and reduced time in port
  The reduction of sailing speed or so-called 'slow steaming' has become common for many cargo ships, especially containers to save bunker fuel costs. Slow steaming is an effective method for reducing CO2 emissions and it could be achieved without installing any new technology. However, in fairway channels or in this case, in reduced speed zone, the ships are already going slow so further speed reduction could increase the fuel consumption or even damage the main engine and increase maintenance costs. The normal operating range for main engines is 70-85% of MCR and while slow steaming is up to 50 to 55% [12]. Another operating measure for reducing emissions in port is to reduce time spent at berth. This could be done with more efficient administrative procedures, port operations, optimized loading/unloading activity, and improved communication between ship crew and port authorities. As seen in results the emissions at berth are mostly from the auxiliary engines, so this measure could have the potential for ships with large installed auxiliary power that spends a long time in port.

6 CONCLUSION

The annual exhaust emissions in 2018 and 2019 year, generated by different types of cargo ships in the cargo Port of Zadar, have been estimated by the 'bottom-up' methodology. This methodology divides the estimated emissions into three activities (cruising, maneuvering hotelling), of which activity hotelling has a significant impact on the port air quality. The overall marine cargo traffic included 64 port calls in 2018. and 72 in 2019. Bulk carriers emitted 20% of total emissions and the highest amount of emissions

are from tanker ships (70%) due to large main and auxiliary engine power and 43 port calls in two years. The obtained results are necessary to prepare the emission database and then to determine the sustainable plan for reducing emissions in port. Moreover, the results are contributing to emission inventory on a national level and they could be compared with inventories in other Croatian cargo and passenger ports. To reach sustainable and energy-efficient objectives, the previously mentioned measures for reducing should be considered not only on a local level but also on a regional and national level.

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