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Emission Inventory of Marine Traffic for the Port of Šibenik

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ABSTRACT

The paper estimates the exhaust emissions of marine traffic in the port of Šibenik. The results of the analysis were obtained by including the following gaseous pollutants: nitrogen oxide (NO_x), sulphur oxide (SO_x), particulate matter (PM), volatile organic compounds (VOCs) and carbon dioxide (CO_2) as greenhouse gas. In order to gain results and estimate the emission of harmful gases in the port of Šibenik, the passenger and the cargo throughput were taken into account. The activities of the ship during which the exhaust gases are emitted into the atmosphere are slow cruising in the reduced speed zone, manoeuvring and hotelling. The "bottom-up" method used in the emission estimation takes into account the ship's engine power, engine load factor, fuel type, the emission factor, time of cruising and time hotelling in the port of Šibenik. The results of the analysis have shown that approximately 70 % of total emissions come from passenger ships (cruise ships) and 30 % from cargo ships.

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1 Introduction

The increase in the maritime transport has had a major impact on the expansion and development of maritime ports and, consequently, on coastal ecosystems. Therefore, it is of great importance to reduce the exhaust emissions from marine engines, i.e. to use alternative, environmentally friendly solutions. The total annual CO_2 emission from maritime transport amounts around 940 million tons, or 2.5 % of global GHG emissions (Greenhouse Gases). In Europe, it is 130 million tons or 13 % of Europe's GHG emissions [1, 2]. An increase in carbon dioxide emissions into the atmosphere caused by human factors (by 2020, expected to increase by 150 %, [21]) resulted in rise of temperature and acidification of inland waters and oceans. The share of marine traffic in global emissions is estimated at 15 % for NO_x and 4 – 9 % for SO_x, [3]. Particulate matter (PM) emission causes the development of cardiovascular diseases and an increases risk of lung cancer, [4]. Global emissions research has shown that the largest emissions are present in the Northern Hemisphere due to the large number of international routes, [5]. It is considered that in the coming years, the total amount of harmful substances in the international maritime transport in Europe's coastal areas could reach land-based emissions [6].

Many research papers deal with the estimation of emission inventories in the ports with the aim of increasing the control of exhaust gases and proposing adequate measures to regulate local costs and reduce emissions, [3, 7, 8, 18, and 19]. Methodologies of emission inventory assessment are mainly based on data on ship's activity and the type of fuel used. To obtain the necessary information, Automatic Identification System (AIS) [7] is used as well. It shows in detail the ship's position, speed, navigation time, engine load. The system was introduced by IMO [20] for the purposes of the maritime management and navigation safety, but it can be used and applied for the assessment of annual emissions for certain ports.

In recent years, Croatian ports Dubrovnik, Split, Šibenik and Zadar have become tourist cruise destinations. The increase in marine traffic has led to an increase in exhaust

Figure 1 The Port of Šibenik and St. Ante Channel [19]

emissions for the region. The port of Šibenik is situated in a closed bay, at the mouth of the Krka River, between the two national parks, i.e. in ecologically sensitive area.

2 Research field and the analysis of the port data

In this paper, the area of emission assessment covers the coast of Šibenik and the port with the infrastructure (Figure 1). The merchant and the passenger ships can access the port from open sea and through the sea of Murter, which is the continuation of the navigation ways from Middle and Pašman Channel. From the open sea, this area is accessible between the island of Žirje and the mainland. South of the Island of Zlarin there is an external pilot station in the position 43°38.6' N, 15°51.9' E, which deals with dangerous cargo ships and all the other ships that request a pilot in the case of adverse weather conditions. Ships sail into the port through the channel of St. Ante, which is accessible through Šibenik Channel and Zlarin Channel. The pilotage is compulsory for all the dangerous cargo ships and ships from 500 Gt and more that navigate through Šibenik Channel. It is accessible through a narrow passage between the islands of Zlarin and Drvenik. Pilot boarding/landing area is located at the internal boarding station situated 0.5 NM from the Drvenik lighthouse on the island of Drvenik. The position of the internal boarding station is 43°41'30" N, 15°52'18" E. The coastal pilotage is required for entering the Port of Šibenik, which is open for the international traffic from the position 43°38'42 " N, 15°52'18" E.

2.1 Reduced Speed Zone

Reduced speed zone covers the distance from the beginning of the pilotage to the port area. The pilotage extends from the island of Drvenik to the Port of Šibenik and is equal to 6.6 NM (12.2 km) (Figure 2). During the pilotage, the average ship's speed is reduced and the time of steaming to the Port increased, resulting in greater exhaust emissions. The estimated ship's speed in the reduced speed zone is 9-12 knots, i.e. 11 knots for the container vessels and 9 knots for all the other vessels [9]. The maximum permitted speed for all the vessels in St. Ante Channel is 10 knots.

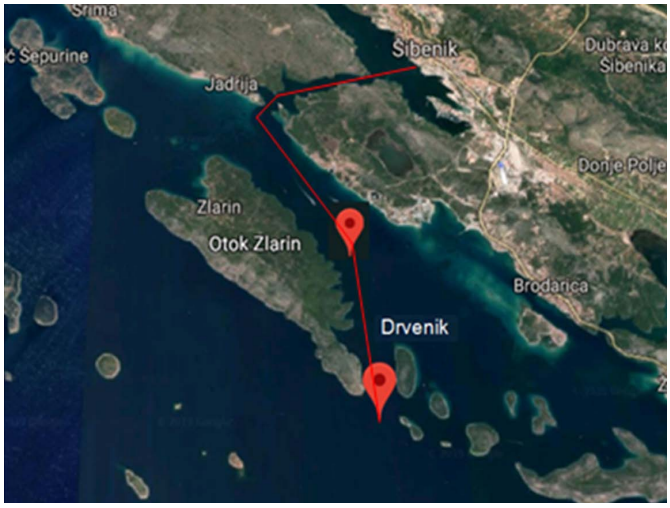

Figure 2 Reduced Speed Zone and pilot boarding stations – pilotage (Drvenik-Šibenik) [source: Authors]

2.2 Marine traffic in the Port of Šibenik

Port emission inventory covers the total international traffic of cargo and passenger ships throughout 2018. The emission assessment does not include vessels smaller than 500 GT, such as fishing vessels, yachts, catamarans and tourist local boats. Table 1 shows the overall marine traffic according to the data gathered by Šibenik Port Authority.

Table 1 Overall marine traffic in the Port of Šibenik in 2018 [20]

PORT OF ŠIBENIK		
Type of cargo / vessel	**Number of vessels**	**Number of arrivals**
General cargo	61	64
Bulk cargo/bulk carrier	5	5
Derivate/tankers	0	0
Refrigerated cargo	0	0
Containerized cargo	1	1
Passenger/cruise ships	16	86

3 Methodology

Two methods are used in estimating exhaust emissions from ships. The first one is a "top-down" method and is based on the estimation of the emissions according to the fuel sales data and the emission factor of the fuel. This method has proven unreliable due to the questionability of the data on fuel consumption. The second method for estimating emissions is a "bottom-up" method. It takes into account all the characteristics of a vessel (main and auxiliary engine installed capacity, load factor, emission factors) and movement time data (cruising, manoeuvring, hotelling), [10]. The latter has been used in this paper. The effects of waves, wind and sea currents, which can increase fuel consumption for 10-20 %, [11] have not been taken into account due to a short and undemanding travel. Due to very low traffic, emissions at container terminals have also been neglected, [12]. These include the emissions from cargo handling mobile units and all other stationary cargo handling equipment.

3.1 The equations for emission estimation

The total emission of the voyage is obtained as the sum of all the activities of the ship (cruising[1], manoeuvring and hotelling) that differently affect the emission of exhaust gases and the fuel consumption [13,14]. For the entire trip, the emissions can be calculated as:

$$E_{\mathrm{T}} = E_{\mathrm{C}} + E_{\mathrm{M}} + E_{\mathrm{H}} \tag{1}$$

For each movement of a ship in navigation, the emission is expressed as follows [8]:

$$E_{\mathrm{C}} = \frac{D}{v} \cdot \left[ME \cdot LF_{\mathrm{ME}} \cdot EF + AE \cdot LF_{\mathrm{AE}} \cdot EF\right] \tag{2}$$

The emission during manoeuvring and hotelling is expressed as follows [8]:

$$E_H = E_M = t \cdot \left[ME \cdot LF_{ME} \cdot EF + AE \cdot LF_{AE} \cdot EF\right] \tag{3}$$

where:

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

3.2 Types of fuel

Emission factors and exhaust emissions are highly dependent on the quality and type of fuel used. The sulphur and carbon content of the fuel affect the estimation of SO_x and CO_2 emissions and depend on the SECA navigation area. According to the Lloyd`s Register [20], the fuel carbon content for all marine distillate fuels is 86.5 %, while the sulphur content is regulated by EU Directive 2016/802 which requires the use of low sulphur fuel (0.1 %) for all the inland waters and EU ports. The assumption of the paper is that ships use low sulphur fuels and that no technologies to reduce SO_2 emissions are installed.

3.3 Engine particulars

Data on installed main and auxiliary engine power of all the vessels that entered the Port of Šibenik were obtained by searching through the available databases, [18] and [19]. The data collected have shown that all cargo ships are fitted with the diesel-mechanical propulsion (70 % being four-stroke engines and 30 % two-stroke engines), while cruise vessels are fitted with diesel-electric propulsion.

3.4 Engine load factor

The load factor as a percentage of the load in relation to the maximum continuous rating (MCR) of the main and auxiliary engines depends on the activity of the ship (cruising, manoeuvring, hotelling) and on the current speed of the ship. The assumed load factors for the main engine during cruising are 80 %, 20 % during manoeuvring, and 0 % during hotelling, i.e. the engines are not running [15]. The auxiliary engines load factor depends on the type of the vessel and its activity, and the auxiliary engines are considered to be running at all times [9]. For cruise ships, the load factor is much higher during manoeuvring due to the use of bow thrusters and the supply of other electricity consumers. The load factor for the auxiliary engines is displayed in Table 2.

[1] Cruising refers to reduced speed zone, i.e. pilotage

Table 2 The auxiliary engines load factor [9]

Type of vessel	Cruising	RSZ*	Manoeuvring	Hotelling
General cargo	0.17	0.27	0.45	0.22
Bulk cargo	0.17	0.27	0.45	0.22
Container	0.13	0.25	0.50	0.17
Cruise ships	0.8	0.8	0.8	0.8
Tankers	0.13	0.27	0.45	0.67
Refrigerated	0.20	0.34	0.67	0.34
RO-RO	0.15	0.30	0.45	0.30

* RSZ – Reduced speed zone

3.5 Emission factors

Data for the emission factors of the certain pollutants have been gathered from the Entec study [10] on estimating the emission inventory (Tables 3 and 4). The emission factors depend on the type of engine (main, auxiliary), fuel used, engine load and ship activities. In the calculation of the NOx emission factor, the year of production of the engine (before / after 2000) of the individual ship was considered, since the engines installed after 2000 must meet the requirements of the IMO Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines, [21]. As for auxiliary engines, the emission factor is the same for all ship operations.

Table 3 Main engine emission factors (g/kWh), at sea, manoeuvring and in port [10]

Type of engine/fuel	NO_x (before 2000)	NO_x (after 2000)	SO_2	CO_2	VOC	PM
At sea						
SSD/MGO	17.0	14.1	0.7	588	0.6	0.3
SSD/MDO	17.0	14.1	5.6	588	0.6	0.3
MSD/MGO	13.2	11.0	0.8	645	0.5	0.3
MSD/MDO	13.2	11.0	6.2	645	0.5	0.4
GT/MGO	5.7	4.7	1.2	922	0.1	0.0
GT/MDO	5.7	4.7	8.7	922	0.1	0.0
Manoeuvring / In port						
SSD/MGO	13.6	11.3	0.8	647	1.8	0.9
SSD/MDO	13.6	11.3	6.2	647	1.8	1.2
MSD/MGO	10.6	8.8	0.9	710	1.5	0.9
MSD/MDO	10.6	8.8	6.8	710	1.5	1.2
GT/MGO	2.9	2.4	1.3	1014	0.5	0.5
GT/MDO	2.9	2.4	9.6	1014	0.5	0.7

SSD – slow speed diesel engine, MSD – medium speed diesel engine, GT – gas turbine, MGO – marine gasoil, MDO – marine diesel oil

Table 4 Auxiliary engines emission factors (g/kWh) at sea, manoeuvring and in port [10]

Type of engine/fuel	NO_x (before 2000)	NO_x (after 2000)	SO_2	CO_2	VOC	PM
M/H SD/MGO	17.0	14.1	0.7	588	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

M/H SD – medium/high speed diesel engine, RO – residual oil

3.6 Duration of the activities

The estimated cruising time (in hours) refers to the time from the beginning of the pilotage to the port entry, or to the breakwater. Time is calculated according to the ratio of the trip's length (in kilometres) and the ship's arithmetic average speed in the reduced speed zone (km/h). The calculation of cargo vessels speed was 9 knots (16.67 km/h) and 11 knots (20.37km/h) for cruise ships. For cruise vessels, the steaming time to the port is 0.6 h, and 0.7 h for the cargo vessels. The cruising times on the arrival and departure are taken together into account. The average manoeuvring time is 1 hour for all the vessels and ports, [15], but it varies depending on the port and the vessel dimensions. Thus, the manoeuvring time for general cargo vessels and bulk carriers totals 1 hour, and 0.8 hour for cruise ships. The manoeuvring time includes overall time of ship's arrival and departure. Hotelling denotes the time a vessel spends in port, at berth. Based on the information received from the Šibenik Port Authority, it was possible to determine the total hotelling time for each ship upon arrival and departure throughout the year.

4 Results

The total annual emission for cargo ships is 17.34 tons for NO_X, 1.25 tons for SO_X, 0.64 tons for VOC and 0.56 tons for PM (Figure 3). Emission information in Figure 3 have been displayed according to the type of the pollutant and the ship's activity. Of all the ship's activities, the greatest share of emissions comes from the hotelling. The emission of the cargo vessels in port is a result of the auxiliary engines operations.

The emission from the cruise ships (Figure 4) is higher than the one from the cargo vessels due to the higher power of auxiliary engines and the slightly higher number of the ships' arrivals. The annual emission represents the sum of the results obtained and totals: 38.48 tons for NO_X, 3.02 tons for SO_X, 2.07 tons VOC and, 1.37 tons for PM. CO_2 emission from cargo vessels and cruise ships have been displayed in parallel (Figure 5).

The annual CO_2 emission totals 968.59 tons for cargo vessels and 2,394.95 tons for cruise ships, i.e. 3,363.54 tons per year. CO_2 emission from cargo vessels was 756.02 tons during hotelling, 166.4 tons during cruising and 46.18 tons during manoeuvring. As for cruise ships, it was 1,236.23 tons during hotelling, 493.59 tons during manoeuvring and 665.14 tons during cruising.

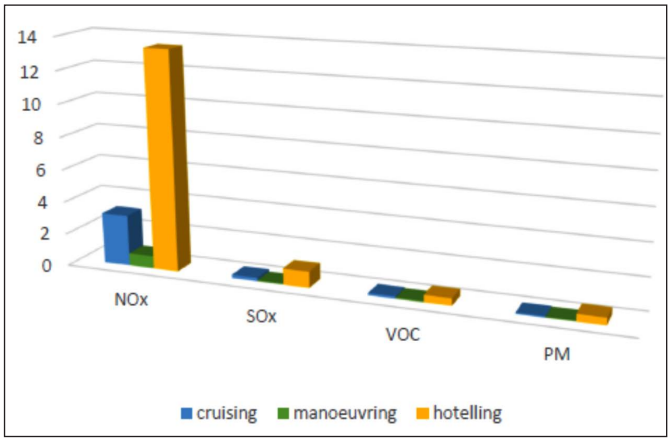

Figure 3 Cargo vessels emission (tons/year)

Source: Authors

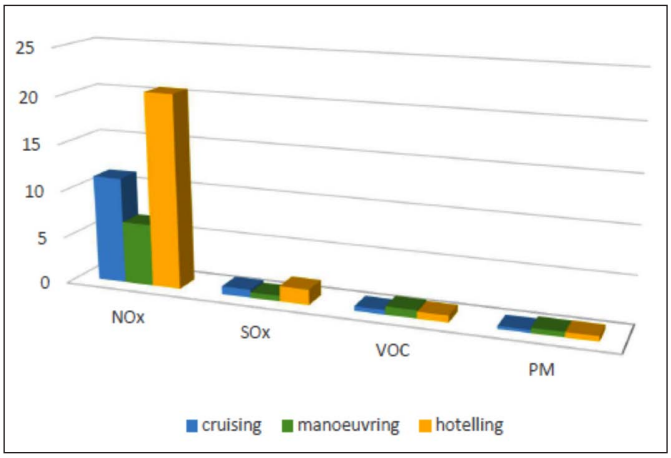

Figure 4 Cruise ships emission (tons/year)

Source: Authors

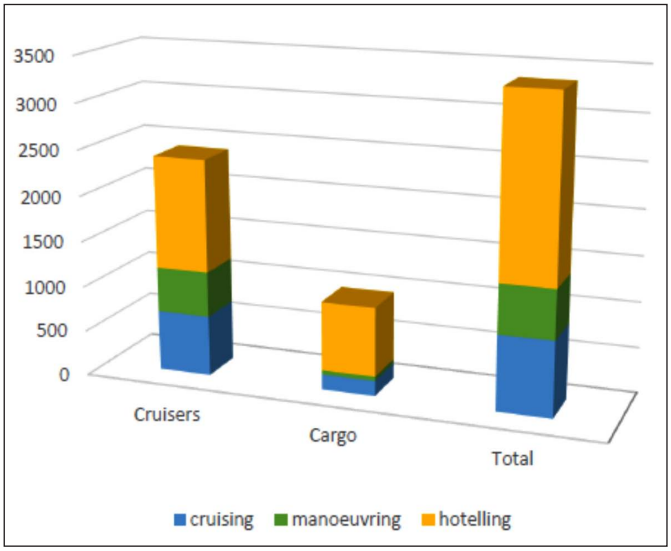

Figure 5 Total CO_2 emission (tons/year)

Source: Authors

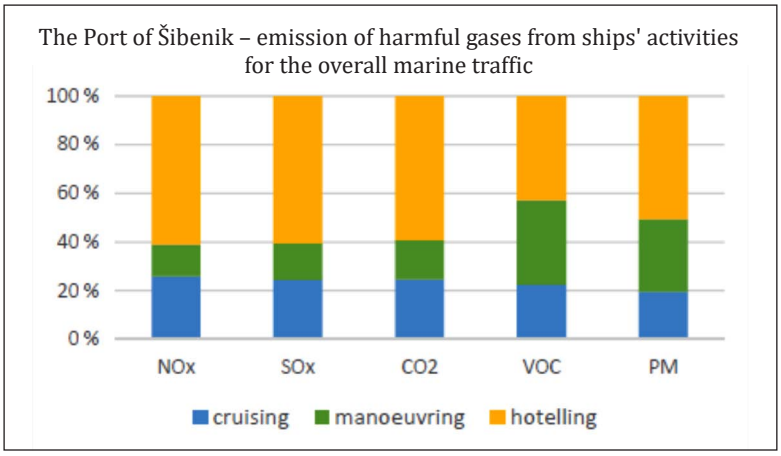

Figure 6 Ships' emission for specific activities

Source: Authors

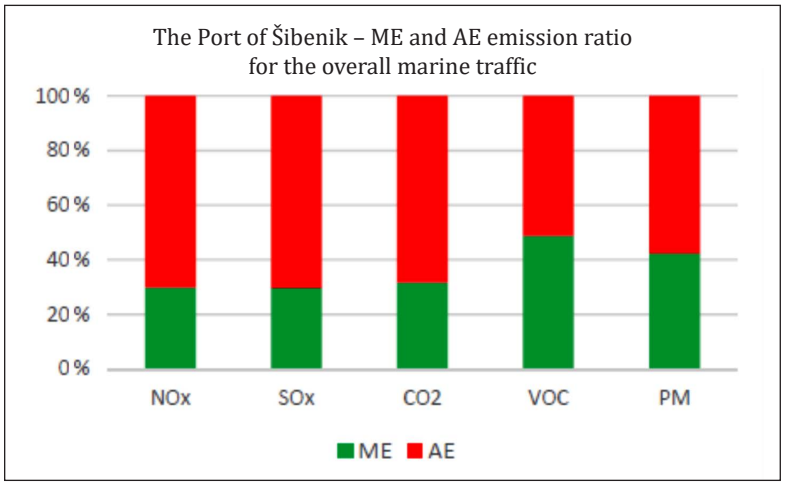

Figure 7 Main (ME) and auxiliary engines (AE) emission ratio

Source: Authors

5 Discussion

Figure 6 shows the proportion of emission from ships for each activity. Some 45 – 60 % refer to the emission during hotelling, 15 – 30 % to the emission during manoeuvring, and 10 – 25 % to the emission during pilotage. The results have shown that most of the emission comes from ships during hotelling, whereas, minor part comes from manoeuvring and pilotage due to the shorter period of these operations. The ratio of main and auxiliary engines emissions is displayed in Figure 7. The auxiliary engines serve as providers of electricity and emit mostly during hotelling, but also in manoeuvring because of the greater load factor. It can also be observed that the auxiliary engines emission ratio is higher for all pollutants than the one of the main engines, except for the VOCs where they are approximately equal.

6 Conclusion

This research has estimated the emission inventory of marine traffic in the port of Šibenik. In 2018, the overall traffic included 86 cruise ships arrivals and 70 cargo vessels arrivals. The "bottom-up" method for emissions assessment takes into account all the characteristics of a vessel: main and auxiliary engine power, types of fuel, load factor, period of cruising and hotelling. The analysis of the harmful gasses annual emission has resulted in the following findings, expressed in tons: 55.82 tons for NO_x, 4.27 tons for SO_x, 3,363.54 tons for CO_2, 2.71 tons for VOC and 1.93 tons for PM. The results (tons/year) have shown that approximately 70 % (2,439.89 tons/year), of the total annual emission in the Port comes from passenger ships and 30 % (988.38 tons/year) from cargo ships. The exhaust gases are mainly emitted during hotelling when they use their aux-

iliary engines. One of the measures for reducing harmful gases emission is the so-called "cold ironing" [16,17], which provides shore side electrical power supply to the vessels at ports, while the main and auxiliary engines are switched off.

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