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The Port of Split international marine traffic emissions inventory

Ladislav Stazić[1], Radoslav Radonja[2], Vladimir Pelić[2], Branko Lalić[1]

[1] University of Split, Faculty of Maritime Studies, Ruđera Boškovića 37, Split, Croatia, email: lstazic@pfst.hr; blalic@pfst.hr
[2] University of Rijeka, Faculty of Maritime Studies, Studentska ulica 2, Rijeka, Croatia, email: radonja@pfri.hr; vpelic@pfri.hr

ABSTRACT

The Port of Split is one of the busiest marine traffic regions in the Adriatic Sea and the third largest passenger port in the Mediterranean. A significant number of the ships is going in and out of the Port, creating a major impact to the environment in the area. That impact is created mostly by emissions from ships, which can be divided into greenhouse gases (*predominantly Carbon dioxide* – CO_2) and the pollutants (Nitrogen oxides – NO_x, Sulphur oxides – SO_x, Particulate matter – PM and Volatile organic compounds – VOC). This paper is presenting emission inventory of international marine traffic in the Port of Split for the year 2017, which amounts to 19065.8 tons of CO_2, 12 tons of SO_x, 11.7 tons of PM, 14.6 tons of VOC and 338.7 tons of NO_x. Emissions are presented in groups according to type of ships, thus enabling comparison of emissions coming from cargo and passenger traffic. Cruise ships activity in the Port of Split during 2018 is added to the paper to highlight the increase of the traffic and consequently emissions.

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1 Introduction

Very large part of global trade is going over the sea (*about 80 % of the world's goods by volume* [1]), making shipping industry one of vital links in global economy. Although maritime transport is more environmental friendly than other transport modes [2], ship exhaust emissions represent significant source of the overall sources of emissions. Emissions, by definition, are the gases and particles released into the air by various sources. Emissions can be divided into greenhouse gases and the pollutants.

Greenhouse gasses are all gasses that trap heat in the Earth atmosphere. Although there are certain scientists who argue that global warming is a natural process and that greenhouse gases were present at all times, in recent history the amount of greenhouse gases in the atmosphere has increased significantly. The primary greenhouse gas in the atmosphere (Figure 1) is CO_2 – Carbon dioxide [3]. Although CO_2 is produced naturally by decay and fermentation, majority of produced CO_2 today comes from burning of the fossil fuels. Shipping industry contribution to the greenhouse gasses emissions is less than 3 % [4], besides the fact that large part of global trade is going over the sea and that majority of all ships are using fossil fuels.

Air pollution from shipping industry is regulated by IMO regulations (Annex VI of the Marine Pollution Convention (MARPOL) [5]), additional input is given by European Parliament in the Directive (EU) 2016/802 [6]. Ports are points where emissions from shipping industry are concentrated in one place and where impact of ship exhaust pollutants (Nitrogen oxides – NOx, Sulphur oxides – SOx, Particulate matter – PM, Volatile organic compounds – VOC) can cause various consequences. ''*Proper estimation and allocation of shipping emissions is crucial for understanding the impact of shipping on air quality and health in harbor cities and coastal regions*'' [7]. The emission inventory, i.e. a process of quantification of all emissions within a specified area (in this case, the Port of Split) is an initial action which has to be taken to evaluate potential impact and to plan and establish adequate emission control or port environmental management system.

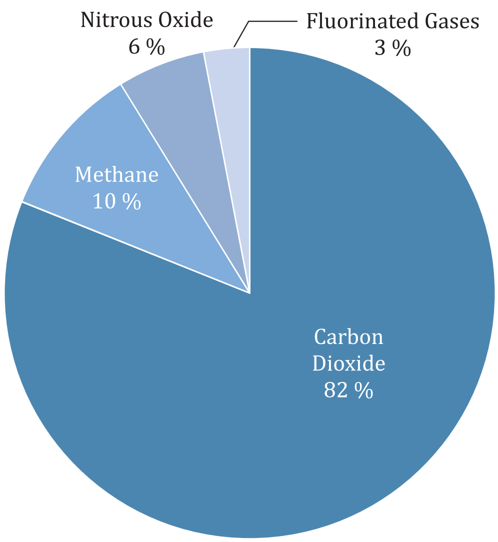

Figure 1 Greenhouse gasses emissions in 2017

Source: [6]

Proper calculation or estimation of emissions generated from marine traffic in the Port of Split, according to our knowledge, does not exist. The current paper represents a contribution in addressing the issue, at least partially creating an inventory of emissions generated by international marine traffic.

The Port of Split consists of several geographically separated units or basins: Gradska luka basin, Vranjic-Solin basin, Kaštela A basin, Kaštela B basin, Kaštela C basin and Kaštela D basin [9].

2 Emissions estimation methodology

Frequently used approach is using ship engines' power [10], recommended by the EMEP/EEA (2009) air pollutant emission inventory guidebook [11]. This method is usually called a full bottom up model, because "*emission evaluation is bottom up, and the geographical characterization of emissions is bottom-up*" [12]. In this model air pollutants emitted by a ship are estimated for every visit in the Port of Split, aggregating estimates for whole list of ships and their visits during the 2017. There are different views on emission inventory. All guidelines consider emissions of concern to be nitrogen oxides (NO_x), sulfur oxides (SO_x) and particulate matter (PM) [10], [13], [14], while on VOC pollution there are different views. Some researchers include unburned VOC into air emissions and some do not, at the same time most of them exclude evaporative losses from fuel and cargos [14]. This inventory will include unburned VOC for some future checks, despite the fact that it is not regulated by present regulation [5].

Bottom up model needs comprehensive data to be collected [10], [14] in order to estimate the amount of emissions. The data is:

- Ship movement data (distance travelled and duration of movement),
- Data of all ships in analyzed area, with details about the ship such as type of ship, propulsion type, type of fuel, installed propulsion engines power and auxiliary engine power,
- Duration of the ship's stay in port and activities during the stay (hoteling and loading/unloading).

Estimation of total emission for any particular area must include various activities which have different impact on fuel consumption, and consequently on the quantity of the emissions. According to [10] the emission (E) of a ship during the trip is:

$$E_{\text{trip}} = E_{\text{at sea}} + E_{\text{maneuvering}} + E_{\text{hotelling}} \quad (1)$$

Each addend must be calculated separately, for parts which are applicable for this calculation:

$$E_{\text{at sea}} = \frac{D}{v} \cdot [(ME \cdot LF_{\text{ME}} \cdot EF) + (AE \cdot LF_{\text{AE}} \cdot EF)] \quad (2)$$

$$E_{\text{maneuvering}} = \frac{D}{v} \cdot [(ME \cdot LF_{\text{ME}} \cdot EF) + (AE \cdot LF_{\text{AE}} \cdot EF)] \quad (3)$$

$$E_{\text{hotelling}} = T \cdot [AE \cdot LF_{\text{AE}} \cdot EF] \quad (4)$$

where:

D – Distance travelled (NM),

v – Average ship speed (knots),

ME – Main engine power (kW),

LF_{ME} – Main engine load factor (%),

AE – Auxiliary engine power (kW),

LF_{AE} – Auxiliary engines load factor (%),

EF – Emission factor, depending on the type of fuel and the engine speed (g/kWh),

T – Average time at berth or maneuvering per calling (h).

Weather conditions can have huge impact on the emissions, "*the estimated increase of hourly fuel consumption can be as high as 10–20 %*" [6]. As pilotage and maneuvering is not performed in bad weather, and distances travelled are short and in quite weather protected areas, this impact [15] has not been taken into consideration.

As different fuel has different content of various ingredients, the exhaust gases emissions directly depend on the type of the fuel. On site investigation in the Port of Split showed that most of vessels use low Sulphur fuels (not exceeding exceed 0.1 % by mass), the fuel recommended by EU Directive 2016/802 [6]. The emissions of CO_2 are dependent on the carbon content in the fuel, which is normally around 87 % [17]. Low Sulphur marine diesel fuel (with less than 0.1 % of Sulphur) has the emissions according to the Table 1.

Table 1 Low Sulphur fuel (less than 0,1 %) marine diesel engine emission

	EF CO_2 (g/kWh)	EF SO_x (g/kWh)	EF PM (g/kWh)	EF VOC (g/kWh)
Slow speed engine	588	0.37	0.4	0.6
Medium speed engine	652	0.41	0.4	0.5

Source: [13], [14], [17]

2.1 Ship movement data

Ship movement data (*maneuvering*) in the Port of Split vary according to distance between pilot boarding point and docking point. Easiest way to determine where the maneuvering starts is to determine the pilot boarding point. The basic requirement for Split pilot is that *''the pilot will normally meet ship 0.5 miles off the City Port Entrance''* [8]. That point is taken as starting point for the maneuvering and as starting (ending) point of emissions inventory for the Port of Split. Maneuvering distances from pilot entrance point are given in Table 2.

Table 2. Average maneuvering distances in Port of Split

Berthing point	Maneuvering distance
Gradska luka basin	0.5 NM
Vranjic-Solin basin	6.93 NM
Kaštela A basin	5.05 NM
Kaštela B basin	5.67 NM
Kaštela C basin	6.52 NM
Kaštela D basin	6.11 NM

Source: Authors

Maneuvering speed is influenced by International Regulations for Preventing Collisions at Sea stating: ''*Every ship shall at all times proceed at a safe speed so that she can take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions''* [18].

Maximum maneuvering speed for the Port of Split is around 6-8 knots [6]. Ships are usually travelling with higher speed, decreasing on arrival to berth [13]. For each ship time in port is known, therefore, hoteling/loading/unloading emission period can be expressed with great precision. Mooring/unmooring period and periods of approach/departure to berths are approximated with the time of 15 minutes each, that time is added to total time in port for calculation of auxiliary engines emission.

2.2 Marine traffic during 2017 in Port of Split

In order to calculate the emission of the marine traffic in the Port of Split it is necessary to obtain the list of all ships and their particulars, as well as the data about time in port during each visit. To avoid numerous small vessels, such as fishing boats, yachts, etc., a limit of the minimal size of the ship is set to 500 GT for this inventory. As smaller ships are not included into the list, all listings for Kaštela basins A and D are eliminated. Table 3 presents marine traffic in the port of Split, categorized according the basin and the type of ship, according to the data provided by Port of Split Authority [9].

Table 3 Marine traffic in Port of Split during 2017

Ship type	Number of vessels
Cruise	232
Bulk Carrier	330
Tanker	115
Container	40
General/other	57
Total	**774**

Source: Authors

2.3 Ship data and engine load factor

Ship data has been collected from several sources in regard to type of ship, propulsion type, type of fuel, installed propulsion engines power and auxiliary engine power. For some ships auxiliary engine power data was not available and in those cases an estimate has been carried out based on data from the Table 4.

Table 4 Auxiliary to Propulsion Ratio for various types of ships

Type of ship	Auxiliary to Propulsion Ratio
Bulk Carrier	0.222
Container	0.220
Cruise	0.278
General Cargo	0.191
Tanker	0.211

Source: [10], [13]

Main engine load factor is a value that vary during maneuvering and sailing in reduced speed areas. For the purpose of calculation of emissions during maneuvering propulsion engines load factor is calculated according to the following Equation [13]:

Table 5 Auxiliary engine load factor

Ship-Type	Cruising	Reduced Speed Zone	Maneuvering	Hotelling
Bulk Carrier	0.17	0.27	0.45	0.22
Container	0.13	0.25	0.50	0.17
Cruise	0.80	0.80	0.80	0.64
General Cargo	0.17	0.27	0.45	0.22
Tanker	0.13	0.27	0.45	0.67

Source: [13]

$$LF_{\mathrm{ME}} = \left(\frac{AS}{MS}\right) \quad (5)$$

where:

LF_{ME} – main engine load factor,

AS – actual speed (knots),

MS – maximum speed (knots).

Auxiliary engine load for each vessel arriving to the port is calculated using the data from the Table 5.

2.4 Emission factors

Legislation controlling the emissions from marine industry was adopted in 1997 by the Marine Environmental Protection Committee (MEPC) of the International Maritime Organization (IMO) [3]. Emissions were addressed in Annex VI of the Marine Pollution Convention (MARPOL).

All ships manufactured in period from 2000 to 2011 must meet requirements TIER I (Figure 2). The revised Annex VI expanded the Tier I rules on most of the engines built between 1990 to 2000 (*for power output of more than 5000* kW). Ships built from 2011 to 2016 must fulfil the Tier II standard, ships built after 2016 must suit the Tier III standard when operating in NO_x emission control areas.

Table 6 presents data of applicability of NO_x requirements on vessels arriving in Port of Split during 2017.

Table 6 Number of ships in port of Split in 2017. as per NO_x regulation requirement

Tier requirement	Number	Percentage (%)
No Tier requirement	386	49.87
Tier 1 requirement	352	45.48
Tier 2 requirement	36	4.65
Total	**774**	**100**

Source: Authors

3 Calculation of emissions and results

The calculation is performed according to Equations 2, 3 and 4, using average maneuvering speed of 8 knots, while the maneuvering distance (*d*) is changed according to data given in Table 2.

Comparison of sources is visible in Figure 3, majority of international marine traffic air emissions (89.54 %) is generated from cruise ships although they represent less than 30 % of arrivals.

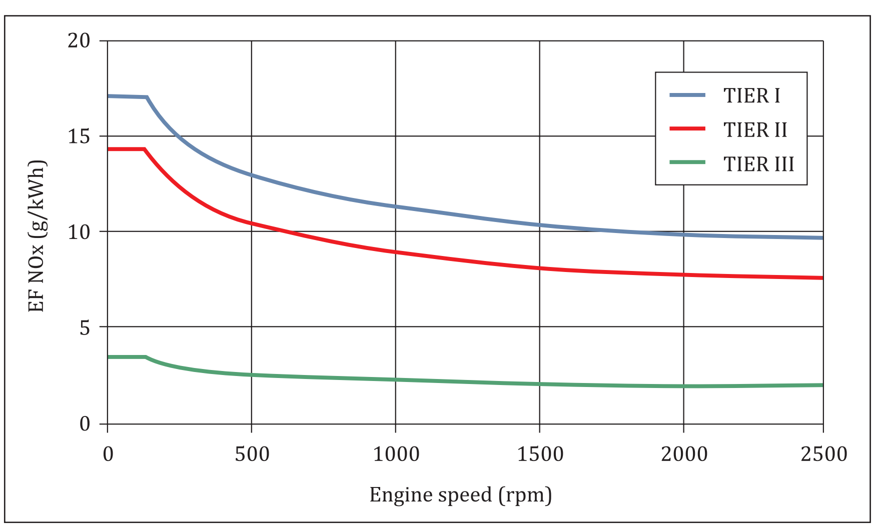

Figure 2 The maximum emission factors for NOx (g/kWh) for marine diesel engines

Source: [17]

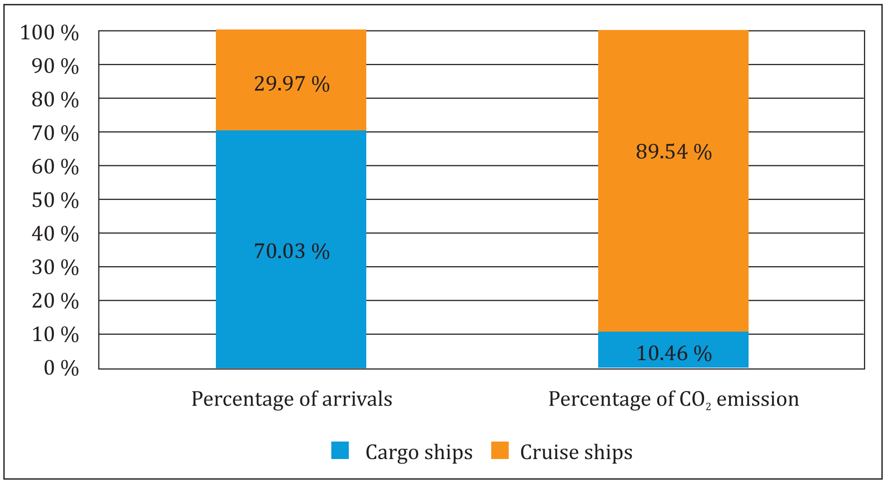

Figure 3 Comparison of sources of emission

Source: Authors

4 Discussion

As shown in Table 3, Port of Split had 774 international arrivals during 2017. According to the Table 7, those ships emitted 19,065.8 tons of CO_2, 12 tons of SO_X, 11.7 tons of PM, 14.6 tons of VOC and 338.7 tons of NO_X. Distribution of the emission can be monitored through CO_2 emission ratio (Figure 4), which represents well enough ratios of all other emissions (Table 7). Figures 3 and 4 and Table 8 display the fact that cruise ships are the major source of air emissions in Port of Split, creating almost 90 % of all air emissions in the Port. Percentage of the emission is not proportional to the percentage of arrivals; cruise ships participate in the traffic with less than 30 % (Figure 3).

Table 7 Marine emissions sorted according to type of ships

Ship type	Emission (kg)				
	CO_2	SO_X	PM	VOC	NO_x
Bulk	1,137,964	715	698	874	22,279
Container	92,529	58	57	72	1712
General cargo	313,111	196	192	240	5,361
Tanker	450,364	283	276	345	7,786
Cruise ships	17,071,868	10,735	10,473	13,092	301,514
Total*	**19,065,838**	**11,989**	**11,697**	**14,625**	**338,653**

Note: * Total calculated emissions in kilograms from ships in period of the one year

Source: Authors

Table 8 Emissions sorted according to the activity

	Emissions during maneuvering (t)					Emissions in port (t)				
	CO_2	SO_2	PM	VOC	NO_x	CO_2	SO_2	PM	VOC	NO_x
Gradska luka*	1,027.41	0.65	0.63	0.79	18.07	16,044.46	10.09	9.84	12.3	283.45
Kaštela B	59.31	0.04	0.04	0.05	1.21	510.44	0.32	0.31	0.39	9.74
Kaštela C	54.34	0.03	0.03	0.04	0.95	576.77	0.36	0.35	0.44	9.88
Vranjic-Solin	92.52	0.06	0.06	0.07	1.82	700.59	0.44	0.43	0.54	13.6
Total **	**1,233.58**	**0.78**	**0.76**	**0.95**	**22.05**	**17,832.26**	**11.21**	**10.93**	**13.67**	**316.67**

Notes: * "Gradska luka" is a port for cruise ships. "Kaštela B and C" and "Vranjic-Solin" are ports for cargo ships. ** Total calculated emissions in kilograms from ships in period of the one year

Source: Authors

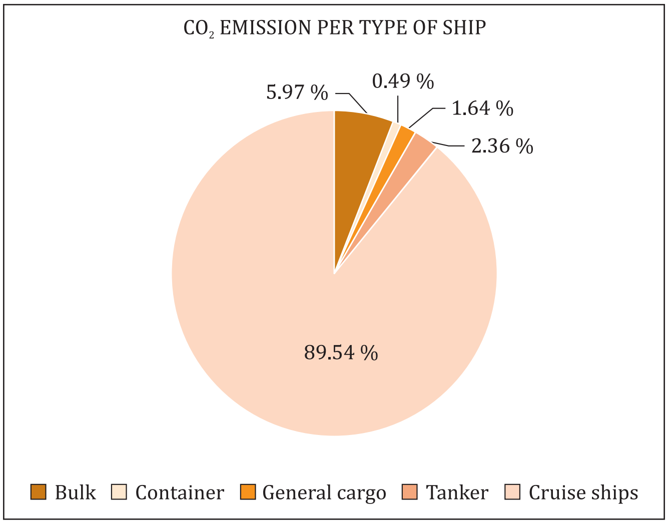

Figure 4 CO_2 emission distribution according the type of ship

Source: Authors

There are several reasons for such results, first reason is indicated in Figure 5. The average main engine power on the cruise ship is 4-12 times larger than on the average cargo ship in basins, thus creating more emissions.

Second reason is given in Table 8. Despite the fact that cruise ships time in port is much shorter than time in port of cargo ships Figure 6, hoteling emissions of cruise ships create 94 % of their emissions.

5 Cruise traffic in 2018

Figures 7 and 8 depict cruise ships dockings and average engine power during 2017 and 2018.

There is an increase of arrivals by 7.7 %, while the size of average engine increased by 32.5 %. Although inventory of emissions for 2018 is in progress, according to these two indicators there will be significant increase of air emissions in 2018, considering that average time in port is almost the same.

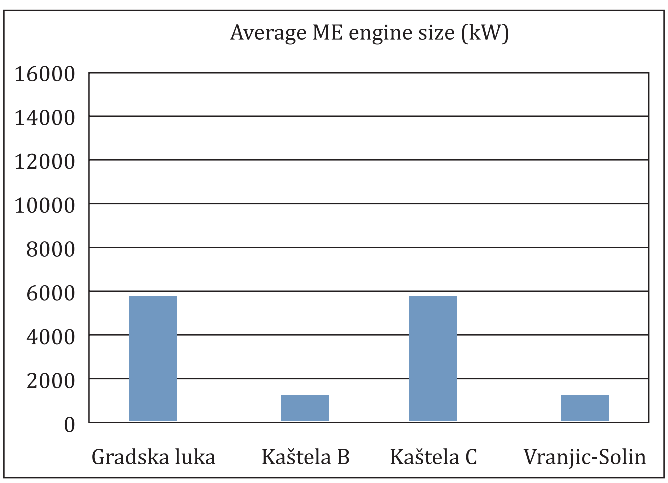

Figure 5 Average ME power

Source: Authors

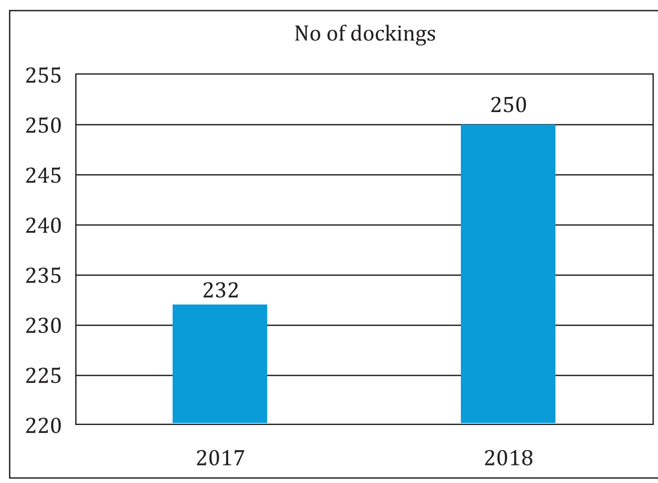

Figure 7 Number of dockings

Source: Authors

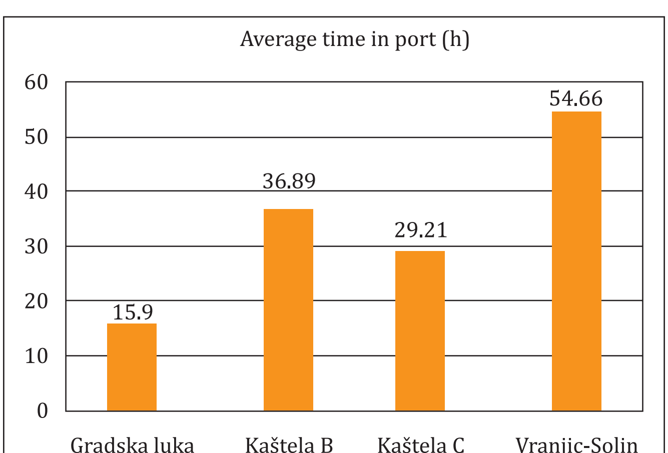

Figure 6 Average time in port

Source: Authors

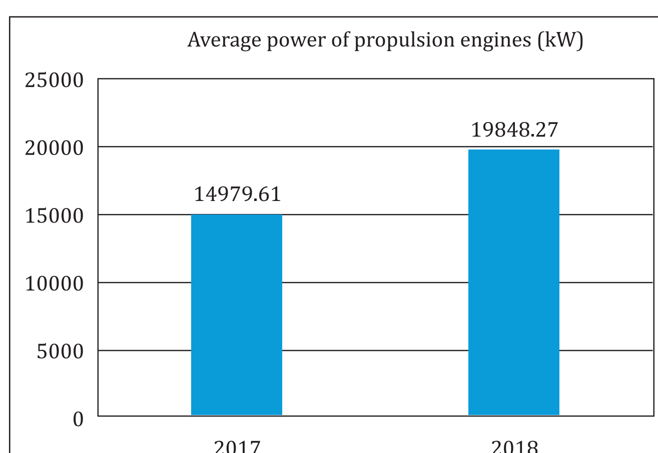

Figure 8 Average ME power

Source: Authors

6 Conclusion

International marine traffic in the Port of Split in 2017 recorded 774 arrivals of cargo and cruise ships. The methodology chosen for the inventory was full bottom up model, a methodology requiring collection of the data about ships characteristics (type of engine, main and aux power, max speed, type of fuel, the load factor) as well as data about activities in the Port (time in port). The analysis of collected data produced figures of air emissions for each basin, and finally the figure for the whole Port of Split.

Total emission in Port of Split amounts to 19,065,8 tons of CO_2, 12 tons of SO_X, 11.7 tons of PM, 14.6 tons of VOC and 338.7 tons of NO_X. Cargo ships released almost 1994 tons of CO_2, 1.3 tons of SO_X, 1.2 tons of PM, 1.5 tons of VOC and over 37 tons of NO_X. That emission is just about 10.5 % of total emission of international marine traffic in the Port of Split, majority (about 89.5 %) of emissions is coming from cruise ships. The size of average cruise ship engine coming in the Port of Split is almost 7 times larger than cargo ship engine, and those ships are working with significant load during hoteling time (in port). Although cruise ships stay in port on average 15.9 hours (cargo ships 40 hours), 94 % of their emission is coming from hoteling. Total emission from cruise ships is 17,071.9 tons of CO_2, 10.7 tons of SO_X, 10.5 tons of PM, 13.1 tons of VOC and over 301.5 tons of NO_X.

Prognosis of future air emissions in the Port of Split cannot be formulated without longer period of monitoring activity of ships and their emissions. Initial research and incomplete emission inventory for cruise vessels during 2018 shows increase of the traffic activity in the Port and consequently increase of the air emission.

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