Emission Inventory of Ships Calling at the Port of Dubrovnik

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ABSTRACT: Cruising tourism is becoming increasingly popular, the number of cruises having seen a continuous increase since the 1970s. In Croatia as well there is an upward trend in the number of cruise passengers and ports. Of all Croatian ports, it is the port of Dubrovnik that has had the most calls by foreign cruisers. The paper analyses the available statistical data on the maritime cruise market in Europe with special reference to the Mediterranean countries. In the national context, a presentation of cruise traffic in the port of Dubrovnik is given. Although this type of tourism contributes to the development and improvement of the economy, it also has a negative impact on the environment through air pollution by CO_2 emissions, subsequently affecting human health as well. The authors investigate the level of CO_2 emissions in the area of the port of Dubrovnik. CO_2 emissions were calculated based on cruiser activity, the calculations being based on CO_2 emissions for three ship navigation modes - slow steaming on arrival and departure, manoeuvring on arrival and departure, and for a berthed ship. The aim of the research was to provide a better insight in the emission inventories in this area. This research can also be applied to other port areas.

1 INTRODUCTION

Compared to other forms of tourism, cruising tourism is a relatively recent phenomenon. The first cruiser, the Oceanic, built exclusively for cruises in North America, was delivered to the Home Lines company in 1965 and this act is considered the beginning of modern cruising. Since 1966, the Norwegian Caribbean Line has been offering a year round cruise itineraries on the Sunward, the first company in the world to provide this type of offer. Thus, the 1960s mark the true beginning of cruising with the first cruises to the Caribbean for US and Canadian passengers. From the 1970s on, there has been a continuous growth of cruises, this trend spreading in the 1990s first to Europe, primarily the United Kingdom, and then to the Asia-Pacific region. Cruise ships today offer a world of innovative facilities and services that aim to satisfy the expectations of a growing population of travellers [1].

Rich social and natural tourist resources are highly valued and recognized by for the cruising industry [2]. Owing to its natural environment, rich history and many cultural and historical monuments, Dubrovnik has reached the very top of the world's tourist destinations. The beginnings of cruising tourism in Dubrovnik date back to the 1980s, and today the port of Dubrovnik occupies an important position regarding the reception of cruise ships.

Sea cruises have a strong impact on the life and development of crushing destinations and affect the social sphere, the economy, and above all the environment [3]. The article deals with the issue of cruising tourism in Dubrovnik related to CO_2 pollution. CO_2 emissions are calculated according to

the activities of cruisers that docked in the port of Dubrovnik in 2019.

2 CRUISE TOURISM MARKET

Cruising tourism market in Europe is constantly growing. The cruise sector should generate more than $ 133 billion in the world. Europe will account for 38.7% of this value [4]. In 2018, European ocean cruise passenger numbers grew by 3.3 per cent against 2017, to 7.17million; following a two per cent growth the prior year [5]. It should be noted that the number of cruise ports in the Mediterranean has doubled in the last ten years. Many of these ports are regarded as "must see" destinations. The Mediterranean is a very valuable area for tourists, attracting hundreds of thousands of visitors from all over the world, i.e. the USA, Japan, China, Germany, France and the Great Britain and the others [6].

Being part of the Mediterranean region and boasting a coastline of 6,278 km, Croatia has also found its place in the cruise market. Its exceptional natural and cultural resources, numerous tourist attractions, nature parks and other protected parts of nature, as well as monuments and a large cultural offer, provide an excellent basis for the development of cruising tourism. It is not surprising, therefore, that the number of cruise calls and passengers in Croatia is increasingly on the rise. About twenty of its ports are included in international cruising, ranging in traffic intensity from the largest of international importance (Dubrovnik, Split, Zadar, Rijeka), through those of domestic importance (Pula, Korčula, Mali Lošinj), to small, local ports such as those on Lopud, Mljet, Šipan and the like.

In 2018, 693 cruises of foreign ships were realized, with 1,033,885 cruise passengers who stayed in Croatia for a total of 1,421 days. Compared to the previous year, the number of foreign cruise ships calling at Croatian seaports in 2018 decreased by 8.5%, the total number of days they stayed in ports decreased by 5,6%, but the number of passengers increased by 9.1% [7]. The leading position in cruise calls is held by the County of Dubrovnik-Neretva, which together with the County of Split-Dalmatia accounts for 80.8% of cruise calls, the remaining 19.2% of cruises having been achieved in other counties. An overview of realized cruises by counties is given in Figure 1.
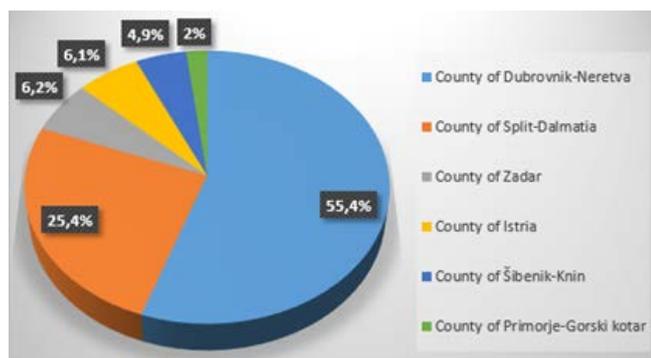

Figure 1. An overview of realized cruises by counties, 2018.

3 THE IMPACTS OF CRUISINF TOURISM ON THE ENVIRONMENT

The economic effects of cruises for the local and regional economy are significant, especially when a port is the place of embarkation/disembarkation of passengers. Cruising tourism is the driver of development of many economic activities and is a source of income for both the private and the public sectors. However, cruising tourism also brings with it certain forms of pollution.

Waste discharge; air pollution; bio-security risks; accidents anchor damage; wildlife and water turbidity have all been identified as adverse environmental impacts [8]. Furthermore, it should be noted that the average daily pollution from a cruiser comprises, respectively, 40 litres of faeces, 360 litres of wastewater and 2.3 kg of solid waste per passenger per day, as well as 60 litres of toxic waste (Photoshop waste, fluorescent lamps, batteries), 2,800 litres of bilge water per day, and 1,000 tons of ballast water changed before entering the port and the exhaust emissions equivalent to 12,240 cars [9].

Ships are responsible for roughly 3% of global CO_2 and GHG emissions (CO_2-eq), emitting approximately 1 billion tonnes of CO_2 and GHGs per year [10]. Air pollution by a ship varies depending on whether the ship is sailing on the high seas, manoeuvring or is at a berth in a port. Studies show that in cities like Vancouver air pollution coming from a ship contributes to the city's greenhouse effect with 58% and participates in sulphur gas emissions with about 95%. Thus, a larger ship arriving in port can emit in one day as many sulphur oxides (SOx) as 2,000 cars and trucks in one year [11].

Air pollution by nitrogen, sulphur and carbon oxides, and suspended particles can have: [12]
- local impact - contribution to smog generation (30% of global smog comes from ships),
- regional effect - contribution to the creation of acid rain that destroys the plant world, changes the pH of stagnant waters and destroys facades and sculptures of limestone origin,
- global impact - greenhouse gases that cause climate change (primarily carbon dioxide),
- direct impact on human health - increasing the risk of lung cancer and asthma.

Additional air pollution refers to pollution from ship incinerators in which larger cruisers burn most of the mixed waste, resulting in dioxin and thiophene emissions [13]. In addition to the direct pollution that comes from the cruiser itself, there is also indirect pollution from the cruiser that is at berth related to the flow of passengers and goods. Buses, trucks, cars and other modes of transport use the terminal to ensure the best possible mobility of tourists and the supply of the ship, which also results in increased CO_2 emissions. When fossil fuels are combusted, the carbon stored in them is almost entirely emitted as CO_2 [14].

Air pollution by CO_2 emissions caused by cruisers by their navigation regime is shown below on the example of the port of Gruž in Dubrovnik.

4 EMISSION ESTIMATION FOR THE PORT OF GRUŽ - DUBROVNIK

The emission estimation area has been divided in a three separate emission category: slow steaming on arrival and departure, maneuvering on arrival and departure, and for berthed ship. For mentioned categories ship's emissions were calculated on the ship activity-based method. Reduce speed zone is defined as the distance from the beginning of the end of sea passage (EOP) point to the commencement of the maneuvering regime in the port during the arrival and also on their departure from the end of the maneuvering regime to full away on passage (FAOP). Mentioned zone including the pilotage area. For port of Gruž mentioned distance is approximately 4 M. The estimated maximum safe speed in the reduced speed zone is 6 knots for cruise ships calling port of Gruž in Dubrovnik. In this zone the average speed of a ship is reduced, but its steaming time to a port is increased, and that will cause higher emissions.

The ship's machinery plant on cruise ships is a complex system because it must ensure the ship's propulsion and provides electrical power to maintain all ship's systems in the operation status. The newer generation of cruiser ships is equipped by diesel electric plant and gas electric plants. On these ships, engines are not connected to propeller shafts, and instead of it they are directly connected to generators in order to produce electricity for ship's propulsion system and other consumer on board ship. The older generations of cruiser ships have most common machinery plant which is configured of one or two main engines (rarely more) and two or more auxiliary engines with a connected generator. Emission reduction usually combines measures involving the choice of fuel type, thus improving engine performance, or special exhausts gas management [15].

The data for the machinery plant of all cruise ships called port of Gruž have been obtained from the pilot company providing pilotage in the mentioned area. Rating powers of the engines mostly have been taken from obtained data and for some of them it has been approximately determined on the gross tonnage basis [16]. The collected data have shown that most of cruise ships were equipped by diesel electric machinery plant.

The assumed average specific fuel consumption of the newer generation of cruiser ships equipped by diesel electric plant were about 170 g/kWh and for older cruiser ships equipped by most common machinery plant were about 223 g/kWh. The engines of the cruise ships calling at the port of Gruž consume low quality fuels (heavy fuel oil) during the steaming segment and Marine Gas Oil (MGO) during slow steaming and the manoeuvring segment as per requirement of EU Directive. The emission factors for these types of fuel depend on the respective type of the engine and the ship's activity. The CO_2 emission factor for the engines installed on the newer generation of cruiser ships equipped by diesel electric machinery is 588 g/kWh for slow steaming, 647 g/kWh for maneuvering and 690 g/kWh for berthed ship. Cruise ships equipped by gas electric machinery have following emissions factors: 922 g/kWh for slow

steaming, 1014 g/kWh for maneuvering and same, 1014 g/kWh for berthed ship. The emission factors for the engines installed on the older cruiser ships are 645 g/kWh for slow steaming and 710 g/kWh for maneuvering. The auxiliary engines on the older cruise ships involved in the study consumed about 223 g/kW MGO, and their respective fuel emission factors was about 690 g/kWh (all the data given in Table 1).

The Intergovernmental Panel on Climate Change IPCC) Guidelines provide a general approach to estimating emissions from the combustion of fossil fuels for navigation. The basic equation is: [17]

$$Emissions = \sum \left(Fuel\ Consumed_{ab} \cdot Emission\ Factor_{ab} \right) \quad (1)$$

where a presents the fuel type (diesel, gasoline, LPG, heavy oil, etc.) and b the water-borne navigation type (i.e., ship or boat, and possibly the engine type). Each ship emission depends on the time passed in the ship activities; the ship's power consumption and emission factors are estimated during the slow steaming and manoeuvring, and in berthed ship. The data for the emission factors of the certain CO_2 have been obtained from the ENTEC ship emissions inventory study [18].

The emissions for the engines installed on the older cruiser ships were estimated through the application of the following expressions:

$$Em(steam) = \frac{D}{V(steam)} \cdot \left(P_{ME} \cdot L_{ME} \cdot EF_{steam} + P_{AX} \cdot L_{AX} \cdot EF_{AX} \right) \quad (2)$$

$$Em(man) = tm_{man} \cdot \left(P_{ME} \cdot L_{ME} \cdot EF_{man} + P_{AX} \cdot L_{AX} \cdot EF_{AX} \right) \quad (2)$$

$$Em(bething) = tm_{berth} \cdot \left(P_{AX} \cdot L_{AX} \cdot EF_{AX} \right) \quad (4)$$

where P_{ME} is the main engine power (kW), P_{AX} the power (kW) of auxiliary machines which drive generators, V is the ship's average speed (steaming or manoeuvring (Nm/h), D is the distance between cruising and manoeuvring (Nm), L_{ME} is the load factor of the main engine (%), L_{AX} the load factor of auxiliary engines which drive generators at steaming, manoeuvring and berthing (%). EF_{Steam} is the emission factor of the main engine in steaming (g/kWh), EF_{man} is the emission factor of the main engine in manoeuvring (g/kWh), EF_{AX} is the emission factor of engines which drive generators for steaming, manoeuvring and berthing (g/kWh). The emissions for the engines installed on the cruiser ships equipped by diesel electric and gas electric engine were estimated through the application of the following expressions:

$$Em(steam) = \frac{D}{V(steam)} \cdot \left(P_E \cdot L_E \cdot EF_{steam} \right) \quad (5)$$

$$Em(man) = tm_{man} \cdot \left(P_E \cdot L_E \cdot EF_{man} \right) \quad (6)$$

$$Em(bething) = tm_{berth} \cdot \left(P_E \cdot L_E \cdot EF_B \right) \quad (7)$$

where PE is engines power (kW), V is the ship's average speed (steaming or manoeuvring (Nm/h), D is the distance between cruising and manoeuvring (Nm), L_E is the load factor of the engines (%), EF_{Steam} is the emission factor of engines in steaming (g/kWh), EF_{man} is the emission factor of engines in manoeuvring (g/kWh), EF_B is the emission factor of engines in port (g/kWh). Ships' activities, load factors and emission factors are shown in Table 1.

Table 1. Ships activities, load factor and emission factors.

Ship's type	No call	Activities	Dur (av. time) (h)	Engine system	Load f. (%)	Emiss f. (g/kWh)
Cruise ship	3	Sl. steam.	0,7	Main E	65	645
				Aux E	80	690
Common machinery plant		Manouv	1,0	Main E	25	710
				Aux E	80	690
		Berth	18,8	Main E	0	0
				Aux E	40	690
Cruise ship	1	Sl. steam.	0,7	Diesel eletric	70	588
Diesel electric machinery		Manouv	0,9	Diesel eletric	60	647
		Berth	10,5	Diesel eletric	50	690
Cruise ship	1	Sl. steam.	0,7	Gas eletric	70	922
Gas electric machinery		Manouv	0,9	Gas eletric	60	1014
		Berth	9,5	Gas electric	50	1014

5 RESULTS AND DISCUSSION

The total annual CO_2 emission of the cruise ships calling at the Port of Gruž is approximately 1699 t. The quantity of CO_2 emission depends on the installed engines type and its activity (slow steaming, manoeuvring, and berthing). The older type of cruise ships also equipped by auxiliary machinery drives generators which provide electric power to all ship systems and emit CO_2 during the slow steaming, manoeuvring and berthing.
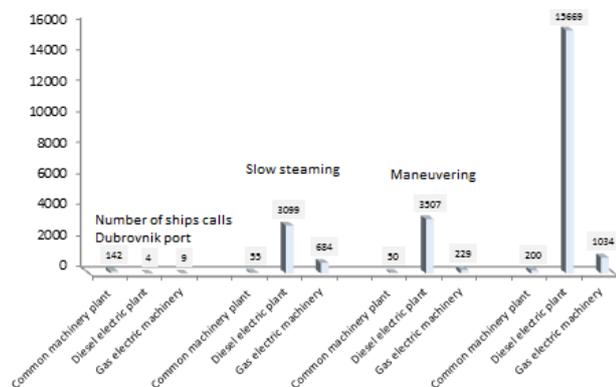

Figure 2. Total exhaust emission for all ship's category calling port of Dubrovnik.

All the ships considered in the study had a great loading factor during manoeuvring and berthing. The longest activity for all ship categories is during berthing (berthed ship). The exhaust gas emissions according to ship types are specified in Figure 2. The highest levels of exhaust gas emissions were generated from cruise ships equipped by diesel electric plants because of the greater number of ship calls. The total CO_2 emission for cruise ships equipped by diesel electric plants is 22277 t. The total emission for cruise ships equipped by gas electric plant was approximately 2521 t. The highest emissions for both ship's categories were generated when the ships were at berth because the manoeuvring and slow steaming periods are shorter than the berthing period. As regards the cruise ships equipped by the common machinery plant, their emissions in the manoeuvring and berthing were higher than during the slow steaming. The total emission for this category of cruise ships equipped by was approximately 305 t.

6 GUIDELINES FOR FURTHER DEVELOPMENT OF THE CRUISING INDUSTRY WITH REGARD TO CO_2 EMISSIONS

The cruising industry is making significant efforts to reduce environmental impacts. The main priorities in the coming years relate to the development and identification of new technologies to use cleaner fuels and make cruise ships more energy efficient. The priority goal is to reduce the CO_2 emission rate by 40% by 2030 compared to 2008. Investments in the energy efficiency of ships amount to more than $ 22 billion. In the coming years it is expected: [19]
- 44% of new build capacity will rely on LNG fuel for primary propulsion,
- 68% of global capacity currently utilizes Exhaust Gas Cleaning System, while 75% of non-LNG new-builds will have Exhaust Gas Cleaning System,
- 100% of new builds will have Advanced Wastewater Treatment Systems,
- 88% of new build capacity will have or be configured to add Shore-side Power.

Additional Areas of Exploration are Battery Propulsion, Advanced Recycling, Reduced Plastics, Efficient Lighting, Solar Energy and Fuel Cell Technology. Developing non-carbon emitting energy is in line with the objectives set by the European Union. The objectives until 2030 are as follows: [20]
- minimizing greenhouse gas emissions by 40%,
- increasing energy efficiency by 27 – 30%,
- increasing the share of energy from renewable sources in total consumption by minimally 27%.

Finally, the IMO seeks to reduce greenhouse gas emissions from international shipping by reducing annual greenhouse gas emissions by at least 50% by 2050 as compared to a 2008 baseline, while at the same time pursuing efforts to phase them out completely [21].

7 CONCLUSION

The trend of increasing the number of cruise passengers and berths is increasingly present in Croatia, with the Gruž-Dubrovnik port holding the lead position. Although cruising tourism is a driver of the development of many economic activities, this type of tourism contributes to air pollution by CO_2 emissions.

Ship emissions are a significant source of air pollution and it causes a cumulative effect that contributes to the overall air quality problems encountered by populations, especially in nearby areas, affects to the natural environment. In this article, the exhaust emissions were calculated with the activity-based emission model for the port of Dubrovnik (Gruž), which is the significant cruise port on Mediterranean. All major cruise lines include Dubrovnik on their Mediterranean itineraries. Dubrovnik handles around 600 cruise ship calls annually.

The emissions generated from ships calling into the Dubrovnik port may have a great impact on the immediate environment and also on the health of people living in its vicinity. This work estimates a quarterly total of emissions released by cruise ships calls Dubrovnik between 1st of March and 1st of June. Although most of these emissions take place at sea, the most directly noticeable part of shipping emissions takes place in port areas and port-towns. The total number of ship calls in the Dubrovnik port for mentioned period was 155 (142 cruise ships equipped by diesel electric plant, 4 cruise ships equipped by gas electric plant and 9 cruise ships with most common machinery plant). The engine powers were approximately determined on gross tonnage basis. The emission factors of CO_2 have been obtained from the ENTEC ship emissions inventory study. Ship's emissions were calculated by the ship activity-based method which involves the application of emission factors for each ship-activity (slow steaming on arrival and departure, manoeuvring on arrival and departure, and for berthed ship). The total quarterly emission of CO_2 was 24530 t (cruise ships equipped by diesel electric plant 22277 t, cruise ships equipped by gas electric plant and 2521 t, cruise ships with most common machinery plant 305 t).

The cruising industry is making positive strides to make cruisers more energy efficient. However, the results of CO_2 emissions reduction will only be visible in the future.

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