International Journal of Scientific and Technological Research www.iiste.org
ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/7-02-01
Vol.7, No.2, 2021

CO_2 Emission Per Capita at a Cruise Voyage in Caribbean Area

Ayhan Salar
Turkish Coast Guard Inventory Management Command, Adnan Menderes Airport
PO box 35410, Gaziemir, Izmir, Turkey
E-mail: ayhansalar34@gmail.com

Kadir Mersin
School of international logistics and transportation, Istanbul Gelisim University
PO box 34315, Avcilar, Istanbul, Turkey
E-mail: kmersin@gelişim.edu.tr

Abstract
In this Study, it was aimed to examine the greenhouse gas emissions caused by sea transportation, especially by cruise passenger ships in the Caribbean region. With this Study Fleet of Princess Cruises was analysed. Central America region was chosen as the study area. So, Sky Princess, Crown Princess, Island Princess, Enchanted Princess and Princess of Caribbean were analysed. Annually and daily CO_2 emission. However, in this Analyse, calculations were made according to formulation was formed by Trozzi and Vaccaro. In this study, it is showed that the cruise holidays are not innocent even marine transportation is the one of the greenest transportation mode. Moreover, lower occupancy rates make higher per capita CO_2 emissions. So, if we assume that a cruise ship is a country, its occupancy rate should be almost 100% to have lowest per capita CO_2 emissions.

Keywords: CO_2 emissions, Cruise Hoiday, Sea Transportation

DOI: 10.7176/JSTR/7-02-01

1. Introduction

Although technology is improving day by day, fuel costs still remain important. Fuel costs vary depending on the type of ship machine, the horsepower of the machine, the type of fuel used and the unit price of the fuel. Maintenance of the main machine regularly, efficiency, age, and training and experience of the personnel working in the engine room are other important factors affecting fuel consumption [1].

The part of the ship that is under the sea shows resistance against the movement of the ship. This resistance affects the main machine's fuel consumption depending on the speed of the ship. In addition, some uncontrollable variables also affect fuel consumption. For example, depending on the weather and sea conditions, the force of the main machine or changing the combustion conditions of the fuel also affect the fuel consumption [1].

Marine transportation causes green house gases (GHG) emissions. The most common ones are CO_2, NOX, SOX. Nevertheless, exhaust emissions per capita at a voyage is lower than the other transportation modes. This is because the ratio of cargo per ton / km is much higher than that of the airline or road, and in this context, the amount of CO_2 per ton / km per unit cargo is the lowest in maritime transport and is shown in figure 1[2].

ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/7-02-01
Vol.7, No.2, 2021

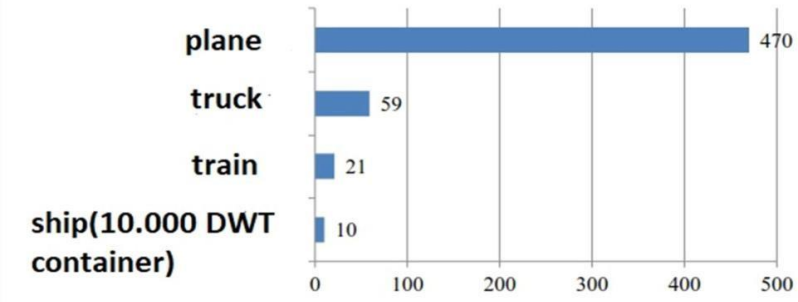

Figure 1. The Comparison of the CO_2 Amount Carried for One Kilometer Carriage of One Ton Cargo in Different Transport Modes (Gram Carbon)[2]

In this study, it is analysed CO_2 emissions of cruise ships. The other emissions were neglected.

2. Literature Review

Alderton [3] published a formula showing the relationship between a ship's fuel consumption and speed. In this formula, the weight of the ship is neglected. Shortly after this study, Ronen [4] and Chrzanowski [5] used this formula in their studies. In these studies, it has been shown that fuel consumption is a force of speed. Barras [6] on the other hand, published a formula for fuel consumption, which does not neglect the weight of the ship, and shed light on the method we will use in this study. Kim et al. [7] determined the amount of fuel and optimum ship speed for a given ship route. Notteboom and Carlou [8] investigated the effects of low speed applications on fuel consumption. They also analyzed fuel consumption and BAF paid by carriers. Khor et al. [9] found the most optimal 19.5 knot speed by installing a model to optimize the speed of ultra-container ships. Doudnikoff and Lacoste[10] revealed differences in speed and cost effectiveness between total transition time inside and outside of SECA and CO_2 emissions. Sheng et al. [11] investigated how ship speed is dynamically determined from the current port to the next port. Poonthalir and Nadarajan [12] found that the changing speed of the vehicle steering program is more suitable for fuel consumption. Mersin et al [13] made a review about CO_2 emission and reducing methods in maritime transportation. Fuel consumption affects not only the cost but also the emission of CO_2 and similar gases. For example, Tokuşlu [14] has worked on the M / V Leyla Kalkavan ship and has shown that the fuel consumption and thus CO_2 emissions are reduced by decreasing service speed. Trozzi and Vaccaro [15], on the other hand, found a correlation between ship grosstone and fuel consumption and calculated approximately daily fuel consumption. In the same article, a new method was found and the exhaust gas emissions of the ships were calculated. A different method was developed by the British company ENTEC [16] in 2005 and an emission inventory study was carried out by creating emission factors for each ship type, including cruise, maneuver and port operating modes.

3. Materials and Methods

There are many formulas related to fuel consumption in the literature. However, in this study, calculations were made according to table 1 which was formed by Trozzi and Vaccaro [17] because Gross register ton (GT) were used in the formulas because of the sample ship is a passenger ship.

Table 1: Daily Fuel Consumption by Ship Tonnage (Tonne)

Ship Type	**Consumption**
Bulk Carrier	C = 20,186 + 0,00049 × GT
Container ship	C = 8,0552 + 0,00235 × GT
Cruise ship	C = 16,904 + 0,00198 × GT
Ro-Ro/Passenger /Cargo Ship	C = 12,834 + 0,00156 × GT
Tanker	C = 14.685 + 0,00079 × GT

ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/7-02-01
Vol.7, No.2, 2021

However, according to the Trozzi & Vaccaro method, the CO_2 emission coefficient is 3.20. So a 1-day CO_2 emission of a cruise ship is $\varepsilon(1) = (16{,}904 + 0{,}00198 \times \mathrm{GT}) \times 3.20$ tonne

Passenger ships do not shut down their engines after they leave the port. In other words, they continue to release CO_2 during the voyage, at the port and during the maneuver. Therefore, 3 different situations should be examined while making calculations. When we assign an operating mode multiplier according to the consumption values in Table 1, this multiplier will be 0.8 for cruise, 0.4 for maneuver and 0.2 for port. Despite the estimated emission factors created by the machine types according to the cruise modes of the ships (cruise, maneuver, hotelling), CO_2 emission is 3.20 for each mode and for each machine type. In the light of all these data, the formula for the total CO_2 emission amount per passenger of a cruise ship is given below.

$$\hat{\varepsilon}(t_{total}) = \sum_{i=1}^{3} \frac{C \times f \times t}{Q \times u} \times p_i \quad (1)$$

Where,

$\hat{\varepsilon}(t)$: The total amount of CO_2 emissions per passenger at t-day sailing.
C: Fuel consumption (tonne)
f = 3.20 (CO_2 emission factor)
t: time (day)
Q: Passenger capacity
u: occupancy rate
p_1: Sailing mode multiplier
p_2: Maneuver, mode multiplier
p_3: Hotelling mode multiplier

4. Emission of Caribbean Princess

MS Caribbean Princess has undertaken cruises from European ports around the British Isles, northern Europe and the Mediterranean and from North American ports to the Caribbean, New England and Canada. The ship in July 2019 left her current home port of Fort Lauderdale, Florida and sailed up to a new home port in New York for cruises to Canada, New England, and Greenland. As of 2020, however, the ship sails primarily in the Caribbean. General characteristics of the ship is given at table 2 [18].

Table 2. Specification of MS Caribbean Princess [19]

Gross Tonnage	112,894 gt
Passengers	4,338
Crew	1,200

MS Caribbean Princess makes 81 voyage in a year. 35 of them is 14-day voyage, 36 of them is 7-day voyage, 6 of them is 10-day voyage, 1 of them is 16- day voyage, 1 of them is 6-day voyage, 1 of them is 13-day voyage and 1 of them is 4-day voyage. According to given data, daily CO_2 emission of MS Caribbean Princess is $\varepsilon(1) = (16.904 + 0.00198 \times 112{,}894) \times 3.20 \times 0.8 = 615.511$ tonnes. That means 0,142 tonnes of CO_2 emission per capita for 1-day sailing. Nevertheless, according to figure 1 we can calculate the CO_2 emission per capita at the 14-day voyage by using eq.1.

$$\hat{\varepsilon}(t_{total}) = \frac{240.43 \times 3.2 \times 3.25}{4338} \times 0.2 + \frac{240.43 \times 3.2 \times 0.07}{4338} \times 0.4 + \frac{240.43 \times 3.2 \times 9.65}{4338} \times 0.8 = 1.49 \text{ tCO}_2\text{/person.}$$

Schedule of 14-day voyage of MS Caribbean Princess is given in figure 2.

ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/7-02-01
Vol.7, No.2, 2021

Figure 2. Schedule of 14-day voyage of MS Caribbean Princess [19]

In this example, we assumed that the number of passengers is 3118. So, total number of people reach 4318 with number of crew. Clearly, decreasing the passenger capacity causes increasing CO_2 emission per capita. The CO_2 emission per capita at 100%, 85% and 70% occupancy rates are given in table 3.

Table 3. The CO_2 emission per capita at 100%, 85% and 70% occupancy rates

Occupancy Rate	**CO2 emission per capita(tCO2/person)**
100%	1.49
85%	1.75
70%	2.13

MS Caribbean Princess does not have only 14-day voyage. The other voyages are given in table 4.

Table 4. Voyages of MS Caribbean Princess

Voyage Name	**Total Port time (day)**	**Total Sailing time (day)**	**Total Manoeuvring time (day)**	**Number of voyage in a year**
14 days, round-trip Caribbean East West Adventurer	3,25	9,65	0,07	35
7 days, round-trip Eastern Caribbean	1,29	5,19	0,04	19
7 days, round-trip Western Caribbean	1,58	4,87	0,04	17
4 days, round-trip Eastern Caribbean Getaway	0,46	1,25	0,02	1
10 days, one-way from Quebec City to New York	2,67	3,96	0,06	3
10 days, one-way from New York to Quebec City	2,79	5,48	0,07	3
6 days, round-trip Western Caribbean Getaway	1,33	4,12	0,03	1
16 days, round-trip Greenland Canada	2,79	12,92	0,07	1
13 days, one-way from Fort Lauderdale to Quebec City	2,88	8,11	0,07	1

Data from the table 4, CO_2 emission per capita can be calculated for all voyages. The values are given in table 5.

Table 5. CO_2 emission per capita at 100%, 85% and 70% occupancy rates

Voyage Name	**per capita at 100% (tCO_2/person)**	**per capita at 85% (tCO_2/person)**	**per capita at 70% (tCO_2/person)**
14 days, round-trip Caribbean East West Adventurer	1,489447	1,752290198	2,127781
7 days, round-trip Eastern Caribbean	0,784983	0,923509933	1,121405
7 days, round-trip Western Caribbean	0,749867	0,882196113	1,071238
4 days, round-trip Eastern Caribbean Getaway	0,195093	0,229521221	0,278704
10 days, one-way from Quebec City to New York	0,660833	0,777450974	0,944048
10 days, one-way from New York to Quebec City	0,881466	1,03701861	1,259237
6 days, round-trip Western Caribbean Getaway	0,633875	0,745735314	0,905536
16 days, round-trip Greenland Canada	1,937097	2,278937074	2,767281
13 days, one-way from Fort Lauderdale to Quebec City	1,257818	1,479785912	1,796883

ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/7-02-01
Vol.7, No.2, 2021

4.1. CO_2 Emission per Capita in the World

Data from the Global Carbon Atlas shows that world average is 4.7 tonnes of emission per capita (tCO_2/person). Luxembourg tops the list, each citizen releasing 40 tonnes of the greenhouse gas every year. However, African countries have the lowest CO_2 emission per capita. Figure 3 shows the top 10 countries in CO_2 emission per capita in 2018.

Rank	Country	tCO_2/person
1	Luxembourg	40
2	Qatar	30
3	Trinidad and Tobago	27
4	United Arab Emirates	25
5	Kuwait	21
6	Singapore	20
7	Brunei Darussalam	19
8	Saudi Arabia	19
9	United States of America	18
10	Hong Kong	16

Figure 3. Top 10 in CO_2 emissions per capita [20]

We know that maritime transportation is one of the greenest transportation mode. Nevertheless, the CO_2 emission of MS Caribbean Princess at 100% occupancy rate is 6461.22 tonnes for 14- day voyage and the CO_2 emissions per capita is 1.49 tCO_2/person which is greater than average value of all African countries in 2018. The average value of all African countries are given in figure 4.

Consumption Per capita (tCO_2/person)

Rank	Country	tCO_2/person
81	Bolivia	1.8
82	India	1.7
83	Sri Lanka	1.7
84	Paraguay	1.5
85	El Salvador	1.5
86	Philippines	1.4
87	Honduras	1.2
88	Guatemala	1.2
89	Pakistan	1.1
90	Africa	1.1
91	Nicaragua	1.1
92	Cambodia	1.0
93	Bangladesh	0.6
94	Nepal	0.6

Figure 4. Ranking of Africa in the table of CO2 emissions per capita [20]

However, it would not be fair to analyse MS Caribbean Princess with just one voyage. If we consider all of the voyages, reduction of the CO_2 emissions per capita can be observed. The annual CO_2 emission per capita at 100%, 87% and 70% occupancy rates are given in table 6.

ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/7-02-01
Vol.7, No.2, 2021

Table 6. The annual CO2 emission per capita at 100%, 85% and 70% occupancy rates

Voyage Name	**CO2 Emission (tonnes)**	**per capita at 100% (tCO_2/person)**	**per capita at 85% (tCO_2/person)**	**per capita at 70% (tCO_2/person)**
14 days, round-trip Caribbean East West Adventurer	6461.220	“ 1.489	1.752	2.128
7 days, round-trip Eastern Caribbean	3405.258	0.785	0.924	1.121
7 days, round-trip Western Caribbean	3252.922	0.750	0.882	1.071
4 days, round-trip Eastern Caribbean Getaway	846.314	0.195	0.230	0.279
10 days, one-way from Quebec City to New York	2866.695	0.661	0.777	0.944
10 days, one-way from New York to Quebec City	3823.799	0.881	1.037	1.259
6 days, round-trip Western Caribbean Getaway	2749.750	0.634	0.746	0.906
16 days, round-trip Greenland Canada	8403.125	1.937	2.279	2.767
13 days, one-way from Fort Lauderdale to Quebec City	5456.415	1.258	1.480	1.797
AVERAGE VALUE	**4141.611**	**0.954**	**1.123**	**1.364**

It is clear that the average value of the annual CO2 emission per capita has the lowest value at 100% occupancy rate. This value increases at 85% and 70% but it is still lower than 4.7 tonnes of emission per capita which is world average.

4.2. CO_2 Emission of the Princesses

In this part of the study, fleet of Princess Cruises will be analysed. Princess Cruises is a cruise line owned by Carnival Corporation & plc. [21] which serves with 18 ships. In this study, Central America region was chosen as the study area. So, Sky Princess, Crown Princess, Island Princess, Enchanted Princess and Princess of Caribbean were analysed. Annually and daily CO2 emission is given in Table 7.

Table 7. Amount of CO_2 Emission.

NAME	**Annually Emission(tonne)**	**Daily (average) Emission (tonne)**	**CO2 Emission Per Capita(tonne)**
PRINCESS OF CARIBBEAN	349,738.326	465.078	1.104
SKY PRINCESS	169,935.141	557.164	1.455
CROWN PRINCESS	61,208.779	501.711	1.306
ISLAND PRINCESS	5,975.105	426.793	1.919
ENCHANTED PRINCESS	216,830.130	573.625	1.200

According to table 7, average value of CO2 emission per capita is 1.21 tonne which is higher than CO2 emission per capita of Nicaragua, Guatemala and Honduras. CO2 emission per capita of Central America is given in table 8.

Table 8. CO2 emission per capita of Central America [20]

Rank	Country	tCO_2/person
1	Trinidad and Tobago	27
2	Panama	5.4
3	Jamaica	2.9
4	Costa Rica	2.5
5	Dominican Republic	2.4
6	El Salvador	1.5
7	Honduras	1.2
8	Guatemala	1.2
9	Nicaragua	1.1
10	Saint Vincent and the Grenadines	No data for selected year
11	Kosovo	No data for selected year
12	Saint Kitts and Nevis	No data for selected year
13	Curaçao	No data for selected year
14	Turks and Caicos Islands	No data for selected year
15	Saint Helena	No data for selected year
16	Saint Lucia	No data for selected year
17	British Virgin Islands	No data for selected year
18	Bermuda	No data for selected year
19	Bonaire, Saint Eustatius and Saba	No data for selected year

5. Conclusions

According to Business Research & Economic Advisors (BREA) 2015 study, the cruise industry's economic impact in the Caribbean and Latin American is significant and continues to grow. A single call from an average ship in the region generates $675,995. Princess Cruises ships serve over 1.8 million passengers yearly with 18 ships. MS Caribbean Princess is one of the ships of this fleet which makes 71 voyage to this region. Nevertheless, each voyage causes CO2 emission in this region. According to Global Carbon Atlas, average value of the annual CO2 emission per capita of this region is 2.2 tCO_2/person.

Many countries in the world still have very low per capita CO2 emissions. In many of African country, the average value is around 0.1 tonnes per year and average value of all African countries in 2018 is 1.1 tCO_2/person. MS Caribbean Princess still have lower per capita CO2 emissions than average of African countries unless occupancy rate of the ship falls below 87%.

In this study, it is showed that the cruise holidays are not innocent even marine transportation is the one of the greenest transportation mode. Moreover, lower occupancy rates make higher per capita CO2 emissions. So, if we assume that a cruise ship is a country, its occupancy rate should be almost 100% to have lowest per capita CO2 emissions.

6. References

[1] Yıldız, M.,2008, *Layner Ulaştırma Sistemlerinde Optimum Filo Planlaması Modeli,* PhD Thesis,İstanbul University.

[2] World Shipping Council, *"Liner Shipping And Carbon Emissions Policy,"* 2009. [Online]. Available:http://www.worldshipping.org/pdf/liner_shipping_carbon_emissions_policy_pr esentation.pdf.

[3] Alderton, P. M. (1981). The optimum speed of ship. *The Journal of Navigation,* 34(3), 341355.10.1017/S0373463300047962.

[4] Ronen, D. (1982). The effect of oil price on the optimal speed of ships. *Journal of Operational Research*, 33, 1035–1040.

[5] Chrzanowski, I.,1989, *An Introduction to Shipping Economics*, Fairplay Publication NL.T.D, United Kingdom.

[6] Barras, B., 2004, *Ship Design and Performance forMasters and Mates*, Elsevier, Oxford, ISBN: 0-7506-6000-7

[7] Kim, H.J., Chang, Y.T., Kim, Y.T., Kim, H.J., 2012. An epsilon-optimal algorithm considering greenhouse gas emissions for the management of a ships bunker fuel, *Transportation Research Part E*, Vol 17 pp.97 - 103.

[8] Notteboom, T., Cariou, P. 2013. Slow steaming in container liner shipping: is there any impact on fuel surcharge practices?, *The International Journal of Logistics Management*, Vol 24, 1, pp.73-86.

[9] Khor, Y.S., Dohlie, K. A., Konovessis, D., Xiao, Q. 2013. Optimum Speed Analysis for Large Containerships, *Journal of Ship Production and Design*, Vol 29, 3, pp.93-104.

[10] Doudnikoff, M., Lacoste, R., 2014. Effect of a speed reduction of containerships in response to higher energy costs in sulphur emission control areas, *Transportation Research Part D* Vol 28, pp.51–61.

[11] Sheng, X., Lee, L. H., Chew, E. P. 2014. Dynamic determination of vessel speed and selection of bunkering ports for liner shipping under stochastic environment, *Spectrum*, Vol 36, pp.455-480.

[12] Poonthalir and R. Nadarajan, "A fuel efficient green vehiclerouting problem with varying speed constraint (F-GVRP),"Expert Systems with Applications, vol. 100, pp. 131– 144, 2018. *(20) (PDF) Route Optimization of Electric Vehicle considering Soft Time Windows and Two Ways of Power Replenishment*.

[13] Mersin, K., Bayırhan, İ., Gazioğlu, C. (2019). Review of CO2 Emission and Reducing Methods in Maritime Transportation, *Thermal Sciences*, 1-8.

[14] Tokuslu, A. (2020). Analyzing the Energy Efficiency Design Index (EEDI) Performance of a Container Ship. *International Journal of Environment and Geoinformatics* (IJEGEO), 7(2): 114-119. DOI: 10.30897/ijegeo

[15] Trozzi, C., Vaccaro, R. (1998). Methodologies for estimating air pollutant emissions from ships. Techne Report MEET. (Methodologies for Estimating Air Pollutant Emissions from Transport) RF98.

[16] ENTEC UK Limited (2005). European Commission, Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market based Instruments, Task 1-Preliminary Assignment of Ship Emissions to European Countries , Final Report, August 2005.

[17] C. Trozzi, R. Vaccaro, Actual And Future Aır Pollutant Emıssıons From Shıps Transport And Air Pollution And Cost 319 – Final Conference – Inrets Graz, Austria 31 May – 2 June 1999.

[18] https://en.wikipedia.org/wiki/Caribbean_Princess

[19] https://www.cruisemapper.com/ships/Caribbean-Princess 558?tab=itinerary#itinerary

ISSN 2422-8702 (Online), **DOI:** 10.7176/JSTR/7-02-01
Vol.7, No.2, 2021

[20] http://www.globalcarbonatlas.org/

[21] https://en.wikipedia.org/wiki/Princess_Cruises