REVIEW OF TOTAL EMISSION OF TRANSIT SHIPS IN THE DARDANELLE WHICH INCLUDING POSSIBLE CO_2 EMISSION OF 1915 CANAKKALE BRIDGE

by

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Canakkale Strait (Dardanelles), is one of two straits that have Turkey with Bosphorus. This strait, which has a length of 38 miles, provides the connection of countries with a coast to the Black Sea to the Mediterranean. 43454 ships pass through the strait annually. According to 2019 data, 45.33% general cargo ship, 21.43% bulk carrier, 21.78% tanker, 6.43% container, 0.65% ro-ro, and 0.61% passenger ship, and 3.77% other type of ship passed. Therefore, by including the Canakkale 1915 bridge which will be completed in 2023, the six most frequent ship types were examined and their emission values were calculated in this study.

Key words: *ship emission, Dardanelle, Canakkale Bridge, CO_2 emission*

Introduction

International maritime trade is the greenest form of transportation compared to other modes of transport and emits the lowest CO_2 emission per unit load per kilometer but, it is responsible for 3.3% of global CO_2 emissions [1].

According to fuel consumption, CO_2, NO_x, and SO_x emissions from exhaust gas emissions from ships correspond to approximately 2%, 11%, and 4% of global anthropogenic emissions [2]. This rate is at a considerable level.

International maritime trade transport covers 90% of world trade. As the need for energy and raw materials continues to increase in the globalizing world, maritime trade continues to be important [3].

Considering the sea trade routes, the importance of the straits becomes apparent. For example, any country with a coast to the black sea needs to pass in order to reach the Mediterranean, Atlantic Ocean and the Indian Ocean. Examples are: Bosphorus, the Dardanelles, Gibraltar Strait and even the Suez Canal.

Importance of the Dardanelle

The Dardanelles is one of Turkey's most important strait that connects the Sea of Marmara to the Aegean Sea. The length of the Dardanelles is 30 miles when measured from the midline. The maximum width is 3200 meters on the northern border and 3600 meters on the southern border. The narrowest part of the strait is between Canakkale and Kilitbahir and it is 1200 meters. Depths range from 50-80 meters across the entire viewing channel. A 50-meter

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equivalent depth line continues along the length of approximately 200 meters from both shores. When entering from the north, the average depth of 70 meters increases to 85 meters until Nara. The deepest point of the strait is the 104-meter depth above the middle line in front of Nara, which is also the narrowest place. The distance from the Dardanelles Strait to the Aegean Sea to the Gibraltar Strait is 1717 nm. The distance to the Suez Canal is 664 nm. [4]

The speeds of the ships passing through the Dardanelles are limited to 10 miles [5]. The number of ships passing through the Dardanelles in the last 14 years is given in fig. 1.

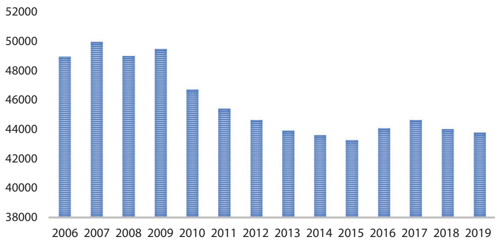

Figure 1. Number of vessels which passed through the Dardanelles [6]

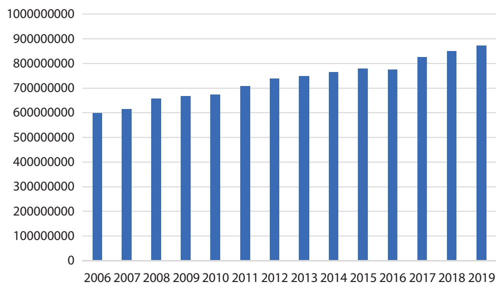

Figure 2. Total gross tonnage [6]

When fig. 1 is examined, it is seen that there is a fluctuation in the number of ships. However, it can be said that it tends to decrease. Also It can be said that this change in ship transitions is proportional to the increase in ship tonnage. In fig. 2, the tonnage of the ships passing through the Dardanelles is given.

According to tab. 2, there is a regular increase in ship tonnage. In this study; container ships, bulk carriers, tankers, general cargo ships, ro-ro ships and passenger ships, which constitute 96% of the number of ships passing through the Dardanelle were examined.

Literature review

There are lots of studies about ships emissions and their port emissions. Buhaug *et al.* [1] presents that CO_2 emissions in 2007 was estimated to be 1,046 millionns by ship, Endresen *et al.* [2] calculated ship emissions by using ship size (gross tonnage) by (AMVER) data set. Eyring *et al*. [7] considered the effect of ship based emission the atmosphere. Corbett *et al.* [8] analysed the mortality that was caused by emissions. Cohen *et al.* [9], Cofala *et al.*, [10], Wang *et al.* [11], Deniz and Kilic [12], EEA, 2013, Viana *et al.* [13], Bayirhan *et al.* [14], and Tokuslu [15] made studies on these subjects and these studies have emphasized that ship-borne air emissions have harmful impacts on human health and environment and concrete measures should be taken to reduce its` effects. Nevertheless, Kesgin and Vardar [16] published a specific paper about exhaust gas emissions in the staraits of Turkey in 2001.

Methodology

In this study, UP DOWN methodology was used by making use of the data of the Ministry of Transport and Infrastructure. According to the Trozzi and Vaccaro [17] methodology, the formula for shipborne air pollution (emission analysis) [13]:

$$E_i = \sum_{jklm} E_{ijklm}, \quad E_{ijklm} = C_{jkm}\left(GT\right) \times P_m \times t_{jklm} \times F_{ijlm}$$

where i is the pollutant (NO_x, SO_x, CO, CO_2, VOC, PM), j – the fuel, k – the ship type, l – the engine type, m – the cruse mod (hotelling, cruising, manoeuvring), E_i – the total emission of pollutant gases, E_{ijklm} – the total emission of fuel type j burned by machine Type l and k type of ship according to the cruise mode of the ship, t_{jklm} – the sailing time, F_{ijlm} – the emission factor, $C_{jkm}(GT)$ – the fzuel consumption, and P_m – the fraction of maximum fuel consumption by driving mode (0.8 for cruise, 0.4 for manoeuvring, 0.2 for hotelling). The 90% of commercial ships use heavy fuel oil (HFO) in their main engines in the cruising mode because it is cheap and widely available. The emission factor (kg pollution/ton fuel) created by the ship and the fuel consumption according to the ship type are given in tabs. 1 and 2, respectively.

Table 1. Emission factors on cruising mode [3]

Type of engine	NO_x	CO_2	VOC	PM	SO_x
High speed Diesel engines	60.000	3.200	1.000	0.520	10.000
Medium speed Diesel engines	57.000	3.200	2.400	1.200	10.000
Slow speed Diesel engines	87.000	3.200	2.400	7.600	54.000

Table 2. Daily fuel consumption (tons/day) [3]

SHIP TYPES	Fuel consumed [tons per day]
Container	CJK = 8.0552 + 0.00235 * tonnage
General cargo	CJK = 9.8197 + 0.00143 * tonnage
Tanker	CJK = 14.685 + 0.00079 * tonnage
Passenger	CJK = 16.904 + 0.00198 * tonnage
Passenger/ro-ro/cargo	CJK = 12.834 + 0.00156 * tonnage
Solid bulk	CJK = 20.186 + 0.00049 * tonnage

Emissions in the Dardanelle

The emissions caused by the ships passing through the Dardanelles in the last 14 years are given in tabs. 3-8 according to the ship types.

Table 3. Emission values of container ships

Years	Number of ship	NO_x	CO_2	VOC	PM	SO_x
2006	4539	36521.75	1496214	1343,058	3675.737685	25447.41474
2007	4709	37889.61	1552252	1393.359798	3813.405763	26400.50143
2008	4947	39804.61	1630705	1463.782315	4006.141072	27734.82281
2009	4649	3740684	1532474	1375.606222	3764.817029	26064.1179
2010	4840	38943.66	1595434	1432.121772	3919.491164	27134.93883
2011	5056	40681.64	1666635	1496.034644	4094.410605	28345.91957
2012	4653	37439.02	1533792	1376.789794	3768.056278	26086.54346
2013	4653	37439.02	1533792	1376.789794	3768.056278	26086.54346
2014	4595	36972.34	1514673	1359.628004	3721.087169	25761.37271
2015	4346	34968.83	1432594	1285.950665	3519.443926	24365.38102
2016	4728	38042.49	1558515	1398.981764	3828.792195	26507.02289
2017	4957	39885.07	1634001	1466.741244	4014.239194	27790.88673
2018	5123	41220.74	1688721	1515.85947	4148.668024	28721.54786
2019	5238	42146.05	1726629	1549.887157	4241.796429	2936.28297

Table 4. Emission values of solid bulk ships

Years	Number of ship	NO_x	CO_2	VOC	PM	SO_x
2006	5636	25284.14294	1480928.372	977.3702314	1721.021494	25071.67115
2007	5455	17407.68354	686453.9357	645.9454898	1762.664811	11605.12236
2008	6283	20049.94971	790648.9603	743.9918446	2030.215034	13366.63314
2009	6876	21942.29734	865271.7254	814.2110335	2221.830108	14628.19823
2010	6045	19290.45774	760699.1827	715.8094382	1953.310501	12860.30516
2011	6458	20608.39969	812670.8555	764.7142022	2086.762484	13738.93312
2012	7442	23748.48412	936496.8267	881.2330586	2404.720719	15832.32275
2013	7048	22491.17389	886916.1025	834.5781507	2277.408174	14994.11593
2014	7525	24013.34897	946941.497	891,0613768	2431.540367	16008.89931
2015	7714	24616.47494	970725.1439	913.441523	2492.611614	16410.98329
2016	8060	25720.61032	1014265.577	954.4125843	2604.414001	17147.07355
2017	8585	27395.96025	1080331.263	1016.579657	2774.056352	18263.9735
2018	8916	28452.22849	1121984.105	1055.774516	2881.011816	18968.15233
2019	9204	29371.27759	1158225.852	1089.877596	2974.072763	19580.85173

Table 5. Emission values of passenger ships

Years	Number of ship	NO_x	CO_2	VOC	PM	SO_x
2006	721	2799.435583	124632.4061	105.4581898	256.9344987	2109.163795
2007	895	4015.136255	235172.2664	155.2069477	273.2991905	3981.395614
2008	807	3620.351908	212049.1832	139.9463763	246.4273148	3589.928783
2009	694	3113.412917	182357.0423	120.3504153	211.9213835	3087.249784
2010	745	3342.208391	195757.9201	129.1946101	227.4948569	3314.122606
2011	886	3974.760583	232807.4056	153.6462074	270.5509305	3941.359234
2012	806	3615.865723	211786.4209	139.7729607	246.1219525	3585.480296
2013	770	3454.363035	202326.9778	133.5299997	235.1289125	3425.334774
2014	692	3104.440546	181831.5177	120.0035841	211.310659	3078.35281
2015	783	3512.68345	205742.8878	135.7844023	239.0986214	3483.165102
2016	190	852.3752944	49924.83867	32.94896096	58.01882256	845.2124768
2017	49	219.8231022	12875.35313	8.497363616	14.96274898	217,9758493
2018	55	246.7402168	14451.92698	9.53785712	16.79492232	244.6667696
2019	101	453.1047618	26538.99319	17.51497398	30.84158462	449.2971587

Table 6. Emission values of tankers

Years	Number of ship	NO_x	CO_2	VOC	PM	SO_x
2006	9567	37145.91	1653756	1399.33218	3409.282037	27986.64359
2007	9271	35996.63	1602590	1356.037278	3303.799913	27120.74556
2008	8758	34004.79	1513912	1281.002532	3120.987988	25620.05065
2009	9567	37145.91	1653756	1399.33218	3409.282037	27986.64359
2010	9252	35922.85	1599305	1353.258213	3297.029101	27065.16426
2011	8818	34237.76	1524284	1289.778526	3142.3695	25795.57052
2012	8998	34936.65	1555399	1316.106507	3206.514035	26322.13014
2013	9299	36105.34	1607430	1360.132741	3313.777952	27202.65483
2014	9250	35915.09	1598959	1352.96568	3296.316384	27059.3136
2015	9524	36978.95	1646323	1393.042717	3393.958621	27860.85435
2016	9481	36812	1638890	1386.753255	3378.635204	27735.06511
2017	9478	36800.35	1638372	1386.314456	3377.566128	27726.28911
2018	9247	35903.44	1598441	1352.52688	3295.247308	27050.53761
2019	9843	38217.54	1701466	1439.70175	3507.636991	28794.035

Table 7. Emission values of ro-ro ships

11.312	Number of ship	NO_x	CO_2	VOC	PM	SO_x
2006	1984	6331.227	249665.4	234.9323	641.0865	4220.818
2007	2127	5668.573	271015.7	215.1575	484.1044	4592.785
2008	2084	5553.976	265536.8	210.8078	474.3176	4499.937
2009	1638	4365.361	208708.9	165.6925	372.8082	3536.898
2010	2064	5500.675	262988.5	208.7847	469.7656	4456.751
2011	2129	5673.903	271270.6	215.3598	484.5596	4597.104
2012	1861	4959.668	237122.8	188.2502	423.5629	4018.417
2013	2115	5636.592	269486,7	213.9437	481.3732	4566.874
2014	2234	5953.734	284649.3	225.9811	508.4576	4823.828
2015	2373	6324.177	302360.3	240.0417	540.0939	5123.968
2016	2473	6590.682	315102	250.1573	562.8539	5339.896
2017	2479	6606.673	315866.5	250.7642	564.2195	5352.852
2018	2243	5977.72	285796.1	226.8915	510.506	4843.262
2019	1957	5215.514	249354.8	197.9611	445.4125	4225.708

Table 8. Emission values of general cargo ships

Years	Number of ship	NO_x	CO_2	VOC	PM	SO_x
2006	23672	34955.97	1564581	1301.808	3085.768	26277.25
2007	24204	35741.56	1599743	1331.065	3155.117	26867.8
2008	23660	34938.25	1563788	1301.149	3084.204	26263.92
2009	24033	35489.05	1588441	1321.661	3132.827	26677.98
2010	21731	32089.73	1436292	1195.066	2832.749	24122.63
2011	20205	29836.32	1335433	1111.146	2633.827	22428.68
2012	18992	28045.11	1255260	1044.438	2475.706	21082.18
2013	17995	26572.86	1189364	989.6098	2345.742	19975.46
2014	17297	25542.13	1143231	951.2243	2254.754	19200.64
2015	16282	24043.3	1076145	895.4058	2122.443	18073.93
2016	16680	24631.02	1102451	917.2932	2174.325	18515.73
2017	16485	24343.07	1089562	906.5695	2148.905	18299.27
2018	15764	23278.38	1041908	866.9191	2054.919	17498.92
2019	14771	21812.04	976276.8	812.3105	1925.477	16396.64

The values in these tables were found by the Trozzi and Vaccaro [17] methodology, according to IMO limitation, sulphur rate of the fuels are restricted to 0.5% in 2020. In this study, this limitation was neglected while calculating SO_x values. Because the data sets belong to 2006-2019 interval. Therefore, the sulphur content in fuels is higher than 0.5%. With this restriction, the sulphur oxide emission of 2020 is expected to decrease further.

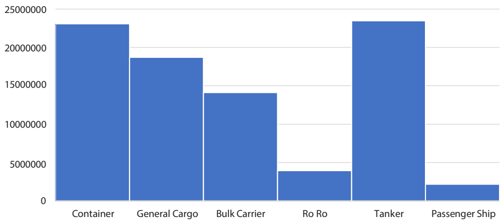

Figure 3. Total emissions of last 14 years

According to the tables, tankers are the biggest pollutant with 23485849.73 tons of emission. However, container ships are the second biggest pollutant with 23085723.63 tons of emission. Figure 3 shows the distribution of 14-year total emission values by ships.

Tier 1 methodology

In the transportation sector, it is generally accepted that fuel consumption and emission values act in proportion. This means that the more fuel consumption causes the more emissions.

In fact, data such as fuel type used for emissions of these gases, combustion technology, working conditions, control technology, vehicle age and characteristics should be used. However, given the fact that most countries do not have such detailed data, a calculation method, which is planned to yield an approximate result, without these improvements, will be followed [18].

Tier 1 approach, which requires the least data in the calculation of exhaust emissions:

$$E_i = \sum_j \sum_m FC_{jm} \times EF_{ijm}$$

where E_i [g] is the emission of pollutant i, FC_{jm} [kg] – the fuel consumption of vehicle type j with fuel m, and EF_{ijm} [gkg^{-1}] – the emission factor.

Passenger cars, light commercial vehicles, heavy commercial vehicles, motorcycles are the categories of vehicles covered in this methodology. Fuels considered include gasoline, diesel, LPG and natural gas. Since national statistics do not include details of vehicle categories, this equation requires the separation of fuel consumption statistics by vehicle categories [19]. According to this method, we can calculate the emission values of a car per km with the help of tab. 9 [20].

Table 9. Emission factors and fuel consumption [20]

Fuel type	Emission factor (CO_2) [gkg^{-1}]	Emission factor (NO_x) [gkg^{-1}]	Emission factor (PM) [gkg^{-1}]	Emission factor (NMVOC) [gkg^{-1}]	Fuel consumption [gkg^{-1}]
Gasoline	3.180	8.73	0.03	10.05	70
Diesel	3.140	12.96	1.10	0.7	60
LPG	3.017	15.20	0.00	13.64	57.5

According to the previous table, the emission values of a car per km are given in tab. 10.

Table 10. Emissions of a car per km

Fuel type	Emission factor (CO_2) [gkg^{-1}]	Emission factor (NO_x) [gkg^{-1}]	Emission factor (PM) [gkg^{-1}]	Emission factor (NMVOC) [gkg^{-1}]
Gasoline	222.6	611.1	2.1	703.5
Diesel	188.4	777.6	66	42
LPG	173.48	874	0	784.3

The 1915 Canakkale Bridge

The 1915 Canakkale Bridge, which is expected to be completed in 2023, will connect Sütlüce village, 10 km south of Gelibolu district center, and Lapseki district on the Asian side. It is designed and constructed with a total length of 4608 meters with 2023 meters of middle span, 770 meters of side openings and 365 and 680 meters of approach viaducts.

When the project is completed, long ferry queues (the average transit time is between 1.5 hours and 5 hours), which occurs with heavy traffic, especially during the summer and holidays, will not occur. In addition, with the development of an alternative route, the traffic load of Istanbul will reduce and this will affect the heavy transit traffic burden between Europe and Anatolia [21].

According to the Environmental and Social Impact Assessment report (ESIA), a total of 600,000 tons of CO_2 emissions are expected to be released during the bridge construction. Again, according to the ESIA report, considering that the amount of vehicles guaranteed to pass daily is equivalent to 45,000 cars, the number of cars expected to pass annually is expected to be 16,425.000. if we assume that all vehicles are car-equivalent vehicles with LPG, CO_2 emission of the Dardanelle which is caused by transit vehicles will increase 1,310,728 tons at least.

Conclusions

When the data of the last 14 years are analysed, it is seen that the total emission which is caused by the ships passing through the Dardanelle is 85511127.88 tons, which means an average of 6107937.71 tons per year. 5855823.35 tons of this emission is CO_2. However, it can be mentioned that this amount of emission increases with the inclusion of the 1915 Canakkale bridge If the CO_2 emission of the cars is calculated with the Tier 1 method, there will be an annual minimum increase of 1310728 tons. This is of course valid when all vehicles are LPG cars. We know that 39% of LPG vehicles in Turkey, uses 33.8% diesel and 26.7% gasoline. According to this calculation, the emission values of the vehicles passing through the bridge will be minimum 14438.74 tons.

According to data of Osman Gazi Bridge, which connects Kocaeli and Yalova, the amount of vehicles guaranteed to pass annually is equivalent to 14,600,000 cars [22].

But, 22306.468 car-equivalent vehicles passed from July 2016 to June 2019 which means 50% lower than expected number. So, road transportation sourced CO_2 emission can be taken as 7219.37 tons [23].

In other words, if 1915 Canakkale Bridge would be completed today, the total annual transit CO_2 emission in the Dardanelle would be minimum 5863042.72 tons. That is greater than emission of transit ships.

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