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REVIEW ARTICLES

Possible Effects of the Canal Istanbul Waterway Project on Ship Emissions: Challenges and Prospects

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ABSTRACT

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Canal Istanbul Waterway Project, officially announced in 2011, will be the third of the Turkish straits if realized. However, the exhaust pollution caused by transit and local ship traffic in the existing Strait of İstanbul already adversely affects human health, comfort, and the environment. Consequently, how the Canal Istanbul will affect emission pollution in this area is a problem that should be studied in advance. For this purpose, this article examined the potential exhaust emissions from ships in Canal Istanbul. In the present study, the forecast analysis of the time series was carried out using Weka (3.8.1). Two different time series forecasting methods, namely, Gaussian processes and sequence minimum optimization (SMO) regression, were employed to predict future traffic and tonnage trends. The SMO regression algorithm's performance measurement values yielded better results than the Gaussian processes. The results of SMO regression algorithm were used in future calculations. Subsequently, the total fuel consumption of the ships was calculated. Second, the Trozzi and Vaccaro method was used, and possible nitrogen oxide (NO_X), carbon dioxide (CO_2), volatile organic compounds (VOC), particulate matter (PM), and sulfur oxide (SO_X) emissions of the ships were calculated.

ADDITIONAL INDEX WORDS: *Strait of İstanbul, Canal Istanbul, exhaust gas emissions, greenhouse gas emissions, vessel traffic.*

INTRODUCTION

Transportation on the Strait of İstanbul (SoI), a natural waterway, poses many navigation safety risks. Increases in the number and size of ships, sharp turns, strong currents, and urban sea traffic intersecting closely with transit ship traffic pose a threat to the Istanbul Metropolis. In addition, due to the one-way traffic organization, the ships have a waiting period. All these reasons motivated the planning of an alternative passage corridor to the SoI. As a result, Canal Istanbul Waterway Project, officially announced in 2011, will be the third of the Turkish Straits if realized.

Given the relevance of the project and its environmental implications, of course, the social and environmental aspects of this project are also widely discussed (Bayırhan, 2020). While the construction is envisioned to increase toward the north of the Istanbul metropolis, new employment areas and added value are expected from active maritime trade. However, the exhaust pollution caused by transit and local ship traffic in the existing SoI is already adversely affecting human health, comfort, and the environment. Therefore, how Canal Istanbul will affect emission pollution in this sense emerges as a problem that should be studied in advance.

Because exhaust gas emissions are becoming a public concern for the maritime industry, restrictions and sanctions on ship-induced carbon emissions have been put in place. The future emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) suggest that ship-based CO_2 emissions will more than double by 2050 if no measures are taken (Eide and Endersen, 2010). Similarly, the International Maritime Organization (IMO) predicts that commercial ship emissions will increase by up to 250% by 2050 (IMO MEPC 59/4, 2009). Anthropogenic greenhouse gas (GHG) emissions observed in the atmosphere continue to increase. Considering the accumulation and residence time in the atmosphere, these greenhouse gases include dangerous emissions such as CO_2. Specifically, exhaust emissions from marine diesel engines comprise nitrogen, oxygen, CO_2, carbon monoxide (CO), SOx, NOx, hydrocarbons, water vapor, and smoke. Furthermore, these emissions from ships are among the most important sources of air pollution in Istanbul (Kural, Çağlar Balkıs, and Aksu, 2018;

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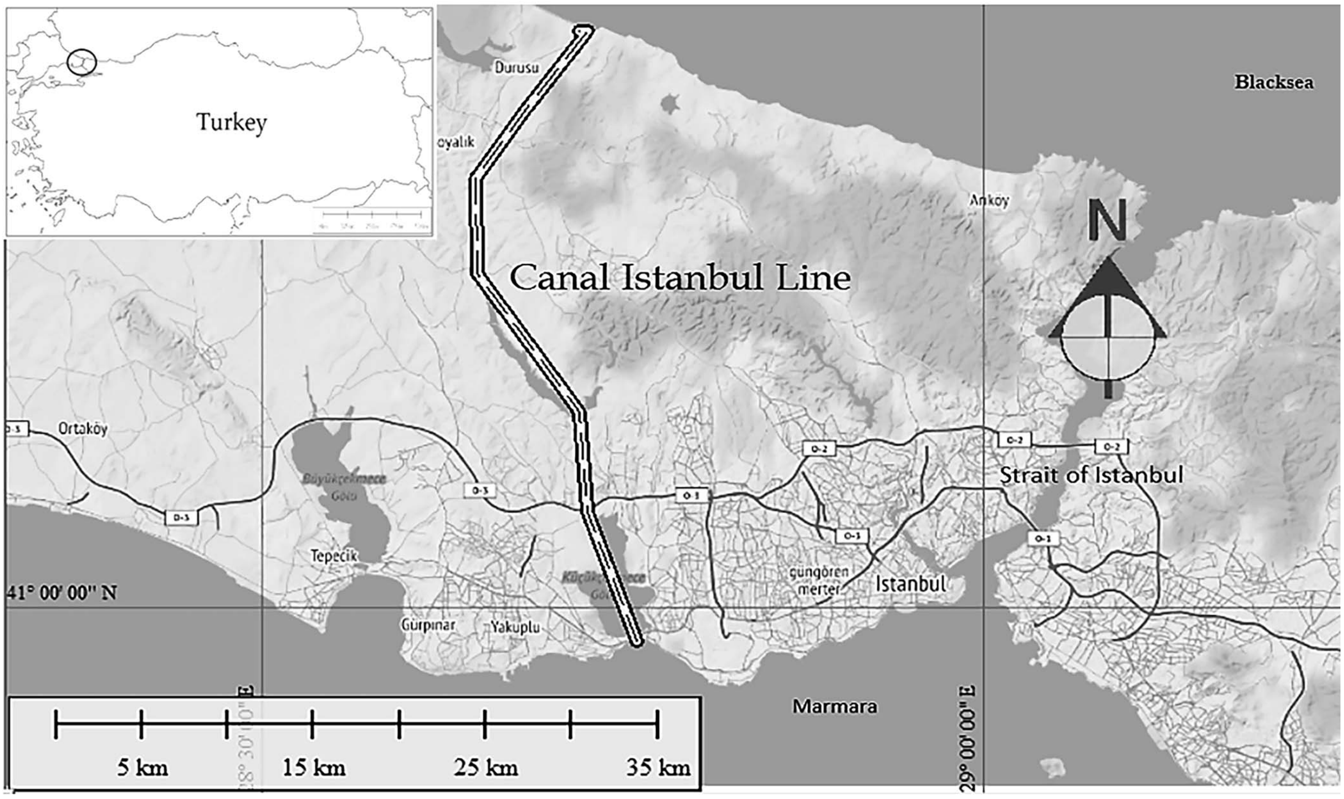

Figure 1. Comparison of the Strait of Istanbul and possible location of Canal Istanbul.

Unal *et al*., 2011). The emissions generated by the existing local and transit vessel traffic in SoI, where approximately 15 million people live, account for about 10% of the current emissions (Deniz and Durmuşoğlu, 2008; Kesgin and Vardar, 2001). Bayirhan *et al*. (2019) investigated exhaust emissions from ships from local companies traveling on SoI in 2019. Their study has shown that the emission values emitted by chimneys of ships operating in the region produce a significant result (Bayirhan *et al*., 2019). The results obtained for the Kandilli station showed that international sea traffic in the Istanbul Strait has an explanatory power on the averages of PM10 in the region (Kodak, 2022). According to a study of flue gas emissions from transit ships passing through SoI in 2015, 18,324 tons of NO_X, 2,138 tons of CO, 5,294 tons of SO_X, 937,017 tons of CO_2, 692 tons of particulate matter (PM), and 693 tons of volatile organic compounds (VOC) were emitted (Tokuşlu and Burak, 2021). Before all artificial channel projects are created, energy efficiency, environmental pollution, and opportunities for safe navigation are among the main concerns of parties to marine transportation (Bayırhan, 2020). These emissions from ships adversely affect human health, comfort, and the environment (Tokuşlu, Bayirhan, and Gazioglu, 2020; Ülker *et al*., 2020). The studies on the Panama Canal after the new enlargement are among the leading developments in this regard: The most significant impact of the change is a significant reduction in GHG emissions as a result of increased ship size that can use the canal. Carral *et al*. estimated that the GHG reduction would be approximately 9.54 million tons of CO_2 (Carral *et al*., 2020). Another future route that could shorten shipping distances for vessels sailing around the Strait of Malacca from East Asia to Europe is across Thailand's Kra Isthmus. The Kra Canal, also known as the Carat Canal, would decrease the East Asia–Middle East route by over 1200 km (Rahman *et al*., 2016). The Kra Canal was shown not to have an emission advantage in terms of pollution emissions. The main reasons for the lack of a significant decarbonizing effect include the Kra Canal's limited shorter sailing distance compared to the Panama Canal and emitting additional significant emissions during the canal sailing period (Tseng and Pilcher, 2022). According to the research on exhaust emissions from ships in the Suez Canal, the Suez Canal receives 8.16 million tons of air pollutants annually. The amount of exhaust emissions will significantly affect the health of those who live nearby, in addition to impacting climate change (El-Taybany

Table 1. *Comparison of Canal Istanbul and SoI*.

	Canal Istanbul	Strait of Istanbul
Length (km)	45	31
Min. width (m)	275	698 (minimum)
Depth (m)	20.75	35

Comparison titles are given in the first column, and the Canal İstanbul and SoI data are given in the second and third columns.

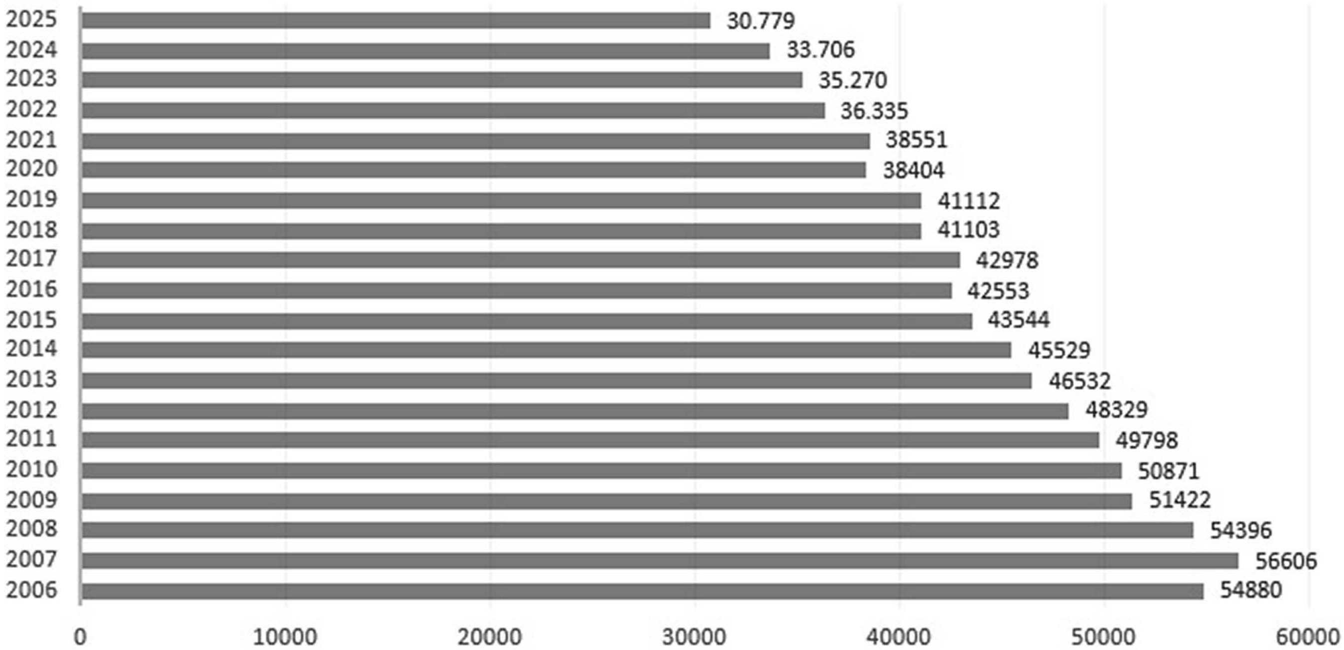

Figure 2. Number of ships passing through the SoI is decreasing.

et al., 2019). For this reason, it is crucial to calculate the ship-sourced exhaust emissions inventory, examine its effects, and follow up with academic studies. To this end, the present study examines the potential exhaust emission to be generated by the ships if Canal Istanbul is opened for use. In addition, the exhaust emissions by years from the ships in Canal Istanbul are calculated

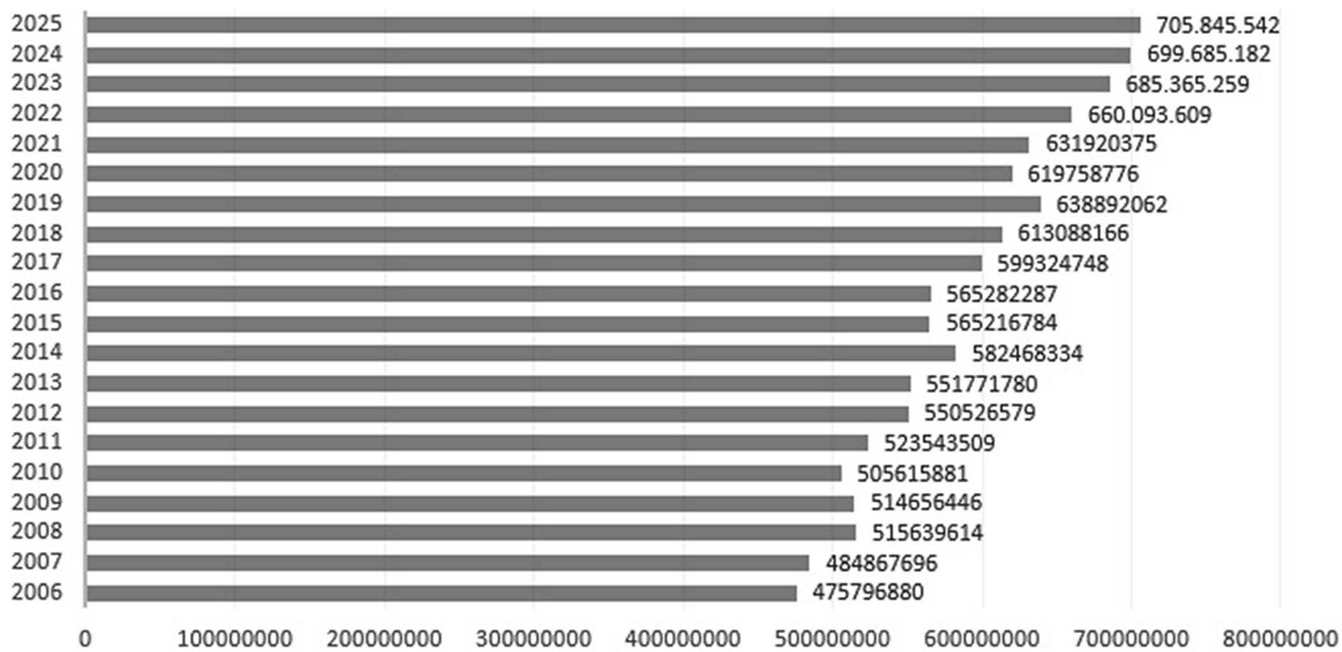

Figure 3. Gross tonnage of ships passing through the SoI is increasing; see Figure 2.

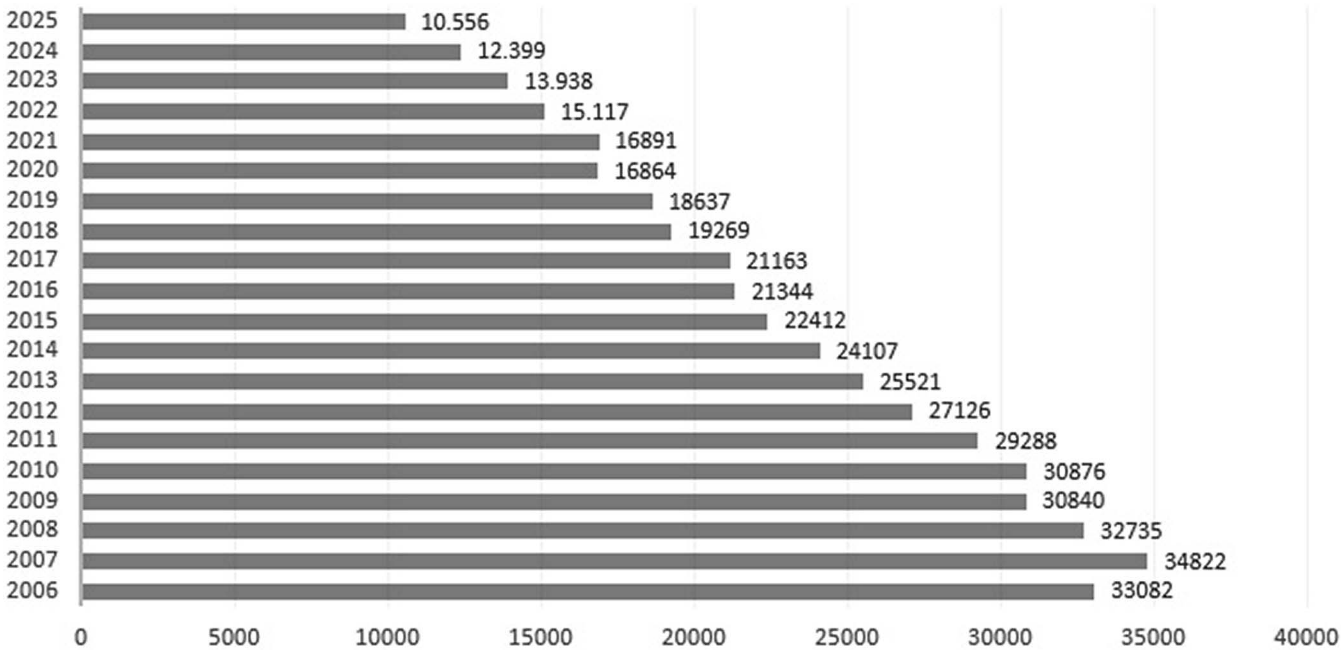

Figure 4. Change in the number of general cargo ships passing through the SoI.

and presented. Studies of this sort are valuable to all stakeholders for policy formulation in terms of traffic congestion issues and environmental sustainability with regard to the Strait of İstanbul.

The remainder of this study is structured as follows: The "Canal Istanbul Project Area and Strait of İstanbul: A Synopsis" section presents a synopsis of Strait of İstanbul.

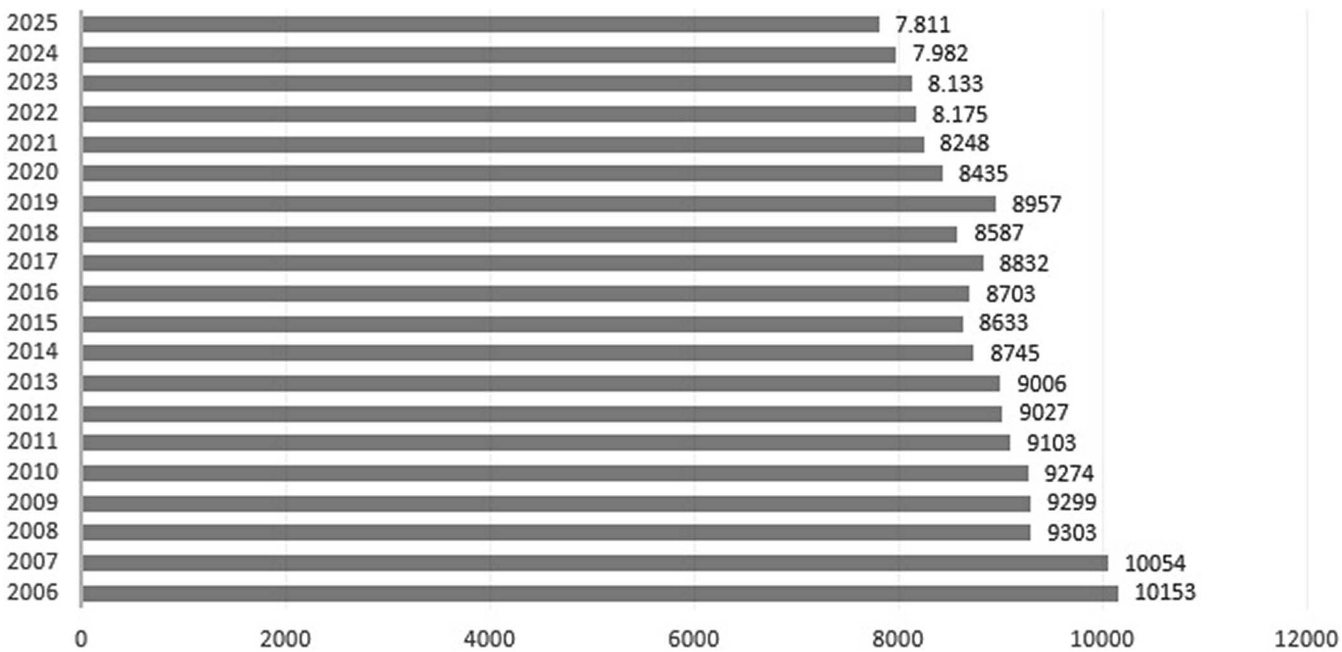

Figure 5. Change in the number of tankers passing through the SoI.

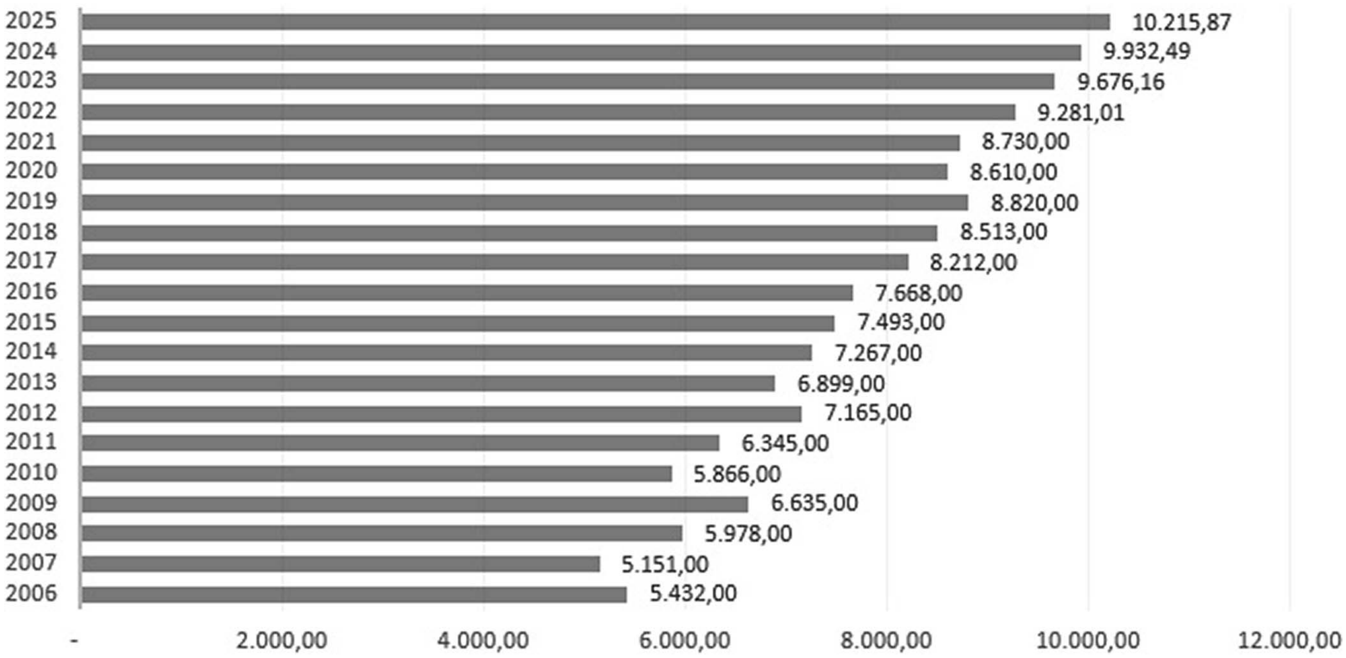

Figure 6. Change in the number of solid bulk ships passing through the SoI.

Subsequently, The "Future Ship Traffic of the Strait of İstanbul" section renders the prospect of Strait of İstanbul and its geographical description. The "Methods" section dwells on the methodology, while the "Results" section discusses the result. Concluding remarks are offered in the "Conclusions" section, with appropriate policy prescriptions.

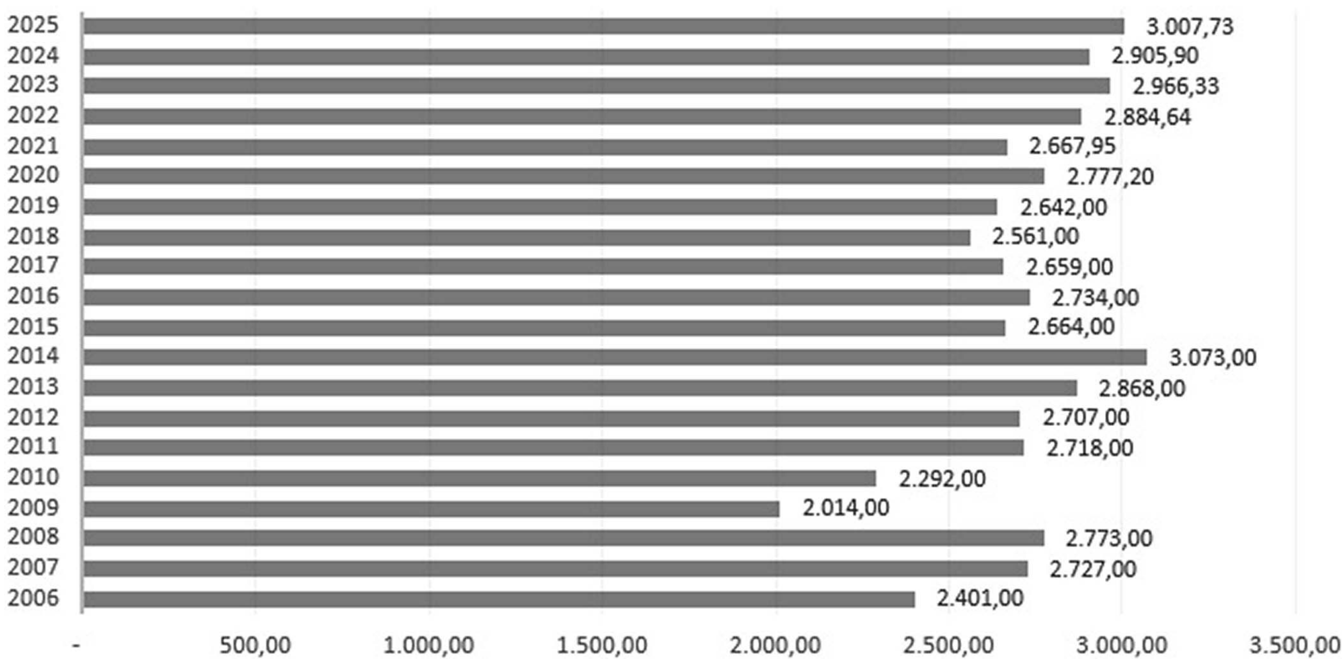

Figure 7. Change in the number of container ships passing through the SoI.

Table 2. *Evaluation matrices of models showing the steps of the calculation.*

	Evaluation tool	Forecasting method	1-step ahead	2-step ahead	3-step ahead	4-step ahead
Total number of ships	MAE	Gaussian	718.1013	801.4219	747.6006	606.5306
		SMO	266.7881	340.8895	417.4363	440.0314
	RMSE	Gaussian	936.3801	1030.995	991.8602	853.6352
		SMO	378.8911	433.3826	489.1994	518.4804
	MSE	Gaussian	876,807.74	1,062,951	983,786.6	728,692.98
		SMO	143,558.49	187,820.4	239,316.1	268,821.94
Gross tonnage of ships	MAE	Gaussian	19,082,781	21,185,144	20,172,992	20,118,775
		SMO	6,078,136.2	5,041,876	7,262,433	6,948,692
	RMSE	Gaussian	21,301,225	23,273,732	22,399,620	22,767,088
		SMO	10,205,177	9,141,948	10,615,775	10,686,083
	MSE	Gaussian	4.537E+14	5.42E+14	5.02E+14	5.183E+14
		SMO	1.041E+14	8.36E+13	1.13E+14	1.142E+14
Number of general cargo ships	MAE	Gaussian	803.4842	881.6109	863.8731	805.3971
		SMO	182.7368	266.4163	314.2681	337.6408
	RMSE	Gaussian	882.5505	944.904	929.5469	873.9634
		SMO	311.2984	361.2245	393.2525	426.2062
	MSE	Gaussian	778,895.46	892,843.6	864,057.5	763,811.98
		SMO	96,906.697	130,483.2	154,647.6	181,651.71
Number of tankers	MAE	Gaussian	163.742	165.5441	162.9679	173.6646
		SMO	74.4522	92.0032	113.8169	132.8824
	RMSE	Gaussian	179.4899	182.174	182.2455	193.7635
		SMO	157.1895	169.6267	176.7239	193.7042
	MSE	Gaussian	32,216.639	33,187.36	33,213.41	37,544.294
		SMO	24,708.548	28,773.23	31,231.34	37,521.324
Number of solid bulk ships	MAE	Gaussian	397.6766	418.8834	405.4341	454.2882
		SMO	144.532	184.1835	221.1702	272.4507
	RMSE	Gaussian	420.7781	443.0968	435.1413	473.1717
		SMO	220.3889	255.2158	269.1141	299.9173
	MSE	Gaussian	177,054.18	196,334.8	189,348	223,891.47
		SMO	48,571.282	65,135.11	72,422.4	89,950.368
Number of container ships	MAE	Gaussian	73.2574	45.1	38.4982	37.3993
		SMO	46.7696	40.5148	39.0775	44.2849
	RMSE	Gaussian	99.6501	48.5671	43.2774	45.534
		SMO	71.5459	58.5683	56.2341	61.3796
	MSE	Gaussian	9930.1396	2358.764	1872.934	2073.348
		SMO	5118.8173	3430.244	3162.278	3767.4608

Canal Istanbul Project Area and Strait of İstanbul: A Synopsis

The Project includes Avcılar, Küçükçekmece, Sazlıdere, and Durusu districts and Küçükçekmece Lake. The length of the Canal will be approximately 45 km, base width of a minimum 275 m, and a depth of 20.75 m. A press conference was held for Canal Istanbul at the beginning of 2018, and it was stated that research was carried out on five different lines for this project. As a result of the research, it was announced that the Küçükçekmece–Sazlıdere–Durusu corridor was determined to be the best route for Canal Istanbul. Located on the Çatalca Plateau, this mega project starts from Küçükçekmece Lake in the south and continues to the end point of the lake. At the lake's exit, it turns slightly in the NW direction and reaches the section where the Sazlıdere Dam is located, reaching the east of Sazlıbosna Village, and from there to the east of Dursunköy (Canal Istanbul official website, 2020).

Table 3. *Trozzi's fuel consumption table.*

Ship type	Daily consumption
Solid bulk	C = 20.186 + 0.00049 × GT
Tanker	C = 14.685 + 0.00079 × GT
General cargo/inland cargo ship	C = 9.8197 + 0.00143 × GT
Container	C = 8.0552 + 0.00235 × GT
Passenger/Ro-Ro/cargo	C = 12.834 + 0.00156 × GT
Passenger ship	C = 16.904 + 0.00198 × GT
High speed ferry	C = 39.483 + 0.00972 × GT

The daily fuel consumption formulas depend on the ship type. The only variable is gross tonnage of the ship.

From the other side, the geographical boundaries of the SoI are determined as the line connecting the Anatolian Lighthouse to Rumeli Lighthouse in the north and the line connecting Ahırkapı Lighthouse to Kadıköy İnciburnu Lighthouse in the south, according to the Istanbul Port Regulation (Turkish Ministry of Transport, 2011). Within these limits, the length of the SoI from the midline is 17 nautical miles (31 km). The route of the Canal Istanbul project and the view of the SoI are shown in Figure 1. The narrowest part of the SoI is 698 m between Aşiyan–Kandilli, the widest point is around 3,500 m in Büyükdere, and the average width is 1,500 m. The SoI is a

Table 4. *Daily fuel consumptions of ships.*

Type of vessel	Daily fuel consumption (tonne)
General cargo	561,794.2792
Tanker	364,893.2736
Solid bulk	503,959.6903
Container	487,266.9663

Daily consumption is the most important parameter for calculating emissions.

Table 5. *Proposed emission factors (kg/ton of fuel).*

Mode	Engine types	NO_X	CO_2	VOC	PM
Cruising	Steam turbines – BFO	6.98	3200	0.085	2.50
	Steam turbines – MDO	6.25	3200	0.5	2.08
	High speed diesel engines	70	3200	3	1.5
	Medium speed diesel eng.	57	3200	2.4	1.2
	Slow speed diesel engines	87	3200	2.4	1.2
	Gas turbines	16	3200	0.2	1.1

These factors are used for calculating the emission of the ship. Daily emissions can be calculated by combining the data of Tables 4 and 5.

waterway that should be navigated carefully, with sharp turns between 45–80 degrees. The average water depth is around 35 m, and the shallows, rocks, and benches are essential issues to consider regarding navigation safety (DGCS, 2020).

The current system in the SoI has a two-layered structure, the surface current between the Black Sea and the Marmara Sea from north to south and the bottom current from south to north between the Marmara Sea and the Black Sea. In addition, "the orkoz" current is also present. This current makes itself felt when strong winds blow from south to north. By causing the waters to rise at the Marmara entrance of the SoI, it creates a reverse current, and from time to time, the speed of this current can reach 6–7 kt. Considering these currents while crossing the SoI and cruising along the SoI is crucial. Being a narrow waterway due to its geographical structure, strong currents, sharp turns up to 45 degrees, adverse weather, sea, and climatic conditions, the SoI maintains its feature of being one of the most challenging straits of the world (Tokuşlu, 2019). The width, depth, and lengths of Canal Istanbul and the SoI are given in Table 1.

It is evident that the SoI is a shorter path for ships and an easily navigable path, with minimum 698 m width and a minimum 35 m depth. Even Canal Istanbul is considered an alternative to the SoI. Only vessels between 275 m and 350 m in length, 49 m in width will be able to pass through the Canal. In addition, these vessels must have maximum 17 m draft.

Future Ship Traffic of the Strait of İstanbul

When the Maritime Statistics of the Ministry of Transport and Infrastructure are examined, the ship traffic in the Turkish Straits, especially in the SoI, shows a tendency to decrease. Figure 2 was prepared based on the Ministry of Transport and Infrastructure Maritime Statistics data.

In Figure 2, the first 16 columns show the number of ships passing through the SoI, and the last four columns show the estimated number of ships using SMOreg. In this study, the number of vessels that pass through the SoI is calculated using SMO reg, and the vessels passing through the SoI are analyzed in four groups. They are general cargo ships, container ships, tankers, and solid bulk ships.

Nevertheless, the total tonnage of the ships passing through the Strait increases yearly. Figure 3 shows the change for the last 16 years and possible changes in the next 4 years.

General Cargo Ships

According to the statistics of the last 16 years, the average number of general cargo ships passing through the Strait is 26,867 per year. That means 56% of ships are general cargo ships. Figure 4 shows the change for the last 16 years and possible change in the next four years.

Figure 4 shows a decrease in the number of general cargo ships passing through the Strait.

Tankers

Considering the number of ships passing through the SoI, tankers take second place. According to the statistics of the last 16 years, the average number of tankers passing through the Strait is 7900 per year. That means 19% of ships are tankers. Figure 5 shows the change for the last 16 years. According to Figure 5 there is a decrease in the number of tankers that pass through the Strait.

Solid Bulk Ships

The number of solid bulk ships increases year to year. According to the statistics of the last 16 years, the number of ships that passed in 2019 was 8820, but the number of ships that passed in 2006 was 5432. It is clear that there is about 62% increase. In addition, the number of ships that will pass in 2025 is expected to be about 10,229. Figure 6 shows the change for the last 16 years.

Container Ships

Container ships are a significant ship type in maritime trade. Of course, container ship traffic in the SoI is expected to increase, but according to the statistics of the last 16 years, container ship traffic can be assumed stable neglecting years 2009 and 2014. Figure 7 shows the change for the last 16 years.

METHODS

In this study, the emissions of the vessels were calculated in two steps. At first, the total fuel consumption of the ships was calculated. Then, the Trozzi and Vaccaro method was used, and

Table 6. *Hypothetical ship emissions in the Canal Istanbul in 2021 and Ship emissions in the SoI in 2021 (tonne).*

	General cargo	Tanker	Solid bulk	Container	Total
Canal Istanbul					
NO_X	2596.365969	1686.376158	2329.079946	2251.933521	8863.755594
CO_2	145,760.8965	94,673.7492	130,755.3654	126,424.338	497,614.3491
VOC	109.3206724	71.0053119	98.06652405	94.81825351	373.2107618
PM	54.66033619	35.50265595	49.03326203	47.40912675	186.6053809
SoI					
NO_X	1725.10394	1120.4792	1547.5110	1496.252622	5889.346835
CO_2	96,847.94051	62,904.0974	86,877.8126	84,000.14723	33,0629.9977
VOC	72.63595539	47.1781	65.1584	63.00011042	247.9724983
PM	36.31797769	23.5890	32.5792	31.50005521	123.9862492

If the construction of Canal Istanbul were completed, the emissions would be as in this table.

Table 7. *Hypothetical ship emissions in the Canal Istanbul in 2025 and Ship emissions in the SoI in 2025 (tonne, SMOreg).*

	General cargo	Tanker	Solid bulk	Container	Total
Canal Istanbul					
NO_X	1752.407365	1123.963224	1271.346616	679.2764636	4826.993669
CO_2	98,380.76437	63,099.68978	71373.84511	38,134.81901	270,989.1183
VOC	73.78557328	47.32476734	53.53038383	28.60111426	203.2418387
PM	36.89278664	23.66238367	26.76519192	14.30055713	101.6209194
SoI					
NO_X	1164.352363	746.7951	844.7211	451.3317914	3207.200332
CO_2	65,367.1502	41.925.3390	47,422.9376	25,337.92513	180,053.352
VOC	49.02536265	31.4440	35.5672	19.00344385	135.040014
PM	24.51268132	15.7220	17.7836	9.501721925	67.520007

According to SMOreg, the emissions will be as in this at the end of the first year of Canal Istanbul.

possible NO_X, CO_2, VOC, PM, and SO_X emissions of the ships were calculated.

In the study, data on the total number of ships, gross tonnage of ships, number of general cargo ships, number of tankers, number of solid bulk ships, and number of container ships for the years 2006–2021 were used. Forecasts were made for the years 2022 to 2025. Time series forecasting was conducted using The Waikato Environment for Knowledge Analysis (WEKA), machine learning software written in Java. WEKA was developed at the University of Waikato, New Zealand. It was created in 1992 (Arora and Suman, 2012). A Time Series Analysis and Forecasting package with several different algorithms is available in WEKA. In this research, two different mining algorithms, namely Gaussian Process and SMO Regression, were used. The forecasted values were submitted from Figures 2 to 7.

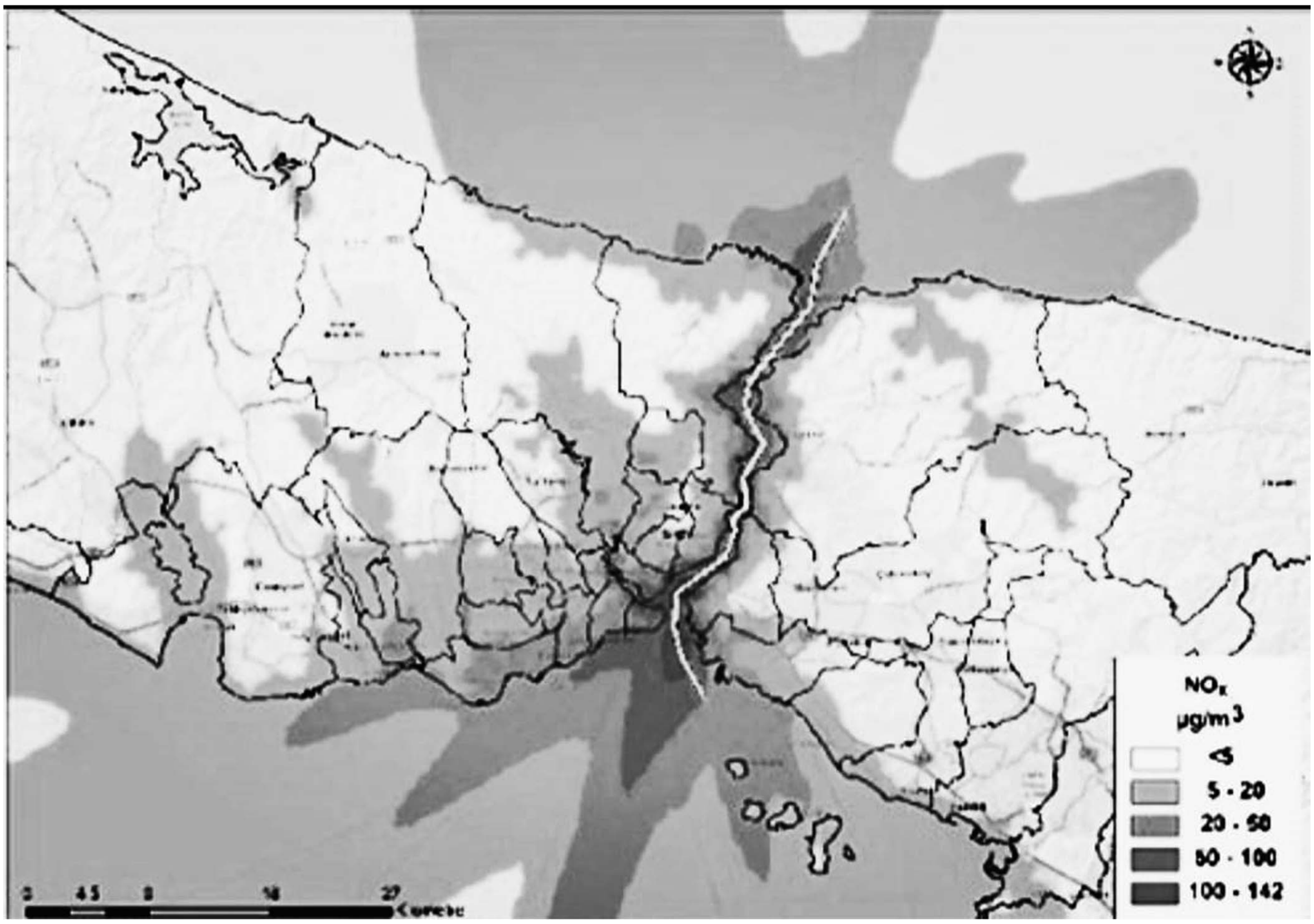

Figure 8. Ship-sourced NO_X emission according to 2017 data. Affected areas are around the SoI.

Figure 9. Possible ship-sourced NO_X emissions. Likely to be affected areas are around the SoI and Canal Istanbul; a large part of the European side of Istanbul is affected.

The Gaussian Process is the first selected algorithm. Normal distribution is the base distribution of Gaussian processes. The other name for normal distribution is Gaussian distribution, named for the famous scientist Johann Carl Friedrich Gauss. The Gaussian Process is the generalization of a multivariate normal distribution to an infinite number of variables (Mori and Nakano, 2016). The Gaussian process classifier used in the WEKA Forecasting Time Series package applies Gaussian processes for regression without hyperparameter tuning. The normalization process on the target attribute was used to simplify an appropriate noise level selection for the missing values, and global mean-mode values are used (Gaussian Processes class web page, 2022).

The following selected algorithm is SMO regression. It was based on the sequence minimum optimization (SMO) algorithm. SMO is a basic machine learning algorithm. It provides a fast and efficient solution to support vector machine (SVM) quadratic programming (QP) issues (Munir and Wardoyo, 2015). SMO does not require extra matrix storage. For every subproblem, SMO does not conduct an iterative numerical process (Dael, Yavuz, and Almohammedi, 2022). These are valuable points of SMO.

Algorithm performance was evaluated through mean absolute error (MAE), root mean square error (RMSE), and mean squared error (MSE).

Mean absolute error (MAE) is one of the simple and fundamental methods in determining forecast accuracy. The absolute differences between actual and forecasted values could be defined as absolute error. Averaging the error terms gives mean absolute error (MAE). MAE exposes the expected average error amount from the projection. MAE is defined as:

$$\mathrm{MAE} = \frac{\sum_{n=1}^{N} |\hat{r}_n - r_n|}{N} = \frac{\sum_{n=1}^{N} \mid e_n \mid}{N} \tag{1}$$

where $\hat{r}_n$means the forecasted value, r_n is the actual value, and N is the total number of points (Wang and Lu, 2018).

The Second evaluation tool is RMSE. It is the measure of the standard deviation of the error. The general usage of RMSE not only depends on easily understanding the scoring system, but also relies upon compatibility with major statistical

Figure 10. Ship-sourced PM_{10} emission according to 2017 data. Affected areas are around the SoI.

assumptions. (Dael, Yavuz, and Almohammedi, 2022). RMSE is defined as:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{n=1}^{N} (\hat{r}_n - r_n)^2}{N}} \tag{2}$$

while $\hat{r}_n$ is the estimated time series, and r_n is the actual value (Van Werkhoven *et al.*, 2008). The last metric is mean squared error (MSE). MSE measures forecast error variability. MSE could be defined as a probability distribution function that evaluates the expected value of squared error loss (Dael, Yavuz, and Almohammedi, 2022) MSE is defined as:

$$\mathrm{MSE} = \frac{\sum_{n=1}^{N} (\hat{r}_n - r_n)^2}{N} = \mathrm{RMSE}^2 \tag{3}$$

while $\hat{r}_n$ is the estimated time series, and r_n is the actual value (Pandey and Rajpoot, 2016).

As a result, the SMO algorithm performed better than Gaussian Process. Finally, possible emissions were calculated by using SMOreg (Table 2).

First: Total Fuel Consumption

In this step, Trozzi's fuel consumption table is used (Table 3). This table shows the relation between ship type, gross tonnage (GT), and daily fuel consumption. Furthermore, the coefficient of this table is called Trozzi's constant in this study.

Proposition

According to this table, the daily fuel consumption of solid bulk carriers, tankers, general cargo ships, and container ships can be calculated using the total gross tonnage of the ships passing through the SoI and Canal Istanbul.

In Equation 4, n is the number of ships, a and b are Trozzi's constant, and G_i and C_i are the gross tonnage of ship i and daily fuel consumption of ship i, respectively, then the total daily fuel consumption of n ship is;

$$\sum_{i=1}^{n} C_i = n \times a + b \times G \quad \text{where} \quad G = \sum_{i=1}^{n} G_i \tag{4}$$

Proof

Let $C_1, C_2, C_3, ..., C_n$ be the daily fuel consumptions of ship 1, ship 2, ship 3, and ship *n,* respectively. It is clear that;

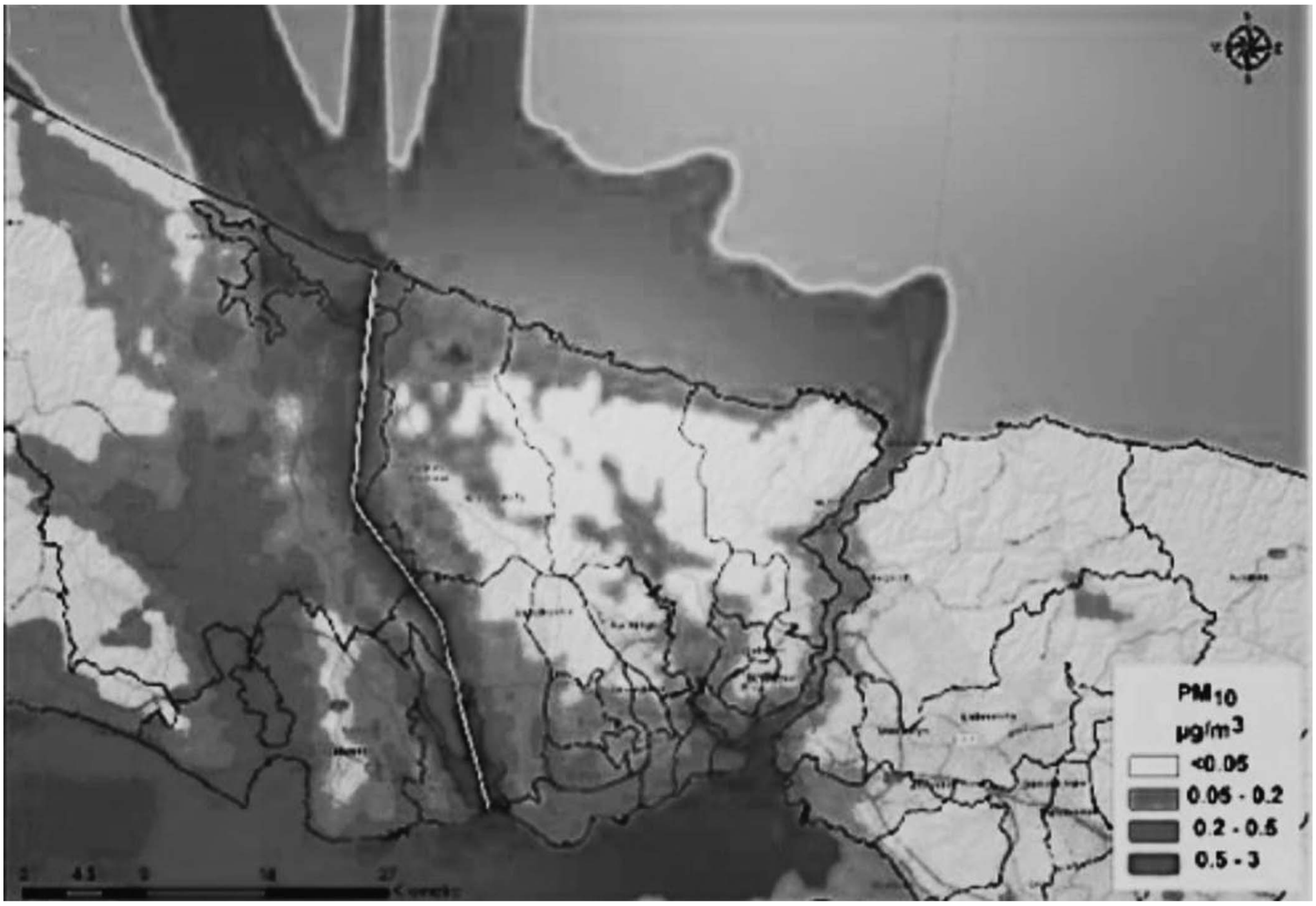

Figure 11. Possible ship-sourced PM_{10} emission. Likely to be affected areas are around the SoI and Canal Istanbul, a large part of the European side of Istanbul is affected.

$$\begin{aligned} C_1 &= a + b \times G_1 \\ C_2 &= a + b \times G_2 \\ C_3 &= a + b \times G_3 \\ &\vdots \\ C_n &= a + b \times G_n \end{aligned} \tag{5}$$

Where G_1, G_2, G_3, ..., G_n are gross tonnages of ship 1, ship 2, ship 3, and ship n. Then,

$$\begin{aligned} C_1 + C_2 + C_3, + \ldots + C_n &= (a + b \times G_1) + (a + b \times G_2) \\ &\quad + (a + b \times G_3) \ldots + (a + b \times G_n) \\ \sum_{i=1}^{n} C_i &= (a + a + a + \ldots + a) + \mathrm{b} \times (G_1 + G_2 + G_3 + \ldots + G_n) \\ &= n \times a + b \times G \end{aligned} \tag{6}$$

Therefore, the desired result is obtained. This formula helps to calculate the total fuel consumption of the ships. According to statistics, total daily fuel consumption of the ships is given in the Table 4.

Second: Trozzi and Vaccaro Method

In the second part of the study, the Trozzi and Vaccaro method is used. According to this method, there is an emission factor for each exhaust gas. So, the calculation formula of this method is as follows:

$$E = C \times f \times t \times 0.8 \tag{7}$$

where, C is fuel consumption (tonne), f is the emission factor, t is time (day), and 0.8 is sailing mode multiplier. Emission factors are given at Table 5.

RESULTS

In the first part of the study, Table 1 shows the differences between Canal Istanbul and The SoI. It is obvious that the Canal is longer than the Strait. So, ships will spend more time if they pass through the Canal. According to the Turkish Straits Maritime Traffic Regulations, the speed of passage of ships through the Istanbul and Çanakkale Straits is 10 kt. Nevertheless, the speed of passage of ships in Canal Istanbul are unknown. So, in this part of the study, the speed of passage is assumed to be 10 kt, and also transit time of the ships can be

Figure 12. Strait of Istanbul.

calculated by using the formula $distance = velocity/time$. Hence, the transit time of ships is 0.10135 day in Canal Istanbul and 0.06734 day in the SoI. The effect of this difference is shown at Table 6.

Table 6 shows that if the ships choose the Canal, total emissions will increase 33.5%. This table is for vessels that have a medium-speed diesel engine. Nevertheless, the engine type of ship does not change this rate. However, these emission values are calculated by using 2021 statistics. The Canal Istanbul project is expected to be completed in 2025. So, possible ship emissions in 2025 can be calculated by using SMOreg (Table 7).

There will be an increase in emission values if ships pass through the Canal Istanbul. Moreover, this increase will affect not only the SoI. Özdemir *et al*. showed the affected areas. Figures 8, 9, 10, and 11 show the affected areas (Özdemir, Tuygun, and Elbir, 2017).

DISCUSSION

Istanbul, Turkey, experiences extremely dense traffic, and, thus, is heavily affected by exhaust gas emissions. For this reason, every investment to be made on the Canal Istanbul route, which has a more natural and sensitive ecosystem, should be carried out by carefully considering environmental criteria. Policymakers should take environmentally friendly measures to achieve lower emissions and sustainability, taking into account the growing emission share of the transport sector. IMO's measures, such as the Energy Efficiency Design Index (EEDI), the Ship Energy Efficiency Management Plan (SEEMP), and the IMO 2020 sulfur convention, must be followed to manage the reduction of greenhouse gas emissions and fuel consumption over the next decade. Authorities should monitor and supervise users in compliance with international regulations and other legal frameworks. The use of Canal Istanbul by ships designed to use alternative fuels, such as hydrogen fuel, in accordance with the general recommendations, should be encouraged.

According to the United Nations Economic Commission for Europe (UNECE) 2013 report, the sector that will be most affected by climate change is maritime transport (UNECE, 2013). The report includes potential impact factors of climate change on maritime trade and other impacts related to these factors. With the change of temperature averages, high energy consumption, low water level, restriction of navigation in inland waters and a longer transportation season occur. For all these reasons, it is clear that a new transportation route needs to comply with sustainability and accessibility standards. Every increasing unit of GHG appears as an environmental problem that threatens human health in the first place.

With today's increased focus on environmental awareness and sustainability, scientists have a duty to avoid creating new environmental problems on top of existing environmental problems. It is possible, before the Canal is built, to conduct both oceanographic and maritime studies, since enough data hypothetically exist. As, for one example, the Black Sea and Marmara will react to a secondary unnatural mixing, and, for another example, the current sea and air pollution will change. The subject needs many more studies.

CONCLUSIONS

Due to historical and positional importance, the SoI is one of the most important straits in the world (Figure 12). Especially for Black Sea Basin countries, the SoI is the only option that links them with the world's oceans and other European countries. So, the traffic in the SoI is quite heavy. Furthermore, shipping boats, city lines, ferries, and recreational boats make this traffic heavier.

Therefore, Canal Istanbul idea emerged to reduce the SoI traffic in 2011. Transit ships will pass through the Canal with this project, which will cost about 10 billion dollars. Nevertheless, the number of transit ships that pass through the SoI decreased by 16,329 in the last 16 years. That means there is a 29.75% reduction in the number of ships. In other words, there is a tendency to decrease traffic density even if the Canal were not built.

Furthermore, if the transit ships pass through the Canal, annual total emissions will increase by approximately 90,000 tonnes, affecting the west of the SoI. Avcilar, Küçükçekmece, and Çatalca will be the most affected districts.

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