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SMART ESTIMATION OF POLLUTANT EMISSIONS FROM MARINE TRANSPORT

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ABASTRACT

The production and analysis of transport statistics is part of the process of maritime transport management and monitoring. As there is strong need to protect the environment through the reduction of greenhouse gas emissions by the transport sector, CO_2 in particular, it is necessary to assess the emissions of pollutants emitted by sea-going ships. The article presents an intelligent method of estimating pollution volumes based on harmonised sets of data on vessel traffic obtained from the monitoring of the Automatic Identification System and developed artificial intelligence models. The created methods allow estimating emissions of pollutants from individual sea vessels, aggregate pollutant amounts in a selected geographical area, or on a selected route and in port. The data obtained can be visualized for conducting statistical analyses. The work was performed under the TranStat project executed jointly with the Central Statistical Office.

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1. MARITIME TRANSPORT AS A SOURCE OF POLLUTANT EMISSIONS – THE IDEA OF FIT FOR 55

The European Union prepared an ambitious plan of reducing greenhouse gas emissions, known as the European Green Deal and Fit for 55 Package [1]. The plan assumes that greenhouse gas emissions will be reduced by 2030 by 55% compared to the base year 1990 and achieving climatic neutrality by 2050. The European Commission also proposed that the plan of emission reduction under the Fit for 55 package should include the maritime sector and be incorporated in the EU Emission Trading System (ETS). This means that shipping will incur the costs of CO_2 emissions. In particular, the plan refers to the inclusion of CO_2 emissions from commercial ships of gross tonnage greater than 5 000 regardless of the flag, which navigate in the European Union area and 50% of emissions from voyages that started or ended in EU ports. In addition, emissions from ships moored in ports will be included. It is also assumed that ships not later than two hours after mooring in a European port will stop emitting CO_2 by switching over to shore power supplies. Sea-going ships will be incorporated into EU Monitoring, Reporting and Verification (EU MRV) System. Therefore, estimation of greenhouse gases emissions becomes a necessity. This need fits in one of the goals of the TranStat project conducted by the Central Statistical Office and the Maritime University of Szczecin, addressing the building of a smart system of production of maritime transport statistics using big data. As part of that goal, the methodology was developed for estimating the volumes of pollutants emitted by ships engaged in sea transport. The methodology is based on monitoring of emissions in the project-covered area, i.e. ports of Gdańsk, Gdynia, Szczecin and Świnoujście. This article presents automatic estimation of CO_2 emissions in the area of Szczecin and Świnoujście ports.

2. CHARACTERISTICS OF THE DESIGNATED RESEARCH AREA AND VESSEL INFORMATION SOURCES

The estimation of CO_2 emissions was determined in the area of cartographic polygon, comprising the perimeter of the two ports, Szczecin and Świnoujście, and the fairway linking the two areas. Figure 1 depicts the port in Szczecin, Figure 2 in Świnoujście.

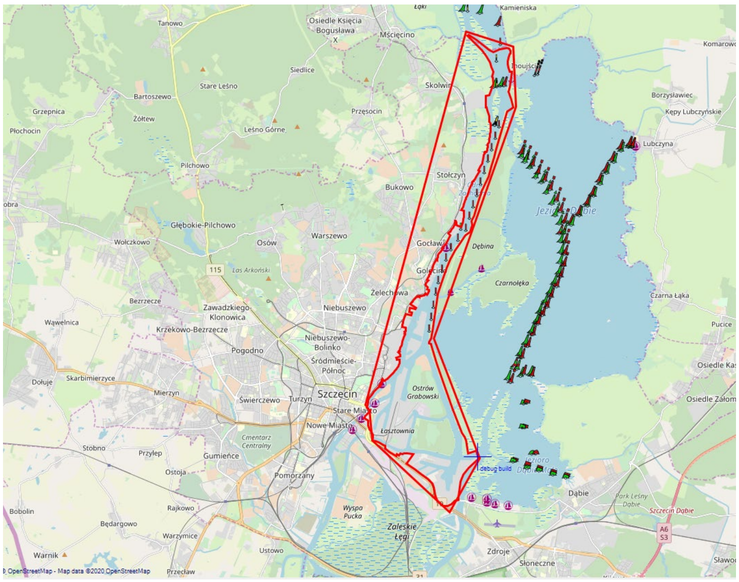

Fig. 1. The boundaries of Szczecin port, internal line - legal boundaries, external line - simplified perimeter.

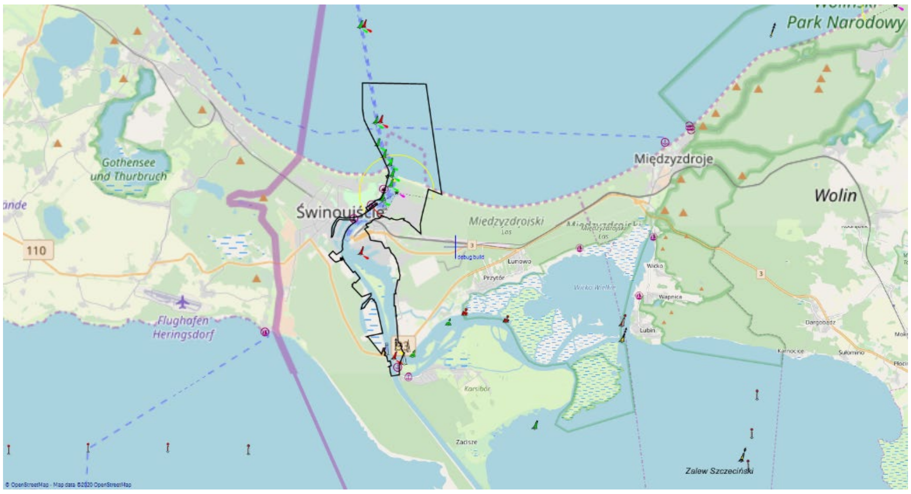

Fig. 2. The boundaries of Świnoujście areas, internal line - legal boundaries, external line - simplified perimeter.

The analysis covered callings of sea-going ships from 08.12.2021 to 21.12.2021. The basic source of information on the occurrence of emission source (ship) and ship movements is the Automatic Identification System (AIS). Two redundant sources were used, i.e. vessel traffic data from the Dataset on Maritime Transport, produced by the Central Statistical Office, and data recorded by AIS base stations located on the buildings of the Maritime University in Szczecin and Świnoujście.

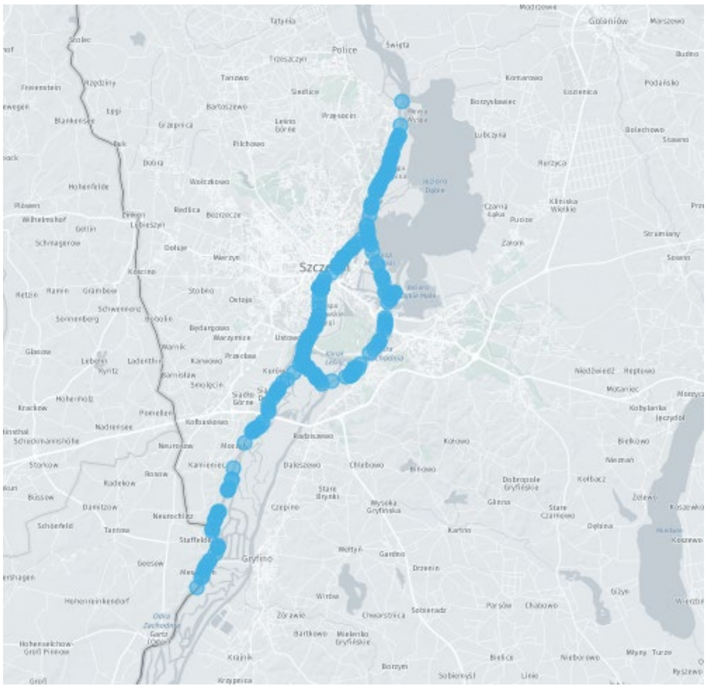

Fig. 3. The visualization of the AIS reception range of the base station at the Maritime University of Szczecin.

Received AIS messages, which in whole may serve as for a multi-faceted analysis, inference and integration with dedicated data sets, in our research made it possible to:

- identify the emission source;
- identify geometric parameters of the emission source;
- perform geolocation of the emission source;
- monitor the emission source;
- determine the time length the source of emission;
- combine AIS data with datasets on the Maritime Transport of the Central Statistical Office (CSO), Fig. 4.

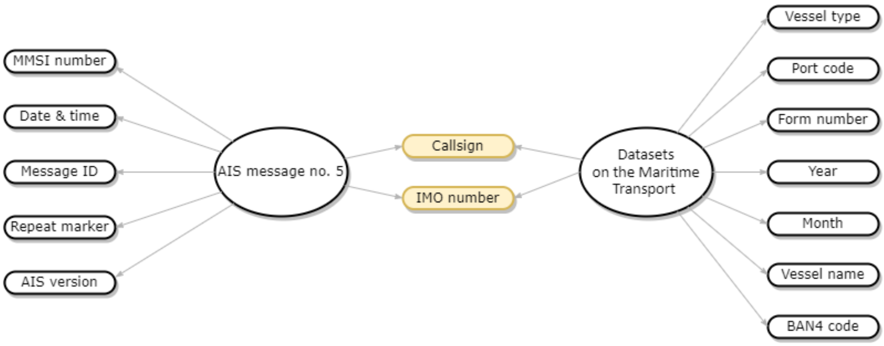

Fig. 4 . Combining AIS messages with the Dataset on Maritime Transport of the CSO.

3. THE METHODOLOGY OF CO_2 EMISSION ESTIMATION

The research problem has been formulated as a question: Is it possible to estimate CO_2 emissions from sea-going ships solely based on AIS messages?

The AIS system is a system of communication, which provides automatic exchange of data useful to ships for collision avoidance, but the AIS main function is to identify ships for land-based vessel traffic services. The AIS transmits the following types of data: dynamic data (ship's position, course, speed, information on course alteration and ship status), static data (name of ship, call sign, flag state, IMO number, MMSI number, year built, ship dimensions) and voyage specific data (port of destination, draft, estimated time of arrival - ETA). The adopted methodology, the AIS system was used to perform five above defined tasks.

The estimation of exhaust gas emissions from ships two general approaches are used for estimation and inventory [3]:

- fuel consumption,
- activity of ships.

The former approach is to estimate fuel consumption by ships, where the consumption figures are obtained from reporting systems and information on the volume of marine fuel sales and emission indicators related to these fuels. This approach is appropriate in estimates of high level of generality, regarding many ships as a whole, e.g. those operating in a given area, under jurisdiction of national administration etc. in a long period of time.

The latter approach is related to the energy-based activity of the given ship. Despite some difficulties in estimations, this approach has essential advantages, such as:

- individualized assessment of emissions,
- estimation of emissions in the context of time, place, water area, type of vessel, etc.,
- higher sensitivity to any changes, including legislation, e.g. in the context of Fit for 55 objectives.

The ship activity approach was adopted in this publication. In particular, the ENTEC method developed by the EU has been employed. It is a simplified method of $C0_2$ emission estimation based on emission indices expressing the mass intensity of pollutant streams associated with the developed power of main and auxiliary engines and generators in a specific time interval.

The ENTEC as a simplified method of emission estimation, but it requires detailed knowledge of engine power generated by ships, the power of propulsion units. These data are in possession of shipowners, classification societies, often are available at maritime administrations and specialized databases. The authors obtained data on ships that called at Szczecin from specialized bases. In the reference period, 193 different ships arrived in the port of Szczecin, some of them several times, a total of 1298 port-to-port passages (Fig. 11). These ships were used to build a model of pollution estimation.

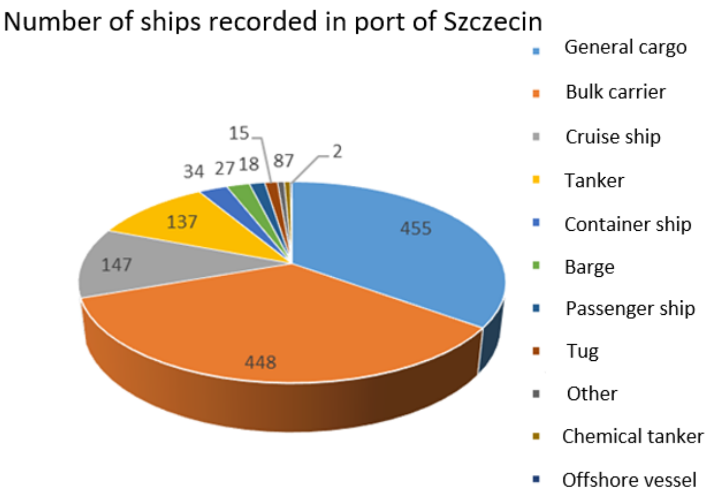

Fig. 5. The number of voyages recorded in Szczecin in 3rd quarter of 2019 by ship type.

4. THE ESTIMATION OF POLLUTION EMISSIONS BY THE ENTEC METHOD

The ENTEC method allows determining emissions of pollutants from a ship, including CO_2, based on the known power generated by its propulsion system. Calculations of pollutant emissions by the ENTEC method require the knowledge of the power of the main engine, auxiliary generators and shaft generators, operational status and type of ship. Using this method, the EU roughly assessed greenhouse gas emissions in its waters divided into 50 km x 50 km squares.

It was essential for the adopted methodology that the ENTEC approach allows estimating gas emissions during three different operational statuses of the ship, i.e. at sea, in port or manoeuvring. For each of these statuses, load coefficients should be used, given in Table 1.

Table 1. Assumption regarding engine operation for the different activities.

	% load of MCR for ME operation	% of time all MEs operating	% electric power from shaft generators	% load of MCR for AE operation
At sea	80	100	50	30
In port (using pumps)	20	100	0	60
In port	20	5	0	40
Maneuvering	20	100	0	50

Then the emission index from Table 2 is read, depending on the currently performed operations, ship type and type of estimated emissions:

Table 2. Emission indices for in-port operation regarding ship type.

In port	NO_x	SO_2	CO_2	HC	PM	sfc	NO_x	SO_2	CO_2	HC	PM
			In g/kW						In kg/tonne fuel		
A11 Liquefied gas	7.5	13.4	884	0,9	2.1	278	33	49	3179	3.7	7.8
A12 Chemical	13.3	12.1	710	1.5	2.2	223	60	53	3179	6.7	9.7
A21 Bulk dry	13.8	12	706	1.0	1.5	222	62	54	3179	4.5	6.8
A24 other bulk dry	13.6	12.0	709	1.0	1.5	223	61	54	3179	4.6	6.9

The emission is calculated as the product of power, load coefficient and emission index for the main engine, auxiliary and shaft generators. The sum is the total emission of the ship.

5. THE ESTIMATION OF POLLUTANT EMISSIONS BY SEA-GOING SHIPS

The access to data needed to calculate the emission by the ENTEC method is troublesome, sometimes impossible in real time. This is because obtaining these data for each examined ship requires access to specialist databases or ship's documents.

We assumed that the designed ships with identical or similar geometric parameters, functional type, engine power necessary for developing the service speed have similar characteristics [4]. Therefore, they will emit similar quantities of pollutants [5]. The adopted method for pollutant estimation utilized artificial intelligence for a reference population of ships, subsequently extended to include initially unknown ships, currently identified by the AIS system. In this connection, we prepared a model of neural network with training data calculated by the ENTEC method. The training data contained AIS reports from 193 ships selected out of 449, varying in service speeds and loading conditions. They were recorded in the vicinity of Szczecin and Świnoujście and the approach channels leading to Świnoujście, and emissions calculated based on parameters of engines and generators installed in those ships.

For computer methods of $C0_2$ estimation we assumed that emissions from the ship caused by fuel combustion will be correlated to the ship's dimensions, i.e. draft, length overall, breadth, its type and currently developed speed. These data can be directly received from AIS messages sent by ships. If there is a correlation between these parameters and emissions from the ship, then once the correlation is established, it will be possible to estimate emissions without further data sources.

The computer-based model was developed in the Python language using the Keras library. In the first step, invalid training data were filtered out as transmitted AIS reports may contain errors regarding vessel dimensions or speed. The important step consists in removing duplicates from messages received from one ship, i.e. messages containing the same or similar speed. The ship can move at constant speed and produce constant emissions for many hours, transmitting hundreds of messages, which were regarded as one training set. Leaving duplicate messages results in local overfitting of the neural network and poor generalization for ships significantly different from those included in training sets.

After many empirical tests, the proper form of a neural network was chosen. Its simplified structure is shown in Fig. 6. The input layer contains 104 neurons: (speed, length, breadth, draft) and all types of ships (0-99) – ship type value is categorical, not real.

The network contains two hidden layers, each with 32 neurons, with an activation function ReLu and an L2 regularization factor of 0.1. The output layer is one neuron – emissions of CO_2 are expressed in kg/h.

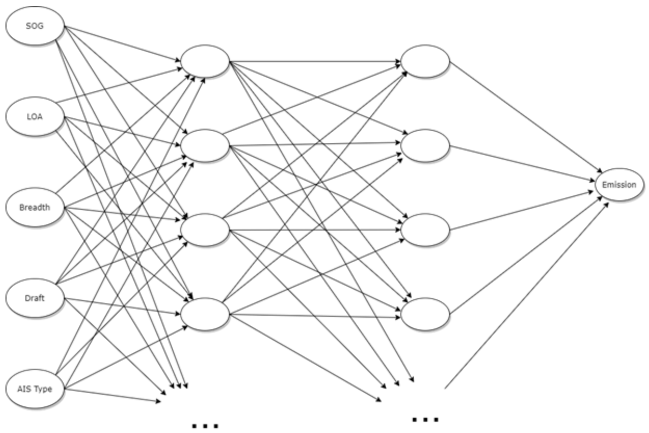

Fig. 6. The structure of the built neural network.

80% of the data held was used to train the network, the remaining 20% of the dataset was used as a test set. The figure below presents the value of emissions determined by the neural network compared to the value from the data. The red line shows a perfect fit.

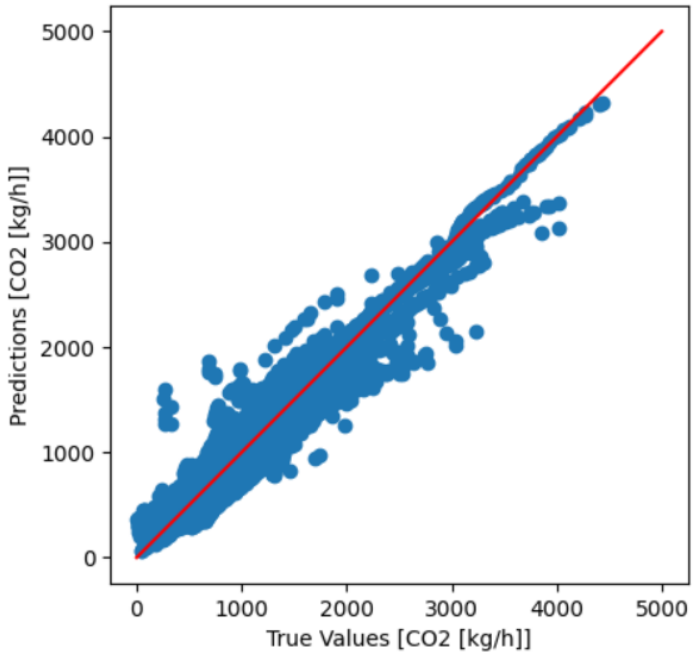

Fig. 7. Values of CO_2 emissions determined for test data compared to values calculated analytically.

The histogram displays errors for test data. It is close to a normal distribution, although it slightly overestimates the determined emissions.

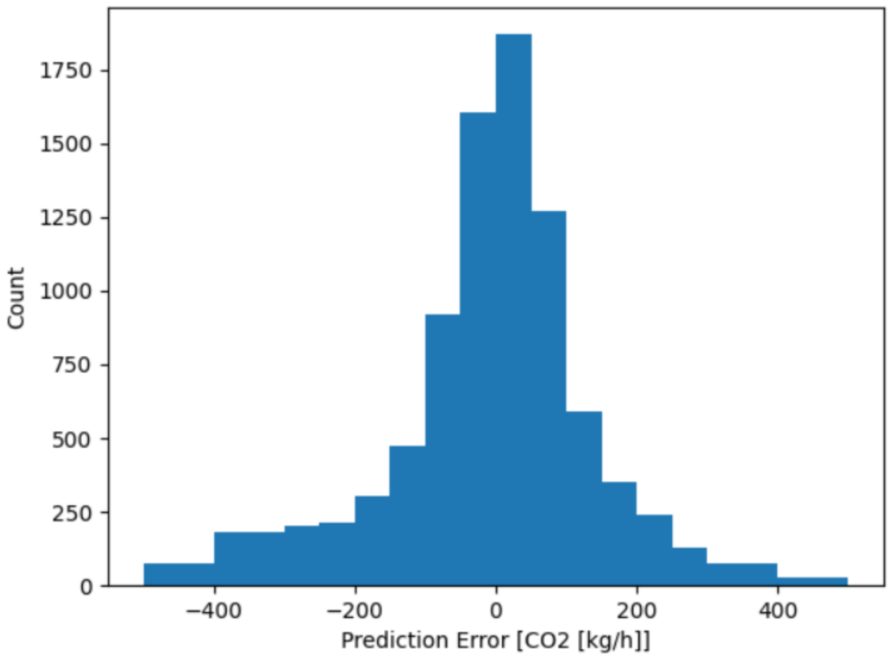

Fig. 7. Histogram of errors in estimations of CO_2 emissions.

6. RESULTS AND DISCUSSION

The use of the model is particularly beneficial when studying a large population of vessels, for instance yearly emissions within an sea or port area, where obtaining precise data of all vessels would be time consuming and expensive. The training dataset was derived from vessels calling at Szczecin and Świnoujście. These ports have different characteristics and the ships mooring there are not representative for the world fleet. Nevertheless, the results confirm that the estimation of CO_2 emission by AI methods is possible.

The CO_2 estimation model was validated for real ship voyages in the period 08.12.2021 - 21.12.2021 in the area covered by AIS receivers of Szczecin Maritime University in Szczecin, Świnoujście and Kołobrzeg, narrowed down to the area limited by the coordinates: 52°50' N - 54°20' N and 014°00' E - 016°20' E (Figure 8). During the period and area surveyed, 353 vessels were observed.

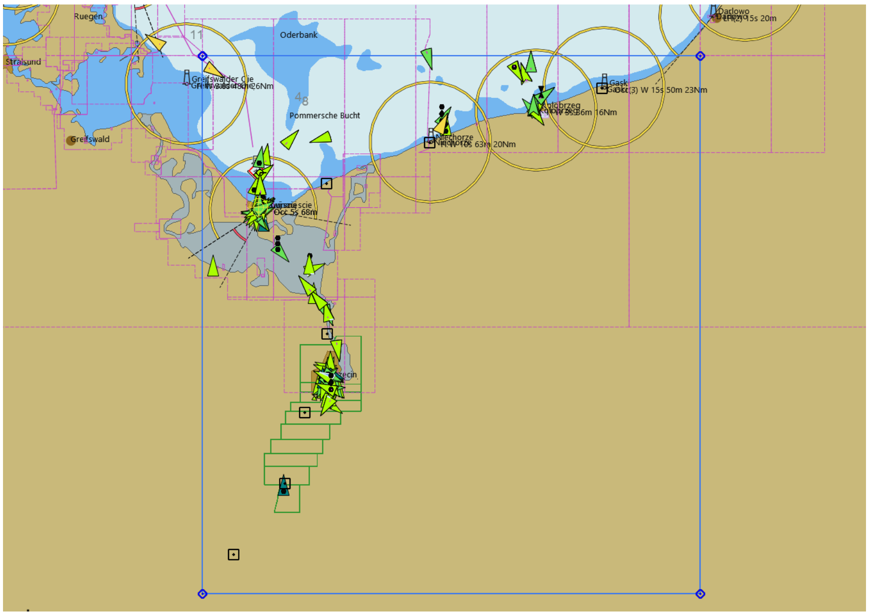

Fig. 8. Area of emissions survey.

Figure 8 shows the total daily CO_2 amounts emitted from 08.12.2021 to 21.12.2021 by all vessels in the entire monitored area. The emissions are given in tons of CO_2.

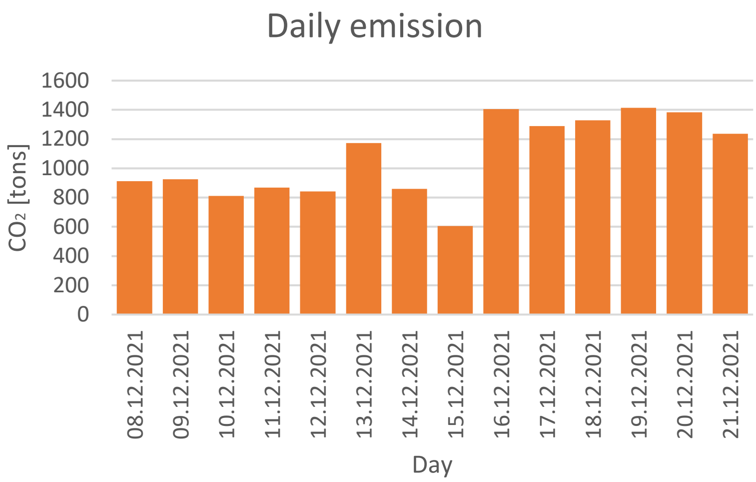

Fig. 9. Total daily emissions of CO_2.

Figure 10 shows the aggregate emissions for the period 08.12.2021 to 21.12.2021 in the same area. Emissions from all vessels have been aggregated to a resolution of 0.1 degrees longitude and latitude. CO_2 emissions are expressed in tons. The three visible spikes are the emissions registered in the ports of Szczecin, Świnoujście and Kołobrzeg. Most of the exhausts comes from ships moored in the three ports.

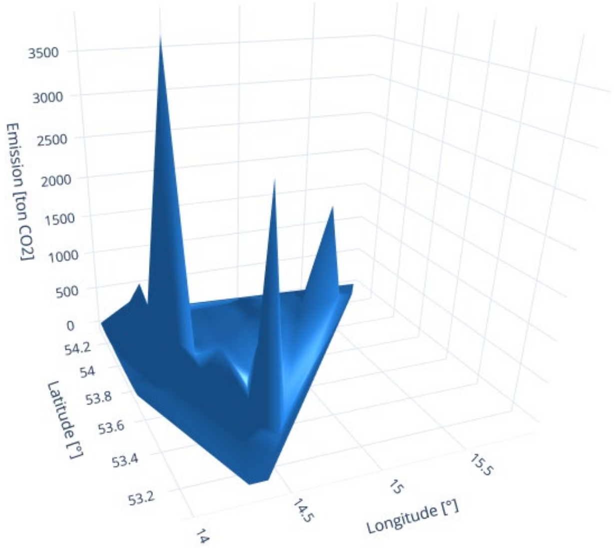

Fig. 10. Exhaust geo-emission of CO_2.

Figure 11 presents the same data as Figure 9 in the form of a heat map. The colour indicates the intensity of the emission and its spatial location. Areas of intense colour are quays occupied by ships mooring or manoeuvring near them.

Fig. 11. Visualization of CO_2 emissions in the port of Szczecin.

Figure 12 shows the Świnoujście harbour with the emissions determined by raster interpolation with spline functions. The data are from 08.11.2021. Unlike previous visualisations, the data contain emissions of specific ships. The colour variation shows emissions ranging from 1 to 224 thousand kg of CO_2.

Emission traces can be seen in specific sections of the fairway, at quays and in the outer harbour. The visualization of emissions allows us to identify places of different intensity, which may be a good tool for spatial analysis, for the identification of places particularly exposed to CO_2 emissions, so as to protect these sites regardless of the CO_2 reduction plan.

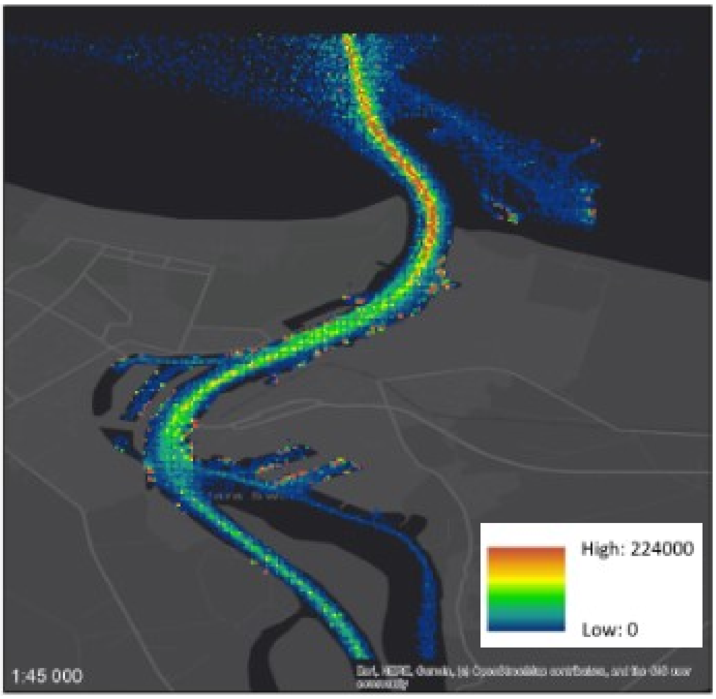

Fig. 12. Daily exhaust emissions in the port of Świnoujście.

SUMMARY

This paper presents a method for estimating CO_2 pollution emitted by sea-going vessels. In view of the European Union's plan to reduce greenhouse gas emissions from shipping, remote monitoring of pollutant emissions seems to be crucial for building awareness and making rational decisions. The authors, utilizing the data on vessel activities from the monitoring of Automatic Ship Identification system, have estimated emissions using an artificial intelligence model of emission estimation. Besides, they determine the total emission of pollutants from many sources (ships) in a selected geographical area, e.g. a port. An important observation made in the research is confirmation of the validity of the requirement, included in the European Union's Fit for 55 plan, that ships should cease CO_2 emissions no later than 2 hours after docking. Technically, this means that at planned stops exceeding two hours, ships should start using power supply from the shore. The obtained emission results illustrate that most of the emissions in ports come from ships at berth. This is due to the fact that ships in motion, in spite of higher unit emission, stay in a given geographical area for such a short period of time that they contribute less to the emission of pollutants than vessels at berth, which permanently emit pollutants in one geographical location.

It should also be objectively pointed out that the total CO_2 emission is due to many factors and emission sources. It is not only the main engine load that generates pollution, but the total energy demand reported on the ship, the adverse effect of which is the generation of CO_2. Energy is also required for cargo handling (cooling, heating, transfer, etc.). This is specific to a particular ship and varies in time, not known in detail. However, the emission accounting for ship specific energy demand can be captured in the estimation with access to information from ship sensors.

The presented method of pollution estimation allows both generating pollution geostatistics, and estimating the volume of pollution emitted by ships in maritime transport. As a result, geovisualization of emitted pollutants is possible. The method proposed by the authors has been implemented under the TranStat project. The method will become an element of the system for producing statistics of pollution emitted by sea-going vessels.

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