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# Analysis of methods for estimating pollutant emissions from marine engines in terms of their use for evaluating ambient air quality

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*This paper discusses a method for estimating pollutant emissions from the ICE of ships for air quality modelling. Three levels of emission estimation and methods for estimating ship pollutant emissions are divided into bottom-up and top-down approaches. The bottom-up approach is based on detailed ship operations and requires knowledge of many input parameters (a more accurate method, but is very time-consuming). The top-down approach is based on the value of the fuel consumed by the ship and is less precise but more accessible to apply. Various data sources are available for estimating pollutant emissions from ships, including studies commissioned by the IMO, which provide reliable emission estimates for different types of ships but lack geospatial information; the CEDS database, which optimises regional emissions information by scaling emissions from ships to national levels; CAMS-GLOB-SHIP, which provides emissions at a resolution of 0.25° × 0.25° for the following substances: CO, $NO_x$, VOC, EC, OC, BC, $SO_x$, $SO_4$; the EDGAR database, which provides annual emissions estimates at a resolution of 0.1° × 0.1°, but only covers the three main GHGs and F-gases; the Automatic Identification System (AIS), which provides high-resolution ship traffic data, allowing for a more realistic description of emitters. Many methods are available for estimating ship emissions, each with advantages and disadvantages. The choice of method depends on the available data and the level of accuracy required. The availability of AIS data allows for more accurate emission estimates, which are significant for a better understanding of the impact of shipping on air quality.*

Key words: *ship, pollutant, IMO, emission modelling*



## 1. Introduction

With the swift growth of the global economy, increasing environmental protection requirements, and the rising demand for maritime transport, the issue of pollutant emissions from vessel internal combustion engines is becoming critically important. Combustion engines, regardless of their purpose (cars, aircraft, vessels, and other machines), are a source of pollutant emissions. The main pollutants emitted by vessel combustion engines operating on international routes and in ports include PM, VOCs and CO, which affect human health; $SO_x$ and $NO_x$, which contribute to acid rain; and GHGs such as $CO_2$, $CH_4$ and $N_2O$, as well as BC, which, although not a GHG, has a strong climate-warming effect due to its ability to absorb solar radiation [1, 9, 28, 33, 35, 47]. Emissions from vessels' internal combustion engines do not just influence the local marine environment, but also the climate and air quality, therefore, precise comparative analysis of pollutant emission estimation methods is becoming increasingly important. In contrast to pollutant emissions from road vehicles, air pollutant emissions from vessels are much higher due to the amount of energy required to operate the vessels. In recent decades, emissions from global shipping have risen substantially, adding to anthropogenic pollution worldwide and significantly impacting air quality through their role in climate change, ozone layer depletion, and the formation of acid rain [30, 33, 40, 42]. Consequently, there are growing concerns about the impact of pollutant emissions from vessels on the environment and human health. Additionally, it is noteworthy that emissions from shipping were not included in the emission reductions discussed at the 21st annual COP because they do not occur within the borders of any specific country [33, 48].

The dispersion of pollutant emissions from ships poses a significant challenge, as research indicates that at least 70% of emissions from vessels on international routes occur within 400 kilometres of the coastline. These pollutants can travel hundreds of kilometres inland, leading to air quality issues even in distant coastal regions [5, 10, 33, 49]. As a major source of air pollution in cities and port areas, emissions from vessels have a harmful effect on the quality of ambient air and significantly contribute to the increase in the concentration of toxic substances in the surrounding areas. As a result, the shipping industry is responsible for higher concentrations of toxic substances in port areas than in inland municipalities. Emissions also arise when vessels are in ports, and most of the environmental impacts result from routine operations, such as their activities in port [30, 33, 42, 43]. These pollutants cause lung cancer, loss of lung function, cardiovascular and cardiopulmonary system, allergies and asthma, especially in coastal communities [9, 11, 29, 33].

Subsequently, a compelling approach technique is required to control the emission of pollutants from vessels into the environment, requiring strong forecasts in terms of observing, measurement, and localization, particularly within the zones with higher oceanic activity. To improve air quality management strategy, it is vital to prepare an emission inventory, which helps to identify significant sources of air pollutants, build up outflow patterns over time and direct administrative activities [45]. The emission inventory for air quality modelling purposes should start with a project plan: the main objective, the definition of pollutants and types of vessels to be analysed, the geographic resolution, the time resolution and the methodology for preparing the emission inventory, and the expected results [8].

In the context of global challenges related to reducing greenhouse gas emissions and air pollutants, understanding the effectiveness of different methods for estimating pollutant emissions from vessels' internal combustion engines becomes crucial. Proper emission estimation is not only essential for monitoring and enforcing environmental regulations, but also a fundamental step towards developing emission reduction strategies and improving energy efficiency in maritime transport and air quality [8, 13, 33, 45].

This article presents an overview of methods for estimating pollutant emissions from vessels' internal combustion engines with a view to using them for air quality modelling purposes. These considerations aim not only to present and compare different methodologies, but also to analyse their data requirements, accuracy levels, spatial and temporal resolution, and suitability for air quality modelling. This analytical perspective allows for identifying each method's trade-offs and practical implications in policy and scientific contexts.

## 2. Estimating exhaust emissions from ships

Because of their immediate and detrimental influences on human existence, emissions from pollution are frequently a key topic of study, as researchers consistently seek innovative methods to lessen their effects. To ensure the successful application of eco-friendly solutions, assessing pollutant emission inventories is essential, enabling targeted actions in the most critical and uncertain scenarios. Since measuring exhaust emissions from every vessel worldwide is impractical, comprehensive databases are developed, relying on various methods to estimate these emissions accurately.

In maritime transport, in contrast to land transport, where there are and are used emission models of pollutants, e.g. HBEFA [15] and COPERT [32], which take into account many factors influencing emissions (e.g. average speed, vehicle structure, traffic share), emission models are less developed and often focus on cumulative categories of ships, which makes it difficult to assess the impact of individual factors on emissions accurately. Estimating emissions from vessels is further complicated by the complexity of modelling GHG emissions and engine exhaust pollutants. The reliability of emission estimates largely depends on the adequacy of the applied engine models and the availability of validated empirical data, as shown in studies evaluating marine engine modelling frameworks [25]. This process demands detailed information, including vessel characteristics (such as length, width, draft, propulsion system condition, type and number of engines, and propellers), operational parameters (like speed and course), environmental factors (such as wind strength and direction, air and water temperature, atmospheric pressure, humidity, and sea conditions), as well as the number of vessels within various categories.

Although emissions from shipping activities have been discussed in many publications, which present different methods of estimating emissions [8, 14, 20, 33, 34] (Table 1), for the purpose however of modelling air quality (spread of pollutant emissions), not only the value of pollutant emissions but also geospatial information (division of emissions in the measurement grid) is needed. As mentioned earlier, there is a need for accurate and reliable data on the amount and distribution of emissions to effectively reduce emissions from ships and their negative impact on human health. Table 1 presents a comparison of the available methods of estimating pollutant emissions.

Table 1. Comparison of pollutant emission estimation methods [6]

| Inventory | Scale | Pollutants | Method used |
|---|---|---|---|
| IMO | Global | PM2.5, $CH_4$, $NO_x$, $N_2O$, VOC | Bottom-up and Top-down |
| CEDS v_2021 | National | $NH_3$, CO, BC, NMVOC, $CH_4$, $N_2O$, OC, $NO_x$, $SO_2$ | Top-down |
| CAMS-GLOB-SHIP v3.1 | 0.25° × 0.25° | $SO_x$, $SO_4$, $NO_x$, EC, CO, VOC, OC, Ash | Bottom-up |
| EDGAR v7 | 0.1° × 0.1° | $CH_4$, F-gases, $N_2O$ | Bottom-up and Top-down |

IMO – International Maritime Organization
CEDS – Community Emissions Data System
CAMS-GLOB-SHIP – Copernicus Atmospheric Monitoring Service Global Shipping
EDGAR – Emissions Database for Global Atmospheric Research

As shown in Table 1, each method differs in scope and scale and data input structure, making their selection highly dependent on the available information and desired output resolution. This article analyses these differences to support appropriate method selection in various modelling contexts.

One notable emissions database is the IMO study, which offers reliable estimates for various vessel and engine types but does not include geospatial details. In contrast, the CEDS database enhances regional emissions data by increasing transportation emissions to national standards over an extended historical period. CEDS covers emissions of CO, BC, $CO_2$, $CH_4$, $NH_3$, $NO_x$, OC, NMVOC, $N_2O$, $SO_2$. The CAMS-GLOB-SHIP v3.1 database provides shipping emissions in a grid resolution of 0.25°×0.25° for pollutants such as $NO_x$, CO, $SO_x$, VOC, OC, EC, BC, and $SO_4$. Meanwhile, the EDGAR v7 database delivers annual emissions estimates in a finer-gridded resolution of 0.1°×0.1°, but it is limited to the three primary GHG ($CO_2$, $CH_4$, $N_2O$) and F-gases [6].

Given the above data, it becomes necessary to assess air pollutant emissions from ships as accurately as possible.

For all sources of pollutant emissions, including shipping, there are methods for estimating pollutant emissions from ships' internal combustion engines. The methodology for estimating GHG emissions is presented in the IPCC guidelines for national greenhouse gas inventories, while for pollutants in the EMEP/EEA air pollutant emission inventory guidebook [8].

Based on the methodology given in the guidelines, there are 3 levels of emission estimation, the choice depends on the availability of data.

The Tier 1 method, the most straightforward approach for creating national and international emission inventories, is employed when detailed data on vessel movements is unavailable [30, 33]. This method relies on information about marine fuel sales and emission factors associated with fuel consumption, expressed as the amount of pollutants per unit of fuel used [8].

The presented equations reflect the methodological framework in international guidelines such as the IPCC and EMEP/EEA. They are included to illustrate each estimation approach's underlying structure and assumptions. While this article does not aim to perform sample calculations, such examples can be found in national emission inventory reports or application-specific studies.

In this situation, the emission is determined using equation (1):

$$E_i = \sum_m (FC_m \cdot EF_{i,m}) \quad (1)$$

where: $E_i$ – emission of pollutant i [kg]; $FC_m$ – weight of m type marine fuel sales within the country [Mg]; $EF_{i,m}$ – emission factor of pollutant i for a specific fuel consumption and m type fuel [kg/Mg]; m – type of fuel (marine diesel oil (MDO), heavy fuel oil (HFO), LNG, petrol).

Marine fuel consumption data is typically obtained from statistical reports.

The Tier 1 method utilizes EFs for each pollutant and fuel type, with certain EFs, such as those for $SO_2$, being influenced by fuel quality.

Tier 2 assumes that data on fuel sales for shipping, categorized by fuel type, is available at the national level. Emissions are estimated according to a specific framework (see Fig. 1).

Tier 3, similar to Tier 1, relies on fuel consumption data categorized by fuel type. However, it also incorporates detailed, country-specific information on the distribution of fuel consumption based on engine type, whether low, medium, or high speed.

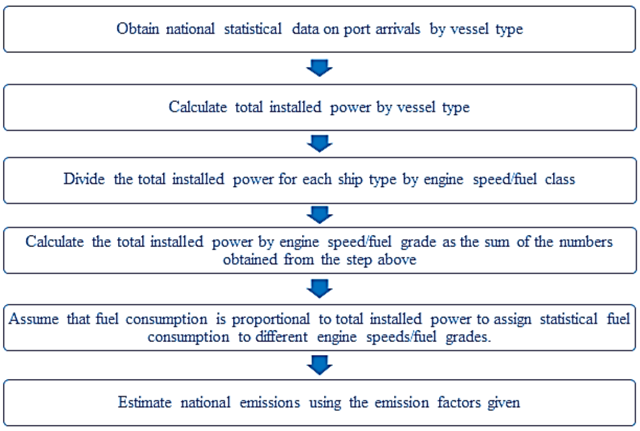


Fig. 1. Emission estimation scheme in Tier 2 method

Pollutant emission in Tier 2 is determined according to the equation:

$$E_i = \sum_m (\sum_j (FC_{m,j} \cdot EF_{i,m,j})) \quad (2)$$

where: $E_i$ – emission of pollutant i [Mg]; $FC_{m,j}$ – weight of m type fuel consumed by vessels from j type vessels [Mg]; $EF_{i,m,j}$ – average emission factor of pollutant i by vessels with j type engine and using m type fuel [kg/Mg]; i – pollutant; j – engine type (gas turbine and steam turbine, slow, medium and high-speed, diesel oil); m – fuel type (marine diesel, heavy fuel oil (HFO), LNG, petrol).

In Tier 2, the indicators represent average conditions throughout the entire voyage. As a result, emission factors determined by taking a weighted total of the indicators across various operational points, where the weights represent the anticipated frequency of the ship's activity at each point throughout the typical journey.

The whole fuel allocation for domestic and foreign (HFO) vessels should be the focus of Tier 2. To apply emission factors more accurately, information on port arrivals must be gathered and categorized by engine type using national data and standard metrics of fuel kinds and ship operations.

The European Union's national port arrival data is gathered and submitted to Eurostat by every Member State by the Maritime Statistics Directive (Council Directive 96/64/EC). Quarterly data covering transportation, travellers, and cargo, classified by destination, collaborating party, and type of cargo, is available via Eurostat's Newcronos maritime database.

This data only covers major ports (but 90% of total traffic). Tiers 1 and 2 calculate emissions estimates by relying on the typical emission profiles of ships and consider fuel sales as the main indicator of activity. Individual vessel traffic data is the foundation of Tier 3 vessel traffic methodology.

This approach is recommended when detailed vessel traffic data and technical information about vessels (such as engine size, technology, installed power, fuel consumption, and operating hours) are available. This method is appropriate for gauging emissions on both a national and international, even though it may take a significant amount of time. To meet the country's overall reporting requirements, fuel adjustments must be made for other significant fuel-consuming divisions to preserve the national energy balance.

This methodology can calculate emissions based on the UNECE/EMEP domestic and international shipping definitions and alternative definitions (e.g., by flag, ownership, or geographical area).

Tier 3 calculates emissions from navigation for merchant vessels by summing the emissions for each voyage. For each trip, emissions can be expressed as:

$$E_{Trip} = E_{Hotelling} + E_{Manouvering} + E_{Cruising} \quad (3)$$

Total emissions are the sum of all trips made by all vessels over a year. Information can occasionally be collected from a typical selection of ships functioning in a designated time frame each year. In these scenarios, the estimated emissions for that selection must be adjusted to reflect the overall emissions from every journey and all ships over the entire year.

When the fuel consumption in each step is known, then the emission of pollutant *i* can be calculated for the entire trip via (4):

$$E_{Trip,i,j,m} = \sum_p (FC_{j,m,p} \cdot EF_{i,j,m,p}) \quad (4)$$

where: $E_{Trip}$ – emission during the entire trip [Mg]; $FC_{j,m,p}$ – fuel consumption [Mg]; $EF_{i,j,m,p}$ – emission factor [kg/Mg];

i – pollutant; m – fuel type (marine diesel oil (MDO/MGO), LNG, heavy fuel oil (HFO), petrol); j – engine type (slow, medium and high speed, gas turbine and steam turbine, diesel oil); p – other phase of the journey (cruise, hotelling, manoeuvring).

Suppose fuel consumption during different phases of the journey is unavailable. In that case, an alternative methodology for calculating emissions is suggested, which relies on the installed power and the time spent in each navigation phase.

Emissions can be estimated using straightforward information about the installed power of the main and auxiliary engines, the load factor, and the total time spent in each phase (in hours) by the following equation:

$$E_{Trip,i,j,m} = \sum_p \left[ T_p \sum_e (P_e \cdot LF_e \cdot EF_{e,i,j,m,p}) \right] \quad (5)$$

where: $E_{Trip}$ – emission during the entire trip [Mg]; $EF_{e,i,j,m,p}$ – emission factor [kg/Mg], depends on the ship's type; $L_{Fe}$ – engine load factor [%]; $P_e$ – engine rated power [kW]; $T_p$ – time [h]; e – engine category (main, auxiliary); i – pollutant; j – engine type (slow, medium and high speed, Diesel engine, gas turbine and steam turbine); m – fuel type (marine diesel oil (MDO), heavy fuel oil (HFO), LNG, petrol); p – other phase of the journey (cruise, hotelling, manoeuvring).

If the cruise time is not known, it can be calculated as follows:

$$T_{Cruising}\ (\text{hours}) = \frac{\text{Distance Cruised (km)}}{\text{Average Cruising Speed (km/hr)}} \quad (6)$$

Activity data, such as engine load factors and an estimate of annual usage hours, should be derived from population data for small boats, categorized by ship type, fuel type, engine type, and technology level. This will help estimate emissions from small vessels for which separated national activity statistics are unavailable. According to fuel type, emission and fuel consumption are calculated as follows (7):

$$E_{i,m} = \sum_b \sum_e \sum_z (N_{b,e,z} \cdot T_{b,e,z} \cdot P_{b,e,z} \cdot LF_{b,e,z} \cdot EF_{b,e,z}) \quad (7)$$

where: $E_{i,m}$ – emissions generated by small boats per year [Mg]; $N_{b,e,z}$ – number of ships [pcs.]; $T_{b,e,z}$ – average operating time of each ship per year [hours/ship]; $P_{b,e,z}$ – nominal engine power [kW]; $LF_{b,e,z}$ – engine load factor [%]; $EF_{b,e,z}$ – emission factor [g/kWh]; b – type of vessel (yawl, cabin boat, sailing, …); e – type of engine (inboard, outboard, 2S, 4S); i – pollutant (NMLZO, $NO_x$, $NH_3$, PM) or fuel consumption; m – type of fuel (petrol, diesel oil); z – technology layer (conventional, 2003/44/EC).

It is worth noting that if the navigation calculations are founded on samples, the effects should be scaled up to obtain an annual sum. A geographic information system (GIS) can be used to disaggregate the data spatially.

If the fuel consumption for a given phase of the journey is unknown, an alternative method of estimating pollutant emissions should be used based on the installed power and the time spent in the individual navigation stages. A thorough understanding of the power output of the installed main and auxiliary engines, the load factor, and the total time (hours) spent in each phase can be used to calculate pollutant emissions.

There are two main approaches used to calculate GHG and pollutant emissions for air quality modelling purposes from all emission sources including ships, which use the methods described above or models derived from them: the bottom-up approach (activity-based – Tier 3) and the top-down approach (fuel-based – Tier 1 and 2) [6, 26, 33]. The schematic of both modelling approaches is shown in Fig. 2.

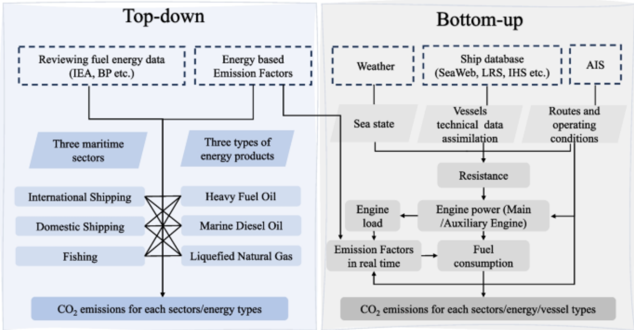


Fig. 2. Schematic approach to estimating emissions from ships [6]

The top-down method is based on the fuel consumption of the vessel [13], where the emission is calculated according to the Tier 1 or 2 method.

The bottom-up method is based on the vessel's activity (i.e. Tier 3), filling the shortcomings of the top-down method and improving the accuracy of the calculation of exhaust emissions from vessels [13]. Although a variety of data types are required, such as sailing time, vessel speed, navigational condition, engine power, load factors, emissions, etc., this method has made a detailed division of the vessel's activities, increasing the accuracy of the emission factor selection. Bottom-up approaches rely on data sources that provide each registered vessel's technical specifications in addition to worldwide shipping activity. In recent research, the AIS has been utilized to measure engine operating hours, instantaneous speeds, and the duration of journeys between locations at sea by analysing detailed vessel traffic data. Meanwhile, specific research from the ground up depends on fuel usage statistics submitted by operators for specific ships [4, 7, 12, 16, 26, 33].

The ambiguity surrounding fleet operations has decreased as a result of the more realistic description of emitters made possible by the availability of AIS data. AIS is an automated tracking system mandated by the SOLAS Convention for all passenger ships, all cargo ships above 500 GT, and all ships over 300 GT involved in international travel. At regular intervals, ships' AIS transceivers send vital information to shore stations and other vessels, including the ship's position, course, heading, speed, dimensions, type, draft, and destination. AIS data can be kept for later examination, making it a great resource for research, even if its main goal is to increase navigation safety. Numerous studies of maritime traffic have made advantage of the large datasets produced by AIS, particularly to describe maritime traffic patterns using unsupervised learning techniques [9, 34, 37–39], to detect maritime anomalies [36, 39], to assess the risk of ship collisions [37, 29, 41], maritime traffic and port management and to assess emissions [3, 22, 44]. Besides, with AIS information, it is conceivable to display high-resolution geological data on emissions and to examine the allotment of these emissions according to regularity, transport type, hail state, and transport routes. Once the specialized characteristics of the vessel are given, debilitated outflows can be demonstrated at exceptionally tall transient and spatial determination. The bottom-up approach permits the estimation of emissions by utilizing the information transmitted by AIS to calculate hourly fuel utilization and outflows for each vessel, where some vessels are distinguished as 'in operation' utilizing the IHS database. In this manner, the use of AIS and other vessel databases to gather information on vessel action and calculate GHG emissions from vessels utilizing the bottom-up strategy has become a common approach.

The AIS-based approach to ship emission inventories has found application in ship emission models. It was first proposed by Jalkanen et al. [16] who introduced the STEAM. Improvements in data assimilation and realistic performance modelling were then introduced, STEAM2 [18], STEAM3 [21], SENEM [31], and MariTEAM [26] models were subsequently published. The STEAM was developed by the FMI to accurately estimate pollutant emissions from maritime traffic. It is an advanced tool that allows dynamic modelling of gaseous and particulate emissions from vessels, taking into account real ship traffic data from the AIS system.

The STEAM model takes into account the type of fuel used to power both the main engines of the vessels and the auxiliary engines, as well as the fuel consumption indicator. The same value of the emission factors and fuel consumption was assumed for all engines. In order to estimate other emission indicators ($SO_x$ and $CO_2$), the model is based on parameters describing fuel consumption (including the type of fuel and the type of engine). The emission profile of marine engines may vary significantly depending on fuel composition, as demonstrated in studies on the use of alternative fuel blends such as n-butanol and marine diesel oil [2]. $NO_x$ emissions in the STEAM model are estimated based on the permissible values of unit emission from the engine speed described in Annex VI of the MARPOL Convention. Another simplification included in the model is the assumption that NOx emission indicators for all engines are the same regardless of their age, and they are independent of the actual fuel consumption. The STEAM model attempts to take into account the sulphur content in the fuel declared by the ship-owner [16]. If such data were not available, a 0.5% sulphur content in the fuel for the main engines and a 0.1% sulphur content for the auxiliary engines were assumed, in accordance with the requirements of Annex VI of the MARPOL Convention for Sulphur Emission Control Areas (SECA), including the Baltic Sea.

Another example is the secluded dispatch emission demonstrating framework (MoSES), which calculates toxin emissions in a spatial-temporal way, based on the ship's position information recorded from the programmed recognition system. MoSES is built in a secluded design, which ensures great extension and conceivable outcomes. A few transport type-specific strategies have been created to assess lost highlights that are vital for toxin emission displaying, such as net tonnage, fundamental or auxiliary motor control, motor control, or working speed, as these highlights are regularly not accessible at the show. In addition, the most recent emission factors for sulphates and particulate matter are taken from the literature on already ignored low-sulphur fuels. MoSES shows itself within the creation of an outflow stock for the North Ocean and Baltic Ocean locale, but it can be effectively connected to other districts as well [16–19].

Model of Emission From Ships At Sea (MEFSAS) is a predictive model and represents tool developed by the Polish Naval Academy in Gdynia, used to estimate emissions from vessels sailing on any stretch of water. This model uses a number of factors to calculate emissions, including the type of vessel, style of sailing (regular or tramp shipping), type and age of engine, type of fuel, and data on ship traffic obtained from the AIS system and meteorological information [23].

The input parameters to the model is information collected in a database created specifically for this purpose, containing [23]:

- vessel identification information (name, IMO number, type, displacement)
- information on the design of the vessel (hull dimensions, draft, year of construction, maximum speed)
- information on the main propulsion engine (engine type and its parameters, type of fuel used to power the engine, methods used to reduce toxic emissions from the engine)
- information on auxiliary engines.

To create this database, technical information on ships from databases including Lloyd’s Register (LR) was used, supplemented by the data from ship-owners, local authorities and shipyards.

The MEFSAS model stands out from other approaches because it performs both retrospective and predictive emission assessments. Unlike models that focus solely on estimating historical emissions, MEFSAS enables simulation of emissions for any given period based on a combination of AIS data, vessel classification, engine characteristics, and meteorological information. It is particularly well suited for application in Baltic Sea regions, where detailed traffic and environmental data are available. Furthermore, MEFSAS introduces a division between regular and irregular shipping, using statistical methods (e.g., Monte Carlo simulations) to estimate movements of vessels with incomplete tracking data. This feature enhances the model’s ability to provide temporally and spatially resolved emission estimates even in cases of limited AIS coverage.

## 3. Summary and conclusions

The presented methods were analysed comparatively regarding their methodological basis (top-down vs bottom-up), input data availability, resolution, and application potential. The analysis highlights that, while bottom-up methods offer higher precision, they demand significantly more detailed data and resources.

It is right now broadly acknowledged that the bottom-up approach is for the most part more exact than the top-down approach; however, extraordinary endeavours are required to diminish information gaps and peculiarities, particularly for large-scale studies [4, 27]. In truth, on a worldwide scale, the activity-based strategy postures challenges due to the utilize of normal input parameters such as motor stack components, time went through in operational modes, fuel utilization calculate and outflow variables, which depend on the measure, age, fuel sort, vessel sort course and advertise circumstance causing instability within the assessed emissions [9, 27].

Hence, the bottom-up outflow calculations will depend on the specialized data around the vessels (sort and/or category of the vessel; length of the vessel, GT, breadth, tallness; control of the most motor (ME) and assistant motor (AE); working speed of the vessel; particular fuel utilization of the motors), data on shipping and activity exercises (vessel speed and speeding up profile; arranged entry and flight times; motor operation data; AIS information) and other nitty gritty information such as fuel sort, day by day fuel utilization and outflow variables.

As for the technical information about the vessels, the best way to obtain the relevant data seems to be to combine data from the LRS database, engine manufacturers, local port authorities, and vessel owners, which allows for the collection of the most complete data for the studied fleet. However, data from commercial databases (e.g. LR) has to be purchased, which may be financially difficult.

As for the specialized information about the vessels, the perfect way to get the important information appears to be to combine information from the LRS database, motor producers, nearby harbour specialists, and vessel owners, which allows for the gathering of the most comprehensive data for the considered armada. Be that as it may, information from commercial databases (e.g. LR) must be obtained, which may be fiscally troublesome.

Displaying of destructive compounds emissions may be an exceptionally vital and at the same time exceptionally complex issue. Numerous endeavours are being made around the world to assess the outflow models of destructive compounds in the discharge of pollutants. Tragically, due to the reality that the structure of the demonstrate depends not as it were on its reason, but moreover, to a expansive degree, on the sum and quality of input information, and numerous considers are based on inadequately sum and quality of information, frequently gotten from numerous different sources and the have to be utilize rearrangements, this altogether influences the unwavering quality of the demonstrate. The models for evaluating toxin emissions displayed in this work are burdened with certain mistakes due to disentanglements constrained by down-to-earth reasons (e.g., a lack of information on the parameters of the vessel, motor, or outflow characteristics). To determine the activity and developments of ships, the use of AIS information appears to be the most solid and precise approach, since this information is much appreciated, it is possible to precisely model the operational profiles of ships. In spite of the focal points, it ought to be noted that AIS information may require filtering to remove irregularities caused by time gaps, which provide inaccurate positions and, thus, inaccurate speeds. Moreover, due to the extensive amount of information, calculations on this sort of information can be moderately complex. The basic difference between the described models, despite the apparent similarity in the general approach to the problem, is the way of approaching the input data. In the case of the STEAM model, an input database of vessels was created, and in the absence of information, it is assumed that it is a tugboat with specific parameters. The authors of the article adopted a different method of determining the vessel parameters and the movement of vessels. The division of vessels into regular shipping vessels (for which we have a database) and irregular shipping vessels was adopted, for which data is determined based on statistical data (using, among others, the Monte Carlo method) [23]. Therefore, MEFSAS can be considered a promising tool not only for reconstructing past emissions but also for forecasting emission scenarios in specific sea areas, thanks to its modular and data-driven structure.

It can therefore be stated that the MEFSAS model, unlike other models, allows not only for estimating the emission of toxic compounds in exhaust gases for the present or past, but also for forecasting emissions at any point in time.

## Nomenclature

| | |
|---|---|
| BC | black carbon |
| CAMS-GLOB-SHIP | Copernicus Atmospheric Monitoring Service Global Shipping |
| CEDS | Community Emissions Data System |
| $CH_4$ | methane |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| COP21 | Conference of the Parties |
| COPERT | Computer Programme to Calculate Emissions from Road Transport) |
| EDGAR | Emissions Database for Global Atmospheric Research |
| EF | emission factors |
| FMI | Finnish Meteorological Institute |
| GHG | greenhouse gas |
| GIS | geographic information system |
| HBEFA | Handbook Emission Factors for Road Transport |
| IMO | International Maritime Organization |
| IPCC | International Panel on Climate Change |
| MEFSAS | Model of Emission From Ships At Sea |
| $N_2O$ | nitrous oxide |
| $NH_3$ | ammonia |
| NMVOC | non-methane volatile organic compounds |
| $NO_x$ | nitrogen oxides |
| OC | organic carbon |
| PM | particulate matter |
| $SO_2$ | sulphur dioxide |
| $SO_x$ | sulphur oxides |
| STEAM | Ship Traffic Emission Assessment Model |
| VOC | volatile organic compounds |

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