

## INTERCOMPARISON OF EMISSIONS ASSESSMENT METHODOLOGIES IN A SHORT SEA SHIPPING FRAMEWORK

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**Abstract.** The objective of this contribution is to compare emissions calculation methods into the context of Short Sea Shipping routes in terms of pollution mitigation. An inventory of methods to calculate fuel consumption and/or CO<sub>2</sub> emissions is elaborated applying them in a Short Sea Shipping route case. Differences between of 16% and 52% are obtained in function of the emission factors and method selected. The potential best suitable method is assessed by combining the monitored parameters and the method inventory. The aforementioned method is found by assessing if the relevant parameters are already monitored/available on board and by analyzing the emissions calculation methodologies in terms of availability of data, accuracy and appropriateness of the method's formulation to be translated into computational language. This analysis is oriented to include the methods in weather ship routing systems.

### 1 INTRODUCTION

Maritime transport is one of the sources for global warming and environmental pollution. The environmental impact of shipping is expressed by atmospheric emissions as result of the combustion of fossil fuel emissions among other impacts as could be spills or underwater noise, for instance. Shipping accounted in 2012 for approximately 2.8% of global greenhouse gas (GHG, including CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) emissions. Shipping is responsible for 15% and 13% of global NO<sub>x</sub> and SO<sub>x</sub> emissions respectively in 2012 [1, 2].

Moreover, it is estimated a growth in the world seaborne trade in the near future on account of world's growing population, which exacerbates air pollution forecasts from maritime transport. As a result, the IMO has developed and adopted more stringent regulations aimed to significantly decrease emissions from vessels. These air pollution regulations focus on reduction of CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub> and PM, since they are the main emissions of vessel engines.

Various measures and methods are proposed to reduce the environmental impact of shipping like slow steaming, the use of alternative fuels like hydrogen or LNG, or technical and design optimizations; although reducing fuel consumption points out as to be the major aspect for achieving shipping competitiveness. This agrees with an increase of the world tendency to reduce air emissions in the framework to mitigate the climate change effects [3].

The objective of this contribution is to identify the best emissions calculation methodology in the Short Sea Shipping (SSS) context evaluating the differences among the methods and determining the best method using a multi-criteria analysis. Therefore, an assessment of the existing emission calculation methodologies (ECM) is included to attain the goal. Computer model will consider the direct emissions methodology of calculation of air pollutants such as NO<sub>x</sub>, SO<sub>x</sub> and PM and the global impact of CO<sub>2</sub> emissions issued during sailing from port of departure to port of arrival. The methods are applied in a SSS route, where the ship type, the sailing scenario and the sailing distance determine the amount of emissions.

Following the introduction section (Section 1), this paper continues with the methodology (Section 2) where the criteria analysis is described. Afterwards, results are discussed (Section 3) where the different calculating methods are inventoried and scored in terms of their suitability. In order to finally present some final remarks and determine the best fitting method (Section 4).

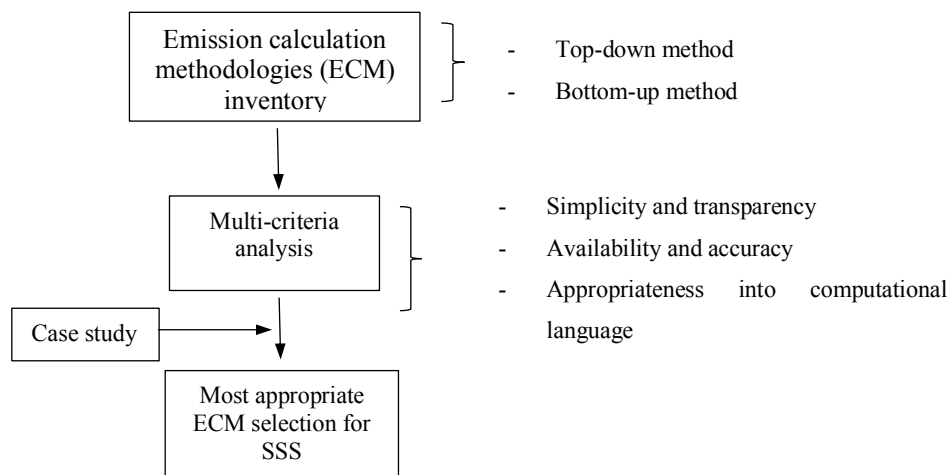
## 2 METHODOLOGY

This paper describes the formal assessment of the different emission calculation methodologies based on a multi-criteria analysis. Figure 1 shows the proposed scheme of this research.

Twelve emission calculation methodologies and the input data they require are proposed as starting point. The emission calculation methodologies can be grouped into 2 types. On the one hand, top-down methodologies combine fuel sales data with emissions factors from available documentation. On the other hand, bottom-up methodologies model fuel consumption and emissions based on vessels' technical and operating conditions. This research has focused on bottom-up methodologies as these are the ones which consider vessels individually.

With the data gathered, each method is qualitatively assessed based on the following criteria:

- Availability and simplicity of assessment method: given by the applied model to calculate the emissions for a certain vessel and the availability of the input data to run the model.
- Accuracy: the accuracy of the data used in an emissions calculation methodology is vital for the integrity of the outcome.
- Appropriateness of the formulation of the method to be translated into computational language: the appropriateness is a subjective concept. The chosen method must be easy to include into the Weather Ship Routing system and has to provide an outcome which represents a realistic value when compared to ship emission inventories from the European Union for the selected type of vessel. [4]



**Figure 1:** Scheme for research methodology

The case study with the selected methods is carried out, describing the route as well as the ship type in order to perform consequent calculations with regards to the environmental performance of maritime transport. For fleet characterization purposes a database formed by a significant number of vessels engaged in SSS services and calling at Mediterranean ports is used [5]. The ship type selected is a Ro-Ro vessel. In the case of Short Sea Shipping routes, besides navigation at sea, maneuvering in port of departure and arrival and hoteling is not taken into account as Weather Ship Routing would not incise in the emission of pollutants generated while maneuvering in port neither in hoteling periods. This research only considers direct emissions during the actual transport, indirect emissions taking place upstream or downstream is not considered due to lack of reliable data. When it comes to air pollutants emissions estimation, the model considers emissions of NO<sub>x</sub>, SO<sub>2</sub>, PM and regarding GHG emissions, only CO<sub>2</sub> emissions are considered. Furthermore, only emission factors for conventional fossil fuels are considered (heavy fuel oil, HFO).

### 3 RESULTS AND DISCUSSION

#### 3.1 Emission calculation methodologies inventory

Twelve methodologies for assessing emissions are considered as a starting point, namely: Bunker fuel tank monitoring; Flow meters for applicable combustion processes; Direct CO<sub>2</sub> emissions measurements (CEM) [6]; On-board monitoring Devices [7]; Use of portable emissions measurement System (PEMS) [8]; Bunker Fuel Delivery Note (BDN) [9]; Use of questionnaires method [10]; Use of tugs [11]; Use of The California Air Resources Board (CARB) Method [12]; Methodologies for estimating shipping emissions in the Netherlands (TNO) [13]; ENTEC UK Limited [14] and Ship Traffic Emissions Assessment Model (STEAM) [15]. The six methodologies mentioned in first place are not taken into account in this research as they deliver direct emissions data or proxies but they are not modelling methods. From the remaining methodologies, only bottom-up methodologies are taken into account because they consider vessels individually. Therefore, this leaves list of three methodologies to

assess. A short description and input data required for these three methodologies are shown in Table 1:

**Table 1.** Inventory for the bottom-up methodologies for assessing emissions

| Methodology                                     | Description   | Input data  |
|---|---|---|
| (TNO)   | Focus on emission factors and activity data to estimate emissions from berthed ships and from inland and sea shipping.  | Fuel consumption, Fuel type<br>Emission factors<br>Statistics of freight transport  |
| ENTEC UK Limited                                | This method makes preliminary assignments of ship emissions to European countries   | Distance sailed, cruise speed, ME Power, Load factor for ME   |
| Ship Traffic Emissions Assessment Model (STEAM) | Evaluation of exhaust emissions of marine traffic, based on the messages provided by the Automatic Identification System. The model also takes into account the detailed technical data of each individual vessel | Data from AIS (location, instantaneous speed)<br>Ship technical data (ship type, ship speed, engine load, fuel sulphur content, multi-engine set up, abatement method, waves) |

### 3.2 Multi-criteria Analysis

In order to develop the multi-criteria analysis, it is necessary to know the input data but also parameters required and general assumption for each selected methodology. Table 2 shows a summary of the parameters pointing out general assumptions. Only Main Engines (ME) contribution to global pollution is taken into account.

**Table 2.** Parameters used and general assumptions for selected methodologies (SFC value taken from manufacturer data;  $V_{transient}$ : speed from AIS,  $V_{design}$ : design speed from Lloyd's Register,  $V_{safety}$ : 0.5 kn;  $P_{inst}$ : Installed Power) [18]

| ME parameters                   | ENTEC                       | TNO                         | STEAM  |
|---------------------------------|-----------------------------|-----------------------------|--|
| Installed power                 | Lloyd's Register (LR)       | LR                          | LR and Ship Owners   |
| Load factor (LF)                | 80% at sea                  | 85% at sea                  | $LF = 0.8 \left( \frac{V_{transient}}{V_{design} + V_{safety}} \right)^2$                  |
| Delivered power                 | $P(kW) = LF \cdot P_{inst}$ | $P(kW) = LF \cdot P_{inst}$ | $P(kW) = 0.8 P_{installed} \left( \frac{V_{transient}}{V_{design} + V_{safety}} \right)^2$ |
| Specific Fuel Consumption (SFC) | 171 g/kWh                   | 171 g/kWh                   | 171 g/kWh  |

Table 3 describes and analyses these three bottom-up methodologies in terms of availability, accuracy and appropriateness as depicted hereby:

**Table 3.** Bottom-up methodologies assessment

| <b>Methodology</b>     | <b>TNO</b>   | <b>ENTEC</b>   | <b>STEAM</b>  |
|------------------------|--|--|---|
|                        | Description  | Description  | Description   |
| <b>Availability</b>    | Based in ship movement data (i.e. ships travelling distances) Additional emission factors are derived from LR's tech. data.  | This assessment model is not too complex as the underlying formulas are simple multiplications. The complexity stems from the amount of data that has to be handled.   | Flexible and versatile methodology. When data is not available, it can be estimated.  |
| <b>Accuracy</b>        | Based on the assumption that the ship can maintain the design speed at 85% of the (Maximum Continuous Rating) MCR, the energy consumption per distance sailed can be calculated. The disadvantage of this method is that it is focused on Dutch waters and, eventhough it can be used for emissions calculations in a preliminary research | The approach is transparent and the underlying assumptions are explicitly stated. The standard deviation for the calculated sea emissions with this method is estimated to be in the order of 15-25%. In order to attain higher accuracy the distance could be recalculated more accurately and instead of the average emission factors for a ship category the emission factors for the engine types employed on a specific ship could be used. | Sets the basis for approximating values through accurate calculations, as engine power or speed's penalty due to wave effect on navigation, for instance. |
| <b>Appropriateness</b> | The results cannot be extrapolated globally.   | The time currently calculated based on an average speed of a ship category and distance travelled could be substituted by AIS data, for instance.  | Provides reliable basis for resistance calculation (hull shape, prop. diam., quasi prop. efficiency...).  |

### 3.3 EMC selection for SSS activity: Case Study

The formulas proposed by ENTEC, NTO and STEAM methodologies are applied to a short

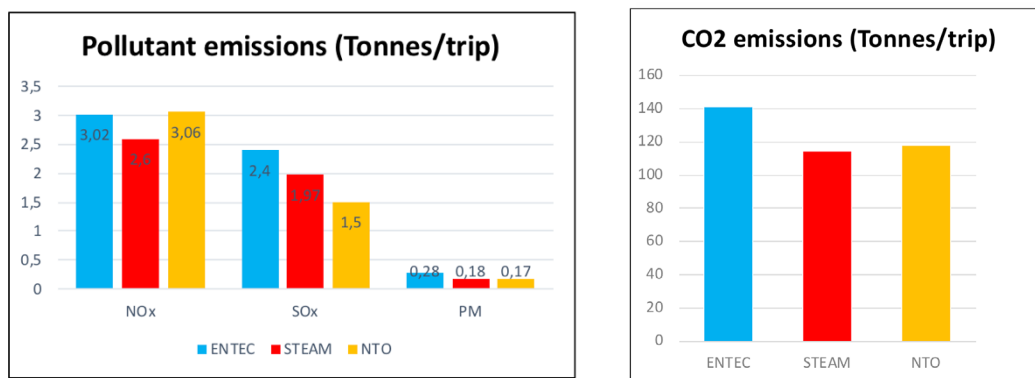
distance route with specific ship type using average values (Table 4).

**Table 4.** Vessel and route's average characteristics considered

| Type of vessel | Av. Speed (km/h) | Av. GT (Tonnes) | Av. Power per engine (kW) | Distance (km) |
|----------------|------------------|-----------------|---------------------------|---------------|
| RO-RO          | 41.67            | 32376.4         | 14400                     | 776           |

These average values have been taken from a typical West Mediterranean SSS route (Barcelona - Livorno). It has also been assumed that a typical configuration of propulsion system for a RO-RO vessel with about 32300 GT would be 2 medium-speed 4 strokes diesel engines developing an average propulsive power of 14400 kW each.

Figure 2 shows the amount of pollutants in terms of NO<sub>x</sub>, SO<sub>2</sub>, PM and CO<sub>2</sub> (respectively) considering a vessel with the characteristics shown in table 4 would free into the atmosphere per engine when sailing a distance of 419 Nautical Miles (776km) burning Heavy Fuel Oil. These figures show the results for the bottom-up methodologies selected in the above section. The results show differences of 16 % for the NO<sub>x</sub>, 46 % for the SO<sub>2</sub>, 52 % for the PM and 17% for the CO<sub>2</sub>.



**Figure 2.** Emissions of NO<sub>x</sub>, SO<sub>2</sub> and PM (in Tonnes/trip; left) and CO<sub>2</sub> (in Tonne/trip; right) for the selected methodologies

The simplest method for assessing emissions is to multiply the installed power with a load factor for each activity; even though, there exist more complex methods which take into account instantaneous speed and wave, wind and currents incidence on navigation.

The aforementioned load factor is a key issue in the calculation of specific fuel consumption (SFC) together with the type of fuel burnt and the type of the engine. In a preliminary stage, a constant SFC per engine type can be used. Emissions factors for pollutants are generally expressed in mass per mechanical energy delivered by the engine (g/kWh). For any given year, emission factors are dependent on which types of fuels and engines or machinery were used. However, the impact differs by pollutant. NO<sub>x</sub> emission factors mostly depend on engine type, with only a small direct effect of fuel quality while SO<sub>2</sub> (and PM) emission factors and CO<sub>2</sub> are dependent on fuel sulfur and carbon content respectively.

Walsh & Bows [16] make a key remark about the use of emission factors to calculate the amount of emissions from energy consumption. If emission factors are used there need to be a

range of emission factors, relevant emission factors. Uncertainty increases when using generalized emission factors. Relevant emission factors are those which apply for mere specific situations and better cover the processes in these situations. Generalized emission factors may be too generalized for the situation and they may end up implying non-transparent assumptions. The emission factors used in this research, will be the ones proposed by each methodology. Next table shows some information and assumptions applied by the three selected methodologies for calculating the emission factors:

**Table 5.** Information and assumptions for emission factors assessment [18]

| <b>Emission factors (EF)</b> | <b>ENTEC</b>  | <b>TNO</b>                                 | <b>STEAM</b>   |
|------------------------------|---|--|--|
| <b>NO<sub>x</sub></b>        | Depend on 5 engine types and 3 fuel types and activity<br>Post-2000: IMO NO <sub>x</sub> Technical code | Depend on engine type, build year and load | Engine manufacturer information<br>Default: IMO Tier I Curve |
| <b>SO<sub>x</sub></b>        | Depend on S content existence of scrubbers  | Depend on S content existence of scrubbers | Depend on S content existence of scrubbers                   |
| <b>PM</b>                    | Depend on engine type, fuel type and activity   | S content, fuel and engine type            | Depend on engine type, S content and engine load             |
| <b>CO<sub>2</sub></b>        | Engine type and load  | Engine type, build year and load           | Engine load  |

#### 4 FINAL REMARKS

Taking a look into figure 2, the tons of pollutants emitted into the atmosphere calculated by the chosen methodologies give different results. Differences between of 16 % and 52% are obtained in function of the emission factors. When analyzing this aspect together with the assessment of bottom-up methodologies, it could be concluded that any of them would be suitable for a preliminary research but the balance would finally turn into STEAM side for being the methodology less “emission factor dependent”. This means that STEAM gives the guidance for calculating emissions factors directly depending on the type of fuel, the specific fuel consumption of the engines and the engines load without having to lean on emission factors derived from other researches. STEAM methodology sets also the basis for approximating values through accurate calculations, as engine power or speed’s penalty due to wave effect on navigation, for instance and, furthermore, this method provides reliable basis for resistance calculation taking into account the shape of the hull, estimating the propeller diameter or calculating the quasi propulsive efficiency, among others.

Besides above aspects, STEAM methodology also handles emission factor values which represent a realistic result when comparing them with Technical Report on air pollutant emission inventory (2016) from the European Environmental Agency, thus complying with appropriateness criteria.

Further research will be developed introducing the calculation processes provided by STEAM (1 and 2) into a weather ship routing system in order to assess the fuel consumption and pollutants emissions in short sea shipping routes in Western Mediterranean Region [17]. In

addition, in terms of Monitoring, Reporting and Verification, it could be concluded that modelling with the aid of AIS – as in STEAM – could be very suitable to use as verification method for shipping emissions. Consequently, this key issue will be also included in future activities.

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