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Maritime sector has always been influencing the global economy. Shipping facilitates the bulk transportation of raw material, oil and gas products, food and manufactured goods across international borders. Shipping is truly global in nature and it can easily be said that without shipping, the intercontinental trade of commodities would come to a standstill.

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DEVELOPMENT OF METHODOLOGY AND MODEL TO ASSESS AND MANAGE SHIP EMISSIONS

Ongoing Research and Literature Review on Emission Factors (EF) using Resources available from Maritime Industry and Academic Institutions

Jai Acharya

Abstract

Emissions from international shipping can be estimated from activity data and also from international fuel statistics data. However, it is observed that the activity-based different ship sizes and types give a better prediction of global fuel consumption and emissions factors from international shipping than fuel statistics due to apparent under-reporting of marine bunker sales.

Considering the different activity-based estimates reported, the lower estimates of fuel consumed by the oceangoing world fleet in 2000 is around 200 Mt, while estimates as great as 290 Mt of marine oil would include all internationally registered ships including fishing vessels, the military fleet and auxiliary engines. This does not account for growth in emissions that may be reflected in estimates for more recent years. The latter is about 110 Mt higher than the reported total (i.e. sum IEA categories Internal Navigation and International marine bunkers) IEA marine sales (IEA, 2003). Despite the ongoing scientific debate regarding whether bunker fuel sale statistics are representative when estimating fuel-based emissions, and whether input data on engine operational profiles for different ship types and size categories are representative, these estimates demonstrate some convergence in terms of uncertainty bounds. More importantly, there is agreement among researchers that better input data on ship activity and improved means of allocating activity geospatially will reduce current differences among inventories.

The current methodologies in the Emission Factors Inventory provide an estimated and good framework for standard practice for estimating and reporting the emissions from ships activities.

The main difficulty and uncertainty lies in the several factors such as variations of fuel specifications between domestic and international use. Consequently, good practice methodologies are particularly needed in order to collect relevant and accurate data on domestic fuel used for marine transportation.

Keywords: Methodology and Model to Assess Ship Emissions, Review on Emission Factors (EF), Emission Factors Inventory System (EF Inventory), Ship Emissions Modelling.

1. INTRODUCTION:

The proposed research studies focus on maritime environmental protection under the regulatory compliance of IMO MARPOL Annex VI addressing ships emission, emission factors (SOx, NOx and PM$_{2.5}$). The research is aimed to provide economically viable solutions to the maritime industry regarding management of emission from ships operating in different conditions and formulation of strategies for environment management for future ship design and operations.
Environmental impact and air pollution from ships have received increasing attention the last decades. Due to poor combustion characteristics of typical marine engines and a wide-spread use of residual unrefined fuel, the global fleet emits significant amounts of SO$_2$, NO$_2$ and particulate matter (PM) to air. Impact assessments and information on emitted amounts are important inputs to decision-making in regulation development and also for ship designers who aim at environmentally improved designs.

In order to assess the impacts caused by ship emissions to air, information on ships’ activities in the regions or the corresponding fuel usage is essential. An emission factor (EF) can be defined as the “mass of pollutants emitted based on the work done or based on the mass of combusted fuel by ship engines or the mass of combusted fuel. The units of emissions factors generally expressed in g/kWh or g/kg fuel are related to each other by the specific fuel consumption (SFC) of the engine.

Ship engines are diverse, and the emission factors are insufficiently quantified for certain operational modes and specific pollutants which makes assessments difficult. Measurements aboard ships are thus conducted in order to determine emission characteristics during manoeuvring periods and for engines operating on fuels of different qualities.

Exhaust emissions from ships includes emissions from the main propulsion engines as well as auxiliary engines used to generate electrical power and auxiliary services within vessels. General process of ship operation can be divided in three operational modes and corresponding stage of engines emission factors (Figure-1: Flow diagram):

Vessels alongside berth during the cargo operations (loading / unloading) or whilst they wait for next voyage are termed as “hoteling”. They can cast off and manoeuvre from their mooring point before sailing away from the port. Upon departure from port / anchorage, the vessel cruises to high seas for its destination which may be coastal area or same country (domestic voyage) or a different country (international voyage). This simplistic pattern may get complicated by other stopping patterns, so does the engine operations and exhaust emission patterns.
2. OVERVIEW OF IMPACTS OF AIR POLLUTION CAUSED BY SHIPS:

Pollutants such as Particulates Matter (PM$_{2.5}$ and PM$_{10}$), NO$_X$, Ozone, SO$_2$ and CO$_2$, all of which are products of combustion of fuel oil, can be classified as either primary or secondary pollutants. ‘Primary pollutants’ is a term used for the pollutants that are formed during the actual combustion process, while ‘secondary pollutants’ are formed in the atmosphere as a consequence of chemical reactions involving the primary species. The potential impact categories influenced by air pollution from oil combustion are health problems, acidification, eutrophication, photo-oxidant formation and climate change, to name the most important. An overview of these pollutants and their corresponding impact categories are illustrated below in Table-1.
3. SHIP ENGINES, FUELS AND POLLUTANT FORMATION:

Marine diesel engines are the predominant form of power unit within the marine industry for both propulsion and auxiliary power generation. In 2010 an analysis of about 100,000 ships indicated marine diesels powered around 99% of the world’s fleet, with steam turbines powering less than 1%.

In an earlier analysis, about 67% of these ships are powered by four-stroke compression-ignition engines (operating on the compression-ignition, or diesel cycle, and therefore referred to as diesel engines). Some 26% are powered by two-stroke diesel engines. Six percent of the ships have “unknown” diesel engines (i.e., either two- or four-stroke) and only one percent are turbine-driven. Most turbine-driven vessels (80%) are steam turbines with oil-fired boilers; the number of aero-derivative gas turbine engines in the commercial fleet is very low. (Corbett and Koehler, 2003)

The only other type of engine highlighted was gas turbines, used virtually only on passenger vessels, and only used in around 0.1% of vessels (Trozzi, 2010). Diesel engines can be categorised into slow (around 18% of engines), medium (around 55%), or fast (around 27%) speed engines, depending on their rated speed. (Carlo Trozzi, EMEP/EEA)

Emissions are dependent on the type of engine, and therefore these will be reviewed further in details in subsequent submissions.

The majority of fuel types used by the international fleet today are variants of bunker heavy fuel oil (also called as Heavy Fuel Oil). Heavy fuel oil contains residues from refineries’ processing of crude oil and are highly viscous and need heating before being used on board a ship. The trend in using heavy fuel oil (HFO) as a marine fuel started in the 1950s (Goodger 1982). In this paper, the term heavy fuel oil will be used for all fuel qualities containing refinery residues, also including so-called intermediate fuel oil (IFO), which is an HFO blended with refined oil qualities. There are HFO being used from Viscosity of 180 Cst to 380 and even up to 650 Cst at 40°C / 50°C and specific gravity from 0.92 to 1.01.

The marine heavy fuel oil is characterized by high sulphur content, high viscosities and densities and also high content of aromatics and minerals.
However, the limits are significantly higher than those for transport modes on land, which can be in concentrations of 10 to 50 ppm.

Table 1: Primary pollutants from the combustion of Bunker Heavy Fuel Oil (HFO) and their major potential impacts.

<table>
<thead>
<tr>
<th>Impact Categories</th>
<th>Pollutant</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>CO₂</th>
<th>HC</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health Effects</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Acidification</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photo-Oxidant Formation</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eutrophication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate Change</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X (CH₄)</td>
<td></td>
</tr>
</tbody>
</table>

4. NITROGEN OXIDE EMISSION FROM SHIPS:

NOₓ is a collective name for NO and NO₂, where NO is by far the most abundant in exhaust gases. About 5 - 7% of NO is converted to NO₂ in the exhaust system or engine (Henningsen 1998). The share of NO₂ in NOₓ that leaves the combustion chamber is partly determined by local temperature conditions (Heywood 1988). According to MAN BandW Diesel, approximately 1% of NO will form N₂O (MAN-BandW, 1996) in slow speed engines than engines of higher speeds (Cooper and Gustavsson 2004).

Additional NO is formed from nitrogen in the fuel or via reactions between molecular nitrogen and the hydrocarbon species in the fuel. Whilst Heywood (1988) states an average nitrogen content of heavy distillates is 1.40% by weight, the nitrogen contents of nine marine HFOs from published emission measurement studies (Lyyränen et al. 1999; Cooper 2003; Fridell et al. 2008; Winnes and Fridell 2009; Winnes and Fridell 2010) were below 0.5%.

Nitrogen in fuel has been shown to be an important source for NO, especially at high air to fuel ratios (lean to stoichiometric conditions) during combustion (Bowman 1975). The lean
combustion of diesel engines and a relatively high concentration of nitrogen in heavy fuel oils make fuel nitrogen a potential contributor to significant NO\textsubscript{X} concentrations in ship exhausts.

5. EMISSION FACTORS:

The emissions produced by ships are a consequence of combustion of the fuel in an internal combustion (marine) engine. The principal pollutants are CO, VOC, NO\textsubscript{x} and PM\textsubscript{10}, in this list PM\textsubscript{2.5} is derived from soot which is mainly have to do with engine technology, and CO\textsubscript{2}, SO\textsubscript{x}, heavy metals and further PM (mainly sulphate-derived) which originate from the fuel speciation.

Specific emissions (mass of pollutant per work performed by the engine or mass of combusted fuel) of pollutant species differ between the operational modes due to the combustion characteristics at different loads and at transient operations.

The units of specific emissions, g/kWh or g/kg fuel are related to each other by the Specific Fuel Consumption (SFC). The SFC also depends on the fuel type due to the differences in specific heating values of fuels. The SFC for modern marine engines range between 165 g/kWh for the most efficient two-stroke engines to around 230 g/kWh for small four-stroke engines (Buhaug et al. 2009).

Emission Factors play an important role in inventories of air pollutants. In the Table shown below, the emissions factors for CO\textsubscript{2}, NO\textsubscript{x}, SO\textsubscript{x}, PM, HC and CO in g/kg fuel used, obtained from emission inventory sources, are presented together with their cited sources.
Table 2: A Typical Study of Researchers on Emission Quantity and Estimates of Fuel Consumption for the International Fleet from Recent Global Inventories

<table>
<thead>
<tr>
<th>Source of emission factor</th>
<th>Corbett and Koehler, 2003*</th>
<th>Paxian et al., 2010</th>
<th>Dalsøren et al., 2008</th>
<th>Buhaug et al., 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Included in the fuel estimate</td>
<td>International shipping, Military vessels</td>
<td>All ships</td>
<td>All ships</td>
<td>Non-military international shipping</td>
</tr>
<tr>
<td>CO₂ (g/kg fuel)</td>
<td>3179</td>
<td>2905</td>
<td>3179</td>
<td>3130/3190</td>
</tr>
<tr>
<td>PM (g/kg fuel)</td>
<td>6.1</td>
<td>6.0</td>
<td>7.6</td>
<td>6.7/1.1</td>
</tr>
<tr>
<td>NOₓ (g/kg fuel)</td>
<td>82.5</td>
<td>76.4</td>
<td>41 – 92</td>
<td>85 and 56**</td>
</tr>
<tr>
<td>S content of fuel (%)</td>
<td>2.5%</td>
<td>2.4-2.6%</td>
<td>54 or 10 (g/kg fuel)</td>
<td>2.7%/0.5%</td>
</tr>
<tr>
<td>HC (g/kg fuel)</td>
<td>2.9</td>
<td>7.0</td>
<td>2.45</td>
<td>2.7</td>
</tr>
<tr>
<td>CO (g/kg fuel)</td>
<td>-</td>
<td>4.67</td>
<td>7.4</td>
<td>7.4</td>
</tr>
</tbody>
</table>

* Original emission factors are in the unit g/kWh; these values have been converted to emissions in g/kg fuel by division of a specific fuel consumption of 206 g fuel/kWh which is used in by Corbett and Koehler (2003)

** kg NOₓ / tonne fuel for slow-speed and medium-speed diesel engines, respectively, independent of fuel type.

The values presented in Table 2 merely demonstrate the difficulties of drawing conclusions on emission factors for even the most abundant pollutants from ship engines. It is to be noted that the inventories cover the global fleet, which makes aggregated factors like the ones presented subject to many estimates, i.e. estimates on average fuel type and average engine type.

Emissions from test bed engines can be suspected of deviating from emissions from engines in operation due to wear on the engine and how it is operated. However, correlations of specific
emissions based on engine size or engine age, have proven to be difficult due to limited datasets and large variations in data (Whall et al. 2002).

The specific emissions from 155 measurements from ships and test bed measurements in Wärtsilä’s facilities shown in Figure 2 (Whall et al. 2002; Agrawal et al. 2008; Winnes and Fridell 2009; Winnes and Fridell 2010). The measurements from Whall et al. are reported in an aggregated way. These measurements are presented as average emission factors at 500 rpm for medium speed diesel (MSD) engines and at 100 rpm for slow speed diesel (SSD) engines. They are also weighted by the number of measurements.

6. MOPSEA EMISSION MODEL – THE METHODOLOGY:

To generate an emission inventory two approaches can be adopted, these being: the so-called “bottom-up” and “top-down” approach. The top-down approach, starts with data describing the total potential polluting activity throughout the whole geographical area of interest, for example the total marine fuel sales for a country. The fuel sold can then further be subdivided into different types of oil: residual bunker fuel oil (heavy fuel oil) and distillate fuel (gas oil and marine diesel oil), or other fuel types.

A geographical break-down of the calculated emissions can then be performed when necessary (M. Vangheluwe, J. Mees and C. Janssen).

The bottom-up method starts, with geographically disaggregated data, for example the number of ship movements on a shipping route. Emission data are calculated for each individual ship or per ship type. To obtain the total emissions for a geographical area the different contributions are summed up. This method requires detailed data and may be quite time consuming to perform.

A bottom-up emission quantification study requires as much information as possible regarding ship movements, shipping routes and ship characteristics to obtain a predetermined accuracy level. This data is provided by several sources like national authorities, private companies, questionnaires and the internet. After analysis, adaptation and correction if necessary, all information is processed into calculation models. Due to analysis and comparison with other data sets, it is possible to determine accuracy, advantages and disadvantages of each data
source. The main data sources are shipping companies, ports authority database, Lloyd’s register (LMIU), internet shipping schedules and seafarer questionnaires.

A different engine load indicates a divergent emission value. This implies that the engine load (of the main and auxiliary engines) is the most important factor in the calculation process of ships’ emissions in combination with the different marine areas and observation methods. The different aspects of the methodology are presented in Figure 1.

Two main classes are identified:
(1) Sea emissions and
(2) Port emissions.

The sea emissions indicate all emissions from shipping in the at Sea. This class is subdivided into two types of activities that take place in the sea area (however with different engine load patterns), namely cruising and anchoring.

“Sea emissions” are divided into emissions from (a) cruising vessels, and (b) vessels at anchor. Cruising vessels represent all merchant ships including dredgers and tugboats that are ‘underway’

7. CALCULATION OF TECHNOLOGY RELATED EMISSIONS:

NOX, CO, HC, and PM are technology related emissions.

Energy use (kWh)
The energy used is calculated by multiplying the used power and the duration:

Energy use (kWh) = power (kW) x duration (h)

The used power is dependent on the maximum installed power and the percentage of the maximum continuous rate (MCR) that is used:

Power (kW) = % of MCR x maximum installed power (kW)

Technology related emissions (ton) are calculated according to the following mathematical expression:
Emission (tons) = Emission factor (g/kWh) x energy use (kWh) x 10^6 ........................ (4)

8. SEA EMISSION CALCULATIONS (CRUISING):

For sea emissions, a specific methodology is developed, based on the best available data with regards to the study area. The methodology is summarized in the following formula:

\[
\sum SE_{1, st, rs} = \sum (T_{st, rs} \ast P_{st, me} \ast EF_{st, rs} \ast LF_{st, me} / CF_{me}) + \\
\sum (T_{st, rs} \ast P_{st, ae} \ast EF_{st, rs} \ast LF_{st, ae} / CF_{ae}) .......................................................... (5).
\]

Where,

*Multiplying sign

SE_{1, st, rs} Sea emissions from ships determined per ship type and voyage route segment
T_{st, rs} Sailing time as acquired by an average speed value route segment, multiplied with the sailed distance per route segment per ship type
P_{st, me/ae} Average installed main or auxiliary engine power per ship type
EF_{st, rs} Emission factors per ship type and activity in gm/kWh
LF_{st, me/ae} Load factor of main engine or auxiliary engine, per ship type while sailing (% of MCR)
CF_{me/ae} A correction factor to compensate for loss of efficiency at reduced load.

9. EMISSION CALCULATIONS DURING MANEUVERING:

During manoeuvres, vessels employ variable loads resulting in higher emission levels. This implies the establishment of port boundaries as an important factor in emission calculation process. The employed methodology for manoeuvring operations is summarized in the following mathematical expression:

\[
\sum MA_{1, st, p} = \sum (T_{st, p, ma} \ast P_{st, me} \ast EF_{st, ma} \ast LF_{st, ma, me} / CF_{st, me}) + \\
\sum (T_{st, p, ma} \ast P_{st, ae} \ast EF_{st, be} \ast LF_{st, ma, me} / CF_{st, ae}) ......................(6).
\]

Where,

MA_{1, st, p} Port emission from manoeuvring vessels determined per ship type and port
T_{st, p, ma} Manoeuvring time as acquired by the specific port database per ship type and port
P_{st, me} \quad \text{Average installed main or auxiliary engine power per ship type}

EF_{st, ma} \quad \text{Emission factor per ship type for 'manoeuvring activities' as determined by database provider (LMIU/ENTEC or similar) in g/kWh}

LF_{st, ma, me/ae} \quad \text{Load factor per ship type for main or auxiliary engine per ship type at berth (% load of MCR)}

CF_{me/ae} \quad \text{A correction factor to compensate for loss of efficiency at reduced speed}

*Multiplying sign

10. EMISSIONS CALCULATIONS FROM BERTHOLED VESSELS (HOTELING PHASE):

During the vessel at berth, most of the time main engines are shut down and auxiliary engines are used to supply electrical power to boilers, galley equipment, refrigeration/air conditioning plants, cargo gear equipment on board like cranes, pumps, ventilation system etc.

The methodology used for these calculations is shown in the following mathematical expression:

\[
\sum BE_{1, st, p} = \sum (T_{st, p, be} \times P_{st, me} \times EF_{st, be} \times LF_{st, be, me} / CF_{st, me}) + \\
\sum (T_{st, p, be} \times P_{st, ae} \times EF_{st, be} \times LF_{st, be, me} / CF_{st, ae}) \quad \text{... (7)}.
\]

Where,

*Multiplying sign

BE_{1, st, p} \quad \text{Port emission from berthed vessels determined per ship type and port}

T_{st, p, be} \quad \text{Lay time at berth as acquired by the specific port database per ship type}

P_{st, me/ae} \quad \text{Average installed main or auxiliary engine power per ship type}

EF_{st, be} \quad \text{Emission factors per ship type for 'activities at berth' provided by EF database provider agencies (ENTEC/LMIU etc.)}

LF_{st, be, me/ae} \quad \text{Load factor per ship type for main or auxiliary engine per ship type at berth (% load of MCR)}

CF_{me/ae} \quad \text{A Correction factor to compensate for loss of efficiency at reduced load}

In above study, it is observed that EMS, MEET and MOPSEA Emission Model are very close in methodology and overlap on several points.
11. PROCESS MODEL FOR SHIP EMISSION:

Figure - 7

12. EMISSION MODEL AND METHODOLOGY ADOPTED FOR THIS RESEARCH TASK:

The emission model and methodology adopted for our research in assessment of ship emissions would be of “bottoms up” activity based MOPSEA basic model with novel methodology and new approach to bring further accuracy in emission assessment addressing the specific requirement of IMO directives illustrated in MARPOL Annex VI and various MEPC on
reductions of CO\textsubscript{2}, SO\textsubscript{X}, NO\textsubscript{X} and PM\textsubscript{2.5} through technical and operational measures.

In March 2010, the MEPC began consideration of making the technical and operational measures mandatory for all ships irrespective of flag and ownership; this was expected to be completed by July 2011 and concluded accordingly. The activity based emission models have made it possible to forecast the emissions from sea-going vessels for near future.

The approach adopted in our emission model is consistent with the methodology for quantifying ship emissions on following information:

- Vessel Type
- Installed engine power
- Type of fuel consumed
- Vessel route, speed and distance travelled (or the time spent during the sea passage)
- Time Spent in port, during maneuvering and anchorage (hoteling phase)
- Main and Auxiliary engines load factor during various phases of vessel activities
- Emission by boiler operations

The research study though our selected emission model and methodology would develop a novel ship emission calculation and inventory with comparative lesser uncertainties due to integration of current methodologies after considerable phasing out of potential uncertainty. Along with the fuel consumption, the following pollutants have been taken in to account in the emission calculations:

- Oxides of Sulphur (SO\textsubscript{X}) - Sulphur Dioxide (SO\textsubscript{2})
- Carbon Dioxide (CO\textsubscript{2})
- Oxides of Nitrogen (NO\textsubscript{X})
- Particulate Matter (PM\textsubscript{2.5})
- Non-Methane Volatile Organic Compounds (NMVOC) – HC
- Carbon Monoxide (CO)

The development of a suitable new emission model is based on shipping movement. It is intended to create a model that is specific vessel type which can be validated on various types
of ship operations at different locations, fuel type and other parameters. The integration of the technological aspects of the sea-going vessels is an important selection criterion for a reproducible emission assessment methodology. Both are important for the scientific relevance for ship emission policy making, economics and for the feasibility.

The ship type selected for emission model is a handy-size bulk carrier installed with a 2 stroke slow speed diesel engine (SSD) powered by bunker fuel oil (HFO 380 cSt) and four-stroke auxiliary engines (MSD) powered by marine diesel (MDO) / (MGO) marine gas oil. The Auxiliary Boilers of the ship type consume marine diesel oil (MDO). The activity data consists of times spent at sea with cruising speed, maneuvering activity time duration, arrival / departure of ports and duration of stay at port and anchorage.

The model itself is based on voyages and hoteling periods of ocean going vessels. The voyage is defined here as the journey of a ship between an entry and exit point. Therefore, a round trip comprises at least two voyages. Further, all the integrated emission factors in the proposed emission model would compute:

- Fuel related emissions - Oxides of Sulphur (SO\textsubscript{X}) - Sulphur Dioxide (SO\textsubscript{2}) and Carbon Dioxide (CO\textsubscript{2}) for SSD and MSD engines and auxiliary boilers.

- Technology related emissions – NO\textsubscript{X}, PM2.5, HC and CO for 2-stroke SSD engines.

13. KEY FINDINGS FROM THE THIRD IMO GHG STUDY 2014:

Shipping emissions during the period 2007–2012 and their significance relative to other anthropogenic emissions further analyzed in subsequent years during MEPC sessions.

For the year 2012, total shipping emissions were approximately 949 million tons CO\textsubscript{2} and 972 million tons CO\textsubscript{2}e (CO\textsubscript{2} equivalent) for GHGs combining CO\textsubscript{2}, CH\textsubscript{4} and N\textsubscript{2}O. International shipping emissions for 2012 are estimated to be 796 million tons CO2 and 816 million tons CO\textsubscript{2}e for GHGs combining CO\textsubscript{2}, CH\textsubscript{4} and N\textsubscript{2}O. International shipping accounts for approximately 2.2% and 2.1% of global CO\textsubscript{2} and GHG emissions on CO\textsubscript{2} equivalent (CO\textsubscript{2}e)
basis; respectively. MEPC 67 (25 July 2014) provides in the annex the complete final report of the "Third IMO GHG Study 2014", which provides an update of the estimated GHG emissions for international shipping in the period 2007 to 2012.

A comparative analysis of GHG illustrated in MEPC 67 in Table (a) and (b)

Table - 5 (a): Shipping CO₂ emissions compared with global CO₂ (values in million tonnes CO₂)

<table>
<thead>
<tr>
<th>Year</th>
<th>Global CO21</th>
<th>Third IMO GHG Study 2014 CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total Shipping</td>
</tr>
<tr>
<td>2007</td>
<td>31,409</td>
<td>1,100</td>
</tr>
<tr>
<td>2008</td>
<td>32,204</td>
<td>1,135</td>
</tr>
<tr>
<td>2009</td>
<td>32,047</td>
<td>978</td>
</tr>
<tr>
<td>2010</td>
<td>33,612</td>
<td>915</td>
</tr>
<tr>
<td>2011</td>
<td>34,723</td>
<td>1,022</td>
</tr>
<tr>
<td>2012</td>
<td>35,640</td>
<td>949</td>
</tr>
<tr>
<td>Average</td>
<td>33,273</td>
<td>1,016</td>
</tr>
</tbody>
</table>
Table - 5 (b): Shipping GHGs in CO2e (compared with global GHGs (values in million tonnes CO2e)).

<table>
<thead>
<tr>
<th>Year</th>
<th>Global CO22</th>
<th>Third IIMO GHG Study 2014 CO2e</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total shipping</td>
</tr>
<tr>
<td>2007</td>
<td>34,881</td>
<td>1,121</td>
</tr>
<tr>
<td>2008</td>
<td>35,677</td>
<td>1,157</td>
</tr>
<tr>
<td>2009</td>
<td>35,519</td>
<td>998</td>
</tr>
<tr>
<td>2010</td>
<td>37,085</td>
<td>935</td>
</tr>
<tr>
<td>2011</td>
<td>38,196</td>
<td>1,045</td>
</tr>
<tr>
<td>2012</td>
<td>39,113</td>
<td>972</td>
</tr>
<tr>
<td>Average</td>
<td>36,745</td>
<td>1,038</td>
</tr>
</tbody>
</table>

This study estimates multi-year (2007-2012) average annual totals of 20.9 million and 11.3 million tonnes for NOx (as NO₂) and SOx (as SO₂) from all shipping, respectively (corresponding to 6.3 million and 5.6 million tonnes converted to elemental weights for nitrogen and sulphur, respectively). NOx and SOx play indirect roles in tropospheric ozone formation and indirect aerosol warming at regional scales. International shipping is estimated to produce approximately 18.6 million and 10.6 million tonnes of NOx (as NO₂) and SOx (as SO₂) annually; this converts to totals of 5.6 million and 5.3 million tonnes of NOx and SOx (as elemental nitrogen and sulphur, respectively). Global NOx and SOx emissions from all shipping represent about 15% and 13% of global NOx and SOx from anthropogenic sources reported in the latest IPCC Assessment Report (AR5), respectively; international shipping NOx and SOx represent approximately 13% and 12% of global NOx and SOx totals, respectively.

Over the period 2007-2012, average annual fuel consumption ranged between approximately 250 million and 325 million tonnes of fuel consumed by all ships within this study, reflecting top-down and bottom-up methods, respectively. Of that total, international shipping fuel consumption ranged between approximately 200 million and 270 million tonnes per year,
depending on whether consumption was defined as fuel allocated to international voyage (top-down) or fuel used by ships engaged in international shipping (bottom-up), respectively.

Correlated with fuel consumption, CO₂ emissions from shipping are estimated to range between approximately 740 million and 795 million tonnes per year in top-down results, and to range between approximately 900 million and 1150 million tonnes per year in bottom-up results. Both the top-down and the bottom-up methods indicate limited growth in energy and CO₂ emissions from ships during 2007 - 2012, as suggested both by the IEA data and the bottom-up model. Nitrous oxide (N₂O) emission patterns over 2007-2012 are similar to the fuel consumption and CO₂ patterns, while methane (CH₄) emissions from ships increased due to increased activity associated with the transport of gaseous cargoes by liquefied gas tankers, particularly during 2009 - 2012.

14. REDUCTION OF GHG EMISSIONS FROM SHIPS:

The IMO led MEPC 69 had agreed to discuss and work on further reducing GHG emissions from ships, taking into account the documents submitted and the related documents referred by MEPC 69 and onwards, *i.e.* MEPC 69/7/1 (ICS), MEPC 69/7/2 (Belgium *et al.*), MEPC 69/7/3 (CSC) and MEPC 69/7/4 (WSC *et al.*), as well as comments made at MEPC 69.

International shipping CO₂ estimates range between approximately 595 million and 650 million tonnes calculated from top-down fuel statistics, and between approximately 775 million and 950 million tonnes according to bottom-up results. International shipping is the dominant source of the total shipping emissions of other GHGs: nitrous oxide (N₂O) emissions from international shipping account for the majority (approximately 85%) of total shipping N₂O emissions, and methane (CH₄) emissions from international ships account for nearly all (approximately 99%) of total shipping emissions of CH₄. In continuation, MEPC 70 further considered in subsequent document MEPC 70/7/2 highlighting a perceived regulatory barrier to the use of non-petroleum fuel oils, related to the general application of regulation 18.3.2 of MARPOL Annex VI.

The Committee noted the information provided by Institute of Marine Engineering, Science and Technology (IMarEST) and invited Member Governments and international organizations to submit relevant proposals for a new output in accordance with this regard, the Committee also
noted information provided by the observer from ISO with regard to a currently ongoing revision of ISO 8217:2012 related to specifications of marine fuels, including changes in its scope allowing it to include synthetic and renewable fuels and their blends.

15. FUEL RELATED EMISSION FACTORS:

The pollutants CO$_2$ and SO$_2$ are fuel related. The emission factors for CO$_2$ in this emission model are corresponding to IMO and IPCC published CO$_2$ emission factors. The SO$_X$ emission factors would be corresponding to IMO MARPOL Annex VI fuel oil Sulphur content requirements for MDO/MGO and HFO (380 Cst) globally and in “Sulphur Emission Control Areas (SECAs) governed by Regulation 14 of MARPOL Annex VI.

Table - 6: CO$_2$ and SO$_2$ emission factors (kg/ton fuel)
[Ref: MOPSEA Project EV43]

<table>
<thead>
<tr>
<th>EF (kg/tonne)</th>
<th>Heavy Fuel Oil (HFO)</th>
<th>Diesel and Gas Oil (MDO/MGO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>3110</td>
<td>3100</td>
</tr>
<tr>
<td>SO$_2$ (… -18/05/2006)</td>
<td>54</td>
<td>4</td>
</tr>
<tr>
<td>SO$_2$ (19/05/2006 – 2009)</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>SO$_2$ (2010 …)</td>
<td>30</td>
<td>4 or 2*</td>
</tr>
</tbody>
</table>

*2 kg of SO$_2$/ton diesel or gas oil at berth (minimum duration of 2 hours)

15.1. Technology Related Emission factors for:

The technology related emission factors for NO$_X$, PM$_{2.5}$, HC and CO for 2-stroke SSD engines are those taken from EMS/ENTEC and other sources. The EMS emission factors are modelled as combination of basic emission factor and correction factors for the technology (age and NO$_X$ Regulation) and the percentage of maximum continuous rate (MCR) of the ship engines.

Emission Factor (g/kWh) = Basic emission factor 
(g/kWh) X CorrAge X CorrNO$_X$ X CorrMCR
15.2. **Correction for technology:**

Two correction factors have to be implemented on the basic emission factor to take account into the technology of the sea-going vessels:

01. Emissions are dependent on the year of construction of vessels because of evolution in engine technology

02. Main engines built after the year 1999 have restrictions for their NO\(_X\) emissions (IMO MARPOL Annex VI Chapter 2)

16. **CORRECTION FACTOR FOR % OF MCR:**

The basic emission factors are based on a test cycle. This is an average of all stages of navigation. Therefore, they are not representative for the individual stages of navigation (expressed in % of MCR). A correction factor has to be implemented on the basic emission factor to get emission factors for the individual stages.

Table – 7: Basic emission factors (g/kWh) for a 2-stroke SSD engine

<table>
<thead>
<tr>
<th>EF (g/kWh)</th>
<th>Heavy Fuel Oil (HFO)</th>
<th>Diesel and Gas Oil (MDO/MGO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>CO</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>NO(_X)</td>
<td>16.00</td>
<td>16.00</td>
</tr>
<tr>
<td>PM</td>
<td>1.70</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Table – 7(a): Correction factor for the NO\(_X\) Regulation (IMO MARPOL Annex VI)

<table>
<thead>
<tr>
<th>Date of Building</th>
<th>g/NO(_X)/kWh</th>
<th>RPM</th>
<th>g/NO(_X)/kWh</th>
<th>CorrNO(_X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2000</td>
<td>14.5</td>
<td>290 - 2000</td>
<td>45(\times)n(^{0.2})</td>
<td>3.10(\times)n(^{0.2})</td>
</tr>
<tr>
<td>&gt;2000</td>
<td>14.5</td>
<td>&gt;2000</td>
<td>9.8</td>
<td>0.68</td>
</tr>
</tbody>
</table>
Table – 7(b): Correction factors for the age of the 2-stroke SSD engine

<table>
<thead>
<tr>
<th>Date of Building</th>
<th>Heavy Fuel Oil (HFO)</th>
<th>MDO/MGO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HC</td>
<td>CO</td>
</tr>
<tr>
<td>&lt;1974</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1975 – 1979</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1980 – 1984</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1985 – 1989</td>
<td>1.00</td>
<td>0.83</td>
</tr>
<tr>
<td>1990 -1994</td>
<td>0.83</td>
<td>0.67</td>
</tr>
<tr>
<td>1995 – 1999</td>
<td>0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>&gt;2000</td>
<td>0.50</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Table – 7(c): Correction factor for the % of MCR for 2-stroke SSD engine

<table>
<thead>
<tr>
<th>% of MCR</th>
<th>HC</th>
<th>CO</th>
<th>NOₓ</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>0.84</td>
<td>0.70</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>80</td>
<td>0.87</td>
<td>0.76</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>75</td>
<td>0.89</td>
<td>0.82</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>70</td>
<td>0.92</td>
<td>0.88</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>65</td>
<td>0.95</td>
<td>0.94</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>60</td>
<td>0.98</td>
<td>1.00</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>55</td>
<td>1.00</td>
<td>1.06</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>50</td>
<td>1.03</td>
<td>1.12</td>
<td>1.00</td>
<td>1.01</td>
</tr>
<tr>
<td>45</td>
<td>1.09</td>
<td>1.23</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>40</td>
<td>1.16</td>
<td>1.38</td>
<td>1.02</td>
<td>1.03</td>
</tr>
<tr>
<td>35</td>
<td>1.27</td>
<td>1.56</td>
<td>1.03</td>
<td>1.05</td>
</tr>
<tr>
<td>30</td>
<td>1.42</td>
<td>1.80</td>
<td>1.04</td>
<td>1.08</td>
</tr>
<tr>
<td>25</td>
<td>1.65</td>
<td>2.14</td>
<td>1.06</td>
<td>1.12</td>
</tr>
<tr>
<td>20</td>
<td>2.02</td>
<td>2.66</td>
<td>1.10</td>
<td>1.19</td>
</tr>
<tr>
<td>15</td>
<td>2.74</td>
<td>3.51</td>
<td>1.17</td>
<td>1.32</td>
</tr>
<tr>
<td>10</td>
<td>4.46</td>
<td>5.22</td>
<td>1.34</td>
<td>1.63</td>
</tr>
<tr>
<td>0</td>
<td>6.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

17. TECHNOLOGY RELATED EMISSIONS FACTORS FOR 4-STROKE MSD ENGINES:

The technology related emission factors for HC, CO, NOₓ and PM for 4-stroke engines are taken in same way from EMS/ENTEC and other sources as mentioned for 2-stroke engines. They are modelled just like for a 2-stroke engine, as a combination of a basic emission factor.
and correction factors for the technology (age and NO\textsubscript{X} regulation) and the percentage of the maximum continuous rate (MCR), which is same as for 2-stroke engine.

Table – 7(d): Basic emission factors (g/kWh) for a 4-stroke MSD engine

<table>
<thead>
<tr>
<th>EF (g/kWh)</th>
<th>Heavy Fuel Oil (HFO)</th>
<th>Diesel and Gas Oil (MDO/MGO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>CO</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>NO\textsubscript{X}</td>
<td>12.00</td>
<td>12.00</td>
</tr>
<tr>
<td>PM</td>
<td>0.80</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Table – 7(e): Correction factors for the age of the 4-stroke MSD engine

<table>
<thead>
<tr>
<th>Date of Building</th>
<th>Heavy Fuel Oil (HFO)</th>
<th>MDO /MGO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HC</td>
<td>CO</td>
</tr>
<tr>
<td>&lt;1974</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1975 – 1979</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1980 – 1984</td>
<td>1.00</td>
<td>0.83</td>
</tr>
<tr>
<td>1985 – 1989</td>
<td>1.00</td>
<td>0.67</td>
</tr>
<tr>
<td>1990 -1994</td>
<td>0.83</td>
<td>0.67</td>
</tr>
<tr>
<td>1995 – 1999</td>
<td>0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>&gt;2000</td>
<td>0.50</td>
<td>0.67</td>
</tr>
</tbody>
</table>

The use of different emission factors influences the emission figures. For the purpose of sensitivity analysis, MOPSEA model has been run with the widely used ENTEC (2005) emission factors. Emissions for the year 2004 have been calculated by using the ENTEC average emission factors per ship instead of the detailed EMS emission factors per individual ship. This resulted in emission figures which are higher than those calculated with the EMS factors.
18. ILLUSTRATION ON THE EF MODEL FOR A SHIP TYPE BY EF ESTIMATION:

Development of Emission Factor (EF) Model for a ship type would be based on methodology which covers emission during activities of all the phases (cruising, maneuvering, hoteling, berthing/anchorage). The basic algorithm for the technology related emission calculations for each activity is adopted from MOPSEA model with a different approach and innovative inputs.

My Literature Review is consistent with ongoing research studies and to be continued…

REFERENCES:


Trozzi.2010 (International navigation, national navigation, national fishing)

Carlo Trozzi; EMEP/EEA,

Lyrränen et al. 1999; Cooper 2003; Fridell et al. 2008; Winnes and Fridell 2009;

Winnes and Fridell 2010


Eyring et al. 2005a; Eyring et al., 2005b.

IPCC 2000

Aircraft Emissions - Kristin Rypdal (Statistics Norway).

Martinez and Marcel

M. Vangheluwe, J. Mees and C. Janssen

Jalkanen et al. (2009, 2012 and 2013)


1Global comparator represents CO₂ from fossil fuel consumption and cement production, converted from Tg Cy⁻¹ to million metric tonnes CO₂, Sources: MEPC 67, Boden et al. 2013 for years 2007-2010; Peters et al. 2013 for years 2011-2012, as referenced in IPCC (2013)

MEPC 69/7/1 (ICS), MEPC 69/7/2 (Belgium et al.), MEPC 69/7/3 (CSC) and MEPC 69/7/4 (WSC et al.), MEPC 70, MEPC 70/7/2

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ABOUT THE AUTHOR

Jai Acharya

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Brief Description

Jai Acharya is currently working as Managing Director of International Shipping Bureau (Singapore) Pte Ltd.

Jai has been appointed as Director of International Ocean Institute – IOI (Singapore), Focal Point since 2012.

Jai obtained MSc (Maritime Studies) from NTU (Singapore) in collaboration with BI Oslo (Norway).

A Graduate in Electrical Engineering with Honours from BITS Pilani (India), Top Class Institute of Technology and Science in India and First Class Marine Engineer (Motor), Jai has forty long years of active experience in the industry covering the most of the sectors in maritime spectrum.

Being a proactive ocean and maritime environmental activist, Jai has keen interest in maritime consultancy projects, maritime education and training (MET) with an emphasis on maritime environmental awareness and protection of oceans.

Jai’s on-going research in maritime emission assessment and emission factors inventory management for his doctoral studies shows his commitment for the ocean environmental protection and green shipping.

Having sailed on-board a variety of merchant vessels in national and multi-national shipping companies, Jai rose to the rank of chief engineer and gathered a wealth of varied hands-on experience in shipboard operations and maritime management.

Jai has obtained the status of Life Fellowship of Institution of Engineers (FIE) and became Chartered Engineer in the vast field of Maritime and Electrical Engineering.

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- Safety Officers Training
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