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Methodology bottom-up for estimation of the Air Emissions Inventory and carbon footprint for tugboats

C. González[1,2], C.A. Pérez-Labajos [1,3,*], J. Oria[1,4], M.A. Andrés[1,5]

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ABSTRACT

In October 2008, the Marine Environment Protection Committee (MEPC) adopted the Annex VI of the revised regulation MARPOL which entered into force in July 2010. Several revisions were made, inter alia, to the rules on Ozone-depleting substances, which is expected to produce a significant benefit for the environment and human health, especially for people living in port cities and coastal communities. At present, the sensitivity of the citizens regarding the emissions originated in the port areas are increasing, perhaps because the most important commercial ports are placed within densely populated cities.

In this context, it is presented in this work about the methodology proposed for the estimation of the emissions inventory for tugboats by analysing their activity. For this purpose, it will be calculated the fuel consumption of each tugboat, including the main engine and the auxiliary engines and then, convert that consumption into atmospheric emissions.

1. Introduction

Nowadays, the air pollution from ships is an issue of general concern and is generating numerous legal regulations at European and worldwide level. In the same way, it is being originated new environmental concepts for the evaluation of the air pollution, accepted and used internationally, such as the carbon footprint.

There is a legal framework that regulates air emissions from the maritime transport which we will refer to. This is the MARPOL (Marine Pollution) 73/78, its Annex VI sets limits for certain air pollutants such as sulphur and nitrogen oxides. These limits must be strictly complied by all ships built from 2005. In addition to these defined limits, the MARPOL Convention defines several areas around the world where the limits for air emissions are even stricter, these areas are known as emission controlled areas (ECAs).

This Annex VI is focused in the air pollution and ship efficiency. This Annex entered into force 19/05/2005. In this context, the IMO force to use fuels with determinate qualities (looking at the sulphur contents) and propulsion systems with design which increase their efficiency (reducing the nitrous oxides emissions) in compliance with the limits established in MARPOL, Annex VI.

The usage of fuels with low sulphur contents is a key point, especially for maritime operations at port levels, because reducing the sulphur contents consequently, the air emissions of poisoning substances for the citizens living nearby the ports locations will decrease.

The atmospheric emissions from the ships are caused by the fuel combustions on board. This combustion emits exhaust gases to the atmosphere producing the air pollution.

This pollution has local and globally consequences, therefore its reporting in the most transparent way will help to get

[1]Ocean and coastal planning and management R+D group. University of Cantabria. Germán Gamazo nº 1, 39004 Santander, Cantabria (SPAIN).

[2]Project Manager at Kyma as Email: cg@kyma.no. Phone: +4740385409

[3]Professor of Marine Economics of the Department of Navigation and Naval Construction Science and Techniques. Tel. (+034) 942201362. E-mail Address: clabajos@unican.es

[4]Professor of Maritime Safety of Department of Navigation and Naval Construction Science and Techniques.. Tel. (+034) 942201329 Email Address: jesusmiguel.oria@unican.es.

[5]Tel. (+034) 942201348 Email Address: manuelangel.andres@unican.es

*Corresponding author: C.A. Pérez-Labajos. Tel. (+034) 942201362. E-mail Address: clabajos@unican.es

a better control and understanding of their origins and consequences, being this of general interest.

The pollutants may be classified in two types. Ones, known as GHG, are the cause of global warming, which main component is the CO_2. The environmental effects of the GHG can be measured by the Carbon Footprint of the activity under analysis.

The other pollutants are known as 'air pollutants', they cause an impact localized in the area where they are emitted having a direct effect on the health of the citizens. These pollutants are Sulphur Oxides, Nitrogen Oxides, Particulate Matter, among others.

Determining the effect caused by the tugboat fleet by means of quantifying the amount of emissions produced and its carbon footprint is important due to the tugboats are part of the maritime transport cycle, therefore, the carbon footprint and the emissions added by the tugs will have effects on the total effect of the maritime transport. In this paper, we focus on the analysis of the effect caused by the emissions of the GHG from the tug boats fleet operating within Spanish ports.

Moreover, currently there is a special sensitivity about the emissions at ports, perhaps because the most important commercial ports are set deep into cities where there is a big population density, so that is needed to know the impact of the ports activity on the health and its global effect, being this at the same time, one of the major concerns of the citizens.

In this context, it is made this study whose has the objective of determination of the methodology for the air emissions inventory and the estimation of the carbon footprint for tugboats fleet.

All the estimations of emissions (emissions factors) are done following the IMO methodology used in its 3rd IMO GHG Study, 2014 for the estimation of ship emissions.

In the following epigraphs, it is presented the methodology proposed and the general conclusions of the research done.

2. Methodological Approach

For the estimation of the GreenHouse Gas emissions (GHG), in consequence the carbon footprint, and the air emissions inventory originated by the tugboats, it is calculated the fuel oil consumption for each tugboat individually and by applying the bottom-up methodology (Buhaug et al., 2006). The level of accuracy acquired depends of the method employed and the purpose of the analysis (Miola et al., 2010).

In the methodology bottom-up, also known as method based on the fleet activity (Eyring et al., 2005), the emissions are directly estimated within a spatial context and the air emissions inventories are being developed for the ship's activity in specific locations.

In the methodology bottom-up, each type of emissions is calculated considering the ship's characteristics, for one location and one determined activity.

It is needed to consider the characteristics and the propulsion type installed for each ship, applying the correct emission factors and/or fuel consumption calculations for each propulsion type.

The methodology bottom-up may have better accuracy, however, the air emissions inventories for wider ranges might give bigger uncertainty due to the estimation of the engines load, ship's speed and ship's location all of these parameters define the spatial distribution of the emissions.

The yearly air emissions inventories elaborated with this methodology have a limited quality when it is selected periods with less than 1 year and it is extrapolated as sample of totalizers for one year.

In this study, it is considered for the calculation of the air emissions for tugboats the main engine and the auxiliary engines.

Every reaction produced by a combustion process will cause atmospheric emissions, release to the air as exhaust gases.

The amount of air emissions originated by the ships depend of the following factors:

- Quantity and fuel type used
- Type and propulsion system design
- Operational mode and operational hours

The marine engines, mainly are diesel engines, this is the predominant selection for the propulsion systems and for the auxiliary engines within the maritime industry. In 2010, it was made an international analysis on approximate 100 000 ships and as result, 99% of the global fleet are using Diesel engines.

Having said that, for the air emissions inventory and the carbon footprint, it is mandatory the estimation of the fuel oil consumption (for each fuel type used).

The fuel type in use for the tugboats is normally distillate fuels (DO), such as Marine Diesel Oil or Marine Gas Oil. These fuels, although they are more expensive, are the primary option as fuel for the tugboats due to the fuel quality restrictions within port areas. However, there are still some ports with less restrictive regulations in terms of fuel quality, therefore, in those ports the tugboats may use residual fuels (RO), such as Heavy Fuel oil (HFO).

Hence, for the calculation of the air emissions inventory and the carbon footprint, is considered the fuel type used and its emission factor for each pollutant.

In the following epigraphs, it is presented the different aspects of the estimations which are forming the proposed methodology.

3. Tugboat Activity

As it was mentioned before, the fuel consumption calculation is dependent of the operational time and the operational mode.

The tugboats have, as standard, 4 operational modes:

- Escort
- Assistance
- Stand-by

- Idle

For our study, it has been considered for the main engines and the auxiliary engines the load defined in the final report made by 'Chevron Richmond Long Wharf Shipping Emissions Model (ICF, 2014), detailed in the table 1:

Table 1: Main engines and the auxiliary engines load for the operational modes: Escort, Assistance and Stand-by

Operational Model	Main Engine Load	Auxiliary Engine Load
Escort	0,31	0,43
Assistance	0,31	0,42
Stand-by	0,31	0,43

Source: ICF(2014)

In this study, it has been considered that the tugboats when they are berthed, they have the main engine stopped and the auxiliary engines are also stopped, getting the power needed for the 'hotel load' and the auxiliary systems' form the 'On shore Power Supply' (OPS). Therefore, during the 'idle' operational mode it is assumed that the engines are not producing emissions.

For the determination of the operational hours for the tugboat in one year, we have made a review of the current literature and we found different assumptions, mainly depending on which port is being use for the study. This paper aims to propose one methodology in general, for any tugboat in any port around the World. Having said that, in this study, the operational time for each tugboat is estimated analysing the maritime traffic of each port, considering that each port call will request one tugboat for 1 hour. It is known that not all the ships need the assistance of tugboats, but the goal of establishing this standard operational time per port call is to balance those ships which need more than one tugboat assistance and compensate any delay in the manoeuvring.

4. Estimation of Fuel Oil Consumption

The tugboats usually have as main engines 'Medium Speed Diesel Engines' (MSD) or 'High Speed Diesel Engines' (HSD). They have a specific fuel oil consumption (SFOC) and it is used the ones defined in the 3rd IMO GHG Study,2014, as it is shown in the table 2.

Table 2: Mean values adopted for the SFOC [g/kWh]. for Main engines. IMO

Engine Age	MSD	HSD
Before 1983	215	225
1984 <age <2000	195	205
After 2001	185	195

Source: IMO(2014)

In order to make a differentiation when the main engines use DO or RO fuel, it is followed the relation proposed by the EMEP/EEA, which is considering that the engines under DO mode are more efficient due to the higher net energy of the distillate fuel. Due to this fact, the SFOC is considered 10 g/kWh lower than under RO mode. This relation is defined in the table 3.

Table 3: Mean values adopted for the SFOC [g/kWh] for Main engines according their age and fuel type

Age	MSD		HSD	
	RO	DO	RO	DO
Before 1983	215	205	225	215
1984 <age <2000	195	185	205	195
After 2001	185	175	195	185

Source: IMO(2014)

In general, it is guessed that each engine type has a load, expressed as Maximum Continous Rating (MCR) where the engine is operated in the most optimal way (Jalkanen et al., 2012).

The changes on the Specific Fuel Oil consumption (SFOCm) are estimated in function of the engine MCR, age, fuel type and engine type as it is shown by the equation 1:

$$SFOC_m = SFOC_p \cdot (0,455 \cdot L^2 - 0,71 \cdot L + 1,28) \ \ [g/kWh] \quad (1)$$

Where:
$SFOC_m$: Specific Fuel Oil Consumption estimated for the main engine and MCR defined, g/kWh
$SFOC_p$: Specific Fuel Oil Consumption pre-defined depending of main engine age, fuel type and engine type, g/kWh
L: Engine load

After estimating the SFOC, it is possible to calculate the fuel oil consumption for the main engine in a d hourly basis, applying the equation 2:

$$CD_{m/i} = \frac{SFOC_m \cdot KW \cdot L_f}{10^6} \quad [Ton/h] \qquad (2)$$

Where:
CD_m: Hourly fuel consumption for main engine, $tons/h$
$SFOC_m$: Specific Fuel Oil Consumption estimated for the main engine and MCR defined, g/kWh
KW: Main Engine Power at MCR, kW
LF: Load factor for Main Engine
i: Fuel type (HFO, MDO, MGO, LNG, etc)

Following the same procedure, the fuel consumption for the auxiliary engines is estimated as the equation 3

$$CD_{m/i} = \frac{SFOC_{ma} \cdot KW \cdot L_f}{10^6} \cdot N \quad [Ton/h] \qquad (3)$$

Where:
CD_{ma}: Hourly fuel oil consumption for auxiliary engines, $tons/h$
$SFOC_{ma}$: Specific Fuel Oil Consumption estimated for the auxiliary engine (Table 4), g/kWh
KW: Auxiliary Engines Power at MCR, kW
LF: Load factor for auxiliary engine (table 5)
N: Auxiliary Engines in operation (Table 3)
i: Fuel type (HFO, MDO, MGO, LNG, etc)

The number of auxiliary engines in operation is defined in the table 4. These values are taken from the 3rd Study GHG IMO, 2014

Table 4: Number of Auxiliary Engines in operation for tugboats. IMO

Ship Type	Aux Engines in operation
Tugboat	1

Source: IMO(2014)

IMO also defines de SFOC for the auxiliary engines in its 2nd IMO GHG study,2009. In that study, IMO took the values from IVL study in 2004. It is shown in the table 5:

Table 5: Specific Fuel Oil consumption (g/kWh) for auxiliary engines

Fuel Type	$SFOC_{motor}$
HFO	227
MDO/MGO	217

Source: IVL(2004)

Usually, the air emissions inventories are calculated per year, therefore, the fuel consumption should be expressed annually too.

The total fuel consumption for the tugboats in one year is calculate according the equation 4:

$$CD_{t,i} = \sum_i (CD_{m/i} + CD_{ma/i}) \cdot T \quad [Tons/years] \tag{4}$$

Where:
CT: Total fuel consumptions yearly basis, $tons/years$
CD_m: Hourly fuel consumption for main engine, $tons/h$
CD_{ma}: Hourly fuel consumption for auxiliary engines, $tons/h$
T: Operational time within one year, hours
i: Fuel type (HFO, MDO, MGO, LNG, etc)
f: Operational mode (Escort, Assistance, Stand-by, Idle)

5. Calculation of the Air Emissions Inventory

As it was stated preciously, any combustion processes produce air pollution by means of the exhaust gases. These emissions are compound by two different types of pollutants. Those which produce a global impact causing the Greenhouse effect, known as Greenhouse gases (GHG); and other type of pollutants with a local impact in within the are where they are emitted, known as air pollutants. These are very poisoning for the human and then, must be minimized as much as possible nearby populations.

The GHG calculated in this study are:

- CO_2
- CH_4
- N_2O

The air pollutants considered in this study are:

- CO
- SO_x
- PM
- NMVOC
- NO_x

The emissions are estimated applying the equation 5:

$$E_i = C_{T,j} \cdot EF_i \quad [Tons/years] \tag{5}$$

Where:
E: Emissions quantity, $tons/year$
CT: Total fuel consumption, $tons/year$
EF: Emission factor
i: Pollutant, Ton pollutant / Ton fuel
j: Fuel type (HFO, MDO, MGO, LNG, etc)

Then, to make the emissions inventory, the equation 5 shall be applied for all the pollutants considered in a yearly basis.

6. Emission Factors

Following the procedure described in the 3rd IMO GHG study, 2014, the atmospheric emissions are calculated in function of the fuel type. The emissions factors considered are defined in the tables 6 and 7

Table 6: Emission factors for CO_2 (Ton CO_2/Ton fuel)

Fuel Type	Emission Factor
Heavy Fuel Oil, HFO	3,114
Light Fuel Oil, LFO	3,515
Marine Diesel /Gas Oil, MDO/MGO	3,206
Liquefied Petroleum Gas (Propane)	3,000
Liquefied Petroleum Gas (Butane)	3,030
Liquefied Natural Gas, LNG	2,750
Methanol	1,375
Ethanol	1,913

Source: IMO Resolution MEPC 245 (66) 2014 'Guidelines on the method of calculation of the attained Energy Efficiency Index (EEDI) for new ships'

7. Sulphur Emission (SO_x), Calculation Method

The SO_x emissions are directly related with the fuel quality, this is in other words, the sulphur contents in the fuel used.

The equation 6 shows the way to calculate the SO_x from the sulphur contents in the fuel used and the fuel consumption

$$E_{SO_x} = \sum_i FC \cdot S \cdot 0,01 \tag{6}$$

Where:
E_{SO}: SO_x emissions, ton/h
FC: Fuel Consumption, ton/h

Table 7: Emission factors (Tons Pollutant/Tons fuel)

Fuel Type	CO emission factor	CH_4 emission factor	N_2O emission factor	NMVOC emission factor	NO_X emission factor	PM emission factor
HFO	0,00277	0,00006	0,00016	0,00308	0,0903	0,00728
MDO/MGO	0,00277	0,00006	0,00015	0,00308	0,0961	0,00097
LNG	0,00783	0,05120	0,00011	0,003	0,0140	0,00018

Source: IMO(2014)

S: Sulphur contents in the fuel used, %
i: Fuel type (HFO, MDO, MGO, LNG, etc)

The sulphur contents will vary depending on where the bunker is made. However, to standardize in this methodology the average sulphur contents, it is used the values adopted by the 3rd IMO GHG study, 2014

Table 8: Average sulphur contents for the different fuel types

Fuel Type	Sulphur contents (%)
HFO	2,5
MDO/MGO	0,1
LNG	0

Source: IMO(2014)

Approximately, the 98% of the sulphur contents in the fuel will be converted into SO_2 and approximated the 2% of the sulphur contents will be found particles emissions (SO_4) (IVL, 2004)

Table 9: SO_2 and SO_4 emissions estimated from the SO_x emissions.

%SO_2% emissions	%SO_4$ emissions
E_{SO_x} 0,98	E_{SO_x} 0,02

Source: ICF(2014)

8. Carbon Footprint

The carbon footprint is defined as 'the totality of all GHG emitted by direct or indirect effect of one individual, organization, event or product. The carbon footprint is measured in mass of CO_2 equivalent'. Hence, for the estimation of the carbon footprint for the analysed fleet, it is considered the emissions of CO_2, N_2O and CH_4, expressing all of them in CO_2 equivalent as it is shown in the equation 7

$$CF = \sum CO_{2eq} \quad [Tons] \tag{7}$$

Where:
CF: Total Sum of the GHG analysed expressed as $CO_2E, Tons$
CO_{2eq}: GHG emissions as CO_2 equivalent, $Tons$

Therefore, all the GHG must be expressed as CO_2 equivalent as it is shown in the table 10

Table 10: CO_2 equivalent conversions (Tons pollutants / Tons CO_2 equivalent) for the GHG

CHG	%CO_2$ equivalent
CO_2	1
CH_4	25
N_2O	298

Source: IPCC(2007)

9. Conculusions

1. This methodology may be used for any ship type within the merchant fleet
2. To corroborate this methodology with the real tugboat operations, it shall be evaluated the actual fuel consumption and operational profile for a sample of tugboats to verify the accuracy of this methodology. In addition, this bottom-up methodology detailed in this study should be crosschecked with the methodology to verify results
3. Although it has been used as operational time for the tugboats 1 hours per port call, for the formalization of the methodology in this study, the operational time for the tugboats shall be used base on the individual activity of each tugboat in order to increase the accuracy of the results
4. Even though it has been used the emissions factor from IMO, the emission factor shall be continuously verified for new coming fuel types
5. The methodology shall be updated with new propulsion systems installed in tugboats (newbuilding)

References

Buhaug, Ø., Halvorsen, E., Brembo, J., Nilsen, J., Hawkes, R., 2006. Flagship d-b1.1 influence of external factors on the energy efficiency of shipping. EU IP TIP5-CT-2006-031406.

Chevron Product Company, 2014. Chevron richmond long wharf shipping emissions model.

Eyring, V., Köhler, H., van Aardenne, J., , Lauer, A., 2005. Emissions from international shipping: 1. the last 50 years. J. Geophys. Res. 110, D17305, doi:10.1029/2004JD005619.

Finn, V., 2011a. Fuel cells in maritime applications. challenges, chances and experiences. 4th ICHS Conference. San Francisco, USA.

Finn, V., 2011b. 'fuel cells in maritime applications. challenges, chances and experiences.' 4th ichs conference. san francisco, usa.

IMO, 2009. International maritime organization, 2nd ghg study 2009, executive summary and final report.

IMO, 2014. International maritime organization, 3rd ghg study 2014, executive summary and final report.

Institute", I. S. E. R., 2004. Methodology for calculating emissions from ships. Swedish Environmental Protection Agency.

IPCC, 2006. Intergovernmental panel on climate change. ipcc guidelines for national greenhouse gas inventories. japan. isbn 4-88788-032-4.

IPCC, 2007. Intergovernmental group of experts on climate change, 4th evaluation report (ar4), 2007.

Jalkanen, J., Johansson, L., Kukkonen, J., 2013. A comprehensive inventory of the ship traffic exhaust emissions in the baltic sea from 2006 to 2009. Ambio Vol 43, pp 311–324.

Jalkanen, J., Johansson, L., Kukkonen, J., Brink, A., Kalli, J., Stipa, T., 2012. Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide. Journal of Atmospheric Chemistry and Physics Vol 12, pp 2641–2659.

MEPC, 2014. Guidelines on the method of calculation of the attained energy efficiency index (eedi) for new ships. MEPC 245 (66).

Miola, A., Ciuffo, B., E., G., Marra, M., 2010. Regulating air emissions from ships, the state of the art on methodologies, technologies and policy options. JRC Reference Reports, Ch 2.

Trozzi, C., 2010. Emission estimate methodology for maritime navigation. EMEP/EEA air pollutant emission inventory guidebook.