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Methodologies for estimating shipping emissions and energy consumption: A comparative analysis of current methods

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ABSTRACT

The debate on the evaluation of maritime emissions offers several different methods of estimating emissions. These methods are not easily compared due to their analysis of different contexts and their underlying different assumptions. The estimates of the International Maritime Organization in confirmed some of the results in the literature, but the debate is ongoing.

In this manuscript, factors from nine methods that have been applied for the evaluation of fuel consumption and emissions are studied and compared. The review and application of these maritime emission inventories reveal no significant differences between these methods. Regarding the total pollutant values, the largest differences correspond to the application of the factors employed by the International Maritime Organization for main engines, and the smallest differences correspond to the application of the factors employed by the Environmental International Corporation for auxiliary engines.

The recommendations made in this manuscript include the use of the STEAM (ship traffic emission assessment model) method, the use of the method developed by Goldsworthy to apply the emission factors and the consideration of the maintenance state of the engines as an additional uncertainty factor.

The analysis made in this manuscript shows more possibly detailed methods that can substantially improve the quality of bottom–up inventory estimates.

1. Introduction

Maritime transport activities have become an important topic in the sustainability debate because emissions from the marine transport sector contribute significantly to air pollution and climate change. In 2005, ships emitted approximately 1.7 million tons of SO_2, which corresponded to approximately 20% of the emissions from land-based sources in the Member States of the European Union (EU-27). The NO_x emissions (2.8 million tons) were equivalent to 25% of the land-based emissions. Approximately 30% of these emissions occurred on the territorial seas of the EU Member States, i.e., within 12 nm (Nautical mile) from the coast. The emissions from the Exclusive Economic Zones (200 nm) comprised approximately 75% of the total emissions [1].

This manuscript is a ship's energy case analysis comparative study. The model chosen contains the ships that passed through the Strait of Gibraltar during 2007 because this database was a prior object of study for the authors of this manuscript.

At present, more than 30 major U.S. ports along the Atlantic Coast, Gulf of Mexico, and the Pacific Coast are located in nonattainment areas for ozone and/or $PM_{2.5}$ [2]. In United States environmental law, a nonattainment area is an area considered to have worse air quality than the one required in the National Ambient Air Quality Standards. On the other hand, the IMO (International Maritime Organization) only defined three sea areas as SECAs (sulfur emission control area) following proposals from Member States, i.e. the Baltic and the North Sea and the English Channel.

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List of abbreviations and acronyms

AE auxiliary engine
AIS automatic identification system
Bottom–up inventory methodology type
Bulk Carriers ships to carry dry goods
CARB California Air Resources Board
Containerships ships to carry containers
Cruise mode the cruise mode emissions in the near ports analysis extend 25 nautical miles beyond the end of the RSZ lanes
EEDI energy efficiency design index
EEZ exclusive economic zone
EF emission factor
ENTEC Environmental Engineering Consultancy
EPA Environmental Protection Agency
FERRY ship used to carry passengers, and sometimes vehicles and cargo
GHG greenhouse gas
General Cargo ships to carry diverse cargoes
HFO heavy fuel oil
HOTELLING hotelling, or dwelling, occurs while the vessel is docked or anchored near a dock
HSD high speed diesel (engine)
IHSF IHS fairplay
IMO International Maritime Organization
IPCC Intergovernmental Panel on Climate Change
L/cyl liters per cylinder
LF load factor
MANOEUVERING manoeuvering occurs within a very short distance of the docks
MCR maximum continuous rating
MDO marine diesel oil
MEPC Marine Environment Protection Committee (IMO)
ME main engine
MGO marine gas oil
MSD medium speed diesel (engine)
nm nautical mile
PASSENGER passenger cruise service vessels
PM particulate matter
REEFER ships that typically carry fruits, vegetables, meats, and other perishable cargos.
RO residual oil
RoRo ships similar to the automobile carrier but can accommodate larger wheeled equipment
RoPax ships built for freight vehicle transport along with passenger accommodation
RSZ lanes the RSZ varies from port to port, though generally the RSZ would begin and end when the pilots board or disembark
SASEMAR Sociedad de Salvamento y Seguridad Marítima (Spanish Maritime Safety Agency)
SECA sulfur emission control area
SFOC specific fuel oil consumption
SSD slow speed diesel (engine)
STEAM ship traffic emission assessment model
TANKER ships which activity at the Port is comprised mainly of crude oil tankers, as well as a few chemical tankers
TNO Netherlands Organisation for Applied Scientific Research
tons a metric system unit of mass equal a 1000 kg also known as a metric ton

The increasing awareness of maritime transport environmental impacts reinforces the argument that both legislative actions, regulating the levels of air pollutant or implementing market based mechanisms, and technological improvements are urgently needed [3]. Under business-as-usual assumptions, the emissions from maritime activities are expected to reach the projected baseline emission levels from land-based sources by 2020 and surpass the target levels established by the European Commission in its Thematic Strategy on Air Pollution for land-based sources [4].

In the appraisal of possible strategies for the reduction of the maritime transportation sector pressure on the European environment, a key role is played by the evaluation of the total amount of emissions deriving from shipping activities (and, possibly, of its evolution) [3]. The main tool for this evaluation is the ship's emissions inventories.

A ship's emission inventory is a highly debated issue, and several contradicting papers have been published during the last 10 years. The manuscripts published by Endresen et al. [6] and Dalsoren et al. [7], Wang et al. [8], Jalkanen et al. [9], Olesen et al. [10], Miola et al. [3], Eyring et al. [12], Paxian et al. [11], and Corbett et al. [13] have not been universally accepted. For example, Endresen et al [6]applied a bottom-up approach similar to those applied previously and they declared that improvement with respect to the previous work is the estimation of the time that a single ship spends at sea.

Results obtained are in a similar range of uncertainty of those reported in Corbett and Koehler [13] and Eyring et al. [12]. Results published by Dalsoren et al. [7], confirm that the estimation problem is still a topic on which is worth investigating. All the other studies seem to pertain to the same range of uncertainties.

The estimations of emissions presented in the IMO report are in accordance with those reported in Corbett and Koehler [13], while in a previous study (IMO, 2007) they considerably overestimate global emissions.

On the other hand, in terms of CO_2 global emissions, Corbett and Koelher [13] (in a study published in 2003) estimated that 805 Mt was emitted, Eyring et al. [12] (published 2005) estimated that 812 Mt was emitted, Wang et al. [8] (published 2008) estimated that 650 Mt was emitted, and Endresen et al. [6] (base year 2000, study published in 2007) estimated that 625 Mt was emitted. Finally, the last IMO [14] (base year 2001) report, which reached some consensus, estimated that 652 Mt of CO_2 was emitted.

In this manuscript, factors from nine inventory methodologies (Corbett [13], EPA (Environmental Protection Agency) [15], ENTEC (Environmental Engineering Consultancy) [16], Endresen et al. [6], Eyring et al. [12], IMO (International Maritime Organization) [17], STEAM (Ship Traffic Emission Assessment Model) [9] and TNO (Netherlands Organisation for Applied Scientific Research) [18]) are considered, and their estimations are compared. Data from a study of emissions in the waters around southern Europe (Strait of Gibraltar) in 2007 by the authors of this manuscript serves as the baseline [5].

The initial approaches adopted in the current study (a full bottom–up approach for emissions and fuel consumption evaluations) depend exclusively on vessel information and on the different assumptions regarding how their activities are performed. In the full bottom-up approach, the evaluation starts from the pollution emitted by a single ship at a specific position [12]. The results section focuses on the fuel consumption, delivered power and the emissions of SO_2, NO_X, CO_2, CO and particulates in 2007.