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The activity-based methodology to assess ship emissions - A review☆

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ABSTRACT

Several studies tried to estimate atmospheric emissions with origin in the maritime sector, concluding that it contributed to the global anthropogenic emissions through the emission of pollutants that have a strong impact on hu' health and also on climate change. Thus, this paper aimed to review published studies since 2010 that used activity-based methodology to estimate ship emissions, to provide a summary of the available input data. After exclusions, 26 articles were analysed and the main information were scanned and registered, namely technical information about ships, ships activity and movement information, engines, fuels, load and emission factors. The larger part of studies calculating in-port ship emissions concluded that the majority was emitted during hotelling and most of the authors allocating emissions by ship type concluded that containerships were the main pollutant emitters. To obtain technical information about ships the combined use of data from Lloyd's Register of Shipping database with other sources such as port authority's databases, engine manufactures and ship-owners seemed the best approach. The use of AIS data has been growing in recent years and seems to be the best method to report activities and movements of ships. To predict ship powers the Hollenbach (1998) method which estimates propelling power as a function of instantaneous speed based on total resistance and use of load balancing schemes for multi-engine installations seemed to be the best practices for more accurate ship emission estimations. For emission factors improvement, new on-board measurement campaigns or studies should be undertaken. Regardless of the effort that has been performed in the last years to obtain more accurate shipping emission inventories, more precise input data (technical information about ships, engines, load and emission factors) should be obtained to improve the methodology to develop global and universally accepted emission inventories for an effective environmental policy plan.

1. Introduction

1.1. Relevance of emission estimation associated with marine traffic

In the course of recent decades, worldwide emissions from shipping have increased considerably, contributing to global anthropogenic emissions and most importantly impacting air pollution, namely through climate change, reduction of ozone layer thickness and acid rain (Miola and Ciuffo, 2011; Saraçoğlu et al., 2013; Song and Shon, 2014; Viana et al., 2014). Maritime transportation is the major cargo transportation mode, in charge of approximately 90% of world trade by volume (Kilic and Deniz, 2010). In addition, cruise tourism has grown quickly in recent years, and turned out to be one of the most active amongst the touristic sector. From 2003 to 2016 interest on cruising worldwide has expanded from 12.0 to 22.0 million travellers which represents approximately 120 billion dollars of the total economy (CLIA, 2016; Maragkogianni and Papaefthimiou, 2015). Consequently recently, public concerns about environmental and health impacts of maritime traffic emissions have been increasing. However, shipping emissions were not accounted for the reduction of emissions discussed at 21st annual Conference of the Parties (COP21), because they don't occur within the boundaries of any specific country (World Maritime News, 2016). The most important pollutants produced by ships in international routes and in-port are particulate matter (PM), carbon monoxide (CO) and volatile organic compounds (VOC), due to their impact on human health, as well as sulphur oxides (SO_x) and nitrogen oxides (NO_x) due to their contribution to the formation of acid rain, particulate matter

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through photochemical pathway and tropospheric ozone (O_3) formation, and finally, carbon dioxide (CO_2), black carbon (BC) and CH_4 due to their role on the greenhouse effect (Beirle et al., 2004; Richter et al., 2004; Eyring et al., 2009; Matthias et al., 2010; Vinken et al., 2014). CO_2 is the most significant greenhouse gas (GHG) released by ships, both in terms of amount and of global warming potential. As indicated by the Third International Maritime Organization (IMO) GHG Study 2014, international shipping emitted 796 million tonnes of CO_2 in 2012, representing 2.2% of total emission volume that year. Additionally, predictions for 2050 preview that 15% of total CO_2 emissions will be attributable to maritime transport (IMO, 2014). Nevertheless, CO_2 emissions from international shipping are only referred as supplementary information in national inventories for communication to the United Nations Framework Convention on Climate Change (UNFCCC), being only mentioned as supplementary information (De Meyer et al., 2008).

Estimations show that ocean-going ships release 1.2 to 1.6 million tonnes of PM_{10}, 4.7 to 6.5 million tonnes of SO_x and 5 to 6.9 million tonnes of NO_x worldwide. Some studies have assessed that about 15% of worldwide NO_X and 5–8% of worldwide SO_X emissions are a consequence from shipping (Song, 2014; Liu et al., 2014).

Recent studies also show that at least 70% of emissions from ships in international routes take place within 400 km of the coast, and the resulting pollutants of these emissions can be transported hundreds of kilometres towards mainland, causing air quality problems even in very remote areas of the coastal zone (Corbett et al., 2007; Song, 2014). Emissions are also generated while ships are at ports and most of environmental impacts associated to ships are caused by routine operations like in-port ship activities (Miola and Ciuffo, 2011; Ng et al., 2013; Song, 2014). These emissions contribute to lung cancer, loss of lung, cardio vascular and cardio pulmonary functions, allergies and asthma, particularly for littoral communities (Eyring et al., 2009; Goldsworthy and Goldsworthy, 2015; Merico et al., 2016; Song, 2014).

Strong efforts have been made to reduce and avoid pollution caused by maritime ships. One of the actions implemented by IMO was the International Convention for the Prevention of Pollution from Ships (MARPOL), which is a highly significant international convention regarding prevention of pollution caused by ships for operational and accidental reasons (IMO, 2016a). In 1997, Annex VI was added to MARPOL 73/78 to regulate air pollution caused by ships. In 2008, IMO has revised the regulation of marine fuel sulphur content (contained in Annex VI of MARPOL). Main changes were a sustained reduction of SO_x, NO_x and PM global emissions and the institution of emission control areas (ECAs) to further reduce emissions. In October 2012, rules have been implemented officially in Europe (IMO, 2016b). Since 2015, ships cruising in the SO_x emission control areas (SECAs) cannot use fuels with more than 0.1% by weight of sulphur content. At present, there are four ECAs: i) Baltic Sea (exclusive to SO_x); ii) North Sea (exclusive to SO_x); iii) North America (SO_x, NO_x and PM); and iv) Caribbean Sea (SO_x, NO_x and PM) (ICS, 2015; IMO, 2016b). In other areas, ships had to reduce sulphur content of its fuel for a maximum of 3.5% by weight in 2012 reaching 0.5% by weight in 2020. IMO has set the year 2018 for the review of this limit, while the European Union (EU) has decided the year 2020 for its implementation (EMSA), 2016a; IMO, 2016b). According to EU legislation settled in 2005, a limit of 1.5% by weight sulphur content will have to be respected by passenger ships traveling outside SECAs. In addition, EU introduced other requirements to improve air quality for protection of human health beyond SECAs such as: i) the maximum of 0.1% sulphur content by weight for ships at berth or anchorage in EU ports; and ii) the introduction of a possibility to test and use the emission abatement technologies. Ship owners may choose different methods to reach this compliance: i) consuming lower sulphur content fuel; ii) use scrubbers; or iii) use LNG (Liquefied Natural Gas) as a fuel (EMSA, 2016a, 2016b). IMO also settled standards for NO_X emissions through MARPOL Annex VI, with a reduction of 16–22% since 2011, compared to the levels of 2000, and a reduction of 80% in 2016 (OECD, 2011). Nonetheless, sulphur limit values are to be applied to the entire fleet, but NO_x emission limits are only for new ships, depending on engine rated speed and installation year. Consequently, the effect of IMO regulations concerning NO_x at present and imminently will be limited (EEA, 2013). In order to comply with international standards, an effective political strategy is needed to control atmospheric ship emissions, requiring a robust forecasting in terms of monitoring, quantification and location, especially in the areas of greater maritime traffic. To promote a procedure for air quality management it is mandatory to develop a complete inventory of emissions. These inventories are used to help in the determination of significant sources of air pollutants establishing emission trends over time and targeting regulatory actions (USEPA, 2016). Any inventory of ship emissions should begin with the plan of the design: main purpose and objective, pollutants and type of ships to analyse, geographic resolution, temporal resolution, and methodology to compile the emission inventory as well as the expected results (EEA, 2013). Thus, it is important to estimate air emissions from ships with the greatest possible accuracy and detail, in order to implement appropriate preventive measures (Entec, 2010; USEPA, 2010).

1.2. Methods to assess ship emissions – historical development and present state

As mentioned in the previous section, policy makers need adequate and reliable information on quantity and distribution of emissions to work efficiently on reducing ships' emissions and related health effects.

Along the years, research is being done to estimate total amount and to characterize emissions from shipping (Johansson, 2011; Miluse Tichavska and Tovar, 2015). Some studies tried to estimate global atmospheric emissions originated from the marine sector, concluding that this sector contributed to global anthropogenic emissions through the emission of pollutants that impair human health and climate (Corbett et al., 2007; Eyring et al., 2007, 2009; Miola and Ciuffo, 2011). Thus, it becomes necessary to evaluate the emissions of air pollutants from ships as accurately as possible.

The two main methods to perform ship emissions inventories can be categorised as fuel-based (top-down) and activity-based (bottom-up) approaches. The first methodology is based on the combination of data on marine fuel sales (quantities and types) and fuel-related emission factors (Song and Shon, 2014). The fuel based approach is commonly used by several countries to prepare domestic and international emission inventories (EEA, 2013). This approach is used when it is not possible to obtain refined data traffic information. Nevertheless, the activity-based method should be used because the input parameters are more accurate: detailed information of ship specifications (e. g., IMO number, ship type and dimensions, engines characteristics and fuel type) plus survey and operational data (e. g., travel distances, maximum speed, port calls, estimated ship operations, ship tracks and real time operations). Hence, in the activity-based method, air pollutants emitted by a ship in a specific spatial context are calculated and aggregated over the time and fleet for total emission estimation (Eyring et al., 2009; Miola and Ciuffo, 2011). Besides the approaches described above there are other methods that combine the top-down and bottom-up approaches (hybrid methodologies). There is one using bottom-up in the evaluation of total emissions and top-down in its geographical characterization. In this case, emissions are