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Review article

Shipping emissions over Europe: A state-of-the-art and comparative analysis

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ABSTRACT

Several emission inventories exist for Europe, which include emissions originating from ship traffic in European sea areas. However, few comparisons of these inventories, in particular focusing on specific emission sectors like shipping, exist in literature. Therefore, the aim of this paper is to review and compare commonly used, and freely available, emission inventories available for the European domain, specifically for shipping and its main pollutants (NOx, SOx and PM10). Five different inventories were considered which include shipping activity: 1) EMEP; 2) TNO-MACC_III; 3) E-PRTR; 4) EDGAR and 5) STEAM. The inventories were initially compared in terms of total emission values and their spatial distribution. The total emission values are largely in agreement (with the exception of E-PRTR), however, the spatial representation shows significant differences in the emission distribution, in particular over the Mediterranean region. As for the contribution of shipping to overall emissions, this sector represent on average 16%, 11% and 5% of total NOx, SOx and PM10 emissions, respectively. Recommendations are given regarding the specific use of each available inventory.

1. Introduction

Due to its dependence on fossil fuel combustion and the fact that it is one of the least regulated anthropogenic emission sources, studies show that ships make a non-negligible contribution to air pollutant emissions (Corbett and Fischbeck, 1997; Eyring et al., 2005a), specifically NOx, SOx and PM10. These pollutants have negative impacts on air quality, human health, and climate change problems at local, regional, and global levels (Isakson et al., 2001; Eyring et al., 2005b; Costa et al., 2014; Viana et al., 2014; Aksoyoglu et al., 2016). Accurate and up-to-date ship emission inventories are key inputs for air quality modelling, and are essential for a better understanding, and cost-effective control, of the impacts of air emissions from shipping activities on the environment and human health. One of the challenges in improving the accuracy of ship emission inventories is due to their mobility, poorly integrated models, and limited data (Matthias et al., 2010). Information on these types of emissions is limited due to a lack of dynamical features, such as the geographical or temporal variations of emissions. This information can be critically important for all transportation emissions, which present a substantial spatial and temporal variation (Jalkanen et al., 2016). For the maritime transport sector, characterization of shipping activity is a challenging task, and has large uncertainties in emission assessments (USEPA - U.S. Environmental Protection Agency, 2004; Wang et al., 2008). Therefore, studies concerning ship emissions in Europe are mainly based on statistical analysis of cargo volumes (Schrooten et al., 2009), vessel arrivals and departures (Whall et al., 2002), voluntary weather reports from ships (Corbett et al., 2007) or search and rescue services (Endresen et al., 2003; Wang et al., 2008). Tools such as the Automatic Identification System (AIS) can significantly reduce the uncertainty concerning ship activities and their geographical distribution. However, these inventories are dependent on real-time information, full access to traffic activity and temporal changes (Jalkanen et al., 2016). Given the large number of ship movements and dynamic shipping routes, this type of data, for the entire European domain, is currently not freely accessible.

The aim of this study is to present a state-of-art of the most up-to-date and available emission inventories regarding ship exhaust emissions in European sea areas. The comparison is performed for the most critical pollutants: nitrogen oxides (NOx), sulphur oxides (SOx) and particulate matter (PM10), based on graphical and quantitative delta analysis.

The most used emissions inventory is from the EMEP Centre on Emission Inventories and Projections (CEIP), which collects data from LRTAP Convention parties (WebDab). In addition, other inventories focused on the European domain, and used in this study, are: EDGAR (EDGARv4.3.1, 2016), TNO-MACC_III (Kuenen et al., 2014), E-PRTR (E-PRTR, 2011) and STEAM (Jalkanen et al., 2016). These inventories are independent from the EMEP database. EDGAR is an emission inventory with global annual emissions data, per country, for the most relevant air pollutants. E-PRTR (European Pollutant Release and Transfer

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Register database) and TNO have gridded emission data from officially submitted national emissions data, furthermore, TNO adds to the data with models and expert estimates. The Ship Traffic Emission Assessment Model (STEAM) provides estimates using AIS and vessel-specific information to model ship emissions.

The purpose of emission inventories is generally reflected in their overall dataset format, such as: mandatory international protocols, regulation purposes; research project/services; datasets for air quality modelling; etc. (Ferreira et al., 2013). The structure of the data is where these differences are most noticeable, in regards to how the sectors are presented (Reis et al., 2009).

According to Winiwarter et al. (2003), comparisons between emission inventories need to be easy to implement, efficient and accurate. The methods used in this paper are an analysis of emission totals, a graphical spatial distribution analysis of each inventory on the same grid, and a quantitative graphical analysis of the differences. These studies can provide useful insight into the structure inventories, allowing for a validation of the emissions and interesting conclusions regarding the distribution of emissions. In addition, an idea of the uncertainty of shipping emissions can be achieved when comparing different inventories with similar methodologies.

The overview of the atmospheric emission inventories proposed in this paper will be important for the characterization and assessment of the differences between available inventories, to estimate uncertainty and to infer their potential impacts on air quality modelling applications.

The paper is organised as follows: in Section 2, the emission inventories analysed are described in detail. Section 3 focuses on the comparison of the shipping emission data, per pollutant. Finally, in Section 4, the main conclusions are summarized.

2. The emission inventories

Five emission inventories with data freely available for the European domain were compared in this review study: EMEP; E-PRTR; EDGAR; TNO-MACC_III and STEAM. Following, they are described in more detail with further information regarding domain, resolution and pollutants, being shown in Table 1. Due to availability of data, and in order to minimize inconsistencies in this comparison, the year 2008 was used for EMEP, TNO and E-PRTR. For EDGAR, 2010 is considered, as there is only data available for this year. Although STEAM emissions are available for 2011 and updated for 2015, 2011 was chosen, as it is closer to the studied year of 2008.

2.1. EDGAR

The Emissions Database for Global Atmospheric Research is a global emission inventory developed jointly at JRC (European Commission Joint Research Centre) and PBL (the Netherlands Environmental Assessment Agency). One of the main advantages of EDGAR is that it provides emissions data, for all countries, determined from a consistent method to breakdown each sector, i.e., technology and activity, applied to all countries. This, whenever possible, accounts for the emission factors recommended by the EMEP/EEA air pollutant emission inventory guidebook. Data is available by country but also on a spatial grid (0.1° x 0.1°) for several greenhouse gases and air pollutants emitted by anthropogenic sources. The latest version available, version 4.3.1, provides gridded data by sector only for 2010, although long time series (from 1970 to 2010) are available for country totals. Here, data for the shipping sector (1A3d + 1C2) was the one considered. More details on the assumptions in this inventory can be found at Crippa et al. (2016). Regarding emissions from shipping activities, the EDGAR approach is a combination of bottom-up and top-down methods. Emission factors and fuel statistics from the IEA (International Energy Agency), taking into account fuel usage of different vessel types, port activities and ship types are used to determine overall ship emissions. While the spatial

Table 1
Summary of the main characteristics of the European emission inventories used in this work.

Inventory	References/link	Resolution	Pollutants	Methodology
EMEP (European Monitoring and Evaluation Programme)	http://www.ceip.at/ms/ceip_home1/ceip_home/webdab_emepdatabase/emissions_emepmodels/	European 0.5° x 0.5°	NOx, SOx, CO, NMVOC, NH_3, PM10, PM2.5, PMcoarse, Heavy metals and POPs	International shipping routes, reported emissions by Member States
E-PRTR (European Pollutant Release and Transfer Register)	http://prtr.ec.europa.eu https://www.eea.europa.eu/data-and-maps/data/european-pollutant-release-and-transfer-register-e-prtr-regulation-art-8-diffuse-air-data	European (0.047°–0.183°) x 0.045°; 5 km × 5 km	NOx, PM10, SO_2, CO, NH_3 and CO_2	Proxy data on worldwide international shipping from Wang et al. (2008). International emissions on inland waterways gridded using traffic volume data Domestic sea shipping based on EUROSTAT statistics on freight and passenger transport
EDGAR (Emission Database for Global Atmospheric Research)	http://edgar.jrc.ec.europa.eu/overview.php?v=431	Global 0.1° x 0.1°	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, CF_6, NF_3, CO, NOx, NMVOC, SO_2, NH_3, PM10, PM2.5, BC and OC	Global shipping proxies from Wang et al. (2008) and population density maps for domestic shipping
TNO (Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek - Netherlands Organisation for Applied Scientific Research)	Kuenen et al., 2014	European 0.125° x 0.0625°	CH_4, CO, NH_3, NMVOC, NOx, PM10, PM2.5 and SO_2	EMEP gridded emissions disaggregated using shipping ANVER – ICOADS grid
STEAM (Ship Traffic Emission Assessment Model)	Jalkanen et al., 2016 and references therein	European 0.0487° x 0.0335°; 2.5 km × 2.5 km	CO_2, NOx, SOx, CO, PM2.5	Emissions calculated by the STEAM model based on AIS (real-time) data and vessel characteristics