Port-Related Shipping Gas Emissions

Subjects: Transportation Science & Technology | Engineering, Environmental
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The global increase in shipping activity has contributed to the degradation of air quality, which particularly affects traffic-dense port areas. Due to the environmental and public health impacts of air quality in port cities, a number of inventories using varying methodologies have been conducted over the past two decades to manage gas emissions in specific areas.

Keywords: shipping emissions ; port sustainability ; Gas Emissions

1. Introduction

Shipping is the most efficient transportation mode in terms of energy usage per tonne of cargo, covering more than 80% of global trade by volume [1][2][3]. Although maritime transportation is still the least environmentally damaging mode of transport, it is responsible for about 2.2%, 15% and 5 to 8% of global anthropogenic carbon dioxide (CO_2), nitrogen oxide (NO_x) and sulphur oxide (SO_x) levels, respectively [4][5]. In addition to the mentioned gases, ships emit large quantities of particulate matter (PM), volatile organic compounds (VOCs) and carbon monoxide (CO). Despite the fact that maritime emissions have worldwide impact, some studies have indicated that about 70% of emissions from ships occur within 400 km of the coast, since most ships spend most of the time either harbored or near a coast [6]. While CO_2 is recognised as the leading greenhouse gas responsible for global climate change, the presence of PM, VOCs, CO, NO_x and SO_x in urbanised port areas requires even more attention due to the negative effects of these pollutants on human health [5]. Pollutants emitted from ships can be responsible for respiratory diseases, cardiovascular disease, lung cancer and even premature death, so it is necessary to monitor them and mitigate their presence in port communities [7][8]. The severity of air quality degradation is all the more serious when taking into account the fact that 90% of European ports are spatially connected to cities [9].

2. Port-Related Shipping Gas Emissions

Mitigation of vessel gas emissions on a global scale was addressed by the International Maritime Organisation (IMO) in 1997 when Annex 6 “Prevention of Air Pollution from Ships” of the MARPOL convention was introduced [10]. The main changes that MARPOL Annex 6 brought in were a global progressive reduction in SO_x, NO_x and PM emissions and the introduction of emission control areas (ECAs) [10]. Over the years, MARPOL Annex 6 has been revised and from January 2020, or January 2025, depending on the availability of low sulphur for ships’ use, the global limit for sulphur content of ships’ fuel is reduced from 3.5 mass by mass percent (% m/m) to 0.5% m/m, while in ECAs the content is pushed down to 0.1% m/m [10]. Requirements for NO_x emissions were defined using a three-tier methodology, where different levels (Tiers) of control apply, based on ship construction date [11]. The less strict Tier 1 applies to vessels constructed on or after 1 January 2000, Tier 2 to vessels constructed on or after 1 January 2011, while the most demanding Tier 3 regulates NO_x emissions from vessels built after January 2016 that operate in the North American and United States Caribbean Sea, the Baltic Sea or the North Sea ECAs.

The issue of air quality inside the European Union (EU) port sector was first recognised in 2004 by the European Sea Ports Organisation (ESPO), while in 2013 it became a top environmental priority and has remained so to this day [9]. Due to the influence of air quality on the environment and public health of port cities, a number of different inventory studies have been conducted throughout the last two decades in order to manage gas emissions in particular interregional, national or local areas. For inventory development, two different approaches that are most commonly applied are the top-down approach and the bottom-up approach.

A top-down approach can be described as a fuel-based (FB) method, where fuel sales statistics are used to estimate the total mass of the fleet fuel consumption (FC) inside a specific area of interest in a certain time period. That information is then combined with the emission factor (EF), which denotes the mass of emitted pollutants per metric tonne (t) of fuel consumed in order to finally obtain the total mass of emitted pollutants (E), which is represented in Equation (1) [12]:

$$E = FC \times EF \quad (1)$$

The main advantage of this fuel-based (FB) concept is that it is not data-excessive. This means that data that only generally describe a particular fleet and its FC and EF can be used. Thus, this approach is recommended for situations where only limited traffic data are available [12]. However, applying generic data that are associated with a level of uncertainty can produce outputs that differ from realistic emissions. The corresponding EFs are highly aggregated, with averaged values, and do not take into account the specific conditions that lead to instantaneous emission production in any given circumstance [13]. Moreover, it has been proven that there is a significant discrepancy between banker fuel sales statistics and the actual fuel used by global fleets, so it cannot accurately reflect emissions in response to specific shipping activities [13][14]. This is especially relevant for small interest areas such as ports, where fuel sales data have lower accuracy. Therefore, the top-down approach is most commonly used in large-scale inventories where it is more practical to gain insight into shipping emissions by acquiring less detailed data based on FC.

When detailed information about a ship's movement dynamics and its technical data (TD) are available, then the bottom-up approach is recommended. This method is characterised as activity-based and data-demanding, since it requires a higher level of input parameters for each movement activity (MA); however, it is able to produce near instantaneous emission estimation on a vessel-by-vessel basis at high resolution (in time and space) [12][13]. In a bottom-up approach, emission estimations are obtained for each movement type by combining engine energy output (EO) or FC with EF and time (T) values that correspond to specific activities (e.g., hoteling, manoeuvring and navigation) [15][16]. To figure out the total shipping emissions in a certain area and time period, all estimated quantities of each activity are combined and scaled up over all trips [12]. In the bottom-up approach, both energy-based (EB) and FB methods can be applied. These methods are shown in the EB Equations (2) and (3), along with the FB Equation (4) [12][16]. When gas quantification is conducted by relying on an EB approach, EO is determined by multiplying total engine power (P) by the actual percentage of engine work output, expressed as load factor (LF). In this case, EF is defined as the mass of pollutants emitted per an engine's energy output:

$$E = EO \times EF \times T \quad (2)$$

$$EO = P \times LF \quad (3)$$

$$E = FC \times LF \times EF \times T \quad (4)$$

Since the bottom-up approach is data-excessive, it is generally applied in small-scale ship emissions inventories in regional and port contexts, and to aggregate the required data the Automatic Identification System (AIS) is often used. AIS transmits near real-time dynamic information about vessel speed, course and position, which is crucial for anticipation of ship-based emissions. Therefore, high-resolution ship motion data from AIS could be a source of reliable relative ship operation profiles, such as travel time and average speed between waypoints at sea in short time intervals, and could be used to identify ship routes [12]. Although the installation of AIS is required by the International Maritime Organisation (IMO) on commercial ships with 300 gross tonnage (GT) and all passenger ships, relying solely on information from this device, a proportion of marine traffic remains invisible [17]. To improve data quality, more than one source of traffic information should be considered in gas emission inventory development. However, regardless of data quality, the method by which it is used is of equal importance.

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