



Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

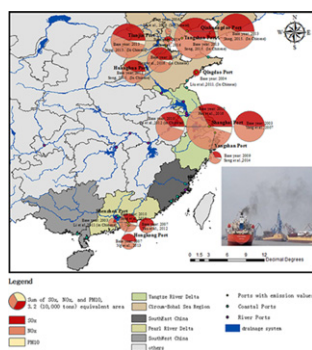
Shipping emissions and their impacts on air quality in China

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HIGHLIGHTS

- The first review of shipping emissions in China
- An overview of the broad field of ship emissions and their atmospheric impacts in China
- Future work in shipping related air pollution field has been outlooked.

GRAPHICAL ABSTRACT



China has >400 ports and waterway infrastructure construction has accelerated over the past years. Shipping emission and their impacts have been paid attentions in China. There have been an increasing number of studies published on shipping and port emissions of the main shipping areas in China, and quantitative contribution of shipping emissions to the local and regional air pollution.

ARTICLE INFO

Article history:

Received 13 October 2016

Received in revised form 3 December 2016

Accepted 14 December 2016

Available online xxx

Editor: D. Barcelo

Keywords:

Ship emission
China
Air pollution
Emission factor

ABSTRACT

China has >400 ports, is home to 7 of 10 biggest ports in the world and its waterway infrastructure construction has been accelerating over the past years. But the increasing number of ports and ships means increasing emissions, and in turn, increasing impact on local and regional air pollution. This paper presents an overview of the broad field of ship emissions in China and their atmospheric impacts, including topics of ship engine emissions and control, ship emission factors and their measurements, developing of ship emission inventories, shipping and port emissions of the main shipping areas in China, and quantitative contribution of shipping emissions to the local and regional air pollution.

There have been an increasing number of studies published on all the above aspects, yet, this review identified some critical research gaps, filling of which is necessary for better control of ship emissions, and for lowering their impacts. In particular, there are very few studies on inland ports and river ships, and there are few national scale ship emission inventories available for China. While advanced method to estimate ship emission based on ship AIS activities makes it now possible to develop high spatial- and temporal-resolution emission inventories, the ship emission factors used in Chinese studies have been based mainly on foreign measurements. Further, the contribution of ship emissions to air pollution in coastal cities, the dispersion of pollution plumes emitted by

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ships, or the chemical evolution process along the transmission path, have so far not been systematically studied in China.

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1. Introduction

Ship emissions with their key components including SO_x, NO_x, HC and PM, which is composed of organic and elemental carbon (OC and EC), sulfates and metals, have a significant influence on coastal atmospheric environment. The global ship emissions and their influence on climate and air quality have been attracting interest worldwide over the past two decades (Corbett and Fischbeck, 1997; Capaldo et al., 1999; Lawrence and Crutzen, 1999; Eyring et al., 2005). However, over the last decade ship emissions in the East Asia region have increased rapidly, and taking NO_x as an example, have reached 2.8 Tg in 2013, which is almost double of 1.49 Tg in 2001 (Liu et al., 2016). Hazardous emissions from ships lead to increasing impacts on the quality of local, regional, and global atmosphere. This is particularly so in China, where with the significant development of the economy and shipbuilding industry, the total number of ships increases rapidly, and where pollution caused by ship emissions is becoming increasingly more serious.

China's shipping industry has experienced a rapid development over the past few years, and it is expected that Shanghai will become the international shipping center by 2020 (State Council of China, 2008). The container throughputs in China in 2014 were 202.4 million TEU, accounting for >25% of the world total. China has reached a nationwide port handling capacity of 12.75 billion tons and was home to 7 of 10 biggest ports in the world in 2015 (MOT, 2015). However, at the same time China has been experiencing heavy regional air pollution. Emissions of ships in ports and along shipping routes have contributed to worsening of the current severe air pollution situation. Recently, a scheme of areas in China has been promulgated for prevention of air pollution from ships (MOT, 2015).

In inland rivers, sea ports and straits, ship emissions are becoming one of the main sources of atmospheric pollution, with a large number of diesel-powered offshore and sea-going ships, of a large variety of types, differing in technical level and, working conditions. However,

very few studies were conducted on ship emissions and ship emission inventories, with just a handful of studies published on ship emission inventories on port scale, port-cluster scale and national scale in China. Most of earlier studies to calculate ship emission were based on ship visa registration data or fuel burning data (Yang et al., 2007; Jin et al., 2009; Zhang et al., 2010; Fu et al., 2012). Recently, researchers have started estimating ship emissions based on automatic identification system (AIS) data (Ng et al., 2013; Fan et al., 2016). The impact of ship emission on atmospheric environment has also attracted recently an increasing level of attention (Liu et al., 2011; Yau et al., 2012; Zhao et al., 2013; Ye et al., 2014).

The aim of this work was to comprehensively review and summarize the studies reporting on all the relevant aspects of shipping emissions and their impacts on air quality in China. The scope of the review included ship engine emissions and control, ship emission factors and their measurements, building of ship emission inventories, shipping and port emissions of the main shipping areas in China, and contribution of shipping emissions to local and regional air pollution.

2. An overview of China's shipping and ports

China has >400 ports and is divided into 5 major port clusters, of which Pearl River, Yangtze River, and Bohai gulf port cluster are the largest and of most significant impacts (Fig. 1). China's waterway infrastructure construction has accelerated over the past years. The number of production berths of Chinese ports reached 31,259, of which 2221 were 10,000-ton-and-above berths. By the end of 2015, there were 169.5 thousands of transport ships across the country, with an aggregate tonnage of 272.4429 million DWT. China's waterway cargo transport volume amounted to 6.136 billion tons, and its waterway cargo turnover and container cargo volume reached 9.177245 trillion ton-

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