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Shipping emission forecasts and cost-benefit analysis of China ports and key regions' control☆

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ABSTRACT

China established Domestic Emission Control Area (DECA) for sulphur since 2015 to constrain the increasing shipping emissions. However, future DECA policy-makings are not supported due to a lack of quantitive evaluations. To investigate the effects of current and possible Chinese DECAs policies, a model is presented for the forecast of shipping emissions and evaluation of potential costs and benefits of an DECA policy package set in 2020. It includes a port-level and regional-level projection accounting for shipping trade volume growth, share of ship types, and fuel consumption. The results show that without control measures, both SO_2 and particulate matter (PM) emissions are expected to increase by 15.3–61.2% in Jing-Jin-Ji, the Yangtze River Delta, and the Pearl River Delta from 2013 to 2020. However, most emissions can be reduced annually by the establishment of a DECA that depends on the size of the control area and the fuel sulphur content limit. Costs range from 0.667 to 1.561 billion dollars (control regional shipping emissions) based on current fuel price. A social cost method shows the regional control scenarios benefit-cost ratios vary from 4.3 to 5.1 with large uncertainty. Chemical transportation model combined with health model method is used to get the monetary health benefits and then compared with the results from social cost method. This study suggests that Chinese DECAs will reduce the projected emissions at a favorable benefit-cost ratio, and furthermore proposes policy combinations that provide high cost-effective benefits as a reference for future policy-making.

1. Introduction

In recent years, the air pollution from Chinese shipping is becoming increasingly prominent. On the one hand, the Chinese share of world seaborne trade is overwhelming. Chinese ports handled 26.5% of the global throughput of containers at ports in 2014 (UNCTAD, 2015). In China, ports are distributed intensively particularly in Jing-Jin-Ji (JJJ, which includes Beijing, Tianjin and Hebei province), the Yangtze River Delta (YRD), and the Pearl River Delta (PRD). In 2016, 6 of the world's top 10 ports as well as 10 of the world's top 20 were located in the above regions (not counting the Hong Kong port as the emission control policy are different) (UNCTAD, 2016). On the other hand, these areas have the highest population density (352, 541 and 502 km^{-2} for JJJ, YRD and PRD) and the fastest developing rate (7.6–8.6% GDP growth annually). Consequently, shipping emissions cause more severe environmental problems in these areas (Corbett et al., 2007; NRDC, 2014). Considering the expansion of international trade and the important role Chinese marine system plays (19.6% increment for China import and export value), shipping emission will continue to increase in the future.

In this background, the Chinese government is paying more attention to the shipping emission issue and has introduced a series of policies. SO_2 emissions are directly proportional to the sulphur content of marine fuel; thus, one of the most straightforward and effective methods of reducing them is to switch from bunker fuel to low-sulphur fuel (Wang and Corbett, 2007). IMO enacts regulations for ships through the MARPOL Convention. Annex VI of this convention was revised in 2008 and allows signatory countries to apply for the designation of an Emission Control Area (ECA) (IMO, 2008). Ships are restricted to use low-sulphur fuel or an approved

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equivalent method in sulphur ECA areas. The established ECA areas are as follows: the Baltic Sea area (SOx), the North Sea area (SOx), the North American area (SOx and NOx), the United States Caribbean Sea area (SOx and NOx) (Simon et al., 2013; Viana et al., 2015). China is one of the signatory countries of Annex VI. In December 2015, the Ministry of Transport of China created three sulphur DECAs: in JJJ, the YRD, and the PRD (The Ministry of Transport of China, 2015).

Analysis of the costs and benefits of implementing ECAs can be found in the studies of Wang and Corbett for the US West Coast (Wang and Corbett, 2007), EPA for the North American ECA (EPA, 2009), Sieber et al. for Europe (Sieber and Kummer, 2013), Antturi et al. for the Baltic sea ECA (Antturi et al., 2016) and AEA for the Baltic Sea ECA and the North Sea ECA (AEA, 2009). Most of these studies found that the health and environmental benefits far outweighed the costs of meeting ECA requirements except that of Antturi et al. Antturi's study found that the annual cost was roughly €465 M, whereas the benefit was €105 M. However, based on their sensitivity analysis, the benefits yet have a potential to exceed the costs. The costs of DECAs in JJJ, the YRD, and the PRD would be specific to the local conditions in China. Therefore, a locally-based cost-benefit analysis must certainly be developed.

Efforts have been made to develop regional-level ship emission inventories and analyze the emission reduction effect in China. Several groups (Li et al., 2016; Liu et al., 2016; Chen et al., 2017; Fu et al., 2017) used an Automatic Identification System (AIS) system to develop the ship emission inventory for China and related regions. A report conducted by two local universities in Hong Kong (Simon et al., 2013), assessed the impacts of emissions from OGVs operating in Hong Kong and the rest of the PRD region. They set and compared four different ship emission control scenarios for Hong Kong and the PRD. Establishing a 100 nautical miles (nm) DECA in the PRD has been revealed to bring a reduction of SO_2 by 95% and PM by 85% and the greatest benefits. The emission reduction effects of DECA in the PRD far overweighed those of other control measures, such as mandatory fuel switching at-berth or only in Hong Kong waters, and restricting vessel speeds to 12 knots in Hong Kong waters for OGVs. The impacts of emission controls from OGVs in JJJ and the YRD are still not reported.

The negative environmental impacts caused by air pollution can be quantified and monetized as environmental costs, although such calculations can be an inevitable source of uncertainties (Hazilla and Kopp, 1990; Clarkson and Deyes, 2002). According to EPA, the social cost includes changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services (IAWG, 2010). In current studies, the concept of social cost is similar to those of external cost, economic cost, marginal cost, and so forth (Gallagher, 2005; Muller and Mendelsohn, 2007; Tichavska and Tovar, 2015). These concepts are deemed to be identical in this study.

Social cost has been used in the calculation of shipping emissions at the port, regional, and national levels. Several European studies addressed the social cost estimation at the port and regional levels, such as those of Tzannatos et al. for the Piraeus port (Tzannatos, 2010), of Kalli et al. for the Gulf of Finland (Kalli and Tapaninen, 2008), and of Tichavska et al. for the Las Palmas Port (Tichavska and Tovar, 2015). There are also investigations at the national and wider regional level such as those for Greece, America, and Europe (Gallagher, 2005; Wang and Corbett, 2007; AEA, 2009; Notteboom et al., 2010; Maragkogianni and Papaefthimiou, 2015). No other previous studies can be found on measuring the social cost of ship emission in China except that on the Yangshan port (Song, 2014).

There has been a debate over whether controlling port emissions or controlling regional emissions should be priority. There are busier shipping transportation and higher concentrations of emissions in port areas, which makes controlling port emissions potentially a better deal. However, some believed that regional control measures were expected to cut more emissions than that of port control measures, even if it might be less economic. This study filled the gaps of previous studies on evaluation and cost-benefit analysis for current and possible Chinese DECA policies, both on port-level and regional-level for a long time scale. In this study, a shipping emission forecast and cost-benefit analysis model was developed to feature: (1) reliable port and regional shipping emission inventory building on the research for developing the East Asia 2013 OGV inventory by Liu et al. (2016); (2) shipping emission forecast in 2020, associated with based on the growth of port throughput, share of ship type, and fuel consumption reduction; (3) evaluation of current DECA policy by applying effectiveness and a cost-benefit analysis; (4) assessment of a DECA policy package set that are likely to be proposed in the future, involving changing the DECA size and the fuel sulphur content limit.

2. Materials and methods

2.1. Study area

The Chinese DECA control measures consist of two phases: control emissions from ships berthed in ports of DECA areas from 2017 to 2018 and control emissions from ships in the whole DECA areas after 2019. To measure and analyze the emission reduction effects, we set up two inventories: the port inventory and the regional inventory, corresponding to the two control phases.

The study area of the port inventory consisted berthing area of all ports in three DECA areas, including 10 core ports (shown in the map in Fig. 1) and 15 non-core ports. The core ports included Tianjin port, Qinhuangdao port, Tangshan port and Huanghua port

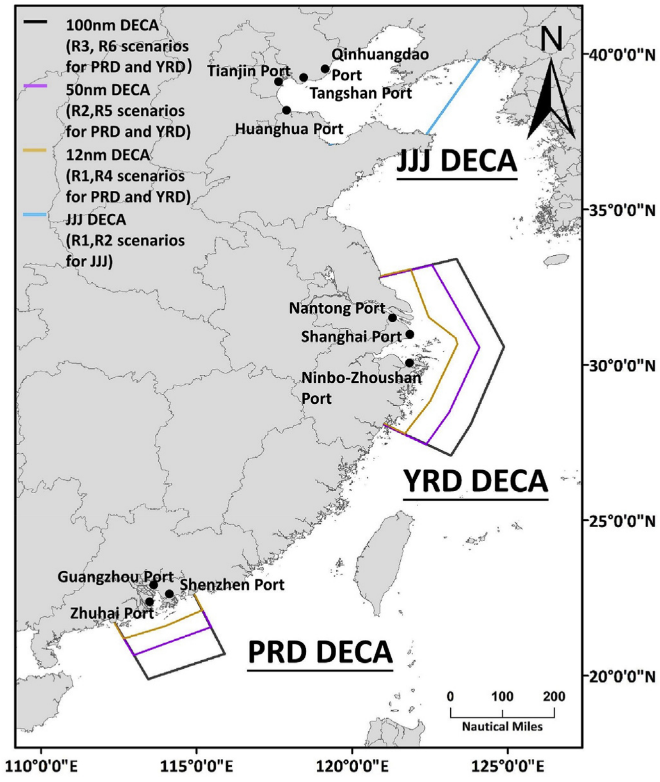

Fig. 1. Maps of the study areas, scenarios of DECA and locations of the core ports.