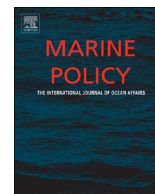




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## Incentive policy for reduction of emission from ships: A case study of China

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## ABSTRACT

Particulate matter (PM) emissions from ships in ports are a major contributor to air pollution and smog in port cities. The issue of how to reduce PM emissions has become a critical concern for port city residents and governments. This paper establishes an incentive policy to reduce PM emissions from ships in ports. Using a Panamax bulk carrier as a case study, eight alternative approaches that could be adopted by shipping companies are compared and their operational benefits are estimated. By restricting the analysis to emission control areas (ECAs), the net present value (NPV) model shows that the diesel particulate filter (DPF) is the most advantageous approach with the highest NPV, while the exhaust gas scrubber (EGS) approach is the most economically inefficient. Meanwhile, due to DPF's excellent performance in PM abatement, it is suggested that governments should prioritize the DPF approach when promoting the application of emission reduction technologies. From the perspective of social welfare, a positive social benefit of about US \$20,000 will be generated over the life cycle of a ship. However, a low government pricing in China will reduce shipping companies' operational performance as the emission control zone (ECZ) gradually expands. As a result, an appropriate subsidy scheme is necessary to encourage shipping companies to apply emission reduction technologies.

## 1. Introduction

Research on marine environmental protection has focused on the prevention of oil pollution from ships, while other subjects such as air pollution, ballast water treatment, and the impacts of antifouling biocides have been neglected due to significant uncertainty in marine vessel inventories [18,6]. Another reason for the lack of previous studies on air pollution from ships is that this source of pollution is not normally associated with any dramatic accident; this contrasts with oil spills, which are highly visibly and raise public outcry [27]. However, recent years have brought greater awareness of the chronic harm to public health and the environment posed by air pollution from ships, and the International Maritime Organization (IMO) has tried to combat this issue by employing a precautionary principle. A study by Per Kågeson [15] on reducing emissions from ships in the Baltic Sea Area reveals that ship emissions are a significant contributor to air pollution. Ships make significant contributions to air pollution through emissions of a range of contaminants, including greenhouse gases (GHGs; [10,28,9,20]), nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>), and particulate matter (PM) [11,22,23]. In particular, ships are a major source of PM emissions to port cities, imposing a severe smog problem as well as

exacerbating several human health conditions, including asthma and heart attacks; smog from ships has also been linked to increased hospital admissions and premature mortality [7]. Winnes and Fridell [29] investigates how emissions of NO<sub>x</sub> and particles from manoeuvring ships could negatively affect local air quality in port cities. Furthermore, Wan et al. [28] finds that the concentration of PM is generally higher in port cities than in inland cities, with this difference mainly attributed to the shipping industry. As a result, the issue of PM emissions reduction from ships has received increasing attention from both local residents and governments of port cities.

Unfortunately, there is no firmly established worldwide policy for the reduction of PM emissions from ships. Rather, regulations are established by individual states or groups of states. Winnes and Fridell [29] reports that emission standards for PM<sub>10</sub>, PM<sub>2.5</sub>, and NO<sub>2</sub> are either established or on the agenda in both the European Union (EU) and the United States (US). These standards take into account emission concentrations in both rural and urban areas, but do not emphasize emissions from ships in ports. On the other hand, the emission control areas (ECAs) established by the IMO introduce more stringent emission controls on toxic substances from the combustion of fuel oil, particularly NO<sub>x</sub> and SO<sub>x</sub>, and thus indirectly regulate PM emissions from ships

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**Table 1**

Summary of major approaches for PM emission reduction.

Source: The estimated method was suggested by [8], and the results were calculated by the authors based on market survey data.

Approach	Applicable models	Technical application	Reduction of PM emissions (average)
Fuel borne catalyst	L, M, H	ships and automotive	35%
Emulsified diesel	L, M, H	ships	60%
Low-sulfur fuel (MDO, MGO)	L	ships	70%
LNG	L, M, H	ships	94%
Exhausted gas scrubber	L, M, H	ships	80%
Diesel Particulate Filter	L, M, H	ships and automotive	90%
FBC + DPF	L, M, H	automotive	94%
Distillate fuel oil + CDPF	L	automotive	96%

Notes: H, M and L indicates high, medium and low speed engine, respectively.

(Review of Maritime Transport, 2016). In China, to reduce the levels of ship-generated air pollution, especially the sulfur content of fuels, the government has decided to establish three ECAs,<sup>1</sup> including the Pearl River Delta, the Yangtze River Delta, and Bohai Bay. However, as these ECAs arose as a matter of Chinese domestic law and are not MARPOL Annex VI designated, they are designated as emission control zones (ECZs) in this paper. This new Chinese legislation will implement a staged process to limit the sulfur content of fuels used within the ECZs, with a maximum allowable sulfur content of 0.5% for vessels operating within any ECZ beginning 1 January 2019. As there is no worldwide regulation on ships or mandates for ports to record their environmental activities, emissions controls are motivated by the “ecological sensitivity” of individual countries [23]. These authors find that, based on eco-efficiency indicators and available data, it is likely that ports can help authorities lower operational expenses and reduce the environmental impact of PM emissions by using policies and managerial tools such as pricing alteration, monitoring and measuring, market access control and environmental standard regulation. Similarly, Chen and Pak [4] uses the Delphi technique to identify a set of applicable and practical green performance evaluation indices for Chinese ports.

Several studies regarding shipping air emission and a port's green performance in the context of sustainable development have been published, but few studies have been specifically aimed at PM mitigation. There are also other gaps in the understanding of the environmental impacts of ships; for instance, a particular dearth of information on the marine environmental problems and potential marine environmental reform of many African ports [1] and a need for improved mapping of links between international supply chains, sustainability, and environment-friendly ports worldwide. According to a survey of port managers in Taiwan, Lu et al. [19] suggests that external requirements including environmental concerns should be integrated into internal decisions of port development. Similarly, Xiao and Lam [30] advocates for integrating economic, social, and environmental criteria during the development of port cities. This integrated approach can also be applied to the initial construction of ships, as described in a study that empirically investigated the forces that push suppliers to participate in green supply chain management (Caniëls et al., [3]).

Studies in the U.S. and China have examined port efficiency. Cheon et al. [5] applies geospatial modelling and data envelopment analysis to investigate the relationship between economic and environmental

performance of U.S. ports. They find that good environmental behavior generally has a positive correlation with economic performance. Similarly, Cui [9] focuses on 10 Chinese ports to measure environmental efficiency, and the RAM-Tobit-RAM model is applied. He finds a negative correlation between port scale and efficiency.

The emissions of carbon dioxide and sulfur dioxide from ships have also received research attention. Mamatok and Jin [20] proposes a flexible framework that serves to estimate and control carbon dioxide in container ports and aims to support sustainable port development. Nikopoulou [22] creates and testes a model calculating the incremental costs of abating NOx and SOx emissions from ships in a North European emission control area. This plan encourages stakeholders to cooperate with basic information collection. With the assistance of stakeholders, Wang and Nguyen [28] puts forward a mechanism to prioritize low-carbon shipping approaches in order to aid decision-making. They apply the Fuzzy-based Technique for Order Preference by Similarity to Ideal Solution and the Fuzzy Quality Function Deployment to handle data, business, and technique uncertainty. Future fuel prices are a main contributory factor to the choice of emission reduction measures. Patricksson and Erikstad [23] develops a two-stage optimization model to evaluate advantage measures for sulfur dioxide mitigation.

A range of practical approaches is available to reduce emissions of PM and has been successfully used in both ships and automobiles. These include fuel borne catalysts, emulsified diesel oil, low-sulfur marine fuel, liquefied natural gas (LNG) fuel, exhaust gas scrubber, diesel particulate filter (DPF), fuel borne catalyst combined with DPF (FBC + DPF), and distillate fuel oil combined with catalyzed DPF (distillate fuel oil + CDPF). Table 1 provides a summary of the aforementioned eight approaches with information on aspects of the applicable models, technical application, and reduction ability. It is evident that shipping companies will incur different expenditures depending on which reduction approaches are adopted.

As there are no internationally binding rules for PM emission reduction from ships, the decision about whether or not to employ reduction approaches depends largely on cost affordability to the shipping companies. In practice, this voluntary adoption of emission control technologies results in limited reduction in PM. From a broader social welfare perspective, both local residents and governments in port cities can benefit significantly from the use of PM emission reduction strategies by shipping companies, which lead to reduced air pollutants and decreased health risk. Accordingly, encouraging shipping companies to apply emission reduction technologies is an important challenge for local governments in port cities.

Using a bulk carrier as a case study, this paper aims to establish an incentive policy to reduce PM emissions from ships in ports. This work can be extended in two ways. Firstly, the economic and social benefits of eight alternative reduction approaches are estimated and compared, helping to identify the most advantageous approach. Secondly, referring to the emission trading system (ETS) in the EU, a conceptual scheme allowing shipping companies to gain profits from emission credit trading is proposed [21].

This paper is structured as follows: Section 2 presents the economic model used to evaluate different PM emission reduction approaches. Section 3 undertakes a case study of a Panamax bulk carrier and investigates the impact of freight rate, fuel price, and ECA range on the shipping companies' operational benefits. Section 4 discusses a conceptual scheme regarding how to encourage shipping companies to apply emission reduction technologies. Conclusions and suggestions for future research are presented in Section 5.

## 2. Methodology

This paper has two goals: 1) identify the most economically efficient approach for PM emission reduction; 2) develop an incentive policy to encourage shipping companies to apply the identified approach to reduce PM emissions from ships in port. Economic efficiency was

<sup>1</sup> New Emission Control Areas in China: <http://www.nepia.com/insights/signals-online/regulation/new-emission-control-areas-in-china/new-emission-control-areas-in-china/>.

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