Study on Ship-based Atmospheric Pollutant Emission Forecasting for Environmental Impact Assessment in Port Planning

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Abstract. Vessels are major contributors to port-related atmospheric pollution. In recent years, as the environmental impact assessment (hereinafter as EIA) in port planning become increasingly standardized, the lens on atmospheric pollution in EIA has gradually broadened from loading and unloading, piling and storage by cargo types to include the impact of ship emissions. However, the impact analysis ship-based atmospheric pollutants in port areas lack quantitative methodologies for accurate calculation, in particular where annual forecasting is commissioned in annual planning. By combining the characteristics of Chinese port planning and mainstream calculation methods of ship emissions in the world, the study arrives at several recommendations on selecting methodologies for the calculating of ship-based emissions in the EIA process that are tailored different planning scenarios and data availability, serving as reference for EIA practitioners in their endeavors to calculate the atmospheric pollutant emissions from ships in the EIA process mandated by port planning.

Key words: planning-driven environmental impact assessment, vessel, atmospheric pollutant emission, dynamic methodology, fuel-based methodology.

1. Introduction
Ship-sourced atmospheric pollutants, mainly originating from fuel combustion of vessel engines, feature SO₂ and NOx and contains CO, VOCs, TSP, PM₁₀, PM₂.₅ as well as GHG led by CO₂. In China, ports are characterized by high levels of population density and vessel activities. With the implementation of port planning, the rising volume of throughput and vessels at ports increase results in an increasingly noticeable impact on public health in port cities, mandating uncompromisable attention to vessel-induced atmospheric pollutants in port areas [1].

Therefore, a series of measures have been introduced to curb vessel pollutions in recent years, including the delineation of emission control areas (hereinafter as ECA for vessels in 2015 and adjustments on scopes and criteria of ECAs in 2018. While conducive to vessel pollution control [2], vessels remain one of the most significant emission sources of atmospheric pollutions in port seas.
China integrated EIA into port planning in 2004. The Technical Key Points of Environmental Impact Assessment in Overall Port Planning promulgated in 2012 warrant that new bulk carriers and tanker ports (operation areas) shall prioritize environmental impact assessment, and that busy river ports assess the impact of exhaust emissions from ships [3-4]. In the Technical Specification for Environmental Impact Assessment of Specialized Transportation Planning Part 2: Port Master Plan released in 2018, it sets forth requirements that the port masterplan in emission control areas (hereinafter as ECA) must produce an impact analysis of ship exhaust emissions. Since then, ship exhaust became EIA’s 3rd target after dust, oil and gas in the planning process [5].

However, ships sources are often overlooked by EIA in practice. EIA on atmospheric environment in port planning began with dust, oil and gas emissions from dry bulk carriers. Over time, a few ship-intensive ports adopted a qualitative approach in analyzing the impact of ship emissions, followed by a handful of ports using analog methods for rough estimation of ship-sourced air pollutants after the implementation of masterplans. In general, precision and accuracy have been absent from the calculation of ship-sourced air pollutants in terms of EIA in port planning, especially when it comes to forecasting the "planned annual" emissions. In order to address that issue, this study combines the characteristics of port planning and calculation methods of ship-sourced emission inventories and proposes calculation methods suitable for EIA in port planning, providing the foundation for precise accounting of ship-based air pollutant emissions by listing all applicable scenarios of each method.

2. Overview on Calculation Methodologies of Ship-based Atmospheric Pollutant Emissions

In-depth studies by researchers around the world on ship-sourced air pollutant emission estimation, emission factor testing, and activity level data survey have led to plentiful of calculation methodologies for air pollutant emissions from ships [6-10], which fall into the categories of top-down or bottom-up approach by system, and activity-based or fuel consumption-based solution by principle.

For the calculation of atmospheric pollutant emissions from ships, the activity-based methodology relies on the engine power and operating time whereas the fuel consumption approach on fuel consumption of the ship. Based on different vessel activity data used in the calculations, the methodologies rely on various basis including AIS (Automatic Identification System, hereinafter as AIS), vessel statistics, regional fuel consumption, passenger and cargo turnover, etc.

All existing calculations are based on known activity levels and emission factors, while the EIA in port planning targets ship emissions in annual planning. Therefore, the challenge resides at how to forecast future ship emissions based on the status quo of ship-based air pollutant emissions.

3. Calculation Methodologies on Ship-based Atmospheric Pollutant Emissions in Annual Planning

By referencing the characteristics of EIA in port planning and calculation methodologies available for ship-sourced atmospheric pollutant emissions, the paper proposes 3 methods addressing different needs and data situations based on AIS dynamics, incoming vessels, and port energy consumption respectively.

3.1. AIS-based Dynamic Calculation Methodology

1) Overview

The AIS-based dynamic calculation assumes that the port throughput is positively correlated to ship emissions. The activity level takes the historical value from a benchmark year of the port region. Following dynamicity as the core principle, the calculation follows a bottom-up approach by discounting the changes of throughput and fuel into the planned annual atmospheric pollutant emissions.

2) Data Requirements

The basic data requirements for the benchmark year: port throughput, AIS data, ship profile (including main engine, auxiliary engine and boiler power, etc.), power-based ship emission factors, main engine and auxiliary engine load factors, engine low-load adjustment factors, control measures adjustment factors, etc. Data requirements for the planned years include port throughput, ship-sourced atmospheric pollutant emission factors, etc.
Among them, AIS data are typically obtained from the AIS equipment onboard. As a digital navigation assistance system, the equipment transmits a message every few seconds to several minutes, which contains information such as the ship position, speed, navigation status and time, boasting great adoption potential and data quality. Data on throughput could be found in port planning documents while information on ship fuel in standards and specifications issued by relevant authorities in port areas.

3) Calculation

In Formula 1

$$E = \left( \sum_{j,k,l,n} \left( P_j \times LF_{j,l} \times T_{j,k} \times EF_{j,k,l} \times LLAF_j \times CF \times 10^{-6} \right) \right) \times A \times B_{i,j,k}$$

where

- $E$: benchmark year aggregate of atmospheric pollutant emissions (t) from all ships in the region;
- $i, j, k, l, n$: represent respectively pollutant category, emitter (main engine, auxiliary engine, boiler), fuel type, operating conditions, total intervals of AIS messages;
- $P$: rated power (kw);
- $LF$: load factor (dimensionless);
- $T$: interval time (h) between two consecutive AIS messages for each ship;
- $EF$: emission factor of ship-based air pollutants in the benchmark year (g/kwh);
- $LLAF$: low-load adjustment factor (only applicable to main engine);
- $CF$: adjustment factor of port emission control measures (dimensionless) such as shore power, ship exhaust treatment facilities, etc.;
- $A$: throughput variation coefficient, the ratio of planned annual to benchmark year throughput;
- $B$: variation coefficient of ship pollutant emission factors by pollutants and emitters between planned years and benchmark year.

First, match AIS data of the benchmark year with the ship data. Calculate the emissions of each ship between two adjacent AIS messages based on engine power and operating time and establish the emissions profile of a port region in the benchmark year by aggregating the results of multiple ships. Next, multiply the variation coefficients of throughput and ship pollutant emission factors with the ship emissions in the benchmark year to obtain the annual ship emissions for port planning.

3.2. Dynamic Methodologies Based on Incoming/Outgoing Vessel Times

1) Overview

Vessel-based methods center on activity-based principle and calculate atmospheric emissions by means of vessel activity levels indicated by the statistical number of vessels at port for a particular planning year. The principle is similar to AIS-based methods, and what’s different is that vessel-based methods group vessels by class and tonnage and take the average numbers, without calculating the emissions of each vessel at each moment.

2) Data Requirements

The basic data requirements for using this method are: number of inbound and outbound vessels for the planning year, average vessel power, emission factors based on power output, engine load factor, sailing distance of the vessels, sailing speed and the working time of the auxiliary engines.

The number of inbound and outbound vessels are calculated with the following approaches: ① a number worked out from the projected throughput of each cargo class and main ship type, which normally is provided by the port in its general planning; ② other approaches such as an analogy method of similar ports in combination with the trend of large-sized vessel and clean fuel as well as the main ship forms. The sailing distance, sailing speed and working time of auxiliary engines of each ship type and tonnage in the port planning year can be obtained by comparative study with other similar ports and ships.

3) Calculation

In Formula 2
Where

\[ E = \sum_{n,m} \left( N_{m,n} \times \left( \frac{P_{j_1} \times L}{u} + P_{j_2} \times T + P_{j_3} \times T \right) \times LF \times CF \times EF \times 10^{-6} \right) \]  

\[ (2) \]

\( E \) is the annual ship air pollutant emissions of the port’s planning year.

3.3. Fuel-based Methodology by Port Power Consumption

1) Overview

The fuel-based methods by port energy consumption assume a positive relationship between throughput and ship emissions, and calculate ship air pollutant emissions in the planning year by combining base year ship fuel consumption in the port area, the air pollutant emission factors per unit of fuel in the base year and the planning year as well as the throughput. This is a top-down calculation method. The accuracy of its results and the classification of ship types, etc. depend mainly on the accuracy and resolution of the acquired fuel consumption data.

2) Data Requirements

The basic data requirements for using this method are: total ship fuel consumption in the port area in the base year, data of port throughput in the base year and the planning year, and air pollutant emission factors of fuel.

3) Calculation

In formula 3

\[ E = \left( \sum_i (F_i \times EF_i) \times 10^{-6} \right) \times A \times B_i \]  

\[ (3) \]

where

\( F_i \) is the ships’ fuel consumption statistics of the \( i \) category of fuel (kg).

\( EF_i \) is the air pollutant emission factor of the \( i \) category of fuel (g/kg fuel).

\( A \) is the coefficient of variation of throughput, the ratio of the annual throughput of the planning year to the base year throughput.

\( B_i \) is the coefficient of variation of air pollutant emission factor of the \( i \) category fuel, the ratio of air pollutant emission factor of fuel in the planning year to that in the base year, and this factor is 1 if the fuel in the planning year remains unchanged.
4. Methodology Recommendations

As one of the largest contributors to pollution identified in the port EIA process, vessels shall be scrutinized for emissions that they produce by means of calculation and forecasting. The ship-induced atmospheric pollution emissions of a planned year could be obtained from a variety of methodologies, which provide various alternatives tailored to different port areas, data availability, convenience, etc.

1) The AIS-based dynamic calculation offers higher time and space resolution as well as accuracy as a more granular approach, which covers diverse ship types, navigation conditions, engines, fuel, etc. The accuracy is of a greater level when applied to single ships. It is recommended to ports with available AIS data.

2) Similar to the AIS-based approach, the dynamic calculation methodology based on incoming and outgoing vessel times requires generalizing and averaging vessels of the same types and tonnage. Though less accurate compared to the AIS trajectory, it calls for much less data in the calculation process. It is recommended for ports where AIS data are not accessible.

Relatively simpler as it is, the port power consumption path depends its accuracy primarily on the precision and resolution of data on fuel consumption. It is recommended to ports without data on AIS or incoming and outgoing vessel times.

5. Conclusion and Outlook

By interrogating the characteristics of EIA in port planning and existing methodologies for calculating ship-based atmospheric emissions from ships, this study proposes 3 alternatives for the calculation needed in planning annual ship-sourced tailored to different needs and data profiles. The conclusion is as follows: 1) It is recommended to ports with available AIS data. 2) It is recommended for ports where AIS data are not accessible. 3) It is recommended to ports without data on AIS or incoming and outgoing vessel times.

Accuracy of forecasting ship emission calculation in the post-implementation stage of port masterplans is vital to the EIA in port planning. The preliminary conclusions derived from the study is beneficial to EIA in the planning process by offering the scientific foundation that is required for improving air quality and green ports following the implementation of port planning.

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