Qingdao Port Ship Emission Estimates & Analysis Using AIS Data

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Environmental Analysis

ABSTRACT

This study focuses on the ‘bottom up’ approach for estimating ship emissions as well as the impact of PM2.5 on the urban environment. Qingdao Port has been the subject of prior studies focused on air quality and ship emissions due to its importance, traffic, and existing Automatic Identification System (AIS) database. The strategies, methods and outcomes of a recent study can be extracted and theoretically applied to The Port of Houston. The Vessel Traffic Service (VTS) Houston-Galveston requires all ships equipped with AIS to actively report positions. The Port of Houston (POH) has also built an emissions inventory based on the ‘bottom up’ approach. These conditions link the Qingdao and Houston ports. POH’s current methods do not take advantage of the temporal spatial nature of the ‘bottom up’ approach to better understand Houston’s near-port air quality. This is contrasted with Qingdao Port’s analysis methods. Additionally, remediation responses are considered which can be applied to both ports.

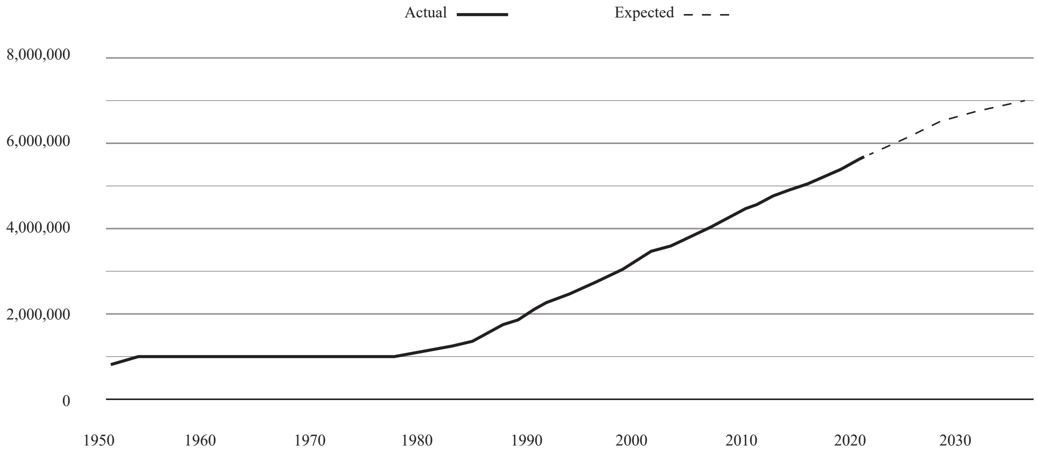
Keywords: Bottom Up, Qingdao Port, Air Quality, PM2.5, AIS, Emissions Inventory.

1.INTRODUCTION

Qingdao:

The city of Qingdao is in Northeast China and enjoys temperate, four-season climate (Zhang and Rasiah 591). The port city is monsoon-influenced and experiences cool-cold winters and hot-humid summers with very few very hot days (NOAA). Its location on the south of the Shandong Peninsular and its coastal condition, with the Yellow Sea defining "730 km of unbroken coastline" (Zhang and Rasiah 591), put the city in a strategic position. Geographic proximity to South Korea and Japan has been paramount in the city's international trade and economic development (Zhang and Rasiah). Because of its advantageous geography, Qingdao was "granted 'central economic city' (CEC) status" (Zhang and Rasiah 592). This has helped create an attractive business environment as well as a social environment in which people want to live (Dollar). Since its designation in 1981 as a "key economic city" (Zhang and Rasiah 592), when the urban population sat at 1,134,000 inhabitants, Qingdao has experienced a population explosion as the number has quintupled in less than forty years (see Figure 1). The population continues to grow as the GDP per capita continues to increase, businesses continue to thrive, and the city continues to attract. This will inevitably increase traffic through the city's port.

Fig. 1. *Total Population*



Data from PopulationStat - World Statistical Data. 2017-2020.

Qingdao Port's economic importance and potential environmental impacts are unquestionable. Four port areas compose The Port of Qingdao and are operated conjunctively: Qingdao Qianwan Port Area, Huangdao Oil Port Area, and Dagang Port Area (Qingdao Port International CO.,LTD.). It is ranked the 7th busiest port in the world and "handles containers, metal ore, coal, petroleum, grains, steel, cars, liquid bulks, and general cargos" (Sun, Tian and Malekian 4). Its strong trade ties with South Korea and Japan establish its competitiveness among China's already strong international trade ports. In 2016 alone, the port's throughput reached 500 million tons transported by 124,880 vessels (Sun, Tian and Malekian 3).

Sponsors:

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Overview:

Ship emissions contribute significantly to "regional air quality, global climate, and human health" (Chen, Wang and Nelson 351). Given the expected increases in maritime trade in the long-term, the impact of ships emissions will only become more severe, "especially for coastal cities with big ports (Chen, Wang and Nelson 352). As a result, stronger regulations on ship and port behavior are becoming increasingly urgent. The motivation for performing an air quality analysis, such as the one performed by Chen et al. on Qingdao Port, is to meet two prerequisites to designing appropriate regulations. These are: "1. Establish an accurate emission inventory with high spatial-temporal resolution 2. Quantify the contribution of ship emissions on the air quality" (Chen, Wang and Nelson). The study calculates exhaust emissions from ships. AIS data is used to estimate the ship's emissions and to create an inventory. A detailed bottom up approach is taken. An accurate emissions inventory and a strong prediction model can provide the knowledge to target specific ship behavior and reduce emissions through effective control measures.

2.ENVIRONMENTAL ANALYSIS & PROPOSED REMEDIATION PROCESS

Analysis Process:

The analysis performed by Chen et al. begins with a ‘bottom up’, activity driven approach to arrive at an emissions inventory. Activity data from Automatic Identification System (AIS) is used to estimate individual ships’ emissions through space and time. Today, China’s Maritime Safety Administration requires that all vessels travelling on coastal waters with cargo of 100 or more gross tonnage (GT) have AIS installed (Fan, Zhang and Ma 1324). AIS uses radio communication devices to share “information such as vessel name, radio call sign, navigational status (e.g., at anchor or under way using engine), speed, heading, type of ship/ cargo, destination, and estimated time of arrival” (U.S. Environmental Protection Agency 29). An emissions inventory based on AIS requires the extraction of some of the information then inserts it into a generic equation that calculates either of a vessel’s particular emitted pollutant (SO2, NOx, PM10, PM2.5, HC, CO) over an interval of specified space and time resolutions. The sum of the emissions from all considered vessel trips is the emissions inventory.

For this study, a full year (2014) of AIS data was applied. The resulting estimated emissions are then analyzed in different sections. These are: total emissions, monthly variation, emissions from different modes and engines, and impact of ship emissions on PM2.5 concentrations in Qingdao. Lastly, conclusions were formed based on the different analytical points of view listed. The results from this inventory provide valuable information that can guide decision making.

Metrics:

The primary aim of Chen et al. is to estimate emissions for a particular pollutant (ton). The main factors for this estimate are the vessel’s energy output and its corresponding emission factor. Energy output (kW·h) is calculated from the product of the output power (kW) of a ship’s given engine type (main engine, auxiliary engine or boiler), and the amount of time (h) under this power condition. The emission factor for a species of pollutant (g/kW·h) is based on engine type (main engine, auxiliary engine or boiler) and fuel type (Residual Oil, Marine Distillate Oil, Marine Gas Oil).

Methods:

Chen et al. gather information on ships activity, attributes, and emission factors. The equation in figure 2 pumps out an emission estimate for a particular pollutant from a specific vessel during a given voyage. The information about a vessels installed power (P) for its engine type (j) was obtained from Lloyd's database and Chinas Classification Society (CSS) (Chen, Wang and Nelson 353). A ships load factor (LF) during a given operational mode (l) is estimated using the Propeller Law (see fig.x). The operational mode of a vessel (l) (cruising, maneuvering, or hoteling) is categorized based on sailing speed (Chen, Wang and Nelson 353). The operating time (T) as well as a ship's speed can be obtained from AIS database. The emissions factor (EF) for each species (i) is related to the engine type (j) the fuel type (k) and the sulfur content of the fuel type (either Residual Oil, Marine Distillate Oil, or Marine Gas Oil). A low load adjust factor (LLAF) is applied to main engines when "their load factors were below 20% in consideration of the lower combustion efficiency during the low main engine loading condition" (Chen, Wang and Nelson 354).

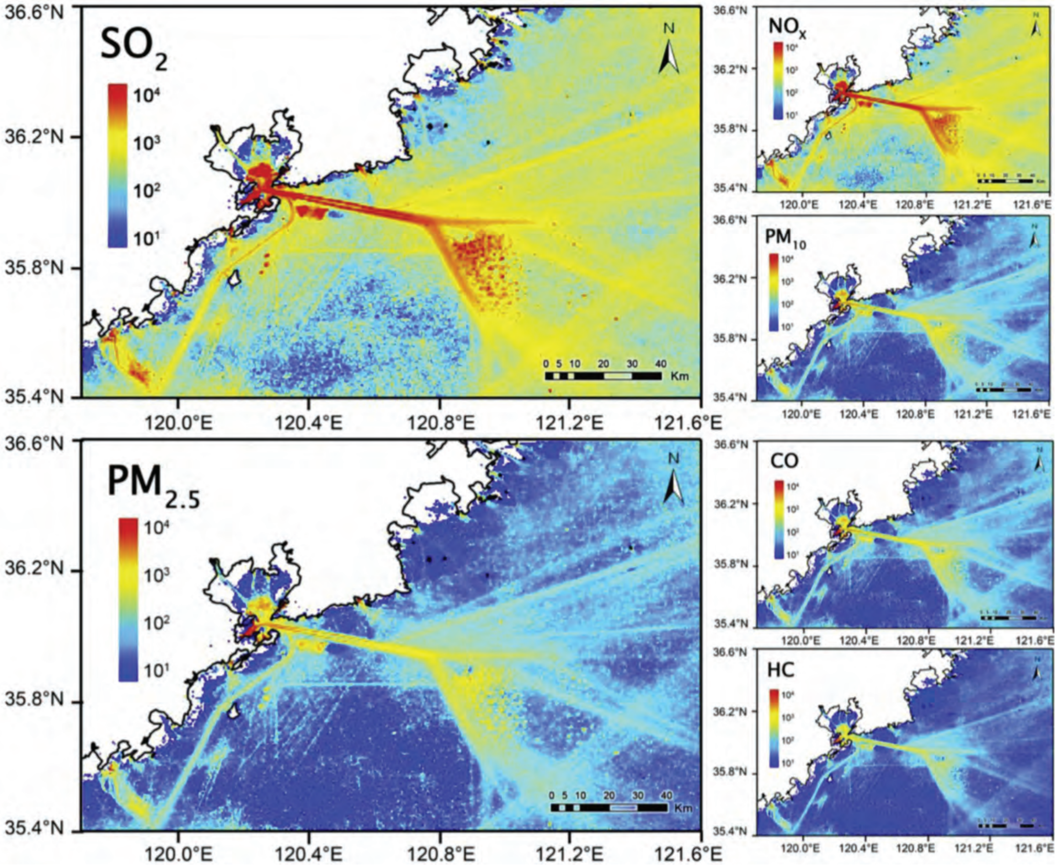
Fig. 2. *Generic 'bottom up' approach equation*

$$E_{i,j,k,l} = \sum_{1}^{n} P_j \times LF_{j,l} \times T_{j,l} \times EF_{i,j,k} \times LLAF_j \Big/ 10^6$$

From Atmospheric Environment 166 (Chen, Wang, and Nelson)

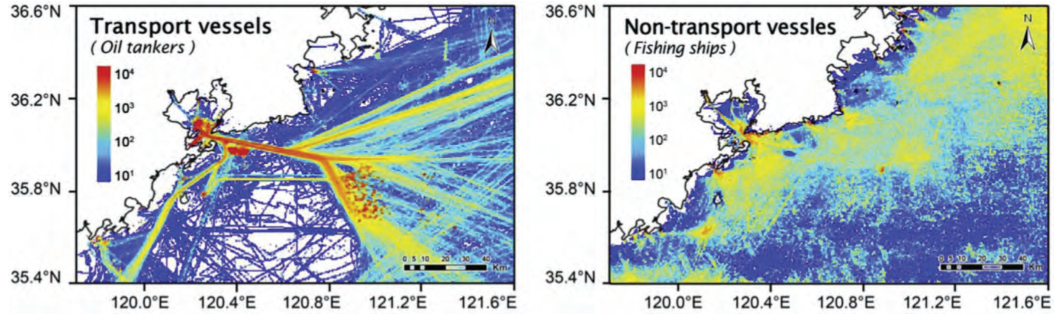
The resulting emission estimates are a sum of all voyages from all ships for each pollutant. The total emissions are quantified and analyzed. Graphic, color coded mapping of emissions reveals the spatial distribution of intensities. These intensities are then mapped according to particular pollutants and vessel types (transport or non-transport vessels) as shown in figures 3 and 4. Clear paths can be seen in the spatial distribution of most pollutants. Points of High emission intensity are located around docks, major challenges, and anchorage areas (Chen, Wang and Nelson 355). The higher amounts of SO2 reveal the high-in-sulfur, low quality fuels that are so widely being used (Chen, Wang and Nelson 355). These visualizations present the origin of emissions as precise and pinpointable.

Fig. 3. *Spatial distribution of annual ship emissions in 2014 (kg/yr/km2).*



From Atmospheric Environment 166 (Chen, Wang, and Nelson)

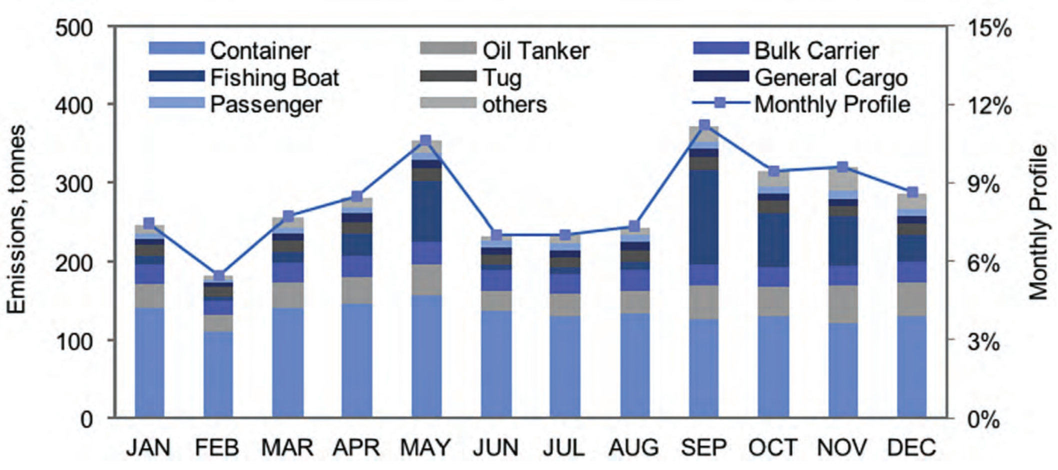
Fig. 4. *Spatial distribution comparison of annual SO2 emissions from transport vessels and non-transport vessels (kg/yr/km2).*



From Atmospheric Environment 166 (Chen, Wang, and Nelson)

Organizing and analyzing the emissions by month revealed additional useful results. There is a clear variation in total emissions between months, with September having the highest total (Chen, Wang and Nelson 355). External conditions are by in large the cause for these variations. For example, around February, when the Chinese New Year is celebrated, transport vessel activity decreases dramatically (Chen, Wang and Nelson 355). During this time, the country is essentially at a standstill as Chinese workers from all fields migrate to visit their families, ultimately affecting the global economy (Elbaz). Later in the year, another decrease in emissions, this time due to fishing vessels, as the fishing moratorium is in effect. The emissions explode again in September, when the moratorium is lifted, reaching 1195.78 tons of total emissions from fishing ships, almost "as much as the emissions from containers" (Chen, Wang and Nelson 355). The graphics in figure 5 show that external conditions, such as legislature and celebrations, can have a significant effect on port emissions.

Fig. 5. *Inter-Monthly variation of SO2 emissions from each vessel type for Qingdao port in 2014*



From Atmospheric Environment 166 (Chen, Wang, and Nelson)

The total emissions from different operational modes are relatively unsurprising. Cruise mode is classified by a vessel speed greater than 8 knots and amounts to 40-44% of emissions (Chen, Wang and Nelson 357). Hoteling is classified by a speed lower than 1 knot and amounts to 23-46% of emission with the smaller percentages being CO and HC (Chen, Wang and Nelson 357) . Maneuvering, which is classified by a speed between 1-8 knots amounts to between 14-37% of emissions (Chen, Wang and Nelson 357). Chen et al. assume this percentage is high in Qingdao Port due to the abnormally large fishing activity around the port which causes an increase of time in this mode. Similar organization of emissions by engine type (figure 7) shows the difference in emissions between the main engine (ME) and the auxiliary engine (AE). The ME, mainly used for propulsion, amounted to 43-71% of total emissions (Chen, Wang and Nelson). In contrast, the AE which is typically used to generate electricity for the ship (lighting, cooking, A/C, heating, etc.), contributed from 28-47% of emissions, mostly during hoteling (Chen, Wang and Nelson). This portion of the analysis shows the contribution of ship behavior (which has a direct relationship to the engine type in use) to the total emissions as well as emissions of a particular species as is the case with the reduced use of HC and CO during hoteling (figure 6).

Fig. 6. *Shares of ship emissions classified by operating modes*

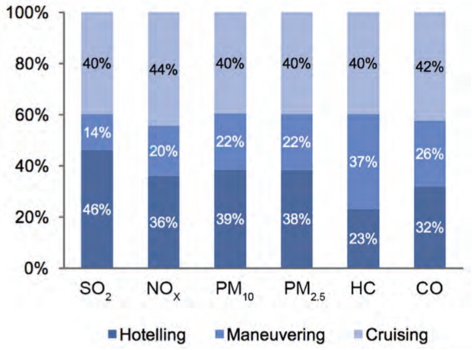
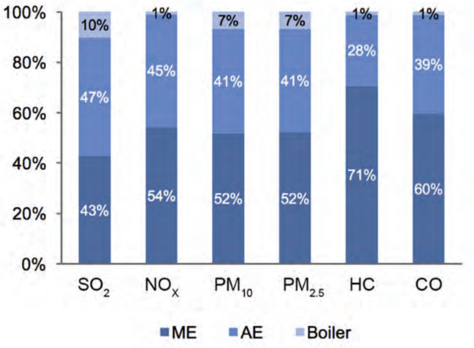


Fig. 7. *Shares of ship emissions from MEs, AEs and boiler*



From Atmospheric Environment 166 (Chen, Wang, and Nelson)

The culmination of the analysis explores the impact of ship emissions on P.M.2.5 concentration in Qingdao. Increases in particulate matter with a diameter of 2.5 microns or less (P.M.2.5) have a particularly harmful effect on public health. Both short-term and long-term exposure can affect heart health and cause heart attacks (Marshall 8756). In the United States, counties with the greatest decrease in P.M.2.5,over a period of two decades, had the largest increase in life expectancy ((Marshall 8756). For this reason, the study performed by Chen et al. pays close attention to the concentrations and presence of this pollutant. Their methodology for this portion of the study consists of a simulated WRF/Chem model that is used to compare PM2.5 concentrations in Qingdao with and without ship emissions. Their results show increases along ship routes and near the coast (Chen, Wang and Nelson 358). The contributions from ship emissions for summer, autumn, spring, and winter were predicted to be 13.2%, 7.3%, 3.3%, and 1.5% respectively (Chen, Wang and Nelson 358). Evidently, summer contributions are significantly larger and thus more problematic to public health. Chen et al. assume this difference is due to south and southeast winds during the month of July. This could push pollutants emitted by ships into the city (Chen, Wang and Nelson 358). It is worth noting the impact that airflow has on PM2.5 levels in the Qingdao. The month-by-month analysis reveals the beneficial effects that a change in ship behavior during a single month could potentially have on public health.

Desired Outcomes:

The study aims at better understanding ship emissions in Qingdao to inform appropriate control measures. Chen et al. desire discovering total emissions, spatial distribution, monthly variation emissions from different operating modes and engines, and the impact of ship emissions on the PM2.5 concentrations in Qingdao. The high resolution spatial-temporal emissions inventory results can give valuable insight on the impact that ship behavior and external time-related conditions can have on the concentrations and spatial distributions of emissions.

3.ORGANIZATION

No information is provided on team organization or responsibilities. No information on team tracking and monitoring of progress is available. Only information on key players and their affiliations was provided. From the Key Laboratory of Beijing on regional Air Pollution Control, Beijing University of Technology, Beijing: Dongsheng Chen, Xiaotong Wang, Na Zhao, Yuehua Zhao, Jianlei Lang, Ying Zhou and Xiurui Guo. From the Department of Environmental Sciences at Faculty of Science and Engineering, Macquarie University in Australia: Dongsheng Chen and Peter Nelson. From the Transport Planning and Research Institute at the Ministry of Transport in Beijing: Yue Li.

4.OUTCOMES

In-depth recommendations are beyond the scope of the study performed by Chen et al. The sum of their recommendations is limited to a single sentence: “The higher percent of contribution from ships indicated the highly demanded emission control measures on ships considering their negative effects to the environment and human health.” (359) Nevertheless, there exist several studies that have explored potential environmental and economic solutions that reduce emissions. For example, Eyring et al. point out that optimizing ships’ propeller and hull can reduce fuel consumption and emissions up to 30 %. Although the fuel savings provide an economic incentive, not all companies are ready to make the investment without additional incentives or regulations. In some regions within China and elsewhere, Emission Control Areas (ECA) are being defined and aim at reducing SO2 emissions from ships. According to Wan et al., reducing SO2 may have the added beneficial effect of also reducing PM. This may be an optimal strategy in the port of Qingdao given the high levels of sulfur resulting from the widely used low quality fuels. The most direct way of accomplishing this reduction is by switching to low sulfur fuels (Wan, Zhou and Zhang 1). This too increases costs for shipping companies. However, Wang et al. noted that different ships have different marginal costs for reducing SO2 levels. In this study, a developed model revealed the potential that economic incentive instruments (as opposed to prescribed regulations) have in reducing more emissions and saving ship owners more money.

A significant finding from the analysis by Chen et al. on the port of Qingdao showed the contribution of summer winds in increasing emission concentrations around densely populated areas. A potential regulation limiting ship speed during these months may greatly improve air quality in the region. Another related outcome from the study is that it revealed the gap in the literature regarding the impact of airflow on the air quality of the port of Qingdao.

5. SUMMARY & CONCLUSIONS

Best Practice and Application:

The goal of this paper is to extract best practice methodology for establishing a port-related air quality analysis and initiating an appropriate remediation response. The lessons learned will later be applied to the Port of Houston. In this section, a concluding comparison will be made between the ship emission analysis of the Qingdao Port and a previous, similar analysis on ship emissions from the Port of Houston.

Chen et al. use the standard bottom-up approach to develop a detailed, emissions inventory for Qingdao Port from AIS data. This approach allows for high temporal-spatial resolution. The Port of Houston Authority (PHA) used the same approach to develop its inventory on vessel activity surrounding the port. PHA's study, however, is much clearer in communicating its methodology for estimating emissions. Regardless, because both studies use the same approach and nearly identical sources for gathering activity and vessel characteristics data, the analyses start off from the same point and are thus easy to compare.

POH categorize the estimated annual (2013) emissions inventory by types of ocean-going-vessels (OGV) and by terminal. In this aspect they are comprehensive. The long list of types includes auto carrier, bulk carrier, container ship, cruise ship, general cargo vessel, ocean-going tug, roll-on/roll-off, tanker chemical, tanker chemical products, tanker crude oil, tanker other, tanker product, tanker LPG. Their findings reveal the differences emitted pollutants from each type. This may be helpful in guiding regulations or control measures depending on the severity of emissions by type. Their comprehensive list of Terminals includes: Non-PHA-related, Barbour's Cut Terminal, Bayport Terminal, Bulk Materials Handling, CAARE Terminal, Industrial Park East, Jacintoport Terminal, Manchester Wharves, Southside Wharves, Turning Basin, and Woodhouse. Insight from this choice of categorizing the emissions are not the most revelatory but may provide guidance for establishing control measures based on which Terminal emits more annually.

The study performed by Chen et al. on Qingdao Port is much more insightful in guiding regulatory emissions. First, the temporal dimension inherent in an AIS derived emissions inventory is better exploited. The inventory results were categorized by month and reveal variations. These variations were attributed to 1. fishing ship behavior, which reduced emissions during the summer due to the moratorium that prevents overfishing and 2. Sociocultural behavior as Chinese New Year festivities slow down activity. These attributions may seem trivial and/or arbitrary but illustrate the significant impact that external conditions can have on ship emissions. The study also categorizes emitted pollutants by vessel type (container, fishing, passenger, oil tanker, tug, others, bulk carrier, general cargo), by engine type (main engine, auxiliary engine, boiler), and by operational mode (hoteling, maneuvering, cruising). Given the huge amount of data, different ways of visualizing, categorizing, and overlapping brings valuable insight that can provide better guidance for making regulatory decisions. Furthermore, Chen et al. give more importance to the impact of ship emissions on PM2.5 concentrations around Qingdao Port. The effort is commendable given the serious health implications that high concentrations of these particles can have on the city's population. The analysis revealed the effect that wind direction during the month of July might have on rising PM2.5 concentrations in densely populated areas of the city. Given that spatial mapping of emissions in this study revealed that high concentrations occur along shipping lanes, changing these lanes during July could positively impact air quality in Qingdao.

The analysis performed by POH should include inter-monthly categorization, Engine and operating mode categorization, and simulation of ship emission impact on air quality. By implementing these methods of analysis, valuable insights could be gained on how to manage the maritime sources of pollution.

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