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NO_X emissions from merchant vessels in coastal China: 2015 and 2030

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Summary

Previously, ICCT analyzed air pollution from nearly 30,000 oceangoing vessels (OGVs) in China's coastal region using Automatic Identification System (AIS) operations data (Mao et al., 2017). Non-oceangoing vessels active in this region, mainly coastal vessels (CVs) and river vessels (RVs) engaged in domestic shipping, were not included in that study, but also contribute to coastal air pollution given their heavy traffic and proximity to the coastline.

In this working paper, we develop a revised emissions inventory for all three categories of merchant vessels—OGVs, CVs and RVs—in China's coastal region. We focus on one pollutant in particular, nitrogen oxide (NO_x), that is of particular concern to policymakers in China. We estimate that in 2015 merchant vessels contributed about 14% of all NO_x emissions in coastal regions, including both landside emissions and shipping emissions out to 100 nautical miles (nm) from China's baseline. China's domestic fleet was responsible for about one third (37%) of merchant ship NO_x in 2015. We project that, if left unchecked, shipping's share of coastal NO_x emissions could nearly triple, from 14% to around 38%, by 2030. These findings highlight the need for further action to control NO_x emissions along China's coast.

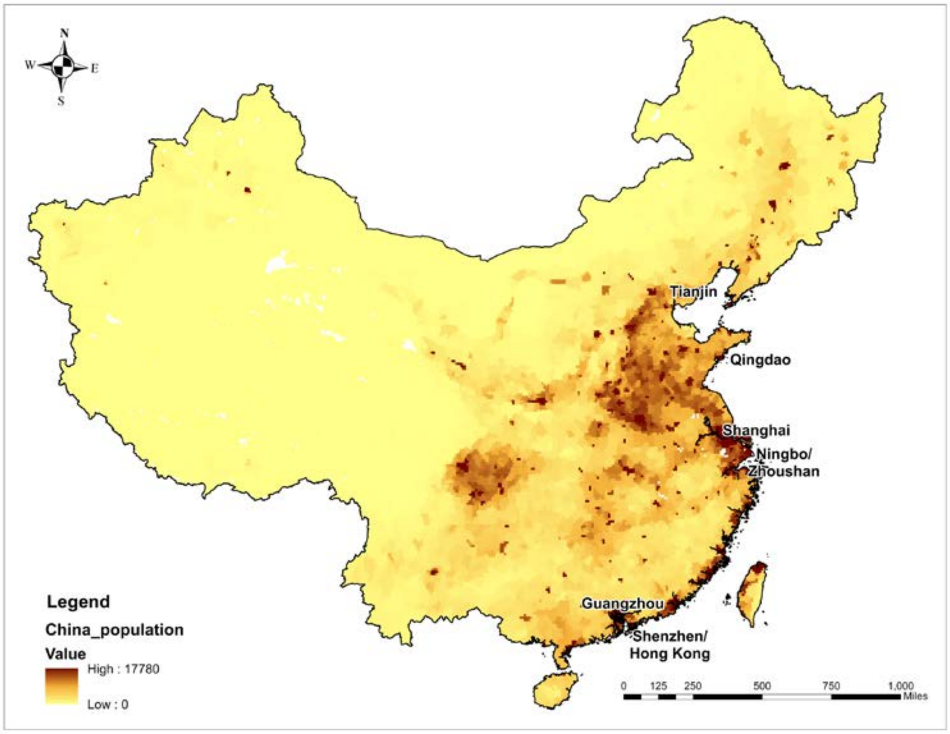

Figure 1. Chinese population density and leading port cities in the world (Hijmans, Guarino and Mathur, 2012)

Introduction

China is the largest trading nation on the planet and the world's second largest economy. Its coastline is frequented by thousands of ships every day, moving goods and people both internationally and domestically. In 2015, the United Nations Conference on Trade and Development (UNCTAD) reported that seven out of 10 world-leading ports by volume were in China. These ports are all located in highly populated areas (Figure 1).

Like most other transportation modes, ships burn fossil fuels and emit air pollutants. When released into the atmosphere, these emissions increase concentrations of ambient fine particulate matter ($PM_{2.5}$) and ozone in the atmosphere. Those pollutants contribute to human health problems, including respiratory illness, cardiovascular disease, and lung cancer. It's estimated that ship emissions in East Asia cause 14,500 to 37,500 premature deaths per year (Liu et al., 2016).

The Chinese government, determined to fight its air pollution problem, has taken steps to control these emissions. At the end of 2015, the China Maritime Safety Administration established three domestic emission control areas (DECA) along China's coastline—the Pearl River Delta, the Yangtze River Delta and the Bohai Rim waters—with gradual mandates for ships to use cleaner marine fuels in order to reduce sulfur oxide (SO_x) emissions. Recently, the Ministry of Transportation (MOT) released a proposal to upgrade the DECA system (MOT, 2018). This includes expanding it to cover the entire coastline, restricting the sulfur content requirement in fuel further down to less than 0.1% by mass (m/m) in two inland waterway systems: the Yangtze River and Zhujiang River systems, as well as 12 nm around Hainan Island,, and to mandate stricter engine NO_x controls. Separately, a marine engine standard that targets NO_x emissions went into effect in July 2018 and will be further tightened in 2021. Figure 2 compares these regulations to the most stringent ones implemented under Emission Control Areas (ECAs) designated by the International Maritime Organization (IMO).

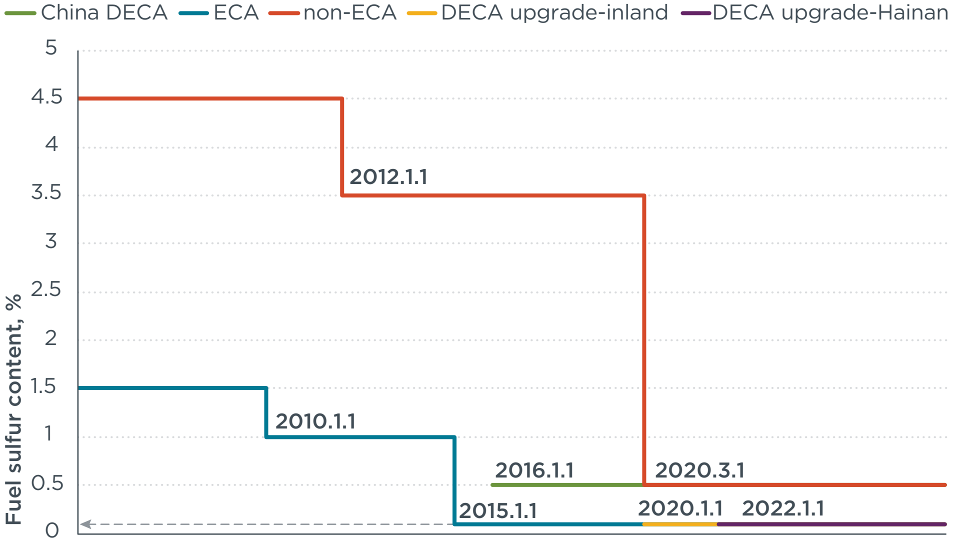

Figure 2a. Marine fuel oil sulfur limits in China versus the rest of the world[2]

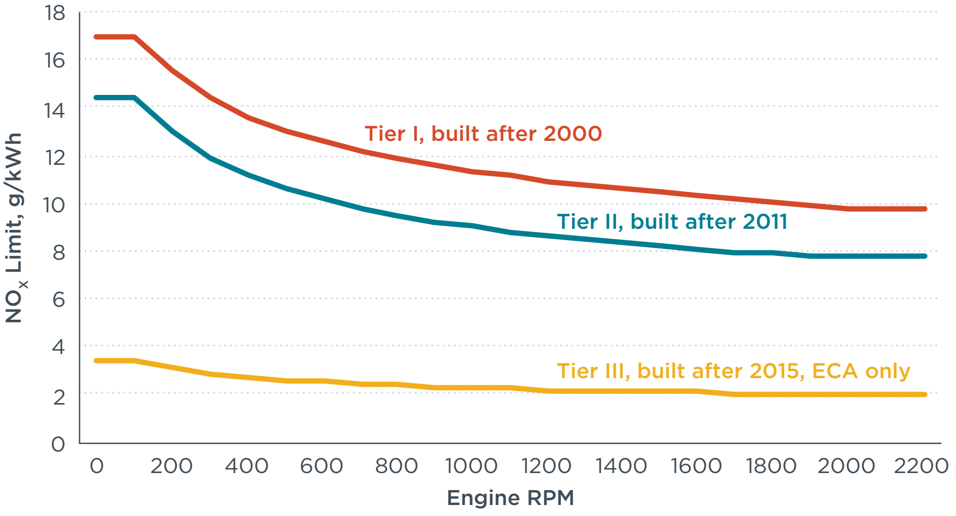

Figure 2b. Ship NO_x emission limits in China versus the rest of the world[3]

Note: China marine engine standards are not set based on engine RPMs, but rather on engine power. In order to be compared with IMO limits assigned for different engine speeds (RPMs) , "China Phase I" and "China Phase II" are drawn as general ranges of NO_x limits. Bigger engines are subject to higher limits and smaller engines are subject to lower limits.

Currently, there are four international IMO designated ECAs—North American, Carribean, North Sea, and the Baltic Sea—requiring a marine fuel sulfur content of less than 0.1% m/m and Tier III engine standards requiring NO_x aftertreatment.[1] China is on track to close the gap with IMO ECA SO_x emission regulations on ships (Figure 2a) but remains behind on NO_x emission controls (Figure 2b). In this study, we advance our understanding of current NO_x emissions from ships in China and how those emissions will change by 2030 relative to air pollution from other coastal sources. Policy actions to bring NO_x emissions from ships under control are also discussed.

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[1] Tier I, II and III are NO_x control requirements set by IMO for new ships built from 2000, 2011, and 2016+ for certain regions, respectively. See IMO (2018) for additional detail.

[2] DECA upgrade plan expands the coverage of 0.5% m/m marine fuel to the entire coastline compared to three port clusters in the original DECA plan.

[3] By the time of publication, the official DECA upgrade plan was released and it harmonized NO_x requirements with IMO NOx limits. The official document can be found here: http://www.vecc-mep.org.cn/tabloid/1207.html. The ICCT will release a policy update soon.

Methods

STUDY REGION AND SUBJECT OF STUDY

To improve our understanding of the shipping industry's contribution to coastal NOx emissions in China, we consider four main regions that run north to south down the country's eastern border (Figure 3). Each region has a seaside and landside geography. The seaside regions are set 100 nm from China's coastal baseline (United Nations, 1982). The landside of China's coastal region includes 12 provincial administrative areas defined by the China Marine Statistical Yearbook (Fang and Xian, 2015). We aggregate these administrative areas to match the geographic extent of the seaside subregions. The four subregions are defined in Table 1. In order to analyze the near-coast distribution of ship emissions, the 100 nm sea region boundaries are further divided into wedges 12 nm wide, 24 nm wide and 50 nm wide from the coast (Figure 3).

Table 1: Regions defined by landside and seaside geographies

Region	Landside provinces	Seaside
1	Beijing, Tianjin, Hebei and Liaoning	Bo Sea
2	Shandong and Jiangsu	Yellow Sea
3	Shanghai, Zhejiang and Fujian	East China Sea
4	Guangdong, Guangxi and Hainan	South China Sea

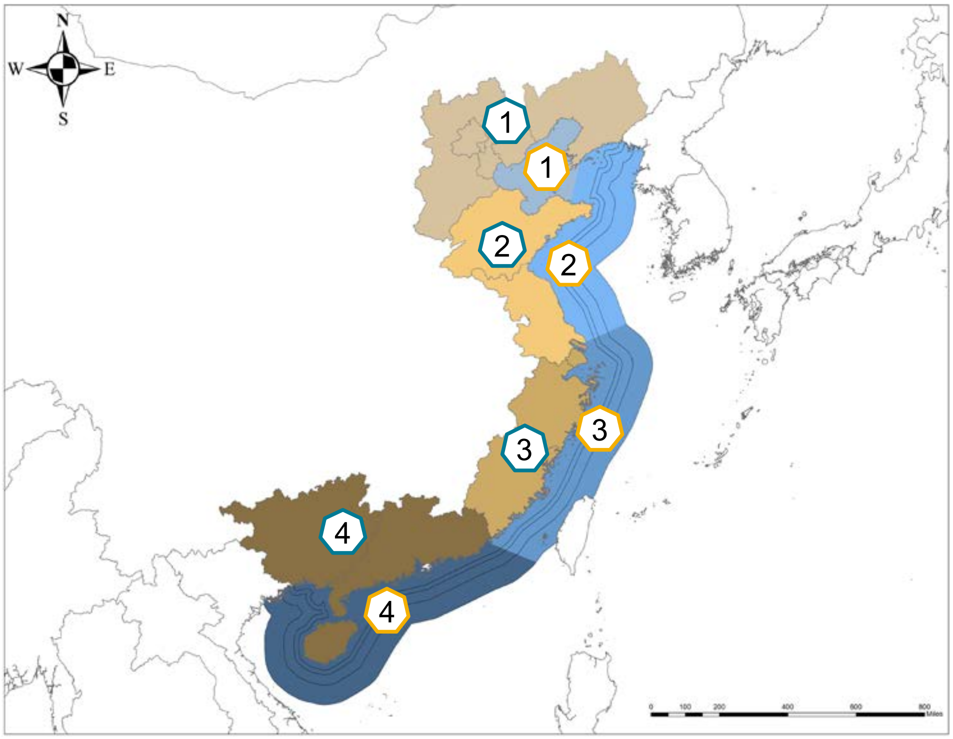

Figure 3. Study region

Our subject of study is NO$_X$ emissions from merchant vessels. Those include both domestic vessels that move cargo and people within China and international oceangoing vessels (OGVs) that engage in trips whose origins and destinations belong to two different countries. Geographically speaking, the country's domestic shipping fleet is comprised of coastal vessels (CVs) and river vessels (RVs), which by design, rarely cross each other's navigational waters.[4] Within our study region, all of the coastal fleet is included, while only river vessels registered to the selected coastal provinces are included. The non-merchant fleet, including the fishing fleet and harbor vessels that provide services like berthing assistance, are not included.

EMISSION ESTIMATION METHODS

Depending on data availability, either a top-down or bottom-up methodology is typically used to estimate air pollution from ships. Top-down methods rely on a vessel's annual fuel consumption and a set of fuel-based emission factors to estimate emissions. Bottom-up methods, which are considered the current best practices (U.S. Environmental Protection Agency, 2009), pair a vessel's activity profile with energy-based emission factors to estimate fuel use and associated air pollution.

Depending on the source of the activity profiles, current practices include using port-call records (Starcrest, 2016) and satellite- and shore-based Automatic Identification System (AIS) data (Smith et al., 2015). AIS data are especially useful when emission inventories are needed as input for air quality modeling, since the data can produce high-resolution gridded inventories. For the purpose of this study, we use a combination of

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[4] River vessels seldom travel into the coastal regions except in certain regions like the Yangtze River Delta and the Pearl River Delta, where the inland waterway system borders the coastline. For simplicity, we assume no river vessel emissions beyond the mouths of rivers, as defined by the land mass.

emission estimation methods for different types of vessels, depending on data availability.

Table 2. Emission estimation methods by vessel group

Vessel group	Method	Input	Output
Oceangoing vessels	Bottom-up	exactEarth AIS activity Energy-based NO$_X$ emission factors Ship characteristics provided by IHS Fairplay	Gridded emissions inventory
Coastal vessels	Bottom-up and Top-down	exactEarth AIS activity Energy-based NO$_X$ emission factors Ship characteristics estimated for qualified ships using GFW and ITU data[1] Annual coastal transport work[2]	
River vessels	Top-down	Annual coastal transport work[2] Fuel consumption rate Fuel-based NO$_X$ emission factors	Annual emissions total

[1] Global Fishing Watch (GFW) and International Telecommunication Union (ITU)
[2] As provided by the China Port Statistical Yearbook (Zhu, 2015)

OCEANGOING VESSELS

In a previous ICCT paper (Mao and Rutherford, 2018), we estimated emissions from OGVs operating within 12, 24, 50, and 100 nm of the Chinese coast. The detailed methodology, which is summarized as the ICCT Systematic Assessment of Vessel Emissions (SAVE) model, can be found in Olmer et al. (2017). The SAVE model marries the AIS data with ship characteristics provided in the IHS database and produces hourly emission profiles for individual ships at high geographic fidelity.

COASTAL VESSELS

We don't have ship characteristics data such as main engine power or design speed for CVs in China, and thus cannot use SAVE directly. In this study, we estimate key characteristics of these ships as follows:

1. Identify CVs from the AIS signals. Details of the identification process are provided in Appendix A.
2. Each CV is associated with a group of AIS signals with instantaneous speed records. The 95th percentile of those records is taken as the ship's design speed.
3. A CV's main engine power is estimated by using a statistical relationship between gross tonnage and main engine power of the OGVs. Details of the statistical model is provided in Appendix B.
4. A CV's gross tonnage is provided by the GFW and ITU databases. If a CV's gross tonnage is missing, the value is estimated by using the statistical relationship between ship length and gross tonnage of the OGVs. Details of the statistical model are provided in Appendix B.
5. A CV's ship length is provided by the GFW and ITU databases. If a CV's length is missing, the average length of the ship's associated ship class is used as a proxy.
6. Other assumptions made that are universal to all CVs are:
    - Main fuel type: residual oil
    - Main engine type: medium speed diesel engine
    - Main engine tier level: Tier I

Using these assumptions, SAVE can then be used to estimate CV fuel use and air pollution. There are cases when a given CV has too few AIS signals to predict its fuel use with SAVE. Poor AIS coverage may lead to a high degree of interpolation, which introduces uncertainty. On average, our previous global assessments interpolated 54% of an oceangoing vessel's hourly AIS records over a given year. For this study, any CV with an interpolation ratio lower than 54% was judged to have a sufficient activity profile for the method outlined above. We call ships below this threshold for which emissions can be directly estimated "qualified CVs."

The SAVE model calculates hourly emission profiles for the qualified CVs. To scale up these emissions to the entire CV fleet, including those with insufficient AIS data, we calculate the ratio between total transport work reported by the China Port Statistical Yearbook (Zhu, 2015) and transport work calculated by the SAVE model for the qualified CVs. The qualified CVs represent about half the size of the total CV fleet in China and performed approximately 73% of the total transport work of the entire CV fleet. As a result, to account for emissions from CVs with insufficient AIS signals, representing 27% of the transport work, we calculate the total emissions as follows:

$$E = \frac{Total\ TW}{TW_{qualified}} \times \sum E_{i,t}$$

Equation 1

Where:

E: NO$_X$ emissions, in grams

$E_{i,t}$: Hourly NO$_X$ emissions of ship i at timestamp t;

$TW_{qualified}$: Total transport work performed by qualified CVs, in tonne-km, calculated by the SAVE model, assuming an 80% utilization rate (ratio of cargo tonne-km to deadweight tonne-km);

Total TW: Total transport work performed by all CVs, in tonne-km, reported by China Port Statistical Yearbook 2015.

RIVER VESSELS

We don't have ship characteristic data for RVs in China, and their AIS data coverage is poor. As a result, RV emissions were estimated using a top-down, fuel-based method provided in the China Ministry of Ecology and Environment (MEE) guidance for non-road emissions inventory (MEE, 2014, referred to simply as "the guidance" thereafter), as follows:

$$E = (0.065 \times TW\_pax + TW\_cargo) \times Fuel\ consumption\ rate \times EF$$

Equation 2

Where:

E: NO_x emissions, in grams;

0.065: The average mass of a person with belongings in tonnes, according to the guidance;

TW_pax: The volume of river passenger transport, in passenger-km, from China Port Statistical Yearbook 2015;

TW_cargo: The volume of river cargo transport, in tonne-km from China Port Statistical Yearbook 2015;

FC: Fuel-consumption rate, assumed to be 50 kg/tonne-km according to the guidance;

EF: NO_x fuel-based emission factors, in grams per kilogram of fuel.

Table 3. Impacts of transport work growth and environmental regulations on future ship NO_x emissions

Ship group	Impact ratios		Overall impact ratio 2030/2015
	Transport work growth (e.g. tonne-nm)	Environmental regulations(e.g. grams pollutant/tonne-nm)	
Oceangoing vessels	1.86	0.90	1.67
Coastal vessels	1.51	0.81	1.22
River vessels	1.92	0.72	1.38

EMISSIONS PROJECTION IN 2030

In order to estimate the future contribution of all merchant ships to coastal air pollution in China, we projected NO_x emissions to 2030 by taking into account the increase of ship activity and trade as well as changes in emission factors due to environmental regulations (see Figure 1 for details).

For OGVs, projected emissions in 2030 were derived from an upcoming ICCT study on the health benefits of a potential Chinese Emission Control Area. CV and RV activities were projected by extrapolating historic (2013 to 2017) transport work data reported by China Port Statistical Yearbook (Ibid.) linearly out to 2030. The impact of environmental regulations on NO_x emission factors are derived assuming compliance with current policies (see details in Figure 2-b). In this paper, we assume that in 2030, 50% of the entire fleet will be Phase I compliant, and 25% will be Phase II compliant. The remaining 25% of the fleet is assumed to be equal to the baseline level in 2015, which is approximately equivalent to IMO Tier I regulations. The result is a table of impact ratios that we derived for each ship group to scale the baseline 2015 inventory out to 2030.

Results

NO_x EMISSIONS FROM MERCHANT VESSELS IN COASTAL CHINA IN 2015

In 2015, OGVs emitted roughly two-thirds of NO_x emissions from the merchant fleet in our study region, followed by CVs and RVs. It is notable that CVs contributed 32% of all NO_x emissions from merchant vessels, emitting nearly half the pollutants of OGVs in coastal China.

Putting RV emissions aside, which only occur in inland waterways, we can divide the OGV and CV emissions into the four, seaside subregions—Bo Sea, Yellow Sea, East China Sea and South China Sea. CV emissions stood out in the northern Bo Sea region, accounting for about 40% of coastal air pollution from shipping in 2015. This is likely due to the fact that the Bo Sea region

Table 4. NO_x emissions from merchant vessels in coastal China in 2015

Vessel group	NO_x emissions (thousand tonnes)	Share
Oceangoing vessels	1126	63%
Coastal vessels	581	32%
River vessels	86	5%

is a large internal sea area enclosed by neighboring countries (see Figure 3). This geography greatly reduces the number of OGVs transiting the region without calling on its ports, leading to the overall smallest merchant shipping inventory at about 200,000 tonnes.

In 2015, CV emissions were especially low in the Yellow Sea region, at about 26% of the total 300,000 tonnes. This should be understood comparatively with the other two external sea regions. The East China Sea region, the gate of China's largest inland waterway system, the Yangtze River, attracts a large volume of coastwise shipping to be further transported inland. Similarly, the South China Sea region, which serves as the gateway to China's second largest inland waterway system, the Pearl River, also receives heavy coastwise traffic. With large overall inventories– 400,000 and more than 800,000 tonnes of NOx in 2015 for the South China and East China Sea regions, respectively—plus very high coastal populations, these two regions are expected to be heavily impacted by air pollution from ships. Comparatively speaking, the Yellow Sea region, where no such inland waterways are situated, showed the lowest share of CV traffic in 2015.

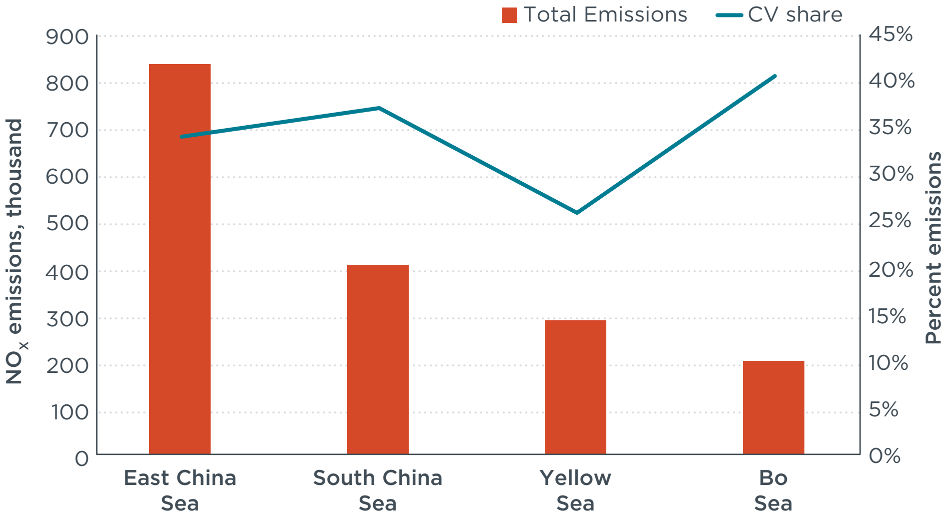

Figure 4. Absolute and relative share of NO$_x$ emissions from coastal and oceangoing vessels in four seaside sub-regions, 2015

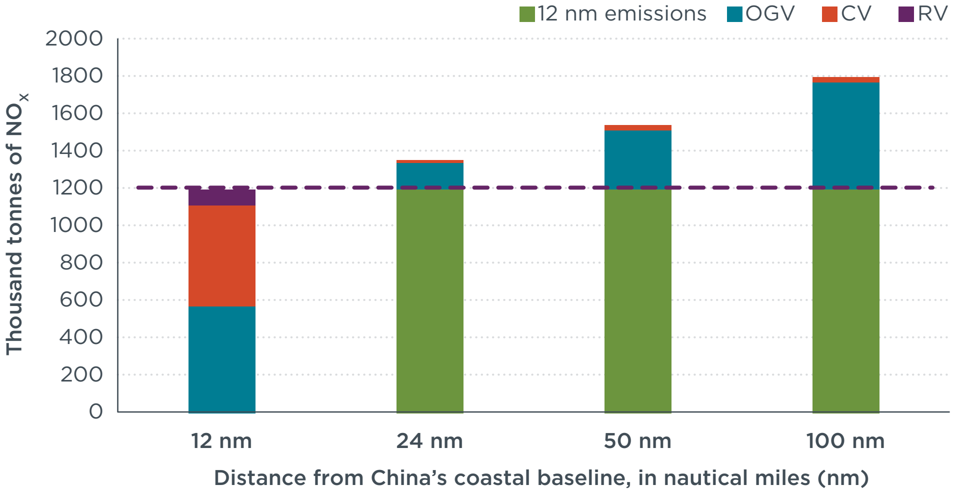

Figure 5. Distribution of NO$_x$ emissions from merchant vessels along China's coastline

Note: "12 nm" on the X axis means any study area within the 12 nm boundary, thus including the land-side portion of the study region. Same with the other labels on the X axis.

GEOGRAPHICAL DISTRIBUTION OF NO$_x$ EMISSIONS FROM MERCHANT VESSELS IN 2015

As shown in Figure 5, NO$_x$ emissions from ships are not evenly distributed, but vary at different geographical boundaries. RV emissions only occur within the coastline. CV emissions, on the other hand, are concentrated within 12 nm of the coastline. This is not surprising since proximity to the coastline generally means shorter distances traveled. But some CV activity and emissions can still be found as far out as 100 nm from the coastline. About half of OGV emissions take place within 12 nm from the coastline. The remaining half is somewhat evenly distributed between 12 nm and 100 nm.

Within 12 nm of China's coastal baseline, which delineates the country's territorial sea, CVs contribute nearly as much NO$_x$ as OGVs, making CVs an important target for NO$_x$ emission control. Beyond the 12 nm, OGVs become the clear culprit for additional NO$_x$ emissions.

CONTRIBUTION OF NO$_x$ EMISSIONS FROM MERCHANT VESSELS, 2015 VS. 2030

In our study region, merchant vessels contributed 14% of NO$_x$ emissions emitted from all sources in 2015. This share rises considerably by 2030, in part because NO$_x$ emissions from land-based sources are projected to drop by up to 60% (Cai, S. et al., 2018).[5] NO$_x$ emissions from merchant vessels, on the other hand, continue to increase. By 2030, NO$_x$ emissions from OGVs increase by 67%, CV NO$_x$ emissions increase by 22% and RV NO$_x$ emissions increase by 38%. In total, the share of overall NO$_x$ emissions from merchant vessels nearly triples, from 14% to 38% (Figure 7), by 2030.

Discussion/Conclusion

In this paper, we estimated NO$_x$ emissions from merchant vessels in China's coastal region in 2015 and then projected those pollutants out to 2030. Our results indicate that merchant vessels have become a non-negligible source of NO$_x$ emissions, and if left unchecked, will become a prominent problem in the near future.

The baseline (2015) results can be compared to other studies. For instance, a study of the Pearl River Delta region (Li et al., 2016) estimated that the domestic shipping fleet in 2013 accounted for nearly 50% of NO$_x$ emissions among all ships within 12 nm of China's coast. This is similar to our study, which found that, nationally, the domestic fleet contributed 53% of NO$_x$ emissions in 2015, although we only evaluated merchant vessels. A more comprehensive study (Chen et al., 2017) suggests that nationally, the domestic shipping fleet contributes 38% of all ship-induced NO$_x$ emissions within the equivalent of China's exclusive economic zone (EEZ). Again, vessel type inclusion and study region vary with our study, but the general

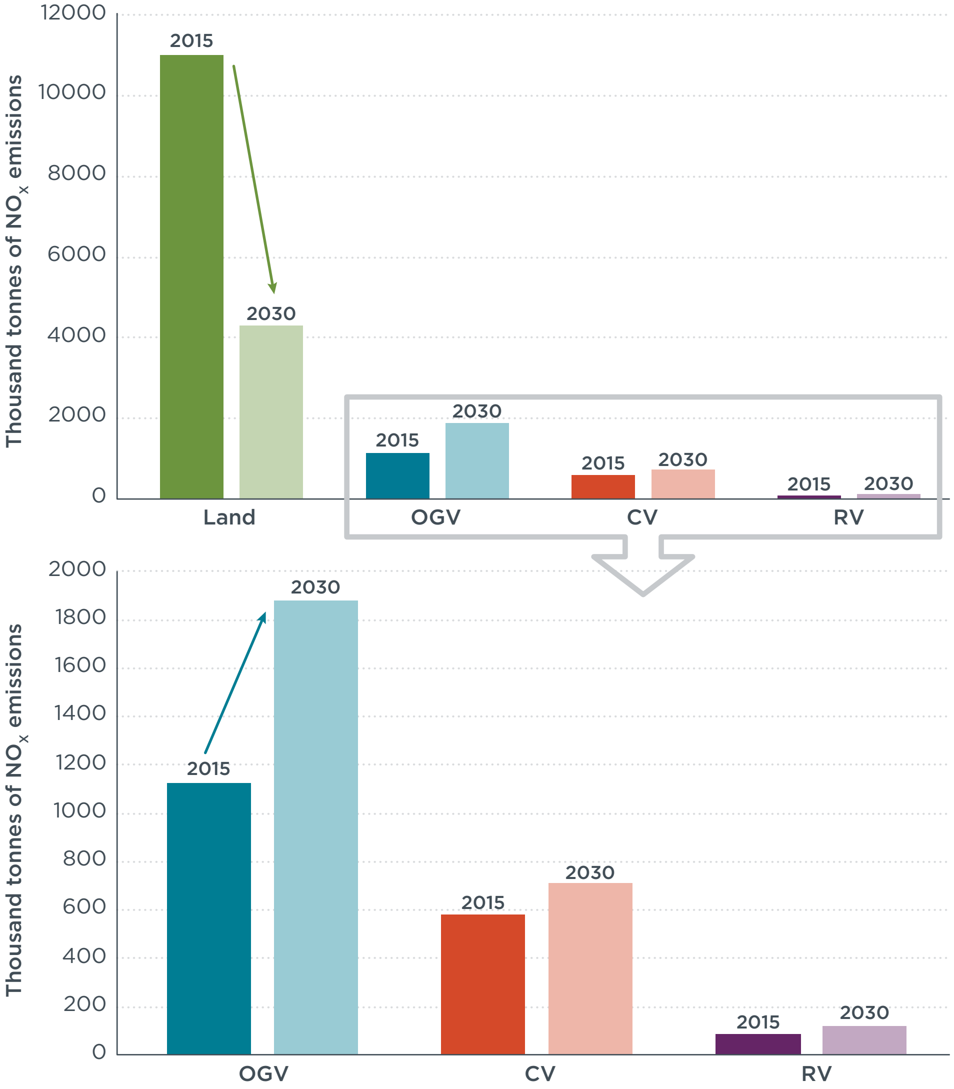

Figure 6. China coastal NO$_x$ emission profiles in 2015 and 2030, the bottom is a zoom-in of the top chart

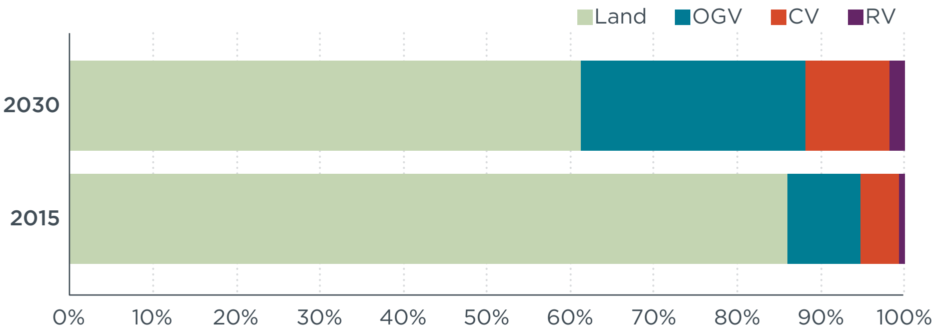

Figure 7. Contribution of merchant vessels to coastal NO$_x$ emissions, 2015 vs. 2030

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[5] According to Tsinghua University, this result is based on assumptions for a maximum reduction scenario. This scenario is chosen to be consistent with an ongoing national ECA feasibility study being completed by research organizations affiliated with China's Ministries of Transport and Ecology and Environment.

picture it presents is very similar to Chen et al. (2017)—of all merchant vessels in the study region, China's domestic merchant fleet contributes 37% NO_x emissions.

In our study region, which includes coastal provinces and coastal waters out to 100 nm from China's coastal baseline, OGVs are the largest NO_x emission contributors among all merchant vessels. Their NO_x emission performances are subject to IMO regulations. Substantial improvements can be made within ECAs, which require newbuild ships to emit 75% less NO_x emissions per unit of energy consumed than IMO's current Tier II requirements.

China has other options to control NO_x emissions that can be implemented immediately and serve as interim actions until an ECA application is put forth. It can include NO_x regulations into its DECA system out to 12 nm, which can be enforced on all vessels, regardless of flag. Additionally, it can enforce more stringent NO_x emissions regulations on all China-flagged vessels regardless of where they operate, at a risk of Chinese-owned ships reflagging under IMO's open registry system to evade those requirements.

Within 12 nm from China's coastal baseline, CVs contribute as much NO_x emissions as OGVs. This finding has profound implications. CVs with larger engines (>130 kW, or most vessels) are already subject to IMO engine emission standards. With the implementation of the domestic marine engine standards, some CVs, especially smaller ones, may face stricter NO_x requirements. Smaller CVs are subject to the domestic marine engine standards as well. That said, if no more actions are taken, the most optimistic estimate is that NO_x emission performance of these vessels will improve about 20%, from IMO Tier I level to Tier II level. This scale of improvement isn't enough to offset the 51 to 92% increases in transport demand shown in Table 3.

The good news is that the Chinese government has complete authority over vessels operating within 12 nm and no actions through IMO are needed to enforce any regulations. As a next step, China could promptly upgrade NO_x regulations on CVs, either by tightening domestic marine engine standards or by implementing special requirements under the DECA system.

For future work, this revised ship emission inventory could be used as input for the air dispersion model, which relates the absolute amount of emissions into ambient concentrations for use in health impacts modeling. The methodology we introduced in this working paper enables us to include CVs into the high-resolution gridded emissions inventory, which together with OGVs, contribute the majority (95%) of ship-induced emissions in China's coastal region. This would be an important addition since CVs, which emit over one-third of all NO_x pollution from merchant vessels, are operated closer to the coastline where populations are more highly concentrated. The resulting ambient concentrations can then be used to estimate their health impacts, which will give us a clearer picture of the different roles OGVs and CVs play in China's coastal air quality and inform policymaking accordingly.

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Appendix A: Classifying merchant CVs based on geographical location and ship type information

Our AIS dataset does not clearly distinguish whether a ship can be classified as a coastal vessel. Thus, we developed the following procedures to identify CVs:

1. Retrieve all non-OGV AIS data within the study region and exclude the foreign fleet based on MIDs.[6] AIS data for OGVs were previously identified in Mao and Rutherford (2018).
2. Identify and exclude non-merchant (work and service) vessels based on the generic ship type information in the ITU dataset.
3. Identify the fishing fleet using the GFW dataset, which applied machine learning to AIS data in order to identify fishing vessels based on navigational patterns. Exclude those ships whose MMSI numbers match those categorized as fishing vessels in the GFW dataset.
4. Lay the remaining ship AIS data over the map in the form of gridded fishnets. This allows us to acquire the geographical concentration and dispersity of AIS points associated with individual ships. This information reflects the distinct navigational patterns for

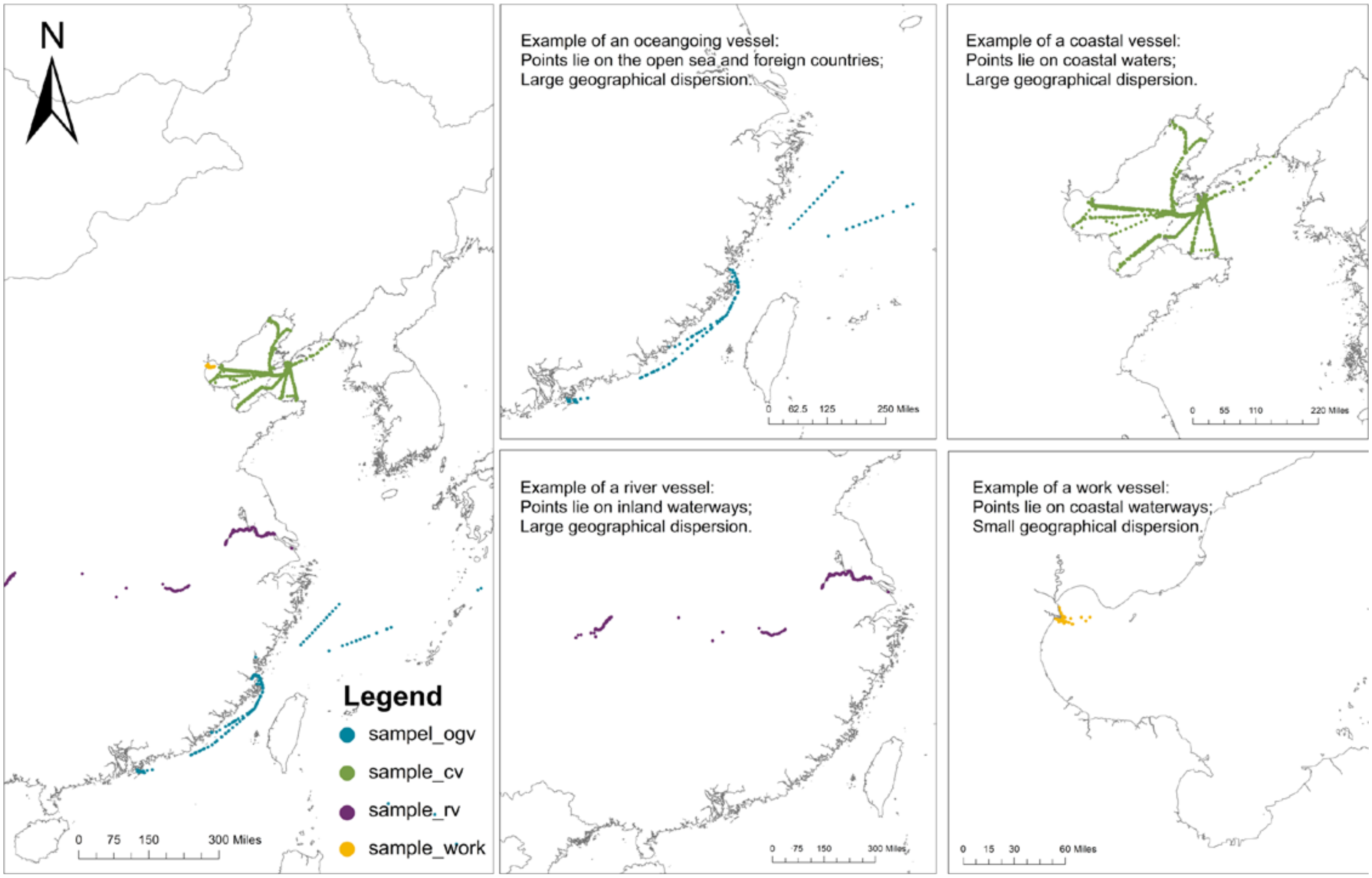

Figure A. Illustration of ship classification methodology

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[6] MID is the first three digits of an MMSI number, which is uniquely assigned to countries by the International Telecommunications Union. A detailed table of MID assignments can be found here: https://www.itu.int/en/ITU-R/terrestrial/fmd/Pages/mid.aspx

coastal vessels, river vessels and non-merchant work vessels.

5. Coastal vessels were defined as those vessels with at least 90% of their AIS signals lying between the coastal baseline and 100 nm and with a coastal dispersity of greater than 4 grid cells.[7] Vessels with less-dispersed operations, or with more than 10% of the signals falling in inland waterways or were beyond 100 nm from shore, were assumed to be either fishing vessels or work and service vessels that the ITU and GFW datasets failed to identify. Those vessels were excluded from the analysis.

We were able to identify 10,300 ships as the Chinese coastal transport fleet using this methodology. The 2015 Statistical Yearbook (Zhu, 2015) identifies 10,721 coastal transport ships.

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[7] The grid cells in coastal waters are 0.2° *0.2° in dimension. Those in inland waterways, however, are 0.05°*0.05° in dimension.

Appendix B: Populating ship characteristics for CVs

The following assumptions were made using available fields in the GFW and ITU datasets to estimate data needed to calculate CV fuel use and emissions:

1. From an engineering point of view, CVs should share common features with OGVs. So, we chose parameters of OGVs made available in the IHS database to estimate those of the CVs.
2. For different ship classes, an OGV's main engine power is correlated to its gross tonnage using a nonlinear (power function) model. The regression coefficients were then used for CVs with the same ship class. When gross tonnage value was missing for an OGV, we used a linear regression model to estimate gross tonnage from its ship length. If the ship length values were missing for a CV, the average ship length by ship class was used as a proxy.
3. Default power demand for auxiliary engines and boilers used for OGVs are used for CVs as well, consistent with the approach taken in the IMO's Third GHG Report (Smith, 2015).
4. The design speed of a CV is assumed to be the 95th percentile of all reported speeds over ground in the AIS database.
5. All CVs are assumed to be running on medium-speed diesel engines burning residual oil. Their engines are assumed to be equivalent to an IMO Tier 1 engine.

In this way, we are able to populate the qualified CVs[8] with key inputs to apply the SAVE model.

Table B. Modeled correlations between a ship's main engine power and gross tonnage and between gross tonnage and ship length

Ship class	Ln(Power) = A*ln (gross tonnage)+B	Gross tonnage = C*Length+D
Container ships	0.92	0.81
Bulk carriers	0.93	0.79
Oil tankers	0.96	0.83
Chemical tankers	0.94	0.85
General cargo ships	0.79	0.73
Liquefied gas tankers	0.96	0.85
Passenger ships	0.96	0.79
RoRo ships	0.91	0.76
All ships	**0.84**	**0.77**

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[8] Qualified CV: CVs whose interpolated records do not surpass 54% of all its AIS records.