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# An overview of non-road equipment emissions in China

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## HIGHLIGHTS

- Non-road equipment emissions research is still at its early stage and there is a huge data gap for both activity and emissions factors in China.
- Five types of non-road equipment were investigated for its current status of emission related research in China.
- A fuel consumption based approach was used to estimate the emissions for non-road equipment.
- Among the five types non-road equipment, emissions from agricultural equipment were the largest with $NO_x$ being the dominant pollutant.
- Due to the existence of large uncertainty, real-world in-use measurements of activities and emissions for the non-road equipment are needed.

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## ABSTRACT

As the vehicle population has dramatically increased in China in the past two decades, vehicle emissions have become one of the major sources to air pollution across the entire country, especially for the metropolitan cities such as Beijing and Shanghai. Most of the non-road equipment are diesel-fueled and have been proved to be a key source for $NO_x$ and PM emissions, contributing significantly to the formation of haze/smog. Therefore, an accurate estimation of emission inventory from non-road equipment is essential for air quality improvement policy making, which mainly depends on the data availability of equipment population, activity, and emissions factor. Compared to on-road vehicles, less studies regarding emissions characterization have been conducted and investigated for non-road mobile sources in China. Thus, in order to identify the data gaps and future research needs, the objective of this study is to review the current status of research in non-road mobile emissions. Five types of non-road equipment were addressed in this study, including agricultural equipment, industrial equipment, river/ocean-going vessels, locomotives, and commercial airplanes, with a focus on the former two. The equipment are further classified mainly based on national standards and data availability to account for fuel type, job duties and others. This investigation has found that the research regarding emissions from non-road equipment is still at its early stage and there is a huge data gap for both activity and emissions factors. For most of the study, data used for emission inventory estimation were based on either literature with similar equipment or as-developed emissions models such as NONROAD or CORPERT. The representativeness of these data to the localities was not much discussed in those studies, which might have weakened the accuracy of the estimated emission inventory. For future study, real-world in-use measurements of activities and emissions for the non-road equipment are desperately needed.



## 1. Introduction

In recent years, emissions from on-road vehicles have been a primary focus of emissions research in China because of their significant contribution to air pollution in China (Zhang and Liu, 2014; Chow, 2001). However, emissions from non-road equipment have not yet been given similar attention. Non-road equipment in China is usually diesel-fueled and covers a variety of equipment (Zhang et al., 2008; Bao et al., 2014) and has been one of the major sources for $NO_X$ and PM emissions (Bao et al., 2014; Andrew and Robert, 2000). For example, research by Zhang et al. (2006) showed that a total of 123,000 tons of $PM_{2.5}$ emissions were from on-road sources while a total of 161,000 tons was from non-road equipment in China in 2001. Thus, in order to improve the air quality, emissions

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from non-road equipment cannot be ignored.

Although there are many studies on emissions from non-road equipment worldwide, few of them are done in China. Due to different working conditions and job duties, different engine technologies deployed, and different regulatory emissions requirement, non-road equipment in China might result in significantly high or low activities and emissions. This indicates that emissions from the same type of equipment in other countries might not be the same as that in China.

An accurate estimation of emission inventory from non-road equipment is essential for air quality improvement policy making, which mainly depends on the data availability of equipment population, activity, and emissions factor. Compared to on-road vehicles, less studies regarding emissions characterization have been conducted and investigated for non-road mobile sources in the last two decades. There exists a huge data gap in equipment population, emission factors, activities, and other information, especially for non-road equipment. Thus, the objectives of this paper are to: review the current status of research in emissions inventory development for non-road equipment, identify the data gaps for emissions inventory development, quantify the emissions of non-road mobile sources of China in 2012, and provide insights regarding future research needs in this regard.

Five types of non-road equipment were addressed in this study, including agricultural equipment, industrial equipment, river/ocean-going vessels, locomotives, and commercial airplanes, with a focus on the former two. The classification, population, activity and emission factor of these equipment were further discussed. Emissions of these equipment were also estimated, which can provide a basis for air quality management and policy making.

## 2. Methodology

In this paper, five types of non-road equipment mentioned above were classified, information regarding the population, activities, and emissions factors for these equipment of China were collected and analyzed based on publicly available technical reports, journal papers, and a national statistics year book. Based on the collected data, emissions of non-road equipment were estimated using different methods. To facilitate the comparisons among existing non-road equipment emissions factor models such as NONROAD (United States Environmental Protection Agency, 2005) (EPA, Environmental Protection Agency), OFFROAD (California Air Resources Board (CARB), 2007) (CARB, California Air Resources Board), and COPERT (Winther and Samaras, 2013) (EEA, European Environment Agency), the published emission data were further subcategorized by equipment type for each of the non-road equipment categories mentioned above. Materials presented in this section include: (1) classification of non-road equipment, (2) emission inventory development, and (3) uncertainty analysis with details given in the following.

### 2.1. Classification of non-road equipment

For each category of agricultural equipment, industrial equipment, river/ocean-going vessels, locomotives, and commercial airplanes, the equipment type was further classified.

Classifications of non-road equipment will impact the difficulties in developing emission inventory and its accuracy. Although a more detailed classification of non-road equipment will provide more accurate emission inventory, the lack of data with same level of details for population, activity, and emission factors will make the classification unreliable and unfeasible for emission inventory development purpose. Thus, in order to classify the non-road equipment for emissions inventory development, the data availability for population, activity, and emission factor for each class of non-road equipment should be also taken into account.

For the agricultural equipment, the classification is based on the Agricultural Industry Standard of the People's Republic of China (NY/T1640-2008) (Ministry of Agriculture of People's Republic of China(NY/T1640-2008), 2008) and China Agricultural Machinery Industry Yearbook (China machinery industry yearbook editor committee, 2013a), the available population of agricultural equipment has been taken into account. For industrial equipment, the classification is based on the China Construction Machinery Industry Yearbook (China machinery industry yearbook editor committee, 2013b). The classification of developed models have been taken into account, such as NONROAD, COPERT and OFFROAD. The agricultural equipment and industrial equipment were further categorized into thirteen and twelve classes, respectively as shown in Table 1.

For vessels, the classification usually can be done based on the job duties and navigation zone. Due to the lack of widely agreed standard in China, the classification of vessels is mainly based on the studies by the ICF International (ICF International, 2009), a consulting firm based on Fairfax, Virginia. Three vessels subclasses were further classified, i.e., river vessels, coastal vessels, and ocean-going vessels. For locomotives, four subclasses were done based on the fuel type, i.e., steam, diesel, gas, and electric locomotives. The commercial airplanes were not further sub-classified, since emissions studies based on the type of the airplane are very limited.

### 2.2. Emission inventory development

This section describes the approaches used for emission inventory development for the five non-road equipment mentioned above. The details are given in the following:

### 2.3. Agricultural and industrial equipment

Two approaches can be used for emissions estimation for agricultural and industrial equipment depending on the data availability. One is based on the fuel consumption, and the other is based on the engine power (Zheng et al., 2013). Since the engine power-based approach requires a variety of data, including the engine power, load factor, duration of usages and others, which are more difficult to collect compared to the fuel consumption, the fuel consumption based approach was used in this study using the eq. (1):

$$EM_{i,j} = \mathrm{EF}_{\mathrm{i,j}} \times FC_j \times 10^{-3} \quad (1)$$

where $\mathrm{EM}_{\mathrm{i,j}}$ is the annual emissions for pollutant *i* and equipment *j* ($10^4$ t/yr); $\mathrm{EF}_{\mathrm{i,j}}$ is the emission factor for pollutant *i* and equipment *j* (g/kg fuel); $\mathrm{FC}_{\mathrm{j}}$ is the total annual fuel consumption for equipment *j* ($10^4$ t/yr); and *i* is the pollutant index, *j* is the equipment index.

### 2.4. Vessels

Similar to the agricultural and industrial equipment, the fuel consumption based approach was also used for emission estimation for vessels. The fuel consumption for vessels can be estimated using the number of passenger-kilometers, freight ton-kilometers, and the average fuel consumption rate (Bao et al., 2014; Yin, 2010; Zhang et al., 2010), which can be acquired from the Yearbook of China Transportation & Communications (China Communication & transportation) and the China Statistical Yearbook (National Bureau of Statistics of the People's Republic of China (2013)). The following equation was used for fuel consumption estimation: