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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):

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

where $EM_{i,j}$ is the annual emissions for pollutant *i* and equipment *j* (10^4 t/yr); $EF_{i,j}$ is the emission factor for pollutant *i* and equipment *j* (g/kg fuel); FC_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:

Table 1
Classification of agricultural and industrial equipment.

Class	Agricultural equipment	Industrial equipment
1	Soil Tillage equipment	Excavators
2	Planting and fertilization equipment	Scrapers
3	Field management equipment	Cranes
4	Harvesters	Industrial vehicles
5	Post-harvest handling equipment	Compaction equipment
6	Raw agricultural products equipment	Paving and Surfacing Equipment
7	Agricultural transporter	Concrete Equipment
8	Irrigation Sets	Pile-driving Equipment
9	Animal husbandry and aquaculture equipment	Decoration and aerial work Equipment
10	Forestry equipment	Bore/Drill Rigs
11	Agricultural Tractors*	Municipal engineering and Sanitation Equipment
12	Farmland construction equipment	Other Special Equipment
13	Others#	N/A

Note: * refer to the tractors except for those being used directly in the farm; # refer to the tractor accessories which are in co-operation with tractors; N/A-not available.

$$FC_j = (N_p \times W_a + N_f) \times E_u^{4,15-16} \tag{2}$$

where N_p is the passenger-kilometers (10^8 person-km); W_a is the average weight of a passenger (65 kg/person); N_f is freight ton-kilometers (10^8t-km); and E_u is the average fuel consumption rate (50 kg/10^4t-km) (Bao et al., 2014).

2.5. Locomotives

The emissions estimation for locomotives is the same as that for vessels. Since only diesel-fueled locomotives were considered, a coefficient will be used to account for the proportion of the total travel distance by diesel-fueled locomotives, which was estimated to be 0.465 in 2012 (National Bureau of Statistics of the People's Republic of China (2013)).

2.6. Commercial airplanes

Emissions from commercial airplanes are estimated based on the LTO (Landing and take-off) cycles. A LTO cycle includes one take-off and one landing. The total numbers of LTO cycle can be obtained from the Civil Aviation Airport Production Statistics Bulletin (Civil Aeronautics Board, 2013). The equation for emissions estimation for commercial airplanes is given in the following:

$$EM_{i,j} = \mathrm{LTO} \times EF_{i,j} \times 10^{-3} \tag{3}$$

where the LTO is total number of landing and take-off cycles and $EF_{i,j}$ has a unit of kg/LTO.

2.7. Uncertainty analysis

The uncertainty analysis for the population, activities, and emissions factors for non-road equipment of China was performed and quantified in this study. Statistics used for this purpose include the arithmetic average, the 95% confidence interval (CI), and the coefficient of variation (CV) of the data.

The 95% CI and CV are calculated using Eqs. (4) and (5), respectively.

$$CI_x = \mu_x \pm 1.96 \frac{\sigma_x}{\sqrt{n}} \tag{4}$$

$$CV_x = \frac{\sigma_x}{\mu_x} \tag{5}$$

where

CI_x = the 95% confidence interval of x
CV_x = the coefficient of variation of x
u_x = the arithmetic average of x
σ_x = the standard deviation of x
n = the number of observations of x
x = variable, can be population, activity, and emission factor, and others

3. Results and discussions

This section mainly presents the current status of research in emission inventory development for non-road equipment. Studies on population, activities, and emission factors that were used for emission inventory development for non-road equipment were summarized and discussed in this section. The details are given in the following:

3.1. Population

For agricultural equipment, the population was acquired from the China Agricultural Machinery Industry Yearbook. Since the classification of the agricultural equipment of this study is slightly different from that in the yearbook, the population for each sub-class was regrouped according to this study's classification. As shown in Table 2, the total population of agricultural equipment has exceeded 110 million in 2012 with irrigation sets having the largest population and forestry equipment having the least. In addition, several types of large equipment, including harvesters, agricultural transportation, tractors and others account for approximately 30% of the total population.

For industrial equipment, assuming a 10-year service life, the population was estimated using sales data, import and export volume as shown in Eq. (6):

$$Q_p = (1 + C) \sum_{i=p-9}^{p} (X_i + A_i - B_i) \tag{6}$$

where Q_p is the total population for industrial equipment in year *p*; C is correction factor, usually 20%–30% (taking 25% in this paper); X_i is the amount of sales in year *i*; A_i and B_i are the amount of import and export in year *i*; and p is the target year. These data can be obtained from the China construction machinery industry

Table 2
Population of five types of equipment in 2012.

Equipment type	Subclass	Population
Agricultural Equipment	Soil Tillage equipment	8,365,029
	Planting and fertilization equipment	962,698
	Field management equipment	5,696,500
	Harvesters	2,399,670
	Post-harvest handling equipment	10,459,200
	Raw agricultural products equipment	3,569,400
	Agricultural transporter	14,842,500
	Irrigation Sets	46,746,600
	Animal husbandry and aquaculture equipment	1,043,055
	Forestry equipment	276,200
	Agricultural Tractors*	11,412,350
	Farmland construction equipment	307,629
	Others	9,430,357
Industrial Equipment	Excavators	1,403,960
	Scrapers	1,829,580
	Cranes	512,521
	Industrial vehicles	1,087,034
	Compaction equipment	133,531
	Paving and Surfacing Equipment	21,764
	Concrete Equipment	311,500
	Pile-driving Equipment	42,368
	Decoration and aerial work Equipment	18,160
	Bore/Drill Rigs	146,447
	Municipal engineering and Sanitation Equipment	43,115
	Other Special Equipment	4781
Vessels	N/A	158,309
Locomotives	Steam locomotives	15
	Diesel locomotives	10,602
	Electric locomotives	10,180
Commercial airplanes	N/A	3589

Note: N/A-not available. *: Part of the tractors is used as a power source for other equipment. A 50% was assumed in this study.

yearbook.

The total population of industrial equipment was estimated to be 5.55 million in 2012 with excavators, scrapers, and industrial vehicles being the top three equipment with largest population. Similar to the agricultural equipment, the yearbook does not specify exclusively the population for each subclass of the industrial equipment, the population was also regrouped accordingly based on this study's classification. This imposes a great challenge for a more accurate estimate of emissions inventory for both agricultural and industrial equipment because emissions vary among different subclasses.

The population of other equipment comes from the China Statistical Yearbook. For vessels and commercial airplanes, since the yearbook only reports the total population for each of these categories, population of the subclasses for each of the two categories were not further estimated. As is shown in Table 2.

Since the classification of non-road equipment will impact the accuracy of the developed emission inventory, in order for better quantification of emissions from these categories for future study, the classifications could be based on equipment's operational characteristics and working range with the corresponding population for each subclass being required. For example, for vessels, subclassification could be lake-, river-, and ocean-going, and further subclassified as commercial and passenger; for airplanes, the subclassification could be based on its carrying capacity, such as small, medium, and large.

3.2. Activity

There are not many studies regarding the activities of non-road equipment in China seen in the literature. For agricultural equipment, there are only several studies available. For example, a study by Fan et al. (Fan et al., 2011) reports that activities of agricultural equipment range from 100 h to 2000 h per year (a factor of 20) depending on equipment type. Research by Ge et al. (2013) and Fu et al. (2013) reported that the activities of harvesters and agricultural tractors are 140–160 h and 400–430 h per year respectively.

Compared to the agricultural equipment, activities study for other non-road equipment is even more limited. For example, only excavators and loaders in the category of industrial equipment were reported to have an activity of 1800 and 1100 h per year, respectively in a study by Li et al. (2012); the activity of a fishing vessel was reported as 1200 h/yr by Ye et al. (2014), which might not be representative due to the boat type selected for the study. There is no study on activities of locomotives and commercial airplanes in China available in the literature. The activities for vessels and locomotives are presented in Table 3.

3.3. Emissions factors

Emissions factor is one of the three factors (i.e., population, activity, and emission factor) for emissions inventory development. Usually, emissions factor is obtained either using laboratory testing, models or real world measurements on preselected representative equipment. Since emissions from mobile sources in China is a relatively new issue compared to other air pollution sources in the past several decades, there have not many studies in this regard been seen in the literature. Real-world measurements of vehicle emissions are limited, especially for non-road equipment. Emission factors for non-road equipment usually were borrowed from existing emission factor model such as NONROAD. Emissions factors used for the non-road equipment mentioned in this study in China are summarized in Table 4.

For agricultural equipment, there are several studies regarding real-world measurement of emissions in China, in which a portable emissions measurements systems (PEMS) was used to estimate the fuel-based emissions on tractors and harvesters (Ge et al., 2013; Fu et al., 2013).

Compared to agricultural equipment, emission factors for other equipment are mainly based on literature and model estimation. For each subcategory of industrial equipment, emission factors were incomplete.

Table 3
Activities and fuel consumption rates for vessels and diesel locomotives (China Communication & transportation; National Bureau of Statistics of the People's Republic of China (2013)).

Equipment	Passenger-kilometers (10^8person-km)	Freight-ton kilometers (10^8t-km)	Average fuel consumption rate (kg/10^4t-km)
River vessels	35.43	7638	50
Coastal vessels	30.23	20,657	50
Ocean-going vessels	11.82	53,412	50
Diesel locomotives	9812.3	29,187.1	26.8

For commercial airplanes, the emissions are based on the LTO cycles. It is reported that the landing and take-off is 6.6 million, so the LTO cycle is 3.3 million.

Table 4
Fuel-based emission factors for non-road equipment.

Class	Description	Emissions factor (g/kg-fuel)				Sources
		HC	CO	NO_x	PM	
Agricultural Equipment	Soil Tillage equipment	3.00	17.24	24.25	2.27	NONROAD[a]
	Planting and fertilization equipment	N/A	N/A	48.3	3.9	Jin et al. (2014)
		11.61	134.82	20.79	2.02	NONROAD[a]
	Field management equipment	3.70	25.30	26.19	2.81	NONROAD[a]
	Harvesters[b]	11.87[c]	30.31[c]	53.08[c]	5.28[c]	Ge et al. (2013)
		4.71[c]	16.42[c]	52.07[c]	4.81[c]	
	Post-harvesters	3.28	16.41	26.73	2.20	NONROAD[a]
	Raw agricultural products equipment[b]	9.46	28.25	71.89	9.76	Li et al., (2013)
		N/A	N/A	48.3	3.9	Jin et al. (2014)
	Agricultural transporter[b]	N/A	N/A	50.93	4.48	Jin et al. (2014)
		N/A	23.33	42.85	5.8	Zhang et al. (2010)
		3.21	19.42	24.94	2.40	NONROAD[a]
	Irrigation Sets	7.91	32.33	51.72	6.47	Li et al. (2013)
	Animal husbandry and aquaculture equipment[b]	N/A	N/A	52.3	4.87	Jin et al. (2014)
		N/A	N/A	48.3	3.9	Jin et al. (2014)
		9.05	22.01	45.45	2.11	NONROAD[a]
	Forestry equipment	N/A	N/A	52.55	3.63	Jin et al. (2014)
		3.39	22.07	25.58	2.60	NONROAD[a]
	Agricultural Tractors[b]	N/A	N/A	52.43	4.25	Jin et al. (2014)
		12.46[c]	48.41[c]	55.84[c]	2.08[c]	Fu et al. (2013)
	Farmland construction equipment	N/A	N/A	50.93	4.48	Jin et al. (2014)
		2.47	14.07	23.85	2.04	NONROAD[a]
	Others	3.3	19.96	25.05	2.51	NONROAD[a]
Average		6.39	31.36	42.36	3.85	na
95% CI	Lower Bound	4.27	15.37	36.36	3.07	
	Upper Bound	8.50	47.34	48.37	4.63	
	CV	0.57	0.92	0.33	0.47	
Industrial Equipment		3.385	10.722	32.792	2.086	Bao et al. (2014)
		6.28	31.38	49.76	5.83	Yin (2010)
		N/A	41.56	66.1	6.3	Zhang et al. (2010)
		N/A	N/A	52.5	3.79	Li et al. (2012)
		N/A	42.65	51.62	6.46	Jia et al. (2014)
		N/A	14.5	50.3	2.3	Tan et al. (2013)
		2.46	10.92	24.79	1.81	NONROAD[a]
Average		4.04	25.29	46.84	4.08	na
95% CI	Lower bound	0	10.83	35.09	2.30	
	Upper bound	8.08	39.74	58.59	5.87	
CV		0.40	0.54	0.27	0.47	
Vessels	River vessels	6.19	23.8	47.6	3.81	Bao et al. (2014)
		N/A	8.94	55.0	1.1	Zhang et al. (2010)
		4.6	8.8	46.3	2.4	Ye et al. (2014)
		5.4	51.7	75.6	7.3	Song (2015)
		4.87	9.16	49.24	2.43	Jin et al. (2009)
		4.64	8.81	46.31	2.38	Jin et al. (2009)
	Coastal vessels	2.7	7.4	79.3	6.2	Bao et al. (2014)
		3.21	7.02	60.12	2.38	Ye et al. (2014), Jin et al. (2009)
	Ocean-going vessels	2.7	7.4	79.3	6.2	Bao et al. (2014)
		2.26	10.48	51.07	2.38	Jin et al. (2009)
Average		4.06	14.35	58.98	3.66	na
95% CI	Lower bound	3.06	4.84	49.58	2.21	
	Upper bound	5.06	23.86	68.39	5.1	
	CV	0.32	0.93	0.22	0.55	
Locomotive		3.11	8.29	55.73	2.07	Bao et al. (2014)
		2.19	4.14	94.34	1.46	Yin (2010)
		N/A	4.11	54.1	2.8	Zhang et al. (2010)
		N/A	7.1	50.3	N/A	Cai et al. (1996)
Average		2.65	5.91	63.62	2.11	na
95% CI	Lower bound	1.75	2.99	35.22	0.75	
	Upper bound	3.55	8.83	92.02	3.47	
CV		0.24	0.31	0.28	0.26	
Commercial airplanes (kg/LTO[a])		2.68	9.14	16.29	0.54	Bao et al. (2014)
		11.14	21.81	19.8	0.49	Zhang et al. (2010), Huang et al. (2014)
Average		6.91	15.48	18.04	0.52	na
95% CI	Lower bound	0	3.06	14.60	0.47	
	Upper bound	15.20	27.89	21.48	0.56	
CV		0.86	0.58	0.14	0.07	

Note:
[a] The unit for emission factor in the NONROAD model is g/hp-hr and has to be converted to g/kg-fuel using a BSFC(brake specific fuel consumption) coefficient (United States Environmental Protection Agency, 2004).
[b] Multiple studies available and listed by different rows in the table.
[c] Data are from real-world emissions.
[d] LTO-landing and take-off; N/A-not available.

3.4. Emission inventory

Emission inventory in this study was developed using a fuel-consumption based approach described in prior section. Thus, the activity is quantified using either the total amount of fuel consumed for most of the equipment or the total amount of LTO cycles for commercial airplanes. All of the fuel consumption data and LTO cycles can be obtained from the national agricultural mechanization statistical report (Ministry of Agriculture of People's Republic of China (2012)), China energy statistical yearbook (Energy Statistics Division of the National Statistics Bureau, 2013) and Civil Aviation Airport Production Statistics Bulletin. It should be noted that the fuel consumption for agricultural equipment was not given directly for each subclass in the year book. The fuel consumption has to be estimated proportionally based on the power capacity. For industrial equipment, the diesel consumption in construction industry mainly comes from the use of industrial equipment (Yin, 2010; Zhang et al., 2010).

Fuel consumption and emission inventory for the non-road equipment mentioned in this study are given in Table 5.

According to the emission inventory, agricultural equipment emissions were highest. For different pollutants, NO_x emissions were higher than other pollutants.

3.5. Uncertainty analysis

The uncertainty of emission inventory mainly results from the population, activity and emission factor. Since there are not adequate data for population, activity, and emission factors, not each subclass of the non-road categories was quantified with the 95%CI and CV for the three factors. Instead, the variation among all subclasses was discussed.

For example, as mentioned before in this paper, the variability in activities for agricultural equipment can be as high as a factor of 20 when comparing the most used equipment to the least used one. As shown in Table 4, emission factors vary by equipment type and different studies as well. The ratio of the maximum emission factor to the minimum one ranges from 1.4 to 4.2 for HC, 2.0 to 9.6 for CO, 1.2 to 3.5 for NOx, and 1.1 to 6.6 for PM, respectively. The upper bound of the 95% CI to its lower bound could be as high as 9 depending on categories and pollutants. The CV of the emission factors for the non-road equipment varies by category and pollutant. For the agricultural equipment, the CV ranged from 0.33 to 0.92, indicating of a large uncertainty in emission factors. Similar ranges of CV are also observed for other categories. Since the available data is very limited, the CV might have underestimated the actual variation of the emissions factors. For example, there are two data points available for commercial airplanes. The CV for PM is 0.07, much less than that for the HC (0.86). However, this does not necessarily indicate that the variations of PM emissions are smaller than that of HC. Furthermore, Thus, in order for an accurate estimate of emission inventory for non-road equipment, uncertainty of population, activities and emission factors has to be taken into account. Due to the lack of studies in this regard, there is an urgent need to fill in these data gaps.

Compared to the three key factors for emission inventory development, i.e., population, activity, and emission factors, activity is relatively difficult to quantify. How the equipment is being used and operated will significantly impact its emissions and thus the total emissions. Since each equipment might has its own operational characteristics and it is not possible to collect the activity data for all the equipment, a reasonable and simple but with adequate details classification of the equipment is necessary for an accurate estimate of emission inventory development. For future work, extensive data collection of the real-world activity including on-site survey, activity and emissions measurements when the equipment is on duty will also be needed. In addition, development of an extensive database of activity and emissions for non-road equipment will help reduce the uncertainty associated with these factors and thus improve the accuracy of emission inventory development.

4. Summary

This paper summarizes the current research regarding the emissions from non-road equipment in China. It was found that only limited researches are available in the literature and huge data gaps exist in all perspectives of emissions inventory development. Non-road mobile source emissions are heavily dependent on fuel quality, operation conditions (e.g., engine cycles, duty cycles),

Table 5
Fuel consumption and emission inventory of non-road equipment in 2012 of China ($\times 10^4$t).

Class	Description	Total annual fuel consumption	Emissions			
			HC	CO	NO_x	PM
Agricultural equipment	Soil Tillage equipment	144.95	0.43	2.50	3.52	0.33
	Planting and fertilization equipment	9.65	0.11	1.30	0.33	0.03
	Field management equipment	43.24	0.16	1.09	1.13	0.12
	Harvesters	269.91	2.24	6.31	14.19	1.36
	Post-harvest handling equipment	85.39	0.28	1.40	2.28	0.19
	Raw agricultural products equipment	129.93	1.23	3.67	7.81	0.89
	Agricultural transporter	1019.3	3.27	21.79	40.34	4.31
	Irrigation sets	312.2	2.47	10.09	16.15	2.02
	Animal husbandry and aquaculture equipment	185.08	1.67	4.07	9.01	0.67
	Forestry equipment	5.65	0.02	0.12	0.22	0.02
	Agricultural tractors	1390.3	17.32	67.30	75.26	4.40
	Farmland construction equipment	110.36	0.27	1.55	4.13	0.36
	Others	N/A	N/A	N/A	N/A	N/A
	Subtotal	3705.97	29.48	121.21	174.37	14.69
Industrial equipment		518	2.09	13.1	24.26	2.11
Vessels	River vessels	382.03	1.96	7.08	20.38	1.24
	Coastal vessels	1032.95	3.05	7.45	72.01	4.43
	Ocean-going vessels	2670.64	6.62	23.88	174.09	11.46
	Subtotal	4085.62	11.63	38.41	266.48	17.13
Diesel locomotives		371.68	0.98	2.20	23.65	0.78
Commercial airplanes		N/A	2.28	5.11	5.96	0.17

Note: N/A-not available.

engine maintenance level, engine technology, and others. Although there are a number of researches in emissions estimation from non-road equipment in other countries and regions, China must come up with its own plans to fill up the gaps, especially in real-world measurements of activities and emissions.

In recent years, China has put tremendous efforts in tackling air pollution in many metropolitan cities across the country, especially for $PM_{2.5}$. Emission inventory plays an essential role in decision-making for air quality improvement, therefore, impacts both environmental condition and economic development. Resources should be prioritized to identify the sources of air pollution and quantify the emissions.

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