Developing a First-Ever National Mobile Source Emissions Inventory for China

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Abstract

The Chinese Ministry of Environmental Protection (MEP) recently initiated a first-ever national pollution source census to be completed in 2009. The Vehicle Emission Control Center of MEP (VECC-MEP) is responsible for the mobile source emissions component of the pollution census. VECC-MEP has undertaken the project in three stages. The first stage, data collection, was completed over the fall and winter of 2007-2008, and entailed the detailed surveying of vehicle population and activity data in 345 cities in China. The second stage, emission factor model development, was completed in December, 2008. VECC-MEP surveyed existing emission factor models, including COPERT, MOBILE, the IVE model, and more, to determine the most appropriate structure and methodology for a China-specific model. The new model is called CVEM, the China Vehicle Emissions Model. Key considerations included Chinese data availability and reliability as well as how to model China's unique populations of 2 and 3-wheelers and heavy-duty vehicles. The third and final stage of the project, completion of the total inventory, is estimated to be completed in late spring, 2009. In this paper, we introduce the key project accomplishments of data collection and model development in China as well as remaining challenges.

1. Introduction

The creation of a first-ever nationwide pollution source census is a key environmental protection task under China's 11th Five-Year Plan. The Vehicle Emission Control Center of the Ministry of Environmental Protection of China (VECC-MEP) is responsible for completing the mobile source emissions component of the census. Under this project, VECC-MEP has two primary objectives. The first objective is, through original real-world and laboratory research, driver and vehicle surveying, and application of international precedent, to estimate total nationwide vehicle emissions in China by vehicle type and pollutant using 2007 as a base year. The second objective is to develop a China-specific mobile source emissions inventory model for use by local Chinese Environmental Protection Bureaus for calculating municipal and regional emissions inventories and for exploring the potential impacts of new vehicle emission policies.

The project lasts approximately two years, from mid-2007 to mid-2009. The final deliverables include the total emissions inventory and software model, as well as base emissions factors plus correction factors for Chinese vehicles operating in a variety of conditions. The specific directive to VECC-MEP is to calculate on-road mobile source emissions for only four pollutants: CO, HC, NOx, and PM. However, VECC-MEP is simultaneously building the model to incorporate off-road mobile sources and to calculate emissions of a fifth species, CO_2. VECC-MEP also plans to calculate historical and projected vehicle emissions in China from 1995 to 2025.

Although China has been implementing progressively stricter tailpipe emission standards over the past decade, there has to date been no systematic and comprehensive national emissions inventory work performed. The development of such a national inventory is critical for many reasons. Accurate estimates of national motor vehicle emissions will assist governmental departments to evaluate and predict environmental quality, to scientifically formulate environmental and vehicle planning policies, to better enforce vehicle emission standards, to improve urban and regional air quality, and to promote a resource-conserving and environmentally-friendly society. The project will also facilitate the national harmonization of individual city-level inventories, especially with regard to methodology and emission factors.

This paper introduces the project structure, data sources, and experimental data, as well as some key conclusions and results obtained so far. All data and results presented in this paper should be considered preliminary, pending final approval from Ministry of Environmental Protection of China.

2. Background

The recent, rapid growth of motor vehicle population in China has been staggering. By the end of 2007, there were almost 44 million on-road civil motor vehicles, nearly three times as many as in 2000 (NBS 2008). In addition, China at the end of 2007 had over 7 million low-speed 3 and 4-wheel vehicles and over 87 million motorcycles and scooters (CATARC 2008). Although the population of all types of vehicles is exploding, the highest recent rates of growth have been for private passenger cars, for which the average annual growth rate of the past ten years has been 30%.

Beginning in 2000, China began nationally implementing progressively stricter tailpipe emission standards following Europe’s precedent. At present, the Chinese nationwide tailpipe emission standard is China III – equivalent to Euro 3/III – while the standard in Beijing is China IV – equivalent to Euro 4/IV. The current nationwide standards in effect are GB18352.3-2005 for light-duty vehicles and GB17691-2005 for heavy-duty vehicles (MEP 2005a, MEP 2005b). As in Europe, the four pollutants regulated by Chinese emission standards are CO, HC, NOx, and PM.

Although a national mobile source emissions inventory has not yet been completed for China, it is already clear that vehicles in China have a large impact on urban air quality. Recent city-level emissions inventory research in Beijing indicates that motor vehicles in Beijing are responsible for about three-quarters of ambient CO and NOx concentrations and about half of VOC concentrations (Hao 2008). Even in rural areas, emissions from low-speed diesel trucks impact the health of drivers and passengers, in addition to affecting crop production, water quality, soil acidification, and more.

3. Emissions Model Methodology Overview

The mobile source emissions model develop by VECC-MEP is called the China Vehicle Emissions Model, CVEM. This section of the report will present a brief overview of the methodology used in the model.

There are a number of factors and conditions that affect vehicle emissions. A strong vehicle emissions model will consider a wide variety of these factors, which may be divided into three categories: environmental factors, vehicle activity factors, and vehicle fleet factors. Table 3.1 shows a list of factors within each category that are considered in CVEM:

Environmental / Location Factors	Vehicle Activity Factors	Vehicle Fleet Factors
- Temperature - Altitude - Fuel properties (ethanol content, sulfur content, RVP)	- Average speed by road type OR Vehicle Specific Power (VSP) bin allocation - Driving share by road type - Annual vehicle miles traveled (VMT) - Number of cold starts per day - Average trip length	- Vehicle population by type, model year, fuel, and emission standard - Odometer mileage by vehicle type

Table 3.1: Key factors affecting vehicle emissions that are considered in CVEM.

CVEM considers two overall types of vehicle emissions – tailpipe and evaporative.[1] Total emissions are a sum of the two:

(1) Total emissions = tailpipe emission + evaporative emissions

Tailpipe emissions are further categorized / modeled in two ways. The first is as either hot running or cold start emissions, which are modeled separately because of the typically higher emissions associated with engines operating during the first few minutes after starting at ambient atmospheric temperatures. The second way tailpipe emissions are categorized is by road type. Different road types are modeled separately because of the different average speeds associated with rural, suburban, and highway driving.

(2) Tailpipe emissions = cold start emissions + hot running emissions

(3) Tailpipe emissions = urban emissions + suburban emissions + highway emissions

Methodology: Hot Running Emissions

The annual hot running tailpipe emissions for each pollutant by vehicle type

[1] A third type of vehicle emissions, particulate emissions from brakes / roads / tire dust, is not considered in the model at present, although this is an important area for future model expansion.

(including fuel type and emission standard) may be estimated by equation (4):

(4) Emissions amount = vehicle amount x VMT x EF

where:

- Emissions amount is total emissions in grams;
- vehicle amount is number of vehicles;
- VMT is annual vehicle miles traveled per vehicle in km; and,
- EF is emissions factor in g/km.

In CVEM, the emissions factors (EF) are calculated differently for different vehicle types. The methodology for light-duty vehicles and motorcycles is essentially an average speed-based methodology similar to that used by international models like the US EPA's MOBILE and Europe's COPERT models. For heavy-duty vehicles and low-speed 3 and 4-wheeled vehicles, on the other hand, CVEM uses a Vehicle Specific Power-based methodology similar to that used in "next generation" models like the US EPA's MOVES and the IVE model.

For light-duty vehicles and motorcycles, the EF is given by equation (5):

(5) EF = BEF x SCF x TCF x LCF x FCF x ACF

where:

- EF is emissions factor in g/km;
- BEF is base emissions factor (also called ZML, zero mileage level) which includes a degradation factor; and,
- SCF, TCF, LCF, FCF, and ACF are correction factors for speed, temperature, load, fuel, and altitude, respectively.

For heavy-duty and low-speed vehicles, the EF is given by equation (6):

(6) $$EF = \sum_{k=1}^{13} (ER_k \times F_k) / v \times CF$$

where:

- EF is emissions factor in g/km;
- k is VSP bin # (total 13 bins);
- ER is emissions rate of vehicles operating in VSP bin k in g/s;
- F_k is percentage time operating in bin k;
- v is average speed in m/s; and,
- CF represents various Correction Factors.

Separate methodologies were chosen for light-duty and heavy-duty vehicles primarily for reasons related to data availability in China. For light-duty vehicles, a large database of base emission factors from emissions certification testing already existed. Combined with vehicle activity and other correction factors, this database formed a strong foundation for an inventory using an average speed methodology. Additionally, because China's light-duty vehicle fleet largely uses international engine and emission control technologies, international precedent for emission factor research could be applied in cases where domestic Chinese data was lacking.

In contrast, very little data on real-world emissions from China's heavy-duty vehicle fleet existed prior to this project. Steady-cycle, engine-only emissions certification testing could not be easily extrapolated to real-world driving conditions for complete vehicles. Plus, China's unique population of heavy-duty and low-speed 3 and 4-wheeled vehicles – using largely domestic technology – required that much original research on emission and correction factors be conducted. Internationally, because the trend of emissions modeling is towards a VSP-based methodology, this was chosen for application to China's heavy-duty vehicle fleet. Eventually, it is expected that the light-duty and motorcycle methodologies will be revised to be based on VSP as well.

Methodology: Cold Start and Evaporative Emissions

Daily excess cold start emissions are estimated by multiplying the average number of cold starts per day by an excess cold start emissions factor determined by VECC-MEP through real-world testing in China. The evaporative emissions methodology used by CVEM is identical to that used by COPERT IV.[2] An important area for future expansion is to conduct original research on evaporative emissions within China.

4. Data Inputs and Research Summary and Scope

A brief introduction to the key data sources and research conduced by VECC-MEP and partners under this project is presented in this section of the report. The primary data collection and research phases of the project occurred during fall-winter 2007-2008. Key results of that research, including Chinese vehicle base emission factors, correction factors, and activity data by region were published internally to the Ministry of Environmental Protection in May 2008 in *First National Pollution Source Census – Technical Report: National Vehicle Pollutant Emission Factor Calculations* (VECC-MEP 2008).

Vehicle Activity Data and Fleet Data

Vehicle activity data was generated from detailed investigations of vehicle driving behavior in 17 typical Chinese cities of various sizes. Separate investigations were performed on light-duty vehicles, heavy-duty vehicles, and buses, with a goal of determining typical driving cycle and driving share by road type for each vehicle type.

[2] The COPERT IV evaporative methodology is described in the COPERT technical support document *Gasoline Evaporation from Vehicles*, available here: http://reports.eea.europa.eu/EMEPCORINAIR5/en/B760vs4.0.pdf.

In addition, motorcycle activity data was collected from seven of these cities. Annual vehicle mileage traveled (VMT) was provided to VECC-MEP voluntarily by typical manufacturers based on annual inspection data across 345 cities in China.

Table 4.1 shows selected results of this research:

Vehicle Type	Annual VMT (nationwide average, km)	Average Speed (nationwide average, km/h)
Taxis	138,000	35.3
Passenger Cars	25,216	35.3
Public Buses	45,757	15.6
Other Buses	114,800	15.6
Light-Duty Commercial Vehicles	44,000	35.3
Heavy-Duty Trucks	105,600	33.8
Low Speed Goods Vehicles	23,000	14.3
Low Speed 3-Wheeled Vehicles	30,900	22.7
Motorcycles	6,612	28.0

Table 4.1: Selected nationwide results for vehicle activity in China, 2007. (Note: results not yet verified by MEP.)

Annual numbers of in-use vehicles and new vehicle registrations was sourced from the China Automotive Industry Yearbook (CATARC 2008). This data was further parsed into emission standard data and fuel type by combining the yearbook data with annual vehicle registration data from China’s Ministry of Public Security.

Base Emission Factors and Correction Factors

Base emission factors, correction factors, and VSP bin allocation were generated from a combination of existing datasets and original VECC-MEP or project partner research. Original research included emissions certification and degradation testing, dynamometer testing, and testing using Portable Emission Monitoring System (PEMS) devices. Certain additional correction factors were taken directly from international precedent; for example, CVEM currently uses altitude correction factors used by the US EPA’s MOBILE model. In expansion and revision of the model, expanding and developing these emissions factors for China is a key area for further research.

5. Preliminary Results – Nationwide NOx Inventory

As mentioned in previously in this report, at the end of 2007 China had over 50 million on-road motor vehicles and over 87 million motorcycles and scooters. Figures 5.1 and 5.2 present the nationwide distribution of these motor vehicles by vehicle type:

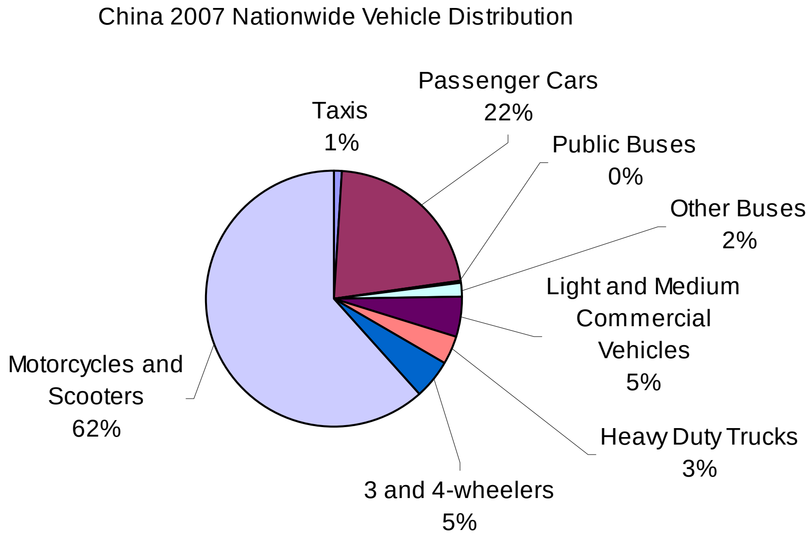

Figure 5.1: China 2007 nationwide motor vehicle distribution by vehicle type (note: results not yet verified by MEP).

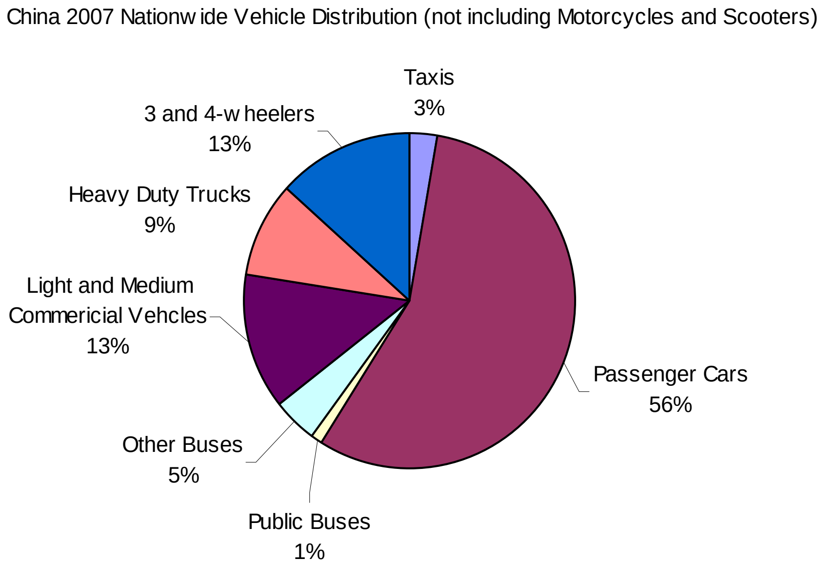

Figure 5.2: China 2007 nationwide motor vehicle distribution by vehicle type, not including motorcycles and scooters (note: results not yet verified by MEP).

In March 2009, CVEM was used to estimate China's total nationwide NOx emissions[3] from on-road vehicles to be 4.70 million metric tons (MMT). The nationwide distribution of these emissions from on-road motor vehicles is shown in Figures 5.3 and 5.4:

[3] NOx has received priority because NOx reductions are expected to be a key goal of China's 12th Five-Year Plan.

China 2007 Nationwide Mobile Source NOx Inventory - Share by Vehicle Type

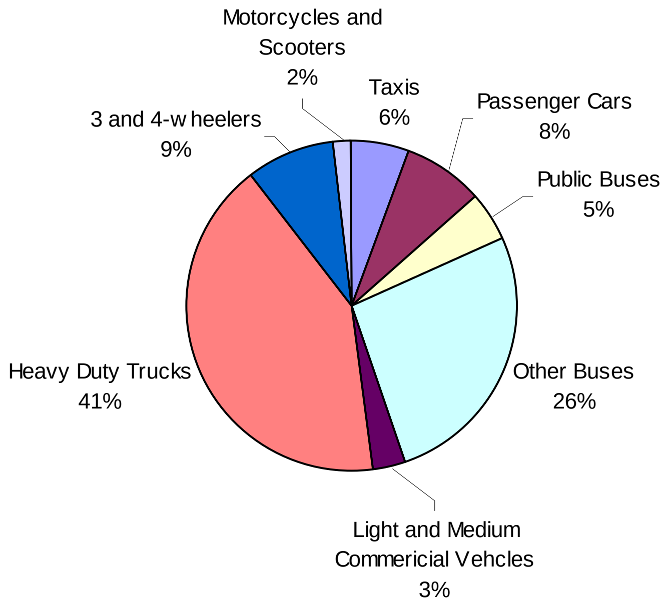

Figure 5.3: China 2007 nationwide on-road mobile source NOx inventory – shares by vehicle type (note: results not yet verified by MEP).

China 2007 Nationwide Mobile Source NOx Inventory - Share by Vehicle Type (not including motorcycles and scooters

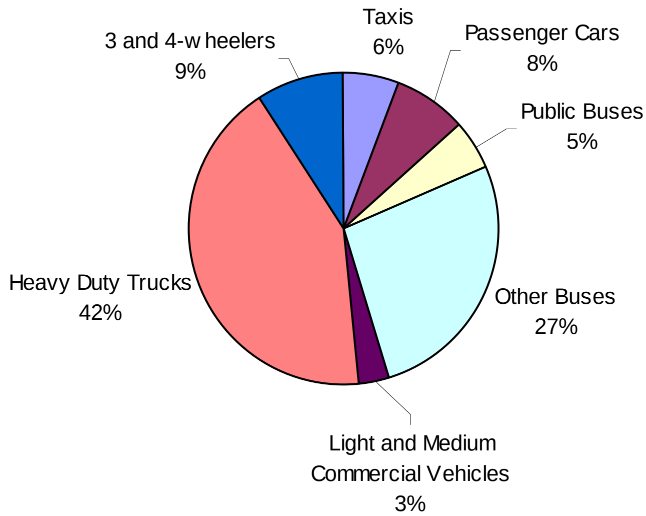

Figure 5.4: China 2007 nationwide on-road mobile source NOx inventory – shares by vehicle type, not including motorcycles and scooters (note: results not yet verified by MEP).

Not including motorcycles and scooters, Table 5.1 shows percentage share of vehicle quantity and NOx emissions for major vehicle types in China (data from

Figures 5.2 and 5.5):

Vehicle Type	Vehicle Quantity Percentage Share	NOx Emissions Percentage Share
Taxis	3%	6%
Passenger Cars	56%	8%
Public Buses	1%	5%
Other Buses	5%	27%
Light and Medium Commercial Vehicles	13%	3%
Heavy-Duty Trucks	9%	42%
3 and 4-wheelers	13%	9%

Table 5.1: China 2007 vehicle quantity and NOx emission shares by vehicle type, not including motorcycles and scooters (note: results not yet verified by MEP).

Table 5.1 shows that passenger cars comprise well over 50% of the vehicle fleet, although contribute only about 8% of total NOx emissions. On the other hand, heavy-duty trucks, which comprise only 9% of the vehicle fleet, emit over 40% of the nationwide NOx. Buses also emit a disproportionately high amount of NOx as compared with vehicle share.

There are two primary reasons for these discrepancies. The first is that while the vast majority (~96%) of passenger cars in China are gasoline-fueled, heavy-duty trucks are majority diesel-fueled (86%), and 3 and 4-wheelers are entirely diesel-fueled. Diesel-fueled vehicles traditionally have much higher NOx emissions than gasoline vehicles. Indeed, as Figure 5.5 shows, the NOx share from diesel vehicles is disproportionately high compared with that of gasoline vehicles:

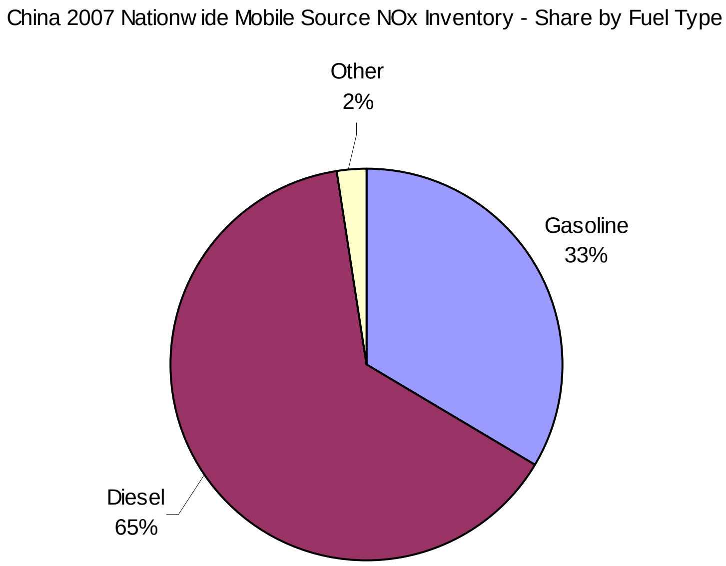

Figure 5.5: China 2007 nationwide on-road mobile source NOx inventory – shares by fuel types (note: results not yet verified by MEP).

The second reason that heavy-duty trucks and buses contribute greater NOx emissions is simply because these vehicles have much higher average annual Vehicle Miles Traveled (VMT) as compared with passenger cars, as indicated previously in Table 4.1. Comparing heavy-duty trucks and passenger cars specifically, trucks travel on average over four times farther per year than passenger cars (105,000 km per year as compared with 25,000 km per year, respectively).

6. Conclusions

The recent, rapid growth of China's vehicle population carries significant challenges for limiting the energy and environmental impacts of the transportation sector. China's efforts to develop a first-ever mobile source emissions inventory represent a critical step towards effective vehicle emissions management and control. When completed in summer 2009, the results of this inventory – coupled with the results from the inventories of other sectors – will become a foundation for the formulation of effective, scientific, targeted national and regional air quality management policies.

7. Sources

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