Characteristics of Vehicle Emissions in China Based on Portable Emission Measurement System

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ABSTRAT

Forty light-duty gasoline vehicles (LDGVs), ninety two diesel trucks (DTs), and twenty rural vehicles (RVs) were measured in Beijing, Xi'an, and Shenzhen in China using a portable emissions measurement system (PEMS). We obtained gaseous emission factors (EFs) for LDGVs of different emission control technologies (including Euro 0, Euro I, Euro II, Euro III and Euro IV), and EFs of fine particular matter ($PM_{2.5}$) and gaseous pollutants for diesel trucks of different emission control technologies (including Euro 0, Euro I, Euro II, and Euro III) under many real-world driving conditions. The results show that LDGVs with more advanced technologies have lower CO, HC and NOx EFs. Compared to the Euro 0 LDGVs, Euro IV LDGVs can reduce CO, HC and NOx emissions by more than 90%. The $PM_{2.5}$ emissions of Euro III DTs are reduced by more than 80% compared to Euro I DTs, but no significant reduction in NOx EF is observed between Euro III and Euro I diesel trucks. RVs' emissions could be significant because of their high population and poor emission control technologies, so more attention should be paid to control their emissions.

INTRODUCTION

In China, motor vehicles have become one of the most important sources of air pollution, especially for large cities, such as Beijing, Shanghai, and Guangzhou. In these cities, emissions of carbon monoxide (CO) and oxides of nitrogen (NOx) from vehicles accounted for over 80% and 40% of total urban pollutant emissions, respectively [1,2]. So, understanding the emissions characteristics and evaluating the emissions levels of vehicles in China are very necessary and important.

During last decades, the vehicle pollution issue has been paid much attention in China. In order to control vehicular emissions, the Chinese government has adopted many vehicle emission control strategies and policies since the mid-1990s, including adopting a series of European emission standards for new light-duty vehicles (LDVs) and new heavy-duty vehicles (HDVs), enhancing the annual inspection and maintenance (I/M) program, improving fuel quality, scrapping high-emitting vehicles, etc [3]. As for now, the third phase of European vehicle emission standard (Euro III) is implemented nationwide. In Beijing, shanghai and the Pearl Delta area, the Euro IV emission standard has been already in place. Thus, a question is raised: how are the effects of these measures? In order to answer this question, it is important to understand the emission characteristics of vehicles under actual running conditions.

In general, the methods to quantify the vehicle emission factors include chassis dynamometer testing, tunnel study, remote sensing and on-road emission testing. In recent years, with the development of the technology for portable emission measure system (PEMS), more and more researchers adopted on-road emission testing by using a PEMS to reflect the real situation of vehicle emissions [4-6]. In China, some studies on real-world vehicle emissions using PEMS have been conducted [7-11]. However, most of these studies focused on light-duty gasoline vehicles only, and few measured diesel vehicles. In addition, there are no studies reported on rural vehicles (RVs)' on-road emissions, even though RVs' emissions could be significant because of their high population and poor emission control technologies [12]. So, more work on understanding vehicle emissions is needed to support the overall strategy of vehicle emission control in China.

The main purpose of this paper is to examine the real-world emission levels of vehicles of various technologies using a PEMS, and based on which to develop a vehicle emission data set for China. In this work, 40 light-duty gasoline vehicles (LDGVs) (including Euro 0, Euro I, Euro II, Euro III and Euro IV), 92 diesel trucks (DTs) (including Euro 0, Euro I, Euro II, and Euro III), and 20 rural vehicles (RVs) (10 three-wheelers and 10 four-wheelers) were measured.

MATERIALS AND METHODS

Testing Equipment

In this work, a combined PEMS (named SEMTECH&DMM) was employed to test vehicle emission factors. This system has two major parts, a SEMTECH-DS unit and a DMM230 unit. Also, this system has a generator to provide power, an air compressor to provide dilution air, and a computer to record the test data.

The SEMTECH-DS was manufactured by the Sensors Inc, and it can measure speed, exhaust gas flow, and the mass emissions of CO, CO_2, HC and NOx from the tested vehicle on one-sec time resolution. The DMM-230 was made by the Dekati Ltd., and it was used to measure the fine particle mass concentrations on a second-by-second basis. This unit uses a particle charging system and a six-stage impactor to determine the particle mass. The particle size measured by DMM ranges from 0 to 1.2 microns. The DMM has proved to be an adequate instrument for measuring the mass concentration of engine exhaust, with results comparable to those from the standard gravimetric filter method [13]. More information on the testing equipment is available in our previous studies [14,15].

For gasoline vehicles, we only used the SEMTECH-DS unit to measure gaseous pollutants from vehicles.

On-road Measurement

The experiments were conducted in Beijing, Xi'an and Shenzhen. In total, 40 LDGVs, 92 DTs, and 20 RVs were tested. The on-road emission factors and driving parameters such as speed and acceleration of the vehicles were collected by using the PEMS. The measured vehicles cover various technologies, as shown in Table 1.

For each type of vehicles, typical test routes were selected according to the use features of the tested vehicle type in the three cities. The test routes need to include different kinds of roads (such as freeways, arterials, residential roads) so vehicle emissions under different driving cycles could be measured and obtained. Take LDGVs in Beijing as an example, the total length of the test routes is about 21.4 km, including 4.8km freeways, 14.6 km arterial roads, and 2.0 km residential roads, which can basically reflect the driving situations of light-duty vehicles in Beijing (see Figure 1). More information about route selection can be found in our previous studies [14,15].

Table 1. Number of the measured vehicles by type in the three cities.

	Beijing	Xi'an	Shenzhen
LDGVs	20 (1 Euro 0, 8 Euro II, 6 Euro III and 5 Euro IV vehicles)	-	20 (1 Euro 0, 5 Euro I, 11 Euro II and 3 Euro III vehicles)
DTs			
Light-duty		29 (1 Euro 0, 5 Euro I, 20 Euro II and 3 Euro III vehicles)	-
Medium-duty	28 (10 Euro I, 11 Euro II and 7 Euro III)	9 (6 Euro I and 3 Euro II vehicles)	-
Heavy-duty	26 (6 Euro I, 5 Euro II and 15 Euro III)		-
RVs			
3-wheelers(3-w)	10	-	-
4-wheelers(4-w)	10	-	-

Figure 1. Test routes of LDGVs in Beijing.

RESULTS AND DISCUSSING

Light-duty Gasoline vehicles

Figure 2 presents the mean values and standard deviation of emission factors (EFs) for the tested vehicles. Obviously, the CO, HC and NOx EFs of Euro 0 LDGVs are the highest. The EFs decrease significantly as the emission control technology improves.

Figure 2. Kilometer traveled-based EFs of LDGVs with different emission control technologies (the error bars represent the standard deviation).

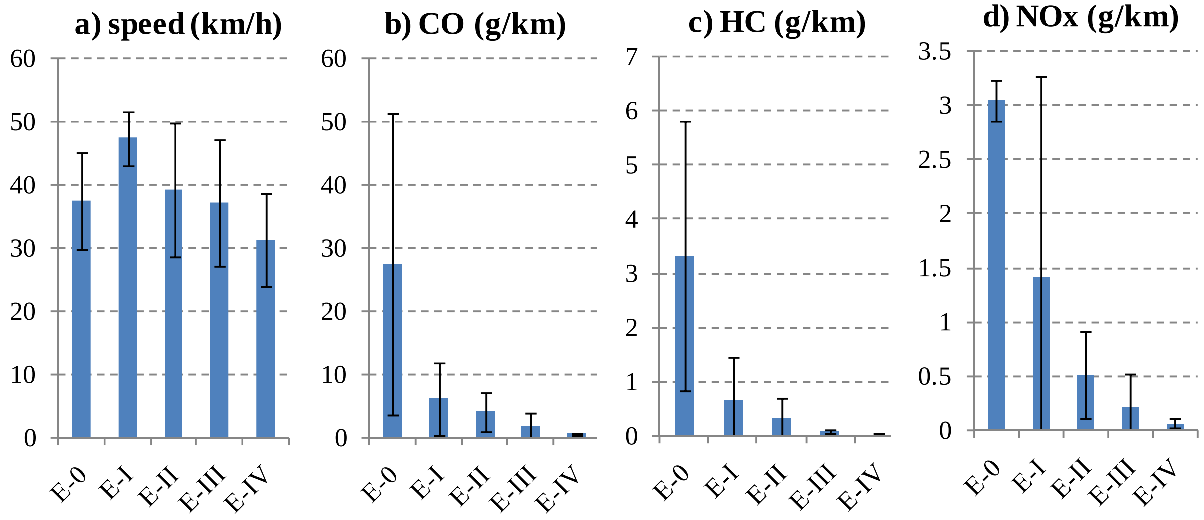
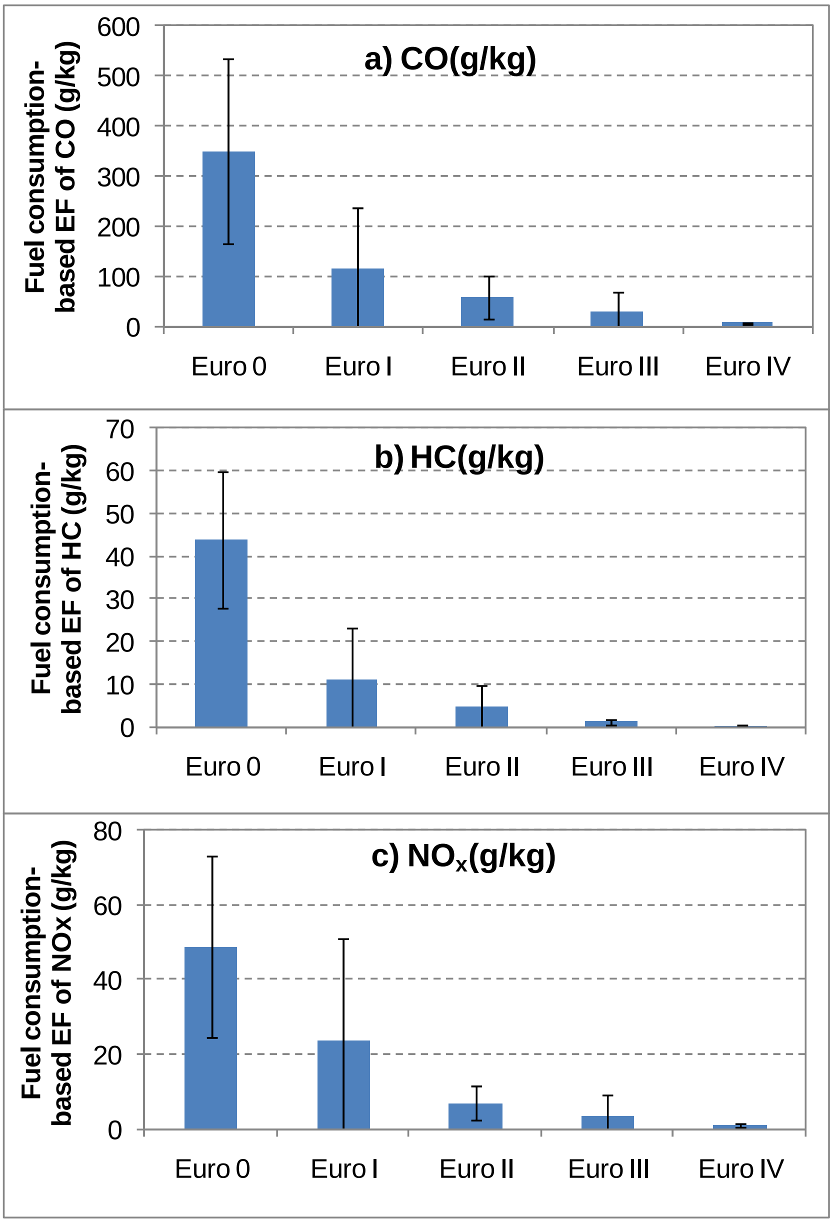


Figure 3. Fuel consumption-based EFs of LDGVs with different emission control technologies (the error bars represent the standard deviation).



We converted the kilometer traveled-based emission factors to fuel consumption-based emission factors to lower the influence of driving cycles on emission factors, as plotted in figure 3. From Figure 3, the fuel consumption-based EFs of CO, HC and NOx of Euro 0 LDGVs are 350.3±184.1 g/kg, 43.9±16.0 g/kg, and 48.9±24.5 g/kg respectively. LDGVs with Euro I, Euro II, Euro III and Euro IV technologies can achieve a reduction in CO emissions by 67%, 83%, 91% and 98% respectively compared to Euro 0 LDGVs, 75%, 90%, 97% and 99% reduction in HC emissions, respectively, and 52%, 85%, 93% and 98% reduction in NOx emissions, respectively. Therefore, the enforcement of the vehicle emission standard for light-duty vehicle has played a very important role on vehicle emission reduction. As the Euro 0 vehicles (called yellow-labeled vehicles in China), are gradually scrapped the benefit of emission reduction will become more significant.

Diesel Trucks

Light-duty diesel trucks (LDDTs)

Figures 4 and 5 demonstrate the kilometer traveled-based and fuel consumption-based EFs of the light-duty diesel trucks (LDDTs) tested. Figure 4 shows that the driving cycles of the tested vehicles are very similar, and the average speed are between 32 km/h and 36km/h. The kilometer traveled-based CO, HC, NOx and $PM_{2.5}$ EFs of Euro 0 LDDTs are 11.95, 1.75, 2.36 and 0.62 g/km, respectively. The CO, HC and $PM_{2.5}$ emission factors decease gradually as the emission control technology improves. Compared to Euro 0 LDDTs, the emission factors of CO, HC and $PM_{2.5}$ for Euro III LDDTs are lower by 85.8%, 30.8%, 93.5%. As shown in Figure 4, the effect of the vehicle emission standard on PM emissions from LDDTs is very significant, but the NOx EFs of LDDTs are observed to increase as the emission control technology improves.

Figure 5 shows the similar variation trend in emissions of different technologies as Figure 4, the fuel consumption-based EFs of CO, HC and $PM_{2.5}$ also deceased gradually as the emission control technology improves, but the NOx EFs show a reverse trend.

Figure 4. Kilometer traveled-based EFs of LDDTs with different emission control technology: E-0, Euro 0 vehicles; E-I, Euro I vehicles; E-II, Euro II vehicles; E-III, Euro III vehicles (the error bars represent standard deviation).

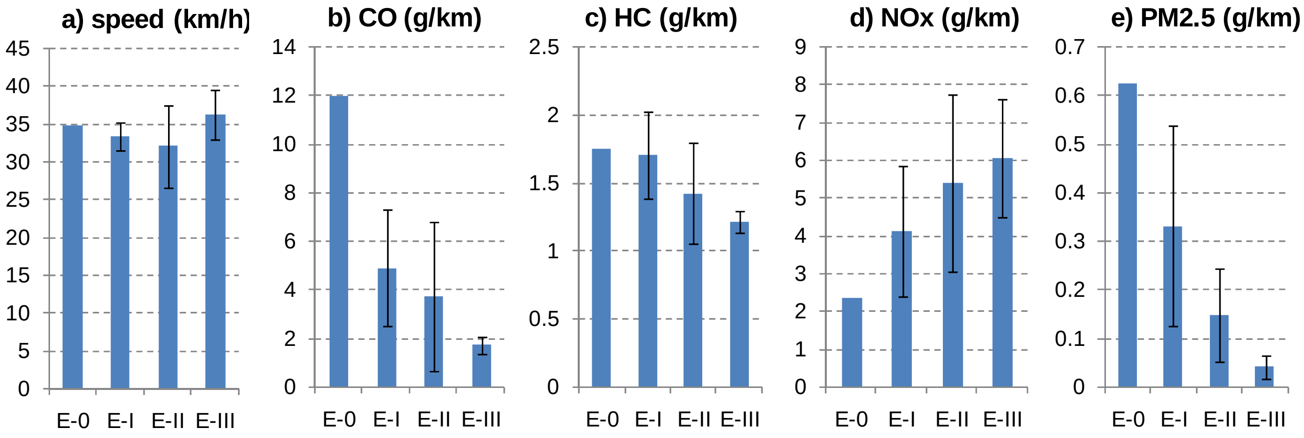
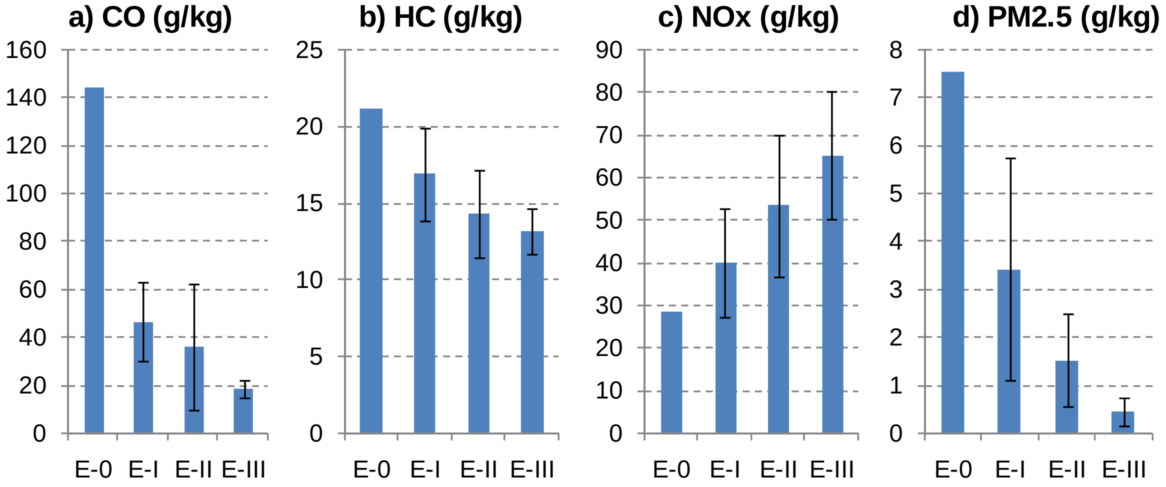


Figure 5. Fuel consumption-based EFs of LDDTs with different emission control technology: E-0, Euro 0 vehicle; E-I, Euro I vehicles; E-II, Euro II vehicles; E-III, Euro III vehicles (the error bars represent the standard deviation).



Medium-duty diesel trucks (MDDTs)

Figures 6 & 7 provide the on-road kilometer traveled-based and fuel consumption-based EFs of MDDTs, respectively. The average speed of the tested vehicles with Euro I, Euro II and Euro III is about 36.0, 36.8 and 37.0 km/h. The kilometer traveled-based EFs of CO, HC, NOx and $PM_{2.5}$ for Euro I MDDTs are 3.58±3.23, 1.44±0.62, 5.50±1.82 and 0.21±0.13 g/km, respectively. As shown in Figure 6, the implementation of the vehicle emission standards has a very significant effect on the reduction in CO, HC and $PM_{2.5}$ emissions, especially for the enforcement of the Euro III standard. The CO, HC and $PM_{2.5}$ EFs of Euro III MDDTs are 53.3%, 66.3% and 82.1% lower than that for Euro I MDDTs, respectively. However, there is no significant reduction in NOx emissions for advancer vehicle technologies. For instance, Euro III MDDTs only reduce NOx emissions by 3.4% compared to Euro I MDDTs.

Figure 7 indicates that the fuel consumption-based CO, HC, NOx and $PM_{2.5}$ EFs of Euro I MDDTs are 30.54±28.14, 12.09±5.44, 45.85±15.47 and 1.79±1.03 g/kg, respectively. Generally, the EFs of the four pollutants of MDDTs decreased as the emission control technology improves. For example, the CO, HC, NOx and $PM_{2.5}$ EFs of Euro III MDDTs decrease by 58.6%, 68.7%, 11.0% and 81.8% compared to their Euro I counterparts. Noted that the magnitude of the reduction in the NOx EF is the smallest as the vehicle emission control technology improves from Euro I to Euro III.

Figure 6. Kilometer traveled-based EFs of MDDTs with different emission control technologies: E-I, Euro I vehicles; E-II, Euro II vehicles; E-III, Euro III vehicles (the error bars represent the standard deviation).

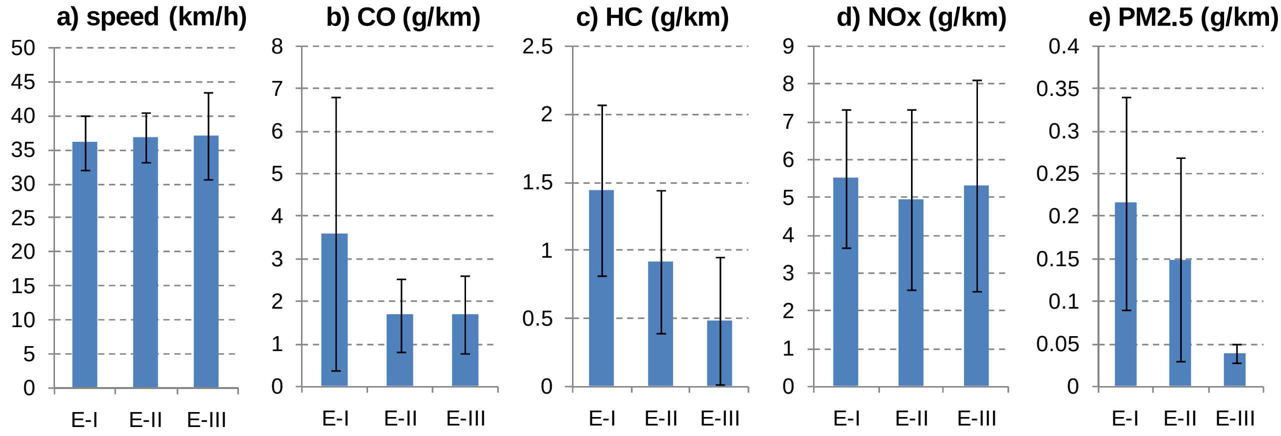
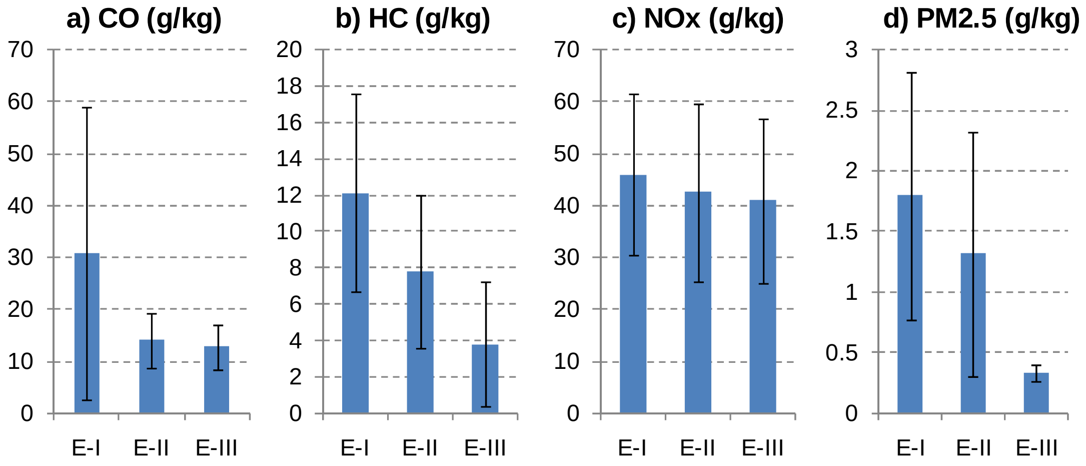


Figure 7. Fuel consumption-based EFs of MDDTs with different emission control technology: E-I, Euro I vehicles; E-II, Euro II vehicles; E-III, Euro III vehicles (the error bars represent the standard deviation).



Heavy-duty diesel trucks (HDDTs)

Figures 8 & 9 presents the kilometer traveled-based and fuel consumption-based EFs of HDDTs. As shown in Figure 8, the kilometer traveled-based EFs of CO, HC, NOx and $PM_{2.5}$ of Euro I HDDTs are 4.52±2.56, 0.68±0.19, 6.32±1.58 and 0.58±0.34 g/km, respectively. The average speed of the tested Euro I, Euro II, and Euro III HDDTs is 33.8±7.96, 33.9±2.02 and 39.4±5.40 km/h. The CO, HC and $PM_{2.5}$ EFs decrease as a result of better emission control technologies employed. The EFs of CO, HC, and $PM_{2.5}$ of Euro III HDDTs decreased by 63.7%, 64.5%, and 86.3% compared to those of Euro I HDDTs, but the NOx EF increases by 9.5%.

As Figure 9 shows, the kilometer traveled-based EFs of CO, HC, NOx and $PM_{2.5}$ of Euro I HDDTs are 28.08±13.21, 4.45±1.45, 40.90±11.42 and 3.59±1.54 g/kg, respectively. The variation trend of the fuel consumption-based EFs of HDDTs with respect to the improvement in the emission control technology is similar to that of the kilometer traveled-based EFs. The fuel consumption-based EFs of CO, HC, and $PM_{2.5}$ of Euro III HDDTs decreased by 61.4%, 63.2%, and 85.2% respectively compared to those of Euro I HDDTs. An increase in NOx emissions (12.6%) is also observed as the vehicle technology improves from Euro I to Euro III.

Figure 8. Kilometer traveled-based EFs of HDDTs with different emission control technologies: E-I, Euro I vehicles; E-II, Euro II vehicles; E-III, Euro III vehicles (the error bars represent the standard deviation).

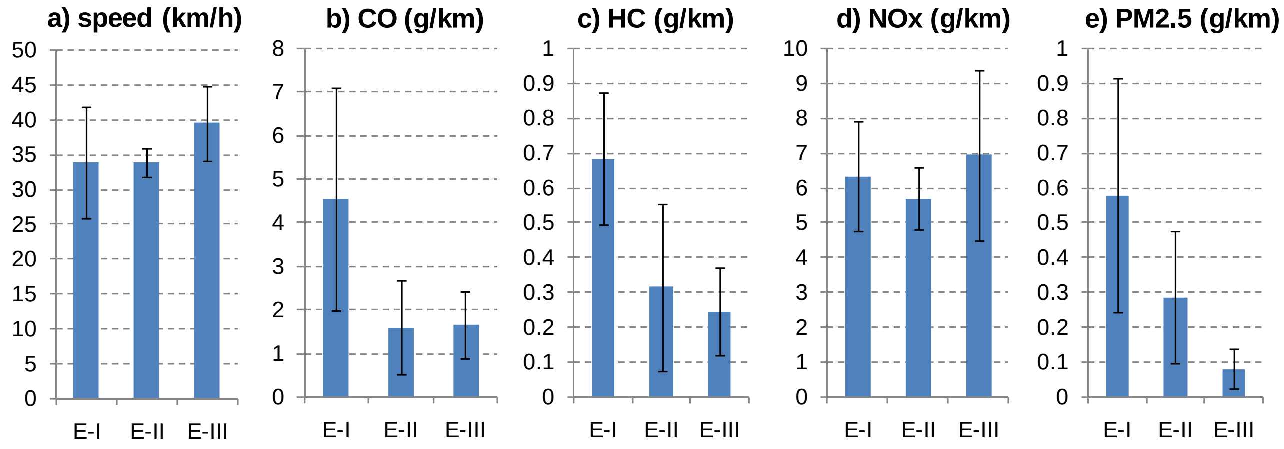
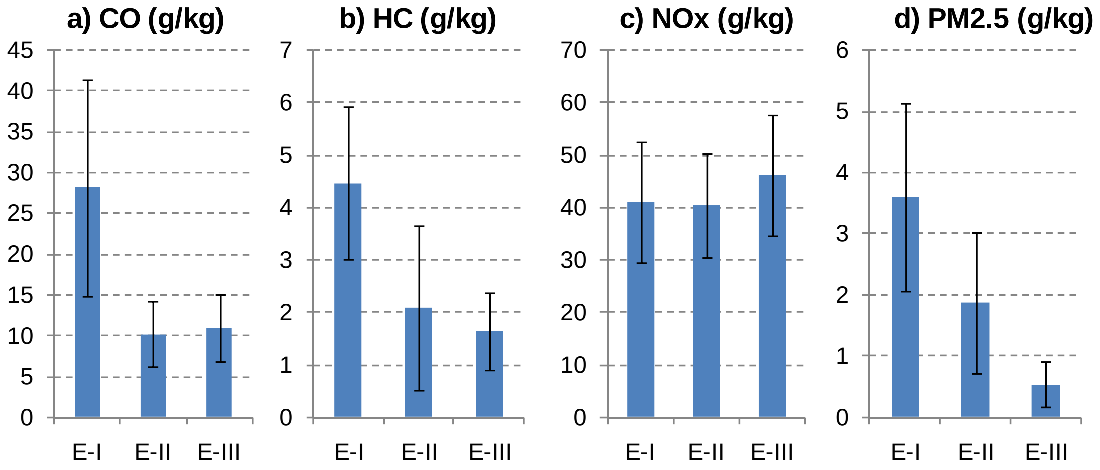


Figure 9. Fuel consumption-based EFs of HDDTs with different emission control technologies: E-I, Euro I vehicles; E-II, Euro II vehicles; E-III, Euro III vehicles (the error bars represent the standard deviation).



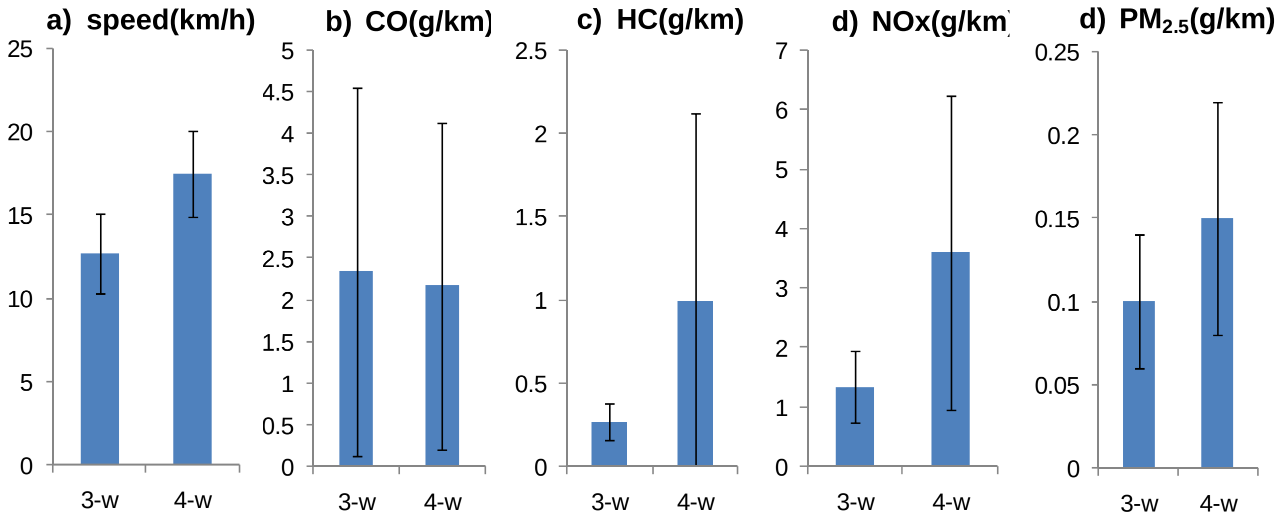
In sum, on the basis of the test results of the diesel trucks, we can conclude that there is a significant reduction in the CO, HC and $PM_{2.5}$ EFs for Euro III diesel trucks compared to Euro I trucks. However, there is no significant reduction observed in the NOx EF as the vehicle emission control technology improves. One of the reasons might be the fact that at present in China the improvement of emission control technology primarily focuses on engines, and there is no after-treatment system such as SCR(selective catalytic reduction) and DPF(diesel particulate filter) until Euro IV emission technology. The improvement can reduce the emissions of CO, HC and $PM_{2.5}$ through the fuel consumption controlling system and other sections, which, however, probably result in higher NOx emissions because of the better conditions for fuel combustion.

It should be noted that our finding about the NOx emissions is not consistent with the national vehicle emission standards of new diesel vehicles. The qualified value of the NOx EF requested by the Euro III emission standard is much lower than that of the Euro I emission standard (same as the CO, HC and $PM_{2.5}$ EFs). However, the NOx emissions doesn't decrease as expected in real operation, which indicates that the existing emission testing procedure of the emission standard may have limitation that makes the standard fail to restrict the real NOx emissions; on the other hand, previous studies on vehicle emissions inventory incline to assume a decreasing trend in NOx emissions factors as request by the emission standards, however, significant misestimation could have been caused because the real on-road NOx emissions of trucks could be totally different from the requirements of the emission standards.

Rural Vehicles

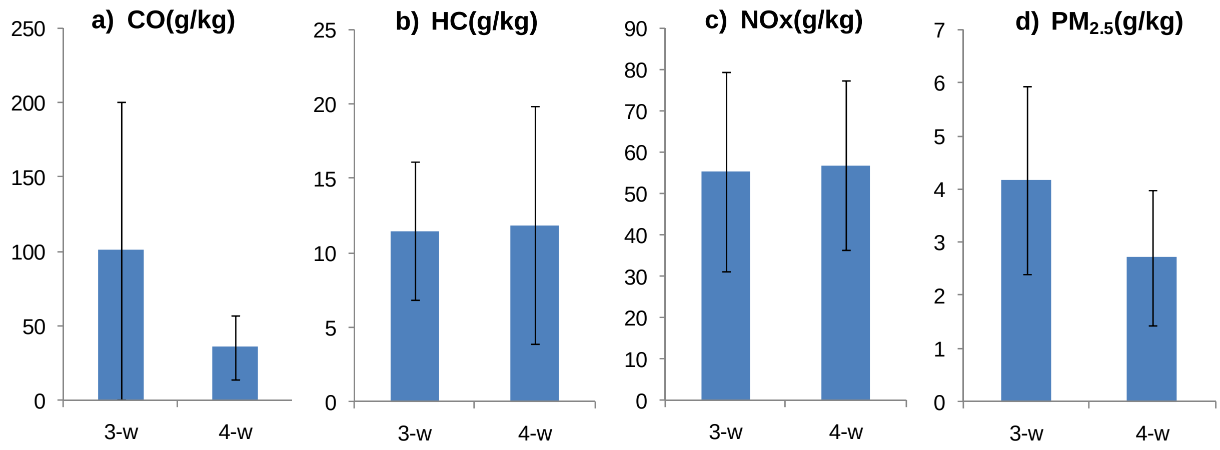
Figure 10 presents the mean values and standard deviations of the actual emission factors of the 3-w and 4-w RVs tested. The on-road CO, HC, NOx and $PM_{2.5}$ EFs of 3-w RVs are 2.34±2.20, 0.27±0.11, 1.34±0.60 and 0.10±0.04 g/km, respectively, and 2.17±1.96, 0.99±1.13, 3.60±2.64 and 0.15±0.07 g/km for 4-w RVs. Generally, the EFs of 4-w RVs are higher than those of 3-w RVs.

Figure 10. Kilometer travel-based EFs of RVs (the error bars represents the standard deviation).



The fuel consumption-based emission factors were calculated, as shown in Figure 11. The g/kg EFs of 3-w RVs are 101±99 g CO/kg, 11.5±4.6 g HC/kg, 55.3±24.0 g NOx/kg, and 4.2±1.8 g $PM_{2.5}$/kg respectively, and the EFs of 4-w RV were 35.8±21.7 g CO/kg, 11.9±8.0 g HC/kg, 56.8±20.5 g NOx/kg, and 2.7±1.3g $PM_{2.5}$/kg respectively.

Figure 11. Fuel consumption-based EFs of RVs (the error bars represents the standard deviation).



To reflect the emission levels of RVs in China, we compared the EFs of RVs and Euro LDDTs, because the Euro II technology is the most popular vehicle type in China. RVs have the similar NOx g/kg-emission factor as to LDDTs, a reason of which could be their lower speed. RVs have lower HC emission factors compared to LDDTs, which might be because of the fact that RV drivers are less aggressive than truck drivers. Nevertheless, RVs have higher CO and $PM_{2.5}$ g/kg-emission factors than do LDDTs. In sum, the emission conditions of RV are poorer than those of LDDTs. Considering the huge population of RV in China (about 22 millions), the emissions emitted from RV might be very significant. According to our previous study [15], RVs contributed 3.4% CO, 3.7 % HC, 17.8% NOx, and 11.0% $PM_{2.5}$ to the total vehicle emissions in 2005. Therefore, the emissions from RVs should be paid more attention.

CONCLUSIONS

The Chinese government has implemented a series of emission control measures for light-duty gasoline vehicles. According to the results from this study, the effects of these measures are very significant. In-use vehicles with more advanced emission control technologies have much lower emission factors than the ones with old technologies. Compared to Euro 0 LDGVs, Euro IV LDGVs can reduce CO, HC and NOx emissions by more than 90%. Therefore, China should promote more stringent emission standards, and at the same time accelerate the scrappage of the vehicles with Euro 0 technology.

For diesel trucks, the effects of emission limitation standard on $PM_{2.5}$ are very significant. The $PM_{2.5}$ emission factors of Euro III diesel vehicles is more than 80% lower than those of Euro I diesel vehicles. But little reduction benefit for NOx EF is observed, especially for light- and heavy-duty diesel trucks. So, the NOx emissions need to be carefully estimated when people develop a vehicle emission inventory in China. In addition, the current emission testing procedure in the national vehicle emission regulations needs to be re-evaluated. Maybe PEMS should be added into the new emission regulations.

RVs' EFs are comparable to those of Euro II LDDTs. RVs could be potentially important because of their high population and poor emission control technologies, and more attention should be paid to control their emissions. The current weak management of RVs could be an obstruction to any regulations or policies associated with RVs. Therefore, it is important for the government to reinforce the management of RVs, which will also be beneficial to the future studies on RVs also. The results of this study could be a very important foundational dataset to refine the current regional and global emission inventories of NOx and PM emissions.

It’s a very long way to quantify the vehicle emission factors and develop reliable vehicle emission inventories in China. This study is a start. Further work on vehicular emissions in China needs to be done. The data and results obtained in this study could be a very important basis for developing a Chinese vehicle emission model and vehicle emission inventories, and they could also be helpful to the implementation of vehicle emission control policies in China.

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KEY WORDS

Gasoline Vehicles
Diesel Vehicles
Rural Vehicles
Emission Factors
PEMS

ACKNOWLEDGEMENTS

We thank the supports of National 973 Program (No. 2005CB422201), National 863 Program (No. 2006AA06A305), and National 863 Program (No. 2006AA06A309).