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# Evaluation of emission factors for light-duty gasoline vehicles based on chassis dynamometer and tunnel studies in Shanghai, China

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## HIGHLIGHTS

- 51 in-use LDGVs were tested using a chassis dynamometer in Shanghai, China.
- Continuous monitoring in a gasoline vehicle dominated tunnel were conducted in Shanghai, China.
- Emission factors of LDGVs were determined based on dynamometer test and tunnel experiment.
- High-emitting vehicles contributed the majorities of emissions from older vehicles in Shanghai, China.
- Emission factors of LDGVs were underestimated due to the overlook of high-emitting vehicles in the previous studies in China.

## ARTICLE INFO

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## ABSTRACT

CO, THC, $NO_x$, and PM emission factors of 51 light-duty gasoline vehicles (LDGVs) spanning the emission standards from Euro 2 to Euro 5 were measured by a chassis dynamometer. High frequencies of high-emitting vehicles were observed in Euro 2 and Euro 3 LDGV fleet. 56% and 33% of high-emitting vehicles contributed 81%–92% and 82%–85% of the emissions in Euro 2 and Euro 3 test fleet, respectively. Malfunctions of catalytic convertors after high strength use are the main cause of the high emissions. Continuous monitoring of a gasoline vehicle dominated tunnel in Shanghai, China was conducted to evaluate the average emission factors of vehicles in real-world. The results indicated that the emission factors of LDGVs were considerably underestimated in EI guidebook in China. The overlook of high-emitting vehicles in older vehicle fleet is the main reason for this underestimation. Enhancing the supervision of high emission vehicles and strengthening the compliance tests of in-use vehicles are essential measures to control the emissions of in-use gasoline vehicles at the present stage in China.


## 1. Introduction

Vehicle emission has been an important source of air pollution. Their $NO_x$, VOCs and primary PM emissions have been recognized the key precursors of $PM_{2.5}$ and ozone pollution in the regions of China (Zhang et al., 2015a; Cheng et al., 2016; Sun et al., 2016; Li et al., 2016a; Shao et al., 2016). Light-duty gasoline vehicles (LDGVs) dominate the total motor vehicle fleet in China. The statistic data show that the population of motor vehicle in China reached 172 million in 2015, of which LDGVs were 140 million, accounting for 86.2% of the total. Correspondingly, their CO, HC and $NO_x$ emissions occupied 83.7%, 71.5%, and 26.7% of the total vehicle emissions, respectively (MEP, 2016). Their primary PM emissions also cannot be ignored according to recent studies (Huang et al., 2013). Furthermore, the SOA productions of gasoline exhaust even exceeded their primary emissions according to the smog experiment studies (Platt et al., 2013; Gordon et al., 2014; Presto et al., 2014; Huang et al., 2015; Liu et al., 2015a). LDGVs are now experiencing rapid growth in China, which has increased by 1.2 times in the last 5 years. It will be very important to accurately

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**Table 1**
Specifications and emission factors of test vehicles in this study.

| No. | Manufacturers | Model year | Odometer (km) | Emission standard | CO (g/km) | THC (g/km) | $NO_x$ (g/km) | PM (mg/km) | Fuel Con. (L·100 $km^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Volkswagen | 2000 | 254,606 | Euro 2 | 2.73 | 0.456 | 0.860 | 1.35 | 6.91 |
| 2 | Volkswagen | 2003 | 176,427 | Euro 2 | 0.25 | 0.081 | 0.060 | 1.85 | 6.40 |
| 3 | Buick | 2003 | 139,898 | Euro 2 | 7.38 | 1.212 | 1.619 | 2.30 | 9.15 |
| 4 | Chery | 2004 | 216,261 | Euro 2 | 5.90 | 1.127 | 2.256 | 94.5 | 6.93 |
| 5 | Volkswagen | 2004 | 165,337 | Euro 2 | 1.75 | 0.235 | 0.623 | 4.96 | 7.96 |
| 6 | Buick | 2004 | 130,963 | Euro 2 | 32.7 | 2.345 | 2.096 | 516 | 14.3 |
| 7 | Buick | 2004 | 102,923 | Euro 2 | 5.87 | 1.087 | 1.300 | 13.6 | 6.74 |
| 8 | Zhonghua | 2007 | 118,153 | Euro 2 | 1.98 | 0.106 | 0.173 | 0.81 | 8.12 |
| 9 | Volkswagen | 2007 | 109,440 | Euro 2 | 21.8 | 2.818 | 0.181 | 49.7 | 8.48 |
| 10 | Nissan | 2006 | 314,110 | Euro 3 | 6.87 | 0.705 | 2.159 | 61.1 | 9.64 |
| 11 | Buick | 2006 | 229,187 | Euro 3 | 0.02 | 0.006 | 0.373 | 3.55 | 10.4 |
| 12 | Hyundai | 2007 | 182,649 | Euro 3 | 10.6 | 1.536 | 2.485 | 123 | 8.87 |
| 13 | Peugeot | 2007 | 161,637 | Euro 3 | 1.87 | 0.221 | 0.101 | 20.6 | 6.57 |
| 14 | Santana | 2007 | 146,916 | Euro 3 | 0.57 | 0.055 | 0.119 | 4.34 | 7.99 |
| 15 | Peugeot | 2007 | 98,389 | Euro 3 | 1.23 | 0.038 | 0.048 | 0.11 | 8.19 |
| 16 | Volkswagen | 2008 | 354,988 | Euro 3 | 1.74 | 0.092 | 0.078 | 0.65 | 8.88 |
| 17 | Audi | 2008 | 248,132 | Euro 3 | 0.34 | 0.041 | 0.039 | 12.7 | 9.41 |
| 18 | Peugeot | 2008 | 117,422 | Euro 3 | 0.26 | 0.022 | 0.447 | 2.28 | 7.34 |
| 19 | Hongxing | 2009 | 84,685 | Euro 3 | 1.65 | 0.025 | 0.688 | 36.8 | 5.35 |
| 20 | BYD | 2009 | 54,201 | Euro 3 | 0.44 | 0.055 | 0.054 | 4.82 | 6.40 |
| 21 | BYD | 2010 | 227,715 | Euro 3 | 14.2 | 0.784 | 0.530 | 28.1 | 7.26 |
| 22 | Chevrolet | 2008 | 139,692 | Euro 4 | 1.77 | 0.121 | 0.087 | 3.53 | 6.57 |
| 23 | Volkswagen | 2008 | 119,755 | Euro 4 | 0.03 | 0.000 | 0.042 | 0.66 | 7.62 |
| 24 | Chevrolet | 2008 | 65,261 | Euro 4 | 0.70 | 0.025 | 0.070 | 2.48 | 6.33 |
| 25 | Mazda | 2009 | 193,880 | Euro 4 | 0.42 | 0.013 | 0.034 | 2.76 | 7.83 |
| 26 | Nissan | 2009 | 99,096 | Euro 4 | 0.39 | 0.039 | 0.021 | 5.42 | 9.83 |
| 27 | Skoda | 2009 | 83,145 | Euro 4 | 0.37 | 0.043 | 0.008 | 11.2 | 6.83 |
| 28 | Buick | 2009 | 67,382 | Euro 4 | 0.74 | 0.001 | 0.086 | 0.26 | 7.47 |
| 29 | Toyota | 2010 | 209,169 | Euro 4 | 1.34 | 0.097 | 0.181 | 3.14 | 9.27 |
| 30 | Chevrolet | 2010 | 147,359 | Euro 4 | 1.30 | 0.081 | 0.083 | 2.81 | 8.22 |
| 31 | Passat | 2011 | 153,529 | Euro 4 | 4.78 | 0.075 | 0.108 | 0.01 | 8.72 |
| 32 | Chery | 2011 | 126,838 | Euro 4 | 1.23 | 0.028 | 0.088 | 1.20 | 7.20 |
| 33 | Toyota | 2011 | 62,323 | Euro 4 | 0.07 | 0.002 | 0.004 | 9.97 | 5.94 |
| 34 | Passat | 2011 | 60,159 | Euro 4 | 0.99 | 0.048 | 0.025 | 2.72 | 7.88 |
| 35 | Chery | 2011 | 31,774 | Euro 4 | 0.04 | 0.008 | 0.018 | 1.30 | 6.45 |
| 36 | Chevrolet | 2012 | 48,741 | Euro 4 | 0.41 | 0.040 | 0.024 | 8.87 | 7.15 |
| 37 | Mazda | 2012 | 26,526 | Euro 4 | 0.74 | 0.001 | 0.086 | 3.84 | 7.83 |
| 38 | Hyundai | 2013 | 145,999 | Euro 4 | 0.59 | 0.056 | 0.040 | 15.7 | 6.24 |
| 39 | Chery | 2013 | 81,460 | Euro 4 | 0.93 | 0.045 | 0.143 | 1.87 | 6.82 |
| 40 | Audi | 2013 | 78,018 | Euro 4 | 0.74 | 0.119 | 0.070 | 28.8 | 7.82 |
| 41 | Volkswagen | 2013 | 16,779 | Euro 4 | 1.04 | 0.074 | 0.064 | 9.03 | 6.95 |
| 42 | Buick | 2012 | 36,902 | Euro 5 | 0.17 | 0.036 | 0.012 | 3.35 | 8.12 |
| 43 | Soueast | 2014 | 57,840 | Euro 5 | 0.08 | 0.012 | 0.016 | 0.65 | 5.57 |
| 44 | Buick | 2014 | 46201 | Euro 5 | 1.38 | 0.038 | 0.036 | 27.3 | 10.2 |
| 45 | Buick | 2014 | 45,820 | Euro 5 | 1.99 | 0.025 | 0.006 | 7.39 | 8.73 |
| 46 | Audi | 2016 | 75,021 | Euro 5 | 0.26 | 0.049 | 0.039 | 31.3 | 8.32 |
| 47 | Buick | 2016 | 51,151 | Euro 5 | 1.69 | 0.052 | 0.024 | 0.86 | 6.91 |
| 48 | Hyundai | 2016 | 13,596 | Euro 5 | 0.85 | 0.054 | 0.029 | 8.19 | 6.72 |
| 49 | Hyundai | 2016 | 10,276 | Euro 5 | 0.69 | 0.026 | 0.012 | 8.18 | 6.75 |
| 50 | Honda | 2016 | 7,857 | Euro 5 | 0.90 | 0.044 | 0.006 | 11.9 | 7.89 |
| 51 | Kia | 2016 | 5,109 | Euro 5 | 0.69 | 0.028 | 0.018 | 2.18 | 6.22 |

quantify their emissions.

Accurate vehicle emission factors are essential to recognize their contribution to air pollution. Vehicle emission models, such as MOVES, COPERT, EMFAC, and IVE, have been widely used to develop vehicle emission inventory in previous studies (Wang et al., 2008; Wallace et al., 2012; Cai and Xie, 2013; Jing et al., 2016). In China, the MEP (Ministry of Environmental Protection of People's Republic of China) released an on-road vehicle emission inventory guidebook (shorten as EI guidebook) which recommended a series of vehicular emission factors based on the local studies (MEP, 2014). However, some measurements on LDGVs demonstrated that the modeled emission factors still have some differences with the measured ones (Fujita et al., 2012; Liu and Frey, 2015). Most of the results from real world measurements by remote sensing and chasing studies indicated that high emitters caused by deterioration of emission control devices tended to be underestimated in vehicle emission inventories (Park et al., 2011; Zhou et al., 2014; Wang et al., 2015; Pujadas et al., 2017). To understand the emission factors of LDGVs, some measurement studies have been conducted in recent studies in China (Huo et al., 2012; Shen et al., 2014; Qu et al., 2015; Li et al., 2016a). However, the test samples were limited and the results still show big differences compared with the

**Table 2**
Adjustment factors of EFs under different speed ranges.

| Pollutants | Average speed (km·$h^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| CO | 2.72 | 1.36 | 1.00 | 0.84 | 0.72 | 0.56 | 0.48 | 0.41 |
| THC | 2.93 | 1.47 | 1.07 | 0.89 | 0.75 | 0.60 | 0.52 | 0.45 |
| NOx | 2.46 | 1.23 | 0.97 | 0.88 | 0.77 | 0.65 | 0.56 | 0.52 |
| PM | 2.25 | 1.13 | 1.03 | 1.02 | 0.91 | 0.66 | 0.56 | 0.45 |