Study on Gasoline Vehicle Emission Inventory Considering Regional Differences in China

Dong Guo, Zhan-gu Wang, Liang Sun, Kai Li, Juan Wang, Feng Sun, and Hai Zhang

1 School of Transportation and Vehicle Engineering, Shandong University of Technology, Zibo, Shandong 255000, China
2 Jilin University State Key Laboratory of Automotive Simulation and Control, Changchun, Jilin 130000, China

Correspondence should be addressed to Feng Sun; sunfeng0904@sina.com

Received 2 January 2018; Revised 8 June 2018; Accepted 12 August 2018; Published 2 September 2018

Copyright © 2018 Dong Guo et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Rapid growth of China’s urban road vehicles, in particular, the increase in the number of gasoline vehicles, leads to an increase in the traffic congestion and problems pertaining to air pollution. The establishment of the emission inventory of gasoline vehicles is influenced by several factors, like environmental characteristics, vehicle conditions, road conditions, and so on. In order to obtain gasoline vehicle emission inventory in accordance with the actual situation in different regions, this study proposed a method of establishing a list of gasoline vehicles with regional differences. Comprehensive consideration and evaluation of various factors that affect the vehicle emissions were carried out and the corresponding correction factors were obtained. According to the formula of comprehensive emission factor for Zibo city, the emission inventory of gasoline vehicle was established. This method can be effectively utilized to obtain the emission inventory of gasoline vehicles in different cities more accurately and provide theoretical support for control strategies of gasoline vehicle emissions.

1. Introduction

With the development of urban economy in China, pollution due to vehicle's emission has become a significant environmental problem. By the end of 2015, the gasoline vehicle population in China reached 172 million, for which the quantity of emission accounted for 65.5% of the total emission of vehicles [1]. Therefore, a strengthened control on gasoline vehicle's exhaust emission is a significant measure to improve the urban air quality. To determine more targeted energy saving and emission reduction strategies, the approach to determine a reasonable and accurate emission inventory of gasoline vehicles becomes one of the most important and challenging tasks.

A series of related studies about vehicle emission inventory is available at home and abroad. Sun et al. [2] took into account the dynamic changes of emission standards and fuel quality, and considering the differences of driving conditions for each vehicle type in urban road, suburban road, and highway, they established a high-resolution vehicle emission inventory based on COPERT model and GIS technology. Li et al. [3] selected Chang-Zhu-Tan urban agglomeration as the research region and established the vehicle emission inventory in this region. Further, they analyzed the space-time distribution characteristics and contribution rate of regional vehicle emissions. Yao et al. [4] selected 12 typical cities in China to establish the vehicle emission inventory from 1990 to 2009 and analyzed the historical evolution trend of vehicle emission in various cities. They finally identified the gasoline vehicle as the main source of the city's carbon monoxide (CO) and volatile organic compounds (VOCs) emissions and provided the results of the contribution rate of different gasoline models to specific pollutants. A high-resolution inventory of greenhouse gas (GHG) emission distribution of the road transport sector in Argentina was established based on GIS map by Pullafito et al. [5] after obtaining regional spatial distribution by DMSP satellite.

Commonly, the studies of vehicle emission inventory do not take into account the comprehensive consideration of the influence of environmental factors, vehicle situations, and
road conditions in different regions. Based on relevant studies of low-carbon urban planning in Beijing, Wang et al. [6] put forward methods for low-carbon urban planning, including preparation of current and proposed carbon emission inventories, analysis of proposed carbon emission scenarios, city low-carbon development madness, selection of strategies, and formulation of policies for low-carbon development. Guo et al. [7] evaluated the International Vehicle Emissions (IVE) model by utilizing a dataset available from the remote sensing measurements on a large number of vehicles at five different sites in Hangzhou, China, in 2004 and 2005. They contrasted the remote sensing data of three pollutants and proposed the adjustment of the basic emission factors from the local study to improve the model. Li et al. [8] investigated the emission profile of exhaust PM$_{2.5}$ of 12 light gasoline vehicles by using vehicle test bench and particle dilution sampling system and analyzed the PM$_{2.5}$ emission characteristics of light gasoline vehicle exhaust. Ni et al. [9] tested gasoline vehicle emissions and fuel consumption at different altitudes. They further studied the mechanism of gasoline vehicle emissions and fuel consumption at different altitudes through emission characteristics of CO, total hydrocarbon (THC), and nitrogen oxides (NOx) and also through changes in fuel consumption. Zhou et al. [10] explored the real-world emission status of light gasoline vehicles by using roadside remote sensing measurement and calculated the emission factors based on fuel and distance by mass balance method. Guo et al. [11-13] analyzed the relationship between light duty electronic fuel injection (EFI) gasoline vehicles emissions and useful life using the vehicle emissions test data from motor vehicle exhaust monitoring center.

In this study, the gasoline vehicle was selected as the research object and the environmental parameters, the average vehicle speed, the load coefficient, and the deterioration coefficient were adopted for correction. Furthermore, the comprehensive emission factor suitable for the regional characteristics was obtained. Finally, the gasoline vehicle’s emission inventory was computed and analyzed based on the established model.

2. Calculation Framework

2.1. Basic Emission Factors. Since 1999, China has begun to adopt the European emission standard (National Phase-I emission standard corresponding to the emission standard of Euro I), and by 2015 it has implemented the five national standards. In light of the investigation results released by the National Bureau of statistics (China Statistical Yearbook 2015), China’s vehicles that have been implementing different emission standards from National Standard I to National Standard V accounted for 2, 4, 12, 54, and 28%, respectively. Based on the national average environmental condition, vehicle condition, and road condition, and related industry standards, the basic emission factors of gasoline vehicle were obtained. Table 1 lists the basic emission factor data of various types of gasoline vehicles under different emission standards.

2.2. Model. First, the regional vehicle population and the annual average distance of various types of gasoline vehicles were obtained pursuant to the Yearbook of National Bureau of Statistics and Local Bureau of Statistics. Second, the basic emission factors of gasoline vehicle were established based on the displacement of various gasoline vehicles and related industry standards. Then the emission correction factors model of gasoline vehicle affected by regional differences were established based on the basic emission factors with a comprehensive consideration of such factual factors affecting gasoline vehicle emission as environmental conditions, vehicle type, engine running status, fuel properties, and vehicle load. Finally, emission inventory of regional gasoline vehicles was acquired by combination of emission factors, local motor vehicle population, and driving mileage of various types of vehicles. The model calculation framework is shown in Figure 1.

Vulcanization correction factors were used to reduce or eliminate the effect of sulfur content in gasoline on other polluting gases.

3. Analysis of Influencing Factors

Environmental condition and vehicle situation are the two standing-out factors influencing the gasoline vehicle exhaust. On the one hand, significant regional differences are observed in temperature, humidity, and altitude, which directly affect the engine operating conditions [14]. On the other hand, running velocity deterioration factor, fuel quality and vehicle load coefficient also have an immediate impact on its exhaust. For these reasons, the emission correction factors of gasoline vehicle considering regional differences are considered in the calculation. In this way, we not only consider regional emission condition, but also to a more realistic emission inventory.

3.1. Environmental Parameter Correction Factors. China is a country with a vast territory of around 9.6 million square kilometers. The far-flung land area and diverse geomorphological characteristics shape a huge environmental difference in different regions of China, making the hot and humid southern area in contrast with the cold and dry northern area. Based on the information released in China Climate Bulletin in 2015, the representative higher and lower values of altitude, temperature, and humidity are listed in Table 2.

Differences in environmental conditions exert direct impacts on engine operating conditions. In the high altitude and frigid region with thin air, engine excess air coefficient $\phi_a$ becomes larger beset by less oxygen, lower atmospheric pressure, and larger intake resistance. Moreover, CO and HC exhaust, on the premise of oxygen deficit and incomplete combustion, increases significantly, which is also aggravated due to low environmental temperature, poor gasoline atomization effect, and insufficient burning of combustible gas mixture in hot and humid environment. In contrast, the engine becomes inefficient, troubled by high environmental temperature, slow engine cooling and heat dissipation, and high operating temperature of combustion chamber,
Table 1: Emission factors for different types of gasoline vehicles.

| Vehicle type       | CO (g km$^{-1}$) | HC (g km$^{-1}$) | NOx (g km$^{-1}$) | PM$_{2.5}$ (g km$^{-1}$) | PM$_{10}$ (g km$^{-1}$) |
|--------------------|------------------|------------------|-------------------|--------------------------|-------------------------|
| Minivan GI        | 6.71             | 0.663            | 0.409             | 0.026                    | 0.029                   |
| Minivan GII       | 2.52             | 0.314            | 0.324             | 0.011                    | 0.012                   |
| Minivan GIII      | 1.18             | 0.191            | 0.100             | 0.007                    | 0.008                   |
| Minivan GIV       | 0.68             | 0.075            | 0.032             | 0.003                    | 0.003                   |
| Minivan GV        | 0.46             | 0.056            | 0.017             | 0.003                    | 0.003                   |
| Middle-sized Coach GI | 21.43       | 2.567            | 1.781             | 0.060                    | 0.067                   |
| Middle-sized Coach GII | 15.37        | 1.443            | 1.461             | 0.018                    | 0.020                   |
| Middle-sized Coach GIII | 4.33         | 0.373            | 0.474             | 0.011                    | 0.012                   |
| Middle-sized Coach GIV | 1.98          | 0.107            | 0.196             | 0.006                    | 0.007                   |
| Middle-sized Coach GV | 1.98           | 0.107            | 0.147             | 0.006                    | 0.007                   |
| Light Duty Truck GI | 26.16           | 3.324            | 2.006             | 0.060                    | 0.067                   |
| Light Duty Truck GII | 21.54           | 2.210            | 1.656             | 0.018                    | 0.020                   |
| Light Duty Truck GIII | 5.61           | 0.61             | 0.534             | 0.011                    | 0.012                   |
| Light Duty Truck GIV | 2.37            | 0.169            | 0.229             | 0.006                    | 0.007                   |
| Light Duty Truck GV | 2.37            | 0.169            | 0.172             | 0.006                    | 0.007                   |
| Other Gasoline Vehicles GI | 16.12       | 1.368            | 1.89              | 0.066                    | 0.064                   |
| Other Gasoline Vehicles GII | 8.25         | 0.869            | 1.52              | 0.044                    | 0.049                   |
| Other Gasoline Vehicles GIII | 5.456        | 0.613            | 1.089             | 0.026                    | 0.026                   |
| Other Gasoline Vehicles GIV | 3.77          | 0.418            | 0.775             | 0.015                    | 0.015                   |
| Other Gasoline Vehicles GV | 3.77          | 0.418            | 0.582             | 0.005                    | 0.006                   |

GI, GII, GIII, GIV , and GV, respectively, represent the national emission standards of Phase-I, Phase-II, Phase-III, Phase-IV , and Phase-V.

Table 2: Extreme statistics of environmental parameters in China.

| Parameter                  | Higher value | Representative | Lower value | Representative | D-value |
|----------------------------|--------------|----------------|-------------|----------------|---------|
| Altitude (M)               | 4025         | Shigatse       | 33          | Tianjin        | 3992    |
| Temperature (°C)           | 46           | Chongqing      | −52.3       | Mohe           | 98.3    |
| Humidity (%)               | 92           | Guiyang        | 32          | Yinchuan       | 60      |

Data from China Climate Bulletin in 2015.

Ultimately leading to aggravation in pollutant emission with increasing fuel consumption. In high relative humidity environment, water molecules present in the air enter into combustion chamber through the engine intake system. This results in incomplete combustion of combustible gas mixture and carbon deposition. This easily leads to surface ignition under high temperature, inducing preignition deflagration and some other tough operating conditions of engine, and thereby dramatically increasing the emission amount of NO$\textsubscript{x}$ and PM$_{2.5/10}$.

According to Technical Guidelines for Preparation of Air Pollutants Emission Inventory of Road Vehicles [15], based on influencing factors such as temperature, humidity, sulfur content, and altitude, the correction factors with similar environmental conditions were integrated based on actual situations, and the environmental parameter correction factors in high state and low state are listed in Table 3.

Definitions of the low state and high state of various environmental factors are summarized in Table 4.

3.2. Average Velocity Correction Factors. Vehicle operating conditions in different provinces and cities in China vary significantly owing to the different landforms, population densities, and road conditions of various regions. According to the data released in the Investigation Report for National Urban Automobiles Driving Conditions in 2015 by National Bureau of Statistics, vehicle operating conditions of six representative cities are listed in Table 5.

Average velocity exerts direct influences on engine operating condition and emissions. When the vehicle runs in idle low load states and low velocity, less amount of mixed gas would get into the engine through its narrower throttle opening, leading to the serious dilution of the mixed gas by residual gas. Besides, slow engine velocity leads to slow inlet
According to the guide, the gasoline vehicle velocity involved in the correction method has been divided into the following five intervals: 0–20, 20–30, 30–40, 40–80, and 80 km h⁻¹. Moreover, the average vehicle velocity correction factors of the gasoline vehicle were worked out and listed in Table 6.

### 3.3. Load Correction Factors

Owing to a sound growth momentum, the transportation industry in China confronts a noticeable problem of spatial development imbalance. For
3.4. Degradation Correction Factors. Exposure of the running vehicle to the external environment such as sunshine, air, wind, sand, rain, and snow is inevitable. Moreover, the interaction of internal parts of vehicle also leads to the heating, wear, and corrosion. Vehicle degradation is usually divided into tangible wear, invisible wear, and general wear. Similar to other mechanical equipment, the vehicle also degrades under the technical conditions and its performance also reduces after a period of use. This is well represented by the reduction of mechanical transmission efficiency and the increase of fuel consumption, as well as poor exhaust ternary catalytic effect. These degradation results lead to direct increase in exhaust pollutant emission.

The selection of service life as a deterioration correction parameter can facilitate the calculation and analysis of emission inventories. Therefore, referring to the data information in the guide, the correction parameters of gasoline vehicle deterioration were obtained as summarized in Table 8.

### Table 5: Typical urban vehicle operating conditions in China.

| Unit  | maximum velocity (km h\(^{-1}\)) | Average velocity (km h\(^{-1}\)) | Idling Time Proportion (%) |
|-------|-------------------------------|---------------------------------|--------------------------|
| Beijing | 70.5                          | 27.7                           | 20.5                     |
| Shanghai | 52.3                         | 21.6                           | 30.2                     |
| Guangzhou | 55.4                        | 25.6                           | 17.3                     |
| Dalian  | 76.3                          | 40.5                           | 8.6                      |
| Wuhan   | 80.5                          | 36.4                           | 15.3                     |
| Lasa    | 105.4                         | 60.7                           | 5                        |

Engine operating condition is directly influenced by vehicle load. With the increase in the loading weight, the vehicle suffers more running resistance and ramp resistance in the course of moving. In order to maintain the average velocity and reserve power, the richer mixed gas should be provided to the engine, which will generate a smaller excess air coefficient of chamber. Under the circumstances, the mixed gas, in which gasoline accounts for a large proportion, burns rapidly with less heat loss, contributing to a higher effective power of engine. However, still its combustion remains incomplete due to the insufficient inlet, thus producing large amounts of CO and HC and leading to carbon deposition. In this case, the probability of ignition and detonation of engine surface gets significantly increased, as also the exhaust amount of PM\(_{2.5}\)/10.

With reference to the index of load correction factors of gasoline vehicle in the guide, the load correction factors were obtained and listed in Table 7.

4. The Vehicle Emission Inventory

4.1. The Combined Emission Factors. The combined emission factors are the most important parameters for establishing the gasoline vehicle emission inventory. The combined correction emission factors of gasoline vehicle were calculated in accordance with the actual situation by correcting the basic emission factors in different regions, like environmental characteristics, vehicle conditions, and so on. These factors were calculated by using formula (1) as follows:

\[
EF_{m,i,j} = \sum_{k=3}^{5} \left( \text{BEF}_{m,i,j} \times \varphi_{j} \times \psi_{j} \times \lambda_{j} \times \alpha_{i} \times \xi_{i} \times \eta_{i} \right) \\
\times \chi_{j} \times \frac{n_{i,j,k}}{n_{i,j}}
\]

The meaning of each symbol in the formula is summarized in Table 9.

\(EF_{m,i,j}\) indicates the \(m\) type emission factor of \(i\) vehicle in the \(j\) region; \(BEF_{m,i,j}\) denotes the \(m\) type basic emission factor of \(i\) vehicle in the \(j\) region; \(n_{i,j}\) represents the \(i\) type vehicle population in the \(j\) region; and \(n_{i,j,k}\) indicates the \(i\) type vehicle pollution in the \(j\) region that conforms to the \(k\) emission standard.

The calculation method of gasoline vehicle emission inventory is represented as follows:

\[
Q_{m,i,j} = EF_{m,i,j} \times VKT_{i,j} \times N_{i,j} \times 10^{-6}
\]

where \(Q_{m,i,j}\) indicates the \(m\) type emission of \(i\) vehicle in the \(j\) region; \(EF_{m,i,j}\) represents the \(m\) type emission factor of \(i\) vehicle in the \(j\) region; \(VKT_{i,j}\) denotes the annual average driving distance of \(i\) vehicle in the \(j\) region; and \(N_{i,j}\) represents the \(i\) type vehicle emission in the \(j\) region.

4.2. Application Analysis

4.2.1. Regional Parameters of Zibo. According to 2015 Statistical Yearbook of Zibo Statistical Bureau [16], Zibo's vehicle population was 719,000 in 2015. The huge emission from vehicles resulted in great pressure to the atmospheric environment in Zibo. Pursuant to statistical data of atmospheric environmental quality released by Zibo Environmental Protection Bureau in 2015, there were only 41 days with good air quality. Therefore, establishment of the gasoline vehicle emission inventory, which is in accordance with the actual situation of Zibo city, was expected to lay the foundation for formulation of a targeted emission control strategy.

The basic environmental parameters and average vehicle running state of Zibo city were obtained by referring to the relevant data released by the Zibo Environmental Protection Bureau and the Zibo Traffic Administration Bureau. The annual average temperature in Zibo is 13.2°C, the annual relative humidity is 57%, and the average altitude is 34.7 m. The average running velocity of gasoline vehicle is 43 km h\(^{-1}\), the average service life of gasoline vehicle is 3–5 years, the average load factor is 50%, and the sulfur content of gasoline...
is less than 50 ppm. The regional emission correction factors of Zibo, as listed in Table 10, were obtained according to Tables 3–8.

### 4.2.2. Regional Vehicle Characteristics

The annual average driving distance and local vehicle population are important indicators for measuring the degree of transportation development in a region, as well as the important basis for establishing regional emission inventory. Through consulting 2015 Statistical Yearbook of Zibo Transportation Administration Bureau, the annual average driving distance and population of different types of gasoline vehicles in Zibo were obtained. The specific data is presented in Table 11, where the numbers 1 to 4 represent minivan, middle-sized coach, light duty truck, and other gasoline vehicles, respectively.

### 4.2.3. The Regional Emission Inventory

The regional combined emission factors can be obtained by combining basic emission factors with correction factors in Zibo. Then the gasoline vehicle emission inventory can be obtained by combining regional vehicle characteristics. The results are listed in Table 12.

### 4.3. Uncertainty Analysis

The uncertain factors that affect the emission inventory of traditional gasoline vehicles include the establishment of local statistical data and emission factors. In this paper, Monte Carlo uncertainty analysis method is applied to quantify the potential uncertainty of gasoline vehicle emission inventory. Simultaneity, the uncertainty range of the emission inventory (95% confidence interval) is obtained by repeated sampling method, as shown in Table 14.

By the careful consideration of various factors that may affect the establishment of emission factors, the overall uncertainty of pollutant emissions does not exceed 35%. Among them, PM$_{2.5}$/PM$_{10}$ has the highest uncertainty, and the relative error of total emissions is ±34.13%; furthermore, there is a significant difference in different vehicle types. This may be due to the fact that there are some differences between the national emission factors and the actual situation in Zibo. When using self-expanding simulation, the uncertainty of
Table 9: The meaning of each symbol in the formula.

| Symbol | Meaning                  | Symbol | Meaning             |
|--------|--------------------------|--------|---------------------|
| BEF    | Basic emission factor    | λ      | Altitude correction |
| i      | Vehicle type             | α      | Velocity correction |
| j      | Regional number          | ζ      | Deterioration correction |
| m      | Pollutants type          | η      | Sulfide correction  |
| k      | Emission standard        | χ      | Load correction     |
| φ      | Temperature correction   | n      | Vehicle population |
| ψ      | Humidity correction      |        |                     |

Table 10: Regional emission correction factor of Zibo City.

| Correction type | φ   | ψ    | η   | λ   | α   | γ | ζ |
|-----------------|-----|------|-----|-----|-----|---|---|
| CO              | 1.00| 1.04 | 0.90| 1.00| 0.39| 1.00|1.14|
| HC              | 1.00| 1.01 | 0.96| 1.00| 0.32| 1.00|1.09|
| NO₅             | 1.00| 0.87 | 0.95| 1.00| 0.86| 1.00|1.12|
| PM₂.₅/PM₁₀      | 1.00| 1.00 | 0.56| 1.00| 0.32| 1.00|1.15|

Data from Tables 3–8.

Figure 2: Emission sharing rate of each pollutant. Notes: M: minivan; MSC: middle-sized Coach; LDT: light duty truck; MDT: medium duty truck; and OGV: other gasoline vehicles.
We are currently conducting larger vehicle road trials to update and obtain more detailed emission factors and develop relevant emissions inventory software to accommodate international research needs, including China.

5. Summary and Outlook

Considering that gasoline vehicle emission conditions differ significantly in different areas, the study determining basic emission factors with reference to the relevant guidelines, correcting factors based on regional differences, combined with driving distance and vehicle population, and other information of local gasoline vehicles finally figures out the method of establishing gasoline vehicle emission inventory, including the following.

(1) The gasoline vehicles are classified into four types based on their usage, and basic emission factors are determined according to the relevant guidelines. Notably, the emission estimation from the revised emission factor and the average emission factor are significantly different. This difference is attributed to the fact that the average velocity of gasoline vehicle in Zibo city is 43 km h\(^{-1}\) and the corresponding velocity correction coefficient is 0.39; thus the velocity correction factor is far less than the standard. Therefore, it is important to identify local emission factors in conjunction with local factors when emissions from an area are estimated. Moreover, velocity is an important factor affecting emissions.

(2) After the analysis of the differences in environmental parameters in different regions, average velocity, load, front of vehicle, and other factors were confirmed. Moreover, their influences on the gasoline vehicle emission were systematically investigated. Comparative analysis of the emission estimations from other provinces or regions in China indicates that the difference in emission factors in different regions is due to different major factors. For example, the major emission factor of Chongqing Province is slope and Zibo city terrain is dominated by plain; therefore, the determination of Zibo city emission factor does not need to consider the slope factor.

(3) The computing method of gasoline vehicle emission inventory for different cities was established, considering Zibo city as an applied research example. Emission share rates of different vehicle types were analyzed, and finally the focus of governance was determined.

This study can extend theoretical support to quantitative evaluation on gasoline vehicle emission conditions in different areas and lay foundation for providing well-targeted regulation measures. In developing countries, medium-sized cities such as Zibo are very common, so this study has practical significance for the international urban emission estimation similar to Zibo urban cluster.
### Table 12: Pollutant emission inventory of gasoline vehicle in Zibo City.

| Vehicle type                   | Total emission volume (t/a) | CO       | HC       | NO\textsubscript{x} | PM\textsubscript{2.5}/PM\textsubscript{10} |
|--------------------------------|----------------------------|----------|----------|-------------------|----------------------------------------|
| Minivan                        | 4138.54                    | 497.61   | 261.71   | 41.45             |
| Middle-sized Coach              | 112.80                     | 8.55     | 10.55    | 0.62              |
| Light Duty Truck                | 2422.53                    | 221.98   | 207.21   | 10.58             |
| Other Gasoline Vehicles         | 160.67                     | 17.42    | 30.89    | 1.08              |
| **Total**                      | **6834.55**                | **745.57**| **510.36**| **53.73**        |

### Table 13: Pollutant emission inventory of gasoline vehicle in Zibo City referring to average emission factors.

| Vehicle type                   | Total emission volume (t/a) | CO       | HC       | NO\textsubscript{x} | PM\textsubscript{2.5}/PM\textsubscript{10} |
|--------------------------------|----------------------------|----------|----------|-------------------|----------------------------------------|
| Minivan                        | 9944.94                    | 1195.76  | 628.88   | 99.61             |
| Middle-sized Coach              | 271.07                     | 20.55    | 25.34    | 1.49              |
| Light Duty Truck                | 5821.36                    | 533.43   | 497.93   | 25.43             |
| Other Gasoline Vehicles         | 386.10                     | 41.86    | 74.24    | 2.59              |
| **Total**                      | **16423.47**               | **1791.60**| **1226.39**| **129.11**      |

### Table 14: Uncertainly analysis of the emission inventory of gasoline vehicles.

| Pollutants | Vehicle type       | Estimated value/t | Simulated average/t | 95% confidence interval/t | Relative error |
|------------|--------------------|-------------------|---------------------|----------------------------|----------------|
| CO         | Minivan            | 4138.54           | 7838.56             | [6214.76, 9462.36]         | ±20.72%        |
|            | Middle-sized Coach | 112.80            | 185.30              | [140.63, 239.98]           | ±25.50%        |
|            | Light Duty Truck   | 2422.53           | 3198.93             | [2128, 4269.51]            | ±33.06%        |
|            | Other Gasoline Vehicles | 160.67           | 260.83              | [178.33, 343.17]           | ±31.58%        |
|            | **Total**          | **6834.55**       | **11483.59**        | [8652.17, 14315.02]        | ±24.66%        |
| HC         | Minivan            | 497.61            | 911.55              | [581.55, 1241.56]          | ±36.20%        |
|            | Middle-sized Coach | 8.55              | 18.26               | [13.69, 22.83]             | ±25.03%        |
|            | Light Duty Truck   | 221.98            | 423.32              | [355.85, 490.80]           | ±15.04%        |
|            | Other Gasoline Vehicles | 17.42           | 27.45               | [19.87, 33.02]             | ±27.81%        |
|            | **Total**          | **745.57**        | **1380.58**         | [970.96, 1790.21]          | ±29.67%        |
| NO\textsubscript{x}           | Minivan            | 261.71            | 340.78              | [314.45, 662.11]           | ±21.09%        |
|            | Middle-sized Coach | 10.55             | 20.77               | [16.10, 25.44]             | ±22.48%        |
|            | Light Duty Truck   | 207.21            | 293.43              | [190.33, 396.52]           | ±35.14%        |
|            | Other Gasoline Vehicles | 30.89           | 67.25               | [50.39, 84.12]             | ±25.07%        |
|            | **Total**          | **510.36**        | **928.23**          | [688.27, 1168.19]          | ±25.85%        |
| PM\textsubscript{2.5}/PM\textsubscript{10} | Minivan            | 41.45             | 80.76               | [58, 109.71]               | ±35.85%        |
|            | Middle-sized Coach | 0.62              | 0.97                | [0.77, 1.16]               | ±20.62%        |
|            | Light Duty Truck   | 10.58             | 16.19               | [11.71, 20.68]             | ±27.67%        |
|            | Other Gasoline Vehicles | 1.08           | 1.73                | [1.35, 2.11]               | ±21.97%        |
|            | **Total**          | **53.73**         | **99.65**           | [65.64, 133.66]            | ±34.13%        |

### Table 15: Comparison of emission inventory between Zibo and other regions.

| Region       | Based year | Vehicle population (veh) | Emissions (×10\textsuperscript{4} t) | Sources               |
|--------------|------------|--------------------------|---------------------------------------|-----------------------|
|              |            |                          | CO | HC | NO\textsubscript{x} | PM\textsubscript{2.5}/PM\textsubscript{10} |
| Zibo         | 2015       | 68.4×10\textsuperscript{4} | 0.68 | 0.08 | 0.05 | 0.0053 | This study |
| Chengdu      | 2012       | 144.3×10\textsuperscript{4} | 2.59 | - | 0.21 | 0.0153 | Chen et al. 2015 |
| Zhengzhou    | 2013       | 123.3×10\textsuperscript{4} | 2.34 | 0.23 | 0.19 | 0.0021 | Gong et al. 2017 |
| Foshan       | 2010       | 70.2×10\textsuperscript{4}  | 1.13 | - | 0.06 | 0.0069 | Zeng et al. 2013 |
| Tianjin      | 2013       | 155.6×10\textsuperscript{4} | 1.82 | 0.20 | 0.14 | 0.0143 | Zhang et al. 2017 |

Note: "-" indicates no data.
Data Availability

We have generated links to all the data for others to get and a webpage is added as follows: Data.htm. Besides, our original data comes from the following URL: https://wenku.baidu.com/view/586194e3b307e87101f696e3.html?qq-pf-to=pqq.c2c.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Acknowledgments

This study was supported by the National Natural Science Foundation of China (Grant nos. 51508315 and 51608313), the Technological Development Project of Shandong Province (Grant no. 2016GGB01539), and the Natural Science Foundation of Shandong Province of China (Grant no. ZR2015PL046).

References

[1] National Bureau of Statistics of the People’s Republic of China, China Statistical Yearbook 2015, China Statistics Press, 2016, http://www.stats.gov.cn/.
[2] S.-D. Sun, W. Jiang, and W.-D. Gao, “Vehicle emission inventory and spatial distribution in Qingdao,” Zhongguo Huanjing Kexue/China Environmental Science, vol. 37, no. 1, pp. 49–59, 2017.
[3] B. R. Li, Z. Liu, X. Y. You, and Y. Huang, “Emission and characteristics of vehicle exhausts in Yanshan—Shenhe-Weiyuan of human province,” Environmental Science & Technology, vol. 39, no. 11, pp. 167–173, 2016.
[4] Z.-L. Tao, M.-H. Zhang, X.-T. Wang, Y.-Z. Zhang, H. Hao, and K.-B. He, “Trends in vehicular emissions in typical cities in China,” Zhongguo Huanjing Kexue/China Environmental Science, vol. 32, no. 9, pp. 1565–1573, 2012.
[5] S. E. Puliafito, D. Allende, S. Pinto, and P. Castesana, “High resolution inventory of GHG emissions of the road transport sector in Argentina,” Atmospheric Environment, vol. 101, pp. 303–311, 2015.
[6] Y. J. Wang and Y. He, “Methods for low-carbon city planning based on carbon emission inventory,” China Population and Resources and Environment, vol. 25, no. 6, pp. 72–79, 2015.
[7] H. Guo, Q.-Y. Zhang, Y. Shi, and D.-H. Wang, “Evaluation of the International Vehicle Emission (IVE) model with on-road remote sensing measurements,” Journal of Environmental Sciences, vol. 19, no. 7, pp. 818–826, 2007.
[8] Y. F. Li, Z. H. Li, J. N. Hu et al., “Emission profile of exhaust PM_{2.5} from light-duty gasoline vehicles,” Research of Environmental Sciences, vol. 29, no. 4, pp. 503–508, 2016.
[9] H. Ni, W. Zhao, L. Liu, M. L. Li, T. Q. Fu, and Y. W. Wang, “A research of effects of altitude on the emissions and fuel consumption of a gasoline vehicle,” Automotive Engineering, vol. 36, no. 10, pp. 1205–1209, 2014.
[10] Y. Zhou, Y. Wu, S. Zhang, L. Fu, and J. Hao, “Evaluating the emission status of light-duty gasoline vehicles and motorcycles in Macao with real-world remote sensing measurement,” Journal of Environmental Sciences, vol. 26, no. 11, pp. 2240–2248, 2014.
[11] D. Guo, S. Gao, X. Y. Wang, and Q. Shang, “Analysis of emissions deterioration rule of light-duty EFI gasoline vehicle,” Science Technology and Engineering, vol. 13, no. 15, pp. 4454–4458, 2013.
[12] D. Guo, F. Sun, and J. B. Zhao, Method for Estimation of Urban Area Vehicle Emission and Reduction Strategy Analysis, China Communications Press, Beijing, 2017.
[13] D. Guo, H. Zhang, C. Zheng, S. Gao, and D. Wang, “Analysis of the future development of Chinese auto energy saving and environmental benefits,” Xitong Gongcheng Lilun yu Shijian/System Engineering Theory and Practice, vol. 36, no. 6, pp. 1593–1599, 2016.
[14] H. Wang, C. Chen, C. Huang, and L. Fu, “On-road vehicle emission inventory and its uncertainty analysis for Shanghai,” Science of the Total Environment, vol. 999, no. 1–3, pp. 60–67, 2009.
[15] Chinese Research Academy of Environmental Sciences, “Technical Guidelines for Preparation of Air Pollutants Emission Inventory of Road Vehicles,” 52P, 2015.
[16] Zibo Statistical Bureau, Statistical Yearbook of Zibo City, China Statistics Press, 393P, 2015, http://tj.zibo.gov.cn/zbtj/pic/2015tjnj.pdf.
[17] J. Chen, W. Fan, J. Qian, Y. Li, and W. Zhao, “Establishment of the light-duty gasoline vehicle emissions inventory in China by the International Vehicle Emission model,” Huanjing Kexue Xuebao/Acta Scientiae Circumstantiae, vol. 35, no. 7, pp. 2069–2075, 2015.
[18] M. Gong, S. Yin, X. Gu, Y. Xu, N. Jiang, and R. Zhang, “Refined 2013-based vehicle emission inventory and its spatial and temporal characteristics in Zhengzhou, China,” Science of the Total Environment, vol. 599-600, pp. 1149–1159, 2017.
[19] X. L. Zeng, H. X. Li, and X. M. Cheng, “Study on traffic exhaust emission characteristics and environmental benefits in Macao with real-world remote sensing measurement,” Journal of Environmental Sciences, vol. 26, no. 11, pp. 2240–2248, 2014.
[20] Y. Zhang, L. Wu, H. J. Mao, J. Teng, and H. Chen, “Research on vehicle emission inventory and its management strategies in Tianjin,” Acta Scientiarum Naturalium Universitatis Nankaiensis, vol. 50, no. 1, pp. 90–96, 2017.
