Chapter 2
Motor Vehicle Development and Air Pollution Control

Huo Hong, Yao Zhiliang, and He Kebin

Abstract This chapter first introduces the general ambient environmental issues caused by vehicles in China and then simulates CO, HC, NO_x, and particulate matter (PM) emissions from vehicles in 12 selected typical Chinese cities during 1990–2009. The results show a decreasing trend in CO and HC emissions but an increasing trend in NO_x and PM emissions in the examined cities. Megacities (e.g., Beijing and Shanghai) have stricter emission standards than the national level, so their vehicle emissions decrease faster than those of other cities. Also, the ambient SO_2, NO_2, and PM_{10} concentrations in Beijing, Shanghai, and Guangzhou show a decreasing trend during the past decade. However, in cities where the emission measures are relatively lenient (e.g., Jinan, Ningbo, and Chongqing), the NO_x and PM emissions increased significantly. Therefore, vehicle pollution is no longer a problem that exists only in large cities. Local governments need to pay great attention to the fact that vehicle pollution is rapidly rising in provincial capitals and prefecture-level cities. This chapter finally discusses the measures implemented during recent 10 years to control vehicle emissions in China.

The rapid vehicle growth in China has caused various environmental issues, especially urban air pollution. Fortunately, the national government and local governments have implemented many measures to control vehicle emissions. It is important to emphasize that vehicle emission-control measures must be in accord with vehicle development in order to protect the urban ambient environment.

Keywords Vehicle emissions • Air pollution • Emission standards

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2.1 Environmental Problems Caused by Motor Vehicles

With the growth of China's economy and urbanization in addition to the continuous improvement in living standards in the country, the number of motor vehicles has rapidly risen over the past several decades. In 32 years from 1978 to 2010, China's vehicle population increased from 1.36 to 80 million (excluding motorcycles, low-speed trucks, and low-speed electric vehicles). The annual average growth rate was 14 %, though since 2000 this rate has reached 17 %. The rapid increase in the number of vehicles has brought greater convenience and a higher quality of life, but it has also resulted in serious environmental problems.

Owing to the relatively low levels of pollution control for motor vehicles as well as the slow development of infrastructure construction and transportation management in China, individual vehicle emission factors are generally higher than in developed countries. At the same time, because of the high density of urban traffic and population, vehicle emission density and pollutant concentrations are generally high, which are greatly injurious to health.

Toward controlling vehicle pollution, China is rapidly undertaking the production of unleaded gasoline, and it has implemented new vehicle emission standards. However, because China was late in starting vehicle pollution control, automobiles with relatively backward pollution-control mechanisms still account for a certain proportion of the vehicle population, and the average emission level is much higher than in the United States and European countries. Further, construction of the supporting infrastructure and transportation management has failed to keep pace with the rapid growth in the number of vehicles. Insufficient transport structure and composition have led to chronic traffic saturation on the major roads of many big cities. Low average running speeds and the high incidence of idling have aggravated the air pollution in China's cities (Sidebar 2.1).

Sidebar 2.1: Impact of Vehicle Pollutants on Health and the Environment

The main vehicle pollutants are carbon monoxide (CO), hydrocarbons (HCs), nitrogen oxides (NO_x), and fine particulate matter ($PM_{2.5}$). These pollutants can cause serious harm to human health. CO and HCs result from incomplete combustion. CO can lead to a decrease in oxygen transmission function in the blood. Low concentrations of CO cause headaches, dizziness, and intoxication; high concentrations are lethal. Among HCs, benzene and polycyclic aromatic substances are proven carcinogens. Among NO_x, NO_2, in particular, is highly toxic. It is a red-brown gas with a pungent smell, and it can greatly damage the human respiratory and immune systems at a concentration of 5 ppm. Following inhalation, $PM_{2.5}$ can become deposited in lungs and lead to diseases in the respiratory system. In addition, it can be very harmful through its surface adsorption of many toxic substances. Furthermore, photochemical

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reactions occur between NO_x and HCs, generating low-altitude ozone and photochemical smog. NO_x are a major source of acid rain, which is also very harmful to human health. Black carbon (BC) in vehicle emissions not only causes decreased visibility but also impacts on the climate.

Table 2.1 Annual change of NO_2 concentration in Beijing ($\mu g/m^3$)

Year	2006	2007	2009
Central city	69.5	67.5	59.3
Outer city (central city excluded)	63.3	61.8	57
Suburbs	50.4	47	45.3

Note: The central city comprises Dongcheng, Xicheng, Xuanwu, and Chongwen; the outer city comprises Haidian, Chaoyang, Fengtai, and Shijingshan; and the suburbs comprise Fangshan, Daxing, Tongzhou, Mentougou, Changping, Shunyi, Pinggu, Yanqing, Huairou, and Miyun

Table 2.2 Contributions of pollution sources to total emissions in Beijing in 2008 (excluding fugitive emissions, %) (Wang et al. 2010)

Pollution source	NO_x	PM_{10}	HC
Power plants	8	2	5
Building materials	10	45	2
Chemical industry	1	4	1
Smelting	1	14	1
Industrial boilers	14	15	11
Mobile sources	66	20	79

Table 2.1 shows the annual change of NO_2 concentration in Beijing (Beijing Municipality's Bureau of Environmental Protection 2007, 2008, 2010). It is observed that the NO_2 concentrations in the central city were 31–44 % higher than in suburban areas. In the traffic-dense central city, the characteristics of vehicle pollution are very clear.

With increased auto emissions, the contribution of vehicle pollutants to air pollution is currently showing an upward trend in Chinese cities. The contributions of vehicles to total CO and HC emissions are more than 50 % in most cities, and it is even over 90 % in megacities. In population-dense city centers, the proportion of vehicle pollutants among both total emissions and emission concentrations is over 80 %, and this figure is continuously rising. Vehicle emissions have thus become a major source of air pollution in cities (Huo 2005; Guan et al. 2006; Guan and Yu 2007; Jin 2009; Li et al. 2010; Yang et al. 2009). In cities that have experienced a rapid growth in vehicle population, such as Beijing, Shanghai, and Guangzhou, automobiles have become the primary source of air pollution. Vehicle pollution has become the top priority in city air pollution control. Table 2.2 shows the contributions of major pollution sources to the total emissions in Beijing in 2008

(Wang et al. 2010). As shown, vehicles were the dominant source of NO_x and HCs, both of which are ozone precursors. Therefore, vehicles are the major cause of air quality deterioration in the city.

In 2006, the CO, NO_x, and HCs from vehicles accounted for over 20 % of the total emissions nationwide. Currently, black carbon (BC) is exerting a important impact both on climate and human health, and it has increasingly drawn attention in global academic community and among policy makers. The BC emissions from vehicles account for over 10 % of total BC emissions in China (Zhang et al. 2009).

2.2 Calculation of Vehicle Pollutant Emissions in Cities

Generally speaking, vehicles produce more pollution in China than in the United States and European countries. Figure 2.1 presents a comparison of per capita vehicle emissions between Beijing and some developed countries (Huo et al. 2011). At present, Beijing produces the same level of per capita vehicle emissions as the United States and European countries. However, the vehicle ownership in Beijing is much lower than in the developed countries (220 vehicles/1,000 people in Beijing versus 600–800 vehicles/1,000 people in the USA and European countries), which indicates that, individually, Chinese vehicles produce far more emissions. In addition, it is notable that the per capita vehicle pollution is decreasing in those

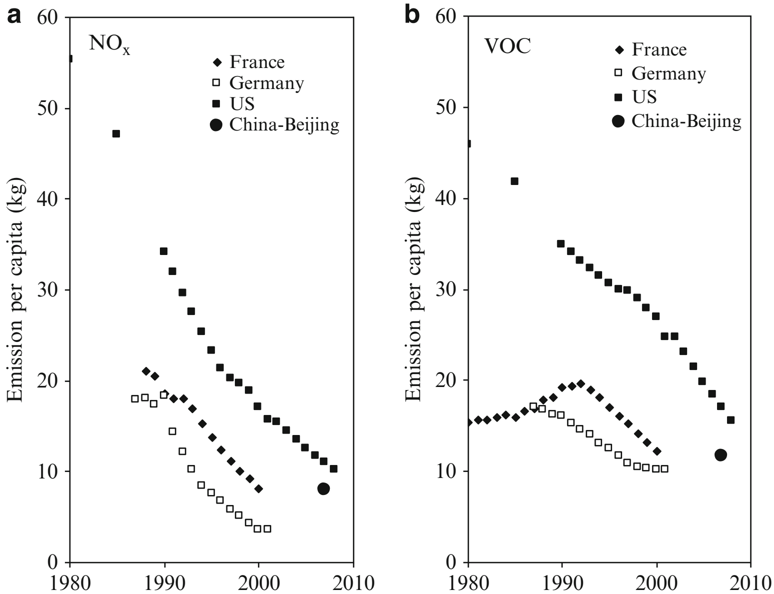

Fig. 2.1 Comparison of per capita vehicle emission in Beijing, the USA, Germany, and France (Revised from Huo et al. (2011), Copyright 2011, with permission from Elsevier)

countries, because the vehicle ownership has become saturated and vehicle emission controls are becoming more stringent. By contrast, China's vehicle ownership per thousand people is increasing. Therefore, it is necessary to impose stricter measures to control vehicle emissions. Because owners may drive their vehicles for about 15 years before buying a new one, the sooner the measures are implemented, the better benefit will be got from the measures. It is also important to put new-energy vehicles on the market as soon as possible to improve the air quality in cities.

To obtain a better understanding of the variations in vehicle emissions in different Chinese cities, this study selected 12 typical cities of various sizes. Vehicles were classified according to type, and the factors that affect vehicles' operation levels and emission factors were analyzed. We developed a vehicle emission inventory method on the basis of available data and examined the vehicle emission characteristics and variations.

The total emission can be calculated using Eq. (2.1):

$$Q_i = \sum_j \left(P_j \times \mathrm{VKT}_j \times \mathrm{EF}_{i,j} \right) \tag{2.1}$$

where i represents the pollutants, including CO, HCs, NO_x, and PM, and j represents the vehicle type, including light-duty gasoline buses, light-duty diesel trucks, heavy-duty diesel buses, heavy-duty diesel trucks, and motorcycles. Q is the total annual emission (tons). P is the vehicle population (million). The registered population of different types of vehicles can be calculated using the method proposed by Huo et al. (2011). In this method, the dynamic vehicle turnover was simulated using vehicle survival function rates, newly registered vehicles, and scrapped vehicles. Vehicle survival functions are variation curves that show, with the aging of vehicles, the changing proportion in the target type's current population with respect to the originally registered population. In this chapter, the motor vehicle survival rates are constant. The target type's population in the target year constitutes the current population that survived to the target year based on the variation in survival rate and the newly registered population. Since sales of China's motor vehicles are currently enjoying robust growth, there is a rapid renewal of automobiles, but there are major regional differences.

In Eq. (2.1), VKT_j is the average annual vehicle kilometers traveled of vehicle type j (km). As an important factor for vehicle operation level and energy consumption, VKT reflects the development of vehicles and transportation. Because there are no official statistics relating to VKT, previous researchers usually obtained VKT data from surveys. The chapter uses the following two methods to determine the traveled distance: (1) questionnaires to obtain data relating to vehicle driving characteristics (including VKT) in different regions (using this relatively easy and feasible method, we could obtain more detailed information, but we would also need a large dataset to ensure reliability) and (2) directly obtain VKT data from transportation management departments (in this way, the data's veracity can be guaranteed, though the information is hard to obtain).

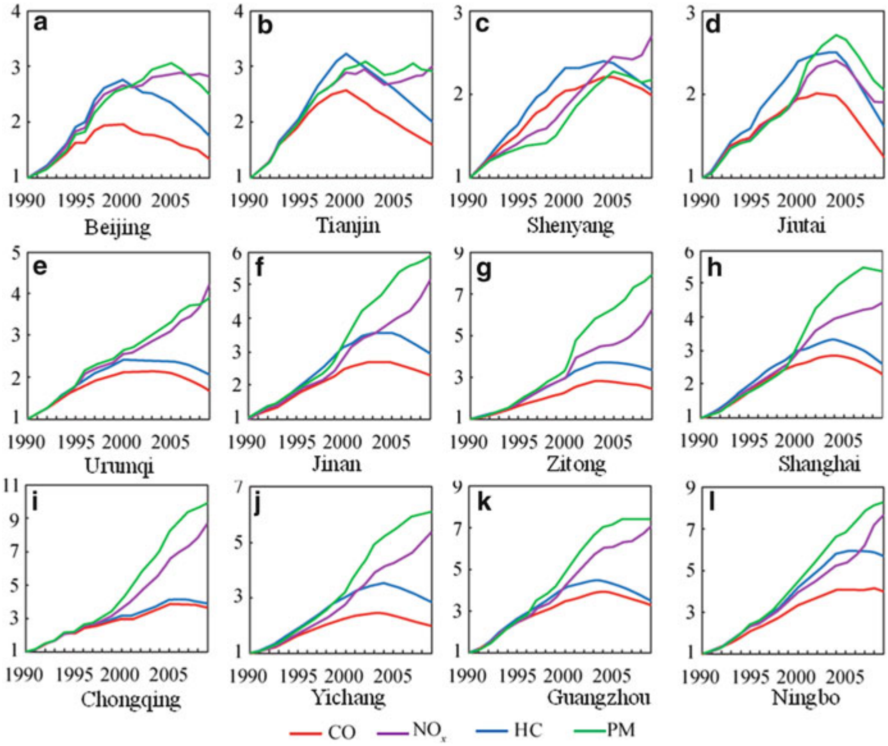

Fig. 2.2 Variation trends of common vehicle pollutants in 12 typical cities from 1990 to 2009. *Note*: The vertical axis represents the growth in emissions as a multiple of the emission level in 1990; the horizontal axis represents years

In Eq. (2.1), EF_i is the emission factor of vehicle pollutant i (g/km). Different emission standards require the different emission limits of vehicle pollutants. Therefore, the EF of the same type of vehicles differs greatly under different emission standards. In order to obtain an accurate vehicle inventory, it is important to simulate the number of vehicles under each emission standard. EF calculation is performed using the International Vehicle Emission (IVE) model.

Figure 2.2 shows the variation trends in vehicle emissions in 12 typical cities from 1990 to 2009. It is observed that there is a decreasing trend in CO and HC emissions but an increasing trend in NO_x and PM emissions. In megacities such as Beijing and Shanghai, owing to the stricter emission standards implemented, vehicle emissions decrease faster than those in other cities; however, in cities such as Jinan, Ningbo, and Chongqing, where the vehicle population is rapidly proliferating and which have been relatively slow to introduce emission measures, the emission of NO_x and PM has increased dramatically. This demonstrates that vehicle pollution is no longer a problem that exists only in large cities. Local governments need to pay great attention to the fact that vehicle pollution is rapidly rising in provincial capitals and prefecture-level cities. Since there are many of these small and medium-sized cities, they will have a greater impact on the overall variation trends in the nationwide emission of vehicle pollutants than the major cities will.

2.3 Air Pollution Status of Three Key Cities

2.3.1 Beijing

In 2008, Beijing had 274 days when the air quality reached the national Class II air quality standard or better, amounting to 74.5 % of the whole year. The average annual concentrations of SO_2, CO, NO_2, and PM_{10} in the atmosphere in Beijing were 0.036, 1.4, 0.049, and 0.122 mg/m^3, respectively, which were 23.4, 30.0, 25.8, and 17.6 % lower than 2007 levels. The concentrations of SO_2, CO, and NO_2 all met the national standards, and that of PM_{10} exceeded national standards by 22 %. In particular, during the 17 days of the 2008 Olympic Games (August 8–24), a series of temporary protection measures were implemented in Beijing and surrounding areas. As a result, there were 10 days with Class I and 7 days with Class II air quality. During the period of the Olympics, the concentrations of atmospheric SO_2, CO, NO_2, and PM_{10} were 0.008, 0.8, 0.023, and 0.057 mg/m^3, respectively, 46.7, 42.9, 57.4, and 53.7 % lower than the corresponding period of the previous year. The commitment toward holding a "Green Olympics" was achieved.

Changes in the concentrations of major pollutants in Beijing from 2000 to 2008 (Beijing Municipality's Bureau of Environmental Protection 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009) are presented in Fig. 2.3. As can be seen, the average annual concentrations of SO_2, CO, NO_2, and PM_{10} significantly decreased

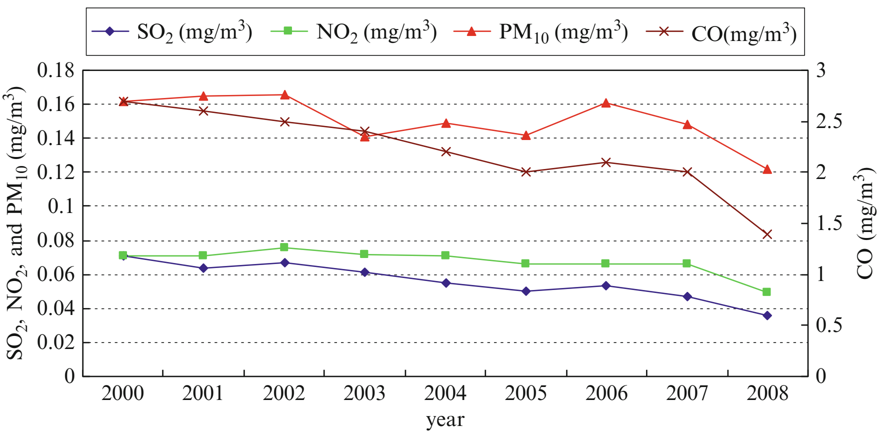

Fig. 2.3 Variation trends in SO_2, CO, NO_2, and PM_{10} concentrations in Beijing from 2000 to 2008

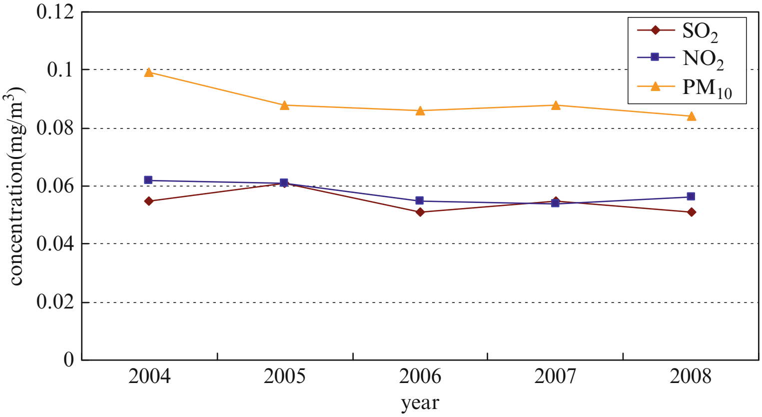

Fig. 2.4 Variation trends of SO_2, NO_2, and PM_{10} concentration in Shanghai from 2004 to 2008

by 49.3, 48.1, 30.9, and 24.7 %, respectively, in 2008, compared with 2000 levels. It can be concluded that air pollution control in Beijing in recent years has been fairly effective, especially regarding SO_2 and CO concentrations. However, it should be noted that the effect of controls on NO_2 and PM_{10} levels is still relatively weak, which indicates that motor vehicle pollution in Beijing remains a rather serious problem, and it has made an ever greater contribution to air pollution.

2.3.2 Shanghai

In 2008, there were 328 days in Shanghai when the air quality was excellent (meeting Class I or Class II), which was about the same number as the previous year. There were 313 days when PM_{10} was the primary pollutant, which amounted to 85.5 % of the entire year; the number of such days for SO_2 was 37, which accounted for 10.1 %; the number of such days for NO_2 was 9, accounting for 2.5 %. There were 5 days when both PM_{10} and SO_2 were the primary pollutants, which accounted for 1.4 %; there was 1 day when PM_{10} and NO_2 were the primary pollutants, accounting for 0.3 %; and there was 1 day when SO_2 and NO_2 were the primary pollutants, which accounted for 0.3 %.

The average annual concentrations of PM_{10}, NO_2, and SO_2 in Shanghai were lower than the Class II of the national air quality standard in 2008. The annual daily average PM_{10} concentration in Shanghai in 2008 was 0.084 mg/m^3, which was 0.004 mg/m^3 lower than in 2007; that of SO_2 was 0.051 mg/m^3, which was 0.004 mg/m^3 lower than 2007 levels; and that of NO_2 was 0.056 mg/m^3, which was 0.002 mg/m^3 higher than in 2007.

The variation trends of the concentrations of major pollutants in Shanghai from 2004 to 2008 are shown in Fig. 2.4 (Shanghai Municipality's Bureau of

Fig. 2.5 Variation trends of SO_2, NO_2, and PM_{10} concentrations in Guangzhou from 2001 to 2008

Environmental Protection 2006, 2007, 2008, 2009, 2010). As is evident in the figure, the concentrations of SO_2, NO_2, and PM_{10} were reduced by 7.3, 9.7, and 15.2 %, respectively, in Shanghai in 2008 compared with 2004 levels. Unlike in Beijing, the concentration of SO_2 in Shanghai was reduced by a relatively small margin, which could be closely related to the strict control of Shanghai's vehicle population. As a result, air pollution in Shanghai is combined by soot and motor vehicle emissions.

2.3.3 Guangzhou

In 2008, air quality in Guangzhou showed an improvement over the previous year, which was the result of continuous improvement efforts. The annual average concentrations of SO_2, NO_2, and PM_{10} were 0.046, 0.056, and 0.071 mg/m^3, respectively, which met Class II of the National Ambient Air Quality Standard. In 2008, dustfall in Guangzhou reached the recommended standard for Guangdong Province. The annual average concentrations of SO_2, NO_2, and PM_{10} in 2008 showed a decrease of 9.8, 13.8, and 7.8 % compared to the 2007 levels, respectively; the monthly average concentrations of dustfall declined by 6.5 %, and the number of good air quality days increased by 3.03 %.

Variation trends in the concentrations of major pollutants in Guangzhou from 2001 to 2008 (Guangzhou Municipality's Bureau of Environmental Protection 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009) are shown in Fig. 2.5. As can be seen in the figure, the concentrations of SO_2, NO_2, and PM_{10} initially showed an increase before gradually declining; the highest values occurred in 2004. The annual average concentrations of SO_2, NO_2, and PM_{10} were 0.077, 0.073, and 0.099 mg/m^3, respectively, in 2004. The concentrations of the three pollutants in 2008 were, respectively, 40.3, 23.3, and 28.3 % lower than in 2004. It is evident that a series of pollution-control measures adopted in Guangzhou has achieved remarkable effects since 2004, particularly in terms of coal-burning pollution, though problems through motor vehicle pollution have become increasingly prominent. The situation is thus similar to that in Beijing. Motor vehicle pollution has become the focus of urban air pollution control.

2.4 Motor Vehicle Pollution-Control and Energy-Conservation Measures

2.4.1 Vehicle Emission Standards for New Vehicles

To deal with pollution problems caused by the rapid development of motor vehicles, developed countries have adopted more stringent new vehicle emission standards. Currently, the vehicle emission regulations of the United States, Japan, and Europe are the three main systems around the world. Many other countries have, to different extent, adopted these regulations and standards. The emission standards and regulations of China are based on the European system.

China's vehicle emission standard system can be roughly divided into four periods. In the first period, which was before 1989, China controlled the CO and HC emissions from gasoline vehicles based on the idling-based measurement and smoke emissions from diesel vehicles by means of free acceleration smoke. The second period started in 1989, when vehicle emission control was extended from vehicle exhaust emissions to crankcase emissions and the measurement was shifted from simple idling method to a preliminary driving cycle-based method. The third period began in 1993 with the establishment and implementation of the GB14761 series standards, and by then, China has established a comprehensive vehicle emission-control system including exhaust emissions, crankcase emissions, and evaporative emissions.

The fourth period began in 2001. This was when the State Environmental Protection Administration (the former Ministry of Environmental Protection) successively implemented national standards, such as the National Emission Standards and Emission Measurement Methods for Light-Duty Vehicles (I, II) (GB18352 series); this was also when the state's control policy of gradually tightening vehicle emission standards began to come into effect. The State Environmental Protection Administration and the State Administration of Quality Supervision, Inspection and Quarantine jointly established three national emissions standards for vehicle pollutant emission on April 16, 2001, and another one was issued on November 27, 2002. These four standards in conjunction with reserved standards together constitute the current vehicle emission standard system in China; they provide unified coverage of motor vehicle emission control in all major aspects of China's vehicle emission standard system.

On July 1, 2004, the phase II of the national light-duty vehicle emission standards (National II), which is equivalent to the Euro II Standards, was implemented nationwide. National II can reduce individual vehicle emissions by 40 % compared to National I vehicles. The implementation of the National II standards shows that the vehicle pollution control in China has entered a new stage. The State Environmental Protection Administration required that all new light-duty vehicles had to meet the emission limit. In July 1, 2008, National III Standard was officially implemented throughout the country, which further reduced the EFs of vehicles.

Because facing more serious vehicle pollution, large cities like Beijing, Shanghai, and Guangzhou have adopted stricter control measures and introduced the new standards ahead of the national level. Taking Beijing, for example, National I, which is equivalent to Euro I, was adopted in 1999; National IV was introduced on March 1, 2008, and National V in 2013. These measures have dramatically reduced the EFs of individual vehicle pollutants.

Current emission standards have produced a tremendous reduction in pollutant emissions. According to estimates by the International Council on Clean Transportation (ICCT), the results of measures adopted in China over the past decade have been very positive. If those control measures had not been introduced, there would have been 80 % more PM, 77 % more HC, 70 % more CO, and 55 % more NO_2 emissions (ICCT 2010).

2.4.2 Fuel Quality

The composition of fuel has a direct impact on vehicle emissions, and hence changing this composition will reduce emissions. The benefit in vehicle emission reduction from improving fuel quality is clear and instant. For example, vehicles using leaded gasoline were responsible for 90 % of lead concentration in many large cities. There is an obvious relationship between the lead content in gasoline and lead concentration in the air, so reducing the amount of lead in gasoline could significantly reduce ambient lead concentrations. As vehicle emission standards become stricter, fuel quality has become a key factor in deciding the success of vehicle emission-control actions.

2.4.2.1 Unleaded Gasoline

Lead is added to gasoline during production to increase the antiknock performance of gasoline. However, lead is an atmospheric pollutant and causes damage to the catalytic converter and oxygen sensor. To remove the hazard of lead in the environment and to ensure long-term normal operation of the catalytic converters and oxygen sensors, it is important to use unleaded gasoline.

Since 1996, the proportion of unleaded gasoline has increased annually in China. According to the annual vehicle pollution report prepared by Chinese Environmental

Science Academy and Tsinghua University in 2001, the proportion of unleaded gasoline among total gasoline was 51.82 % in 1990, 56.30 % in 1994, 65 % in 1997, and 80 % in 1998. Following the notice by the General Office of the State Council about banning production, sales, and use of leaded vehicle gasoline (State Council Document No. [1998] 129), the production of leaded gasoline was banned nationwide on January 1, 2000; from July 1, 2000, it was prohibited to sell or use leaded gasoline. In this way, the fuel quality in China has dramatically improved, allowing in-depth cleaning of vehicle exhausts.

2.4.2.2 Low-Sulfur Fuel

The sulfur content of fuel has a great impact on vehicle emissions, especially for the vehicles that meet the National III standards or higher. Sulfur can damage the catalytic converter, particulate trap, and other post-processing parts, which significantly reduces the effects of emission purification and means that vehicles fail to meet the emission standard.

Constrained by fuel-refining technology, China implemented the National II fuel standard (equivalent to Euro II) nationwide before 2009, in which the sulfur content of gasoline was 350 mg/kg and that of diesel 2,000 mg/kg. China planned to adopt fuel standards that were equivalent to Euro III in 2010 throughout the country. In 2010, the sulfur content of gasoline was limited to 150 mg/kg and that of diesel 350 mg/kg. In order to meet the new vehicle emission standard, some large cities such as Beijing have already adopted National IV, which calls for a further reduction in the sulfur content of gasoline to 50 mg/kg and that of diesel to 50 mg/kg. National IV was implemented on October 1, 2009 in Shanghai. In Beijing, the National V fuel standard was implemented in 2012, which requires the sulfur content to be lower than 10 mg/kg (Sidebar 2.2).

Sidebar 2.2: Effect of Improving Fuel Quality on Energy Saving

At present, fuel quality is a major issue for applying high-efficient diesel engine technologies. In China, fuel quality cannot meet the demands of the high-efficiency vehicle technologies. Therefore, improving fuel quality is beneficial not only to the successful implementation of emission standards but also to the development of high-efficient technologies.

2.4.3 Controlling Emissions from In-Use Vehicles

Emissions from in-use vehicles deteriorate as their accumulative mileages increase. In addition, vehicles with low accumulative mileages may have a high-emission level if they are improperly maintained. Therefore, timely measures need to be taken to detect improper maintenance to avoid a rise in vehicle emissions. Through routine inspections, the inspection/maintenance (I/M) programs are one means of identifying vehicles that are poor with respect to emissions; in this way, relevant parts can be cleaned, replaced, or properly adjusted so that they can return to a normal working condition in a timely fashion.

With routine inspection and maintenance, the automobile emission-control system is able to function properly. This plays a very important role in controlling in-use vehicle pollution for the following reasons. First, I/M programs can identify those vehicles that are producing high emissions through malfunction or other mechanical problems. Pollutants emitted from this small number of high-emission vehicles often account for a large proportion of total emissions. Related foreign studies indicate that high-emission vehicles, which account for 20 % of the entire vehicle population, contribute over 60 % of total vehicle emissions. Second, I/M programs can also be used to identify emission-control failure and prevent the removal of emission-control equipment on vehicles. If there is failure in the functions of catalytic converters or oxygen sensors, CO and HC emissions can be increased by over 20-fold, and NO_x emission can be increased by three- to fivefold. However, because malfunctions of emission-control equipment do not affect driving performance, drivers are usually not aware of this problem. The advantage of the I/M programs lies in their ability to identify vehicles with emission-control problems and require them to be repaired and undergo maintenance, which ensures that vehicle emissions remain at an appropriate level, thereby effectively preventing abnormal vehicle emissions and helping to control vehicle pollution.

Some large cities in China, such as Beijing and Shanghai, have implemented the I/M programs. In Beijing, for example, before 2003, the main method for gasoline vehicle inspection was the dual-idling method. Since March 2003, the method for inspecting vehicles has been under simple driving conditions. Three sets of emission limits were adopted according to the differences in vehicle type, technology, and vehicle weight. For diesel vehicles, the free acceleration test mode was replaced by the lug-down smoke test mode. The I/M programs currently being conducted in Beijing are different from the general type of programs that exist elsewhere in the country. Outside Beijing, there are centralized programs that are responsible only for testing and also decentralized programs that combine inspection and maintenance. The size of the inspection facilities is relatively small. Annual inspections of vehicles in Beijing are mainly carried out by collective and state-owned enterprises in addition to the police, the military, and other such institutions. At all testing stations, there is a combination of traffic-management and safety tests, and repairs can also be carried out at these testing stations. Vehicles that pass the emission test can proceed to security checks and registration. Vehicles that fail the emission test must be kept at an affiliated service station of the inspection facilities or at an independent service station and then returned for rechecking. I/M programs play an active role in controlling vehicle emissions in Beijing.

2.4.4 Eliminating Vehicles with Dated Technology

According to the new standards for vehicle scrappage issued in 1997, automobiles that exceed the national emission standards even after maintenance should be scrapped. The drivers of in-use vehicles that meet the national standards are encouraged to update their emission-control systems, though it is not mandatory requirement. Taxing old vehicles is also an effective and appropriate method of keeping these automobiles out of key cities. Based on these principles, local environmental government and vehicle management should introduce economic policies toward effectively eliminating old vehicles. It is therefore necessary to establish vehicle supervision and management sectors to eliminate old vehicles that do not meet national standards.

From the perspective of emission performance, renewing a car's engine can help it meet the emission standards, and this achieves the same effect as taking the vehicle off the road. Renewing car engines is a method that has been used in some developing countries to reduce urban vehicle emissions. In such places, efforts are made to remove old vehicles from key urban areas and to replace them with low-emission automobiles that use closed-loop three-way catalytic purification. Depending on the local situation, incentives such as partial vehicle tax exemption and offering preferential loans (such as for renewing taxis) may be provided.

In China, vehicles that fail to meet the National I standards are referred to as "yellow-label vehicles." The emission levels of these vehicles are quite high, and they can be several times higher than vehicles that conform to National II. The elimination of yellow-label vehicles will significantly reduce emissions. During the period of the Beijing Olympic Games, yellow-label vehicles were forbidden to travel in urban areas, and this produced positive results. Additional measures have since been taken to accelerate the elimination of yellow-label vehicles in Beijing. Since October 1, 2009, yellow-label vehicles have not been allowed within and on the Sixth Ring Road. This measure is playing an important role in reducing vehicle pollution in Beijing (Sidebar 2.3).

Sidebar 2.3: Effect of Eliminating Old Vehicles on Energy Saving

Eliminating old vehicles can also benefit energy saving. China introduced its fuel-economy standards in 2005, but older vehicles are free from such standards. If older vehicles retired quickly from the fleet, the average fuel-economy level of the entire fleet would be elevated. To speed up the fleet's technological renovation and stimulate the automobile market, United States and European countries have offered incentives to encourage drivers to dump their old vehicles. For example, in 2009 when the global economy was in recession, the United States Congress devised a scrappage program, referred

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to as “cash for clunkers,” under which consumers could trade in their old, “gas-guzzling” vehicles and receive vouchers worth up to $4,500 to help pay for new, more fuel-efficient cars and light-duty trucks. This measure improved the overall fuel economy of American vehicles. It also helped stimulate the American automobile market and helped it somehow recover in 2010.

2.4.5 *Promoting Alternative Fuels*

China launched the Clean Vehicle Action Program in 1999. Headed by the Ministry of Science and Technology, together with 13 ministries and commissions, including the former State Development Planning Commission, the former State Environmental Protection Administration, and the former Ministry of Construction, the National Clean Vehicle Action Coordination Group was established. This program was originally executed in 12 cities and regions, including Beijing, Shanghai, Chongqing, and Sichuan; it was later expanded to 19 cities and regions. In 2006, China initiated the energy-efficient and new-energy vehicle high-tech plan, which promoted the rapid development of natural gas vehicles. By the end of 2009, more than 1,000 natural gas stations had been constructed, most of which were concentrated in the vicinity of natural gas sources, such as in Sichuan, Chongqing, Urumqi, Xi’an, and Lanzhou. A convenient natural gas supply and low prices have been the main forces behind the development of vehicles using compressed natural gas. Currently, about one-fourth of taxis and one-sixth of buses in China are equipped with natural gas engines.

In addition, China began to promote ethanol gasoline in 2001. Bioethanol gasoline (E10, 10 % ethanol blended in gasoline by volume) is widely used in 6 provinces (Heilongjiang, Jilin, Liaoning, Henan, Anhui) and 27 cities of 4 provinces (Hebei, Shandong, Jiangsu, and Hubei) (Sidebar 2.4).

Sidebar 2.4: Effect of Alternative Fuels on Energy Saving

Whether alternative fuels are able to reduce pollutant emissions is still a matter of debate. Researchers in China and overseas are performing tests and simulations to study the differences in emissions between vehicles combusting alternative fuels and conventional gasoline. Nevertheless, because alternative fuels are mainly extracted from coal, natural gas, and biomass, so then can save significant amount of oil.

2.4.6 Developing Electric Vehicles

Electric vehicles (EVs) are powered by electricity, which is mainly generated from coal and hydraulic power in China. Compared with conventional vehicles, EVs can reduce oil use by over 90 %. Emissions from EVs are mainly determined by energy consumption and emission level of the power generation processes (Huo et al. 2010) (Sidebar 2.5).

Sidebar 2.5: Developing EVs and the Environment

Evaluating the total emission of an EV throughout its life cycle first demands an investigation of the pollutant emission level of China's thermal power plants. The EF of NO_x emitted from thermal power plants differs according to the sizes of boilers, control techniques for NO_x emission, and coal quality. In recent years, with an increasing proportion of large-scale boilers and widespread use of low nitrogen burning (LNB) technology, the average EF of NO_x emitted from thermal power plants has gradually reduced—from 89 g/kg of coal in 1995 to 74 g/kg in 2004. The usage of LNB amounted to 62 % in 2005, and it reached 77 % in 2010. Since newly built power plants are obliged to install LNB facilities, the LNB rate is expected to reach 90 % or higher. When it does so, the average EF will be reduced to 5 g/kg of coal. Selective catalytic reduction (SCR) technology can substantially reduce NO_x emissions. At present, the penetration rate of SCR technology in China is only about 10 %.

Regarding NO_x emissions from vehicles, China is currently implementing National III emission control standards (except for Beijing and other large cities where National IV/V has been introduced). National IV and National V standards are expected to be adopted within a decade. By 2030, Chinese vehicles will meet European IV standards or even stricter.

To make EVs more attractive in China, the government should introduce certain policies. The government can make low-carbon districts the main markets for EVs. Although some advanced power-generation techniques and pollution-control techniques (SCR) have high costs, there are no technical barriers. Therefore, the government should promote these techniques as quickly as possible through a series of policies, especially in view of the benefits to the regional environment and health. It is also notable that since power plants usually have a longer life cycle than vehicles, it takes longer to make a technical update of such plants; thus, the government needs to coordinate with the policies of power and transportation departments to promote the development of clean EVs.

2.4.7 Temporary Traffic-Control Measures

In addition to common control measures, temporary traffic-control measures can be adopted to ensure good air quality and traffic conditions during special periods. Beijing implemented the following temporary transportation-control measures during the period of the 2008 Olympic Games:

1. Private vehicles had to abide by the odd-and-even license plate rule, which requires that vehicles with certain last digit on plates (odd or even) not to run on roads on certain weekdays.
2. During the event, 70 % of governmental vehicles were banned from the roads.
3. Trucks were allowed to go within the Sixth Ring Road only between midnight and 6 a.m.
4. Yellow-label vehicles were banned from the roads of Beijing.

As a result, the total vehicle travelled distance was reduced by 32.0 %. The average driving speed was increased from 25 to 37 km/h. During the event, the HC, CO, NO_x, and PM_{10} emissions in Beijing were reduced by 55.5, 56.8, 45.7, and 51.6 %, respectively (Wu et al. 2011; Zhou et al. 2010).

2.5 Challenges and Prospects

As has been noted, although the air quality of China has been improved in recent years, the absolute concentrations of pollutants, especially NO_2 emissions, are still high. In most Chinese cities, vehicle exhausts are the major source of air pollution. Vehicle pollution control needs to be more rigorous. A series of regulations and measures has been taken to control vehicle pollution since the period of the Ninth Five-Year Plan (1995–2000), and some progress has been made. However, these gains have been mostly offset by the explosive growth of the vehicle population and other traffic problems. In addition, with the development of Chinese society, the public has greater expectations regarding environmental issues.

In the Twelfth Five-Year Plan (2010–2015), NO_x was for the first time listed as an object of total emission control. Motor vehicles are the second-largest source of NO_x emissions, and thus they are a key to achieving NO_x control objectives. Since the autumn of 2011, $PM_{2.5}$ pollution over a period of consecutive hazy days attracted the public's concern regarding air quality conditions. In the new Ambient Air Quality Standard (Second Exposure Draft) developed by the Ministry of Environmental Protection in 2011, $PM_{2.5}$ and ozone 8-h period concentrations were listed in the Routine Air Quality Evaluation System, and the standard limits for PM_{10} and NO_2 became stricter. Studies of many Asian cities show that motor vehicles contribute 20–35 % of the total $PM_{2.5}$ emission. Therefore, implementing new standards will offer a full range of strategic choices regarding gasoline and diesel vehicles, alternative fuels, new-energy vehicles, and exhaust gas purification for the future China.

In progressing toward vehicle pollution control, there are two key factors—activity level and EFs. To this end, the following strategies are proposed.

2.5.1 Developing Public Transportation

Since it is impossible to control the vehicle population at the current stage, the main measure for controlling the activity level is to guide the public's choice of transport. Therefore, clean, convenient, inexpensive public transportation should be developed, and the public transport network needs to be perfected. This would encourage more people to choose public transportation, which would reduce the use of private cars and ultimately control vehicle emissions.

2.5.2 Improving Traffic Management

Improving traffic management will have a significant effect on vehicle emissions. At present, traffic management in Chinese cities is still at a relatively low level. Supervision at traffic intersections should be enhanced to alleviate traffic pressure, improve traffic flow, and thereby reduce emissions. Economic measures, such as using electronic toll systems on congested roads and increasing parking fees in central city areas, could be adopted to control travel in urban areas and thus reduce the harm to the environment caused by vehicle pollution in densely populated city centers.

2.5.3 Implementing Stricter Emission and Fuel Standards

As noted above, measures have been undertaken in China to control vehicle pollution, and some progress has been made. Stricter emission and fuel standards, such as the Euro V and Euro VI, should be implemented as soon as possible to reduce the EFs of individual gasoline and diesel vehicles.

2.5.4 Faster Development of Alternative Fuels

In addition to reducing emissions by gasoline and diesel vehicles, new ways should be explored to control emissions. For example, alternative fuels could be used as substitutes for gasoline and diesel. Though some progress has been achieved in China, investment in scientific and technological research into alternative fuels should be increased to deal with problems in using such alternative fuels and reduce costs as much as possible. With stricter vehicle pollution control, improvements in new fuels technology, and the popularization and use of alternative fuels, the pressure that the vehicle growth places on oil resources and the environment can be significantly relieved.

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