DOI 10.15302/J-SSCAE-2018.01.011

Principal Contradiction and Coordination Development Strategies of Automobile Industry and Emission Control in China

Wu Xiaomeng, Wu Ye, Hao Jiming

Tsinghua University, Beijing 100084, China

Abstract: The rapid development of the automobile industry brings substantial environmental challenges to China. Therefore, integrated development strategies targeting both the automobile industry and emission control, although difficult, are essential. According to a localized model, this paper analyzes the characteristics of and historical trends in China's vehicle emissions and quantifies future trends under various emission control scenarios. The research summarizes and combs the bottlenecks and main contradictions in the process of synergetic development of China's future automobile industry and environmental improvement, proposes a roadmap for the synergetic development applicable to China, and presents corresponding development proposals and control strategies.

Keywords: automobile power; coordination development; vehicle emission control

1 Introduction

With the rapid development of China's social economy and the deepening of urbanization, the number of registered automobiles has grown explosively [1,2]. The source appertionment report of China's major cities, such as Beijing, Shanghai, Guangzhou, Shenzhen, and Hangzhou, shows that mobile pollution sources such as automobiles have become the most important local pollution sources. How to achieve the coordinated development of the automobile industry with environmental protection becomes a problem, among others, that needs to be solved jointly by the current automobile industry and stakeholders in air pollution prevention and control.

Owing to the long-term neglect of priority development of urban public transportation systems (especially large-capacity metropolis rail transit networks), China's cities are generally characterized by the rapid increase of registered automobiles, high-frequency use of automobiles, and a high density of automobile traffic, bringing a severe challenge to China's energy security, air quality, land use, and other socioeconomic aspects.

Since 2000, China has implemented a series of emission control measures to curb the rapid growth of total automobile pollutant emissions. These measures have achieved a remarkable overall result, but many severe social issues remain to be solved [3]. For example, a relatively complete, integrated "vehicle−fuel−road" control scheme is still missing in a series of pollutant emission control measures, and the measures are obviously discordant with one another at different control sections. Vehicle fuel quality standards are not implemented in a synchronous manner with the implementation of the new-vehicle emission standards across the country; that is, the improvement of vehicle fuel quality has severely lagged behind the implementation date of new-vehicle emission standards. Moreover, traffic

Received date: January 15, 2018; **Revised date:** February 10, 2018

Corresponding author: Wu Ye, Tsinghua University, Professor. Major research field is air pollution control and motor vehicle pollution control. E-mail: ywu@tsinghua.edu.cn

Funding program: CAE Advisory Project "Research on Automobile Power Strategy" (2015-XZ-36)

Chinese version: Strategic Study of CAE 2018, 20 (1): 074–083

Cited item: Wu Xiaomeng et al. Principal Contradiction and Coordination Development Strategies of Automobile Industry and Emission Control in China. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2018.01.011

management and market-based economic instruments are insufficient because vehicle emission control is historically focused on new-vehicle emission standards and administrative means.

The rapid increase of registered automobiles and the resulting environmental problems, especially air-quality problems, are key issues that China faces and must solve for building a prosperous society in all respects. Thus, the experiences of other developed countries initating emission control and treatment only after their automobile industry had undergone rapid development and a mature and stable automobile market had been formed, are not fully applicable in China. In the process of China's rapid motorization development, the various environmental problems introduced by the rapid development of the automobile industry present a major challenge for the development of the automobile market. However, the process of solving these problems provides an important opportunity for China to rapidly improve its comprehensive management level in the automobile society and develop automobile emission reduction control technologies for vehicles.

In this study, to elucidate the current status and historical trend of automobile pollutant emissions and to fully understand the future development trend, the pollutant emission characteristics of automobiles in China are evaluated, and a simulation analysis of China's current automobile pollution situation is performed. The key issues to be resolved in future development of the automobile industry are identified, and a development direction is proposed. The findings of this study provide important methods and data for the future development of a coordinated development policy for China's automobile industry and environmental protection, as well as a research focus and direction for solving the main issues in the coordinated development of the automobile industry with environmental protection.

2 Analysis of automobile pollution emission characteristics

2.1 Emission status research

In this study, by conducting surveys and collecting statistics, province-specific data on automobile activity level, automobile type, and number of registered automobiles conforming to different emission standards was obtained. According to the emission factor model for the Beijing vehicle fleet (EMBEV) developed by Tsinghua University and the *Compiling Technology Guide of Air Pollutants Emissions Inventory of Road Vehicles (Trial Implementation)* issued by the Ministry of Environmental Protection, a province-specific motor vehicle emission inventory for China was established.

In 2013, the total emissions from on-road vehicles in China were 4.16×10^6 t of hydrocarbons (HC), 2.742×10^7 t of carbon monoxide (CO), 7.72×10^6 t of nitrogen oxides (NO_X), and 3.7×10^5 t of fine particulate matter (PM). The absolute amounts of automobile pollutants discharged in some provinces and cities in China are shown in Fig. 1 [4]. The following provinces have large absolute amounts of emissions of the aforementioned four pollutants: Guangdong, Shandong, Hebei, Henan, and Jiangsu. These five provinces have a higher ranking than many other provinces regarding population size, gross domestic product, or geographical area, and they each have a large number of registered automobiles. In addition, some provinces (such as Hebei and Henan) have a relatively low level of automobile emission control, which partially accounts for the high total emissions.

The pollutant emission contribution rates for different vehicle types are shown in Fig. 2, indicating that among all the investigated vehicle types, light-duty passenger cars are the main emission sources of HC and CO, while medium- and heavy-duty trucks are the main emission sources of NO_X and $PM_{2.5}$. Figs. 3 and 4 show technology-specific emission contribution rates for light-duty gasoline passenger cars and heavy-duty diesel trucks, respectively. For light-duty gasoline passenger cars, although registered light-duty gasoline passenger cars conforming to China IV account for >50% of the total registered light-duty gasoline passenger cars, the emission factor a China IV car is relatively lower; thus, China IV cars contribute between 10% and 30% of the total pollutant emissions of light-duty gasoline passenger cars. The light-duty gasoline passenger cars registered before the implementation of China I account for <5% of the total registered light-duty gasoline passenger cars but contribute nearly 20% of the total pollutant emissions. Moreover, the light-duty gasoline passenger cars conforming to China I—which account for 10% of the total registered light-duty gasoline passenger cars—contribute >20% of the pollutant emissions [4]. Therefore regarding the control of small passenger cars, it is necessary to enforce the elimination of those falling in the category of yellow-label vehicles (gasoline vehicles before the China I emission standard or diesel vehicles before the China III emission standard) and accelerate the phasing out of old, high-emission vehicles conforming to China I.

For heavy-duty trucks, the main emission contributors are yellow-label vehicles and vehicles conforming to China III. In particular, China III heavy-duty trucks account for a large portion of the registered heavy-duty trucks, mainly because of the delayed implementation of China IV, which leads to a long sale period for China III heavy-duty trucks in the market. Real-world emission test results show that the emissions of China III heavy-duty trucks have not obviously improved compared with previous emission standards; in particular, the NO_X emission is not significantly different from that of China II heavy-duty trucks [5]. Therefore, it is necessary to actively promote the implementation of new-vehicle emission standards and fuel standards; accelerate the use of advanced post-treatment equipment, including selective catalytic reduction (SCR) equipment and diesel particulate filters (DPFs); strictly inspect vehicle-type conformity and in-use compliance for new vehicles; and promote advanced emission control technologies such as advanced vehicle technology and clean alternative fuels to control the NO_X emissions of heavy-duty vehicles.

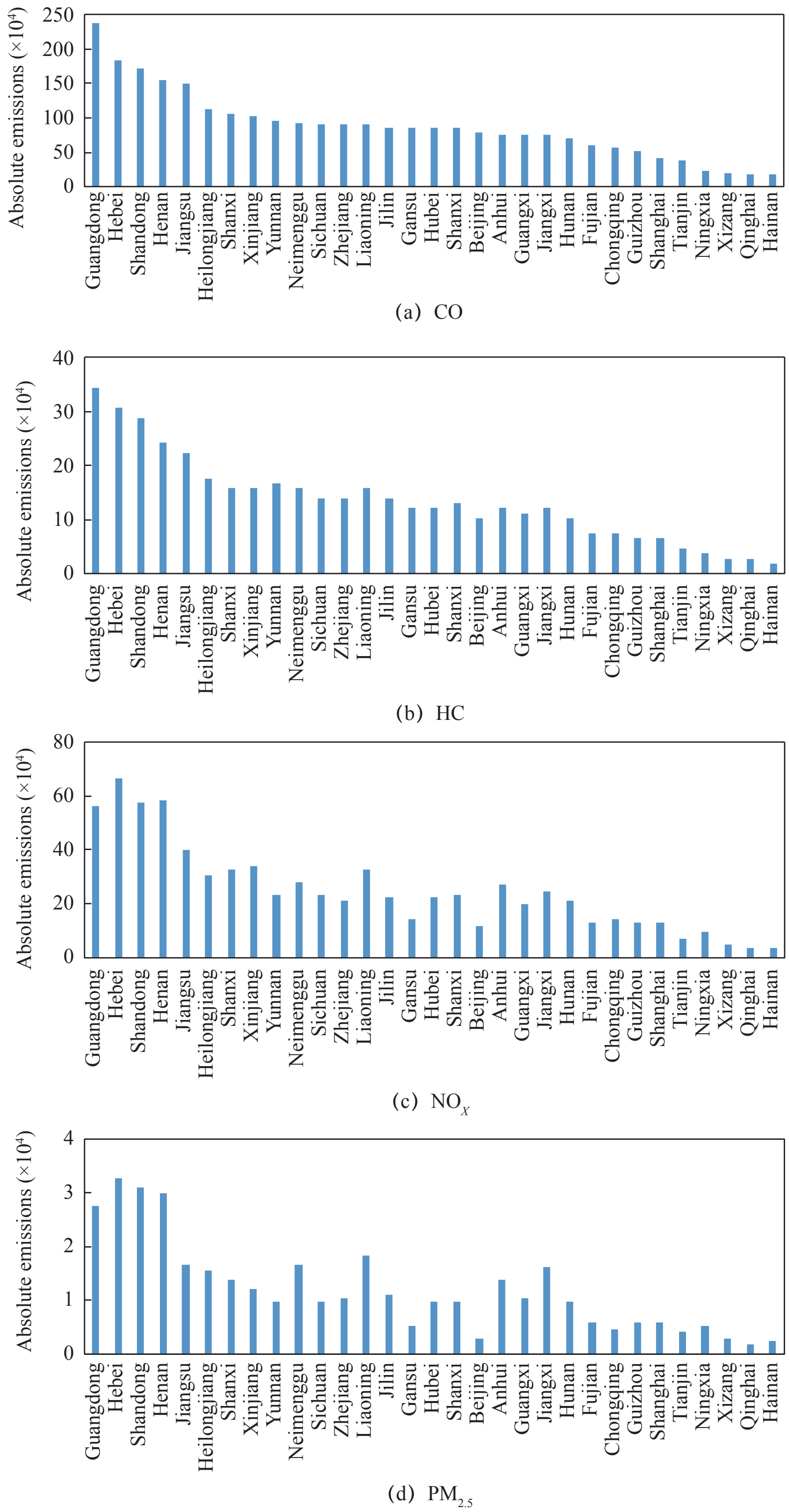

Fig. 1. Absolute emissions of automobile pollutants in provinces and cities of China.

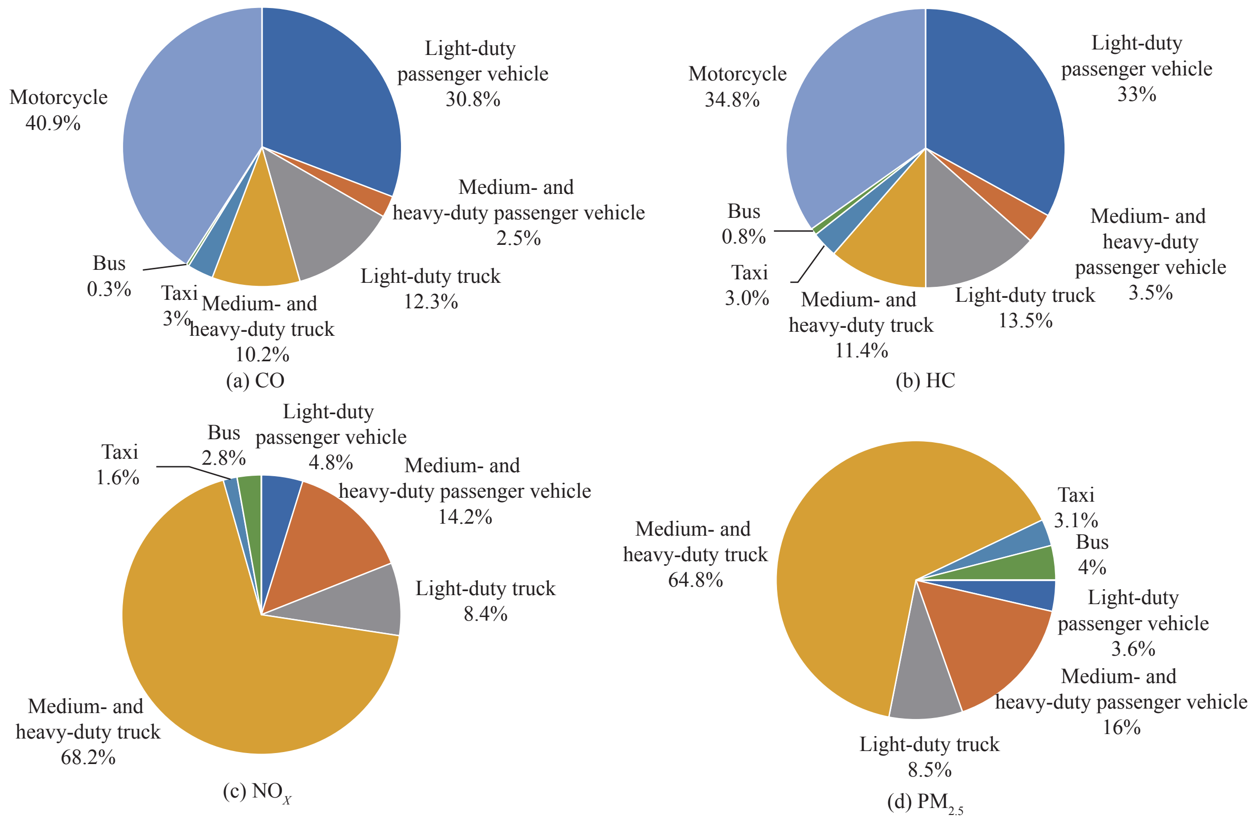

Fig. 2. Contribution rates of different types of vehicles for pollutant emissions.

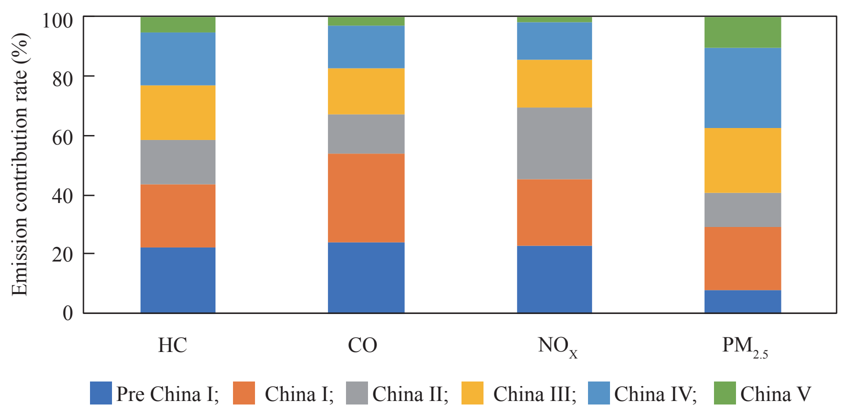

Fig. 3. Contribution rates of light-duty gasoline passenger cars using different emission standards of pollutant emissions.

2.2 Historical trend analysis

Fig. 5 shows a historical development trend of pollutant emissions of motor vehicles in China. Before 2007, the total emissions of HC and CO continued to increase, peaking around 2007. Since 2007, owing to the increasingly stringent regulations for gasoline vehicles and motorcycles in China in recent years, the HC and CO emissions have been steadily declining, with annual reductions of 6 % and 8 %, respectively, despite that the total number of registered motor vehicles in China has increased by a factor of nearly 2.5. There was a significant decline in the total emissions of $PM_{2.5}$ from 2002 to 2008, different from the trends of HC and CO during the same period. However, in the period of 2009–2011, the $PM_{2.5}$ emissions exhibited a short-term rebound, primarily attributed to the fact that the economic incentives implemented by China during the international financial crisis stimulated the sales of diesel trucks. With the number of diesel trucks gradually approaching stabilization, China III trucks began to enter the market, and the total $PM_{2.5}$ emissions of motor vehicles began to decline rapidly, with an average annual reduction as large as 8%. However, unlike the other three pollutants, NO_X showed a continuous growth trend in its total emissions from 1998–2013 without any decline; in particular, the growth rate gradually increased in the later stage of this period, with an annual growth rate as high as nearly 10% for the total NO_X emissions from motor vehicles during 2008–2013.

Regarding vehicle types, light-duty passenger cars have been rapidly increasing in recent years, while public vehicle fleets such as taxis are subject to stricter regulations on emission standards and service years, with the fast replacement of old fleets. Thus, light-duty passenger cars have gradually become the main HC and CO emission contributors among all types of investigated vehicles, concomitant with a dramatic decrease in the emission contribution rate of taxis. For $PM_{2.5}$, medium- and heavy-duty trucks and heavy-duty passenger vehicles are the main emission contributors. The continuous increase in NO_X emissions is mainly attributed to the rapid increase in emissions from heavy-duty vehicle fleets, and the rapid increase is mainly attributed to the ever-increasing registration speed of heavy-duty vehicle fleets, which has led to a significant increase in the number of registered heavy-duty vehicle fleets. Moreover, China IV for heavy-duty vehicles has been postponed nationwide; thus, the actual NO_X emission factors of on-road heavy-duty trucks have not yet been improved.

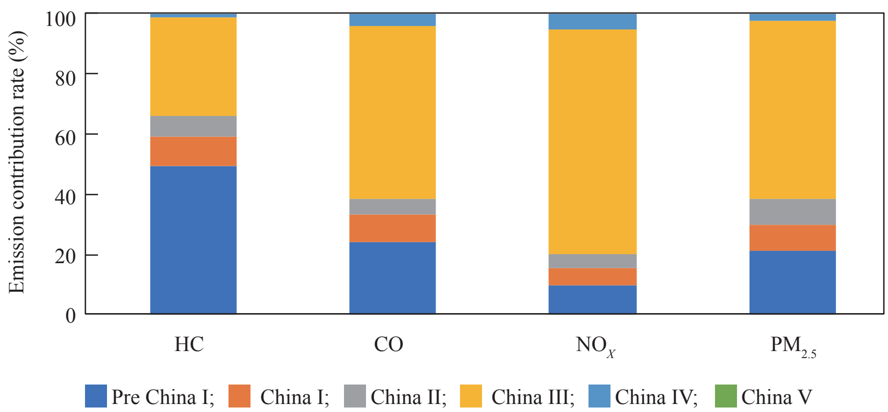

Fig. 4. Contribution rates of heavy-duty diesel trucks using different emission standards of pollutant emissions.

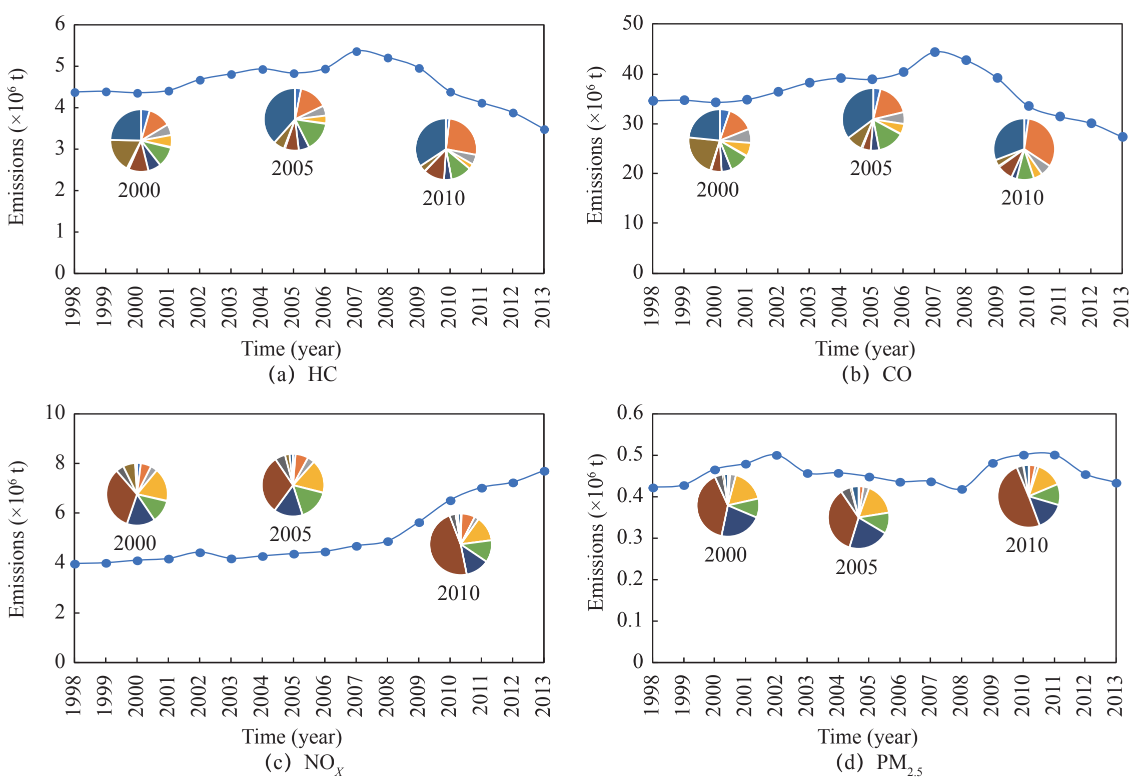

Fig. 5. Historical emission trends of motor vehicle pollutants in China.

3 Analysis of future emission trends of motor vehicle pollutants

3.1 Predictive analysis of the number of registered motor vehicles

To more accurately predict the future growth trend of motor vehicles, a motor vehicle prediction model was constructed and is presented in this paper, which takes into account the historical change trend of each vehicle type, future social and economic development trend, and other related factors. Fig. 6 shows the predicted trends of the number of registered motor vehicles in China, indicating that by 2030, China will have 390 million automobiles—nearly 280 automobiles per 1000 people—and the number of motor vehicles will reach 490 million.

3.2 Predictive analysis of vehicle emission factor

For this study, a variety of research results were combined to predict the future trend of vehicle emission factors; and the potential vehicle emission reduction technologies and vehicle emission regulatory limits in European and the U.S are mainly referred.

To improve the fuel economy while reducing their pollutant emissions, the Euro-V emission standard places higher requirements on the fuel economy compared to those previously established, introducing advanced energy-saving control technologies, such as variable valve timing, gasoline direct injection (GDI), and turbocharging [6]. In particular, GDI technology can significantly improve fuel economy, but the $PM_{2.5}$ emitted is higher in concentration than that emitted from traditional gasoline vehicles having multi-point injection fuel systems [7]. Therefore, the Euro-V emission standard sets $PM_{2.5}$ emission limits specifically for vehicles with GDI technology [8]. The Euro-VI emission standard further strengthens the control of particulate emissions, requiring vehicles with GDI technology to be equipped with a gasoline particulate filter to reduce $PM_{2.5}$ emissions [9].

As new energy vehicles gradually enter the market, the benefits of pollutant emission reduction for hybrid electric vehicles (HEVs), plug-in HEVs (PHEVs), and battery electric vehicles (BEVs) should be investigated in order to obtain an accurate model of the emission reduction benefit. In this study, only the energy consumption and pollutant emissions are considered for an operating vehicle; therefore, the emissions and fuel consumption of a BEV can be considered to be zero. Related research [10] and on-road test data show that HEVs have approximately 30% less emissions compared with traditional gasoline vehicles, and PHEVs are assumed to have 50% less emissions compared with traditional gasoline vehicles [11]. The predicted pollutant emission levels of light-duty vehicles are presented in Fig. 7.

Most European heavy-duty vehicles have adopted SCR technology in the implementation stage of the Euro-IV emission standard, and such technology has been constantly improved and

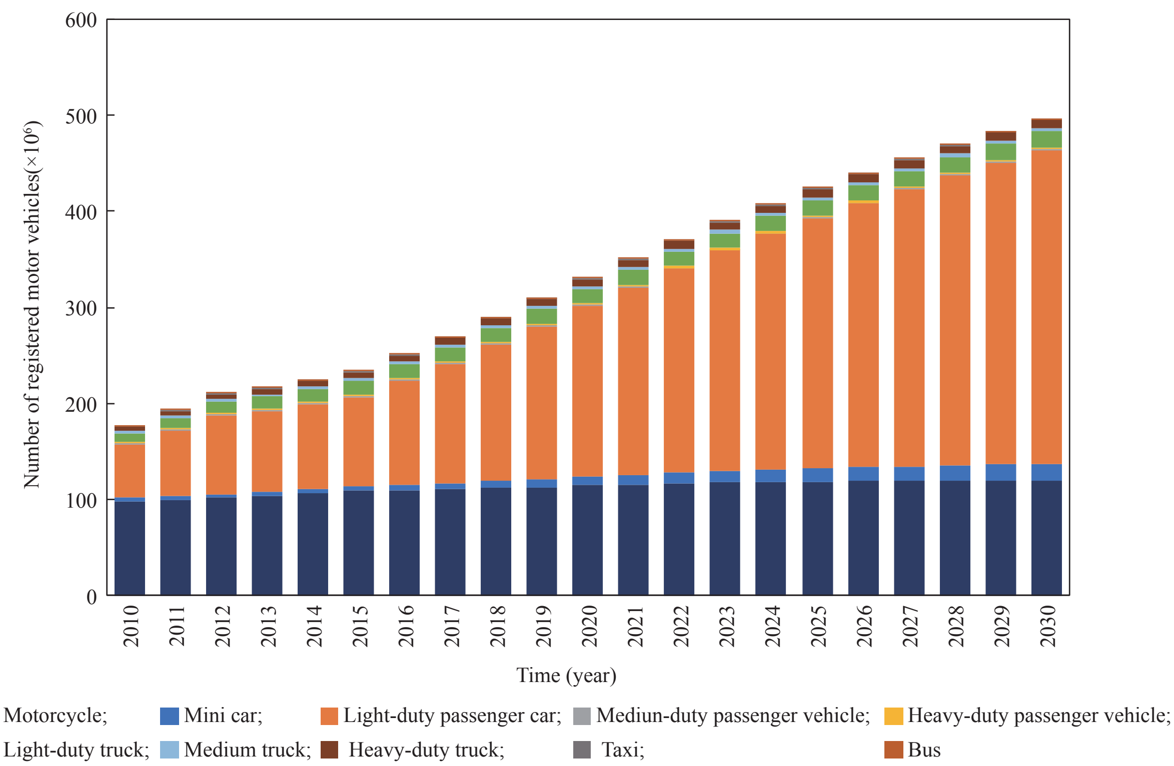

Fig. 6. Predicted trends of the number of registered motor vehicles in China in 2030.

adopted in the implementation stages of the Euro-V and Euro-VI emission standards. SCR uses a urea-based reducing agent that provides a high conversion efficiency to remove NO_X and results in a small concentration of NO_2 among the NO_X residuals in the exhaust gas [12]. Additionally, the Euro-V and Euro-VI emission standards require the addition of DPF to reduce exhaust $PM_{2.5}$ emissions.

In this study, it is hypothesized that China IV and China V heavy-duty diesel trucks have 30%–50% less NO_X emissions compared with China III heavy-duty diesel trucks. With the implementation of China VI, emissions will decrease by 80%, in accordance with the relationship between the Euro-VI and Euro-V emission limits for NO_X. The $PM_{2.5}$ emissions of China IV heavy-duty diesel vehicles can be reduced by nearly 60% compared with China III heavy-duty diesel vehicles owing to the optimized combustion of the engine. Moreover, heavy-duty diesel vehicles using DPF in the future are expected to reduce $PM_{2.5}$ emissions by >90% compared with China III heavy-duty diesel vehicles.

In light of the current technical experience of European countries, to satisfy the ever-increasing emission control demand, the Euro-VI emission standard—which is representative of European emission standards—adopts the technical route of the exhaust-gas recirculation device (EGR)+DPF+SCR, i.e., adding EGR to the engine body while using the traditional SCR technology in the post-treatment process to reduce NO_X emissions and adopting the DPF technology for particulate capture.

The emission factors of heavy-duty vehicles adopting several main technical routes in the future are shown in Fig. 8. According to the European technical experience, in this study, China VI heavy-duty vehicles are assumed to reduce $PM_{2.5}$ emissions by 30% relative to China V heavy-duty vehicles.

3.3 Trend analysis of pollutant emissions

According to the aforementioned trend analysis results for the registered vehicle quantities and single-vehicle emission factors, in this study, a future-emission trend analysis for various types of pollutants was performed. In view of the main problems facing the coordinated development of China's automobile industry with environmental protection, vehicle emission control measures to be implemented in the future for achieving coordinated development are proposed. They involve setting up five increasingly rigorous emission control scenarios: "baseline," "restricted emission," "travel optimization," "vehicle purchase restriction," and "introduction of new energy vehicles." The specific control measures for each emission control scenario are presented in Table 1.

Fig. 9 shows the predicted emission trends of various pollutants (HC, CO, NO_X, and $PM_{2.5}$) for China's motor vehicles under different emission control scenarios.

In the baseline scenario, the total automobile emissions of CO and HC in China will continue to decline until 2020. After

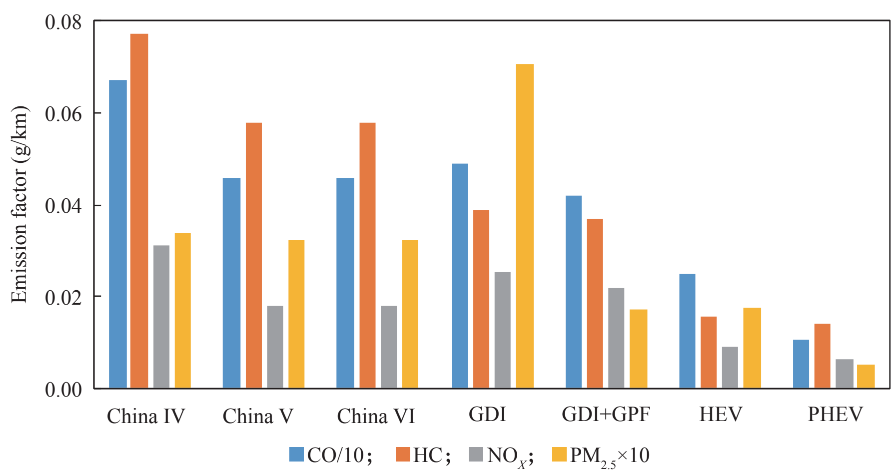

Fig. 7. Predicted pollutant emission levels of China's future light-duty vehicles.

Table 1. Control measures under each emission control scenario.

Scenario number	Scenario name	New-car emission standard	Fuel standard	Travel limit on small passenger cars	Vehicle purchase restriction	Allowed to add new energy vehicles
1	Baseline scenario	Baseline	Baseline	No	No	No
2	Restricted emission	More rigorous	More rigorous	No	No	No
3	Travel optimization	More rigorous	More rigorous	Travel optimization	No	No
4	Vehicle purchase restriction	More rigorous	More rigorous	Travel optimization	Yes	No
5	Introduction of new energy vehicles	More rigorous	More rigorous	Travel optimization	Yes	Yes

2020, despite the full elimination of old, high-emission vehicles, i.e., China I vehicles and those before China I, owing to the pressure of the increasing number of registered vehicles, it is anticipated that the emission of CO and HC in the baseline scenario will stop reducing and even begin to gradually increase. As previously mentioned, the NO_X emission factor of heavy-duty diesel vehicles before China III did not significantly improve with the tightening of emission standards. Therefore, in the scenario without any emission control measures, the total vehicle emissions of NO_X in China will not show any decline within 20 years from 2010. With the continuous growth of road transport demand and the increasing number of registered heavy-duty vehicles, the total national NO_X emissions from automobiles will reach 1.027×10^7 t by 2030, i.e., a 37% increase from 2010, amounting to an average annual growth rate of 1.6%. Therefore, it can be foreseen that if the automobile emission control of NO_X is not strengthened as soon as possible, China will face a severe challenge in achieving its goal of reducing the NO_2 concentration and controlling the level of $PM_{2.5}$ nitrates in its urban atmospheric environments, which will directly affect the total

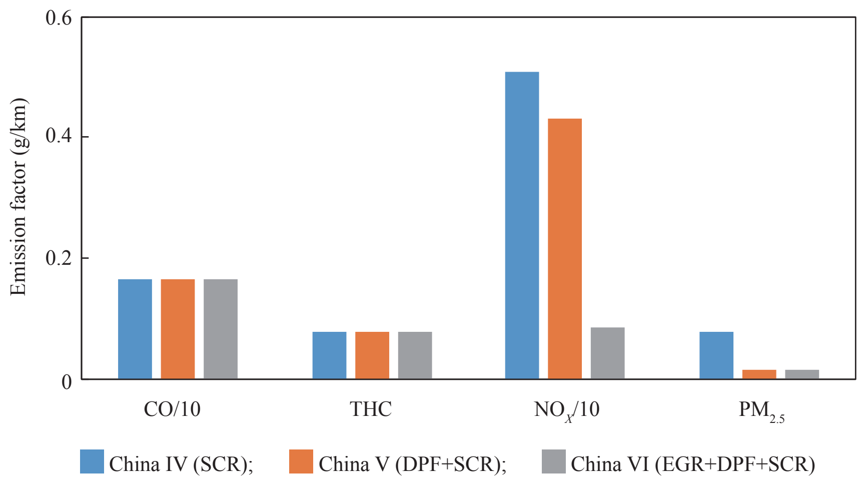

Fig. 8. Emission factors of the main technical routes of China's heavy-duty vehicles in the future.

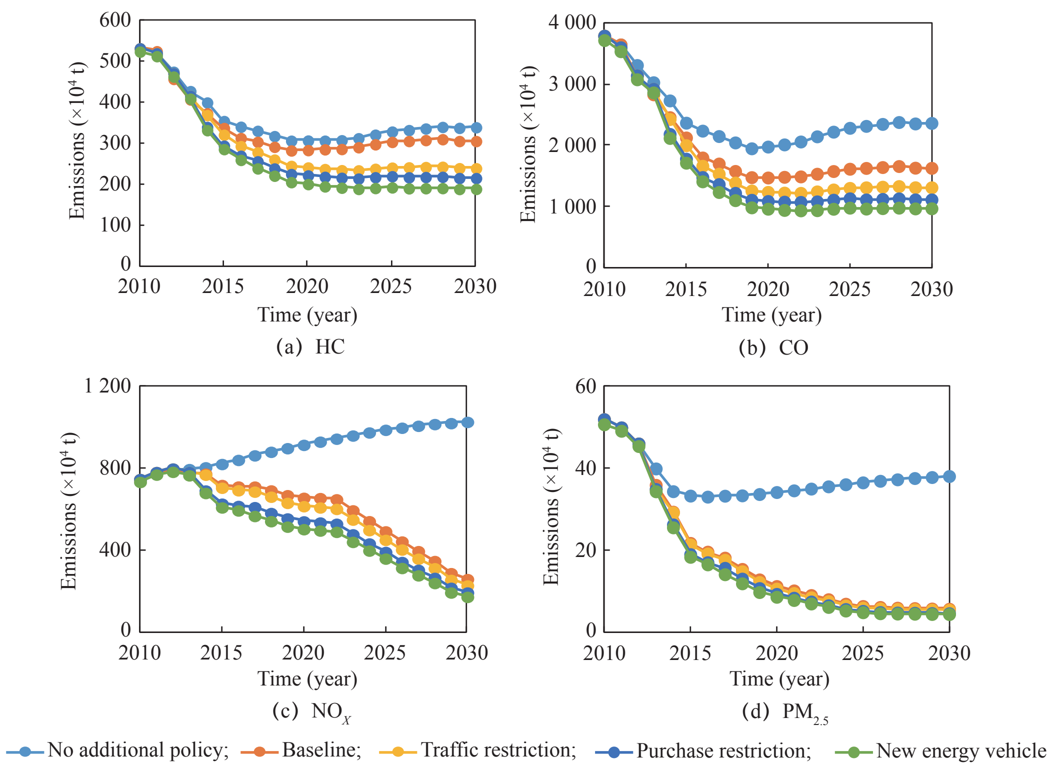

Fig. 9. Predicted emission trends of China's vehicle pollutants under different scenarios.

emissions of atmospheric pollutants.

In the case of stricter emission control, with the gradual increase of emission standards and vehicle fuel quality, the total CO and HC emissions will gradually reduce relative to the baseline scenario. By 2020, for example, the emissions of CO and HC in the restricted emission scenario will decrease by 61% and 47%, respectively, compared with those in 2010. CO and HC emissions—compared with those for the baseline scenario in the same period—will further reduce by 25% and 8%, respectively. However, relevant data show that HC has a limited contribution rate for further emission reduction.

Heavy-duty diesel vehicles with updated emission standards (China IV, V, and VI) will be gradually introduced in the restricted emission scenario to promote NO_X emission control. These vehicles conforming to new standards will rely on advanced post-treatment devices such as SCR equipment to control NO_X emissions. From 2012 to 2020, the total NO_X emissions will reduce by 18%, amounting to an average annual reduction rate of approximately 3%. This is mainly due to the gradual increase in the market share of China IV/China V heavy-duty diesel vehicles, as well as the continuous reduction of the market share of diesel trucks before China III. Subsequently, the market share of the heavy-duty diesel vehicles conforming to the new emission standards will grow in an accelerated manner, resulting in a faster reduction of total vehicle NO_X emissions. Given these assessment results, it is proposed that in a restricted emission scenario, the vehicle NO_X emissions of China will decrease annually by approximately 6% within 10 years from 2020, amounting to a total emission reduction of approximately 50%.

Regarding $PM_{2.5}$ in the restricted emission scenario, more rigorous emission control is anticipated with the gradual widespread use of heavy-duty diesel vehicles conforming to new emission standards and the elimination of heavy-duty diesel vehicles conforming to old emission standards, which will alleviate the problem of high emissions, with automobile $PM_{2.5}$ being similar to automobile NO_X in terms of the total emission trend. From 2020–2030, the total emissions of automobile $PM_{2.5}$ will reduce by 39% in the restricted emission scenario, amounting to an annual average emission reduction of 5%. If no stricter emission control measures have been implemented by 2030, the total emission of automobile $PM_{2.5}$ will tend to stabilize without significant reduction.

Implementation of more stringent control measures, including travel optimization and new-car purchase restrictions, will significantly reduce the number of registered light-duty vehicles and the annual mileage. This will improve traffic conditions, thereby continuously and effectively reducing HC and CO emissions. The assessment results of this study indicate that by 2030, implementation of a more stringent scenario, such as new-vehicle purchase restriction and travel optimization, can reduce HC emission by 33% compared with a typical scenario. If further efforts are directed toward vigorously advocating new energy vehicles and enabling them to rapidly enter the private vehicle market, HC emission will be further reduced by 8%. For NO_X and $PM_{2.5}$, the implementation of the aforementioned stringent control scenario can reduce emissions by 28% and 22%, respectively, compared with the restricted emission scenario.

4 Route and key direction for coordinated development of automobile industry with environmental protection

The overall goal for the coordinated development of China's automobile industry with environmental protection is to reshape the public transportation system in the urbanization process, encourage ecofriendly and sustainable travel modes, and build a comprehensive vehicle–fuel–road-integrated emission control system.

In accordance with the overall goal, the route and key direction for the coordinated development of China's automobile industry with environmental protection are proposed, as follows:

(1) Planning and developing a roadmap for automobile emission pollution control technology and a roadmap for the development of the automobile industry that are suitable for China's socioeconomic development characteristics;

(2) Reshaping the urban public transportation system and encouraging an ecofriendly and sustainable travel mode;

(3) Establishing an integrated environmental management system incorporating new vehicles, in-use vehicles, and vehicle fuel quality;

(4) Establishing and improving a vehicle emission supervision system and strengthening the supervision of the in-use vehicle fleet emission;

(5) Organizing and implementing the "Clean Diesel Engine Action Plan" as soon as possible in the framework of national strategies, such as the "Belt and Road" Initiative and the "China Manufacturing 2025" Plan;

(6) Scientifically evaluating the emission reduction effects of advanced technologies and alternative fuels and actively promoting the application of new energy vehicles in public and private vehicle fleets in a step-by-step manner.

Specific recommendations are as follows:

(1) It is mandatory to plan and develop a roadmap for automobile emission pollution control technology and a roadmap for the development of the automobile industry that are suitable for China's socioeconomic development characteristics. The simultaneous establishment of an advanced public transportation system and a rigorous vehicle emission control system should be the future development direction of China's urban vehicle emission control. A complete urban vehicle emission control system should include new vehicle control, in-use vehicle control, vehicle fuel control, traffic management, and economic instruments,

with all aspects complementing one another and being indispensable. In the future, it is necessary to pay close attention to the simultaneous control of fuel economy and pollutant emissions and to develop control strategies integrating key regions. There are various types of vehicle pollution emissions, and the control effects differ significantly. NO_X is a primary pollutant in vehicle emission and is the most difficult pollutant to curb given current vehicle emission control technology, and the control strategies vary dramatically among different vehicle types. For example, NO_X control should focus on heavy-duty diesel vehicles, while light-duty gasoline vehicles should also be taken into consideration.

(2) It is mandatory to reshape the urban public transport system and encourage ecofriendly and sustainable travel modes. It is necessary to vigorously develop the public transportation system in key areas and cities (or city groups); prioritize the development of ecofriendly travel modes such as subways, buses, and public bicycles; and guarantee the right of bus routes to promote bus priority. Traffic management and economic policies should be made full use of to regulate the level of private vehicle activities in key areas and large cities and to strive to limit the annual average mileage of private, small passenger cars to 10 000 km by 2030. The environmental benefits of measures such as traffic regulation and economic management/incentives should be evcluated scientifically. Relevant measures in a timely manner, e.g., conducting traffic restrictions based on the last digit of vehicle plate numbers and the traffic areas (low-emission vs. high-emission areas) and increasing parking fees and traffic congestion charges, should be promoted to effectively reduce the use of private vehicles.

(3) For integrated environmental management of new vehicles, in-use vehicles, and fuel quality, it is necessary to build a full-chain vehicle pollution prevention and control system integrating regional coordination, Internet of Things, and big data technology. A unified China VI emission standard should be implemented in a step-by-step manner. For megacities such as Beijing and Shanghai, it is necessary to begin the development of a roadmap for control standards after China VI so that the megacities can transition to stringent emission standards after 2020 while simultaneously implementing the China VI standard for vehicle fuel quality. It is necessary to utilize the Internet of Things and transportation-emission big data technology to build a real-time, dynamic, regionally unified environmental management system and law enforcement platform for mobile pollution sources, so as to achieve information sharing within the region and implement collaborative supervision. It will be more important to perform management of vehicle emission reduction using economic incentives and refined management, for establishing an integrated management and control mode that combines environmental trading platforms, low-emission zones, and strengthened supervision of old vehicles. This will limit the intensity of old-vehicle activities and encourage the timely elimination of old vehicles.

(4) Management of large vehicle fleets should be the focus of future vehicle emission control. It is necessary to vigorously promote the implementation of the enhanced in-use vehicle inspection/maintenance system and encourage the adoption of advanced detection techniques. For example, it is desirable to use the acceleration simulation mode or IG195 to detect light-duty vehicles and the lug-down test mode to detect heavy-duty vehicles. These technologies may be combined with the deployment of advanced on-board diagnostic systems and portable emission measurement systems, as well as the use of chasing measurement and remote sensing testing technologies, to strengthen vehicle supervision. An efficient in-use vehicle maintenance system should be established to ensure that regulated high-emission vehicles are maintained in a timely manner. It is necessary to enforce the implementation of the elimination and replacement system for old vehicles and to completely eliminate heavy-duty yellow-label vehicles nationwide by the end of 2017. It is also necessary to implement measures for China II and some China III heavy-duty diesel vehicles in key areas, install post-treatment equipment such as DPFs, encourage technology upgrades for in-use vehicles, and strengthen emission monitoring of modified vehicles. It is necessary to encourage the use of economic and other means to establish a regular elimination system for in-use vehicles. For vehicles with high-intensity usage, such as taxi fleets and bus fleets, it is necessary to rigorously conduct mandatory periodic replacement of post-treatment equipment.

(5) In light of the successful experiences of Europe and the United States, the launch of the "Clean Diesel Action Plan" in the framework of national strategies is wrgent, such as the "Belt and Road" Initiative and the "China Manufacturing 2025" Plan. The "Clean Diesel Action Plan" will focus on the implementation of special unified clean-up projects for diesel engines in on-road diesel trucks, construction machinery, agricultural machinery, and ships, among other key application fields of diesel engines, along with project demonstrations in key regions. Advanced technologies such as DPF should be applied as quickly as possible to as many vehicles and engines as possible to greatly reduce the emissions of pollutants such as fine particles and black carbon. It is necessary to design a mandatory scheme requiring high-emission diesel engines to be eliminated within a prescribed time period and adopt a variety of means, such as financial support and market support, to increase the rate of elimination of old diesel engines. It is necessary to optimize the vehicle fleet structure and build an ecofriendly, low-carbon, and intelligent regional freight system.

(6) It is necessary to scientifically evaluate the emission reduction effects of advanced power technologies and alternative fuels and actively promote the application of new energy vehicles in public and private vehicle fleets in a step-by-step manner.

Given that advanced power technologies and alternative fuels can be used via a variety of technical combinations, it is necessary to perform a scientific, lifecycle-based potential assessment of energy conservation and emission reduction for different combinations of fuel scenarios, different vehicle power technologies, and different types of post-treatment equipment. According to the assessment, it is necessary to vigorously advocate the technical combination that has a satisfactory overall performance in energy conservation and emission reduction. With regard to the energy advantages and emission control priorities in each region, it is necessary to preferentially promote the use of new energy vehicles equipped with a variety of technologies—such as natural-gas vehicles, HEVs, and BEVs—in public vehicle fleets with high-intensity use, such as city buses and taxis. According to the experience with public vehicle fleets, it is necessary to promote the use of the aforementioned ecofriendly vehicles in private vehicle fleets. Attention should be paid to the differences between vehicle technologies regarding their energy conservation and emission reduction performance for the same fueling system.

5 Conclusion

The current status and historical trends of China's automobile emissions are modeled and quantitatively evaluated, and the environmental impact of China's automobile exhaust emissions in various emission-reduction scenarios is analyzed. The bottlenecks and main issues facing the coordinated development of China's automobile industry with environmental protection are identified and analyzed. Finally, the route and key direction for the coordinated development of China's automobile industry with environmental protection are proposed, along with relevant suggestions.

References

[1] National Bureau of Statistics of the PRC. China Statistical Year book 2015 [M]. Beijing: China Statistics Press, 2015. Chinese.

[2] China Association of Automobile Manufacturers. China Automotive Industry Yearbook 2015 [M]. Beijing: China Commercial Publishing House, 2015. Chinese.

[3] Wu X, Wu Y, Zhang S, et al. Assessment of vehicle emission programs in China during 1998—2013: Achievement, challenges and implications [J]. Environmental Pollution, 2016, 214: 556–567.

[4] Wu X M. Integrated emission mitigation strategies of air pollutants and CO2 for on-road vehicles in China. [D]. Beijing: Tsinghua University (Doctoral dissertation), 2016. Chinese.

[5] Wu Y, Zhang S J, Li M L, et al. The challenge to NO*X* emission control for heavy-duty diesel vehicles in China [J]. Atmospheric Chemistry and Physics, 2012, 12(19): 9365–9379.

[6] Andress D, Das S, Joseck F, et al. Status of advanced light-duty transportation technologies in the US [J]. Energy Policy, 2012 (41): 348–364.

[7] Zhan R, Eakle S T, Weber P. Simultaneous reduction of PM, HC, CO and NO*X* emissions from a GDI engine [R]. Sea World Congress & Exhibition, 2010, 8(2): 102–106.

[8] Fontaras G, Franco V, Dilara P, et al. Development and review of Euro 5 passenger car emission factors based on experimental results over various driving cycles [J]. Science of the Total Environment, 2014, 468–469: 1034–1042.

[9] Quiros D, Hu S H, Hu S S, et al. Particle effective density and mass during steady-state operation of GDI, PFI, and diesel passenger cars [J]. Journal of Aerosol Science, 2015 (83): 39–54.

[10] Bennion K, Thornton M. Fuel savings from hybrid electric vehicles, NREL/TP-540-42681 [R]. Golden: National Renewable Energy Laboratory, 2009.

[11] Millo F, Rolando L, Fuso R, et al. Real CO2 emissions benefits and end user's operating costs of a plug-in Hybrid Electric Vehicle [J]. Applied Energy, 2014, 114: 563–571.

[12] Cooper J, Phillips P. Final analysis: NO*X* emissions control for Euro 6 [J]. Platinum Metals Review, 2013, 57(2): 157–159.