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Review

Reducing energy consumption and pollution in the urban transportation sector: A review of policies and regulations in Beijing

Lishan Sun [a], Tong Zhang [a], Shuli Liu [b,*], Kun Wang [a], Tom Rogers [c], Liya Yao [b], Pengfei Zhao [a]

[a] Key Lab of Traffic Engineering, Beijing University of Technology, No. 100 Pingleyuan, Chaoyang District, Beijing, 100124, China
[b] School of Mechanical Engineering, Beijing Institute of Technology, China
[c] School of Energy, Construction and Environment, Coventry University, Coventry, CV1 2FB, UK

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ABSTRACT

With the rapid growth of urbanisation and associated vehicle numbers in China, urban transportation has become responsible for a large increase in the country's energy consumption and, consequently, its air pollution levels. Beijing has been making significant efforts to reduce transportation sector energy consumption and pollution. However, owing to the existence of a large number of private cars, the implementation of effective energy consumption and emission reduction measures has been difficult to achieve. This paper reviews the policies and regulations that have so far been developed to tackle Beijing's transportation sector issues. Perspective and analysis are given on the specific policies and regulations that have been employed, focusing on the overarching regulation mechanism, public transportation infrastructure, vehicle technology-related measures, vehicle activity-related measures and eco-driving -related measures, relevant experiences and lessons are summarised. A key finding concludes that the implementation of driving restriction policy can restrain pollutants emissions significantly, it shows energy consumption and emission reduction should not only be applied to public transportation, but the effective control of emissions from private cars should also attract more attention. To better control energy consumption of urban transport, various measures and solutions are proposed and discussed, including the further popularizing of eco-driving and the widespread application of e-mobility. Specific proposals for developing urban transportation policy are also discussed.

Contents

* Corresponding author.
E-mail address: shuli79@126.com (S. Liu).

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1. Introduction

Rapid economic development in China over the last 30 years has seen Beijing's urban transportation mode change and expanded significantly (Feng and Wang, 2018; Peng et al., 2015). This has been accompanied with an increase in the sector's primary energy consumption (Yang et al., 2017; Li and Zhao, 2015) and, consequently, its impact on air pollution (Duan, 2018; Li and Zhao, 2015). Given its high emission levels, Beijing's urban transportation system has become a target for Energy Conservation and Emission Reduction (EC&ER) (Zhang et al., 2019; Yang et al., 2017; Li et al., 2019; Wang et al., 2018), in particular the emissions from the vehicle exhausts. This links to a wider, more global question about how to effectively control vehicle emissions in cities, particularly in developing countries, which tend to have far higher pollution problems than developed countries (Yang et al., 2017; Kelly and Zhu, 2016). A large number of researchers have carried out a series of studies in both theory evaluation and practice application (Yang et al., 2017; Li, 2017; Zhou et al., 2011). Measures for reducing energy consumption and emissions in the field of transportation have been summarised and reviewed (Lu et al., 2019; Wu et al., 2017; Hao et al., 2015), with the most retrospective papers and research related to the topic of this article summarised in Table 1.

Of the above listed articles, six studied energy consumption and pollutant emission individually (Lu et al., 2019; Ji et al., 2019; Wu et al., 2017; Lee et al., 2017; Meng et al., 2017; Han et al., 2014); six interpreted the field of energy consumption and emission reduction policies (Chen et al., 2019; Wu et al., 2017; Ong et al., 2012; Huo et al., 2012); and two articles covered the sustainable development of the transportation industry (Wang, 2019; Lee et al., 2017). However, there is evidently a lack of an interpretation of the whole city's energy consumption and emissions reduction policies. There is also no study that compares and analyses the effect of public transport and private vehicles on energy consumption and emissions reduction respectively. Therefore, these two points are reviewed and analysed in this article.

Private cars make up an increasing proportion of vehicles in Beijing over the last 17 years, a trend that is expected to continue in the coming years (Fig. 1) (National Bureau of Statistics of China, 2019.). Therefore, implementing EC&ER policies in just the public transport system alone will not have the desired results on the reduction of energy consumption and air pollution, and more attention to the control of private vehicles is evidently required.

Moreover, a better understanding of EC&ER for urban transportation will prove beneficial in the design of an integrated transport framework, and help to implement policies for solving urban expansion issues such as energy, planning, traffic and pollution. Beijing's Transportation Management Department has accumulated good experiences and lessons in reducing EC&ER through the careful design of policy and strategy plans, and related research and applications in recent years. Facing pressure from the rapid growth of urban transportation demands in China today (Tang et al., 2016), it is necessary to summarise and filter these experiences to help with the city's future development. In this research, the experiences and lessons learned from Beijing urban transportation in EC&ER are analysed, including public transportation and private vehicles. The effects of EC&ER in these two aspects have been compared and some noteworthy experiences are summarised, as are the challenges and predictions for promoting EC&ER in other mega-cities around the globe.

2. Method

According to above research purpose and refer to literature similar to this article (Gustav Sandin et al., 2018), the method used in the literature review consists of two steps:(i) identifying the literature to study, by a search in data bases combined with a set of rules for selecting the relevant pieces of literature, and (ii) mapping

Table 1
Key studies related to energy consumption and emissions reduction in urban transportation.

	Authors of key studies	Research focus	Findings and results
Energy	Lu et al. (2019)	Potential energy conservation and CO2 emissions reduction related to China's road transportation	Achieve China's energy conservation and emissions reduction goals, quantity and structure should be emphasized in the short term
	Lee et al. (2017)	Green transportation and low emission technologies are key aspects for climate-resilient economic growth	Energy efficiency improvement in Asia will be a key factor to tackle the climate change issues
	Meng et al., 2017	Exploring the sustainability of innovation in public urban transportation systems	Innovative Bus Rapid Transport shows better resource use and environmental performance
Consumption	Han et al., 2014	Province-level motorised travel, energy consumption and GHG emissions in China	Significant regional disparities on urban passenger transport are observed
	Hao et al. (2015)	Energy consumption and greenhouse gas emissions from China's passenger vehicles	Fuel consumption regulation plays an essential role in constraining GHG emissions growth
Policy	Chen et al., 2019	Analyzing the traffic policies on energy and environment systems (EES)	An electric cars' policy is enhanced by increasing the ratio of its power generated from renewable sources
	Ji et al., 2019	Impact of regional traffic pollution control measures on OC and EC in urban Beijing, China	Traffic policies executed in Beijing resulted in night time peaks of OC and EC, improvement of the air quality in Beijing benefits from strict control measures
	Wu et al., 2017	Vehicle emission controls in China are reviewed including measures related to vehicle, fuel, traffic and economic aspects	Strict standards, lowering usage and promoting electrification are essential to reduce CO_2 emissions
	Ong et al. (2012)	Analysing the trends of energy patterns and emissions of road transport	There is an urgent need to adopt suitable energy policy to balance energy demand and reduce emissions
	Huo et al., 2012	Various policies evaluated with a fuel economy and environmental impacts model	Fuel-consumption improvement policy could achieve greater benefit in reducing oil use
Sustainable development	Wang, 2019	Assessing road transport sustainability	Disposable income, governance quality and urbanization are significantly associated with the level of transport sustainability
	Lee et al. (2017)	The latest developments in water and energy conservation, green transportation, and low emission technologies are reviewed	The use of a holistic management system to integrate key areas for a long-term sustainability goal
EC&ER	Peng et al., 2015	Pollutants emissions of Tianjin's urban passenger transport sector between 2010 and 2040 under four scenarios	Emission standards are the most effective measure to reduce pollutant emissions
	Gao et al., 2015	Scenario prediction of energy consumption and environmental emissions of Beijing urban passenger transport between 2015 and 2030	The public transport scenario conducts better than the new energy vehicles scenario with respect to energy saving, but the new energy vehicle scenario performs better than the public transport scenario with respect to the reduction of SO_2 emission

the content of the selected literature by extracting information using a set of questions. These two steps are described below.

2.1. Identifying literature

We searched for literature in the Science Direct and Google Scholar databases, in September and October of 2019, using the following Boolean search string: ("transportation energy consumption" OR "transportation emissions reduction" OR EC&ER OR (Beijing energy consumption OR Beijing emissions reduction)) AND (transportation energy OR transportation consumption OR Beijing transportation energy policy OR energy sustainable development). To ensure identification of all relevant literature, we also included relevant studies encountered when screening or reviewing other studies. To select a relevant and manageable set of studies among the identified pieces of literature, we set up the following selection rules:

1. Exclusion of studies in other languages than English or Chinese (the languages the authors of this report handle fluently).
2. Exclusion of duplicates (e.g., if a technical report was later published in a peer-reviewed journal, or if a peer-reviewed paper was later included in a doctoral thesis, we only consider the peer-reviewed paper).
3. Inclusion of any type of available study (published, whether peer-reviewed or not).
4. Inclusion of studies on any category of Transportation energy (Transportation energy consumption, Transportation energy policy, Transportation energy consumption, etc.).

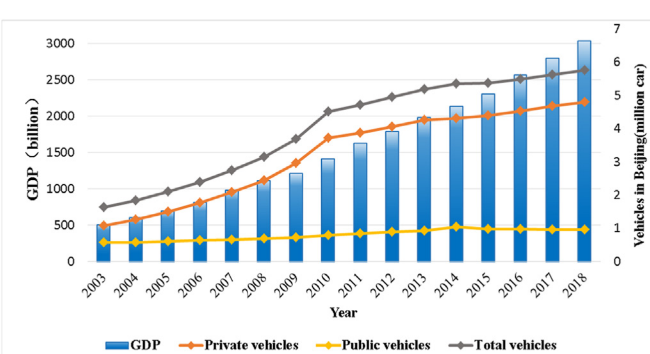

Fig. 1. Beijing's economic development vs. vehicle population from 2003 to 2018.

2.2. Mapping content

The content of the selected studies were mapped by extracting information using the following questions.

1. What is the aim(s)?
2. What method(s) is used?
3. What transportation mode(s) is aimed?
4. What transportation policy(s) is studied?

5. In the case of transportation policy, is it on transportation regulations mechanism, transportation technology, traffic activity or transportation infrastructure?
6. What are the conclusions regarding EC&ER of policies and regulations in Beijing?

3. Background

3.1. Research background of transportation, GDP, energy consumption and pollution for Beijing

According to the National Bureau of Statistics of China, Beijing's vehicle fleet has increased from 1.07 million in 2003 to 5.746 million in 2018, and is expected to maintain its recent growth rate into the future (Beijing Municipal Bureau of Statistic, 2019). With accelerating urbanisation, the quick development of China's economy and its urban population growth has had a considerable impact in its energy consumption in recent years (Yang et al., 2017). Figs. 1 and 2 show the relationships between economic growth, population growth and the size of the vehicle fleet. The GDP of Beijing's economy increased to 3032 billion USD in 2018, over 6 times its 2003 value, which is mirrored by an increase in its private vehicle numbers (Since, 2010, Beijing has embarked 'Vehicle Purchase Restricted Policy' to restrict car growth.). Public vehicle numbers increase steadily, reflecting the quick development of the city's subway transport system; with larger and more efficient subway trains resulting in more users per vehicle.

(National Bureau of Statistics of China, 2019).

In 2019, Beijing covered an area of 16,411 km^2 and had a permanent resident total population of 21.53 million, with a density of 1311 residents per km^2. This is nearly 1.5 times the population density in 2003 (890 residents per km^2) and this substantial increase population, along with economic activity, has generated a large demand for urban transportation. The total number of public vehicles was 0.956 million in 2018, 0.396 million more than 2003. Private vehicles rose to 4.79 million in 2018, over 4.47 times its 2003 level, with a proportion of 83.3% of the total vehicles (National Bureau of Statistics of China, 2019). There is a clear link between the urban population and the increase in the number of vehicles, which share a similar growth trend. Figs. 1 and 2 illustrates this link and both are motivating factors impacting the continuous growth of vehicle numbers.

(National Bureau of Statistics of China, 2019).

Peking University's Guanghua Management School reports that Beijing has experienced pollution levels that exceed emissions standards 437 times between 2013 and 2017, an average of 1.7 times per week (Guanghua School of Management, 2018) and each time, these occurrences last an average of nearly three days.

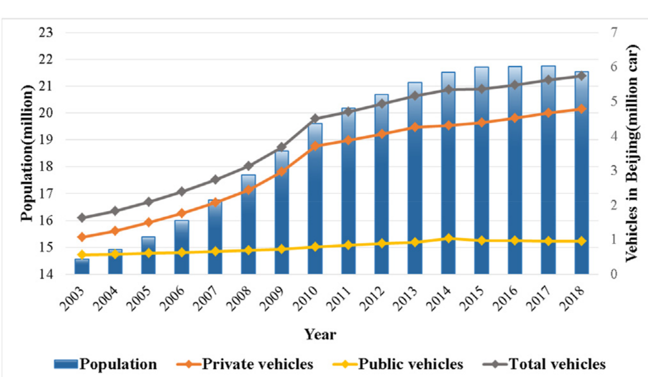

Fig. 2. Beijing's population statistics vs. vehicle numbers.

Compared with the data of 2015, the average PM 2.5 pollution of 2016 and 2017 had significantly increased by 10.4% and 7.4%, respectively. In other words, Beijing was in the pollution state for 119 h (almost five days) per week on average. Moreover, 370 out of 437 times (85%) of the pollution events reached a serious pollution level.

Urban transport development has caused a series of crises in energy consumption, air pollution, and daily traffic jam. Energy consumption and emissions in the transport sector of Beijing have shown an escalating trend from 2005 to 2018. Fig. 3 shows the gasoline consumption in Beijing's urban transportation sector rose from 0.52 million toe in 1990 to 4.83 million toe in 2018. In 2018 the total amount of fuel consumed by motor vehicles was over 0.7 million toe and the vehicle carbon monoxide (CO), nitrogen oxide (NO_X) and Hydrocarbon (HC) emissions account for 86%, 56% and 32% of the total emissions of Beijing respectively (Beijing Municipal Ecology and Environment Bureau, 2019).

As displayed in Fig. 3, the growth of motor vehicles is consistent with the overall trend of energy consumption rise, which is accompanied with serious vehicle pollution. The number of public transport vehicles remained almost unchanged from 2003 to 2010, but the energy consumption increased rapidly, induced by the large increase in private vehicles. The growth of gasoline consumption is mainly from private cars. Fig. 3 shows that the number of buses has remained stable in recent years and the subway sues the electric rather than gasoline which is the main developing travel mode in public transport.

(National Bureau of Statistics of China, 2019).

3.2. Successful case studies of pollution control measure in developed counties

From cases experienced by developed countries in the 1990s, it is possible to understand methods to reduce air pollution by comprehensive management and control. In 1993, the countries making up the Organisation for Economic Cooperation and Development (OECD) owned 70% of the world's cars. The largest car owner in the OECD was the United States, with 58% of households owning more than two cars, and 20% of households owning more than three cars. In terms of car ownership, the United States had 561 cars per 1000 people. In all OECD member countries, car ownership was still steadily rising, and there was no sign of market saturation. For the United States, which heavily relies on cars, reducing car ownership is very difficult to implement. Therefore, the Government adopted the comprehensive emission's improvement method and the effect of

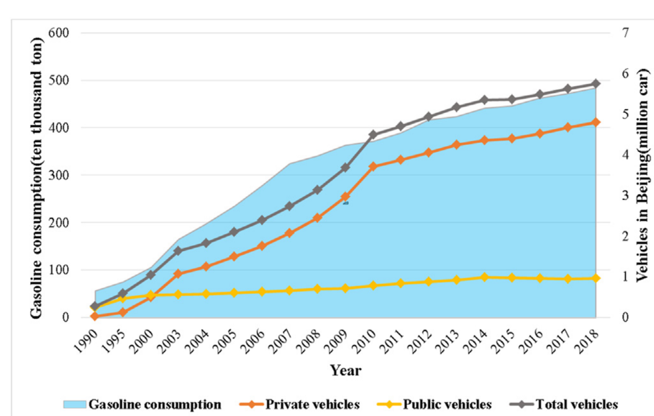

Fig. 3. Share of motor vehicles, and gasoline consumption for Beijing, in calendar years.

this decision was notable. Through 20 years of effort, the US economy continued to expand, and car mileage increased exponentially, while vehicle emissions pollutants decreased (Hao, 2011).

Taking the Californian city of Los Angeles as an example, in 1976 there were 279 air pollution days. The risk of bronchitis was 33% more likely than in other areas of the US and asthma was 74% more likely. In order to alleviate pollution, air quality in Los Angeles has been placed under three levels of management. The highest level is the United States National Environmental Protection Agency, the next is the California State Government, and the third is the Southern Coast Air Quality Zone (Zhang, 2014).

The effect of integrated pollution control measures was significant. Over the next 20 years, while the population and economy of the south coast of California continued to grow, its air quality improved. Fig. 4 shows the trend of motor vehicle ownership, daily driving mileage and air pollution index in Los Angeles from 1975 to 2000 (Hao, 2011; Zhang, 2014). During the 1980s–1990s, the number of days of photochemical smog in Los Angeles continued to decline and the downward trend has continued (Fig. 4). The concentration of CO_2 in the atmosphere has also decreased. The results show that the annual number of pollution exceeding standard days reduced from over 100 during the 1970s to 10 in 2000.

(Hao, 2011; Zhang, 2014)

From the Los Angeles case, it can be learned that employing pollution control measures for vehicles can ease the air pollution pressure in Beijing. To reduce the pollution emissions from vehicles, the Beijing Transportation Management Department has implemented a series of policies and applications, which are analysed from four different perspectives in the following sections, namely, overall regulation mechanism, public transportation infrastructure, vehicle technology-related measures and vehicle activity-related measures.

Furthermore, this paper will summarise the achievements and challenges of the transportation field that Beijing is facing. The experiences and lessons of Beijing in the field of transportation are applicable to similar large cities with rapid population growth, high-density population and rapid economic development, including Bangkok, Mexico City, Mumbai.

3.3. Organisation of the paper

A technical roadmap for this paper is shown in Fig. 5. Section 4 of this paper analyses the mechanism of relevant regulations controlling the transportation sector's energy consumption and emissions. Section 5 introduces the control measures related to public transportation, including public transit EC&ER control measures, and infrastructure construction. Section 6 describes the technological advances of EC&ER in Beijing's private vehicle transportation. Section 7 summarises the controls of vehicles' activities in terms of the vehicle population, driving restriction, parking policies, eco-driving. Lastly, Section 8 concludes the experiences and lessons from the urban transportation EC&ER in Beijing and predicts the challenges, trends and needs in the future.

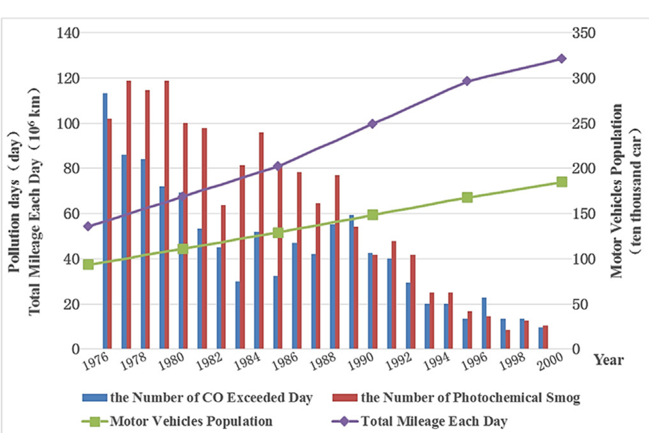

Fig. 4. Excessive pollution days, motor vehicle population, and total mileage each day in Los Angeles.

4. Overview of regulations mechanism to control transportation energy conservation and emission reduction (EC & ER)

4.1. Environmental protection law and regulation

The Chinese Government has paid great attention to the management of industrial environmental protection policies and released the relevant laws and regulations for the EC&ER of urban transportation (Zhu and Jiang, 2002). As early as 1989, China generated the "Environmental Protection Law of People's Republic of China" (State Bureau of Environmental Protection of China, 1989), which structured the legal foundation of environmental protection in China. After that, more than 15 laws and regulations at the National level and for the city of Beijing have been enacted focusing on the field of energy consumption and emissions reduction, and 8 of these related to the transportation sector. In 2004, the State Council promulgated "The air pollution prevention and control law of China" (State Bureau of Environmental Protection of China, 2005), which put forward the mandatory requirements on motor vehicle emission standards: Any institute and individual cannot manufacture, sell or import motor vehicles and vessels whose pollutant emissions exceed the prescribed emission standards.

As superior fuel oils (unleaded petrol and low-sulphur diesel) are less harmful substances, the Chinese Government promoted two policies to encourage and support the production and consumption of superior fuel oil, titled, "The People's Republic of China Renewable Energy Law (2005)" (Li and Wang et al., 2005), and "The medium and long-term special plan for energy saving" (2005) (China Council for International Cooperationon Environment, 2005). These two also put forward suggestions for EC&ER of urban traffic including rational planning transportation development mode, accelerating the development of public transport, and improving the efficiency of the comprehensive transportation system.

In practice, Beijing has developed a series of relevant EC&ER standards, regulations and measures. As early as 1999, Beijing formulated the "Beijing implementation measures of the People's Republic of China energy consumption law". With the heavy atmospheric pollution conditions in Beijing, another policy "Measures for the administration of environmental protection in Beijing city" was established in 2005. To further regulate the environmental standards, Beijing drafted "The Beijing air pollution prevention regulations" in 2012.

4.2. Action plan

Beijing Government has taken a series of actions to achieve EC&ER such as limiting the number of private vehicles, easing traffic congestion, advocating public transportation, clearing traffic field emission status, promoting private car energy saving and emission reduction and giving priority to the development of public transport. Distribution of EC&ER policies in the traffic field of Beijing municipal government departments is shown as Fig. 6 (Duan, 2018; Huo et al., 2012). A total of 6 action plans are recognised, as follows:

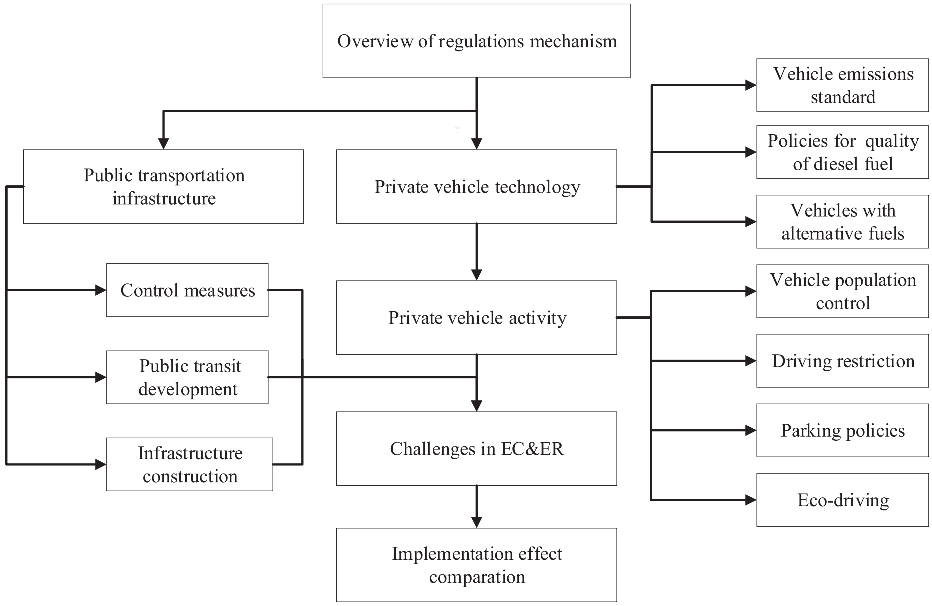

Fig. 5. Technical roadmap for this paper.

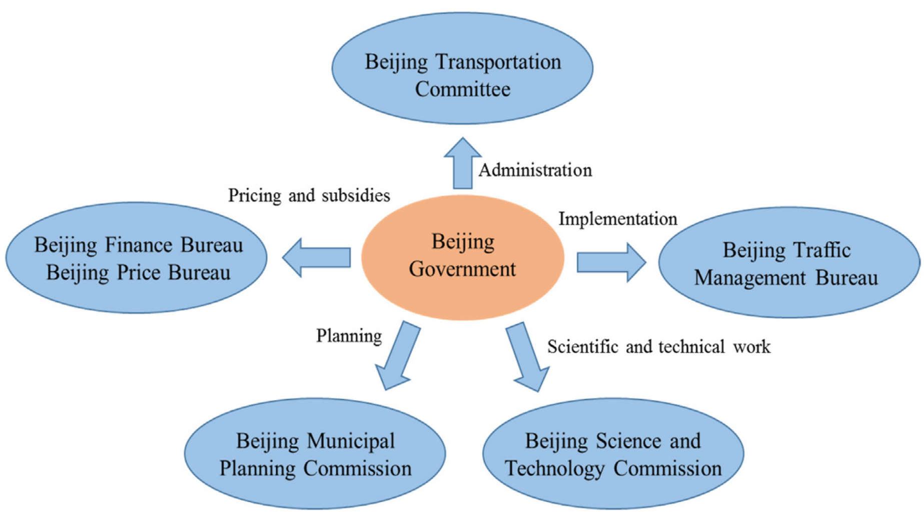

Fig. 6. The division of labour of the Beijing government on EC&ER in traffic field.

1. Since 1999, according to the different vehicle emission standards, Beijing has divided the city's vehicle fleet into yellow label vehicles and green label vehicles, and has begun to issue "Yellow" or "Green" environmental protection logos to all new vehicles. A yellow label is the abbreviation for heavy-polluting vehicles and means that the gasoline vehicles does not meet the China (I) Emission Standard or the diesel vehicles does not meet the China (III) Emission Standards. In comparison, a green label indicates that the vehicle emissions reach the China (I) or (III) Emission Standard or above.
2. In 2010, the Beijing Government announced "The opinions about promoting the scientific development of traffic in Beijing and supporting the work of reducing traffic congestion", which aimed to put forward comprehensive measures for relieving traffic congestion from the aspects of planning, construction, organisation and management.
3. In 2012, the Beijing Government released an action named "The strategic plan for energy consumption and emission reduction in the field of transport in Beijing (white paper) 2012–2020". Through the development of 9 special studies, the current situation of energy consumption and pollutant emission in the transport sector is systematically tackled in this white paper.
4. "Beijing city in 2012–2020 air pollution control measures", which has been promulgated in the same year, proposes the emission targets and safeguards for major pollutants, especially for PM2.5.
5. In October 2013, Beijing formulated the "Beijing 2013–2017 motor vehicle emission pollution control work program", which makes it clear that public transportation is essential for energy savings in its urban traffic system.
6. In 2019, the Beijing Government proposed "Regulations of Beijing Municipality on the prevention and control of motor vehicle pollution", which aimed to forbid drive motor vehicles that fail to pass the emission inspection on the road.

As a pioneer in controlling vehicle emissions in China, Beijing released the "Clean Air Action Plan 2013–2017" document in August 2013 to improve its urban air quality. This plan contains the most stringent emission control policies and strategies to be adopted for on-road vehicles of Beijing, including strict controls on the number of motor vehicles, rigid standards for new car exhaust emissions and fuels, an accelerated removal of old motor vehicles with high emission levels, actively promoting clean energy derived vehicles, an improvement in management policies, and an investigation into stricter punishment for the use of unregulated vehicles. Table 2 summarises the various laws and action plans that impact public and private vehicles in Beijing.

5. Beijing's control measures related to public transportation infrastructure

5.1. Control measures

Electric bus: As well as the laws and action plans listed in Table 2, the Beijing Government has been promoting electric vehicles (EV) since 2015. Beijing has electric buses as a demonstration of new energy vehicles. The new energy vehicles include electric vehicles, fuel cell vehicles and alternative energy vehicles. The "travel right restriction" and "ownership restriction" policies started in 2008 are not applicable to electric vehicles, which offer new opportunities for the development of EVs in Beijing. 50 electric buses and 25 hybrid buses have come to service in the city since 2008. To further reduce the transport sector's energy consumption and emissions, and improve the "green index" for vehicles, the Public Transportation and Taxi industry will have 20,000 new energy taxi vehicles into work in 2020. Compared with the large number of electric buses in Beijing, by 2019, there are only about 2200 electric buses in Europe and only 300 in the United States, which is mainly due to the lack of electric bus industry and support policies in these countries, and the policies related to electric vehicles mainly tend to private cars.

Table 2
Law and action plans affecting public and private vehicle ownership in Beijing.

Aspect	Laws and action plans	Implementation effect
Motor Vehicle	"Environmental Protection Law of People's Republic of China" "The air pollution prevention and control law of China" "Yellow label vehicles and green label vehicles"	The Government has invested on average 158 thousand USD every year to encourage the uptake of green cars. From 20th December 2015, yellow label vehicles have been prohibited from driving in the administrative region of Beijing at all times (Beijing Transportation Committee, 2015). From 2013 to 2018, Beijing eliminated 2.172 million old vehicles with yellow labels.
	"Beijing implementation measures of the people's Republic of China energy consumption law" "National action plan for energy consumption and emission reduction in Beijing in the 12th Five-Year"	Implementing China V Vehicle Emission Standard. The Government encouraged the elimination and renewal of old motor vehicles and promoted the intelligent oil saving device. The "seamless" P + R (Park-and-Ride) System was established and car parks have been planned and built around the subway stations located in the 5th Ring Road (General Office of the People's Government of Beijing (2012)). By the end of 2019 there have been 24 bicycle parking lots near metro lines and another 47 new bicycle parking lots are being planned. The Government encourages people to use public transport and bicycle travel. The City Traffic Committee has tasked companies with improving the bicycle rental network. (General Office of the People's Government of Chaoyang District in Beijing, 2015)
	"Measures for the administration of environmental protection in Beijing city" "On further promoting the development of the capital of traffic science to increase efforts to ease traffic congestion in the work of opinions"	These measures enhance the Odd-Even Day Vehicles (detailed account in 6.2) Prohibition measure, and tighten vehicle quantity control measures. The Government also established standards and an evaluation system for preventing road congestion (General Office of the People's Government of Beijing, 2018).
	"The Beijing air pollution prevention regulations" "The strategic plan for energy consumption and emission reduction in the field of transport in Beijing (white paper) 2012–2020″ "Beijing city in 2012–2020 air pollution control measures"	From 2014 to 2018, the concentration of PM2.5 in Beijing decreased from 85.9 g/m^3 to 51.0 g/m^3, with a decrease of 34.9%. In terms of motor vehicle emissions reduction, Beijing took the lead in implementing "Jing V″ vehicle emission standards. In the first half year of 2015, the fifth stage standard for Heavy-duty diesel vehicle was implemented. In January 2020, Jing-Jin-Ji Regions implemented the national VI motor vehicle emission standards (General Office of the People's Government of Beijing, 2018).
Public Transport	"The People's Republic of China Renewable Energy Law" " Beijing 2013–2017 motor vehicle emission pollution control work program"	Beijing is vigorously developing public transport, in order to enable cleaner travel options and promote the collaborative development of Jing-Jin-Ji Regions. By the December of 2019, the total mileage of Beijing subway reached 699.3 km, carrying more than 12.4 million passengers per day and the subway continues to expand. Beijing Transportation Committee has strengthened the construction of the overground bus network. 99 bus routes have been optimised and adjusted, and 22 new bus routes opened in 2019. In order to guide the public choice towards cleaner modes of travel, Beijing has enabled a number of real-time public transport information platforms, which are freely available. To more effectively reduce vehicle exhaust emissions, Beijing has started a project titled "Promoting the use of clean energy bus" and "Zero discharge travel" (General Office of the People's Government of Beijing, 2018).
	"The medium and long-term special plan for energy saving" "Clean Air Action Plan 2013–2017 document" "National action plan for energy consumption and emission reduction in Beijing in the 12th Five-Year"	New energy vehicles are being promoted to the public and private users, the Government has introduced some incentives such as financial subsidies and Odd-and-Even register number rule (detailed account in 5.3.1). There were 224,800 new energy vehicles in the city in 2018. In 2013, the proportion of public transport trips was up by 46%, which increased to 50% by 2016. Rapidly development of the public transport system has included accelerating railway construction and speeding up the construction of the city's non-motorised system (pedestrian and bicycle routes) (General Office of the People's Government of Beijing, 2019a,b).

P + R parking lots: The P + R parking lot, which is the functional combination of "parking and transfer", is usually set up at the periphery of the city and connected with the public transport hub. It is a kind of traffic demand management measure that can reduce the traffic pressure in the central urban area, and increase the attractiveness of public transport (Kimpton et al., 2020). The development of the P + R parking lots in the United Kingdom, the United States, the Netherlands, Canada and other countries is relatively mature with a history of 60 years. For example, in the 1960s, the P + R parking lots had been periodically adopted by the United Kingdom. In the 1980s, the British Government began to subsidize the local development of the P + R parking lots. Up to now, it can still be subsidized through transport policies. In 1997, as pointed out in Chapter 6 "The Development of Town Center and Retail Industry" of the revised "Planning Policy Guidances" in the UK, the P + R facilities should be used as an alternative way of parking in urban centers. And then, as mentioned in "The 10 Year Plan" formulated in 2000, in the busy central urban areas, the P + R parking lots can be adopted as an effective way to reduce traffic congestion (Zhen et al., 2012). After years of development, the P + R parking system in the UK has been relatively well developed.

In London, for example, there are 45 P + R parking lots with a total number of 8624 parking space, all of which are outside the central activity areas and more than 10 km away from the city center. These parking lots effectively alleviate the traffic congestion in central London (Beijing Transportation Committee, 2018). By 2018, the development status of P + R parking lots in some cities is shown in Table 3.

To encourage more private car owners to travel by public transport and bicycles, the Beijing Government has planned and constructed P + R parking lots. As of 2019, there were around 45 P + R parking lots near the stations of terminal subway lines, more than 70 P + R parking lots will be built in the future, and more than 10,000 parking spaces will be provided. The construction of P + R parking lots will be considered for the new subway lines in Beijing at the same time. About the charging standards of the P + R parking lots, Beijing Municipal Commission of Development and Reform issued "A Letter on the Charging Policy of Parking and Transfer Vehicles in city parking lots" in 2018 (Beijing Municipal Development and Reform Commission, 2018). It requires that from January 1, 2019, all transfer vehicles parked in the P + R parking lots within a specified period of time will be charged 2 yuan per time on the basis of the record of taking public transport (including rail transit and electric buses) on the same day. This pricing is more favorable than many foreign cities.

Although the P + R parking lots in Beijing have developed rapidly with the support of the policy, there still exist some defects compared with London, Washington and other cities, such as: (1) the commuting demand in Beijing is large, and the number of P + R parking spaces is still scarce; (2) the three-dimensional parking facilities are insufficient and the utilization of parking space is unreasonable; (3) due to the lack of publicity, there are still some citizens who do not know what the P + R parking lot is or cannot specify the specific location. Therefore, the P + R parking lots in Beijing still have great potential for development and need to be paid more attention by the management department.

5.2. Public transit development

Since 1985, the commitment "To develop urban public transport" has been clearly stated "Policy in China" and public transport development has received more attention. In order to accelerate the construction of public transport system, at the end of 2006, the Beijing Government issued the "Priority development of public transport advice" overall strategy to prioritise public transport. This resulted in the Beijing Government setting a strategy that supported the urban railway and rapid bus transit systems becoming the major network of urban transportation, with the ground public transportation as the dominant player and taxi transport as a supplementary option. To ensure that this strategy is delivered efficiently, the City introduced another policy titled "the opinions of the People's Government of Beijing Municipality on the construction of public transport in the city and the promotion of public transport service capacity". This document further addressed the importance of public transport development in urban transport, and put forward specific measures to promote the development of Beijing's public transport network.

Underlining the above, the public transport network of Beijing has rapidly developed in the last ten years. Fig. 7 shows that by the end of 2018 Beijing had 22 subway lines with the total length of 637 km, 888 buses routes with a total operating length of 19245 km and using 24,076 public transport vehicles (Beijing Municipal Bureau Statistics, 2019). Fig. 8 indicates that the City's residents using public transport (bus + subway) increased from 35% in 2007 to 50% in 2018 (Public petrol/electric vehicles 28%, urban railway transport 22%). It also shows that, even the people population and vehicle numbers

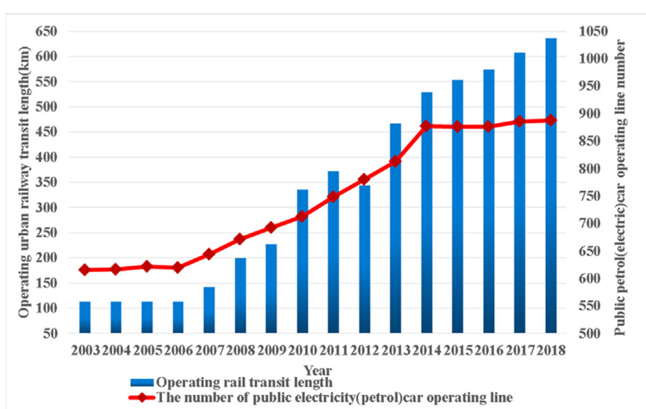

Fig. 7. Development of urban railway and ground public transportation in Beijing.

Table 3
The development status of P + R parking lots in some Cities.
(Beijing Transportation Committee, 2018).

City	The Number of P + R Parking Lots	The Number of Parking Spaces	Parking Charges
London	45	8624	£5.40 per day
Washington	80	75,000	Free transfers to public transportation Transfer to rail transit: average $4.85 per day
Houston	25	34,471	Average $5 per day
Amsterdam	7	3826	Average €5 per day
Vancouver	21	7967	Average $3.5 per day

Source: Beijing Transportation Committee (2018).

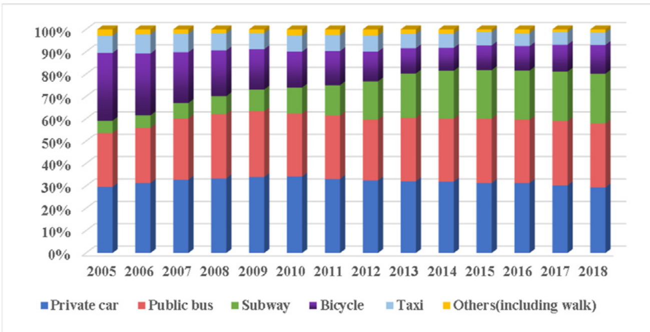

Fig. 8. Percentage of different travel modes in Beijing.

have been continually increasing in Beijing from 2003 to 2018 shown in Figs. 2 and 4, the share of private cars, public buses and taxis remained almost unchanged, and bicycle travel is replaced by subway travel. Therefore, it can be seen that the mode of travel remains roughly the same and the energy and environmental issues increase due to rising population, which requires the people change their travel mode and habits to fit into the new era.

(Beijing Municipal Bureau of Statistic, 2019).

(Beijing Municipal Bureau of Statistic, 2019).

5.3. Infrastructure construction

A number of parallel actions have been taken to alleviate energy consumption and emissions reduction through infrastructure construction. These are outlined below:

Setting bus lanes: Since 1997, the first bus line in Beijing was officially opened, which has increased at a rate of 30 km/year. At the end of 2019, the bus lane mileage in Beijing reached 952 km (Beijing Municipal Bureau Statistics, 2019).

Development of Beijing BRT: Beijing Bus Rapid Transit (BRT) system, opened in December 2004, was the earliest BRT system in China. The BRT continues to combine national and international advanced technologies and experiences such as Intelligent Vehicle Location Technology, Real-time Information Feedback Technology and Intelligent Vehicle Scheduling Technology, etc. Now with 7 routes (including 4 main routes and 3 branch routes), the BRT system plays a major role in easing the traffic congestion in urban areas and serves as a powerful and auxiliary transport facility for the Beijing urban railway transit.

Construction of Beijing Municipal Transportation Operation Coordination Centre: For monitoring, organising and forecasting the city's traffic conditions, Beijing built China's first Municipal Transportation Operation Coordination Centre (TOCC) 2011. Transport related information including the Automatic Fare Collection (AFC) system data of 17 subway lines and 701 regular buses routes, GPS data of 66,700 taxis, video feeds of the urban road network, flight data from Beijing's two airports, and Meteorological data have been gathered in the TOCC system. This allows the primary capability of collecting and managing the transportation information on the city level as shown in the Fig. 8 (Beijing Transportation Information Centre, 2013).

In addition, the TOCC provides multiple channels of information services for the city's commuters. Real-time traffic information services are provided through Beijing TV media, websites, microblogs, hotlines, mobile phone applications and other means. Comprehensive traffic information is posted through micro-blogs in the morning and evening peak-times of working days. During holidays, the Central and Beijing TV, radio and other authoritative media, broadcast, wired reported comprehensive traffic information and travel reference data, and the Beijing Transportation Commission website and its micro-blog release the real-time traffic information to help commuters plan their journeys.

Construction of Beijing Transport Energy & Environment Centre: To effectively carry out the motor vehicle exhaust emission test and control, Beijing Transport Energy & Environment Centre was founded in 2012. Aiming at saving resources, improving air quality, and playing a more active role to tackle climate change in the urban traffic areas, the centre is equipped with three institutions, including Traffic Energy Monitoring Platform, Energy and Environment Lab and Transport Energy Monitoring Station, as shown in Fig. 9.

6. Control measures related to vehicle technology in beijing

6.1. Vehicle emissions standards

To control pollution emissions from vehicles, China has implemented a series of policies, including continuing to raise the vehicle emission standards for new vehicles and phasing out aged and high-emission vehicles. Vehicle-Emissions Standards are the technical criteria to implement the laws and regulations for EC&ER. It has been observed that automobile fuel economy standards have been effective in controlling oil demand and reducing pollutant emissions from the transportation sector in many countries and regions around the world (Lepitzki and Axsen, 2018; Zhang, 2014). There are two main ways to control vehicle emissions:

New vehicle management methods: whereby supervision and inspection systems are established for new cars leaving the manufacturing facilities along with implementing new car technologies.

Vehicle use management method: Including the restriction of vehicle use during busy periods, the elimination of aged vehicles, the establishment of monitoring system for manufacturer emission guarantees and recall issues, fuel quality improvement, adding auxiliary cleaning devices for exhausts, advocating the use of alternative fuel vehicles, strengthening the inspection and maintenance system of vehicles and the implementation of I/M system (Inspection/Maintenance Program) (Hao, 2011; Zhang, 2014).

I/M is a regulation system released by the Chinese Government in order to control vehicle emissions. It is protected by Chinese law and is based on quality standards to check the emissions from vehicles that are in use, whether regularly or irregularly. If the emissions from the in-use vehicles exceed the set standards or there is an illegal change of the emission control devices, the owners are instructed to repair and fix their vehicles within a certain number of days to ensure vehicle

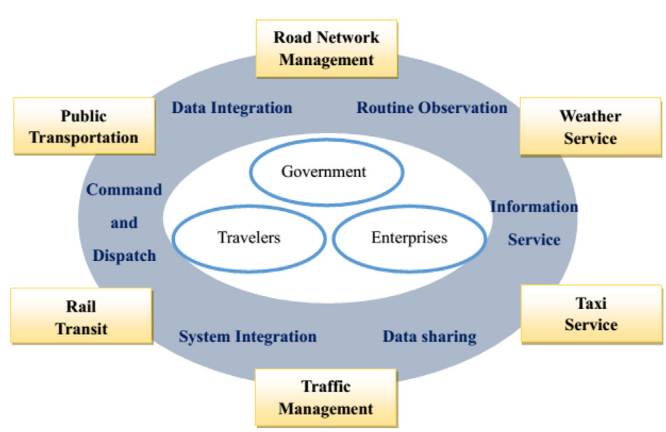

Fig. 9. Diagram of beijing municipal transportation operation coordination centre.

emissions are kept to a minimum. Research shows that regular checks and maintenance of a vehicle can ensure its emissions remain at reasonable levels, which play an important role in vehicle emission control. The I/M system helps to identify vehicles with high emissions as a result of engine failure or other mechanical problems.

Since the early 1980s, China and its capital in Beijing have published policies for controlling vehicle emissions, somewhat later than developed countries. These policy introductions can be separated into two phases:

Phase 1:The development of automobile emission control standards (1983–1999) (Jiang et al., 2008).

In 1983, China issued the first series of motor vehicle emission standards mainly focussed on gasoline vehicles, motorcycles and diesel vehicles. These standards laid the foundation for the prevention and control of air pollution for urban transportation in Beijing and China. At the beginning of 1990s, China promulgated a series of pollutant emission standards for quality control, including light vehicles, heavy vehicles and motorcycles, which encouraged manufacturers to improve product quality and technology levels.

Phase 2:Stricter emission restrictions resulting in a substantial reduction in emissions (1999 – present day).

At the end of 1990s, China's automobile industry entered a period of rapid growth, and the pollution caused by vehicle emissions becomes more serious and prominent resulting in the country adopting a more stringent environmental protection policy. In 1999, the national stage I and II emission standards for light duty gasoline vehicles and heavy diesel vehicles were established.

In order to further promote the sustainable development of the automotive industry, and address the growing contradiction between car pollution and the rapid development of the automotive industry, the Government further tightened vehicle emission standards in 2005, and the national stage III and IV emission standards for light duty gasoline vehicles and heavy diesel vehicles were established. As the key emission control area of China, Beijing has been the strictest region for the implementation of energy-saving emission reduction standards, implementing stage V straight away.

According to statistics, the NO_X emissions of gasoline vehicles has decreased by approximately 43% since Beijing implemented the Beijing stage V emission standard, and PM2.5 emissions have also decreased significantly. Encouraged by these results, Beijing is planning to start implementing the sixth phase emissions and fuel standards of motor vehicle, and will encourage individuals to buy and use new energy vehicles (a goal is that the number of new energy vehicle reach to 200,000 by the beginning of 2018). Fig. 10 lists the implementation process of automobile emission standards in China and Beijing since the stage I national standard (General Office of the People's Government of Beijing, 2019a,b; Wang et al., 2012). The emission standards in China are now similar to European car emission standards, as shown in Table 4 (General Office of the People's Government of Beijing, 2019a,b; Fan et al., 2015).

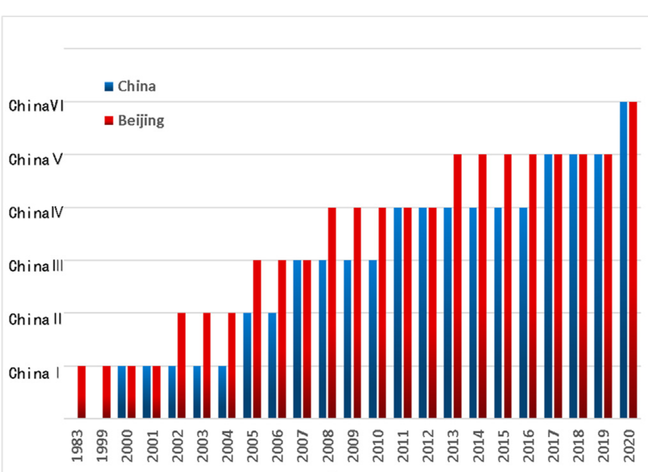

Fig. 10. Comparison of emission standards in China and Beijing.

(General Office of the People's Government of Beijing, 2019; Wang et al., 2012).

6.2. Policies for improving the quality of diesel fuel

Energy efficiency in the transportation industry is mainly to improve the utilization of automotive fuel. At present, the main national policies relating to automotive fuels are: the implementation of automobile fuel national standard, including the standard limiting fuel consumption of vehicles and system of circulation and publication; the implementation of fuel consumption labelling laws and regulations, and; corresponding assistant measures for reducing fuel consumed by vehicles.

The Chinese Government has carried out a series of projects aimed at improving the quality of diesel fuel. In 2001, the State Economic and Trade Commission, the State Environmental Protection Administration, the State Administration of Quality Supervision, along with six government ministries initiated the Fuel Economy Standards Steering Committee. The China Automotive Technology Research Centre is responsible for the establishment of China's automotive fuel economy standards and Policy Studies Project Team (Zhang, 2014). China Automotive Technology Research Centre is responsible for the establishment of China's automotive fuel economy standards and Policy Studies Project Team since 2001 (Zhang, 2014).

Since diesel vehicles produce more traffic pollution than other existing types of vehicles, to carry out the EC&ER is important. According to China Automotive Technology Research Centre statistics (Li, 2015), compared with the ordinary diesel vehicle that has the same displacement level, the diesel vehicle with cleaning technology can save up to 30% diesel, reduce carbon dioxide emissions by 25%, and increase power by 50%. Beijing urban transportation EC&ER for diesel vehicles have adopted five main measures shown in the following Table 5 (Zhang, 2014; Wang et al., 2012; Fan et al., 2015).

6.3. Vehicles with alternative fuels and new energy source

With the rapidly growing number of automobiles, hybrid vehicles and new energy vehicles have been used to mitigate the dependence of the automobile-industry on petroleum so as to reduce pollutant emissions (Yuan et al., 2015). Vehicle electrification has been seriously considered as an industrial revolution so as to achieve sustainable transportation in China (Dominković et al., 2017). By enabling the efficient conversion from highly polluting energy sources to clean energy sources, new energy is an important solution of EC&ER in urban transport systems. In 2011, the Beijing local government further promoted the use of new energy vehicles and an expansion plan of 6000 new energy vehicles was produced. In 2013, Beijing added another 2200 pure electric vehicles. By the last of 2018, Beijing had a total of 224,800 registered electric vehicles. At the same time, the Government is also stimulating the development of fuel cell vehicles, natural gas vehicles and other new energy vehicles.

As one of the key cities of the country's "one thousand new energy and energy saving cars in 10 cities" programme, Beijing has promoted new energy vehicle in different transport sectors,

Table 4
Comparison of emission limit in China I to VI standards and EURO I to VI standards.

	China I	EURO I	China II	EURO II	China III	EURO III	China IV	EURO IV	ChinaV	EUROV	China VI	EURO VI
	Emission limits for the first category motor vehicles (g/km)											
CO	2.72	2.72	2.2	2.2	2.30	2.30	1.00	1.0	1.0	1.0	0.7	1.0
HC	–	–	–	–	0.20	0.2	0.10	0.1	0.1	0.1	0.1	0.1
NO_X	–	–	–	–	0.15	0.15	0.08	0.08	0.06	0.06	0.06	0.06
HC + NO_X	0.97	0.97	0.5	0.5	–	–	–	–	–	–	–	–
PM	–	–	–	–	–	–	–	–	–	0.005	0.005	0.005
	Emission limits for the second category motor vehicles (g/km)											
CO	4.5	2.72	4.0	1.0	2.1/5.45	0.64	1.5/4.0	0.5	1.5/4.0	0.5	1.5/4.0	0.5
HC	1.1	–	1.1	–	0.66/0.78	–	0.46/0.55	–	0.46/0.55	–	0.13/0.16	0.08
NO_X	8.0	–	7.0	–	5.0/5.0	0.5	3.5/3.5	0.25	2.0/2.0	0.18	0.4/0.46	–
HC + NO_X	–	0.97	–	0.7	–	0.56	–	0.3	–	0.23	–	0.17
PM	0.36	0.14	0.15	0.08	0.10/0.16	0.05	0.02/0.03	0.025	0.02/0.03	0.005	0.01	0.005

Note: The first category of motor vehicles includes the vehicles that the number of seats does not exceed six, and the maximum total mass does not exceed 2500 kg. The second category of motor vehicles refers to all motor vehicles except the first category.
Source: General Office of the People's Government of Beijing. (2019) and Fan et al. (2015).

Table 5
Beijing diesel emissions control technology (EC&ER) summary.

ID	Measure	Mechanism
1	Add desulfuriser	The sulphur and the sulphate particles are reduced by adding a desulphurisation agent into the diesel, with the performance of the diesel engine being ensured.
2	Applying Fuel Borne Catalyst (FBC)	Particle generation and carbon particle activation energy are reduced by adding FBC quantitatively into fuel, promoting the fuel through the engine fuel supply system, combustion system, and exhaust system at low temperature.
3	Applying particulate matter discharge Corona Purifier (DCS)	Mass and emission number of particulate matters are reduced.
4	Applying Particle Filter (DPF)	For purifying the particulate matter in the exhaust of diesel vehicle, DPF is installed in the vehicle exhaust system to filter particulate matters from the exhaust (including carbon particles, the ash particles, metal particles, particulate organic, inorganic salt particles) via intercepting, and then removing accumulated particles on the filter media regularly for restoring the filtering function. If the DPF has a catalyst, it transfers other harmful substances into less harmful substances, such as HC, CO, etc.
5	Applying Oxide Converter (DOC) Oxide Catalytic Converter	DOC converts organic substances in the exhaust gas into harmless substances through oxidation. The gaseous CO, HC, and organic components of solid or liquid particulate matter are converted into gaseous CO_2 and H_2O, etc. The conversion efficiency of gaseous organic substances such as HC and CO were 90%. The conversion efficiency of particulate matter depends on the proportion of organic matter in particulate matter, and usually the conversion efficiency is 20%–40%.

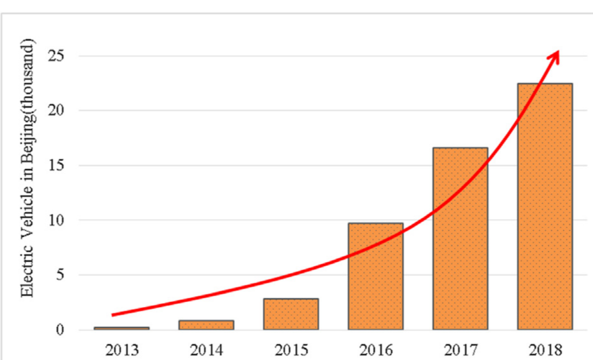

Fig. 11. Electric vehicles number of recent years (Beijing Municipal Bureau Statistics, 2019).

including public transport, sanitation services, logistics, etc., as shown in Fig. 11. The number of new energy vehicles has risen quickly since 2013 and is still rising (Beijing Municipal Bureau Statistics, 2019).

6.3.1. Electric vehicles

Support **policies:** Beijing firstly started the electric vehicles with the introduction of electric buses, and then introduced policies to encourage taxi companies and car rental companies to use electric vehicles (Section 4.1). The Beijing Government has made great efforts to motivate people towards purchasing and using electric vehicles. In May 2011, the Beijing Science and Technology Commission and the Beijing Finance Bureau issued a policy titled "Beijing electric car personal purchase subsidy policy". This subsidy varies in different scales related to the different types and prices of electric vehicles. The maximum subsidy for the plug-in hybrid electric vehicles is US$7538/vehicle and for the pure electrics is $9046/vehicle. In addition, the Central Government also subsidized the users who buy electric vehicles, therefore the maximum subsidy amount is increased to $18,092 for buying a pure electric vehicle in Beijing, which is more than half of the electric vehicle price (Sun et al., 2017). Table 6 lists the subsidies offered by some countries to encourage the sale of electric vehicles (Wang et al., 2019). By contrast, the subsidies for the purchase of electric vehicles in Beijing is above the average level in the world.

Charging facilities: The Beijing Government uses the "register number lottery draw rule" to control the total vehicles number on the roads at any one time. Residents enter into a draw system with their personal ID and driver's license and if their name is drawn then they are allowed to have a car register number enabling them to purchase a car. This rule is not applicable for electric vehicles however the distribution of the charging facilities and the technical development of the electric vehicle (mainly range) are the most critical factors at present that are impacting on sales of electric vehicles (General Office of the People's Government of Beijing, 2018). Therefore, to promote the use of electric vehicles by individuals, the Beijing Municipal Planning Commission has developed a new policy stating that *"In the next three years, major charging facilities will be slow charger units, with fast charger stations and battery replacement stations added as a supplement"*. It also

Table 6
The subsidies for the purchase of electric vehicle in some countries.

Country	Subsidies
Germany	4000 euros for pure electric vehicles, 3000 euros for hybrid electric vehicles
France	12,600 euros for pure electric vehicles, 6300 euros for hybrid electric vehicles
The United States	2500−7500 dollars for electric vehicles
Korea	230,000 won for pure electric vehicles, 3,300,000 won for hybrid electric vehicles
The United Kingdom	5000−8000 pounds for electric vehicles
Sweden	4000 kroner for pure electric vehicles, 20,000 kroner for hybrid electric vehicles
Belgium	5000 euros for electric vehicles
Spain	5500 euros for electric passenger cars, 8000 euros for electric trucks, 20,000 euros for electric buses

Source: Wang et al. (2019).

states that in new residential areas at least 18% of the parking spaces should be designed with charging units for electric vehicles (Beijing Municipal Science and Technology Commission (2019)). In addition, to motivate the purchase of electric vehicles, the Beijing Traffic Management Bureau has issued another policy that electric vehicles will not be limited by the odd-and-even register number rule. This is a rule initiated by the Beijing Government to reduce the cars on the road. For example, on Monday cars with an odd number as its last registration number are allowed on the roads whilst cars with even numbers are not allowed. Based on the latest data provided by Beijing New Energy Vehicle Service Agency, there are 40,541 charging units opened to the public in Beijing since 2018 (Beijing Development and Reform Commission, 2016).

With the implementation of these policies, the number of registered electric vehicles in Beijing reached 51,000 in 2017, which increased to 54,000 at 2019 (Beijing Municipal Bureau Statistics, 2019). As shown in Fig. 11, the new energy vehicles kept increasing in the last two years. With these policies, the Beijing Government expected the number of electric vehicles to reach 400,000 by the end of 2020 (Beijing Municipal Bureau Statistics, 2019). In addition, the small sized electric vehicle can now be purchased in any motor vehicle shop in Beijing, thereby achieving a positive initial success in the application and promotion of the electric vehicle market.

With the implementation of these incentives, electric vehicles have been well promoted in Beijing, however there are still some obstacles to the development of the electric vehicle market that need to be resolved, such as the high parking fee for the charging station and high electricity fees, the less travel mileage of electric vehicles and the lack of location information about the charging station. (Sun et al., 2017; Beijing Development and Reform Commission, 2016).

6.3.2. Fuel cell vehicles

Technology advantages: Hydrogen fuel cell vehicles and pure electric vehicles are both electric vehicles. The difference is that the pure EV is charged directly to the battery, while the fuel cell vehicle uses hydrogen to generate electricity by chemical reaction of hydrogen with oxygen ions. Hydrogen fuel cell vehicles have several technical advantages, for instance, the fuelling process takes only 10 min, comparing to the fast charging of pure electric vehicle, which needs half an hour, whilst slow charging extends to six or 7 h. The lifetime of a hydrogen fuel cell is much higher than the ordinary battery or rechargeable battery. And hydrogen fuel cell vehicles can travel up to 500 km without refuelling, and it is expected that future range can be increased to between 600 and 700 km, which is comparable to traditional fossil fuel powered vehicles. The only emissions from the hydrogen fuel cell vehicles is water vapour, with very little noise. In addition, the pollution generated through the whole industry chain of fuel cell is low. At end-of-life fuel cell components such as the carbon and metal plates can be recycled, and this is a common advantage of electric-powered vehicles. The advantage of hydrogen fuel vehicle in China is that there is a large amount of cheap byproduct hydrogen. Hydrogen fuel cell vehicles have attracted the attention of global automotive manufacturers, with Toyota, Nissan, General Motors, the first to develop hydrogen fuel cell vehicles. Based on all of this information the development of hydrogen fuel cell vehicles may be larger than pure electric vehicles (Beijing Development and Reform Commission, 2016). In the future the pure electric vehicle will be used for short term and the hydrogen fuel vehicle can be used for long distance.

Using examples: There are some precedents for the trial of Hydrogen fuel cell buses in Beijing. During the 2008 Beijing Olympic Games, the hydrogen fuel cell bus provided a serviced for marathon spectators. From August 2008 to August 2009, three Fukuda hydrogen fuel cell buses completed a one-year operation trial in Beijing. In 2016, Beijing's new energy car leasing companies purchased 100 hydrogen fuel cell vehicles, which will be used for time-share leasing within the range of hydrogen fuelling stations.

Disadvantages and relevant promoting actions and policies: Compared with other new energy vehicles, fuel-cell commercial vehicles are more expensive. To compensate for this disadvantage, state government offers fuel cell vehicles owner higher subsidies than other new energy vehicles. In addition, the infrastructure cost for a hydrogen powered transport sector is huge compared to battery powered electric vehicles, and the number and distribution of the hydrogenation station are not systematic in the early stages of development. The limited number of hydrogen stations (only one hydrogen fuelling station in Beijing) restricts the popularization of hydrogen fuel cell vehicles, as the Hydrogen fuel cell vehicle industrialisation started quite late in China. The Beijing Government takes public transport vehicles as a pilot project. Since the bus line is fixed, building the hydrogen station in a concentrated place can effectively solve these problems (Li, 2010).

Future outlook for fuel cell vehicles: In June 2016, the National Development and Reform Commission and the National Energy Board issued an “energy technology innovation action plan (2016−2030)" and “energy technology innovation focus on innovative action roadmap”. Hydrogen and fuel cell technology innovation are two of 15 key tasks within this plan (National Development and Reform Commission, 2016; Beijing Municipal Science and Technology Commission, 2016). “The plan of scientific and Technological Innovation Centre Construction during Beijing's 13th Five-Year plan” was officially released in September 2016. This policy focuses on fuel cell vehicles, with local Government participating in the rapid development of the fuel cell vehicle industry (Dominković et al., 2017). The Government plans to make Beijing become the largest market in China for new energy vehicle research, development, and application in 2020. The aim of this project is both to improve the production capacity of pure electric vehicles and to achieve batch-bulk production of fuel cell vehicles.

Beijing, as the main city using new energy vehicles, will accelerate the commercial development of fuel cell vehicles, and in the near future more cities will be involved with the fuel cell vehicle industry. Beijing will put more than 100 fuel cell buses into operation in 2017. As of February 2018, hydrogen fuel cell vehicles are still in the demonstration stage, but by 2020 it is envisioned that there will be mass application.

7. Beijing's control measures related to vehicle activity

7.1. Vehicle population control policies

To relieve the urban traffic congestion and strictly control the number of the motor vehicles in Beijing, in December 2010, Beijing officially announced "the number of small passenger cars Interim Regulation in Beijing", commonly known as "the purchase order". In 2011, 2012 and 2013, the annual total amount of private cars registration numbers issued was capped at 240,000 (20,000 per month) (Sun et al., 2017). The Government distributed the purchase qualifications by "a license-number lottery system" for free. From 2019, the annual total available registration numbers for private cars was set at 100,000/year, with the quota for traditional fossil fuel cars set at 40,000/year and new energy vehicles set at 60,000/year. In addition, people living in Beijing without Beijing ID need to provide a proof-of-continuous 5-years' tax status if they want to register with lottery system. Anyone without a Beijing registration number is forbidden from driving on the road within central Beijing during peak times (including within the Fifth Ring Road).

7.2. Parking policies

Reasonable parking facilities and parking policies are key infrastructure for a transport network, and by varying parking fee they have been used as an effective measure to control private car use in urban areas. Private car owners are encouraged to use public transportation to avoid city centers with high parking fee. Beijing Price Bureau released the "Notice of the adjustment of the motor vehicle parking fee standards". This notice introduced a car parking charge for open-air parking of US$0.16 per hour for cars and US$0.32 per hour for trucks regardless of location.

Beijing has considered the parking fee as a management measure to reduce the traffic congestion since 2004. In 2019, the policy entitled "Notice of the vehicle parking fees adjustment (Beijing Development and change [2019])" (Beijing Transportation Planning Research Center, 2019), revised the parking fee standard, which changed the parking fee from every 1 h to every 15 min as an accounting unit. A parking strategy has been applied to divide the parking areas and various fees for Beijing as displayed in Fig. 12 (Beijing Municipal Development and Reform Commission, 2018). The parking fee varies according to the traffic congestion situation, with the suggestion that traffic congestion will be alleviated as people will select parking outside the circles where there is lower parking fee. The charge fee structure of each area increases gradually in line with density of the population and the congestion level from the outside to the inside. The first level is the highest charge, followed by the second level, and the third level.

7.3. Driving restriction

In Beijing, policies including the odd and even register number alternative driving rule and regional traffic control during peak periods has been applied.

Odd-and-even register number rule: To ensure smooth traffic and good air quality during the Beijing Olympic Games and Paralympic Games in 2008, Beijing developed and implemented strategies to force cars to be driven alternatively on the road according to their last registration number: odd or even. The results showed that during the Olympic Games period, the air pollution index was 36% lower than the average of previous 8 years. Detailed experiments show that this method significantly reduced the environmental PM 2.5 index. The average PM2.5 was 17 $\mu g/m^3$ for ten days and dropped by 75% when compared to the previous tests (National Bureau of Statistics of China, 2009).

In November 2014, during the Economic Cooperation Asia-Pacific conference (referred as APEC), Beijing placed temporary traffic management measures on vehicles (including temporary registered vehicle). The city prohibited 70% of motor vehicles belonging to Government and state-owned enterprises from using the roads. This measure resulted in a significant reduction in air pollutant emissions, of which the contribution rate of PM2.5 reduction was 39.5%. This measure employed a series of actions that are outlined in Fig. 13.

(National Development and Reform Commission, 2016).

Traffic restriction policy during peak congestion periods: After the attempt to implement the policy during the 2008 Beijing Olympic Games succeeded and achieved certain results, Beijing municipal government decided to impose traffic restriction policy on 2009, and issued the "Notice of Beijing Municipal People's Government on the implementation of the working day peak period of the regional traffic restriction management measures". According to the last number on a vehicle's registration plate, motor vehicles were divided into five groups. Each day, the vehicles with specified numbers could not use the roads in the city centre. In

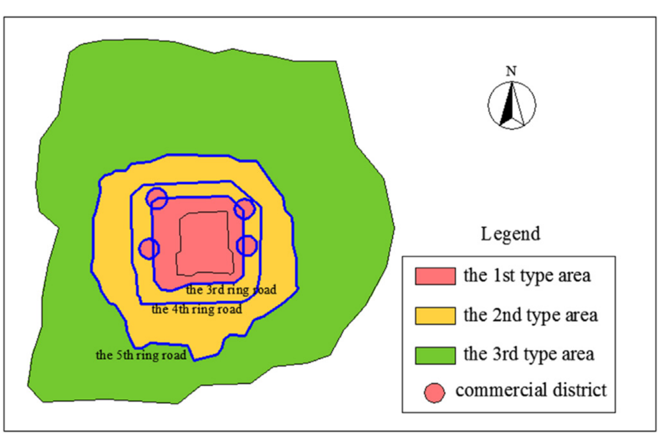

Fig. 12. Division of three category of parking areas in Beijing.

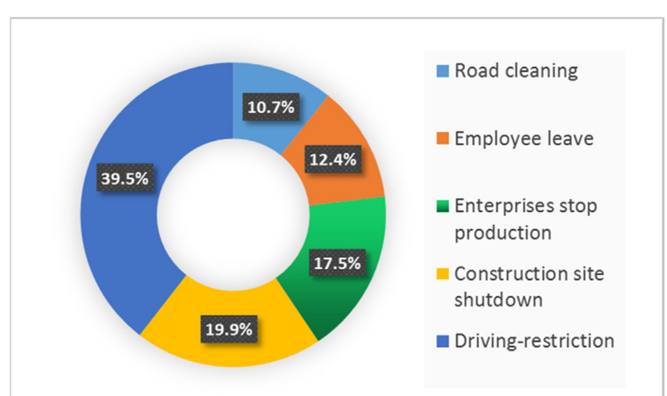

Fig. 13. Contribution of contemporary measures in reducing PM2.5 during APEC.

March 2014, when these traffic restriction measures expired, the Beijing Government issued a "Notice of the Municipal People's Government on the implementation of the Beijing regional weekday rush hour traffic restriction management measures" again. This measure remains in operation (Wu et al., 2017). The main purpose of Beijing's traffic restriction policy is to reduce journeys volume, thereby relieving traffic jams. Scholars have verified that the smooth operation of urban traffic can effectively reduce the emission of pollutants such as NO_X, PM2.5 and SO_2 from motor vehicles (Li et al., 2019), so as to purify the urban air environment.

7.4. Eco-driving

7.4.1. EC&ER potential

Driving behavior has a great impact on fuel consumption and pollutant emissions. Similar to safe driving, eco-driving is an environment-friendly concept. It is a measure to improve fuel efficiency and reduce traffic accidents and noise by changing drivers' driving decisions and improving drivers' travel behaviors (Martin et al., 2012). Previous studies that adopted field trials show that eco-driving has the potential to reduce fuel consumption by an average of 5–10% (Caban et al., 2019), thus maximizing fuel efficiency, thereby reducing the emissions of global greenhouse gas (GHG) and other air pollutants, such as NO_X. Statistics show that if all drivers in Beijing choose to use eco-driving strategies, there would be a substantial decrease of CO_2 emissions by 85,000 tons/year, CO emissions by 85,000 tons/year, NO_X emissions by 523,000 tons/year, CH emissions by 334,000 tons/year, and petrol consumption by 340,000 tons/year (Wu and Zhao, 2014).

Eco-driving includes behavior decisions (travel behaviors and travel time choices) and driving operational decisions that can improve vehicle fuel economy and reduce vehicle pollution emissions (Caban et al., 2019). Among them, conducting driving operations in a more economical and environmentally friendly way is the main method. In the process of driving, acceleration, deceleration, shifting, idling, braking and other operations are closely related to the fuel consumption of vehicles (Table 7) (Wu and Zhao, 2014).

Since the concept of eco-driving was introduced into China, Beijing has actively promoted eco-driving through a series of measures, including formulating relevant policies, distributing brochures, organising eco-driving training and developing eco-driving dynamic feedback system to provide real-time guidance on eco-driving habits. These measures have made a lot of progressing.

7.4.2. Supporting policies

Beijing traffic and environmental management department has been actively promoting eco-driving. In 2013, Beijing municipal traffic management department established a statistical and monitoring platform for EC&ER in the field of Beijing's transportation. It is used to monitor the energy consumption and pollution emissions of buses, taxis, freight vehicles and rail transit systems, which provide support for EC&ER potential analysis of eco-driving (General Office of the People's Government of Beijing, 2014). On this basis, Beijing Municipal Commission of Transportation released "The Guide for Using Energy Feasibly of Commercial Vehicle for Cargos Transportation", which provides a systematic guide of using energy feasibly from six aspects: vehicle selection, use of vehicle, driving operation, energy consumption statistics and energy conservation management (Beijing Transportation Committee, 2014). Subsequently, in order to promote eco-driving in the taxi industry, Beijing Municipal Transportation Commission issued the Beijing local standard "Guidelines for Using Energy Feasibly of Taxi" in 2015, which stipulated the requirements for EC&ER works, such as energy conservation management requirements for taxi companies, energy consumption statistics of taxi companies, selection of vehicles and fuel saving products technology, maintenance of motor vehicles, and driving energy saving (Beijing Transportation Committee, 2015a). In 2018, the Article 73 of Beijing's Regulations on the Prevention and Control of Atmospheric Pollution, which was revised under the auspices of Beijing Municipal Government, pointed out that in the periphery and parking lots of schools, hotels, shopping malls, parks, office spaces, communities, and hospitals, motor vehicle drivers should turn off the vehicle's engine when they stop for more than 3 min (General Office of the People's Government of Beijing, 2018c).

In addition to the policies on driving operation, Beijing has also issued behavioral decision policies related to eco-driving, mainly including carpooling and off-peak travelling. Carpooling is a kind of shared travel mode in which car owners release travel information in advance, and people with the same travel routes choose to take the owner's vehicle, share the travel costs (fuel fees and tolls) or help each other free of charge. It is an ecological travel mode chosen by car owners. In July 2016, the General Office of the State Council issued "The Guideline on Deepening Reform and Promoting the Healthy Development of the Taxi Industry". The policy encourages the development of carpooling, and governments should encourage and regulate its development (General Office of the State Council, 2016). In the same year, "The Guideline on Promoting Green Consumption" formulated by the Ministry of Ecology and Environment and other ministries also clearly pointed out that it supports the development of sharing economy, encourages the efficient use of individual idle resources, and develops online booking of carpooling (Ministry of Ecology and Environment of China, 2018). After that, in order to further standardize and encourage the carpooling of private cars in Beijing, the Beijing Municipal Commission of Transport, the Beijing Municipal Public Security Bureau and other departments jointly formulated "The Opinions of the Beijing Municipal Commission of Transport on Passenger Car Carpooling" and "The Guidelines on Beijing Private Passenger Car Carpooling". These policies stipulate the qualifications of carpooling participants, the obligations of carpooling companies, carpooling rules and carpooling fees to protect the legitimate rights of the carpooling participants (Beijing Transportation Committee, 2018).

Off-peak travel is also one of the behavioral decisions of eco-driving. Companies are encouraged to adopt flexible working hours. Moreover, the off-peak commuting policy "The Guideline on Flexible

Table 7
Potential fuel-efficiency savings from eco-driving habits.

Driving behaviour	Fuel consumption comparison
Steady acceleration, avoiding sudden acceleration	Using 5 s to accelerate from 0 to 20 km/h could save 11% fuel
Decelerating in advance and slowly	Decelerating in advance could save 2%~6% of the fuel
Avoiding long time idle	For every 3-min that an engine is turned off rather than idling, the fuel savings could result in an additional 1 km of travel.
Check tyre pressure regularly	Insufficient tyre pressure can increase fuel consumption by 2%–4%.

Source: Wu and Zhao (2014).

Working of Social Units in Commercial Finance and Industrial Parks" is expected to be released soon (Beijing Transportation Committee, 2016).

In the future, off-peak travel can be promoted through formulating policies to appropriately adjust the commuting time, reasonably charging congestion fees and parking fees and determining the charging standards for different periods of time.

7.4.3. Reform of driving training

Driving training is the most direct promotion method of eco-driving. Based on experiential eco-driving strategy, the driving training enables drivers to integrate energy-saving driving operations into daily operations, increase their operational proficiency and eco-driving experience, and form many eco-driving habits, so as to achieve the goal of long-term energy saving (Wu et al., 2018).

In 2001, the European Climate Change Programme (ECCP) pointed out that eco-driving training can significantly reduce CO_2 emissions. Since 2001, countries such as the Netherlands, Germany, Finland and Switzerland has promoted eco-driving in driving training and driving test (Caban et al., 2019). By 2019, among the 13 member countries of the European Committee of International Driver Test, more than 90% of the countries have taken eco-driving as the training content of driving schools, and more than 60% of the countries have also taken eco-driving as the content of driving test (Fu et al., 2019). The status of whether eco-driving contents is included in driving training and driving test in European countries is shown in Table 8.

In order to make it easier for drivers to accept eco-driving, since 2007, the Japanese government designated November as the Eco-driving Month and distributed eco-driving manuals to call on people to improve their eco-driving skills for reducing fuel consumption. In addition, the Tokyo government has teamed up with institutions such as driving schools and energy saving centers to conduct eco-driving training for drivers and distribute eco-driving manuals. At present, eco-driving has been incorporated into driver training materials in Japan. (Gu et al., 2015).

Source: Fu et al. (2019).

European countries conducted eco-driving training based on the "Five Golden Rules", which are predicting traffic flow as much as possible, driving smoothly, changing gear as early as possible, checking tire pressure and reducing unnecessary fuel consumption (Fu et al., 2019). Japan has "Ten Methods of Eco-driving", which are starting smoothly, maintaining a stable driving speed, reducing the number of rapid acceleration and deceleration, reducing the use of vehicle accessories, inspecting and maintaining vehicles timely, forecasting traffic flow in advance, choosing the best driving path, switching off the engine when idling for a long time and other daily driving operations (Gu et al., 2015).

Table 8
The status of whether eco-driving contents is included in driving training and driving test in European countries.

Country	Driving training (whether eco-driving contents is included)		Driving test (whether eco-driving content is included)	
	Theory	Practice	Theory	Practice
Holland	✓	✓	✓	✓
Poland	✓	✓	✓	×
Spain	✓	×	✓	✓
Britain	✓	✓	✓	✓
Germany	✓	✓	✓	✓
Italy	✓	×	✓	✓
Greece	✓	✓	✓	✓
Austria	✓	✓	✓	×
Czech Republic	✓	×	×	×
Croatia	✓	✓	✓	✓
Finland	✓	✓	✓	×
Hungary	✓	✓	✓	✓
Lithuania	✓	✓	×	×

Beijing has a relatively late start in eco-driving training. Although eco-driving contents have not yet been formally included in driving training and driving test, the preparatory work of eco-driving training has been carried out already. For example, driving simulators are used to conduct eco-driving driving training for professional drivers, so as to explore the EC&ER potential of promoting eco-driving in Beijing (Wu et al., 2018). Moreover, "The Manual of Automobile Energy Saving Driving" compiled by the Ministry of Transport and "The Training Manual on Eco-driving Behavior in Renting Vehicle Industry" compiled by the Beijing Transportation EC&ER Center provide many eco-driving suggestions, include driving route selection, vehicle preheating, gear selection, braking and deceleration, which standardizes drivers to achieve soft and predictive driving (Beijing Municipal Science and Technology Commission, 2019). Furthermore, by brochures, knowledge competitions, media reports, large-scale exhibitions and other forms, the publicity of eco-driving knowledge for most drivers in Beijing has been realized.

In order to realize the practical application of eco-driving, Beijing transportation and environment department developed on-board diagnostic equipment for eco-driving. By 2020, more than 3000 taxis in Beijing have installed this device. At the same time, App for eco-driving has been installed on the corresponding drivers' phones, so that drivers can know the high fuel consumption operations in the driving process and get corresponding driving behavior suggestions, and then continuously improve eco-driving behaviors. Finally, in the intelligent evaluation of drivers' professional qualification, the average energy consumption of taxi is reduced by 4.46%−11.49%, and the pollution emissions is reduced by 8.31%−11.69%, which verifies the EC&ER potential of eco-driving training (Beijing Municipal Science and Technology Commission, 2019).

Besides, the accelerated popularization of new energy vehicles through formulating policies is also a main way to promote eco-driving in Beijing. The relevant policies for the new energy vehicles in Beijing can be found in Section 6.3.

8. Discussion and conclusion

8.1. Challenges in EC&ER reduction from Beijing's transportation sector

As a metropolis with the function of China's politics, economic and cultural centre, Beijing plays a key role in developing EC&ER policy, and related technology research and application. However, there are still some shortcomings, especially when compared to the advanced technologies and experiences of other countries. Facing the reality that there are huge number of private cars in Beijing, the Government should continue to enhance the public transport, and further develop policies, measures and rules for energy saving and emissions reduction for the private cars sector. The challenges for the future relate to: organising the tenure and usage of motor vehicles, improving energy saving consciousness and eco-driving, better supervision and management systems for vehicle quality control, and carefully orchestrating the technological breakthroughs of new energy vehicles (see Fig. 14).

8.1.1. Restriction of vehicle ownership and usage

The management of vehicle quality and quantity will be the most important factor of Beijing's EC&ER in future years. Because of the trend of continued global urbanisation and mechanisation, capital wealth and human resources will be continually

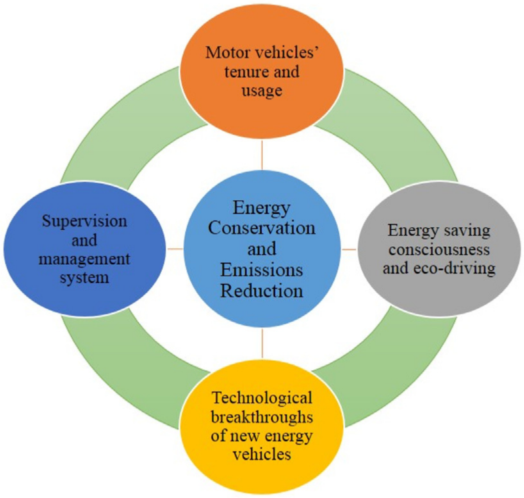

Fig. 14. Challenges of urban transportation energy consumption and emissions reduction.

accumulated in Beijing, resulting in the aggravations of urbanisation and mechanisation and the growth of vehicle ownership and usage. Moreover, since the Beijing Metropolitan Area (Beijing-Tianjin-Hebei) has become one of China's national development strategies, the traffic facilities in this area will be significantly improved.

With the implementation of the 'Integrated Transportation Plan of Beijing-Tianjin-Hebei Coordinated Development', the convergence of various modes of transportation and the connection of broken roads will build a whole traffic operation system, will be connected well to the whole traffic operation system, leading to a traffic volume increase among the Beijing, Tianjin and Hebei areas, as well as the aggravation of traffic pollution. Experiences in reducing vehicle usage from overseas are mainly through the efforts to enhance the public transport service quality and size, along with the application of advanced intelligent transportation technology (Hong and Yan, 2014; Rafiq et al., 2013) and the construction of rapid transport system (Lin et al., 2014; Gkritza and Karlafti, 2013). Therefore, if Beijing is to reduce its vehicle ownership and usage, and cut down urban traffic energy consumption and emissions, then the following measures should be considered:

I. Speeding up the integration of the public transportation system both in construction and operation, enhancing the quality of public traffic and reducing private vehicle usage through policy control;
II. Accelerate the implementation of a unified traffic operation and management policy for Beijing, Tianjin and Hebei, and integrate and systematize the regional traffic supervision system;
III. To further improve the construction of the urban traffic information and integration system, rely on advanced technology to develop a safe, smooth, fast and convenient traffic network.

8.1.2. Eco-driving and energy saving consciousness

From statistics generated by the China's National Bureau of Statistics, Beijing's motor vehicles and fuel consumption are maintaining rapid growth, whilst Beijing's urbanisation and mechanisation growing at a steady pace. This emphasises that current residents' awareness of energy consumption and emission reduction is low. Considering that the number of private vehicles will not reduce in recent years (Figs. 1–3), the energy saving effect of eco-driving is considerable. In many developed countries, governments were the first to use low emissions and energy efficient vehicles as an example for EC&ER. For example, in the United States, the various state governments have implemented fuel-efficient and low-emissions vehicle programs in order to reduce energy consumption and pollution in their transportation sectors. In Canada, their Ministry of Finance, Ministry of Natural Resources, and Environment Department of Coordination set environmental goals for government vehicles through the "Green Procurement" policy and other supporting measures, to cut energy consumption in transport (Holmberg et al., 2012).

EC&ER for urban transportation is an extremely complicated and systematic task, which will require continued additions to laws, regulations and policies, in tandem with technology development. This technology development will largely focus on transport system management technology, vehicle energy consumption and emissions reduction technology, and research into improving environmental driving behaviour (Barla et al., 2017). The Government of Beijing, as the biggest public participant, will become the biggest beneficiary through further enhancing the awareness of clean travel and putting the green actions into practice.

As an initiative, eco-driving is still a relatively new concept for Beijing, with great potential for further research, such as how to target different driver groups in different traffic situations, and understanding the potential for fuel savings from eco-driving and how they will vary. In addition, driver training policies and standards are not ready, which needs practical application to create positive results (Jamson et al., 2015). Therefore, in order to reduce urban transportation energy consumption and emissions reduction, the Government should actively guide and promote eco-driving, and emphasise the significance of its residents' awareness of eco-driving, whilst optimising the release of policies aimed at EC&ER. At the same time, the transportation sector should speed up research into eco-driving and its application, and carry out the eco-driving education programmes for bus companies, taxi companies, etc. Private car owners, as the majority in Beijing, should accept eco-driving education as part of their initial driving licence application and through regular training sessions that are organised by the Government and accompanied with the driver's license examination. In addition, relying on the Internet of Vehicles Technology, Automatic Driving Technology and Information Transmission Technology, combined with Eco-driving to establish an intelligent transportation system is a future trend of transportation, which should be fully considered in policy formulation by the department of transportation and environments.

8.1.3. Supervisory management system

Even though Beijing has established, released and implemented a lot of actions through various organisations aimed at reducing energy consumption and pollution emissions, the laws and regulations are still not perfect enough to have the good control of the environment, as there is no supervisory institute to support the efforts from various input methods. From other countries' experiences in EC&ER (Matsumoto et al., 2018; Andriosopoulos et al., 2017), it is necessary to make a law and build a suitable enforcement body. This would help to not only reach the targets for energy consumption and emissions reduction, but also to improve the credibility of Government.

The transportation management department has been suggested to carry out car fuel environmental management, promote gasoline quality growth scientifically and strictly, correctly handle the relationship between fuel and emissions, and to speed up the revision and publicity of the atmospheric law and other relevant laws as soon as possible in order to eliminate the consequences of long-term management lag. Populace participation should be motivated, non-profit projects from multi-fields for energy consumption and emission reduction and funding organisations should be established, and various EC&ER activities should be carried out.

8.1.4. Technological breakthroughs of new energy vehicles

Compared with international new energy automotive technology, the research and development in China started late but is now growing quickly, and there is still a large gap with the rest of the world. Some manufacturers still lack the core technologies such as energy storage devices, and motor and system integration technologies (Yang et al., 2017). In addition, corresponding to the development of electric vehicles, Beijing urban transportation should also explore the use of renewable energy sources in order to ensure that electric vehicles are powered by clean sources of energy, such as solar, hydro and wind. These energy conservation and emissions reduction technologies have been applied in other cities worldwide, including Mumbai, New Delhi and Bangkok (Yang et al., 2017). Technological competition for new energy vehicles is becoming more competitive on the completely open car market in China. There is therefore a substantial challenge and opportunity to strengthen the development of new energy, new technologies, high performance and low pollution cars and buses in China.

8.2. Future analysis and policy development

1. To strengthen the control of motor vehicles usage, to control the demand for cars, and encourage the use of public transport;
2. To promote the formulation of support policies on eco-driving, accelerate the reform of driving training and driving test, such as incorporate eco-driving into driver training and driving test, and implement the eco-driving re-education for drivers who want to renew their licenses.
3. To adjust the transportation structure and strengthen the priority strategy of public transportation including infrastructure development, awareness training for public travel and other policies;
4. To stimulate the development of alternative energy and clean energy to ensure electrification of the transport sector does not impact on a country's greenhouse emissions restrictions. The incentives should be improved effectively, and the Government should give financial support to construct facilities for using new energy vehicles in large-scale;
5. To enact carefully formulated energy consumption law, air pollution prevention law and other related laws and regulations;
6. To promote the assessment of energy consumption, to speed up the legislation of motor vehicle pollution laws;
7. To make good use of public transport systems as early adopters of energy saving and emission reduction policies and pilot projects.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2020.125339.

References

Andriosopoulos, K., Silvestre, S., Andriosopoulos, K., 2017. French energy policy: a gradual transition. Energy Pol. 106, 376–381.
Barla, P., Gilbert, G.M., Castro, M.A.L., 2017. Eco-driving training and fuel consumption: impact, heterogeneity and sustainability. Energy Econ. 62, 187–194.
Beijing Development and Reform Commission, 2016. Special planning of electric vehicle charging infrastructure in Beijing. http://www.chinaequip.gov.cn/2016-04/23/c_135333592_3.htm. (Accessed 29 July 2020).
Beijing Municipal Bureau Statistics, 2019. Annual macro data of Beijing. http://tjj.beijing.gov.cn/. (Accessed 29 July 2020).
Beijing Municipal Development and Reform Commission, 2018. Announcement on issues related to parking fee policy of parking and transfer vehicles in parking. http://fgw.beijing.gov.cn/zwxx/zcfg/xcwj/qtwj/201912/t20191226_1506676.html. (Accessed 29 July 2020).
Beijing Municipal Development and Reform Commission, 2018a. The announcement of parking fee increases in Beijing. http://www.bjmtg.gov.cn/bjmtg/zwxx/qlqd/201812/1015921.shtml. (Accessed 29 July 2020).
Beijing Municipal Ecology and Environment Bureau, 2019. Annual macro data of Beijing. http://sthjj.beijing.gov.cn/. (Accessed 29 July 2020).
Beijing Municipal Science & Technology Commission, 2019. Want to save gas? Ecological driving has a magic tric. k. http://kw.beijing.gov.cn/art/2019/11/11/art_1438_455150.html. (Accessed 29 July 2020).
Beijing Municipal Science and Technology Commission, 2016. Planning for strengthening the construction of scientific and technological innovation centre in Beijing. http://www.gov.cn/zhengce/content/2016-09/18/content_5109049.htm. (Accessed 29 July 2020).
Beijing Transportation Committee, 2014. Guide to rational use of energy for operating trucks. http://jtw.beijing.gov.cn/xxgk/flfg/jthy/201912/t20191231_1548090.html. (Accessed 29 July 2020).
Beijing Transportation Committee, 2015. A notice on reducing the emission of pollutants by means of traffic management measures. http://www.beijing.gov.cn/zfxxgk/110018/gfxwj22/2014-03/28/content_461498.shtml. (Accessed 29 July 2020).
Beijing Transportation Committee, 2015a. Notice on soliciting opinions of beijing local standard guide to the rational use of energy by taxi companies. http://jtw.beijing.gov.cn/zmhd/myzj/201912/t20191218_1280605.html. (Accessed 29 July 2020).
Beijing Transportation Committee, 2016. The policy of off peak commuting is expected to come out this year. http://society.people.com.cn/n1/2016/0206/c1008-28114866.html. (Accessed 29 July 2020).
Beijing Transportation Committee, 2018. Notice on printing and distributing "The guiding opinions of Beijing Municipality on the combined travel of private minibuses". http://jtw.beijing.gov.cn/xxgk/zfxxgk/fgwj/gfxwj/202001/t20200116_1584286.html. (Accessed 29 July 2020).
Beijing Transportation Committee, 2018a. Research on park and ride (P + R) abroad and its enlightenment to beijing. https://www.sohu.com/a/279229981_99949100. (Accessed 29 July 2020).
Beijing Transportation Information Centre, 2013. Research on Beijing Transportation Operation Coordination Centre (TOCC) Function and Operation Mode. Beijing Transportation Information Centre, Beijing.
Beijing Transportation Planning Research Center, 2019. Beijing Annual Report of Traffic Development. Beijing Transportation Planning Research Center, Beijing.
Caban, J., Vrabel, J., Sarkan, B., Ignaciuk, P., 2019. About eco-driving, genesis, challenges and benefits, application possibilities. Transp. Res. procedia. 1281–1288.
Chen, C., Zeng, X., Huang, G., 2019. Robust planning of energy and environment systems through introducing traffic sector with cost minimization and emissions abatement under multiple uncertainties. Appl. Sci. 9 (5), 928.
China Council for International Cooperation on Environment, 2005. Study on Transportation Energy and Environment Policy in China. People Communications Press, Beijing.
Dominković, D.F., Bačeković, I., Pedersen, A.S., 2017. The future of transportation in sustainable energy systems: opportunities and barriers in a clean energy transition. Renew. Sustain. Energy Rev. 82 (2), 1823–1838.
Duan, M.S., 2018. Coordinations between China's emissions trading system and policies of energy efficiency and renewable energy. J. Environ. Econ. Manag. 2, 1–10.
Fan, S.B., Tian, L.D., Zhang, D.X., 2015. Emission factors of vehicle exhaust in beijing. Environ. Sci. 36 (7), 2374–2380.
Feng, C., Wang, M., 2018. Analysis of energy efficiency in China's transportation sector. Renew. Sustain. Energy Rev. 94, 565–575.
Fu, R., Zhang, Y.L., Yuan, W., 2019. Progress and prospect in research on eco-driving. China J. Highw. Transp. 32 (3), 5–16.
Gao, X.L., Ren, Z.J., 2015. Scenario prediction of the energy consumption and the environmental emissions of Beijing urban passenger transport. J Automotive Safety and Energy (China) 6 (3), 259–264.
General Office of the People's Government of Beijing, 2012. Beijing 12th Five-Year energy-saving emission reduction action plan. www.gov.cn/gzdt/2012-01/10/

content_2040751.htm. (Accessed 29 July 2020).
General Office of the People's Government of Beijing, 2014. Discussion on "construction project of statistical monitoring platform for traffic energy conservation and emission reduction" by Municipal Transportation Commission. http://www.beijing.gov.cn/shipin/fangtan/15404.html. (Accessed 29 July 2020).
General Office of the People's Government of Beijing, 2018. Decision of the Standing Committee of the Beijing Municipal People's Congress on Amending seven local laws and regulations such as the regulations of Beijing Municipality on the prevention and control of air pollution. http://www.beijing.gov.cn/zhengce/dfxfg/201905/t20190522_61138.html. (Accessed 29 July 2020).
General Office of the People's Government of Beijing, 2018a. Notice on printing and distributing the administrative measures of Beijing Municipality for the promotion and application of new energy vehicles. http://www.beijing.gov.cn/zhengce/zhengcefagui/201906/t20190626_99356.html. (Accessed 29 July 2020).
General Office of the People's Government of Beijing, 2018b. Action plan and key points of 2018-2020 of Beijing-Tianjin-Hebei coordinated development. http://www.beijing.gov.cn/zfxxgk/110002/gzdt53/2018-08/08/content_129cd499ac764dfaa32cc29fc9632cc0.shtml. (Accessed 29 July 2020).
General Office of the People's Government of Beijing, 2018c. Regulations of Beijing Municipality on the prevention and control of air pollution. http://www.beijing.gov.cn/zhengce/dfxfg/201905/t20190522_61138.html. (Accessed 29 July 2020).
General Office of the People's Government of Beijing, 2019a. 2013-2017 Beijing air cleaning action. http://www.beijing.gov.cn/zfxxgk/110001/szfwj/2013-09/12/content_cae7ba16b4bb46d68d78a11e928aebcd.shtml. (Accessed 29 July 2020).
General Office of the People's Government of Beijing, 2019b. Notice of Beijing Municipal Bureau of ecological environment on the implementation of the sixth national motor vehicle emission standard. http://www.beijing.gov.cn/zhengce/zhengcefagui/201912/t20191219_1311796.html. (Accessed 29 July 2020).
General Office of the People's Government of Chaoyang District in Beijing, 2015. The strategy of Beijing urban construction and people's livelihood. http://www.bjchy.gov.cn/dynamic/news/8a24fe834b17530e014b33b17a420410.html. (Accessed 29 July 2020).
General Office of the State Council, 2016. Guiding opinions of the general office of the State Council on deepening reform and promoting the healthy development of the taxi industry. http://www.gov.cn/zhengce/content/2016-07/28/content_5095567.html. (Accessed 29 July 2020).
Gkritza, K., Karlaftis, M.G., 2013. Intelligent transportation systems applications for the environment and energy conservation. J. Intell. Transport. Syst. 17, 1–2.
Gu, J.C., Yao, C., 2015. A review of international experiences on promoting eco-driving training. Road Traffic & Safety 15 (5), 50–54.
Guanghua School of Management, 2018. Air Quality Assessment Report. School of life sciences-Peking University, Beijing.
Gustav, S., Greg, M.P., 2018. Environmental impact of textile reuse and recycling - a review. J. Clean. Prod. 184, 353–365.
Han, H., Geng, Y., Wang, H., 2014. Regional disparity of urban passenger transport associated GHG (greenhouse gas) emissions in China: a review. Energy 68 (8), 783–793.
Hao, J.M., 2011. Control of Urban Vehicle Emission. China Environmental Science Press, Beijing.
Hao, H., Liu, Z., Zhao, F., 2015. Scenario analysis of energy consumption and greenhouse gas emissions from China's passenger vehicles. Energy 91, 151–159.
Holmberg, K., Andersson, P., Erdemir, A., 2012. Global energy consumption due to friction in passenger cars. Tribol. Int. 47, 221–234.
Hong, T., Yan, H., 2014. Solving intelligent technology in energy saving and emission reduction application strategy. Inf. Technol. J. 12 (17), 4332–4335.
Huo, H., Wang, M., Zhang, X., 2012. Projection of energy use and greenhouse gas emissions by motor vehicles in China: policy options and impacts. Energy Pol. 43 (3), 37–48.
Jamson, S.L., Hibberd, D.L., Jamson, A.H., 2015. Drivers' ability to learn eco-driving skills; effects on fuel efficient and safe driving behaviour. Transport. Res. C Emerg. Technol. 58, 657–668.
Ji, D., Gao, W., Maenhaut, W., 2019. Impact of air pollution control measures and regional transport on carbonaceous aerosols in fine particulate matter in urban Beijing, China: insights gained from long-term measurement. Atmos. Chem. Phys. 19 (13), 8569–8590.
Jiang, G.H., Hao, R.L., Mai, R.L., 2008. China's Light-duty Vehicle emissions standards development process. Transport energy conservation and environmental protection (China) 1, 19–22.
Kelly, F.J., Zhu, T., 2016. Transport solutions for cleaner air. Science 352 (6288), 934.
Kimpton, A., Pojani, D., Sipe, N., Corcoran, J., 2020. Parking behavior: park 'n' ride (PnR) to encourage multimodalism in brisbane. Land Use Pol. 91, 104304.
Lee, C.T., Hashim, H., Ho, C.S., 2017. Sustaining the low-carbon emission development in Asia and beyond: sustainable energy, water, transportation and low-carbon emission technology. J. Clean. Prod. 146, 1–13.
Lepitzki, J., Axsen, J., 2018. The role of a low carbon fuel standard in achieving long-term GHG reduction targets. Energy Pol. 119, 423–440.
Li, J., 2010. Research on the development of hydrogen fuel cell vehicle. Transportation World (China) 1, 36–40.
Li, K.S., 2015. Is China suitable for developing diesel cars? Environ. Econ. 24, 33-33.
Li, L., 2017. Structure and influencing factors of CO_2, emissions from transport sector in three major metropolitan regions of China: estimation and decomposition. Transportation 4, 1–25.
Li, J.F., Wang, Z.Y., 2005. The Interpretation of the Renewable Energy Law of People's Republic of China. Chemical Industry Press, Beijing.
Li, Y.M., Zhao, J.F., 2018. Decomposition Analysis of Growth in Transportation Carbon Emissions and Low-Carbon Path Exploration in Beijing, Low-Carbon City and New-type Urbanization (China), pp. 337–345.
Li, P., Zhao, P., Brand, C., 2019. Future energy use and CO_2 emissions of urban passenger transport in China: a travel behavior and urban form-based approach. Appl. Energy 211, 820–842.
Li, Y., Zheng, J., Dong, S., Wen, X., Jin, X., Zhang, L., Peng, X., 2019. Temporal variations of local traffic CO2 emissions and its relationship with CO2 flux in Beijing, China, Transport. Res. Part D-Transport. Environ. Times 67, 1–15.
Lin, W.B., Xie, L.N., Yang, C.Y., 2014. Europe's New Energy Development Policy and the Enlightenment to Our Country, vol. 1. Academic Exchange, China, pp. 72–77.
Lu, Q., Chai, J., Wang, S., 2019. Potential energy conservation and CO2 emissions reduction related to China's road transportation. J. Clean. Prod. 118892.
Martin, E., Chan, N., Shaheen, S., 2012. How public education on eco-driving can reduce both fuel use and greenhouse gas emissions. Transport. Res. Rec. 2287 (1), 163–173.
Matsumoto, K., Shiraki, H., Kazmerski, L., 2018. Energy security performance in Japan under different socioeconomic and energy conditions. Renew. Sustain. Energy Rev. 90, 391–401.
Meng, F., Liu, G., Yang, Z., 2017. Energy efficiency of urban transportation system in Xiamen, China. An integrated approach. Appl. Energy 186, 234–248.
Ministry of Ecology and Environment of China, 2018. Guidance on promoting green consumption. http://zfs.mee.gov.cn/hjjj/gjfbdjjzcx/qtjjzc/201606/t20160620_354782.shtml. (Accessed 29 July 2020).
National Bureau of Statistics of China, 2009. 2008 Beijing Statistical Yearbook. China Statistics Press, Beijing.
National Bureau of Statistics of China, 2019. Annual macro data of Beijing. http://data.stats.gov.cn/. (Accessed 29 July 2020).
National Development and Reform Commission, 2016. Energy technology innovation action plan (2016-2030). http://www.nea.gov.cn/2016-06/01/c_135404377.htm. (Accessed 29 July 2020).
Ong, H.C., Mahlia, T.M.I., Masjuki, H.H., 2012. A review on energy pattern and policy for transportation sector in Malaysia. Renew. Sustain. Energy Rev. 16 (1), 532–542.
Peng, B., Du, H., Ma, S., Fan, Y., Broadstock, D.C., 2015. Urban passenger transport energy saving and emission reduction potential: a case study for Tianjin, China, Energy Conv. OR Manag. 102, 4–16.
Rafiq, G., Talha, B., Patzold, M., 2013. What is new in intelligent transportation systems: an overview of European projects and initiatives. IEEE Veh. Technol. Mag. 8, 45–69.
State Bureau of Environmental Protection of China, 1989. The Environmental Protection Law of the People's Republic of China. State Council of the PRC, Beijing.
State Bureau of Environmental Protection of China, 2005. Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution. Environmental Protection, Beijing.
Sun, L., Huang, Y., Liu, S., 2017. A completive survey study on the feasibility and adaptation of EVs in Beijing, China, Appl. Energy 187, 128–139.
Tang, B.J., Zhou, B., Zhang, K., 2016. Analysis of energy consumption affecting factors and energy saving and emission reduction in Beijing. China, Energy 8 (38), 25–32.
Wang, D.D., 2019. Assessing road transport sustainability by combining environmental impacts and safety concerns, Transport. Res. Part D-Transport. Environ. Times 77, 212–223.
Wang, X., Westerdahl, D., Hu, J., 2012. On-road diesel vehicle emission factors for nitrogen oxides and black carbon in two Chinese cities. Atmos. Environ. 45, 45–55.
Wang, Z., Zhu, H., Ding, Y., 2018. Energy efficiency evaluation of key energy consumption sectors in China based on a macro-evaluating system. Energy 153, 65–79.
Wang, N., Tang, L., Pan, H., 2019. A global comparison and assessment of incentive policy on electric vehicle promotion. Sust. Cities Soc. 44, 597–603.
Wu, Y.P., Zhao, X.H., 2014. A pilot study to explore the potential of eco-driving on fuel consumption reduction. Road Traffic and Safety (China) 14 (1), 53–59.
Wu, Y., Zhang, S., Hao, J., 2017. On-road vehicle emissions and their control in China: a review and outlook. Sci. Total Environ. 574, 332–349.
Wu, Y., Zhao, X., Rong, J., 2018. The effectiveness of eco-driving training for male professional and non-professional drivers, Transport. Res. Part D-Transport. Environ. Times 121–133.
Yang, L., Wang, Y., Han, S., 2019. Urban transport carbon dioxide (CO_2) emissions by commuters in rapidly developing Cities: the comparative study of Beijing and Xi'an in China, Transport. Res. Part D-Transport. Environ. Times 68, 65–83.
Yuan, X., Liu, X., Zuo, J., 2015. The development of new energy vehicles for a sustainable future: a review. Renew. Sustain. Energy Rev. 42, 298–305.
Zhang, X., 2014. Emission Pollution and Control of Vehicle Engines. Beijing Jiaotong University Press, Beijing.
Zhang, D.Y., Liu, G.Y., Chen, C.C., 2019. Medium-to-long-term coupled strategies for energy efficiency and greenhouse gas emissions reduction in beijing (China). Energy Pol. 127, 350–360.
Zhen, X., 2012. Experience and enlightenment of developing P + R abroad. Transport Business China (China) (11), 82–84.
Zhou, J., Cui, S.H., Lin, J.Y., Li, F., 2011. An analysis of emission reduction of chief air pollutants and greenhouse gases in Beijing based on the LEAP model. Environ. Sci. Technol. 34, 164–170.
Zhu, S.L., Jiang, K.J., 2002. Energy demand and pollutant emission of urban traffic in Beijing. China Energy 6, 26–31.