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Transport decarbonization in big cities: An integrated environmental co-benefit analysis of vehicles purchases quota-limit and new energy vehicles promotion policy in Beijing

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Abstract: In the deep decarbonization era against climate change, big cities set ambitious targets for road transport. As China's capital, Beijing has very strict vehicles quota-limit policies. This study contributes to the literature for its innovations on the evaluation of quota-limit executive policy for big cities which few studies have studied, and its improved method with integrated analysis model which distinguish itself for including future co-benefit estimation and enterprise-level data analysis. This study estimates the energy consumption and health environmental co-benefit up to 2030, results show that the ambitious policy will significantly reduce both CO₂ and key atmospheric pollutants emissions. Besides, the health economic loss from different illnesses attributed to NO_x, CO, PM_{2.5} and HC will be 65%, 61%, 19% and 57% lower than reference scenario in 2030. During the energy transition, gasoline will still occupy the biggest proportion of the passenger sector fuel use in Beijing. However, the quota-limit policy will have significant integrated impact on both emission mitigation and avoiding public health damage. This study provides a good reference for big cities in other countries for both its improved method and the effectiveness of administrative decree policy for urban transport planning.

Keywords: decarbonization in cities; environmental co-benefits; New Energy Vehicle; purchase quota-limit

Highlights:

- The nonnegligible environmental health co-benefit is considered in Beijing road transport sector.
- Beijing's electric vehicles policy are studied under different level of EV market penetration.
- The strict electric vehicles policy in Beijing will help the city to fulfil its low carbon city target.
- The quota-limit policy and EV promotion in Beijing has substantial positive health co-benefit.
- It provides a reference for effectiveness analysis of administrative decree policy in big cities.

1. Introduction

Road transport, as one of the key sectors in cities, is in a critical stage of city energy transformation targets.. In past few decades, Beijing, the capital of China, has impressive economic development and advancement of transport sector. So that Beijing meet big challenges to achieve pollutant emission reductions and energy consumption mitigation in transportation sector. According to Beijing Transport Institute, as shown in Fig.1., the total ownership of motor vehicles in Beijing increased approximately 129% from 2005 to 2017 (Road Traffic Operation Analysis Report 2006; Beijing Transport Development Annual Report 2018), which resulted in a huge amount of energy consumption. In 2017, energy consumption in the transport sector accounted for 19.4%

(Beijing Statistical Yearbook 2018; China Environmental Management of Motor Vehicles Annual Report 2018.) of Beijing’s total consumption, which is around 71.3 Mtce. Comparing all sources of emissions, the local mobile in Beijing caused 45% of PM_{2.5} concentration, with nearly 77% from gasoline vehicles emission. (Beijing Statistical Yearbook 2018). And diesel vehicles caused the most NO_x (Nitrogen oxides), PM (Particulate Matter) and CO (Carbon Monoxide) emissions, with 70%, more than 90% and 70% of the total vehicle emissions respectively. (China Environmental Management of Motor Vehicles Annual Report 2018). Therefore, it is of much importance to focus on Beijing road transport policies, and answer the question that how effective of Beijing’s NEV policies on carbon mitigation, local pollutant reduction and public health.

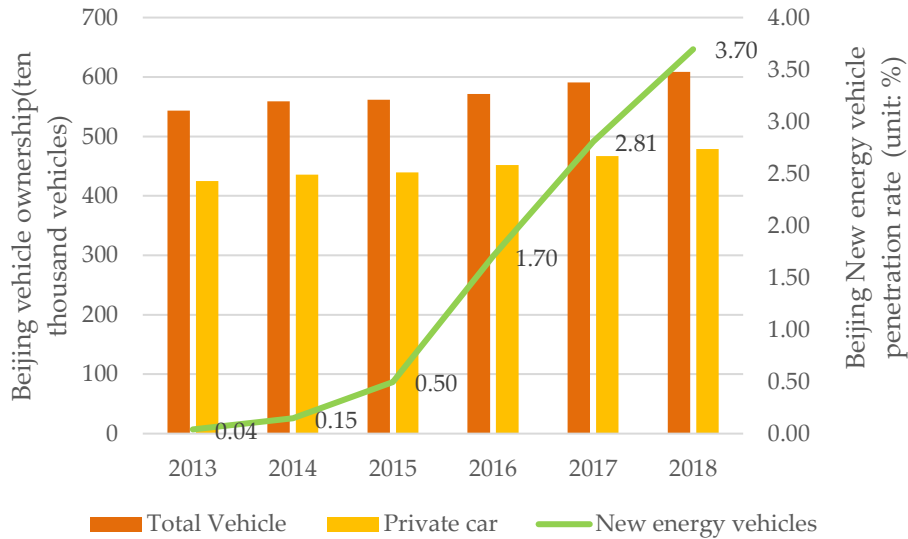


Fig.1. Vehicle Ownership in Beijing

Developing countries like China and India, are promoting their electric vehicles (EVs) with very ambitious measures (Dhar et al. 2017; Dhar and Shukla, 2015; Tang et al. 2019; Lin et al. 2018) and quite differently for various big cities on their road transport. China’s vehicle purchase quota-limit policy and Electric vehicles (EVs) promotion policy have drawn much attention worldwide. In China, some big cities have a series of purchase and quota-limit policies on vehicles according to their different transportation situation. “Purchase-quota-limit” refers to a policy design where in the government has a limited quota of the number of annual vehicles that can be sold to consumers, and consumers enter a lottery to decide who will be able to get a vehicle. **Table 1** shows the detail of quota-limit policy in Beijing, compared to Shanghai and Tianjin. The vehicle purchase restriction policy is divided into license plate lottery system and green-car license plate queuing system. Beijing sets the type of ladder winning rate lottery for normal vehicle purchase and restrict the configuration quota only for pure electric driven passenger cars. While the green car types in Shanghai is various, which not only includes pure electric vehicles, but involves plug-in hybrid vehicles and fuel cell vehicles, and the vehicle license plate can be gained via auction. And green-car can get license plate directly without lottery or bidding in Tianjin.

In the foreign countries, most of big cities take different measures more on electric vehicle from economy perspective including tax subsidy, parking and congestion fees and purchase subsidy aspect. From the perspective of tax subsidy policy, in Spain, main city councils (eg Madrid, Barcelona, Zaragoza, Valencia etc) are reducing the annual circulation tax for electric and fuel efficient vehicles by 75%. In London, all purely electric cars, vans and other vehicles are currently congestion charge-exempt because of zero tailpipe emissions. In Italy, Milano grant electric and hybrid vehicles special waivers from parking fees and from paying the circulation tax. Some big cities implement the purchase subsidy policy on the EV market. Amsterdam city offers a subsidy scheme for the purchase

of electric utility vehicles used frequently in the city. In Hamburg, the share of PEV bought by public authorities shall rise to at least 20 % of all new vehicle purchases. A budget of 100 million EUR was dedicated to this purpose. (IEA policy database). From the above EV policies for foreign big cities, most policies focus on the economic measures of EV development, while lacking of the design of purchase limitations policy on general gasoline vehicle.

Table 1
Vehicle Purchase Restriction Policy in Beijing, Shanghai and Tianjin

CITY	Vehicle Purchase Restriction Policy	
	License Plate Lottery System	Green-car License Plate Queuing System
Beijing	<ul style="list-style-type: none"> Set the ladder winning rate If the lottery fails within 6 times, the winning rate shall be the current benchmark winning rate. If the lottery fails for 7 to 12 times, the winning rate will rise to 2 times than the current benchmark winning rate. 	<ul style="list-style-type: none"> The Green-car refers to pure electric driven passenger cars. The Green-car quota are configured by waiting mode. Personnel can't ask for general passenger car configuration quota and green-car configuration quota at the same time.
Shanghai	<ul style="list-style-type: none"> Private Passenger Car with no more than 9 seats use venues auction conducted via the Internet, telephone, etc. Enterprise Passenger Car use regular auctions 	<ul style="list-style-type: none"> NEV refer to pure electric vehicles, plug-in hybrid vehicles and fuel cell vehicles Not applicable to public transportation vehicles
Tianjin	<ul style="list-style-type: none"> Hybrid passenger car, general passenger car, private passenger car and enterprise passenger car do license plate lottery separately. 	<ul style="list-style-type: none"> Green-car can do license plate directly without license plate lottery or bidding.

From above policies of cities from China and foreign countries, the combination of purchase quota-limit and EV promotion policies is less applied comprehensively to the current cities' EV policy. The effect of policy also has regional differences. In Beijing, the previous temporary transportation control policy in 2008 Olympic game shows good performance in pollutant emission reductions, whose emissions of volatile organic compounds (VOC), carbon monoxide (CO), nitrogen oxides (NOx) and particulate matter with an aerodynamic diameter of 10 μm or less (PM10) during the 2008 Olympics were reduced by 55.5%, 56.8%, 45.7% and 51.6%, respectively, as compared before the Olympics. (Zhou Y et al., 2010). And the license plate quota policy has shown significantly increase effect on the annual sales of NEVs in Chinese city like Tianjin, Hangzhou, Shenzhen, and Haikou.(Chi Y et al., 2021). However, the related EV substitution policies might not be effective. For example, free parking was found not significantly influential in China (Wang et al., 2017; Zhuge, C. et al., 2020). In the current studies, most studies focused on the EV promotion or substitution policies in big cities (Dhar S., et al. 2017., Fan J.-L., et al. 2017., Donato T., et al. 2015., Alimujiang A., et al. 2020., Lin J., et al. 2018), while the environmental effect of quota-limit policy (mainly for gasoline private vehicles in

Beijing) is lack of study. This study contributes to the literature for filling this research gap and provide references to the big city policy implementation.

Under the circumstances of high pressure of traffic emission reduction and energy conservation, the purchase quota-limit policy and promotion of new energy vehicles can be effective measures. We put mainly effort on different specific automobile enterprises and vehicle types to analyze and predict that under the scenario of full development of electric vehicles and purchase-quota-limit policies, considering the health benefits, whether the government has the impetus to implement it, and evaluate the car enterprises' development space related to production plan and consumers' purchase in the future. Therefore, this study has a more comprehensive significance for the future planning reference of transportation department.

This work aims to solve 2 detailed questions. First, this study answered the un-well answered question: what is the energy and environmental impact of quota-limit policies in big cities like Beijing? We aim to use consistent and realistic scenarios, with settings at technological levels to analyze the potential impacts of combined polices. China has issued series of policies to promote the application of NEVs, including both target constraints and financial support. Beijing has also promulgated its own NEV policies based on national plans (Table A1). Since 2011, various vehicle purchase-quota-limit policies have been introduced to control gasoline vehicles and promote NEVs. In terms of local financial subsidies, the Beijing Municipal Government has formulated municipal subsidies for NEVs, mainly for battery electric vehicles and fuel cell vehicles, based on the national standards. The subsidies for electric passenger vehicles in Beijing are listed in Table A2. Yet, few studies have taken a holistic approach and consider all these policies combined.

Second, this study further improves the methodology for road transport in cities. The self-developed bottom-up model has more vehicle technologies described based on company level information, i.e. BYD e6 (a vehicle type of BYD company) and Tesla models. The prediction method further expanded the method from traditional sectoral level study to the technological level, with enterprise-level data. Third, the public health co-benefit and economic cost avoided is based on local VSL, and the emission co-efficient is set based on vehicle group level, which has further disaggregated vehicles, i.e. miniature cars, Light-Duty Vehicles or compact cars, medium sized cars, medium and large vehicles, MPVs, and SUVs. With these improvements, we can inform current discussions on transition measures by providing concrete empirical results on the effectiveness of Beijing's administrative decrees.

In order to answer the research question and fulfill the study targets stated above, the paper is structured as follows: Section 2 states the work's contribution to the literatures. In section 3, we introduce the methodology of this study, including the bottom-up model we developed for the Beijing transport sector, the scenario design (with detailed tables in the annex), and the simplified environmental benefit analysis functions. Since a large amount of data work has been done for this study, we separately have a section 4 for key data description. Section 5 gives the results for energy system optimization and environmental health co-benefit evaluation. Conclusions and discussion are in section 6, including main conclusions, further study topics, and policy applications for big cities in developing countries.

2. Main contribution to literatures

In recent years, studies draw more attention to transportation sector on environmental impact of carbon mitigation targets under constraint of global temperature or emissions peaking (Tian et al, 2019; Lin et al, 2018). Some researchers assess the impact of national or regional plans on future energy systems and air quality, involving the 2030 electrification plan (Peng et al, 2018), transport mode optimization (Liu et al, 2018; He and Qiu, 2016), and updated emissions standards (Liu et al, 2017). Research in the field of political science has confirmed the vital role of cities' transportation in carbon mitigation and energy transition (Fraundorfer, 2017; Rohracher and Späth, 2014). And the significance of policies in big city transport in developing countries, such as China, India, and other South Asian countries, has recently become the focus of emerging studies (Kwan et al. 2017; Pathak

and Shukla 2016; Gao et al. 2017; Tang et al. 2019; Lin et al. 2018). While many literatures show that the effect of policy implementation in different cities are asymmetric in city level and environmental health co-benefits.

As there are differences in economic development, population, culture and other factors between different cities in one country, especially countries with a vast territory such as China, not all cities adapt to the policy of EV substitution. Researcher found that in 2017, the adoption of EVs in all regions can reduce NO_x emissions, but only in the south of the Yangtze River can it reduce SO₂ emissions, and the future potential for emissions reduction is mainly from southern provinces (Li F et al., 2019). As a heavy industrial city, Shenyang adopt public transport vehicle substitution policy, showing that CNG bus has the best economic and environmental performances, while hybrid and electricity vehicles are not suitable as public transportation tools for the current stage (Geng Y., et al. 2013.). Some studies focus on Xiamen, the middle city with restrictions on electricity supply and rapid population growth (Lin J., et al. 2018.), implement a series policy involving the NEV substitution, fuel economy regulations and motor vehicle controls indicating that enacting controls on private vehicles would be most effective to GHGs mitigation. (Xue X., et al. 2015.). Therefore, facing these regional differences, it is imperative to conduct specific target-based research in different cities.

Countries beyond China is facing the same heterogeneity of plan making effect. Although the high EV penetration scenario presents slightly higher benefits with respect to the underground rail and transition vehicles policy in southeastern European cities, the limitation of popularity of EV will not affect the air quality of urban agglomeration slightly (Sarigiannis D. A., et al. 2017.). Furthermore, the cities which put the vehicle fuel type substitution into policy consideration also shows the various environmental benefit. Greater Kuala Lumpur in Malaysia focus on the strategic master plan for the 2 MRT lines development to improve the environmental quality, which would reduce 6% of CO₂ equivalent emission from private motor vehicles (Kwan S. C., et al. 2017.). In Dublin, Ireland, considering the varying degree vehicle fuel type substitution and traffic management strategies, shows that health impacts at a local scale can be very different from the whole city. (Tang J et al., 2020.). Dhar S. shows that EV promotion policies on the co-benefit of electric vehicles and different regions have asymmetric (Dhar S., et al. 2017.).

Based on the recent literatures, different EV policies adopted in different cities have different environmental co-benefit impacts. Besides, the above studies also indicate that most scholars assess the impact of the strategic about vehicular fuel substitution and the EV promotion degree, while rarely consider the environmental impact of vehicle type replacement, enterprises development and purchase policy. Our paper aims to consider evaluating the combination policy effects of EV promotion and quota-limit policy in Beijing at the activity level to enrich literatures.

After the establishment of research policy, it is necessary to evaluate the environmental health co-benefits brought by the policy implementation. On the co-benefit evaluation method, the recent study of transportation environmental co-benefit, the scholars have different research emphasis. Some researchers focus on the co-benefit only based on avoided GHG emission, while ignoring the health impact (Dirgahayani P. 2013., Panwar M., et al. 2018., Fan J.-L., et al. 2017.). The other studies calculate the health impact, but they have no further evaluation for health economic effect (Kwan S. C., et al. 2017.). For example, Fridell E. only calculated weighted per capita exposure response under different scenarios about HC emission from transportation sector (Fridell E., et al. 2014.). CO₂, SO₂, NO_x and PM_{2.5} emission caused deaths in Beijing has been quantified without considering the economic loss (Wu Yuting., 2016). There are few scholars taking both related deaths and economic effect into account on the big city level. The health economic effect from PM, NO_x and SO₂ emission including public health cost and vehicle cost has been measured in Xiamen, without incorporating the HC and CO emission (Xue X., et al. 2015.). When it comes to the selection of the parameter of VSL using in exposure-response method when evaluating the health co-benefit, some researchers choose the value from the World Bank (Xue X., et al. 2015.) and the result of USA study adjusted to different regions using fixed ratio (Li Y., et al. 2011.) as approximation of VSL. Our study not only consider the emission of, but adopt direct value of inhale fraction, sensitivity of human health to human pollutants to simplify the accounting method and use domestic VSL (Wang and Mullahy., 2006. Zeng et al.,

2010., Xu et al., 2013., Gao et al., 2015., Wang 2015). It is of necessity to have the monetary health evaluation for environmental co-benefit. This paper dedicates to enrich the studies in the area of EV policies' impact on environmental co-benefit considering the main local pollutant emission, including HC, NO_x, SO₂ and PM_{2.5}. and further evaluates the economic costs avoided due to co-benefit, aiming to show more intuitive that how much of the policy cost could be offset, when considering co-benefits.

From the methodology applied to EV development, the electric vehicles' impact on energy saving and emissions reduction have been discussed widely by using kinds of methods. In the short term, the main researches on EV technology factors mostly involve the parameters of the EVs driving distances, driving speed and charging Station (Yuan et al., 2015; Karmaker et al., 2018). Among these, LCA (life cycle assessment) methods are frequently used by researchers on vehicle characteristics and assumptions of the EV during their life cycle in the short term which have the absence of policy implementation sustainability discussion. (Faria et al., 2013; Qiao et al. 2019; Yu et al. 2018). Furthermore, many meaningful studies use WTW (well-to-wheel model) (F. Li et al., 2019), and CTG (cradle-to-grave assessment model) (Shi et al. 2019) analyze the detailed technology to reveal the fuel standard and electricity energy mix use on vehicle performance and vehicle emission from the process of vehicle manufacturing and recycling. In the long term, some researchers have used top-down model, such as CGE (Computable general equilibrium) models, laying particular emphasis on environment tax, energy investment and adjustment of energy price on the macroeconomic level instead of detailed technology in transport sector, which suggested that the model have restrictions to analyze the specific technology substitution in EV penetration. (W. Li et al., 2017; Li W et al., 2017)..Tian X., et al. integrates 3 models, including GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model, Health model and GGE model evaluates the health impacts of PM_{2.5} pollution at the activity level (Tian X., et al. 2018.)

The bottom-up model is also a suitable choice to measure the EV promotion effect on environment and human health. TIMES model (Olivier Bahn et al., 2013.), ANSWER MARKAL model (Subash Dhar et al., 2017) and LEAP model (Liu L et al., 2018.) are applied to study the electrification of transportation sector in Canada, India and China respectively. The environmental impact is calculated from the energy consumption and the emission factors, which depend on the class of vehicles and the fuel types at the activity level. The calculation based on the vehicle type and enterprise level is less considered in the recent studies. In our study, we use bottom-up model after taking detailed techniques, economic measures, policies and transportation related parameters into consideration, the local pollutant emission calculation is based on the vehicle level, instead of the activity level and linked to technologies by their emissions coefficients. Therefore, to combine these two sides, a future impact assessment for specific policies with detailed vehicle technologies are required. This paper aiming to make contribution to the current literatures in this way.

3. Methodology

3. Methodology In this paper, the MAPLE (Multi-pollutant Abatement Planning and Long-term benefit Evaluation) model is applied to study the impact of the promotion of NEVs on energy structure and regional emissions in Beijing. MAPLE is a bottom-up model with rich technologies. With 2015 as the base year, energy consumption, CO₂ emissions, and emissions of conventional polluted gases in the transportation sector are predicted through 2030 with a five-year interval based on MAPLE. The optimization principle is to minimize the total system cost. The technical roadmap of this study is shown in Fig.2.

The MAPLE model distinguishes from other models for three aspects: first, compared to the frequently used CGE model, when applied in transport sector, CGE model always carry out analysis at sectoral level, without information of technological details. For Beijing road transport sector, MAPLE model takes different types of vehicles into account, including private cars, taxis, buses, and trucks with

different fuel types. The private vehicles data are also classified at enterprise level, i.e. BYD, BAIC, Tesla, Zotye, etc.

Second, compared to other bottom-up models, some models have no local pollutant module. For local pollutant, the emission coefficient is developed based on the vehicle level, instead of the activity level. Thus, in addition to carbon dioxide, the typical local pollutant emissions like NO_x, CO, and HC are directly linked to technologies by their emissions coefficients. Thirdly, further health damage impact and economic costs are linked to MAPLE model. The setting of health damage impact is based on the VSL value, instead of EPA (United States Environmental Protection Agency) or the national level. Moreover, the analysis of economic impact prompts the model to analyze the policy costs avoided by co-benefit, which is a necessary improvement for the regional model to embody the regional heterogeneity. For typical gasoline vehicles, different levels of fuel economy and emissions standards are considered. The linking at the vehicle level using rich technology detail aims to complete the missing information if modeling were done only at the transport mode level.

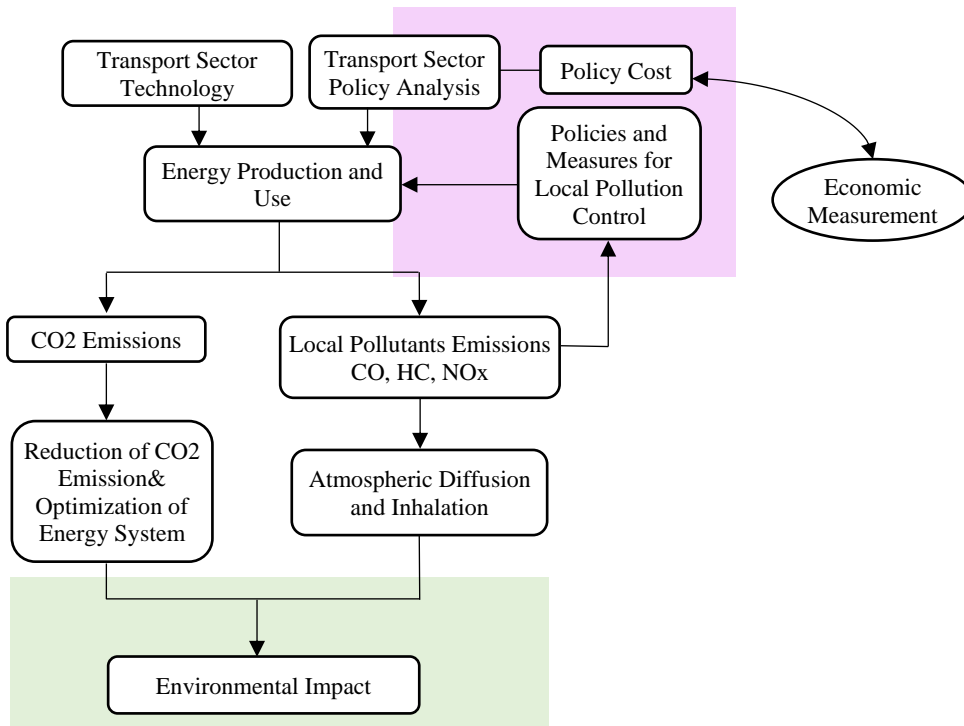


Fig. 2. Reference Energy System

3.2 health co-benefit evaluation

Health co-benefits have been long ignored for the transport sector (Dirgahayani P., 2013; Panwar M et al., 2018). The environmental health impact analysis here is simplified for the health evaluation, but with detailed emission coefficient for each vehicle technologies, directly linked to the local pollutant module in TIMES. We take local statistical data for the VSL (Value of statistical life) instead of WHO (World Health Organization) data from other countries. The intake fraction (inF) is an important parameter in environment and health damage studies. According to the equation for calculating inF, as shown below in Equations (1) and (2), it can be converted to an equation to calculate the concentration change in emissions.

$$inF = \frac{\text{population intake}}{\text{total emission}} = \frac{Pop \cdot \Delta C \cdot BER}{Pop \cdot BR} \quad (1)$$

$$\Delta C = \frac{EM \cdot inF}{BR \cdot Pop} \quad (2)$$

ΔC is the concentration change of air pollutants, Pop is population, BER means pollutant emission rate in g/day and BR is breathing rate in m³/day (estimated at 14.5 m³/day), inF is the intake fraction, EM is emission rate in g/day. The intake fraction for CO is 36, which selected from the foreign country's study result because of the lack of research in China. As for intake fraction for NO_x is 42, we use the local survey result which, is available for transportation sector in China (Yang .2012, P. Holnicki,2018).

$$HL = VSL \cdot ND \cdot \frac{\exp(\beta \times \Delta C) - 1}{\exp(\beta \times \Delta C)} \quad (3)$$

The evaluation of health loss is show in equation (3). HL is health losses from air pollutant emissions, VSL is the value of a statistical life, ND is the number of deaths, and β is the sensitivity of human health to air pollutants. The value of a statistical life (VSL) used in this paper is based on literature review and hospital data research. We obtained the VSL from some local surveys about VSL in China by different scholars and research groups (Wang and Mullahy 2006; Zeng and Jiang 2010; Xu et al. 2013; Gao et al. 2015; Wang 2015). The VSL data distinguish from other studies for the value selection source. Some researchers selected the VSL of the USA converted to the domestic situation in a fixed proportion (Li Y., et al., 2011.) and applied the statistics from the Word Bank (Xue X., et al. 2015.) ignoring the local situation. Because the local survey results measure the willingness to pay of local people is better, we use the local survey results of VSL instead of the conversion values or The World Bank value. The data on disease deaths was collected from the Chinese Center for Disease Control and Prevention.

3.3 Scenarios

Three scenarios are described as follows: REF scenario (no policy scenario), LCE scenario (low carbon NEVs policy scenario), ELCQ scenario (Enhanced low carbon NEV policy with quota-limit). The REF scenario is a benchmark scenario where the government does not adopt any promotional policies for electric vehicles, in which the penetration level of Electric vehicle still maintains 0.5% (Beijing Transport Annual Report, 2019) so by 2030, the proportion of electric vehicles in Beijing will be the same as in 2015. According to the existing policies, by 2020, the penetration rate of NEV is 6.3% (Beijing Traffic Development and Construction Plan for the 13th Five-Year Plan Period., 2016 and Beijing's Three-Year Action Plan for Winning the Blue-Sky Defense War, 2018). We use linear interpolation method to estimate the penetration level in 2025 and 2030, from which the result show that the penetration level in 2025 is 11.7% and in 2030 is 17.5%. We assume that the middle level of penetration rate is 11.7% and the high level is 17.5% The LCE scenario is a low carbon policy scenario, which refers to a series of related transportation development plans and energy saving and emission reduction plans during the 13th Five-Year Plan period in Beijing with the 11.7% penetration level (Table A3). By 2030, the proportion of electric vehicles has increased significantly due to policy promotion, and the fuel economy has increased year by year. The ELCQ scenario is a scenario of purchase-quota-limit and larger penetration of electric vehicles. It is assumed that by 2030, the NEVs will account for a larger proportion than that in the LCE scenario, with 17.5% promotion level of EV. Specific scenarios are described in **Table 2**.

Table 2. Detailed Description of Scenario Settings

Scenario	Description
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REF ¹ Scenario	The government does not adopt any NEV ² promotion policy. By 2030, the proportion of EVs in Beijing will be the same as 0.49% in 2015. The proportion of electric buses, electric taxis, electric buses and electric trucks will be 0.5%, 4.6%, 7.9% and 0.2%.
LCE ³ Scenario	Referring to Beijing's transportation development plan and energy saving and emissions reduction plan during the 13th Five-Year Plan period (TableA3), the penetration of new energy vehicles will maintain at the middle level by 2030 accounting for 11,7% of the whole motor vehicle market. The proportion of new energy private cars, taxis, buses and trucks will be 20%, 30%, 30% and 10% by 2030, respectively. In 2020, the fuel economy of all kinds of automobiles is 10% higher than that in 2015, and in 2030, the fuel economy of all kinds of automobiles is 20% higher than that in 2020.
ELCQ ⁴ Scenario	More powerful quota-limit policy and NEV promotion policies are assumed to be implemented in this scenario, with at a high level of 17.5% NEV penetration and a higher share target of 40%, 50%, 50% and 30% by 2030 for new energy private cars, taxis, buses and trucks, respectively.

¹ REF scenario (No policy scenario)

² NEV (New energy vehicle)

³ LCE scenario (Low carbon NEVs policy scenario)

⁴ ELCQ scenario (Enhanced low carbon NEV policy with quota-limit).

4. Data

4.1. Vehicle Ownership, Fuel Economy, Average Annual Mileage, and Single Vehicle Cost

There are four main types of vehicles in our study: private cars, taxis, buses, and road trucks, each of which is divided into smaller categories according to fuel types (gasoline, electric, diesel, CNG, LNG, etc.). The vehicle ownership data of various types of vehicles in Beijing in the base year 2015 are shown in **Table A4**. The total ownership data of private cars in Beijing are derived from the number of owners of private passenger cars in Beijing in the China Transport Yearbook 2016 (China Transport Yearbook 2016). The ownership data of electric vehicles and CNG vehicles comes from the Beijing Electric Vehicle Charging Infrastructure Special Plan (2016-2020) (Commission Beijing Electric Vehicle Charging Infrastructure Special Plan (2016-2020)) and the research of Wang et al. (Wang et al, 2015). The ownership of further subdivided vehicles is converted to the proportion of sales data in 2015. Taxi ownership data are collected from the Beijing Transport Development Annual Report 2016 (Beijing Transport Development Annual Report 2016) and the China Transport Yearbook 2016 (China Transport Yearbook 2016). The data on bus ownership comes from the Beijing Transport Development Annual Report 2016 (Beijing Transport Development Annual Report 2016), the China Transport Yearbook 2016 (China Transport Yearbook 2016), and the Beijing Bus Group Corporate Social Responsibility Report 2015 (Beijing Bus Group Corporate Social Responsibility Report 2015). The ownership data of trucks are derived from the statistics of the China Transport Yearbook 2016 (China Transport Yearbook 2016).

Fuel economy refers to the ability to complete unit transportation with minimal fuel consumption. **Table 3** shows the fuel efficiency of private cars, taxis, buses and trucks of Beijing in 2015, which uses data from the China Automotive Fuel Consumption Query System of the Ministry of Industry and Information Technology (Ministry of Industry and Information Technology 2019) and the research of Wang et al. (Wang et al, 2015). The difference between the private car type and bus type is that the control of the bus type is publicly owned and private car have a freedom to trade.

The average annual mileage of private cars, taxis, and buses in Beijing in 2015 (**TableA5**) came from the Beijing Transport Development Annual Report 2016 (Beijing Transport Development

Annual Report 2016). The average mileage of trucks came from statistics released by Manyixing APP (Sohu News, 2019).

The retail price of vehicles is applied as the cost of a single vehicle. According to the China Automobile Industry Yearbook 2016, 32% of the cars sold in 2015 were between 120,000 yuan and 180,000 yuan, followed by 80,000 yuan to 120,000 yuan, accounting for 21% of total sales (China Automobile Industry Yearbook 2016). The referenced data mainly comes from the China Automobile Industry Yearbook 2016 (China Automobile Industry Yearbook 2016).

4.2. Emissions factors of traffic atmospheric pollutants

The emission factors of traffic pollutants are important parameters for the model analysis. The emissions of CO, NO_x and HC are the main ones considered in this study. The pollutant emissions factors of different types of vehicles reference the research about traffic emissions factors in Beijing by Fan et al. 2015 from the Beijing Municipal Research Institute of Environmental Protection. The parameters of traffic pollutant emissions factors for different types of vehicles are shown in **Table A6**.

5. Results

5.1. Total End-use Energy Consumption and Energy Structure of Passenger Transportation

The results in **Table 3** show the end-use energy consumption of passenger transport in Beijing under different scenarios. Compared with the REF scenario, the total energy consumption in the LCE scenario is 16.9% less than that in the REF scenario in 2025, and 14.7% less in 2030. In the ELCQ scenario, the total energy demand will drop by 16.4% in 2025 and 26.1% in 2030 compared with the REF scenario.

In the short and medium term, the energy-saving effect of ELCQ scenarios in 2025 is similar to the LCE scenarios, but in the long run, by 2030, ELCQ scenarios will save more energy consumption than LCE scenarios. That means the effects of vigorously promoting NEVs makes little difference compared with the mild policies in the short and medium term. It can be explained that in the short and medium term, the development of NEVs' fuel economy and other technical levels have limitations, which limits the energy-saving effect of substituting a large proportion of NEVs. But in the long run, after the corresponding improvement of technology, a large proportion replacement of NEVs will have a more significant energy-saving effect.

Table 3. The end-use energy consumption of passenger transport in Beijing (Mtce)

	REF ¹	LCE ²	ELCQ ³
2025	8.47	7.04	7.09
2030	10.84	9.25	8.01

¹ REF scenario (No policy scenario)

² LCE scenario (Low carbon NEVs policy scenario)

³ ELCQ scenario (Enhanced low carbon NEV policy with quota-limit).

As for the energy consumption structure of passenger transport (**Fig.3**), the results of all scenarios show that gasoline will still account for the largest proportion in the future. The proportion of diesel oil in the LCE scenario and ELCQ scenario will decline to 14.81% and 10.86% in 2030, while in the REF scenario, it is 16.61%. For electricity, the results of the LCE scenario and ELCQ scenario show an increase of 1.4% and 4.7% respectively compared to the REF scenario in 2030. The composition of natural gas increases almost 4 times in the ELCQ scenario compared to REF scenario.

Thus, with the application of NEV policy, although gasoline and diesel still account for the majority of fuel use in the future, the energy consumption structure will be improved with the gradually increasing use of electricity and natural gas, but the improvement will be gradual and slow because it is a long-term process.



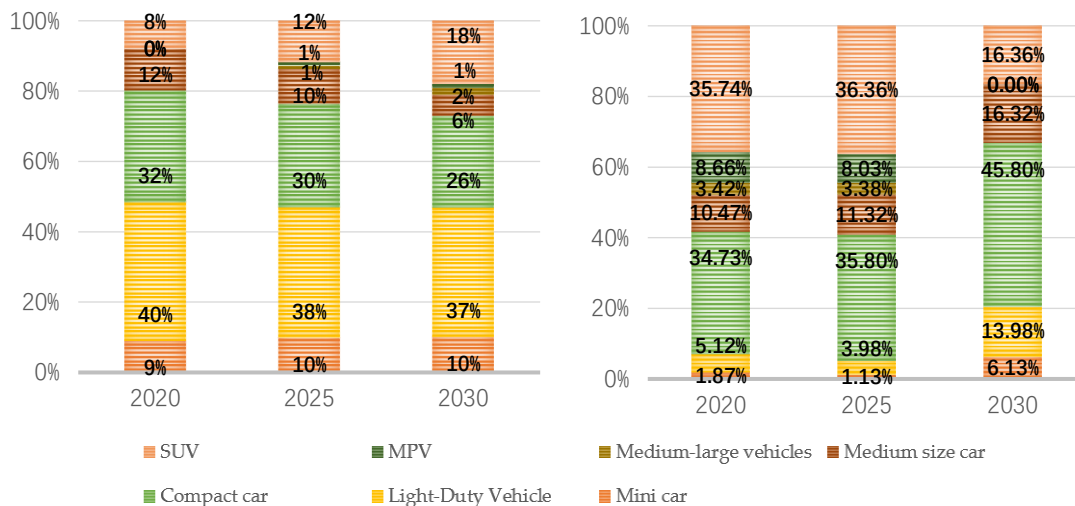
Fig 3. Passenger Fuel Consumption Structure of Beijing under Different Scenarios

5.2. Energy Consumption Structure of Different Traffic Types

5.2.1 Private Cars

The development of electric vehicles has become a mainstream trend in various vehicle enterprises. For example, the number of electric vehicles of BYD accounted for 43.6% of its production, and the market share in 2015 and 2018 was 11% and 20% respectively. With the strict policy of vehicle restriction and license plate lotteries, electric vehicles will become mainstream private cars in Beijing.

In Fig.4., we forecast the composition of vehicle types of private electric cars and the proportion of the gasoline vehicles. In 2030, light-duty vehicles and compact cars will be the main types of EVs, with a total proportion of 63%, but SUVs (Sport Utility Vehicles) also increase significantly from 8% in 2020 to 18% in 2030. For gasoline vehicles, the proportion of SUVs will experience a decline, and compact cars will replace SUVs to be the main type of gasoline vehicle.



(a) Proportion of private electric vehicles

(b) Proportion of private gasoline vehicles

Fig.4. Forecast of the Structure of Private Vehicle Type

Fig.5-(a) shows the fuel composition of private cars. Under the three scenarios, gasoline consumption will still account for the largest proportion in the future. In the LCE scenario, the proportion of gasoline in 2030 will be 85.40%, about 9.10% less than that in REF scenario. In the ELCQ

scenario, in 2030, the proportion of gasoline decreases 18.3% compared to the REF scenario. The proportion of electricity was 4.74 times that of the REF scenario. The proportion of fuel ethanol and hydrogen will reach 0.78% by 2030.

Under the two scenarios of policy promotion, the fuel structure of private cars will gradually diversify, which was dominated by gasoline in the past. Under the policy scenario, EVs will replace a large proportion of gasoline vehicles to make the energy structure more balanced. Moreover, although the proportion of electricity and hydrogen energy increases slowly in the short term, it will increase rapidly in the long run, due to the development of better technology as well as the reduction of the total cost.

5.2.2 Taxis

Taxis in Beijing make up a significant share of vehicles - 5.9% of non-private vehicles in 2018. The administrative decree on gasoline taxi controls, intended to promote natural gas and pure EVs, has obvious impact on the energy system. **Fig.5-(b)** shows the composition of fuels for taxis. In all three scenarios, gasoline will still account for the largest proportion.

In the LCE scenario, the proportion of electricity increases slowly in the short run but rapidly in the long run, reaching 15% in 2030, 6% higher than that in REF scenario. Natural gas rose from 6% in 2020 to 10% in 2030, 4% higher than the REF scenario.

In the ELCQ scenario, although gasoline still accounts for the majority, it has fallen to 55% by 2030. The proportion of electricity has increased considerably, to 27% by 2025 and to 34% by 2030, which is about 3.8 times higher than that under the REF scenario. Natural gas also reached 11% in 2030, 1.8 times that of the REF scenario.

5.2.3 Buses

Buses in Beijing have been updated to natural gas and electricity very rapidly in recent years. However, as is shown in **Fig.5-(c)**, diesel will still be the largest component of bus fuel. With the promotion of NEVs in the LCE scenario, by 2030, the proportion of diesel oil will drop to 64%, 9% lower than that in the REF scenario. The proportion of electricity is growing rapidly, increasing by 4% over the REF scenario. Natural gas increases by 6% in 2030 compared with the REF scenario.

If more powerful policies with higher targets are applied in the ELCQ scenario, diesel fuel will be only 50% by 2030, decreasing 23% compared with the REF scenario. The proportion of electricity will reach 21% by 2030, 15% higher than that of the REF scenario. The proportion of natural gas reaches 1.4 times that of the REF scenario in 2020, and 1.86 times that of the REF scenario in 2030. Thus, the promotion of new energy buses will play a more significant role in the energy structure for buses.

5.2.4 Trucks

The study also evaluates the fuel structure of trucks, as shown in **Fig.5(d)**. In the future, diesel will remain the largest fuel source for trucks. The proportion of diesel oil in the LCE scenario will drop to 68% in 2030, 12.8% lower compared with the REF scenario. The share of electricity rises slowly, accounting for about 2% in 2030, twice as much as that in the REF scenario. When comes to the ELCQ scenario, the proportion of diesel oil declined rapidly, one fifth less than that in the REF scenario in 2030. Electricity grows from nearly zero in 2015 to 6% in 2030, increased by six times compared with the REF scenario by 2030.

The promotion of NEVs has little effect on the fuel structure of the freight transport sector, as diesel and gasoline trucks are still difficult to replace. Therefore, in the freight sector, in addition to promoting the application of new energy trucks, it is more important to control the emissions of diesel and gasoline trucks, as well as to introduce stricter emission standards.



Fig.5. Consumption structure of different types of vehicles

5.3. CO₂ Emissions

The promotion of EV exerts a strong influence on CO₂ emission reductions. Under the REF scenario, CO₂ emissions from the transport sector increased from 40.18 million tons in 2025 to 41.16 million tons in 2030.

In the LCE scenario, in 2025 and 2030, CO₂ emissions will be 24.4% and 30.9% , which are lower than those in the REF scenario respectively. In the ELCQ scenario, CO₂ emissions decline more rapidly, decreasing by 34.1% and 45.2% in 2025 and 2030 respectively compared with the REF scenario, and decreasing 12.9% and 20.7% in 2025 and 2030 respectively compared with the LCE scenario.

Results show that the promotion of NEVs has a considerable effect on controlling CO₂ emissions. With the promotion and replacement ratio of NEVs, CO₂ emissions will be reduced more rapidly. Moreover, the reduction rate of CO₂ emissions shows a declining tendency. In addition, this study does not use a life cycle analysis framework, which may produce different results.

5.4 Local Pollutant Emissions

Fig.6. shows that the LCE scenario and ELCQ scenario both have small effects on the reduction of local pollutant emissions, mainly CO, NOx, HC and PM 2.5, from Beijing's passenger transport sector. Especially for the ELCQ scenario, the reduction of CO emissions can be decreased by 51% and 61% in 2025 and 2030 respectively, compared with the REF scenario. For NOx emissions, 59% and 66% can be reduced in 2025 and 2030, respectively, when compared with the REF scenario. When it comes to HC emission, the decrease of 43% and 57% can be reached in 2025 and 2030, respectively, compared with the REF scenario. The emission of PM 2.5 can bring the reduction of 13% and 19% in 2025 and 2030, respectively.

Under the LCE scenario, the local pollutant emissions also have different degrees of decline. Compared with the REF scenario, NOx emissions will decrease by 44% and 53% in 2025 and 2030, respectively. The reduction of CO emissions accounted for 34% and 47% in 2025 and 2030. The emissions of HC can be decreased by 37% and 46% in 2025 and 2030, respectively. The PM 2.5 emission can be reduced by 5% and 9% in 2025 and 2030 respectively.

The results show that the promotion of NEVs for the transport sector plays an important role in reducing emissions. Especially in the ELCQ scenario, the application of vigorous promotion policies can reduce the emissions of pollutants by more than half, which will have more marked effect than LCE scenario.

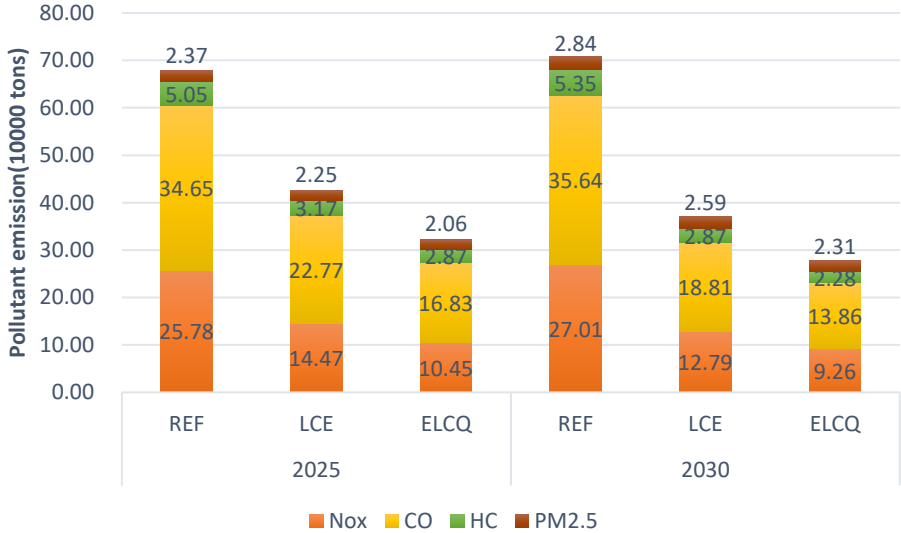


Fig.6. Atmospheric Pollutants from the Beijing Passenger Transport Sector under Different Scenarios

5.5 Avoided Deaths

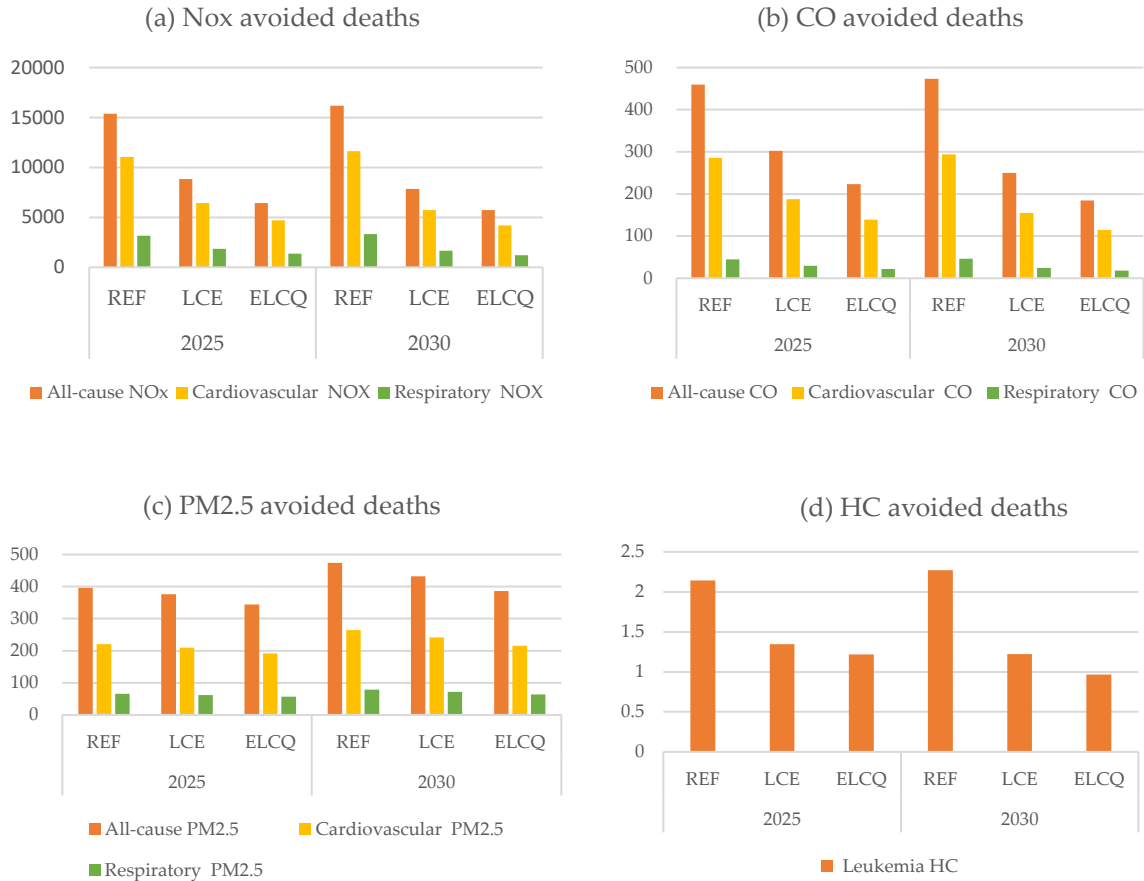


Fig. 7. Air Pollution-Related Deaths from Beijing Passenger Transport under Different Scenarios (person)

In this paper, we consider 4 types of health terminal, involving all-caused deaths, cardiovascular disease and respiratory disease caused by inhalation of NOx, CO and PM2.5. and leukemia caused by exposure to HC. Fig.7. indicates that the promotion of NEVs can indeed bring about a reduction in the number of deaths caused by NOx, PM2.5, HC and CO emissions from Beijing passenger transport under the LCE and ELCQ scenarios. Under the ELCQ scenario, in 2025 and 2030, the total deaths caused by NOx can be reduced by 58% and 65% respectively, including the deaths caused by cardiovascular disease and respiratory disease, which would both decrease by 57% and 64% respectively when compared to the REF scenario. For the deaths caused by CO, in 2025 and 2030, the aggregate deaths can be reduced 51% and 61% respectively, of which the reduction of deaths caused by cardiovascular disease and respiratory disease is 51% and 61% respectively, compared with the REF scenario. For the perspective of PM 2.5 emission, the all-caused deaths, cardiovascular caused deaths and respiratory caused deaths both have 13% and 19% reduction in 2025 and 2030 respectively. The variation of leukemia deaths induced by HC emission can be reduced from 2.14 to 1.22 cases, from 2.27 to 0.97 cases in 2025 and 2030 respectively.

When it comes to the comparison between the LCE scenario and the REF scenario, firstly, in 2025 and 2030, for the NOx pollutants, deaths can be reduced by 43% and 51% respectively, in which the cardiovascular deaths and respiratory deaths will both lessen by 42% and 51%. Secondly, for CO pollutants, in 2025 and 2030, 34% and 47% of total deaths can be avoided, representing cardiovascular deaths and respiratory deaths respectively. The emission of PM 2.5 pollutant can avoid 5% and 9% all-caused deaths, as the same proportion in cardiovascular caused deaths and respiratory caused deaths. 0.8 and 1.05 person of leukemia deaths induced by HC emission can be avoided in 2025 and

2030 respectively. From the above analysis we can conclude that, if Beijing conducts enhanced carbon NEV policies, the number of deaths will be greatly reduced compared with LCE policies.

5.6 Environmental co-benefits of the main pollutants

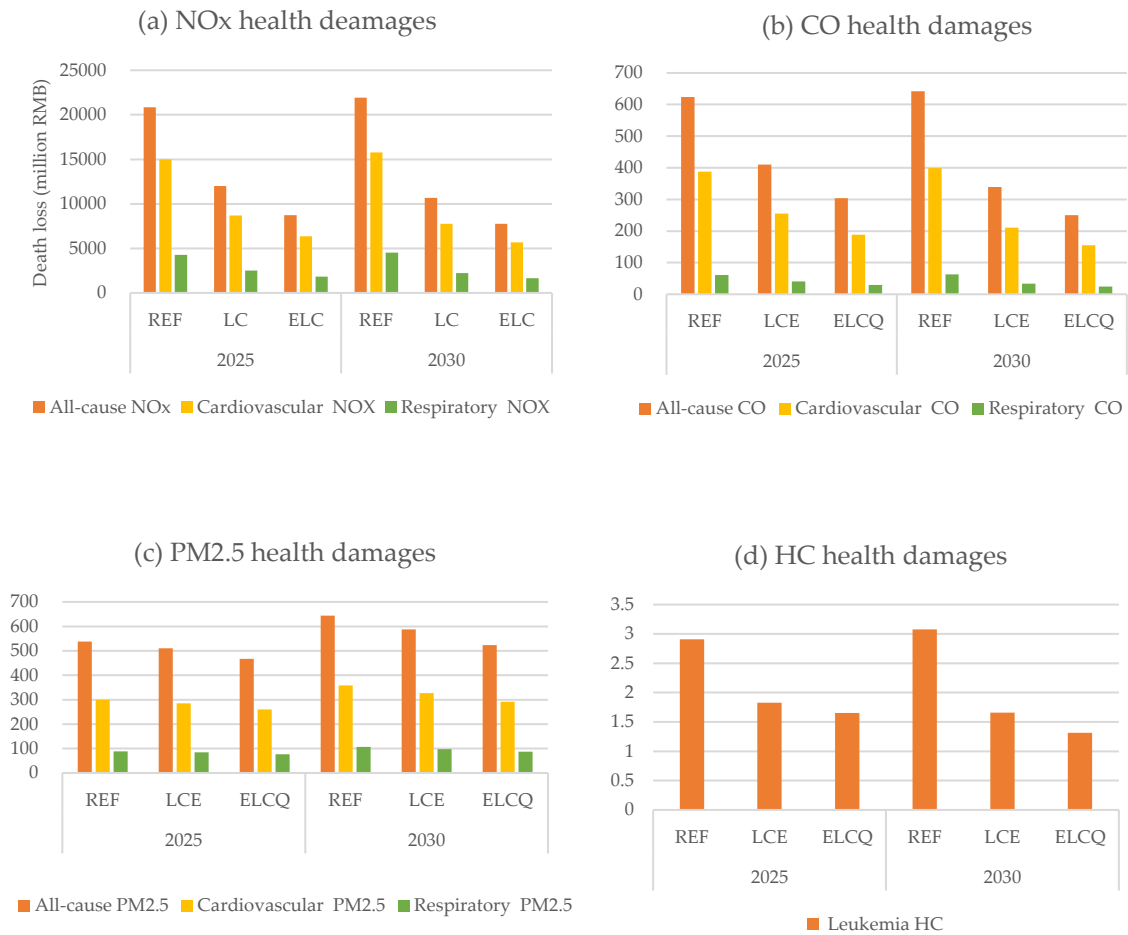


Fig.8. Reduction in Number of Air Pollution-Related health damage from Beijing Passenger Transport under Different Scenarios (million RMB)

Fig.8. shows the health damages related to the main air pollutant emissions from the transport sector across scenarios from 2025 to 2030 in Beijing. In 2025, the health loss of different illnesses, including the aggregate, cardiovascular, and respiratory illnesses related to NO_x, CO, PM_{2.5} and HC shows a significant decline, especially in the ELCQ scenario, with a reduction of 12,128, 8,607, and 2,450, million RMB below REF in NO_x, 321, 199, and 31 million RMB below REF in CO and 70, 39 and 12 million RMB below REF in PM_{2.5}. The leukemia illness related to HC have a reduction of 1.25 million RMB. For the LCE scenario, health damages were lower by 8,872, 6,268, 1,781 million RMB in 2025, 214, 133, 21 million RMB and 27, 15, 5million RMB reduction in terms of the all-caused, cardiovascular, and respiratory illnesses related to NO_x, CO and PM_{2.5}. 1.08 million RMB health damage of leukemia illness caused by inhalation of HC can be avoided

In 2030, comparing the ELCQ scenario with the REF scenario, the all-caused of the health damages could be reduced by 14,171 million RMB, 392 million RMB and 130 million RMB in the damages related to NO_x, CO and PM_{2.5} respectively, with the reduction of cardiovascular illness from NO_x, CO and PM_{2.5}, which could save 10, 103, 243 and 67million RMB. In this scenario, it would see a reduction in health damages of respiratory illness by 2881, 30 and 9.34 million RMB, respectively.

The reduction of leukemia health damage will reduce by 1.77 million RMB. As for the LCE scenario, health damages, NO_x, CO and PM_{2.5} will decrease by 11,279, 8,013, and 2,282 million RMB related to NO_x, 303, 188, and 30 million RMB related to CO and 57, 32 and 10 million RMB related to PM_{2.5} in 2030. 1.42 million RMB health damage would be avoided caused by leukemia disease.

6. Conclusion and Discussion

6.1. Conclusion

We conducted this study at the city level and applied parameters with regional characteristics, which makes the study and its policy implications more targeted. The paper makes contributions to evaluate the health co-benefit impact using local VSL based on vehicle enterprise level under the promotion of EV combined with quota-limit policy. According to our research, the application and promotion of NEVs combined with the quota-limit policy will exert positive effects on, energy consumption structure, regional emissions reductions and health impacts.

For energy consumption, the vigorously promoting EV and powerful quota-limit policy have slightly reduction power on the total energy demand, with reduction of 26.1% in 2030 compared with the REF scenario. In the long run, the gasoline still accounts for the largest proportion in the energy consumption structure around 74.4%. More vigorous combined policy will accelerate the electrification of transportation sector as 6.1% proportion of energy use in 2030. In addition, the enhanced combined policy has a considerable potential benefit on environmental decarbonization and local pollutant emission. Specifically, the CO₂ emission decline by 45.2% compared with REF scenario. And the reduction of CO, NO_x, HC and PM_{2.5} can be decreased by 61%, 66%, 57% and 19% respectively.

Secondly, we improve the prediction method on the enterprise-level, which show the clear energy consumption variation trend about different types of vehicles under more powerful policies with higher target of popularizing EV. For the private car, the gasoline still account for the large proportion of fuel use. In the ELCQ scenario, the proportion of gasoline decreases 18.3% compared to the REF scenario. In 2030, light-duty vehicles and compact cars will be the main types of EVs, with a total proportion of 63%. For taxis, the proportion of nature gas vehicle and electric vehicle has increased to 11% and 34% respectively in strict policy. For buses, the slightly decrease trend of diesel oil use can be seen in ELCQ scenario only accounting for 50%, and the NEV have slightly increased. For trucks, the promotion of NEVs has little effect on the fuel structure of the freight transport sector with small electrification because of difficult replace of diesel and gasoline trucks.

With the strictly measure of EV application and quota limit based on local VSL, the profound public health co-benefit and economic cost can be avoided. In 2030, the deaths avoided related to NO_x, CO, PM_{2.5} and HC emission under the enhanced low carbon NEV policy with quota-limit will be 65%, 61% 19% and 57% lower for than the REF scenario, which larger than the reduction rate of 51% in NO_x, 47% in CO, 9% in PM_{2.5} and 46% in HC under middle level policy restriction. The result of economic cost show that the total health co-benefits of reducing 14,171 million RMB for NO_x, 120 million RMB for PM_{2.5} 392 million RMB for CO and 1.77 million RMB for HC, which have higher avoided economic loss under LCE scenario with 11279, 303, 56, 1million RMB in NO_x, CO, PM_{2.5} and HC emission. The result indicates that Beijing would benefit significantly from implementing the high penetration of NEV and quota-limit policy with bringing substantial health co-benefits

6.2 Discussion

6.2.1 Comparison with other studies

The results are further compared to other studies to ensure their consistency for the reference scenario. **Table 4** and **Table 5** summarize the existing research results on energy consumption and CO₂ emissions of Beijing's transport sector. In our study, under the reference scenario, the total energy consumption demand of Beijing's passenger transport is 10.84 Mtce in 2030. Compared with previous research results, the predicted results and scope are within a reasonable range. When it comes to CO₂

emissions, the range of our results for all scenarios in 2030 is 22.54-41.16Mton, which is near the range of the related studies. We believe that our results on energy consumption and CO₂ emissions is within a credible interval.

Table 4. Comparison of Results on Energy Consumption in Beijing’s Transport Sector

Author	Vehicle Type	Energy Consumption/Mtce			
		2020		2030	
		Benchmark Scenario	Scope of all scenarios	Benchmark Scenario	Scope of all scenarios
This study	Passenger	6.13	5.47~6.13	10.84	8.01~10.84
Gao.et al.2014	Passenger	6.2	4.8~6.2	10.5	5.8~10.5
Liu. et al.2015	Passenger	10.5	3~10.5	/	/
Fan. et al.2017	Passenger	7.3	6.1~7.3	10.72	6.18~10.72

Table 5. Comparisons of the results on CO₂ emissions in Beijing’s Transport Sector

Author	Vehicle Type	CO ₂ Emissions/MTonne			
		2020		2030	
		Benchmark Scenario	Scope of all scenarios	Benchmark Scenario	Scope of all scenarios
This study	Passenger	38.22	29.4~38.22	41.16	22.54~41.16
Zhang.et al.2010	Passenger	21.58	18~25.34	29.29	22.01~37.27
Yu. et al.2013	Passenger	40	29.6~40	/	/
Yang. et al.2014	Passenger	32.2	25.3~32.2	/	/
Yu. et al.2015	Passenger & Freight	37.8	22.5~37.8	37.5	16.5~37.5

The following table (Table 6) shows the results of the existing studies on local pollutant emissions from Beijing's transport sector. In our study, under the REF scenario, CO, NO_x and HC emissions reached 346, 268 and 50 thousand tons respectively in 2025. This result has been compared to the existing studies, and our predicted results are consistent with these studies for the benchmark scenario. Since the scenario design is different, the scenario results might vary. The prediction of local pollutant emissions of this study is consistent with the other studies.

Table 6 Comparisons of the results on local pollutant emissions in Beijing’s Transport Sector

Pollutant (1000tons)	Author	2020		2025	
		Benchmark Scenario	Scope of all scenarios	Benchmark Scenario	Scope of all scenarios
CO	This study	336.6	207.9~336.6	346.5	168.3~346.5
	Guo et al., 2016	380	300-380	/	/
	Zhang et al., 2020	/	/	362.7	210.7-362.7
NO _x	This study	244	149~244	258	104~258
	Pan et al., 2013	243	83	/	/
	Guo et al., 2016	550	480-550	/	/
	Zhang et al., 2020	/	/	115	54-115
	Wu Yuting., 2016	225	125-225	250	75-250
HC	This study	48.5	34.7~48.5	50.5	28.7~50.5
	Guo et al., 2016	50	41-50	/	/
	Zhang et al., 2020	/	/	36.6	19.1-36.6
PM _{2.5}	This study	19.8	19.8	23.7	20.6-23.7
	Wu Yuting., 2016.	18.5	11.5-18.5	22.5	7.5-22.5
	Zhang et al., 2020	/	/	2.4	0.93-2.4
	Pan et al., 2013	58	37-58	/	/

6.2.2 Limitations

This study only focuses on the impact of the promotion of NEVs on energy consumption and regional emissions in Beijing's transport sector, but in fact, the energy system in the transport sector is also affected by many other factors, such as regional economic development, residents' travel habits, prices of transportation and fuel, etc. The interaction between the transport sector and other economic sectors is not taken into account in this model. There is a lack of statistical data and although most of the data are obtained from official statistics, some of this data can only be obtained from previous literature and enterprise statistics, which may lead to some deviations between the results of the study and the actual situation. Due to data limitation, the study does not use a life cycle assessment framework, which can be explored by further research. In view of the limitations mentioned above, future research can be carried out through data improvement, life cycle analysis and multi-model combination.

6.2.3 Policy Implications

For major cities, transport carbon mitigation policies are mostly market driven with target guidance. In Europe, the United Kingdom has adopted an Automated and Electric Vehicles Bill. In North America, California introduced a new energy vehicle compensation plan and the Zero Emissions Vehicle Program. Similar trends are also occurring in developing countries. The Indian government put forward its National Electric Mobility Mission Plan 2020. In China, Beijing, Shanghai, and other cosmopolitan cities have sought to constrain the use of gasoline driven vehicles for a long time. Beijing has drawn attention for its ambitious promotion on battery electric vehicles and the strict rules on vehicle purchase-quota-limits.

This study takes a close look at the effectiveness of this administrative decree policy, attempting to give some reference for other city transport systems. For other cities in China, the successful implementation of Beijing policy has a good reference for them, that is, the combination of EV with quota-limit policy will bring obvious environmental co-benefits. Shenyang considers the vehicle substitution of different fuels and the environmental benefits about the vehicle cost, while it does not specify and regulate on the market penetration of EV. In Xiamen, the policies to control environmental emissions mainly involve fuel economy control, private car management and other measures. Due to geographical factors, large-scale promotion of EV has no significant effect on emission reduction. From that, our result can confirm that under the existing conditions, economic measures and EV promotion should be strictly combined to achieve better environmental synergy effect.

As for some big cities in developing countries, our results indicate that the development of EV strict promotion in big cities of developing countries has significant effects on optimization of urban energy system and environmental problems. In India, under the scenario of promoting electric vehicles, there is no policy to control and restrict the vehicle purchase, resulting in policy asymmetry and the CO₂ emission of the transport sector is still high. Furthermore, India promotes EV development by upgrading technology and improving cost lacking of high market penetration. Therefore, in addition to the policy of electric vehicle market penetration, controlling the number of vehicles and reinforce the EV promotion power is advisable.

In cities in Europe, there are similarities in policy settings. Among them, in Germany, we have encountered the same problems as those in some developing countries, that is, and the gradual increase in vehicle purchase will offset the impact of technological progress which will not have a great impact on CO₂ emissions (Heinrichs H. et al., 2014). In Eastern European cities, although zero emissions are generated locally, the popularity of electric passenger vehicles is limited and will not seriously affect air quality. In Dublin, Ireland consider the speed limit of vehicles (Tang J et al., 2020) Our research shows that the combination of purchase-quota-limit policy and EV promotion will have obvious emission reduction effect and healthy economic benefits. It is also important to promote the penetration rate of EV and improve the energy structure of vehicles.

In the future, NEVs can play a positive role in energy system optimization and greenhouse gas and atmospheric pollution emissions reduction in the transport sector. The impact of NEV promotion on energy systems is a staged process that cannot be achieved overnight. In formulating policies, the government must also take into account exogenous factors. Technology, for example, though seemingly irrelevant to the environmental impact assessment of the NEV promotion policies in the short term, can be decisive in the long term. Governments should attract private and public investment in research on the improvement of the NEVs' energy-saving technology and reduction of the production and utilization costs of NEVs. In addition, restrictive measures such as quotas simply make the least able to adapt worse off. Moreover, the changing ratio between conventional vehicles and NEVs suggests the decrease of employment opportunities in the former industry. Further studies will take consumption heterogeneity and public behavior preferences into consideration.

6.2.4 Suggestions

For the future research, our study develops the methodology on road transportation, which has more vehicle technologies described based on company level information. Furthermore, the local pollutant emission calculation is based on the vehicle level, instead of the activity level and linked to technologies by their emissions coefficients. The method offers a new research perspective and thoughts on environmental co-benefit on road transportation for researchers. And the results are also helpful for enterprises operation planning and government policy making. On the basis of the result, in the future, electric vehicles will become a new on-road trend. New energy vehicles play a positive role in the optimization of energy structure, the reduction of greenhouse gas emissions in the transportation sector. Beijing should continue to promote new energy vehicles combined with quota-limit policy, providing specific policy subsidies and tax incentives at the present stage and improving the relevant infrastructure construction on building charging piles. According to the actual situation, the government should consider the influence of exogenous factors, such as technology and economy, and formulate appropriate promotion policies for new energy vehicles in the short term. Besides, the travel choice in the field of private transportation is more easily affected by consumers' economic level, consumption concept and other factors. Therefore, the government and enterprises should strengthen relevant publicity to improve the public's awareness and acceptance of new energy vehicles.

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Appendix A

Table A1. The Policies about NEV¹ Promotion in Beijing

Category	Main Policies
Target Guidance	<ul style="list-style-type: none"> • Work Program of Emission Pollution Control of Motor Vehicle in Beijing for 2013-2017 (Jingzhengbanfa [2013] No.53) • Circular of Beijing Clean Air Action Plan for 2013-2017 (Jing Zhengfa [2013] No.27) • Beijing Electric Vehicle Promotion and Application Action Plan (2014-2017) (Jingzhengbanfa [2014] No.39) • Management Methods for New Energy Commercial Vehicles Promotion and Application in Beijing (Jingkefa [2017] No.123) • Management Measures for NEV Promotion and Application in Beijing (Jingkefa[2018]No. 25)

	<ul style="list-style-type: none"> Beijing Energy Conservation and Climate Change Response Planning during the 13th Five-Year Plan (Jingzhengfa [2016]No.34)
Financial Subsidy	<ul style="list-style-type: none"> Interim Measures for Municipal Subsidies for Promotion and Demonstration of Pure Electric Vehicles in Beijing (Jingcaijing1 [2011] No.2730) Rules for the Management of Financial Subsidy Funds for Demonstration and Application of New Energy Passenger Vehicles in Beijing (Jingcaijing1 [2014] No.449) Beijing Management Methods for Demonstration and Application of New Energy Passenger Vehicles (2015 Amendment) (Jingkefa[2015] No.458) Rules for the Management of Financial Subsidy Funds for Demonstration and Application of New Energy Passenger Vehicles in Beijing (Amendment) (Jingcaijing1[2016] No.52) Circular on the Adjustment of the Relevant Policy about the Demonstration and Application of New Energy Passenger Vehicles in Beijing (Jingkefa1 [2017]No.25) Circular on Adjusting and Perfecting the Financial Subsidy Policy for the Promotion and Application of NEV in Beijing (Jingcaijing1[2018] No.1296)

¹ NEV refers to New Energy Vehicle

Table A2. The Subsidy Policy for Passenger NEV in Beijing (2014-2018)

Year	Type	Mileage/km	¹ Subsidy/10000 yuan per vehicle		
			National	Beijing	Total
2014	Pure electricity	80≤R<150	3.325	3.325	6.65
		150≤R<250	4.75	4.75	9.5
		R≥250	5.7	5.7	11.4
	Plug-in Hybrid Fuel Battery	R≥50	3.325	/	3.325
			19	19	38
2015	Pure electricity	80≤R<150	3.15	3.15	6.3
		150≤R<250	4.5	4.5	9
		R≥250	5.4	5.4	10.8
	Plug-in Hybrid Fuel Battery	R≥50	3.15	/	3.15
			18	18	36
2016	Pure electricity	80≤R<150	2.5	2.5	5
		150≤R<250	4.5	4.5	9
		R≥250	5.5	5.5	11
	Plug-in Hybrid Fuel Battery	R≥50	3	/	3
			20	20	40
2017	Pure electricity	80≤R<150	2	1	3
		150≤R<250	3.6	1.8	5.4
		R≥250	4.4	2.2	6.6
	Plug-in Hybrid Fuel Battery	R≥50	2.4	/	2.4
			20	10	30
2018	Pure electricity	80≤R<150	1.5	0.75	2.25
		150≤R<250	2.4	1.2	3.6
		250≤R<300	3.4	1.7	5.1
		300≤R<400	4.5	2.25	6.75
		R≥400	5	2.5	7.5
	Plug-in Hybrid Fuel Battery	R≥50	2.2	/	2.2
		Standard	6000yuan/kW	3000yuan /kW	9000yuan /kW

¹ Data are collected from national and Beijing NEV policies from 2013-2018

Table A3. Reference Policies of Beijing’s NEV planning for LC Scenario Settings

Reference Policy	Details
Beijing's Three-Year Action Plan for Winning the Blue-Sky Defense War (2018)	By 2020, the total number of NEVs in the city will reach about 400,000, and pollutant emissions should be reduced by 30% compared with 2017.
Beijing Traffic Development and Construction Plan for the 13th Five-Year Plan Period (2016)	By 2020, the total number of motor vehicles should be under 6.3 million. The proportion of new energy vehicles in the public transport industry reaches 65%.
Beijing Electric Vehicle Charging Infrastructure Special Plan (2016-2020). (Jingfagai [2016] No.620)	By 2020, there will be about 600,000 electric vehicles in the city, including 450,000 private cars, more than 15,000 electric buses, 10,000 electric vehicles in taxis, and more than 40,000 electric vehicles leased. The demand for electric vehicles in other fields such as business, logistics and so on will be about 40,000.
Medium-Long Term Development Planning of Automobile Industry	<p>By 2020, the specific energy density of power batteries will reach 300 ~ 350 watt-hours/kg. The specific energy of the system will reach 260 watt-hours/kg and the cost will be reduced to less than 1 yuan/watt-hours. The application rate of energy-saving technologies such as engine idling start-stop will exceed 50%.</p> <p>By 2025, new energy vehicles will account for more than 20% of automobile production and sales, and the specific energy density of power battery systems will reach 350 watt-hours/kg.</p>

Table A4-a. Vehicle Ownership and Efficiency, Beijing 2015

	Fuel	Type	Ownership(kVs)	Efficiency ¹
Private Car	Gasoline	Mini car	48.214	6.71
		Light-Duty Vehicle	318.099	5.74
		Compact car	1539.318	6.18
		Medium sized car	452.734	6.53
		Medium and large vehicles	93.744	8.88
		MPV	599.405	8.16
		SUV	1221.138	7.82
	Electricity	KandiPandaEV	3.339	10.5
		BAIC E-EV	2.732	15
		ZotyeCloud100	2.429	10
		JAC iEV	1.821	13
		Chery eQ	1.214	11.9
		BYD e6	1.214	10.9
		Chery QQ EV	1.214	15
ZotyeE20	0.911	14.9		
AD D1/D2	0.911	9.8		

		Kandi K10EV	0.911	10.5
		JMC E100	0.911	9.9
		Tesla Model S	0.911	18
		Others	1.182	12.45
	CNG		1.543	6.8
	Total		4293.9	
Taxi	Gasoline		63.134	7.4
	Electricity		3.150	12
	CNG		2.000	6.8
	Total		68.284	

¹The unit of gasoline oil efficiency is L/100km, electricity efficiency is kWh/100km, CNG efficiency is m³/km. The unit KVs is thousand vehicles.

Table A4-b. Vehicle Ownership and Efficiency, Beijing 2015

	Fuel	Type	Ownership (kVs)	Efficiency ²
Bus	Diesel Oil	Guo III	5.312	34
		Guo IV	7.279	34
		Guo V	0.754	30
		Guo VI	0.361	30
	Electricity		1.836	106
	CNG		2.500	32
	LNG		5.195	36
	LPG		0.050	62
	Total		23.287	
Truck	Diesel Oil	Heavy	4.380	24
		Medium	2.170	17
		Light	14.810	10
	Gasoline		91.625	17
	Electricity		0.675	60
	Total		305.9	

²The unit of diesel oil efficiency is L/100km, electricity efficiency is kWh/100km, CNG efficiency is m³/km, LNG efficiency is kg/km, LPG efficiency is L/100km. The unit KVs is thousand vehicles.

Table A5. Average Annual Mileage of Various Types of Vehicles in Beijing in 2015

Type	Annual average mileage Km/Vehicle per year
Private Car	12584
Taxi	86376.75
Bus	58148
Truck	72000

Table A6 Emissions factors of private cars and taxis (g·(km·veh)⁻¹)

Type	Fuel		CO	NOx	HC
Private Car	Gasoline	Mini car	0.16	0.078	0.011
		Light-Duty Vehicle	0.16	0.058	0.011
		Compact car	0.16	0.058	0.011
		Medium sized car	0.16	0.058	0.011
		Medium-large vehicles	0.16	0.058	0.011
		MPV	0.16	0.058	0.011

		SUV	0.16	0.058	0.011
	CNG		0.16	0.058	0.047
Taxi	Gasoline		0.16	0.078	0.11
	CNG		0.16	0.058	0.047
Bus	Diesel Oil	Guo III	3.019	11.284	0.606
		Guo IV	1.434	6.773	0.079
		Guo V	2.847	8.149	0.046
		Guo VI	1.491	0.800	0.037
	CNG		1.000	10.000	1.300
	LNG		1.000	10.000	1.300
	PNG		1.000	10.000	1.300
Truck	Gasoline		2.850	0.052	0.022
	Diesel Oil	Heavy	0.419	1.010	0.038
		Medium	0.419	1.010	0.038
		Light	0.419	1.010	0.038

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