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China's Electric Vehicle Deployment: Energy and Greenhouse Gas Emission Impacts

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Received: 12 November 2018; Accepted: 28 November 2018; Published: 30 November 2018

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Abstract: The explosion of the vehicle market in China has caused a series of problems, like energy security, climate change, air pollution, etc. The deployment of electric vehicles (EVs) is considered an effective solution to address these problems. Thus, both the state and local governments in China have launched some policies and incentives to accelerate the development of EVs and the EV industry. Do EVs can effectively solve these problems in short term, viewed from the fleet point? Based on China's most up-to-date deployment plan for EVs, this paper analyzes the energy consumption and greenhouse gas (GHG) emissions caused by China's road transport sector in three different scenarios. The results indicate that, based on current planning, the energy consumption and GHG emissions of the whole fleet will peak in 2025 and 2027, at the level of around 403 mtoe (million tons of oil equivalent) and 1763 mt CO_2 eq. (million tons of CO_2 equivalent), respectively. The introduction of EVs will significantly reduce the reliance on fossil fuel in the long term, with increasing ownership, while, in the short term, the fuel economy regulation will still play a more important role. Policy makers should continually pay attention to this. Meanwhile, commercial vehicles, especially heavy-duty trucks will account for a bigger and bigger proportion in the energy consumption and GHG emissions of the whole fleet. Thus, to some extent the focus should shift from passenger vehicles to commercial vehicles. More measures could be implemented.

Keywords: electric vehicle; energy consumption; greenhouse gas emissions

1. Introduction

Coupled with the rapid economic growth is the increasingly important political role of China in the world. In addition to economy and politics, energy resources and the environment are also becoming essential influence factors. From an international viewpoint, China has already made a commitment to greenhouse gas (GHG) emission reduction, and the state government is supposed to take the corresponding responsibility. In terms of national development, the energy consumption and GHG emissions are not only related to energy security, but also to peoples' livelihood. Thus, it is really essential for China to solve the current energy and environment problems.

The transportation sector is an important branch of China's industry, resulting in massive energy consumption and GHG emissions. Road transportation is an integral part of the transport sector. With the expansion of the middle class and the improvement of living standards in China, the demands for vehicles and traffic will inevitably increase. According to the data released by the government, by the end of 2017, car ownership had reached 217 million, on the equivalent of around 156 cars/1000 people. Wu et al. predicted that the automotive stock in China could reach around 200 to 300 million in 2020, and 350 to 550 million in 2030 [1]. Based on a Gompertz function method and a computable general equilibrium model, Wu et al. got the results that in 2050, the vehicle stock in China would be 300–463 million [2].

Thus, to realize the reduction of energy consumption and GHG emissions with the expansion of vehicle market, the improvement of fuel economy and the promotion of electric vehicles (EVs) are both considered promising strategies. The most powerful safeguard measures and motivations for these solutions are policies and regulations. Because China is a policy-oriented country, the state and local governments' attitudes are critical to the industry development. Incentives have played an essential role in expanding the EV stock size in China in the past few years. Though purchase subsidies or other incentives will probably be reduced or even canceled in the future, with more EVs acceptance by customers and lower maintenance costs, the sales of EV would probably increase continually. Zhao et al. evaluated the regulations of fuel consumption rate in China and gave technology suggestions about "energy saving vehicles" and "new energy vehicles" to the automotive manufacturers [3]. Zheng et al. summarized the strategic policies and demonstration programs of EVs in China, reported a survey done in some pilot cities and finally gave some recommendations for existing policies [4]. Hao et al. comprehensively considered the measures of constraining vehicle registration, reducing vehicle travel demand, strengthening fuel consumption rate limits, vehicle downsizing and promoting EVs, and analyzed the fuel consumption and GHG emissions of passenger vehicles in China until 2050 [5]. Many other researchers have also built models to account for and forecast the energy consumption and GHG emissions of the vehicle fleet based on the historical data and various goals endorsed by the government [6–9].

The development of policies and plans always experiences an improvement process. There are always new policies to address emerging problems and difficulties. China's auto market still has great potential for development. Therefore, with the expansion of the market, the various governments' policies and plans are continually being updated and upgraded. This paper aims at building a bottom-up model to calculate China's vehicle fleet energy consumption and GHG emissions, according to Chinese governments' and industry associations' latest plans for the automotive industry. The calculation of energy consumption and GHG emissions of vehicle fleet in China in the future can demonstrate the effectiveness of existing policies. Plans for alternative fuel vehicles are an important part as the research basis. This study mainly focuses on the update of plans for the deployment of EVs in China. Three different scenarios based on various EV deployments are assumed and analyzed.

2. Literature Review

The deployment is one of the hot topics about EVs. Ou et al. did a study about the impact of a dual-credit policy on EV sales and industry profits in China. Compared with existing rules on the market, the dual-credit policy would significantly promote more battery electric vehicles (BEVs) and is less capable of promoting plug-in hybrid electric vehicles (PHEVs) deployment [10]. Zhang et al. summarized incentive policies and EV adoption in China [11]. Wang et al. did a study to evaluate the influence of incentive measures on EV sales in 41 pilot cities in China. Charger density, license fee exemptions, no driving restrictions, and giving priority to charging infrastructure construction lands are the top four customer chosen factors [12]. He et al. gave a prediction from the perspective of customers. The result indicated that customers' perceptions and personality play an essential role in any purchase intention. People with higher personal innovativeness and environmental concerns are more likely to be potential buyers [13]. Ouyang et al. also did the review of consumer behavior for purchasing and using EVs in China [14]. However, all of these studies paid too much attention to policy impact or customer choice about different vehicle types, but ignored the overall planning at a country level and the environmental influence of EVs.

Some studies have analyzed the individual car's impact on the environment from a life cycle perspective. Qiao et al. focused on the CO_2 emissions of BEVs from the production perspective [15]. Yu et al. compared the life cycle carbon emissions of electric and gasoline vehicles in China. Under the best electric power structure scenario, an EV can reduce CO_2 emissions by 14% from a life cycle perspective, and the results indicated the importance of clean energy in the power generation mix [16]. Hao et al. examined life-cycle cost and GHG emissions of BEVs and compared them with other fuel type vehicles. BEVs exhibited excellent potential for improving cost-effectiveness in the long term [17], but although the authors provided a relative comprehensive comparison between conventional vehicles and EVs, the impact on the country was not considered.

The proliferation of EVs also has an impact on other industries. Osorio et al. predicted the network load profile, based on EV owners' driving habits [18]. Sadok et al. compared the machine and vehicle failure, carbon penalty and maintenances actions of a manufacturing system with EVs or petrol vehicles [19]. Mazur et al. reached the results that instead of technology progress, financial incentives or buyer expectation changes, the introduction of automated vehicles would become the most essential switch for EVs [20].

Previous studies also performed some scenario analyses about the market penetration rates of different vehicle technologies to evaluate the impact on energy consumption or GHG emissions, none of which are in line with the latest plans [5,9,21,22]. Besides, most of them only considered the deployment of EVs as passenger vehicles and assumed with no EVs in the commercial vehicle fleet [21,22]. Besides, the penetration rates of EVs considered in former studies like those of Ou et al. and Hao et al. are relatively low. Ou et al. assumed that the share of EVs in sales would reach 2.5%, 10% and 40% in 2020, 2030 and 2050 for passenger vehicles, buses and mini trucks, respectively [22]. Hao et al., although they took EVs into consideration, in their research hybrid electric vehicles (HEVs) would account for more than BEVs [5], although nowadays HEVs are only considered "energy saving vehicles" instead of "electric vehicles". BEVs, PHEVs and fuel cell vehicles (FCVs) are usually defined as EVs. Due to the fact that there are few FCVs, BEVs and PHEVs are treated as the main part of EVs nowadays. Compared with previous scenarios, the deployment of EVs in the latest policies is more aggressive. Thus, in this research the data is updated to recalculate the impact of EVs in the vehicle fleet's energy consumption and GHG emissions.

All in all, first, it is essential to evaluate the impact of EVs on the whole vehicle fleet. This will provide sufficient support for policy makers to make future planning. Individual vehicle assessments cannot reflect the overall energy and GHG emissions influence, because the deployment will play an important role. This paper calculates the fleet energy consumption and GHG emissions to get a result at the macro level. Then, the latest policies and planning are critical for the final results. With incentives, EVs have developed rapidly in the past. The ownership in previous studies cannot reflect the real situation. Thus, new research should be done to provide a more precise result. Finally, scenario analysis will offer comprehensive references for policy makers.

This paper is organized as follows: Section 3 introduces EV development plans set by the state and some local governments. Section 4 describes the methods, and the data sources. Section 5 presents the results and some discussions. Section 6 concludes the whole study.

3. China's Up-To-Date Plans on EV Deployment

3.1. State Government Plans

The state government and industry associations have made several plans about the development of EVs, including sales prediction, stock scale forecast, and so on, as Figure 1 shows. In 2012, the State Council first released the plan for new energy vehicles (NEVs) development. The Energy Saving and New Energy Automotive Industry Development Planning (2016–2020) pointed out that during this period, great progress should be made in the process of EV industrialization. By 2015, the cumulative production and sales of BEVs and PHEVs should reach 500 thousand. As a fact, in 2015, the total production of BEVs and PHEVs in China reached 340,000 and the sales reached 331,000. The stock by 2015 was about 583,000, greater than planned. By 2020, the production capacity of BEVs and PEHVs should reach 2 million units, and the cumulative amount was supposed to be 5 million (as usually defined in China, only BEVs, PHEVs and FCVs are considered as EVs, and hybrid electric vehicles are treated as a kind of energy saving vehicle).

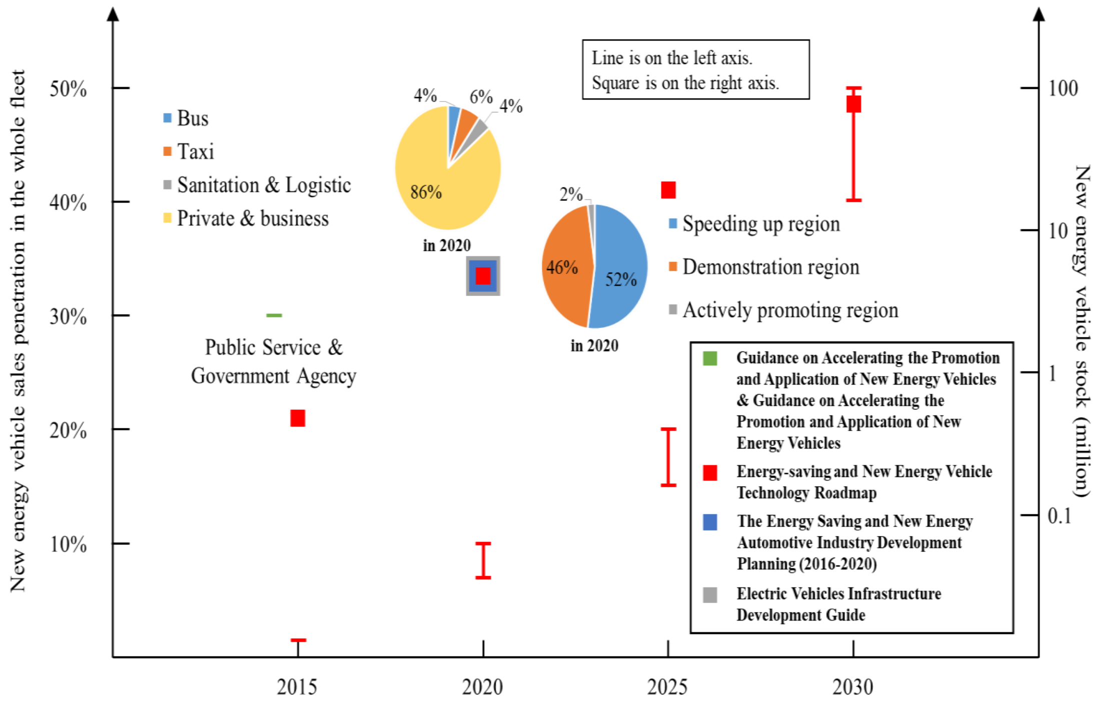


Figure 1. Summary of state EV development plans (the sales penetration of NEV was given in a scope and lines indicates the error bars).

In 2014 the State Council published another document named Guidance on Accelerating the Promotion and Application of New Energy Vehicles. It mentioned the penetration target of NEVs in public service and government agencies at the "NEV promotion cities". NEVs should account for at least 30% of new purchase or replacement vehicles in the fields mentioned above.

In 2015, the National Development and Reform Commission issued the Electric Vehicles Infrastructure Development Guide. As noted in the document, by 2020, the EV stock would reach 5 million, including over 200,000 electric buses, over 300,000 electric taxis, and over 200,000 sanitation and logistic electric vehicles and over 4.3 million private and business electric vehicles. An uneven regional distribution would also exist. In the "speeding up" regions, like Beijing, Tianjin, etc., the total EV stock would exceed 2.66 million units. In the "demonstration" regions, like Shanxi, Jilin, etc., the scale would reach 2.23 million. In the "actively promoting" regions, like Guangxi, Qinghai, etc., the expected goal was 0.11 million.

In 2016, in the Guidance on Accelerating the Promotion and Application of New Energy Vehicles released by National Development and Reform Commission stressed again the deployment of NEV in public departments. At the end of 2016, SAE-China published the Energy-saving and New Energy Vehicles Technology Roadmap. The target proportions of NEVs in total sales in 2020, 2025 and 2030, set in the roadmap, were respectively 7%, 15% and 40%. The NEV stock would be over 5 million, 20 million and 80 million in 2020, 2025 and 2030 and FCV stock would reach 5000, 50,000 and 1 million respectively.

In 2017, the NEV industry was included in the Guidance Catalog of Strategic Emerging Industries Key Products and Services which was set by National Development and Reform Commission. It accentuated the importance of NEV industry. Then, the Ministry of Industry and Information Technology, National Development and Reform Commission and Ministry of Science and Technology of the People's Republic of China issued the Medium-long Term Development Plan of Automotive Industry. The plan announced that by 2020, the annual production and sales of NEVs would reach

2 million. By 2025, NEVs would account for more than 20% of all automotive production and sales in China.

3.2. Local Government Plans

To correspond with the national plans, local governments have also set series of planning to support the development of EVs. Depending on the different vehicle market backgrounds, the policies and plans vary from regions to regions. Table 1 exhibits the plans implemented locally in recent years in provincial level.

Table 1. EV promotion plans set by local governments.

Province	EV Development Plan	Target
Tianjin	Tianjin New Energy Vehicle Charging Infrastructure Development Plan (2016–2020)	Promoting 160 thousand NEV (2016–2020); NEV will account for 35% of new added or replaced city buses, taxi, and city logistic vehicles, 30% of sanitation vehicles by 2020
Hebei	13th Five Year Development Plan of New Energy Vehicle Industry in Hebei Province	Accumulatively promoting 300 thousand NEV until 2020; NEV will account for 50%, 60%, 70% and 80% of new added or replaced city buses from 2016 to 2019
Liaoning	Implementation Plan of Accelerating the Development of New Energy Vehicles	NEV will account for 30% of new added or replaced city buses by 2020
Shanghai	13th Five Year Development Plan of Comprehensive Transport in Shanghai	NEV and clear energy vehicles will account for 30% of new added or replaced city buses by 2020
Jiangsu	13th Five Year Implementation Plan of New Energy Vehicle Promotion in Jiangsu Province	Accumulatively promoting 250 thousand NEV in the 13th Five Year period; NEV and clear energy vehicles will account for 80% of new added or replaced city buses
Anhui	13th Five Year Development Plan of Automotive and New Energy Vehicle Industry in Anhui Province	Production and sales of NEV will reach 200 thousand
Fujian	Accelerating the Promotion and Application of New Energy Vehicles in Fujian Province	Accumulatively promoting 350 thousand NEV until 2020; Private passenger NEV will exceed 150 thousand; All city buses will be changed into NEV by 2020
Shandong	13th Five Year Development Plan of Charging Infrastructure in Shandong Province	NEV stock will reach 320 thousand in 2020
Henan	Accelerating the Promotion, Application and Industrialization of New Energy Vehicles in Henan Province	Promoting 18, 22, 28, 38, 50 thousand NEV respectively from 2016 to 2020
Guangdong	Opinions on Accelerating the Promotion and Application of New Energy Vehicles in Guangdong Province	Accumulatively promoting 250 thousand NEV until 2020; Private passenger NEV will exceed 200 thousand
Guangxi	Guangxi New Energy Vehicle Development Action Plan (2016–2020)	Promoting 10, 12, 15, 20, 30 thousand NEV respectively from 2016 to 2020
Gansu	Plan of Creating National Demonstration Area of New Energy Application in Gansu Province	Promoting 30 thousand NEV until 2020

4. Methods and Data

4.1. System Boundary

Bottom-up and top-down methods are both popular in accounting the energy consumption and GHG emissions generated in the transportation sector. Bottom-up methods are used more frequently when detailed technology improvement, policy influences and individual behavior changes are considered. Top-down methods are more concentrated on the macro economy or energy targets [23]. Thus, to evaluate the impacts of policies and plans on the vehicle fleet more clearly, bottom-up method is applied in this paper.

Life cycle assessment (LCA) is widely used to calculate the energy consumption and GHG emissions [24,25]. In terms of vehicles, the scope is usually divided into fuel cycle and vehicle cycle. In this paper, as shown in Figure 2, only fuel cycle is considered. We calculated the energy use and GHG emissions generated in upstream process and consumption phase.

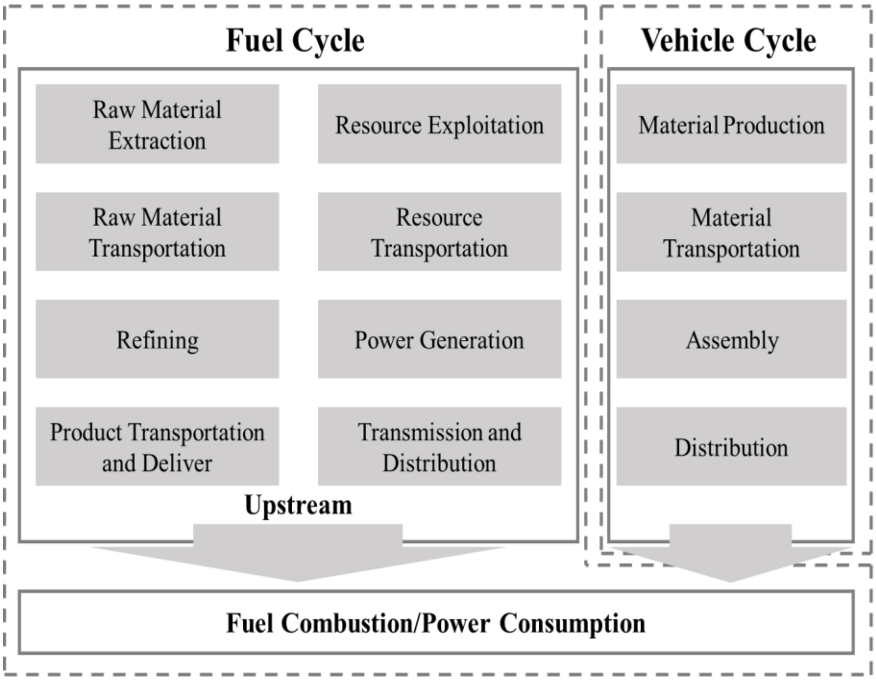


Figure 2. Research framework.

4.2. Methods

Equations (1) and (2), respectively, indicate the calculation of conventional fuel vehicle fuel consumptions in tank to wheel stage and GHG emissions in well to wheel stage. The calculations are based on the vehicle sales, survival rate, fuel consumption rate, mileage and GHG emission intensities of different fuels. Energy consumption is fixed by vehicle ownership (depending on vehicle sales and survival rate), use intensity (depending on annual mileage) and fuel economy (depending on fuel consumption rate). GHG emissions are also affected by GHG emissions intensity of fuel types:

$$EC_{t,i} = \sum_k \left(\sum_{i=j-l_{t,k}}^{i} Sale_{t,j,k} \times SR_{t,i-j} \times FCR_{t,j,k} \times VKT_{t,i-j} \right) \times HV_k \times \rho_k \quad (1)$$

$$GHG_{t,i} = \sum_k \left(\sum_{i=j-l_{t,k}}^{i} Sale_{t,j,k} \times SR_{t,i-j} \times FCR_{t,j,k} \times VKT_{t,i-j} \right) \times GI_k \times HV_k \times \rho_k \quad (2)$$

where, $EC_{t,i}$ is the energy consumption of vehicle type t in year i (MJ); $Sale_{t,j,k}$ is the sales of vehicle type t of fuel k in year i (unit); $SR_{t,i-j}$ is the survival rate of vehicle type t in the $(i-j)$th year (%); $FCR_{t,j,k}$ is the fuel consumption rate of vehicle type t of fuel k in year j (L/100 km); $VKT_{t,i-j}$ is the mileage of vehicle type t in the $(i-j)$th year (100 km); HV_k is the heat value of fuel k (MJ/kg); ρ_k is the density of the fuel k (kg/L); $l_{t,k}$ is the life span of vehicle type t of fuel k; $GHG_{t,i}$ is the GHG emissions of vehicle type t in year i (mt CO_2 eq.); GI_k is the GHG emissions intensity of fuel k in whole life cycle (g CO_2 eq./MJ).

GHG emissions are dependent on the energy consumption and GHG emissions intensities. GHG emissions intensities in this paper are from the life cycle perspective. Both the upstream phase and the combustion phase are considered as mentioned before.

Equations (3) and (4), respectively, show the methodology of this study for PHEV:

$$\begin{aligned} EC_{t,i,PHEV} = & \left[\sum_{i=j-l_{t,PHEV}}^{i} Sale_{t,j,PHEV} \times SR_{t,i-j,PHEV} \times FCR_{t,j,PHEV} \times VKT_{t,i-j,PHEV} \right. \\ & \left. \times (1-\alpha)\right] \times HV_{PHEV} \times \rho_{PHEV} \\ & + \sum_{i=j-l_{t,PHEV}}^{i} Sale_{t,j,PHEV} \times SR_{t,i-j,PHEV} \times PC_{t,j,PHEV} \times VKT_{t,i-j,PHEV} \\ & \times \alpha \end{aligned} \tag{3}$$

$$\begin{aligned} GHG_{t,i,PHEV} = & \left[\sum_{i=j-l_{t,PHEV}}^{i} Sale_{t,j,PHEV} \times SR_{t,i-j,PHEV} \times FCR_{t,j,PHEV} \times VKT_{t,i-j,PHEV} \right. \\ & \left. \times (1-\alpha)\right] \times GI_{PHEV} \times HV_{PHEV} \times \rho_{PHEV} \\ & + \sum_{i=j-l_{t,PHEV}}^{i} Sale_{t,j,PHEV} \times SR_{t,i-j,PHEV} \times PC_{t,j,PHEV} \times VKT_{t,i-j,PHEV} \\ & \times \alpha \times GI_{electricity} \end{aligned} \tag{4}$$

where, $EC_{t,i,PHEV}$ is the energy consumption of vehicle type t of PHEV in year i (MJ); $Sale_{t,j,PHEV}$ is the sales of vehicle type t of PHEV in year i (unit); $SR_{t,i-j,PHEV}$ is the survival rate of vehicle type t of PHEV in the $(i-j)$th year (%); $FCR_{t,j,PHEV}$ is the fuel consumption rate of vehicle type t of PHEV in year j (L/100 km); $VKT_{t,i-j,PHEV}$ is the mileage of vehicle type t in the $(i-j)$th year (100 km); is the fraction of travel distance that is powered by electricity, so $(1-\alpha)$ presents the fraction of travel distance powered by conventional fuel; HV_{PHEV} is the heat value of conventional fuel used for PHEV; ρ_{PHEV} is the density of conventional fuel used for PHEV; $PC_{t,j,PHEV}$ is the power consumption of vehicle type t in year i (kWh/100 km); $l_{t,PHEV}$ is the life span of vehicle type t of PHEV; $GHG_{t,i,PHEV}$ is the GHG emissions of vehicle type t of PHEV in year i (mt CO_2 eq.); GI_{PHEV} is the GHG emissions intensity of conventional fuel used for PHEV; $GI_{electricity}$ is the GHG emissions intensity of electricity.

Fuel consumption and GHG emissions for BEV are calculated by the following expression:

$$EC_{t,i,BEV} = \sum_{i=j-l_{t,BEV}}^{i} Sale_{t,j,BEV} \times SR_{t,i-j,BEV} \times PC_{t,j,BEV} \times VKT_{t,i-j,BEV} \tag{5}$$

$$GHG_{t,i,BEV} = \sum_{i=j-l_{t,BEV}}^{i} Sale_{t,j,BEV} \times SR_{t,i-j,BEV} \times PC_{t,j,BEV} \times VKT_{t,i-j,BEV} \times GI_{electricity} \tag{6}$$

where, $EC_{t,i,BEV}$ is the energy consumption of vehicle type t of BEV in year i (MJ); $Sale_{t,j,BEV}$ is the sales of vehicle type t of BEV in year i (unit); $SR_{t,i-j,BEV}$ is the survival rate of vehicle type t of BEV in the $(i-j)$th year (%); $PC_{t,j,BEV}$ is the power consumption of vehicle type t of BEV in year (kWh/100 km); $VKT_{t,i-j,BEV}$ is the mileage of vehicle type t in the $(i-j)$th year (100 km); $l_{t,BEV}$ is the life span of vehicle type t of BEV; $GHG_{t,i,BEV}$ is the GHG emissions of vehicle type t of BEV in year i (mt CO_2 eq.).

4.3. Data

4.3.1. Vehicle Sales and Stock

Economic development will bring greater travel and logistic demands. Thus, total vehicle sales will continue to grow. With the increasing vehicle stock, annual growth rate of sales will gradually decline compared with the past 20 years. According to the prediction of industry associations, the vehicle sales in 2020, 2025 and 2030 will be 30, 35 and 38 million. As the result, in this study, the vehicle registration in 2050 will reach 458 million. Passenger vehicles will still have a great potential market. The bus will still account for a relatively low percentage of total sales, and its growth will not be prominent either. According to the historical sales data, the truck sales fluctuated greatly affected by the market economy. According to the research of Hao et al., the truck registration could exceed 100 million in 2050 [18]. Thus, with the growth of logistics demand, the truck sales will also continue to increase. Compared with Hao's study, a relatively conservative estimation of truck stock is applied in this study, around 67 million in 2050. The survival rate used in this study is based on the research of Yan et al. [26].

4.3.2. Fuel Consumption Rate

Fuel consumption rate regulations in China are getting stricter and stricter for both passenger vehicles and commercial vehicles. To meet these regulations, many technologies have been applied to vehicles. For passenger vehicles, GB 19578-2004, GB 19578-2014, and GB 27999-2014 are used as references for vehicle fuel consumption rates from 2005 to 2020. Besides, based on the plans set by industry associations, in 2020, 2025 and 2030, the fuel consumption rate of passenger vehicles will decrease to 5, 4 and 3.2 L/100 km, respectively. The fuel consumption rate will not continuously decline, so, in this paper, the lower limit for passenger vehicle fuel consumption rate is set as 3.2 L/100 km. The fuel consumption rate of passenger vehicles in other years are decided by the historical data, the development trend and latest regulations and plans [27]. China is one of the only four countries already with heavy-duty truck fuel consumption rate standards. The first stage of fuel consumption limits for heavy-duty commercial vehicles was set as automotive industry recommendation standards. By 2014, the regulation was changed into national compulsory standard. Trucks, tractors, buses, dump trucks and city buses are all included in the latest regulations for heavy-duty commercial vehicles. Besides, the fuel consumption rate regulation for light commercial vehicles was introduced in 2007 in the form of mandatory standards. In 2015, this standard was updated. Data in the rest of the years are based on historical reference data or developing tendency. For the whole commercial vehicle fleet, average fuel consumption decline rates will reach 10%, 15% and 20% in 2020, 2025 and 2030, respectively, based on 2016. The power consumptions of BEVs (kwh/100 km) are dependent on existing market data and future plans, as shown in Figure 3 [27,28]. The development of battery is hard to predict. Thus, the forecast can only be used as a reference. The charging loss is assumed to be 10%, according to the research of Yuan et al. and Vliet et al. [29,30]. Previous studies showed the results that there was a gap between real world fuel consumption and statistic data from tests for ICEVs [31–34]. Thus, in this paper, we assume that the difference between the regulation targets and real-world fuel consumption rate is 10% for both conventional fuel passenger vehicles and electric passenger vehicles under a conservative estimation.

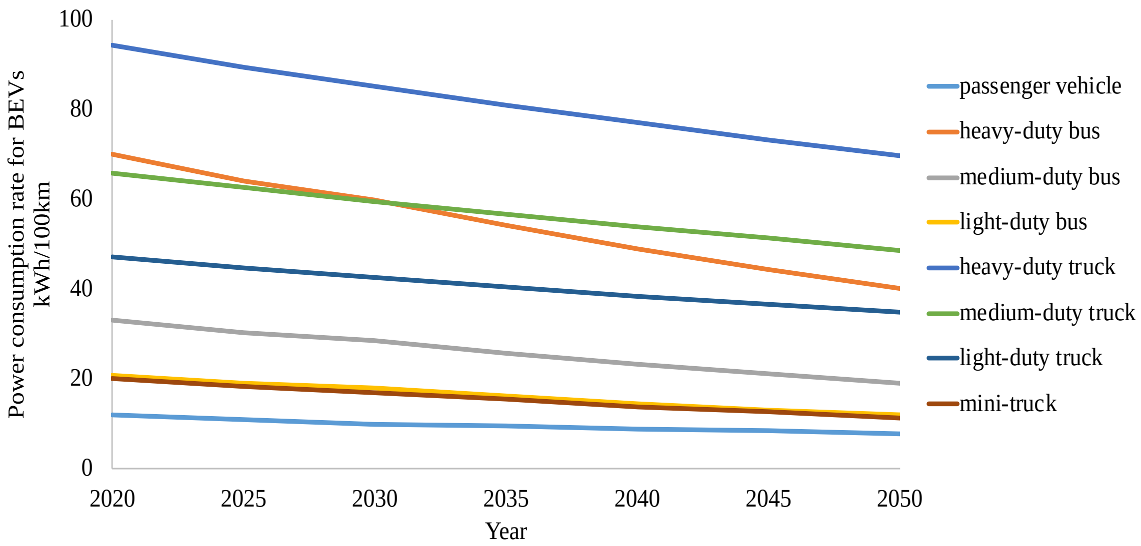


Figure 3. Power consumption rate for BEVs assumed in this study.

4.3.3. Vehicle Travel Distance

Vehicle travel distance is fluctuating, individual data which is subject to many factors. Usually only the average data can be collected and used as reference. Many researches related to energy consumption and GHG emissions of vehicle fleet involve the travel distance of different types of vehicles [35–37]. Some of these researches also include specific cases in China. According to the life-based or annual average data, and combined with the breakage of vehicles, the travel distance is determined in this paper. The life span of vehicles is also considered in the assumption. The annual travel distance for each type of vehicles is shown in Table 2. Samaras et al. [38] estimated the percentage of daily travel that could potentially be powered with electricity with various PHEV configurations. In this paper, the driving mileage of PHEVs relying on electricity is refitted, based on the Chinese situation [39].

Table 2. The life-long travel distance of each type of vehicles.

Vehicle Type	Annual Travel Distance (km)
Passenger vehicles	20,000
Light-duty and medium duty bus	50,000
Heavy-duty bus	70,000
Mini truck	30,000
Light-duty truck	32,000
Heavy and medium-duty truck	40,000

4.3.4. GHG Emissions Intensity

For conventional fuels, energy use and GHG emissions of vehicle fuels mostly result from the fuel combustion phase, while, for EVs, most of GHG emissions are generated from the upstream phase. Energy consumption and GHG emissions of gasoline, diesel and natural gas in the upstream phase are relatively stable. There is little room for further improvement. Thus, the results of previous studies are summarized. The life-cycle GHG emissions intensities of gasoline and diesel vary from 86 to 100.8 g-CO_2 eq./MJ and 87 to 102.5 g-CO_2 eq./MJ, respectively [22,38,40]. As for the natural gas, different pathways lead to different results [24,41–46]. In summary, combining with the Chinese situation, we use the data as Table 3 shows. As for electricity, currently power generation in China is mostly from coal. This situation will gradually improve with the increasing penetration of renewable energy in power industry. Thus, based on several predictions, the emission factors of electricity will continue to decline steadily. Most of papers only calculate the GHG emissions in power generation phase, as shown in Figure 4 [47–49]. Different scenario analyses also lead to various results. According to Requia et al. [50] electricity transmission and distribution losses accounted for around 7.9% of the fuel cycle. With consideration of all the factors, the upstream GHG emissions factors of electricity are obtained. Massively deployment of EVs will also have impact on the power grid in China, especially with the development of vehicle-to-grid technology. While, it is not clear how much influence will be brought. In this paper, this influence factor is not taken into consideration, but the framework can accept more precise input once better data are available. The GHG emissions intensities in this paper are assumed to include CO_2, CH_4 and N_2O.

Table 3. Physical properties of vehicle fuels.

Fuel Type		Low Heat Value (MJ/kg)	Density (kg/L)	Life Cycle GHG Emissions Factor (g-CO_2 eq./MJ)
Gasoline		43.0	0.73	100.8
Diesel		46.0	0.84	102.5
Natural Gas	CNG	38.0	0.72	69.4
	LNG			75.4

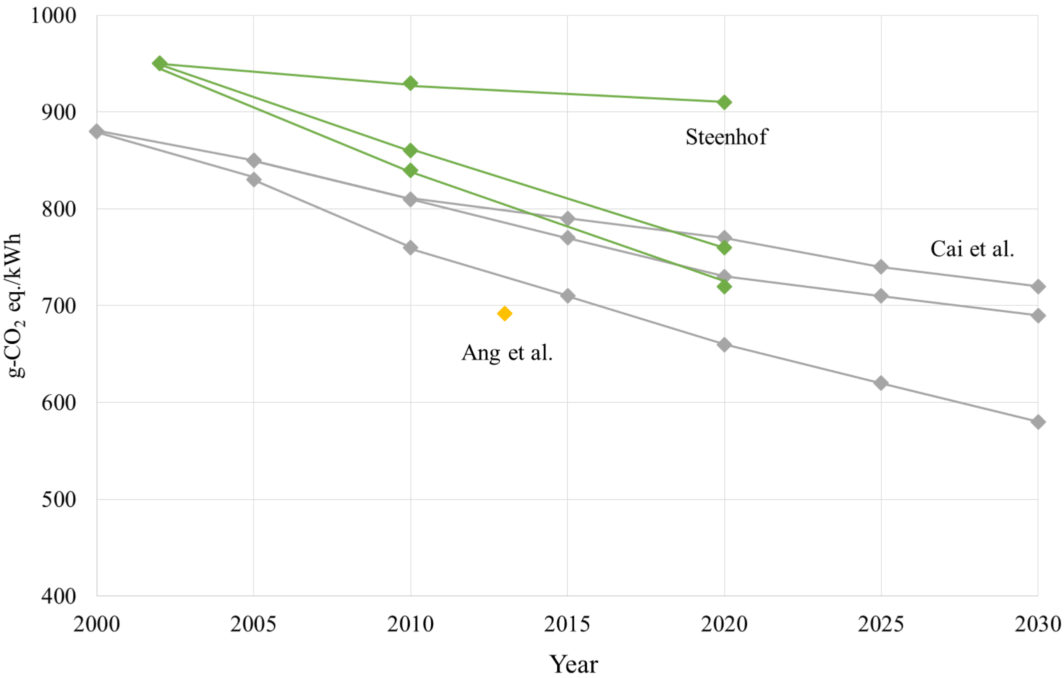


Figure 4. Different researches about electricity GHG emissions intensities.

4.4. Scenarios

Three different scenarios are analyzed in this paper, including business as usual (BAU), Conservative and Optimistic scenario. Different EV penetrations are applied in each scenario, as shown in Figure 5.

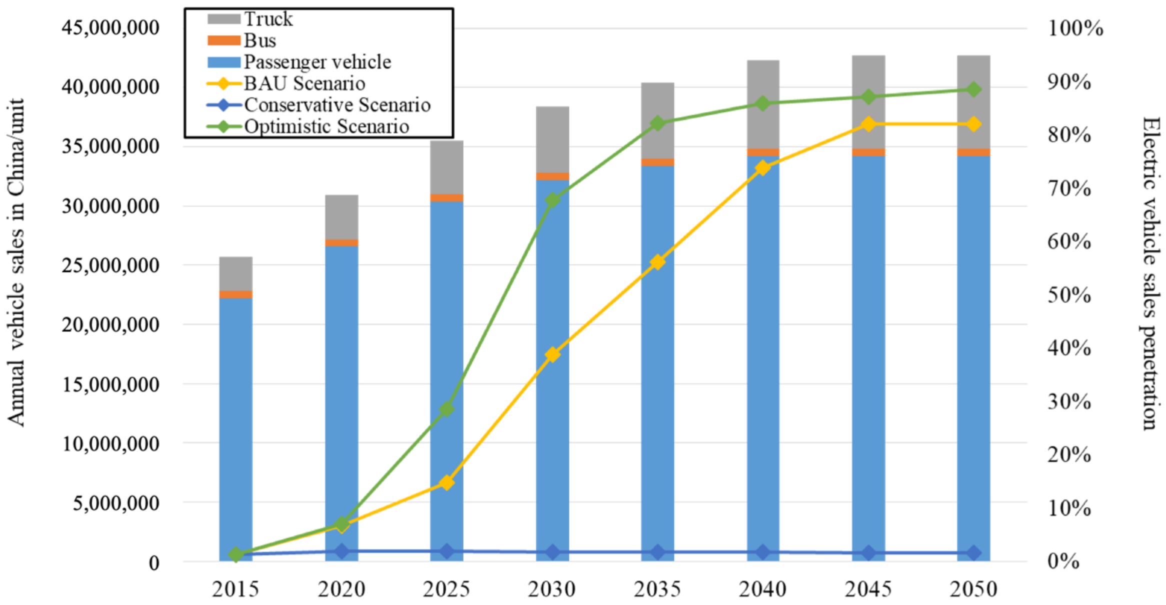


Figure 5. Different researches about electricity GHG emissions intensities.

4.4.1. BAU Scenario

Under the BAU scenario, the EV penetration depends on the existing plans made by the governments and industry associations. Thus, the BAU scenario is dependent on current policies. That means there will be no great changes in government management about the automotive industry development. The development of vehicle fleet under BAU Scenario is shown in Figure 6.

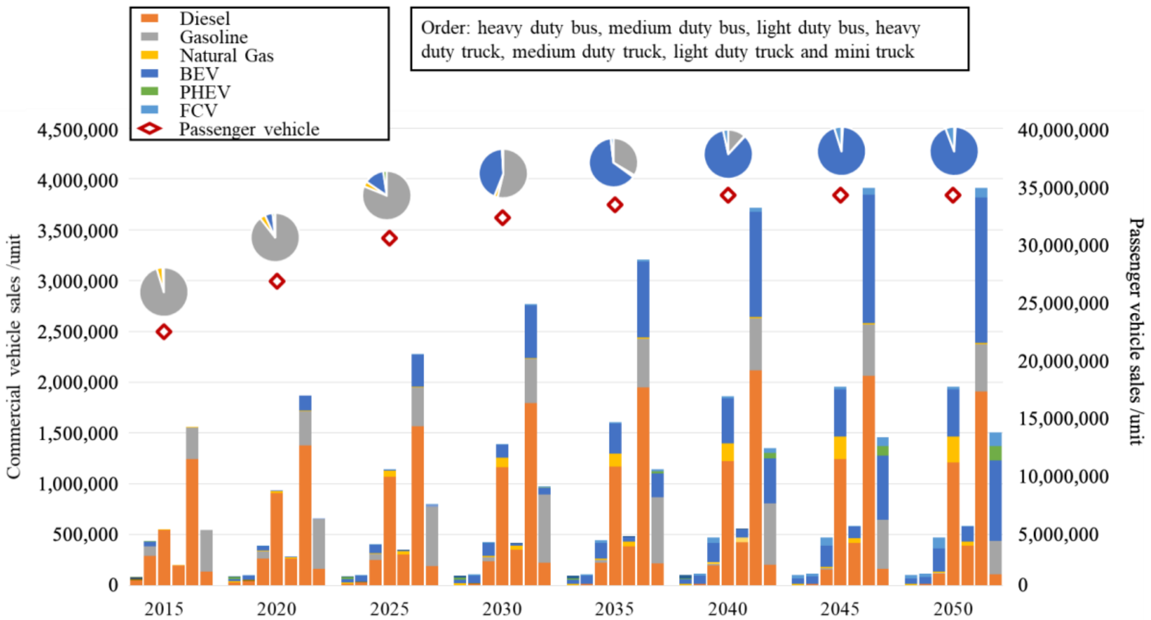


Figure 6. Vehicle sales under BAU scenario.

The penetration of EVs follows the assumptions of SAE-China and national ministries. The ratio of EVs sales to total sales will reach 7%, 15% and 40% in 2020, 2025 and 2030, respectively. Besides, the vehicle stock of FCVs will reach 5000, 50,000 and 1 million in 2020, 2025 and 2030. The rest of sales and stock of EVs are dominated by BEVs and PHEVs. The penetration of natural gas vehicles, including compressed natural gas (CNG) and liquefied natural gas (LNG) vehicles, remains at a relatively stable level. Based on the Natural Gas Development Plan in the 13th Five Year Plan the stock of all kinds of natural gas vehicles will reach around 10 million in 2020. In a certain period of time, gasoline and diesel will remain the main fuel for vehicles, particularly for commercial vehicles. Some researchers have analyzed the feasibility of electric trucks, and reached the result that electric trucks might replace diesel truck in the long term, but not now. Besides, Tesla and Mercedes-Benz both have already introduced electric truck products [51–53]. Thus, the assumption includes some electric heavy-duty truck deployment in a small proportion in the future.

4.4.2. Conservative Scenario

In this scenario, the number of total vehicle sales continues to grow consistent with trends assumed in the BAU scenario, but the penetration of EVs is kept unchanged at the current level. Therefore, the reductions of energy consumption and GHG emissions are almost entirely dependent on the improvement of fuel consumption rates. This is an extreme assumption with a very small probability of becoming a reality.

4.4.3. Optimistic Scenario

The optimistic scenario assumes that EVs will be promoted rapidly in the whole fleet. The penetrations of EVs in the whole vehicle fleet will reach 7%, 29% and 68%, respectively, in 2020, 2025 and 2030, and be 89% in 2050. The increase in penetration is mainly driven by the rapid growth of the electric passenger vehicle fleet. The development of electric commercial vehicles is also accelerated. With the cleanness of power network, EV deployment will effectively promote the low-carbon development of the whole vehicle fleet.

5. Results

Under the assumptions of different EV deployments, the results are shown as follows. Figure 7 indicates energy consumption and GHG emissions in different scenarios. Following current plans, as BAU scenario assumes, the energy consumed by the vehicle fleet will reach the peak in 2025 and GHG emissions generated by the fleet will peak in 2027. If the EV deployment is frozen in the current level, the energy consumption and GHG emissions will not reach peaks until almost 2050. The peak times under the Optimistic Scenario will be a little earlier than that under the BAU Scenario. The high penetration of EVs and cleanness of electricity network will effectively reduce energy consumption and GHG emissions in the long term.

5.1. BAU Scenario

Under the BAU Scenario, energy consumption of the whole vehicle fleet will peak in 2025 and reach 403 mtoe, and of the passenger vehicles will peak in 2022 with 164 mtoe, as Figure 8a shows. Because of the penetration of EVs and the cleanness of power structure, energy consumed by passenger vehicles will decrease dramatically. Commercial vehicles, especially trucks, will account for more proportion in energy consumption in the long term. The optimization of trucks' fuel construction and efficiency still cannot compensate the fast growth of truck sales, especially for the heavy and light duty trucks. Thus, from the perspective of vehicle fuels, gasoline consumption will decrease continuously after the peak and reach a relative low level, while the diesel consumption will almost be unchanged for a long time.

GHG emissions follow almost the same trend as energy consumption, as Figure 7 indicates. The whole fleet GHG emissions will peak in 2027 with 1763 mt CO_2 eq., around 16% higher than that in 2015, and in 2046, GHG emissions will drop back to the level in 2015. GHG emissions generated by passenger vehicles will reach the peak in 2022, earlier than the whole vehicle fleet in 2027. In 2050, the GHG emissions of passenger vehicles are only 40% of that in 2015 and 29% in 2022. GHG emissions of heavy and light duty trucks will reach the peak emissions in 2047 and 2039 respectively.

Following the development trend of industry planning, passenger vehicle fleet will be able to quickly achieve the emissions reduction target. In the future, the freight demand will continue to grow, so the rapid expansion of truck fleet size will increase the pressure on reducing energy consumption and GHG emissions. Besides, the EV penetration in the truck fleet is also much lower than that in passenger vehicles and buses. In addition, it is more difficult for trucks to reduce fuel consumption rates significantly. Thus, the proportion of trucks accounted in energy consumption and GHG emissions of the whole fleet will gradually increase.

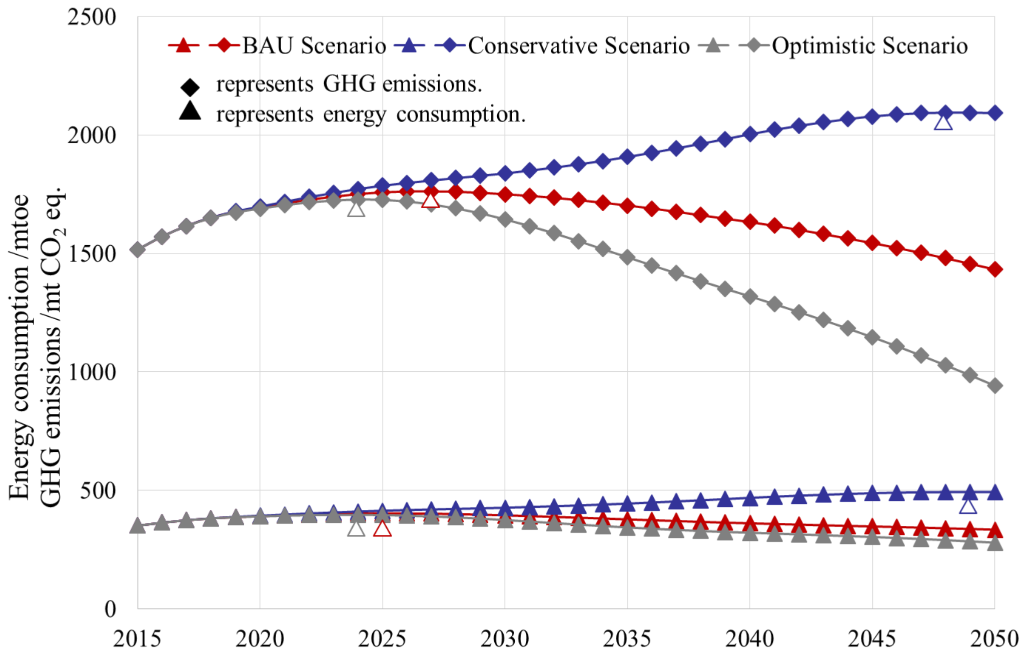
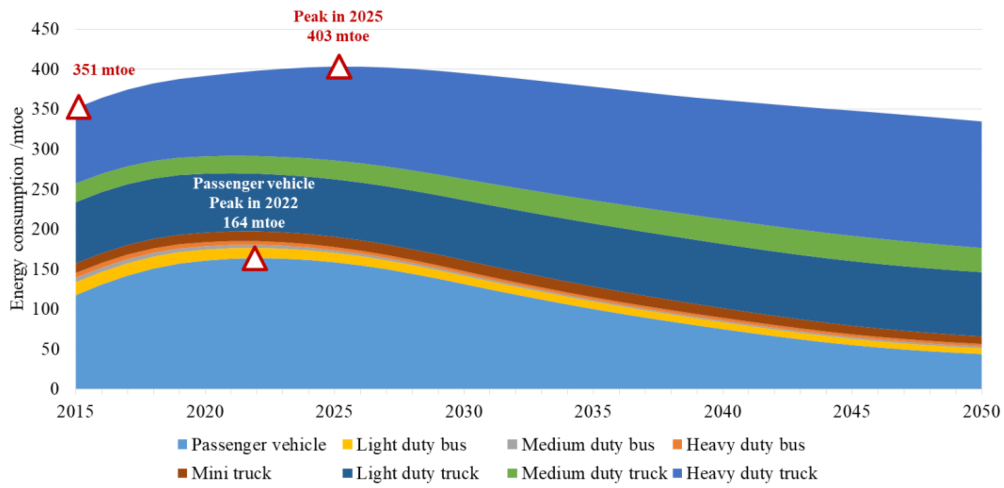


Figure 7. Energy consumption and GHG emissions under three different scenarios 2015–2050.

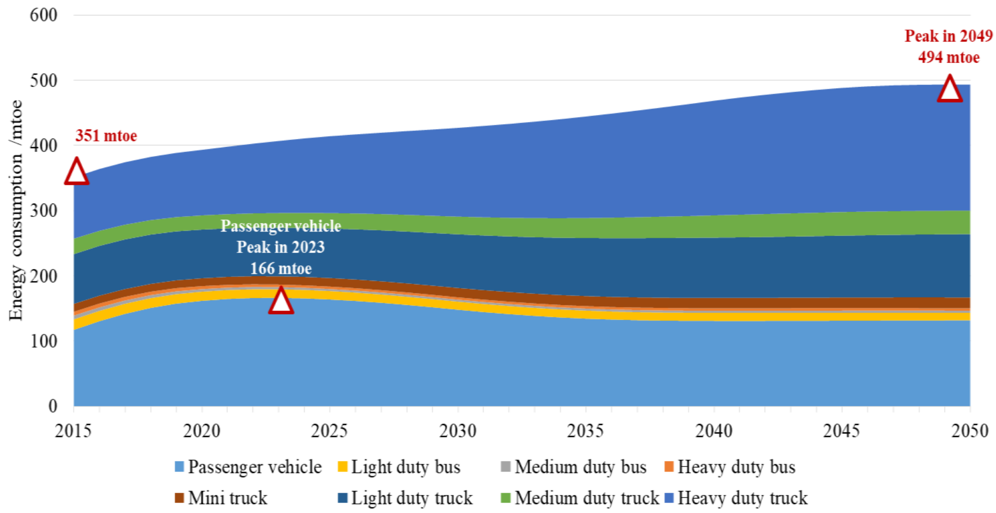
5.2. Conservative Scenario

For passenger vehicles, there will be not much differences in peak time and peak value of energy consumption under the conservative scenario, compared with the BAU scenario. As a whole, because there is no improvement in the EV deployment for commercial vehicles, especially for trucks, the peak time of the whole fleet will be greatly delayed. Energy consumption will reach the highest value until 2049, with 494 mtoe, 1.22 times of the peak value under BAU. As for the vehicle fuels, the consumption of gasoline will decline a little after the peak and keep stable since 2035. The diesel consumption will continue to grow due to the low penetration of EVs in the truck fleet. Energy consumption of passenger vehicles will peak in 2023 with 166 mtoe, as Figure 8b shows. However, in the long term, by 2050, passenger vehicles will consume three times the energy compared to BAU. GHG emissions almost follow the same trend as energy consumption. In 2048, the GHG emissions will reach its highest value of 2095 mt CO_2 eq., 18% higher than the peak value under BAU scenario.

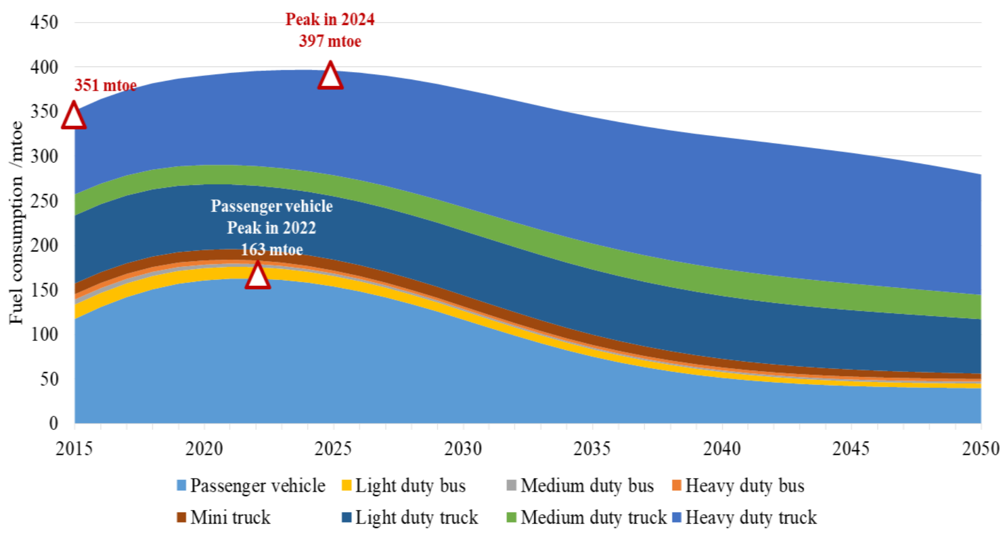
Though the conservative scenario is extremely unlikely to happen, it indicates that relying solely on the improvement of fuel consumption rate is insufficient to achieve the goal of rapid peak in energy consumption and GHG emissions in the road transport sector. Especially for the commercial vehicles, the decline in fuel consumption rate is not enough to compensate for the growth of travel and logistics demand. There is still a need for a certain EV penetration to drive the reduction of energy consumption and GHG emissions.



(**a**)



(**b**)



(**c**)

Figure 8. Energy consumption under BAU, Conservative and Optimistic Scenarios. (**a**) BAU Scenario; (**b**) Conservative Scenario; (**c**) Optimistic Scenario.

5.3. Optimistic Scenario

High energy efficiency and low GHG emissions characteristics of EVs show their prominent effect on the whole fleet. Promoting EVs will effectively achieve the overall clean development of vehicle fleet. The optimization of power structure also plays an essential role. Under the optimistic scenario, the energy consumption peak time and value of passenger vehicles and total fleet are basically consistent with that in BAU scenario. As for the whole fleet, energy consumption will reach the peak in 2024 with 397 mtoe. The passenger vehicle fleet and commercial vehicle fleet will peak in 2022 and 2039, respectively, with 163 mtoe and 270 mtoe, as shown in Figure 8c. Due to the lifespan of vehicles, with the increased penetration of EVs, energy consumption is greatly reduced compared with BAU in the long term.

Meanwhile, gasoline consumption will drop dramatically after the peak and diesel consumption will gradually decline. Consistent with the energy consumption, both passenger vehicles and commercial vehicles GHG emissions will fall at a faster pace after the peak. By 2050, GHG emissions of the vehicle fleet will be 942 mt CO_2 eq., only 66% of that under BAU Scenario. The average annual decline rate will be 2.4% from 2025 to 2050.

5.4. Discussion

A comprehensive consideration of three scenarios indicates that the passenger vehicles are bound to reach energy consumption and GHG emissions peaks before 2025. The improvement of fuel consumption rate is sufficient to support the reduction of energy consumption and GHG emissions in short terms. While, in the long run, the increasing penetration of EVs will lead to significant reductions of energy consumption and GHG emissions for passenger vehicle fleet and reduce the dependence on the conventional fuels. With the increase of transport and logistic demand, the sales and stock of commercial vehicles will continue to maintain the growth trend. Meanwhile, due to the improvement of fuel consumption rate is limited, it is really essential to promote the deployment of EVs in commercial vehicle fleet. Commercial vehicles, especially heavy-duty trucks and light-duty trucks will affect the overall fleet to a large extent. Simultaneously, high fuel consumption from commercial vehicles will cause heavy burden on the oil refining industry. High diesel-to-gasoline ratio will not match the production structure of oil refining industry. Thus, the promotion of EVs in both passenger vehicles and commercial vehicles will play an essential role in future development.

6. Conclusions

This study builds up a bottom-up model, assumes different EV penetrations, and predicts future energy consumption and GHG emissions of China's road transport sector. It is based on the latest national planning at a macro level and emphasizes the important role of EVs. Scenario analysis makes the result more comprehensive, and the findings provide references for policy makers.

The BAU scenario is based on the most up-to-date regulations and plans made by governments and industry associations. The results show that energy consumption and GHG emissions of the whole vehicle fleet will peak in 2025, with 403 mtoe and in 2027, with 1763 mt CO_2 eq. Under the conservative scenario, the proportion of EVs in total vehicle sales will remain at the current level. Thus, the energy consumption and GHG emissions will reach the peak in 2049, with 494 mtoe and in 2048, with 2095 mt CO_2 eq. The optimistic scenario presents the aggressive EV development situation. The penetrations of EVs in the whole fleet will reach 7%, 68%, 87% and 89% in 2020, 2030, 2040 and 2050, respectively. Under this scenario, the energy consumption and GHG emissions will reach the highest value in 2024, with 397 mtoe and 2024, with 1728 mt CO_2 eq.

Some main findings in this research can be summarized as follows. First, the results indicate that due to the lifespan of vehicles, it is hard for EVs to reach a significant penetration in vehicle stock in a short run, if the GHG intensity in electricity production drops in parallel. However, in the long term, with the deployment of EVs in large amounts, there will be marked reductions in energy consumption and GHG emissions. Therefore, the government should make long-term plans to ensure the sustained and stable development of EVs, instead of being too focused on short-term effects. Second, the results of passenger vehicles in the short term are little affected by the promotion of EVs, but rather by the strict fuel consumption rate regulations, while EV deployment will significantly cause less fuel consumption and GHG emissions, and reduce the dependence on conventional fuels in the future. Thus, it is essential for policy makers to stick to the fuel economy regulations in the short run. Short-term planning and long-term planning are supposed to be differentiated. Finally, the passenger vehicles will reach the peak earlier than the whole vehicle fleet both in energy consumption and GHG emissions no matter which scenario is considered. Both the fuel economy improvement and the EV deployment will contribute to this result. Commercial vehicles will become the key part of remaining fossil fuel use. In the future, policy makers should consider taking more measures to reduce commercial vehicle energy consumption and GHG emissions. Because of the limitation of fuel consumption rate improvement, it will be essential to promote alternative fuel vehicles in the commercial vehicle fleet. Though there are already some BEV models for heavy-duty trucks, they are not considered as the best option. FCVs may become a choice or other renewable liquid fuels can be considered.

While, uncertainties do exist. GHG intensity in electricity production plays an essential role in the result. Despite the rapid development of renewable energy power generation in China, it is still difficult to shut down all coal-fired power plants in a short period. Besides, BEVs may also cause impacts on the grid, and the development and application of the technology are still unclear. Therefore, as mentioned, more precise data input is needed. Meanwhile, it is really hard to provide a prediction of product ownership highly coincidence with the real market. Particularly, EVs are still in the early stage of development with a limited scale. With their proliferation, markets may lead to new change.

All in all, based on current study, both fuel economy regulations and EVs deployment can lead to energy-savings and GHG emissions reduction. Due to the gradual market share increase, there will be a time delay for EVs to show their role in emission reduction. Policy-makers should provide different plans for short term targets and long term ones. Besides, more measures should be applied to eliminate the energy consumption and GHG emissions from commercial vehicles, especially heavy-duty trucks.

Author Contributions: F.L., F.Z. and H.H. designed the whole study; F.L. conducted data collection, modeling, results analysis and wrote the original draft paper; H.H. and Z.L. revised and edited the paper.

Funding: This study is sponsored by the National Natural Science Foundation of China (71774100, 71690241, 71403142), Young Elite Scientists Sponsorship Program by CAST (YESS20160140).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Wu, Y.; Yang, Z.; Lin, B.; Liu, H.; Wang, R.; Zhou, B.; Hao, J. Energy consumption and CO_2, emission impacts of vehicle electrification in three developed regions of China. *Energy Policy* **2012**, *48*, 537–550. [CrossRef]
2. Wu, T.; Zhang, M.; Ou, X. Analysis of Future Vehicle Energy Demand in China Based on a Gompertz Function Method and Computable General Equilibrium Model. *Energies* **2014**, *7*, 7454–7482. [CrossRef]
3. Zhao, F.; Hao, H.; Liu, Z. Technology strategy to meet China's 5 L/100 km fuel consumption target for passenger vehicles in 2020. *Clean Technol. Environ. Policy* **2016**, *18*, 7–15. [CrossRef]
4. Zheng, J.; Mehndiratta, S.; Guo, J.Y.; Liu, Z. Strategic policies and demonstration program of electric vehicle in China. *Transport Policy* **2012**, *19*, 17–25. [CrossRef]
5. Hao, H.; Wang, H.; Ouyang, M. Fuel conservation and GHG (Greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet. *Energy* **2011**, *36*, 6520–6528. [CrossRef]
6. He, K.; Huo, H.; Zhang, Q.; He, D.; An, F.; Wang, M.; Walsh, M.P. Oil consumption and CO_2, emissions in China's road transport: Current status, future trends, and policy implications. *Energy Policy* **2005**, *33*, 1499–1507. [CrossRef]
7. Ou, X.; Yan, X.; Zhang, X.; Liu, Z. Life-cycle analysis on energy consumption and GHG emission intensities of alternative vehicle fuels in China. *Appl. Energy* **2012**, *90*, 218–224. [CrossRef]

8. Wang, C.; Cai, W.; Lu, X.; Chen, J. CO_2, mitigation scenarios in China's road transport sector. *Energy Convers. Manag.* **2007**, *48*, 2110–2118. [CrossRef]
9. Hao, H.; Liu, Z.; Zhao, F.; Li, W.; Hang, W. Scenario analysis of energy consumption and greenhouse gas emissions from China's passenger vehicles. *Energy* **2015**, *91*, 151–159. [CrossRef]
10. Ou, S.; Lin, Z.; Qi, L.; Li, J.; He, X.; Przesmitski, S. The dual-credit policy: Quantifying the policy impact on plug-in electric vehicle sales and industry profits in China. *Energy Policy* **2018**, *121*, 597–610. [CrossRef]
11. Zhang, X.; Bai, X. Incentive policies from 2006 to 2016 and new energy vehicle adoption in 2010–2020 in China. *Renew. Sustain. Energy Rev.* **2017**, *70*, 24–43. [CrossRef]
12. Wang, N.; Pan, H.; Zheng, W. Assessment of the incentives on electric vehicle promotion in China. *Transp. Res. Part A* **2017**, *101*, 177–189. [CrossRef]
13. He, X.; Zhan, W.; Hu, Y. Consumer purchase intention of electric vehicles in China: The roles of perception and personality. *J. Clean. Prod.* **2018**, *204*, 1060–1069. [CrossRef]
14. Ouyang, D.; Zhang, Q.; Ou, X. Review of market surveys on consumer behavior of purchasing and using electric vehicle in China. *Energy Procedia* **2018**, *152*, 612–617. [CrossRef]
15. Qiao, Q.; Zhao, F.; Liu, Z.; Hao, H. Comparative study on life cycle CO_2 emissions from the production of electric and conventional vehicles in China. *Energy Procedia* **2017**, *105*, 3584–3595. [CrossRef]
16. Yu, A.; Wei, Y.; Chen, W.; Peng, N.; Peng, L. Life cycle environmental impacts and carbon emissions: A case study of electric and gasoline vehicles in China. *Transp. Res. Part D Transp. Environ.* **2018**, *65*, 409–420. [CrossRef]
17. Hao, H.; Cheng, X.; Liu, Z.; Zhao, F. Electric vehicles for greenhouse gas reduction in China: A cost-effectiveness analysis. *Transp. Res. Part D Transp. Environ.* **2017**, *56*, 68–84. [CrossRef]
18. Osorio, G.J.; Shafie-khah, M.; Coimbra, P.D.L.; Lotfi, M.; Catalao, J.P.S. Distribution system operation with electric vehicle charging schedules and renewable energy resources. *Energies* **2018**, *11*, 3117. [CrossRef]
19. Sadok, T.; Nidhal, R. Study of a Manufacturing System with Transport Activities in Urban Area. *IFAC-PapersOnLine* **2016**, *49*, 419–423. [CrossRef]
20. Mazur, C.; Offer, G.; Contestabile, M.; Brandon, N. Comparing the effects of vehicle automation, policy making and changed user preferences on the uptake of electric cars and emissions from transport. *Sustainability* **2018**, *10*, 676. [CrossRef]
21. Hao, H.; Wang, H.; Ouyang, M. Fuel consumption and life cycle GHG emissions by China's on-road trucks: Future trends through 2050 and evaluation of mitigation measures. *Energy Policy* **2012**, *43*, 244–251. [CrossRef]
22. Ou, X.; Zhang, X.; Chang, S. Scenario analysis on alternative fuel/vehicle for China's future road transport: Life-cycle energy demand and GHG emissions. *Energy Policy* **2010**, *38*, 3943–3956. [CrossRef]
23. Vuuren, D.P.V.; Hoogwijk, M.; Barker, T.; Riahi, K.; Boeters, S.; Chateau, J.; Scrieciu, S.; Vliet, J.; Masui, T.; Blok, K.; et al. Comparison of top-down and bottom-up estimates of sectoral and regional greenhouse gas emission reduction potentials. *Energy Policy* **2009**, *37*, 5125–5139. [CrossRef]
24. Beer, T.; Grant, T.; Williams, D.; Waston, H. Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles. *Atmos. Environ.* **2002**, *36*, 753–763. [CrossRef]
25. Yan, X.; Crookes, R.J. Energy demand and emissions from road transportation vehicles in China. *Prog. Energy Combust. Sci.* **2010**, *36*, 651–676. [CrossRef]
26. Yan, X.; Crookes, R.J. Reduction potentials of energy demand and GHG emissions in China's road transport sector. *Energy Policy* **2009**, *37*, 658–668. [CrossRef]
27. SAE-China. *Energy-Saving and New Energy Vehicle Technology Roadmap*; Mechanical industry press: Beijing, China, 2016.
28. Ministry of Industry and Information Technology; National Development and Reform Commission and Ministry of Science and Technology of the People's Republic of China. Medium-long Term Development Plan of Automotive Industry. 2017. Available online: http://www.most.gov.cn/tztg/201705/t20170510_132694.htm (accessed on 30 November 2018).
29. Yuan, X.; Li, L.; Gou, H.; Dong, T. Energy and environmental impact of battery electric vehicle range in China. *Appl. Energy* **2015**, *17*, 75–84. [CrossRef]
30. Vliet, O.; Brouwer, A.S.; Kuramochi, T.; Broek, M.; Faaij, A. Energy use, cost and CO_2 emissions of electric cars. *J. Power Sources* **2011**, *196*, 2298–2310. [CrossRef]

31. Ke, W.; Zhang, S.; He, X.; Wu, Y.; Hao, J. Well-to-wheels energy consumption and emissions of electric vehicles: Mid-term implications from real-world features and air pollution control progress. *Appl. Energy* **2017**, *188*, 367–377. [CrossRef]
32. Triantafyllopoulos, G.; Kontses, A.; Tsokolis, D.; Ntziachristos, L.; Samaras, Z. Potential of energy efficiency technologies in reducing vehicle consumption under type approval and real world conditions. *Energy* **2017**, *140*, 365–373. [CrossRef]
33. Ntziachristos, L.; Mellios, G.; Tsokolis, D.; Keller, M.; Hausberger, S.; Ligterink, N.E.; Dilara, P. In-use vs. type-approval fuel consumption of current passenger cars in Europe. *Energy Policy* **2014**, *67*, 403–411. [CrossRef]
34. Zhang, S.; Wu, Y.; Liu, H.; Huang, R.; Un, P.; Zhou, Y.; Fu, L.; Hao, J. Real-world fuel consumption and CO_2 (carbon dioxide) emissions by driving conditions for light-duty passenger vehicles in China. *Energy* **2014**, *69*, 247–257. [CrossRef]
35. Hou, C.; Wang, H.; Ouyang, M. Survey of daily vehicle travel distance and impact factors in Beijing. *IFAC Proc. Vol.* **2013**, *46*, 35–40. [CrossRef]
36. Lin, X.; Tang, D.; Ding, Y.; Yin, H.; Ji, Z. Study on the distribution of vehicle traveled in China. *Res. Environ. Sci.* **2009**, *22*, 377–380.
37. International Energy Agency. The Future of Trucks, Implications for Energy and the Environment. 2017. Available online: https://www.iea.org/publications/freepublications/publication/TheFutureofTrucksImplicationsforEnergyandtheEnvironment.pdf (accessed on 30 November 2018).
38. Samaras, C.; Meisterling, K. Life cycle assessment of greenhouse gas emissions from plug-in hybrid vehicles: Implications for policy. *Environ. Sci. Technol.* **2008**, *42*, 3170–3176. [CrossRef] [PubMed]
39. Hou, C.; Ouyang, M.; Wang, H.; Xu, L. An assessment of PHEV energy management strategies using driving range data collected in Beijing. In Proceedings of the 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 17–20 November 2013; pp. 1–10.
40. Ou, X.; Yan, X.; Zhang, X. Using coal for transportation in China: Life cycle GHG of coal-based fuel and electric vehicle, and policy implications. *Int. J. Greenh. Gas Control* **2010**, *4*, 878–887. [CrossRef]
41. Tong, F.; Jaramillo, P.; Azevedo, I.M.L. Comparison of Life Cycle Greenhouse Gases from Natural Gas Pathways for Medium and Heavy-Duty Vehicles. *Environ. Sci. Technol.* **2015**, *49*, 7123–7133. [CrossRef] [PubMed]
42. Ercan, T.; Yang, Z.; Tatari, O.; Pazour, J.A. Optimization of transit bus fleet's life cycle assessment impacts with alternative fuel options. *Energy* **2015**, *93*, 323–334. [CrossRef]
43. Arteconi, A.; Brandoni, C.; Evangelista, D.; Polonara, F. Life-cycle greenhouse gas analysis of LNG as a heavy vehicle fuel in Europe. *Appl. Energy* **2010**, *87*, 2005–2013. [CrossRef]
44. Bariety, M.; Kohler, D. Life-Cycle analysis of GHG emissions for CNG and Diesel buses in Beijing. In Proceedings of the IEEE EIC Climate Change Conference, Ottawa, ON, Canada, 10–12 May 2007; pp. 1–6.
45. Hekkert, M.P.; Hendriks, F.H.J.F.; Faaij, A.P.C.; Neelis, M.L. Natural gas as an alternative to crude oil in automotive fuel chains well-to-wheel analysis and transition strategy development. *Energy Policy* **2005**, *33*, 579–594. [CrossRef]
46. Song, H.; Ou, X.; Yuan, J.; Yu, M.; Wang, C. Energy consumption and greenhouse gas emissions of diesel/LNG heavy-duty vehicle fleets in China based on a bottom-up model analysis. *Energy* **2017**, *140*, 966–978. [CrossRef]
47. Cai, W.; Wang, C.; Wang, K.; Zhang, Y.; Chen, J. Scenario analysis on CO_2, emissions reduction potential in China's electricity sector. *Energy Policy* **2007**, *35*, 6445–6456. [CrossRef]
48. Steenhof, P.A. Decomposition for emission baseline setting in China's electricity sector. *Energy Policy* **2007**, *35*, 280–294. [CrossRef]
49. Ang, B.W.; Su, B. Carbon emission intensity in electricity production: A global analysis. *Energy Policy* **2016**, *94*, 56–63. [CrossRef]
50. Requia, W.J.; Adams, M.D.; Arain, A.; Petros, K.; Mark, F. Carbon dioxide emissions of plug-in hybrid electric vehicles: A life-cycle analysis in eight Canadian cities. *Renew. Sustain. Energy Rev.* **2017**, *78*, 1390–1396. [CrossRef]
51. Cabukoglu, E.; Georges, G.; Kung, L.; Pareschi, G.; Boulouchos, K. Battery electric propulsion: An option for heavy-duty vehicles? Results from a Swiss case-study. *Transp. Res. Part C Emerg. Technol.* **2018**, *88*, 107–123. [CrossRef]

52. Zeilinger, M.; Wohlfarth, E. Locally emission-free and quiet freight transportation with the Mercedes-Benz eActros. *MTZ Worldw.* **2018**, *79*, 30–35. [CrossRef]
53. Pereirinha, P.G.; Gonzalez, M.; Carrilero, I.; Ansean, D.; Alonso, J.; Viera, J.C. Main trends and challenges in road transportation electrification. *Transp. Res. Procedia* **2018**, *33*, 235–242. [CrossRef]