Reducing Greenhouse Gas Emissions by Electric Vehicles in China: the Cost-Effectiveness Analysis

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Abstract

Compared with conventional vehicles, electric vehicles (EVs) offer the benefits of replacing petroleum consumption and reducing air pollutions. However, there have been controversies over greenhouse gas (GHG) emissions of EVs from the life-cycle perspective in China's coal-dominated power generation context. Besides, it is in doubt whether the cost-effectiveness of EVs in China exceeds other fuel-efficient vehicles considering the high prices. In this study, we compared the life-cycle GHG emissions of existing vehicle models in the market. Afterwards, a cost model is established to compare the total costs of vehicles. Finally, the cost-effectiveness of different vehicle types are compared. It is concluded that the GHG emission intensity of EVs is lower than reference and hybrid vehicles currently and is expected to decrease with the improvement of the power grid. The total cost of EVs is relatively high compared with reference gasoline vehicles in 2014 but it is expected that EVs will possess an improved cost-competitiveness in the future. In terms of cost-effectiveness, medium-range EVs do not have an obvious advantage over other fuel-efficient vehicles currently. But the cost-effectiveness of EVs is predicted to become better in the next ten years.

Keywords

Cost-effectiveness, Electric vehicles, Greenhouse gas emissions, Life-cycle, China

1. Introduction

In the past few years, China's vehicle market has experienced a rapid growth, and is currently the largest vehicle market in the world. In 2014, China's vehicle production reached 23.72 million, with an increase rate of 6.9%. [1] However, along with the rapid growth of the vehicle market, severe energy and environmental issues begin to emerge in China. [2]

According to Ref. [3], China's petroleum dependence rate has reached 50% since 2009. In 2014, this rate was 59.6% and is expected to increase in the future. Among China's overall petroleum consumption, road transport sector takes a main responsibility. It is estimated that China's on-road vehicles (mostly by passenger vehicles) account for 87% of China's domestic gasoline consumption. [4]

In addition, large amounts of CO2 emissions has been emitted by passenger vehicles in China. [5] China has long been the largest CO2 emitter in the world. In order to take responsibility for the global warming issue, the Chinese government has promised that to reach the peak of national total carbon emission before 2030. [6] Among China's CO2 emissions, the road transport sector is estimated to account for about 6.9% [7]. This proportion is believed to increase in the future in view of the great growth potential of China's vehicle market.

Compared with conventional gasoline or diesel vehicles, electric vehicles (EVs) offer the benefits of replacing petroleum consumption. By replacing gasoline vehicles with EVs, the pollution are transferred from the vehicles to the power plants, which has the potential of improving air quality in densely populated cities. With clean power generation processes, EVs can also reduce GHG emissions. In consideration of resolving energy and environmental issues in China, the Chinese government has been promoting EVs in numerous cities and has put forward a series of policies, including tax exemptions and financial subsidies.

However, there are controversies with regard to whether EVs can reduce GHG emissions from the life-cycle perspective. Besides, compared with other types of fuel-efficiency vehicles, the price of EVs are rather higher, which makes it in doubt whether electrification is a relatively cost-effective technology pathway.

Intensive studies have been conducted on the life-cycle GHG emissions of EVs. However, the results vary widely. Huo et al. [8] studied six interprovincial power grids in China and concluded that EVs do not have much benefit in reducing CO2 emissions currently. In contrast, Yuan et al. [9] concluded that in the current situation, EVs with electric ranges of less than 300km are able to reduce life-cycle GHG emissions. Que et al. [10] employed the Tsinghua-LCAM module in analyzing this problem and concluded the life-cycle GHG emissions of EVs are lower than internal combustion engine vehicles in China at present. Zhao et al. [11] predicted that with future's decreasing share of heavy-emission electricity generation sources, the GHG emissions of EVs will be reduced significantly.

However, in terms of the cost-effectiveness of EVs, there are a few studies on situations in Europe and America, while few on China's situation specifically. Björn Nykvist et al. [12] investigated the battery price of EVs. By studying the historic data, the study predicted that the learning rate of battery will be 9% for the whole industry in the next 10 years. Martin Weiss et al. [13] studied the price of heavy hybrid as well as electric vehicles in the future and concluded that the price of EVs will remain high in the next 20 years and heavy hybrid vehicles is more likely to dominate in the foreseeable future. J. Seixas et al. [14] studied the cost-effectiveness of EVs in terms of GHG emissions reduction in European countries. The study found that EVs will not be cost-effective until 2030. Bickert et al. [15] studied the situation in Germany in particular and found that the total cost of EVs will remain higher than conventional vehicles in the next few years and therefore weakens their cost-effectiveness.

With an aim of filling research gaps, the GHG emissions of conventional vehicles, hybrid vehicles and EVs are estimated from a life-cycle perspective. Besides, a vehicle cost model is established so as to assess the total costs of different types of vehicles. By integrating the results above, it will be feasible to evaluate the cost-effectiveness of different kinds of vehicles in China.

2. Methodology and Data

2.1. Vehicle Models to be Compared

With the regard that the market share of diesel passenger vehicles is less than 1% in China, diesel vehicles are not taken into our consideration. In this study, reference conventional gasoline vehicles, hybrid vehicles as well as EVs are chosen as examples. In order to increase the credibility of the results, the compared vehicles are assumed to be of the same chassis architecture and appearance. Therefore, the vehicles can be considered comparable and the comparable benchmarks of these vehicles can be set up based on their parameters.

In this study, Nissan Tiida (Versa Note in America) and the electric model Leaf are chosen as examples of reference vehicles and EVs. Their parameters are based on the official data. [16][17] The heavy hybrid vehicle is assumed to be equipped with a power-spit hybrid powertrain and the parameters of heavy hybrid vehicles is based on the Toyota Corolla hybrid in the Chinese market. [18]

As for the power system, the reference vehicle is equipped with a 1.6L gasoline engine which provides 93 kW power at maximum while EV with an electric motor of 80kW at maximum. The hybrid vehicle has a 1.6L gasoline engine along with an electric motor, which can provide 100kW power at maximum in total. Besides, for the EV model, the battery capacity is 24kWh and the weight of the battery system is 218kg. Therefore, the specific energy of the battery system is calculated to be 110Wh/kg.

The curb weight of the reference vehicle is 1206kg. However, due to an increased weight of the battery system, the curb weight of the Leaf is approximately 300kg higher and increased to 1494kg. As for the heavy hybrid vehicle, its curb weight is assumed to be 100kg higher than the reference vehicle, by referring to [18].

The gasoline consumption of the reference vehicle under the new European driving cycle (NEDC) is 6.4L/100km. The gasoline consumption of the heavy hybrid vehicle is assumed to be 33% less than the reference vehicle, which reduces to 4.3L/100km [19]. The official electricity consumption of Leaf under NEDC is 14.6kWh/100km.

Parameters of different vehicle models are shown in Table 1.

Table 1. Parameters of vehicles models to be compared

Parameters	Reference vehicles	Heavy Hybrid Vehicles	EVs
Power system	1.6L Engine	1.6L Engine/Electric	Electric
Maximum power/kW	93	100	80
Battery capacity/kWh	/	1.6	24
Curb weight/kg	1206	1306	1494
Specific energy of battery system/Wh/kg	/	110	110
NEDC energy consumption	6.4L/100km	4.3L/100km	14.6kWh/100km
Electricity range/km	/	/	175

Apart from the vehicle models above, we also took the mild hybrid vehicles into account. In this study, the mild hybrid vehicle has an incremental integrated starter generator and the fuel reduction level is assumed to be 8.6%, by referring to [19].

EVs with different range capacities are also taken into consideration. Higher range capacities lead to higher battery capacities and curb weights. In this study, the coefficients of rolling and air resistance are assumed to be 0.012 and 0.28, by referring to parameters of Nissan Leaf [20]. The average vehicle speed during NEDC is 33.6km/h [21]. In this study, it is assumed that the energy consumption of EVs is proportional to the driving resistance. The battery capacities have an influence on the curb weight, thus will influence the NEDC energy consumption and the range capacities. Therefore, iteration methods is required in calculating the parameters of EVs with different range capacities. The results are shown in Table 2.

Table 2. Parameters of EVs with different range capacities

Parameters	Short range EV 100km	Medium range Leaf	Long range EV 300km
Range capacity/km	100	175	300
NEDC energy consumption	13.9kWh/100km	14.6kWh/100km	15.9kWh/100km
Battery capacity/kWh	13	24	44
Curb weight/kg	1395	1494	1683

2.2. GHG Emissions Analysis

The GHG emissions intensity of reference vehicles is assumed to be 150g/km, based on the fuel consumption. The GHG emissions intensities of mild hybrid and heavy hybrid vehicles are 137g/km and 101g/km, respectively. Due to more stringent fuel efficiency regulations in the future, the fuel consumption of future's gasoline vehicles in China is assumed to decrease. In this study, we assume the fuel consumption of reference vehicles will decrease from 6.4L/100km in 2014 to 5.6 L/100km in 2020 and 5.2L in 2025. Besides, mild and heavy hybrid vehicles are assumed to have the same effect of fuel consumption reduction in the future, compared with 2015. As for gasoline's upstream GHG emissions, it is assumed to be 15% of the usage stage, by referring to [22].

In terms of EVs, according to Ou et al. [23], the GHG emissions intensity of coal in China's coal-power plants is 87.3g/MJ. The electric power transmission loss in China is assumes to be 7% [22]. The charging efficiency of EVs is assumed to be 90% [24]. With a certain coal power share and efficiency, the GHG emissions intensity of China's coal-dominated power gird can be calculated. Afterwards, the GHG emission intensity of EVs from the life-cycle perspective can be figured out.

2.3. Total Cost Analysis

In this study, the total cost of a vehicle includes three main parts: vehicle price, fuel cost, and maintenance cost.

2.3.1. Vehicle Price

According to Ref [25], the vehicle price coefficient is 1.5, which suggests the price is 1.5 times of the manufacturing cost, considering administrative costs as well as profits. Therefore, to evaluate the vehicle price, we started from the manufacturing costs by establishing a manufacturing cost model of different kinds of vehicles.

The cost of the battery has decisive effects on the total cost of EVs. In this study, by referring to Nykvist [12], the average manufacturing cost of battery is assumed to be 2511 yuan/kWh in 2014. The learning rate of batteries is predicted to be 9% in the future. Therefore, the manufacturing cost of the batteries can be calculated from the cumulative global battery production, as shown in Formula (1).

$$C = 2542 \times (1 - 0.09 \log P) \tag{1}$$

Where C is the manufacturing cost of battery (yuan/kWh), P is the cumulative global battery production (MWh).

In the study, the average battery capacity of EVs in the global market is assumed to be 22 kWh, taking the plug-in hybrid electric vehicles (PHEV) as well as battery electric vehicles (BEV) into consideration. With our predictions for future's global EV productions (shown in Figure 1), the manufacturing costs of batteries can be predicted, as

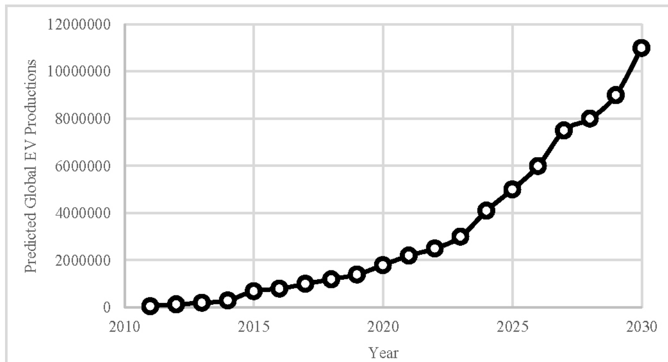

Figure 1. Predicted Global EV Productions

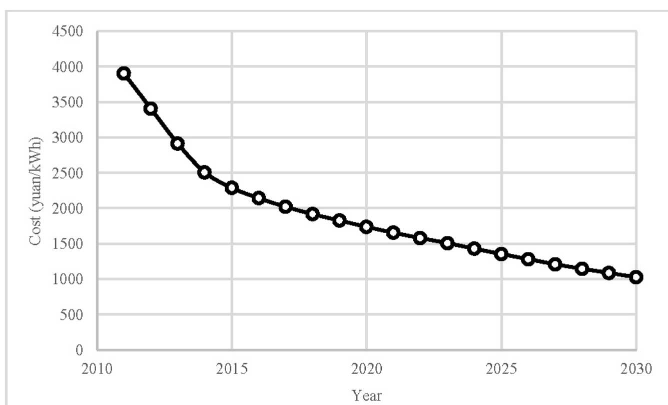

Figure 2. Predicted cost of batteries

Due to the mass production of batteries in the future, the manufacturing cost of batteries will decline to 1740 yuan/kWh in 2020 and 1029 yuan/kWh in 2030. The decline of battery cost is believed to have a great influence on EV's price in the future.

The manufacturing costs of other components except for the battery are assumed by referring to Steve Plotkin et al [26]. Since the costs is expressed under the American situation in that study, the data are multiplied by 1.1 to fit China's situation, which is extracted from the comparison of typical vehicle prices of the two markets.

The manufacturing costs of different kinds of vehicles in 2014 are shown in Figure 3. The cost is expressed in RMB in 2014 and the exchange rate between RMB and US Dollar is assumed to be 6.4:1.

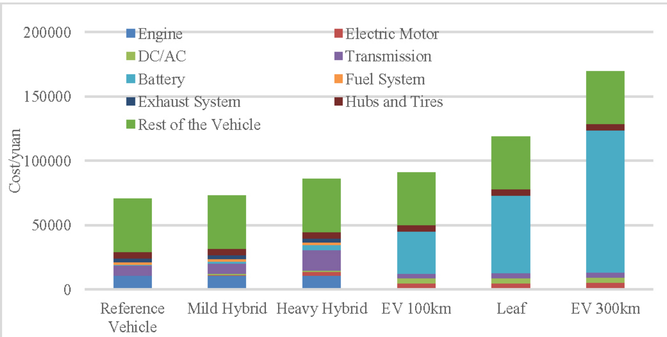

Figure 3. Manufacturing Cost of Components of Different Vehicles

2.3.2. Fuel Cost

Apart from the vehicle price, the fuel cost also takes up a considerable portion of the total cost.

The price of 93# gasoline, comparable to 87# gasoline in the United States, has been increasing, with fluctuations in recent years. Since the gasoline price is a key parameter for the total cost of reference and hybrid vehicles, it is necessary to consider the gasoline price under different scenarios. By referring to the study of Energy Information Administration (EIA) [27] and China's historical gasoline prices, we assumed three scenarios: low oil price scenario, reference oil price scenario and high oil price scenario. The average gasoline price under the reference oil price scenario is assumed to be 6.25 yuan/L in the next 10 years, while the average prices under low and high oil price scenarios are assumed to be 5.14 and 9.29 yuan/L, respectively.

Electricity price in China differs depending on different charging patterns. The electricity price at public charging infrastructures is 0.7 yuan/kWh, added by 0.92 yuan/kWh at maximum as service fee. On the other hand, the electricity price for private owned charging piles is 0.47 yuan/kWh. In this study, we assumed EVs are charged with private piles and the electricity price is assumed to be 0.47 yuan/kWh.

In this study, the discount rate is assumed to be 6%, by referring to Hao et al [28]. Previous study suggests the distance per private passenger vehicle (PPV) decreases 3 % annually as vehicle age grows. The average distance per PPV annually in China is 16900km in 2009, according to Ref. [29].

2.3.3. Maintenance Cost

Gasoline vehicles bear a higher maintenance cost than EVs. In this study, the maintenance cost of gasoline vehicles is assumed to be 0.41 yuan/km while the cost of EVs is assumed to be 0.27 yuan/km, by referring to Bickert et al. [15]. Both the maintenance cost and the fuel costs are calculated in 10 years, based on the assumptions of Siddiki et al. [30].

2.4. Cost-Effectiveness Analysis

In the cost-effectiveness analysis, results are presented in cost per unit of emissions reduced. The results are often used to determine the technology pathway of the least cost to achieve a given emission reduction goal. In this study, results of the reference vehicles are set as comparative benchmarks.

The total cost can be calculated by adding the three cost segments discussed in Section 2.3. In terms of GHG emissions, by integrating the GHG emissions intensities and the annual distances, the GHG emissions of different vehicles from the life-cycle perspective can be figured out.

3. Results

3.1. GHG Emissions Analysis

According to Ref. [31], the coal power share is 75.2% and the coal power efficiency is 38.6% in 2014 in China. Since there are wide ranges on coal power shares among different regions in China, situations are considered in which the coal power share ranges from 40% to 99%. According to Ou et al. [34], the efficiencies of subcritical thermal unit, supercritical thermal unit and ultrasupercritical thermal unit are 33.1%, 41.5%, and 42.1%, respectively. Therefore, in this study, the coal power efficiency is assumed to range from 32% to 42%.

The GHG emissions from other types of power plants is very low compared with coal power plants in China. In this study, GHG emissions from other types of power plants are not taken into consideration. With the methodology discussed in Section 2, the GHG emissions intensities of reference vehicles, Leaf as well as heavy hybrid vehicle can be figured out, as presented in Figure 4. EV 100km and EV 300km are not shown in Figure 4.

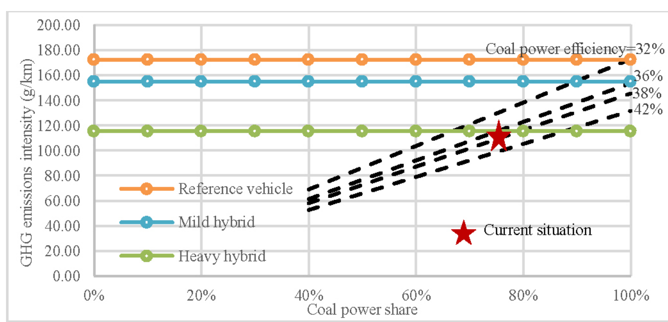

Figure 4. GHG emissions intensities of different vehicles

In Figure 4, the GHG emissions intensity of Leaf is shown as a cluster of dotted lines under different coal power shares and efficiencies. Each straight line represents a situation with a certain coal power efficiency. With the coal power efficiency remaining constant, the GHG emissions intensity of EVs will decline with the decrease of coal power share. With the coal power share constant, along with the increase of coal power efficiency, the GHG emissions intensity of Leaf also declines accordingly.

Under the current situation of China's power grid, the GHG emission intensity of Leaf is 108.5g/km, which is 37.1% lower than reference vehicles (172.5g/km), 31.2% lower than mild hybrid vehicles (157.6g/km) and even 6.1% lower than heavy hybrid vehicles (115.6g/km). It can be concluded that under the current situation, EVs have greater potential of reducing GHG emissions in China, compared to reference and hybrid vehicles.

The coal power shares and efficiencies are predicted to change rapidly in China in the next few decades, which will have great influence on EVs' GHG emissions intensities. Out of this consideration, the coal power shares and efficiencies in China are predicted based on historical data, which are shown in Table 3.

Table 3. Predictions of coal power shares and efficiencies in China

Year	Predicted thermal power share	Predicted thermal power efficiency
2020	71%	39.1%
2025	67%	39.3%
2030	64%	39.5%

The fuel consumption of reference or hybrid vehicle will remain unchanged once produced. With the regard that the GHG emissions of gasoline will not change significantly, the GHG emissions intensities of these vehicle kinds are assumed to remain unchanged in the next few years. However, in terms of EVs, their GHG emissions intensities are influenced by future's improvements of the electric power grid. Figure 6 shows the future's GHG emissions intensities of different kinds of vehicles manufactured in 2014.

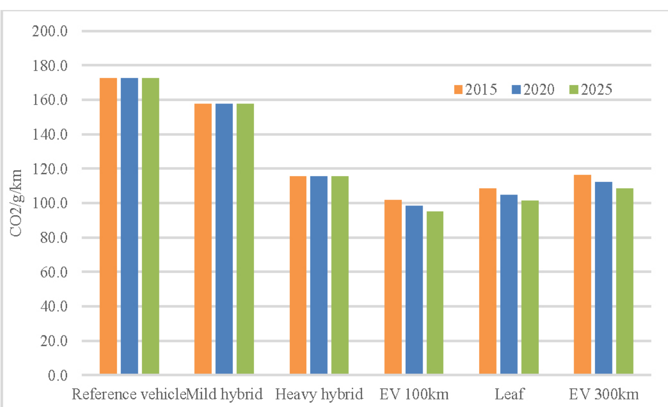

Figure 6. Future's GHG emission intensities of different vehicle kinds

From Figure 6, the GHG emissions intensities of EVs is predicted to decrease in the next 10 years and remain lower than reference and hybrid vehicles. Taking Leaf as an example, the GHG emissions intensity is 108.5g/km in 2015, while it is predicted to decrease to 104.7g/km in 2020 and 101.1g/km in 2030. In terms of different electric ranges, it can be figured out that under similar situations, GHG emissions intensities of EVs will increase with the increase of electric ranges, mostly due to higher driving resistances cause by higher curb weights.

3.2. Total Cost Analysis

According to the price model established in Section 2.3.1, future's prices of different kinds of vehicles can be predicted. The price predictions are shown in Figure 7.

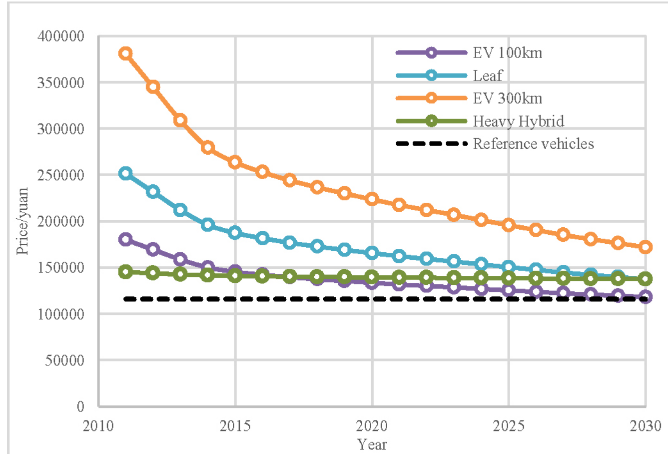

Figure 7. Price predictions for different vehicle kinds

The price of reference vehicles is assumed to remain unchanged. However, the price of heavy hybrid vehicles and EVs will both experience a decrease in the future while the decreasing rate of EVs is expected to be much higher. According to our prediction, the price of 100km EV will reduce from about 150,000 yuan in 2014 to about 119,000 yuan in 2030, close to the price of reference vehicles. The price of Leaf is expected to decrease from about 196,000 yuan in 2014 to about 138,000 yuan in 2030, approaching the price of heavy hybrid vehicles. The price of 300km EV is predicted to decrease from about 280,000 yuan in 2014 to about 172,000 yuan in 2030.

By taking the fuel as well as maintenance cost into consideration, the total cost of different kinds of vehicles can be calculated. The reference fuel price scenario (6.25 yuan/L) is firstly considered. The results are shown in Figure 8.

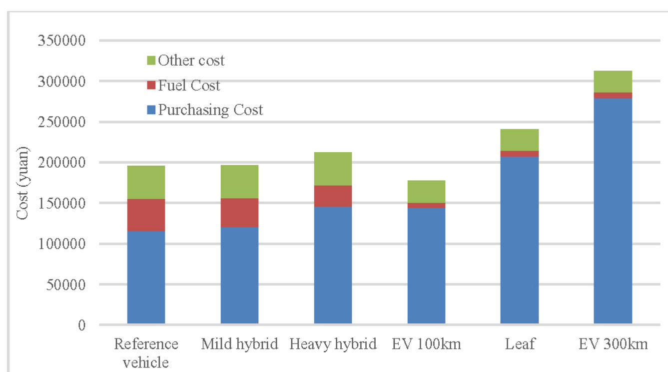

Figure 8. Total cost components of different vehicle kinds (reference fuel price scenario)

From Figure 8, it can be concluded that the fuel cost of EVs is much lower than reference and hybrid vehicles. For example, the life-cycle fuel cost of Leaf is less than 7,000 yuan, approximately one seventh of the fuel cost of the reference vehicle. Besides, the maintenance cost of EVs is also lower than gasoline vehicles. Despite lower fuel and maintenance costs, the total costs of EVs are still relatively high mostly due to their high prices. For example, the total cost of Leaf is about 241,000 yuan, which is almost 45,000 yuan higher than the reference vehicles. With longer electric ranges, the total costs of EVs become higher. For instance, the total cost of EV 300km is about 313,000 yuan, approximately 117,000 yuan higher than reference vehicles.

Besides, compared with reference vehicles, the mild hybrid ones only increase the total cost for about 1,000 yuan, which implies that the saved fuel cost can offset most of the cost of the mild hybrid system. However, in terms of the heavy hybrid vehicles, the total cost is about 17,000 yuan higher than reference vehicles.

With different scenarios of gasoline price, the fuel cost of reference and hybrid vehicles will change accordingly. Higher gasoline prices bring extra cost advantages for the adoption of EVs. Under the high oil price scenario of 9.29 yuan/L, the total cost increase of Leaf compared with reference vehicles will decrease from about 45,000 yuan to 26,000 yuan. However, under the low oil price scenario of 5.14 yuan/L, the total cost increase of Leaf is expected to increase to about 52,000 yuan.

Based on the predictions for future's energy consumptions and prices, future's total costs of different vehicles are predicted. Since the reference oil price scenario is the most probable prediction, the results are only considered under that scenario. The results are shown in Figure 9.

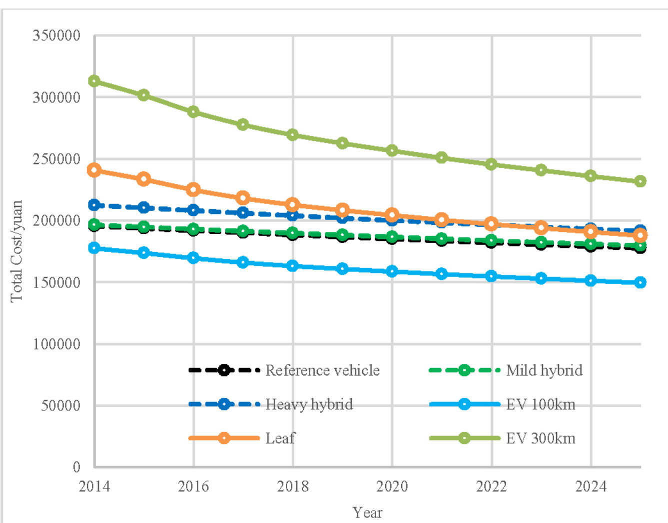

Figure 9. Total cost predictions for different vehicle kinds

From Figure 9, the total cost for reference and hybrid vehicles is slowly decreasing because of the decreasing annual distance and the improving fuel efficiency. At the meantime, the total cost of EVs is decreasing even more rapidly, mainly attributed to the rapid decline of the battery cost.

As for EVs with different ranges, the total cost for EV 100km ranks the least among all the vehicle kinds and its cost advantage is expected to maintain in the future. As discussed above, in terms of the total cost, Leaf is not competitive enough with other kinds of vehicles currently. However, its total cost is expected to decline in the next ten years. According to our predictions, the total cost of Leaf will be 19,000 yuan higher than reference vehicles in 2020 and will be only 10,000 yuan higher in 2025. The total cost of EV 300km is also decreasing rapidly in the next ten years, although it will still be the vehicle kind of the highest total cost. It is predicted that short and medium-range EVs are expected be cost-competitive with reference and hybrid vehicles after 2020, while long-range vehicles lack cost-competitiveness in the next ten years.

3.3. Cost-Effectiveness Analysis

By considering both the GHG emissions reduction (shown in Figure 10)and total cost increase (shown in Figure 11) compared with reference vehicles, the cost effectiveness of different vehicle kinds can be figured out, as shown in Figure 12. In this section, for similar reasons discussed in Section 3.2, only the reference oil price scenario is discussed.

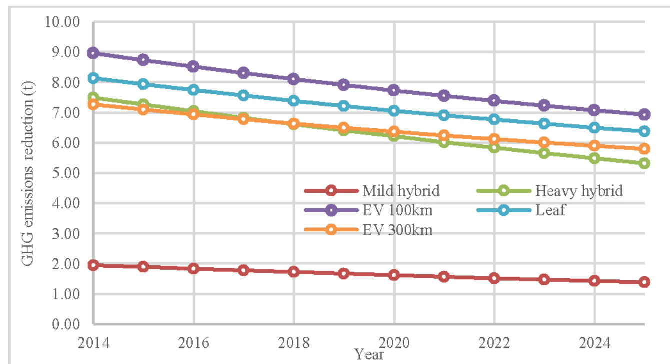

Figure 10. GHG emission reduction compared with reference vehicles

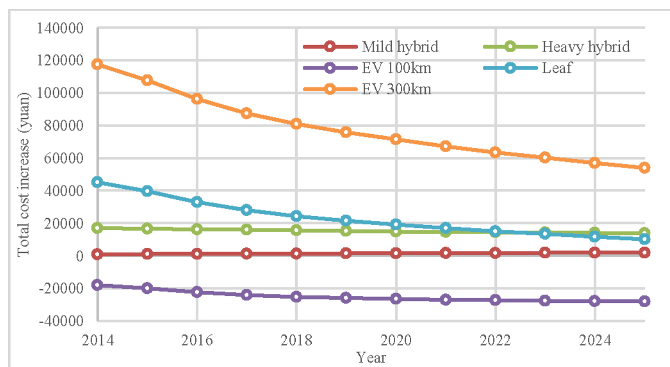

Figure 11. Total cost increase compared with reference vehicles

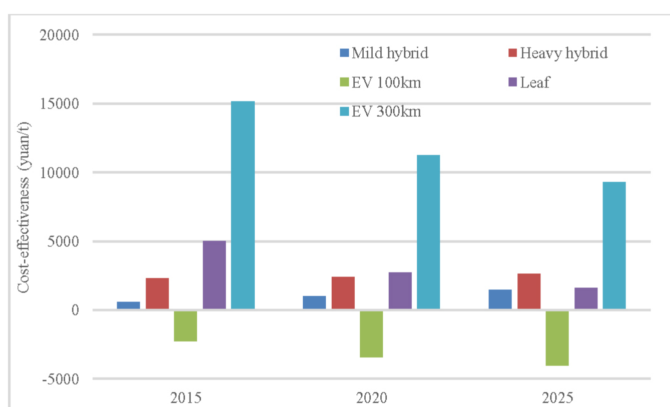

Figure 12. Cost-effectiveness of reducing GHG emissions

From Figure 12, it can be concluded that 100km EV is the most cost-effective vehicle kind in 2015 and is expected to expand its leading in the next ten years. However, since its relatively short electric mileage, it shows disadvantages in meeting customers' mileage demand and is less likely to be mass commercialized.

Currently, Leaf is less cost-effective compared with mild hybrid and heavy hybrid vehicles. However, along with an improved power grid as well as the rapid decrease of the vehicle cost, the cost-effectiveness of Leaf is expected to experience a rapid improvement in the next ten years. In 2025, it is predicted that the cost-effectiveness of Leaf will become close to mild hybrid vehicles while better than heavy hybrid ones.

EV 300km possesses the least cost-effectiveness in the current situation because of its higher GHG emissions as well as cost. From Figure 12, it is concluded that the cost-effectiveness of EV 300km will also experience a rapid decline in next ten years but will still be the least cost-effective in 2025. Due to the poor cost-effectiveness of EV 300km, it can be concluded that the electric ranges of EVs have great influence on the vehicle's cost-effectiveness and should be designed scientifically.

As for hybrid vehicles, the cost-effectiveness of mild hybrid vehicles is predicted to become worse in the next five years. This phenomenon is mainly caused by two factors: the decrease of annual distance and the decrease of fuel consumption of reference vehicles. Both the two factors will lead to less GHG emissions reduction and less saved cost, which will result in worse cost-effectiveness. However, even with a worsening cost-effectiveness, mild hybrid vehicles are still a relatively cost-effective technology pathway in reducing GHG emissions in the next ten years. On the other hand, the cost-effectiveness of heavy hybrid vehicles is predicted to remain relatively stable in the next ten years and fall behind Leaf after 2020.

4. Policy Implications

This study concluded that EVs have the potential of reducing GHG emissions with a clean power grid. The coal power shares and efficiencies of the power grid have significant impacts on the GHG emissions of EVs. Therefore, in order to reduce national GHG emissions, the Chinese government is recommended not only to focus on the popularization of EVs but also to pay attention to the improvement of the power grid.

The total cost of EVs without subsidies is relatively high compared with conventional vehicles at present. It is expected to decrease in the future due to the decrease of battery costs. Therefore, in the process of EV's deployment, it is recommended that the government support the industrialization of the domestic battery in order to promote the decrease of the battery cost.

EVs don't possess much advantage on cost-effectiveness currently but are expected to have better cost-effectiveness in the future. For instance, in 2025, under a moderate hypothesis of gasoline price, medium-range EVs are predicted to have similar cost-effectiveness with mild hybrid vehicles. Therefore, the government's effort in promoting EVs can be justified. Besides, as long-range EVs have relatively poor cost-effectiveness, the government is suggested to promote EVs with short and medium range capacities.

As for hybrid vehicles, mild and heavy hybrid vehicles are relatively cost-effective technology pathways in reducing GHG emissions currently. It is suggested that the government consider the promotion of mild and heavy hybrid system in order to reduce gasoline consumption and GHG emissions in the short term.

5. Conclusions

In this study, we compared the GHG emissions of existing vehicle models in the market. Afterwards, a cost model is established to compare the total costs of different vehicle kinds. Finally, we adopted a cost-effectiveness analysis for different kinds of vehicles.

As for GHG emissions, the GHG emission intensity of EVs is dependent on the coal power shares and efficiencies. In the current situation, medium-range EVs emit 37.1% less GHG emissions compared with reference vehicles. It is predicted that with lower coal power shares and higher coal power efficiencies, the GHG emissions intensity of EVs will even much lower in the future.

As for the cost analysis, the price of EVs is much higher than reference vehicles currently, mainly due to the high cost of the battery system. However, lower cost in the operating stage will partly offset the price gap between EVs and reference vehicles. Under the moderate gasoline price scenario, it is concluded that the total costs of EVs are higher than reference vehicles currently but will decrease dramatically in the future.

In terms of cost-effectiveness, EVs don't have an obvious advantage over other fuel-efficient vehicles currently. However, due to an improved power grid and rapid decrease of the total cost, the cost-effectiveness of EVs will be greatly improved in the next few years. In 2025, it is predicted that medium-range EVs will have similar cost-effectiveness with mild hybrid vehicles, while much better than heavy hybrid ones. Besides, from this study, it is shown that higher range capacities of EVs lead to worse cost-effectiveness of the vehicles.

Further studies are required on different scenario analysis and more detailed data assumptions. For example, in this study, the use intensity of EVs and gasoline vehicles are assumed to be the same. However, in reality, the use intensity of EV may be different from gasoline vehicles and the drive pattern may also be different. Due to a lack of credible data in China, we didn't take this into consideration in this study but further studies on this topic are required.

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Definitions/Abbreviations

EV - Electric vehicle

GHG - Greenhouse gas

NEDC - New European driving cycle

PPV - Private passenger vehicle

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