Research on carbon emission reduction calculation and user subsidy mechanism of electric vehicles

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Abstract. Under the goal of carbon neutralization and carbon peak, China's electric vehicle industry will usher in a high-speed development stage. Electric vehicles can achieve carbon emission reduction from two aspects of electric energy substitution and clean energy substitution. In this paper, the carbon emission reduction benchmark of electric vehicles is determined, and the Bass model is used to predict the number of electric vehicles. On this basis, the carbon dioxide emissions reduced when electric vehicles replace fuel vehicles to meet the travel requirements and the carbon dioxide emissions of electric vehicles with different proportions of renewable energy generation are analyzed. Finally, the benefits of carbon emission reduction under decentralized and centralized modes are studied to determine the subsidy range of electric vehicle users.

1. Introduction

Urban transportation is the main source of greenhouse gas emissions after the electric heating production activities. In order to achieve greenhouse gas emission reduction, guided by the concept of "low carbon economy", electric vehicles with zero emissions in the driving process are the primary choice. Under the control of aggregation operators, scattered electric vehicle resources can participate in market transactions, give priority to the consumption of new energy power generation, reduce the loss of wind power and photovoltaic power generation, and further achieve energy conservation and emission reduction.

Recently, scholars have done a lot of research on the prediction of electric vehicle ownership and the calculation of electric vehicle carbon emission reduction. Literature [1] summarizes and compares the existing prediction methods of electric vehicle ownership, namely time series method, elastic coefficient method and Bass model, and expounds the shortcomings of these methods. In literature [2], Bass model is used to predict the number of electric vehicles in 2020 under the condition of benchmark oil price and high oil price. It is believed that the rise of gasoline price will promote the promotion of electric vehicles. In reference [3], the bass diffusion model and grey Lotka Volterra model are used to study the historical data, and the short-term ownership of electric vehicles is predicted based on the model after parameter fitting. In reference [4], taking gas electric hybrid vehicle as the research object, the carbon emission reduction of gas electric hybrid vehicle was calculated by CDM methodology, and the influencing factors of carbon emission reduction of gas electric hybrid vehicle were explored. In reference [5], the "carbon pinch" method is used to predict the future power supply structure in China. According to the prediction results, the greenhouse gas
emissions and energy consumption of the two kinds of vehicles are calculated.

It is beneficial to improve the green energy consumption level and operation efficiency of power grid to encourage electric vehicle users to participate in the aggregation response to power grid demand by giving subsidies and make full use of the regulation ability and value of electric vehicle load. This paper analyzes the carbon emission reduction process of electric vehicles and the carbon emission coefficients of different energy sources, and forecasts the number of electric vehicles by using Bass model. On this basis, it analyzes the carbon dioxide emissions reduced when electric vehicles replace fuel vehicles to meet the travel requirements, and the carbon dioxide emissions of electric vehicles with different ratios of renewable energy generation. According to the benefits of new energy consumption and carbon emission reduction after EV participating in aggregation, the user subsidy range is determined and some mechanism suggestions are put forward.

2. Determination of carbon emission reduction benchmark for electric vehicles

2.1. Formation process of electric vehicle carbon emission reduction
Fuel vehicles will emit CO, CO2, NOx, SO2, inhalable particulate matter and other pollutants in the process of driving. With more and more fuel vehicles, air pollution and greenhouse effect have become urgent problems to be solved. At present, domestic power generation mainly relies on fossil fuels. Nearly 75% of the electricity in the power grid is generated by burning coal. The main reason why electric vehicles can promote carbon emission reduction is that they can achieve zero emission in the process of driving. When electric vehicles participate in polymerization, they can absorb a certain proportion of renewable energy and improve the utilization rate of clean energy. Electric vehicles can achieve carbon emission reduction from two aspects of electric energy substitution and clean energy substitution.

2.2. Carbon emission coefficient of different energy sources
The carbon emission factors of different energy sources are different. According to “The guidelines for the compilation of greenhouse gas inventories at county (District) level in Guangdong Province” and “The general rules for the calculation of comprehensive energy consumption (GBT2589-2020)”, the reference of energy carbon emission coefficient can be obtained as shown in Table 1:

| Energy name | Mean low calorific value (KJ/kg) | Conversion coefficient of standard coal (kgce/kg) | Carbon content per unit calorific value (Tons of carbon/TJ) | Carbon oxidation rate | Carbon dioxide emission factor (kg-CO2/kg) |
|-------------|---------------------------------|-----------------------------------------------|----------------------------------------------------------|----------------------|------------------------------------------|
| raw coal    | 20908                           | 0.7143                                        | 26.37                                                    | 0.94                 | 1.9003                                   |
| coke        | 28435                           | 0.9714                                        | 29.5                                                     | 0.93                 | 2.8604                                   |
| gasoline    | 43070                           | 1.4714                                        | 18.9                                                     | 0.98                 | 2.9251                                   |
| diesel oil  | 42652                           | 1.4571                                        | 20.2                                                     | 0.98                 | 3.0959                                   |

In the "carbon footprint" of daily life, according to statistics, every kilowatt hour of electricity saved is equivalent to 0.997 kg of CO2 emission reduced; Saving one liter of fuel will reduce the emission of 0.785 kg CO2.

3. Calculation of carbon emission reduction under the new situation

3.1. Prediction of electric vehicle ownership
By the end of 2020, the total number of electric vehicles in China has reached 4.92 million, accounting for 1.75% of the total number of vehicles. Since 2018 to 2020, the increment of electric vehicles has exceeded 1 million for three consecutive years, showing a sustained high-speed growth trend. The
number of electric vehicles in recent 10 years is shown in Table 2. According to the growth trend of the number of electric vehicles in China from 2011 to 2020, this paper uses cubic function fitting and Bass model to predict the number of electric vehicles in China.

| particular year | 2011 | 2012 | 2013 | 2014 | 2015 |
|-----------------|------|------|------|------|------|
| Electric vehicle ownership (10000 units) | 6    | 9    | 15   | 22   | 42   |
| Electric vehicle ownership (10000 units) | 2016 | 2017 | 2018 | 2019 | 2020 |
| Electric vehicle ownership (10000 units) | 91   | 153  | 261  | 381  | 492  |

Using MATLAB to fit the data from 2011 to 2020, the cubic function is obtained as shown in formula (1):

\[
N(t) = 0.37782t^3 + 2.9895t^2 - 20.282t + 29.367
\]

Table 3. forecast results of electric vehicle ownership in 2021-2025 (cubic function fitting)

| particular year | 2021 | 2022 | 2023 | 2024 | 2025 |
|-----------------|------|------|------|------|------|
| Electric vehicle ownership (10000 units) | 671  | 869  | 1101 | 1368 | 1672 |

Bass model is a nonparametric conditional likelihood model, which uses three input variables, namely maximum market potential, innovation coefficient (external influence coefficient) and imitation coefficient (internal influence coefficient) to predict the annual number of consumers of electric vehicles.

\[
n(t) = \frac{dN(t)}{dt} = p[m - N(t)] + q \frac{N(t)}{m} [m - N(t)]
\]

\[
N(t) = m \frac{1 - e^{-(p+q)t}}{1 + \left(\frac{t}{p}\right)e^{-(p+q)t}}
\]

\[
n(t) = m \frac{p(p + q)^2 e^{-(p+q)t}}{[p + qe^{-(p+q)t}]^2}
\]

Where N(t) is the cumulative adopters at time t, n(t) is the number of adopters at time t, and p is the external influence coefficient; q is the internal influence coefficient; m is the total number of final adopters, i.e. market potential. Combined with the above formula and the existing historical data, the nonlinear least square method is used to calculate by SPSS statistical software. When the iteration reaches 16 times, the model stops, at this time, m = 688, p = 0.001, q = 0.712. The electric vehicle ownership from 2021 to 2025 can be calculated by bringing these three parameters into formula (3). The prediction results are shown in Table 4:

Table 4. forecast results of electric vehicle ownership in 2021-2025 (Bass model)

| particular year | 2021 | 2022 | 2023 | 2024 | 2025 |
|-----------------|------|------|------|------|------|
| Electric vehicle ownership (10000 units) | 605  | 645  | 666  | 677  | 683  |

3.2. Carbon emission reduction calculation

At present, consumers have two choices when buying cars: traditional fuel vehicles and electric vehicles. Some consumers choose to buy electric vehicles because of their own environmental protection concept and requirements for vehicle performance; Some consumers who originally want to buy fuel vehicles choose to buy electric vehicles because of price subsidies, charging facilities construction, policies and other factors. When users use electric vehicles instead of fuel vehicles to meet the travel requirements, carbon dioxide emissions are reduced.
\[DE_{CO_2} = [\alpha M + (1 - \alpha)\beta M] \times S \times OC_{\text{hundred}} \times \frac{\zeta}{2} \] 
\[n(y) = \alpha M + (1 - \alpha)\beta M \] 

Where \( DE_{CO_2} \) is the carbon emission reduction by using electric vehicles, \( M \) is the total number of car buyers in that year, \( \alpha \) represents the proportion of the total number of people who are willing to buy electric vehicles before they are affected by external factors, \( 1 - \alpha \) represents the proportion of the total number of people who are willing to buy fuel vehicles before they are affected by external factors, \( \beta \) refers to the proportion of consumers who originally want to buy fuel vehicles and switch to electric vehicles due to external influence, \( S \) is the mileage of the vehicle from the beginning of use to the end of life, \( OC_{\text{hundred}} \) is the fuel consumption per 100 km, \( \zeta \) is the carbon dioxide emission reduction per liter of fuel saved, \( n(y) \) is the number of new electric vehicles in \( y \) year. According to the "energy saving and new energy vehicle industry development plan" issued by the State Council, the average fuel consumption of new passenger cars in China will be reduced to 5 liters per 100 km by 2020; There is no limit on the service life of small and micro non operating passenger vehicles, and the reference maximum mileage of scrapped vehicles is 600000 km. For the convenience of calculation, \( OC_{\text{hundred}} = 5, S = 6000, \zeta = 0.785 \), According to the forecast results of electric vehicle ownership in 2021 and the number of electric vehicles in 2020, the number of new electric vehicles in 2021 is: \( n(2021) = 1130000 \), so the carbon dioxide emission of electric vehicles put into operation in 2021 will be reduced by 13305750 tons in the whole life cycle from use to scrap.

According to the research, the power consumption of 100 km pure electric vehicles is between 13kwh and 18kwh, and the carbon emission of the power plant in the process of producing electric vehicle charging is as follows:

\[EE_{CO_2} = (1 - \lambda) \times \gamma \times OE_{\text{hundred}} \times S \times n(y) \] 

Where \( EE_{CO_2} \) is the carbon emission in the process of producing the electricity required for charging electric vehicles, \( OE_{\text{hundred}} \) is the power consumption per 100 km, \( \lambda \) is the proportion of new energy power generation in the total power, and \( \gamma \) is the carbon dioxide emission per 1kW / h power consumption in full proportion coal-fired power generation. For the convenience of calculation, the average power consumption of 100 km of pure electric vehicles put into operation in 2021 is 15 kW / h. In the case of different proportion of new energy power generation, the carbon emissions in the process of electric vehicle charging are different, as shown in Table 5:

| Proportion of new energy | 0       | 25%     | 50%     | 75%     |
|-------------------------|---------|---------|---------|---------|
| CO2 emission (ton)      | 10139490| 7604617.5| 5069745 | 2534872.5|

Under the background of coal-fired power supply structure in China, compared with traditional fuel vehicles, electric vehicles have weak advantages in energy saving and emission reduction from the perspective of the whole life cycle. When the proportion of renewable energy generation in the total power generation increases to a certain extent, electric vehicles have obvious advantages in energy saving and emission reduction. New energy has no pollutant emission in the process of power generation, so if the power consumption of electric vehicles in the charging process comes from a large proportion of renewable energy, the carbon dioxide emission can be reduced from the two stages of charging source and use process of electric vehicles.
4. Benefits of carbon emission reduction under different modes

4.1. Decentralized
In the decentralized mode, electric vehicle users arrange their charging time according to their own travel demand, power state and time flexibility, but due to the influence of electric vehicle users' living habits, the charging time of electric vehicle will coincide with the peak load period of power system. In this mode, the accurate information of power demand elasticity in different time periods is difficult to obtain, and the connection between electric vehicle users and the power grid is in a split state. Electric vehicle users cannot obtain the power regulation information of the power grid to respond. At this time, most of the electric vehicle charging comes from household electricity, which accounts for 75% of the thermal power generation, Electric vehicles can not achieve the purpose of promoting new energy consumption and achieving clean energy substitution.

4.2. Centralized
Electric vehicle charging load aggregators can obtain the power control authority of electric vehicles by signing contracts with electric vehicle users, and adjust the power or start stop control of some electric vehicles according to the tasks issued by the dispatching center, so as to reduce the randomness and uncertainty of electric vehicle users' autonomous response. Under the centralized control mode of electric vehicles, aggregators can sign low price electricity contracts with renewable energy power producers in advance by integrating the demand of electric vehicles users to participate in the polymerization. It makes electric vehicle users give priority to photovoltaic, wind and other renewable energy power generation when charging, improves the proportion of renewable energy consumption, and reduces part of the carbon dioxide emissions in the process of thermal power generation.

In the process of aggregating electric vehicle users to participate in electricity trading, aggregators can obtain benefits by signing low price electricity purchase contracts with renewable energy power producers:

$$I_i = \theta \sum_{t=1}^{T} \sum_{i=1}^{N} q_{i,t} (M_t - M_{\text{renewable}})$$

Among them, $I_i$ is the income obtained by signing the low price power purchase contract, $\theta$ is the proportion of all electric vehicle users participating in the demand response, which can also be approximately taken as the proportion of all electric vehicle users participating in the demand response in the power consumption process, $N$ is the number of all electric vehicle users, $q_{i,t}$ is the power consumption of the i-th user in t period, $M_t$ is the unit price of the electricity market, and $M_{\text{renewable}}$ is the unit price of the low price electricity purchase contract signed between the electric vehicle load aggregator and the renewable energy generator.

The process of EV load aggregators aggregating EV users to participate in market trading to increase the proportion of new energy consumption is also a process of reducing carbon emissions. When EV load aggregators reach the standard of participating in carbon trading, they can get a return by selling carbon dioxide emission rights to enterprises with emission reduction obligations. National carbon emission trading includes bidding, agreement transfer, paid bidding and other ways approved by the Ministry of ecological environment; The minimum unit of change for trading declaration of national carbon emission trading is 1 ton of carbon dioxide equivalent. Based on the carbon price data released by China's carbon trading website, Guo Lei[6] calculated the average carbon price of seven carbon trading markets. Among them, the price of Beijing carbon trading market is the highest among the seven carbon trading markets. The average trading prices of Beijing and Shenzhen carbon trading markets are much higher than other pilot markets, which are 56.1 yuan / ton and 34.1 yuan / ton respectively. The average trading prices of carbon trading markets in Guangdong, Tianjin, Shanghai and Hubei are 10-30 yuan / ton; The average price in Chongqing is the lowest.
\[ I_2 = 0.75 \gamma \cdot \vartheta \sum_{t=1}^{T} \sum_{i=1}^{N} q_{i,t} \times \frac{p_t}{1000} \]  

(9)

Among them, \( I_2 \) is the income from the sale of carbon dioxide emission rights to enterprises with emission reduction obligations. When the electric vehicles are not involved in the polymerization, the electricity consumption is grid power generation (thermal power generation accounts for 75%). \( \gamma \) is the carbon dioxide emission per 1kW / h of electricity consumed in full proportion coal-fired power generation (unit: kg), and \( p_t \) is the transaction price at time \( t \).

### 4.3. Subsidy range for electric vehicle users

When electric vehicle load aggregators and renewable energy generators sign low price power purchase contract, the power purchase price will fluctuate, \( I_1 \in [I_1^{\text{min}}, I_1^{\text{max}}] \); The price of carbon transaction in different periods also changes due to the change of market supply and demand, so the subsidy provided by aggregators to the responding EV users will also change in different periods, \( I_2 \in [I_2^{\text{min}}, I_2^{\text{max}}] \).

\[
B_{\text{subsidy}} \in \left[ \varphi \cdot \left(\frac{I_1^{\text{min}} + I_1^{\text{max}}}{k}\right), \varphi \cdot \left(\frac{I_1^{\text{max}} + I_2^{\text{max}}}{k}\right) \right]
\]

(10)

Among them, \( B_{\text{subsidy}} \) is the subsidy given by EV load aggregators to EV users, \( \varphi \) is the proportion of subsidies allocated to electric vehicle users from the proceeds obtained from activities such as signing low price power purchase contracts and selling carbon dioxide emission rights to enterprises with emission reduction obligations, and \( K \) is the number of electric vehicle users participating in the aggregation.

### 5. Conclusion

Through the above prediction of electric vehicle ownership and carbon emission calculation, we can see that electric vehicles are the primary choice for energy conservation and emission reduction. If the power consumption of electric vehicles is reduced and the proportion of new energy power utilization is increased, the proportion of new energy vehicle emission reduction will be further increased. In order to improve the carbon emission reduction, this paper puts forward the following suggestions:

1. Electric vehicle manufacturers can collect the total mileage and driving energy consumption of users through the vehicle engine system, so as to calculate the "carbon emission reduction" and participate in the transaction after reaching the carbon trading access standard, and return the income to users in a certain proportion, which is conducive to the expansion of publicity of electric vehicle manufacturers, increase the willingness of consumers to buy electric vehicles, and improve the ownership of electric vehicles.

2. At present, the carbon trading market is still in its infancy, and the price of carbon trading fluctuates greatly. The quota allocation, business model, carbon emission reduction statistics and other mechanisms for electric vehicle load aggregators to participate in carbon trading need to be further explored.

3. The commercial activities of the electric vehicle load aggregators depend on the support of government policies. Properly reducing the deviation assessment intensity of EV load aggregators participating in the power market is conducive to increasing the income of aggregators, so as to improve the compensation allocated to EV users and encourage EV users to participate in the aggregation.

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