Analysis of Emission Reduction Benefits of Electric Vehicles

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Abstract. The increasing environmental and energy issues have made the promotion and use of electric vehicles an important measure to respond to energy conservation and emission reduction. This paper considers two different types of electric vehicle emission reduction measures: the emission reduction achieved by electric vehicles instead of fuel locomotives and the total reduction of V2G(Vehicle-to-Grid) peak-shaving. On this basis, this paper uses the typical monetary value method of carbon emission to convert carbon emission reduction from weight to monetary level, which is more suitable for the assessment of energy transformation and benefit comparison. Finally, we verify the emission reduction potential of electric vehicles when the grid factor adopts the BM algorithm.

1. Introduction

Energy and environmental issues are hot issues in recent years. Various human activities are inseparable from energy and environmental support, but uncontrolled energy activities will increase a series of environmental negative effects and exacerbate the energy crisis. At present, vehicle energy accounts for a higher proportion of urban energy consumption in first-tier cities, while car ownership and vehicle energy consumption in second- and third-tier cities are also rising rapidly[1].

The literature [2] compares the energy efficiency and CO2 emissions of traditional vehicles and electric vehicles based on the predicted development level of electric vehicles in 2020, taking into account the electric vehicle's own travel characteristics (billion fuel consumption, travel mileage, etc.) and the benefits of load fluctuations, but do not make a specific distinction between the characteristics of different types of electric vehicles. The literature [3] calculates the electric vehicles from the perspective of full-cycle energy efficiency. It is concluded that If the proportion of coal power is constant, electric vehicles cannot achieve emission reduction. The literature [4-5] calculated the carbon emissions of urban traffic in Beijing and Shanghai through the characteristics of residents' travel and vehicle characteristics. The literature [6] pointed out that most China's electric energy comes from coal-fired power plants, and whether the access of a large number of electric vehicles can truly achieve the reduction of carbon emissions requires further research.

In the context of the above research, this paper will consider the electric vehicle's own characteristics, consider the different types of electric vehicles' mileage, the number of travel miles and the electric vehicle clusters participating in the grid to stabilize the load fluctuations in order to evaluate the emission reduction benefits of electric vehicles. At the same time, this paper will use the carbon emission monetary value method to convert carbon emission reductions to currency scale[7], which can be used as one of the indicators to evaluate social economic benefits, and can more accurately evaluate the low-carbon economic benefits of urban rail transit. Energy saving and emission reduction effects. It can provide reference for the formulation and implementation of national energy planning.
and carbon emission targets, it also can provide pre-assessment methods and theoretical basis for the formulation and implementation of low-carbon transportation policies.

2. Status of carbon emission reduction benefit assessment methods

The current carbon emission reduction stays on the increase or decrease of the carbon emission quantity. In many cases, the weight magnitude of carbon emission reduction and other benefit analysis (money level) belong to two levels, and it is impossible to make comparative judgment. Therefore, it is necessary to formulate reasonable carbon. The emission reduction benefit assessment method unifies the emission reduction level to the monetary level. Current mainstream calculation methods include: Social Cost of Carbon (SCC) and Marginal Abatement Cost (MAC).

2.1. MAC

Abatement Cost is the cost of reducing environmental negative behaviors such as pollution. Marginal Cost is an economic concept for measuring additional unit costs. Marginal abatement Cost (MAC) refers to an additional reduction in unit carbon dioxide. The economic cost of emissions, focusing on the implementation costs of technical emission reduction measures. The Marginal abatement Cost Cave (MACC) is usually used to define the emission reduction potential and abatement costs of different emission reduction technologies to support technological decisions [8]. The marginal abatement cost curve has often been used in the past to illustrate economic factors that mitigate climate change and to help make decisions in the context of climate policy. However, this method is very limited by the region. Different technical indicators in one province or even one city will lead to different calculation results. Therefore, this paper does not use MAC to calculate the social benefit cost of carbon emission reduction.

2.2. SCC

The US Environmental Protection Agency defines SCC as: the monetary value of a new year's carbon dioxide emissions caused by damage. Such damage includes "non-market" effects on the environment and human health. From a more precise definition, it is a discounted value of the consumption utility calculated as the current consumption per unit of additional emissions. The SCC is more inclined to estimate the environmental damage caused by the emitted carbon dioxide, and to assess the impact and loss of the united carbon dioxide on the social environment by establishing a corresponding model. The computational logic of these models is roughly the same. The climate and economy are integrated into a model framework, and the emissions are converted into atmospheric CO₂ concentrations and then converted into temperature changes. The temperature changes affect the normal growth of the economy. Damage caused by the economy. In the model, the future estimated damage is discounted to the contemporary year through the discount rate, which becomes the current value loss.

In this paper, the value of Chinese SCC calculated in literature [7] is 24$/tCO₂, which is equivalent to about 168rmb/tCO₂.

3. Electric vehicles participate in grid interaction

3.1. Different types of electric vehicles travel characteristics

According to the "2018 Beijing Traffic Development Annual Report"[9], the average travel mileage, travel time, and travel speed of various travel modes (traffic modes used in one trip) are shown in Table 1:

| Travel mode          | Average travel distance (Km) | Average travel time(min) | Average travel speed(Km/h) |
|----------------------|------------------------------|--------------------------|---------------------------|
|                      | Early peak                   | Late peak                | Early peak                | Late peak             |
| Bus steam (electric) | 10.9                         | 66.1                     | 67.2                      | 9.9                   | 9.7                   |
| taxi                 | 9.2                          | 41.4                     | 43                        | 11.7                  | 10.1                  |
| Car                  | 13.9                         | 46.5                     | 47.1                      | 16                    | 15.8                  |

Table 1. The average travel distance/travel consumption/formation speed of each mode.
3.2. Establishment of electric vehicle charging and discharging model

3.2.1. Domestic calculation method. This paper assumes that the electric vehicle maintains the same power during charging and discharging. In this paper, the charging and discharging behavior of electric vehicles is modeled according to the charging and discharging model of ordinary batteries:

The electric vehicle is charged at the time \( t \) at the same charging power as \( P_{c,i} \):

\[
SOC_i(t + \Delta t) = P_{c,i} \eta_{c,i} \Delta t / C_i + SOC_i(t)
\]

In the formula, \( SOC_i(t + \Delta t) \) is the state of charge of electric vehicle \( i \) at time \( t + \Delta t \), and \( SOC_i(t) \) is the state of charge of electric vehicle \( i \) at time \( t \), \( P_{c,i} \) is the charging power of the electric vehicle \( i \), \( C_i \) is the battery capacity of the electric vehicle \( i \), \( \eta_{c,i} \) is the charging efficiency of the electric vehicle \( i \), and \( \Delta t \) is the time interval.

3.2.2. Relationship between SOC of electric vehicle and travel distance. This paper assumes that the amount of electricity stored in the vehicle battery during the driving process of the electric vehicle is linearly negatively correlated with the distance traveled, so that the relationship between the SOC and the electric vehicle's driving distance after the last charging can be obtained at this time:

\[
SOC_i(t_{\text{start},j+1}) = (SOC_i(t_{\text{end},j}) - d / D) \times 100\%
\]

where \( SOC_i(t_{\text{end},j}) \) represents the SOC of the electric vehicle \( i \) leaving at the time \( j \) after the network is fully charged; \( SOC_i(t_{\text{start},j+1}) \) indicates the initial SOC of the electric car \( i \) in the \( j + 1 \) time point in-network; \( d \) represents the driving distance of electric car \( i \) between \( j \)th and \( j + 1 \)th time point; \( D \) represents the cruising range of the \( i \)th electric car.

3.2.3. The relationship between SOC and schedulable potential.

1). Only provide charging scheduling

The state of charge of such electric vehicles satisfies the following inequalities:

\[
SOC_i(t) < SOC_{i,\text{min}}
\]

In the formula, \( SOC_i(t) \) is the SOC of \( i \)-th-electric vehicle at time \( t \), and \( SOC_{i,\text{min}} \) is the discharge scheduling threshold of electric vehicle \( i \).

Because the battery continues to be too low or remains charged, it is a loss to the battery, which can affect the battery life.

2). Only provide discharge scheduling

\[
SOC_i(t) > SOC_{i,\text{max}}
\]

where \( SOC_{i,\text{max}} \) is the charging schedule threshold of electric vehicle \( i \).

The above equation shows that if the state of charge of the electric vehicle is greater than its charge scheduling threshold, then the electric vehicle at this time can only provide discharge scheduling.

3). Provide charging or discharging scheduling at the same time

\[
SOC_{i,\text{min}} \leq SOC_i(t) \leq SOC_{i,\text{max}}
\]

The above formula shows that if the state of charge of electric vehicle \( i \) is between the discharge threshold and the charging threshold, the electric vehicle at this time has discharge potential and charging potential, and can provide two-way scheduling.

3.3. Electric vehicle peak clipping and valley filling determination indicators

\( f_1 \) indicator measures the frequency of electric vehicle state switching frequently:

\[
f_1 = \begin{cases} 
0, & t_i \leq t_{\text{limit}} \\
\frac{t_{\text{dura}}}{t_{\text{dura}}}, & t_i > t_{\text{limit}} 
\end{cases}
\]

where \( t_{\text{dura}} \) represents the time between the change of one state and the other state, and \( t_{\text{dura}} \) represents the maximum time interval between the control of the electric vehicle from one state to another. \( t_i \) indicates the time interval between the two states of the \( i \)-th electric vehicle, which is easy to get \( f_1 \in [0,1] \). The larger the \( f_1 \), the higher the priority should be.
$f_2$ represents the controllable coefficient of the electric vehicle:

$$f_2 = \begin{cases} 
0, & \frac{t_{\text{off}} - t_{\text{on}}}{T_{\text{MIN}}} \leq 1 \\
\frac{t_{\text{off}} - t_{\text{on}}}{T_{\text{MIN}}} = \frac{T_{\text{SET}}}{T_{\text{MIN}}} - 1, & \frac{t_{\text{off}} - t_{\text{on}}}{T_{\text{MIN}}} > 1
\end{cases} \quad (7)$$

$$T_{\text{MIN}}^i = \frac{(S_{\text{OC}}^i - S_{\text{OC}}^i)}{\eta_i P_{\text{N}}^i} C_B^i \quad (8)$$

In the formula, $t_{\text{on}}^i$ and $t_{\text{off}}^i$ indicate the time when the $i$-th car is connected to the grid and the preset stop charging time of the vehicle owner. $T_{\text{MIN}}^i$ indicates the minimum charging time requirement for an electric vehicle to enter the grid charging.

$f_3$ indicates the current state of charge of an electric vehicle:

$$f_3 = \begin{cases} 
S_{\text{OC}}(t), & P_{\text{reg}}(t) < 0 \\
\frac{1 - S_{\text{OC}}(t)}{1 - S_{\text{OC}}^\text{max}}, & P_{\text{reg}}(t) > 0
\end{cases} \quad (9)$$

$S_{\text{OC}}^\text{max}$ and $S_{\text{OC}}^\text{min}$ are the maximum and minimum values of the state of charge of the electric vehicle at the current time.

$f_4$ represents the economic indicators of electric vehicle dispatch:

$$f_4 = \begin{cases} 
0, & P_{\text{car}}^i \geq P_{\text{marginal}} \\
P_{\text{marginal}} - P_{\text{car}}^i, & P_{\text{car}}^i < P_{\text{marginal}}
\end{cases} \quad (10)$$

$P_{\text{marginal}}$ represents the cost price required for the grid to issue additional units of electricity, and $P_{\text{car}}^i$ represents the price at which the $i$-th electric vehicle is reversely discharged to the grid.

In summary, the aggregation model for establishing an electric vehicle is as follows:

$$F = f_2 f_4 (w_1 f_1 + w_2 f_3) \quad (11)$$

We select the appropriate $w_1$ and $w_2$ as the weighting factors for the indicators $f_1$ and $f_3$. In different time periods and regions, the frequency of state switching and the proportion of SOC are not the same.

### 3.4. Electric vehicle cluster control method

**3.4.1. Scenario Settings.** Assuming that 100 electric vehicles participate in the dispatch, the index $f_1$ assumes that the charge-discharge switching frequency obeys a normal distribution with a mean of 0.5 and a variance of one; The index $f_2$ is calculated as follows: the final SOC set by the vehicle owner is full, assuming that the rated charging and discharging power of the electric vehicle is 3KW/h, and the battery capacity $C_B$ of the electric vehicle is 30KWH, the charging and discharging efficiency $\eta$ is 0.9, assuming that the $S_{\text{OC}}^\text{DN}$ of the battery when the electric vehicle is connected to the grid is randomly and evenly distributed between [0.2, 0.5]. According to the literature [10], we choose the time for starting the charging of the electric vehicle at 9:00, and the charging time at 17:30, totally 510 minutes (eight and a half hours), each 15 minutes is a regulation period, totally 34 time periods; We set $P_{\text{marginal}}$ 1.5 yuan/unit power. We assumed the dispatching price of 100 electric vehicles obeys a normal distribution with a mean value of 0.5 and a variance of 1.

**3.4.2. Analysis of the effect of electric vehicles participating in V2G emission reduction.** In this example, the share of centralized power grid regulation and peak clipping can be satisfied by the charging and discharging of electric vehicle V2G, that is, there is no need to increase the number of new standby generator sets to participate in power grid clipping. Beijing belongs to the North China regional power grid category. According to the reference[10] 2017 annual emission reduction project, China's regional power grid baseline emission factor results show that the carbon emission factor of the North China regional power grid is 0.968 tCO2/MWh when the marginal emission factor (OM) is used. When the marginal emission factor (BM) is used, the carbon emission factor of the North China regional power grid is 0.4078tCO2/MWh. Assuming that the grid regulation command requires generator set compensation, the total required power generation is
59572.5 kWh, and the carbon emissions under the two emission factors are: 57.67t and 27.27t, respectively.

![Electric vehicle peak shaving map.](image)

**Figure 1.** Electric vehicle peak shaving map.

### 4. Analysis of Emission Reduction Benefits of Electric Vehicles

According to the 2018 Beijing Traffic Development Annual Report data, by the end of 2017, the number of motor vehicles in Beijing was 5.90 million, of which 165,806 were owned by new energy vehicles. This part of the new energy bus replaced the traditional vehicle. China's new energy vehicles are mainly divided into pure electric and plug-in hybrids (the share of fuel cell vehicles and other energy vehicles is small). According to the official data released by the Traffic Management Bureau of the Ministry of Public Security, the number of new energy vehicles in the country as of the end of June 2017. There are 1.99 million vehicles, of which 1.62 million are pure electric vehicles, accounting for 81.4% of the total number of new energy vehicles. Pure electric vehicles account for a large proportion of new energy vehicles. Therefore, it is assumed that all electric vehicles are pure electric vehicles, namely there are 165,806 pure electric cars.

#### 4.1. Analysis of self-energy reduction benefits

In this paper, the pure electric bus adopts BYD6490SBEV pure electric multi-purpose passenger car parameters in the 313 catalog [11] of the Ministry of Industry and Information Technology: 500 under the driving range (Km, working condition method), and the power consumption per 100 km under working conditions (KWh/100km) is 17.9. The 2018 Beijing Traffic Development Annual Report shows that the mileage of bus operation in 2017 is 132.357 million kilometers. The pure electric private car adopts BYD7008BEVA2 pure electric car parameters. The specific parameters are shown in Table 2.

| multi-purpose passenger car of pure electric | Pure electric private car |
|---------------------------------------------|--------------------------|
| Driving range (Km, working condition method) | 500                      | 420                       |
| 100 km power consumption (KWh/100km)        | 17.9                     | 13.8                      |

#### 4.1.1. Private car

As an important tool in life, private cars are generally used for commuting between home and work. The results of the Beijing Transportation Development Research Center show that the annual mileage of private cars is 12,566 km/year, equivalent to approximately 34.4 km per day. According to the 2018 Beijing Traffic Development Annual Report data, by the end of 2017, The new energy vehicles of Beijing will be 165,806. So we suppose the rest are all electric private cars.

| Table 3. Mileage of private cars of Beijing in 2017. |
|-----------------------------------------------------|
| Survey sample number | Working day | Holiday |
|-----------------------|-------------|---------|
| Average daily mileage | 15000       | 50.16   | 51.63   |
| Average mileage       | 15000       | 11.46   | 11.92   |
4.1.2. Bus. According to the "Beijing 2018 Statistical Yearbook" data[12], in 2017, Beijing has 30,966 public transportation vehicles, including 25,424 public electric vehicles. In 2017, the operating mileage was 132.357 million kilometers.

4.1.3. Taxi. According to the “Implementation Opinions of the Ministry of Transport on Accelerating the Promotion and Application of New Energy Vehicles in the Transportation Industry”[13] (The proportion of new energy vehicles in new or updated urban buses, taxis and urban logistics distribution vehicles in the Beijing-Tianjin-Hebei region Not less than 35%) According to the Beijing 2018 Statistical Yearbook, the number of passenger cars rented by Beijing passengers in 2017 was 68,484, assuming that 35% of them were new energy taxis, or 23,969. In 2017, the operating mileage was 457.05 million kilometers.

According to the above statistics, the data of new energy vehicles of various models in Beijing in 2017 are shown in Table 4:

| Table 4. New Energy Vehicle Data of Beijing for 2017. |
|-----------------------------------------------------|
| **Total amount (vehicle)** | 30,966 | 68,484 | / |
| **New energy vehicle (vehicle)** | 25,624 | 23,969 | 11,6213 |

There are 249 working days and 105 public holidays in 365 days of 2017. According to the above data, the total mileage of working days and holidays of all pure electric vehicles of Beijing in 2017 can be calculated as shown in Table 5.

| Table 5. Mileage of different vehicle types in 2017. |
|-----------------------------------------------------|
| **Pure electric private car(km)** | 14,514,81776 | 90,293,0000 | 3,117,960000 |
| **Pure electric bus(km)** | 63,000,8105 | 42,064,0000 | 14,525,400000 |

This paper uses the parameters of the carbon content and carbon oxidation rate of the unit fuel required by the reference method in the “Guidelines for the Compilation of Provincial Greenhouse Gas Inventories”[14] and the data on gasoline and diesel in the Statistical System of Energy Consumption of Public Institutions[15]. As shown in Table 6:

| Table 6. Fuel data. |
|---------------------|
| **the carbon content of one unit calorific value (tons of carbon / TJ)** | **Oxidation rate** | **Calorific value** | **CO2 emissions (tCO2/kg)** |
|---------------------|----------------|------------------|-----------------|
| Gasoline 18.9       | 0.98           | 43070.48kJ/kg    | 0.002925        |
| Diesel 20.2         | 0.98           | 42652.32kJ/kg    | 0.003096        |

This paper selects 5.2L/100Km, 7L/100Km and 6L/100Km for private cars, buses and taxis according to the literature [16-17]. The density of diesel and gasoline was 748kg/m^3 and 830kg/m^3 according to the literature [18-19].

4.2. Analysis of total emission reduction benefits

According to the above calculation results and data, it can be concluded that in 2017, when Beijing electric vehicles participated in grid frequency regulation and their own carbon emission reduction, the emission reduction effects are shown in Table 7:
Table 7. Emission reduction effects of electric vehicles

| Vehicle type | EF(OM)tCO2 | EF(BM)tCO2 | OM difference(tCO2) | BM difference(tCO2) |
|--------------|------------|------------|---------------------|---------------------|
| Private car  | 193894.7416 | 91699.3928 | -28753.5            | 73441.87            |
| Bus          | 84159.0027  | 39801.6440 | -12480.3            | 31877.06            |
| Taxi         | 156452.487  | 73991.6823 | 5960.879572        | 88421.68            |

Table 8. Monetary value of carbon emission reduction(¥).

| Vehicle type | BM difference |
|--------------|----------------|
| Private car  | 12338234.9     |
| Bus          | 14854842.9     |
| Taxi         | 35672791.9     |

Table 7 shows the carbon emission reduction benefit of the replacement of traditional fuel locomotives by new energy vehicles in Beijing in 2017. The OM difference (tCO2) indicates the emission reduction effect of electric vehicles when the grid emission factor is 0.968 tCO2/MWh. The BM difference (tCO2) represents the emission reduction effect of the electric vehicle replacement when the grid emission factor is 0.4578 tCO2/MWh. It can be seen that the calculation of the grid emission factor is different, and the value of the grid will affect the specific emission reduction effect of electric vehicle electric energy replacement. In response to the problem of China's electric vehicle access to the power grid, which is demonstrated in the literature [6], it is still under further study due to the thermal power ratio. On this basis, if we consider the participation of electric vehicles in the third quarter to reduce the effect of generators participating in the shifting peak-to-valley reduction, there will be some changes (due to the specific scheduling command requirements, this article will not do a specific example analysis). The values after converting the carbon emission reduction into the currency dimension are shown in Table 8. It can be seen that the electric vehicle has certain emission reduction benefits when the BM calculation method is adopted for the carbon emission factor of the power grid.

5. Conclusion
This paper divides the emission reduction benefit of electric vehicles into the sum of the benefits of electric energy replacement and the benefits of electric vehicles participating in power grid regulation to reduce the operation of generator sets. In the process of V2G, consider the demand of the electric vehicle cluster in response to the power grid peak-filling command, reducing the output of power generation, and we calculate the emission reduction benefit from the unit's power generation energy consumption. Finally, the total emission reduction benefit is converted into a currency dimension by monetary value method for comparison with various other strategies. It is concluded that the emission reduction effect of electric vehicles under the current grid carbon emission factor in China is still not obvious, and reducing the proportion of thermal power generation is still an arduous task.

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