A Calculation Model for Greenhouse Gas Emission Impacts of Electric Vehicle Carsharing

Liang Hu, Ming-quan Wang and De-yang Kong

Abstract To deal with global warming and maintain the harmonious relationship between people and the nature, low-carbon city and transportation have become the important strategies of sustainable development. Carsharing is a new means of transportation in China, and some research has indicated that it holds considerable benefits to both society and environment. In recent years, electric vehicle (EV) has become the trend of automotive industry and some EV carsharing programs have been launched; therefore, it is necessary to study their greenhouse gas (GHG) emission impacts on cities. By comparing traditional carsharing with EV carsharing, the authors analyze the households' travel behaviors before and after participating in EV carsharing, which are described by 12 travel behavior parameters. Adding three energy consumption parameters and three emission parameters, the authors propose a calculation model for the GHG emission impacts of EV carsharing. The impacts on low-carbon cities and transportation can be assessed based on this model after acquiring specific data of those parameters by conducting questionnaire surveys, recording with instruments, or referring to research papers.

Keywords EV carsharing · Low-carbon · Greenhouse gas (GHG) emissions · Calculation model

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1 Introduction

With the development of Chinese economy and the increase in disposable income per capita, a rising number of Chinese households can afford a car. Chinese car ownership was only about 9.7 million in 2002, but this figure had grown to about 88.4 million by 2012 (National Bureau of Statistics of China 2013), a 24.7 % annual increasing rate on average. However, the popularity of private cars and the increasing number of vehicle kilometers traveled (VKT) have intensified the greenhouse gas (GHG) emissions. According to some research, the amount of CO_2 emitted by the transportation area in China represented around 8 % of all CO_2 emissions nationwide (Wu 2007), and the petroleum consumption of transportation accounted for 45.6 % of total consumption in China in 2011 (National Bureau of Statistics of China 2013).

Carsharing originates in Switzerland and Germany. It is an innovative means of transportation between private cars and public transportation. The members should make reservations by telephone or the Internet before using the cars, and they pay a membership fee in some combination with per-hour and per-kilometer charges rather than the costs of private vehicle ownership. By the July of 2012, the United States (USA) had 26 carsharing programs, 806,332 members, and 12,643 vehicles (Carsharing 2014). However, carsharing is still young in China and the first carsharing company was registered in 2010 (Introduction to Edoauto carsharing 2014).

In recent years, electric vehicles (EVs) are more widely used in carsharing service due to their low operation costs and emissions. 'Autolib,' which is the largest EV carsharing program in the world at present, was launched in December 2011 in Paris. This program plans to offer 3,000 shared EVs and to establish charging pillars by the road (2014). China has also initiated several EV carsharing programs such as 'EV Beijing' in Beijing, 'EV CARD' in Shanghai, and 'Weigongjiao' in Hangzhou.

Research shows that carsharing may offer significant social and environmental benefits. Cervero and Tsai studied a carsharing program in Los Angeles called 'City CarShare' (Cervero et al. 2007; Cervero and Tsai 2004), and the results indicated that the members had reduced their VKT after joining carsharing. Martin and Shaheen (2011) studied the GHG emission impacts of traditional carsharing in North America. They conducted an online questionnaire survey among the members in 11 carsharing programs and acquired 6,281 effective samples. The results showed that every carsharing household can reduce 0.58 t (observed impact) and 0.84 t (full impact) CO_2 emissions per year on average. Xia et al. (2007) researched into an informal carsharing project in Beijing from the perspective of economic and ecological efficiency, concluding that the efficiency of shared cars is 2.34 times as many as that of private cars. Zhang et al. (2012) conducted a questionnaire survey among 271 residents in Shanghai, and the results suggested that the VKT dropped by 228,520 km per year and the GHG emissions fell by 61,035 kg annually.

However, almost all the above research focuses on traditional carsharing. EV is the trend of global automotive industry, so it is necessary to study the environmental impacts of EV carsharing. By studying the households' travel behaviors before and after joining EV carsharing and the differences between traditional and EV carsharing, the authors propose a calculation model for the GHG emission impacts of EV carsharing.

2 Households' Travel Behaviors

This research first studies the change in households' travel behaviors before and after EV carsharing and then proposes a calculation model for the GHG emissions of every household. The unit of analysis is household because an individual's carsharing use can affect the travel decisions of all household members (Martin and Shaheen 2011).

2.1 Households' Travel Behaviors Before EV Carsharing

Families can be categorized into three types, which are one-car family, several-car family, and no-car family, based on the number of cars owned by families. Zhang et al. (2012) conducted a questionnaire survey about carsharing among Shanghai residents, showing that one-car family accounted for 44.6 %, several-car family only 8.5 %, and no-car family 46.9 %.

Car-owning families travel mainly by private car. Statistically, 78 % of all private cars travel within 64 km daily on average in the USA (Mineta et al. 2003) and 80 % within 49.2 km in Beijing (Wu 2013). Getting the data of total VKT of several-car families requires the total travel distance of all their cars. Meanwhile, families also plan to purchase one more car if they have higher income or existing cars cannot meet their demands, bringing about potential emissions subsequently.

No-car families travel mainly by bicycle, bus, and subway before joining EV carsharing. At present, more Chinese families plan to purchase a car and this phenomenon is illustrated by a study showing that 72.4 % of no-car families in Shanghai plan to buy a private car within 5 years (Zhang et al. 2012). Apart from traditional internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs) and EVs are gradually accepted by consumers. Qin, a plug-in HEV designed by BYD, sold at 6,457 in total between January and July of 2014, has become the best selling new-energy vehicle in China (2014). Our survey shows that 46, 35, and 11 % of 1015 respondents plan to buy a gasoline ICEV, HEV, and EV, respectively (see Fig. 1). Only a few people plan to buy a natural gas ICEV or a diesel ICEV.

As a result, the households' travel behaviors before EV carsharing can be described by six parameters—'number of cars owned,' 'annual VKT of every car,' 'plan to buy a car or not,' 'plan to buy an ICEV or not,' 'plan to buy a HEV or not,' and 'plan to buy an EV or not.' The last three parameters are mutually exclusive.

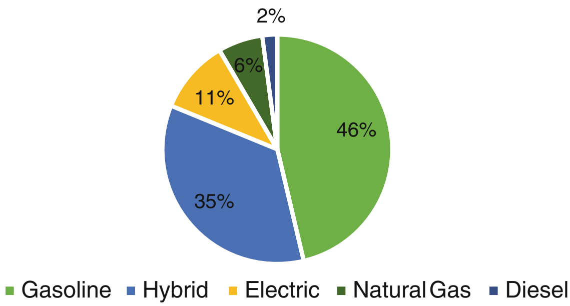

Fig. 1 Fuel/Energy types of vehicles planned to purchase

2.2 Households' Travel Behaviors After EV Carsharing

The 1,015 respondents expect to share different types of vehicles (see Fig. 2). HEV gains most popularity and next comes gasoline ICEV. About 20 % of respondents think EV is most appropriate for carsharing. However, carsharing programs in China only provide gasoline ICEVs and EVs at present.

Some research indicates that households' travel behaviors have changed after traditional carsharing (Cervero et al. 2007; Glotz-Richter 2012): No-car family travels more distance by car; car-owning families not only sell some or even all their private cars, but also drive less. So the changing amount of GHG emissions can be calculated based on the total change in VKT.

However, the differences of EV carsharing are that the members travel by both ICEV and EV, and the two have different emission impacts. The reasons are as follows. First, no-car families' VKT increases because a part of public transport travel is replaced by driving shared vehicles. Second, car-owning families reduce their car ownership, and they use EV carsharing as well as drive private cars. Third, car-owning families even sell all their cars and only use EV carsharing with less VKT. As for the purchasing plan, this paper assumes that all potential car consumers abandon their plans after joining EV carsharing.

Consequently, households' travel behaviors after joining EV carsharing can be described by three parameters—'number of cars owned,' 'annual VKT of every car,' and 'annual VKT of using EV carsharing.'

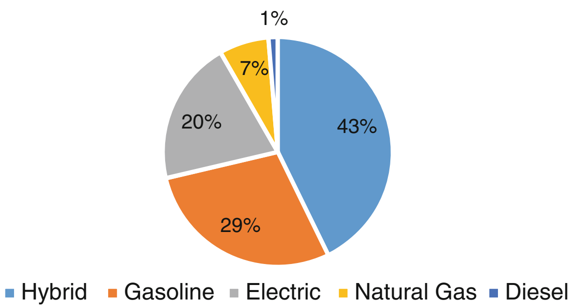

Fig. 2 Fuel/Energy types of vehicles expected for carsharing

3 Calculation Model and Its Parameters

3.1 Calculation Model

Before participating in EV carsharing, every household's travel behaviors can be described by six parameters—'number of cars owned,' 'annual VKT of every car,' 'plan to buy a car or not,' 'plan to buy an ICEV or not,' 'plan to buy a HEV or not,' and 'plan to buy an EV or not.' Besides, the fuel economy parameters of ICEVs, HEVs, and EVs as well as the emission parameters of gasoline and electricity are needed to calculate the corresponding amount of GHG emissions.

Under such scenario, the GHG emissions come from four aspects: first, emissions from driving private cars; second, potential emissions from purchasing ICEVs in the future; third, potential emissions from purchasing HEVs in the future; and fourth, potential emissions from purchasing EVs in the future. The second to the fourth aspects have not occurred yet, so they should be calculated based on the projected values of households' VKT.

As a result, the amount of annual GHG emissions on average of every household before joining EV carsharing is given in (1).

$$
\begin{aligned}
f = {} & N_b \cdot L_b \cdot C_{\mathrm{ICE}} \cdot \mathrm{GHG}_{\mathrm{ICE}} \\
& + D \cdot D_{\mathrm{ICE}} \cdot L_{\mathrm{E-ICE}} \cdot C_{\mathrm{ICE}} \cdot \mathrm{GHG}_{\mathrm{ICE}} \\
& + D \cdot D_{\mathrm{HEV}} \cdot L_{\mathrm{E-HEV}} \cdot C_{\mathrm{HEV}} \cdot \mathrm{GHG}_{\mathrm{HEV}} \\
& + D \cdot D_{\mathrm{EV}} \cdot L_{\mathrm{E-EV}} \cdot C_{\mathrm{EV}} \cdot \mathrm{GHG}_{\mathrm{EV}}
\end{aligned} \tag{1}
$$

In this equation, the unit of f is kg; N_{b} is the number of cars owned by families before joining EV carsharing, and the value is 0 for no-car family; L_{b} is the annual VKT on average of every private car (in km); $L_{\mathrm{E-ICE}}$, $L_{\mathrm{E-HEV}}$, and $L_{\mathrm{E-EV}}$ are the projected households' annual VKTs on average of driving ICEVs, HEVs, and EVs, respectively (in km); C_{ICE} is the fuel economy parameter of ICEVs (in L/100 km); C_{HEV} is the fuel economy parameter of HEVs; C_{EV} is the fuel economy parameter of EVs (in kWh/100 km); $\mathrm{GHG}_{\mathrm{ICE}}$ is the GHG emission parameter of ICEVs (in kg/L); $\mathrm{GHG}_{\mathrm{HEV}}$ is the GHG emission parameter of HEVs; $\mathrm{GHG}_{\mathrm{EV}}$ is the GHG emission parameter of EVs (in kg/kWh); D, D_{ICE}, D_{HEV}, and D_{EV} stand for 'plan to buy a car or not,' 'plan to buy an ICEV or not,' 'plan to buy a HEV or not,' and 'plan to buy an EV or not,' respectively. Value 1 means 'Yes,' while value 0 means 'No.'

After joining EV carsharing, households' travel behaviors will change and can be described by three parameters—'number of cars owned,' 'annual VKT of every car,' and 'annual VKT of using EV carsharing.'

Since this paper assumes that all potential car consumers will abandon their purchasing plans after joining EV carsharing, the emissions under this scenario come from two aspects: first, emissions from driving remained ICEVs, and second, emissions from using EV carsharing. So the amount of annual GHG emissions on average of every household after joining EV carsharing is given in (2).

$$q = N_a \cdot L_{a-ICE} \cdot C_{ICE} \cdot GHG_{ICE} + L_{a-EV} \cdot C_{EV} \cdot GHG_{EV} \quad (2)$$

In this equation, the unit of q is kg; N_a is the number of cars owned by families after joining EV carsharing; L_{a-ICE} is the annual VKT on average of remained ICEVs (in km); L_{a-EV} is the annual VKT on average of using EV carsharing (in km).

Combining Eqs. (1) and (2), the annual changing amount of GHG emissions on average brought by all households who join EV carsharing is given in (3).

$$\Delta_{GHG} = \sum (q_i - f_i) \quad (3)$$

In this final equation, f_i and q_i are the ith household's emissions before and after EV carsharing, respectively. Minus Δ_{GHG} means that EV carsharing can cut down GHG emissions.

3.2 Travel Behavior Parameters

In the calculation model, there are 12 travel behavior parameters—N_b, N_a, L_b, L_{E-ICE}, L_{E-HEV}, L_{E-EV}, L_{a-ICE}, L_{a-EV}, D, D_{ICE}, D_{HEV}, and D_{EV}. For every family who joins EV carsharing, the data of L_b, L_{a-ICE}, and L_{a-EV} can be recorded by instruments, and the data of the remaining 9 parameters can be acquired by conducting questionnaire surveys.

Take L_{E-ICE}, L_{E-HEV}, and L_{E-EV} for instance. In our survey, the 1,015 respondents predict their annual VKT of driving new cars. Some respondents plan to buy diesel or natural gas cars but they are hardly sold in Chinese market. After deleting them, there are 899 effective samples remained. Figure 3 shows that people who plan to purchase ICEVs expect to drive the longest distance, and next come HEVs and EVs. It indicates that people who travel longer distance tend to buy ICEVs, while people who travel shorter distance tend to purchase EVs.

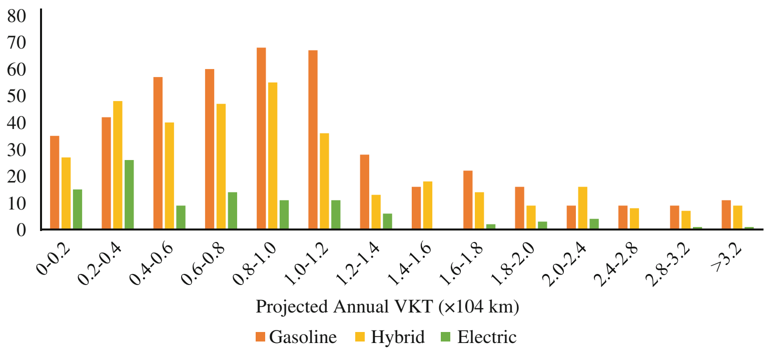

Fig. 3 Projected annual travel distance of driving new cars

3.3 Energy Consumption Parameters

In the calculation model, C_{ICE}, C_{HEV}, and C_{EV} are the energy consumption parameters.

C_{ICE} is the gasoline consumption of ICEVs every 100 km. Referring to the Chinese official limit (8.6–9.5 L/100 km) for passenger vehicles (2004), the value of C_{ICE} is set to be 9 L/100 km in this paper.

C_{EV} is the electricity consumption of EVs per 100 km. Now, there are a few EV carsharing programs in China. For example, 'EV Beijing' is a platform for Beijing Municipality to promote the use of EVs. This program provides BAIC E150 EV as the shared vehicle and has constructed several stations such as one in TusPark (2014). Another example is 'EV CARD' located in Jiading District, Shanghai, initiated by Shanghai International Automobile City Company and Tongji University. The target customers are university teachers and students, and the shared cars are ROEWE E50 and SHANGHAI GM SPRINGO (2014). Related parameters of the above three EVs are listed in Table 1.

The electricity consumption per 100 km of the three models is all 15 kWh, so the value of C_{EV} is set to be 15 kWh/100 km in the calculation model.

There are many different types of HEVs, and each has different driving range, so the value of C_{HEV} is set to be the average number of C_{ICE} and C_{EV} values which means HEVs consume 4.5 L gasoline and 7.5 kWh electricity per 100 km.

3.4 Emission Parameters

In the calculation model, $\mathrm{GHG}_{\mathrm{ICE}}$, $\mathrm{GHG}_{\mathrm{HEV}}$, and $\mathrm{GHG}_{\mathrm{EV}}$ are the emission parameters, representing the GHG emissions of ICEVs, HEVs, and EVs, respectively.

Gasoline produces GHG such as CO_2 during the process of not only combustion but also exploitation and refinement. Similarly, although EVs only consume electricity and produce no emission during running, the emissions produced during the process of electricity generation using fossil fuels such as coal and crude oil cannot be ignored. Argonne National Laboratory in the USA proposes a well-to-wheel (WTW) life cycle assessment system (see Fig. 4) and an assessment model called GREET (Wang 1996). The WTW can be divided into two stages—well-to-tank

Table 1 Related parameters of three shared EV models

EV model	Battery capacity (kWh)	C_{EV} (kWh/100 km)
BAIC E150 EV	25.6	15
ROEWE E50	18	15
SHANGHAI GM SPRINGO	21.4	15

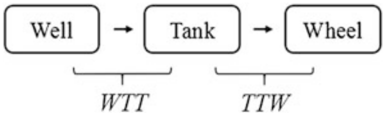

Fig. 4 Well-to-wheel life cycle assessment system

(WTT) and tank-to-wheel (TTW), evaluating the emissions of gasoline and electricity during the whole process of production and usage (Wang 2002).

Therefore, the model in this paper calculates the life cycle GHG emissions of ICEVs, HEVs, and EVs. Based on the GREET model, Liu et al. (2007) concluded that consuming 1 L gasoline releases 3.03 kg CO_2 and consuming 1 kWh electricity releases 1.10 kg CO_2. The amount of CO_2 emissions is the equivalence of all GHG such as CO_2, CH_4, and NO_2 based on their greenhouse effects. The emission intensity of HEVs is set to be the average level of ICEVs and EVs.

4 Conclusion

Before participating in EV carsharing, the households' travel behaviors can be described by six parameters—'number of cars owned,' 'annual VKT of every car,' 'plan to buy a car or not,' 'plan to buy an ICEV or not,' 'plan to buy a HEV or not,' and 'plan to buy an EV or not,' while after joining EV carsharing, the households' travel behaviors change to be described by three parameters—'number of cars owned,' 'annual VKT of every car,' and 'annual VKT of using EV carsharing.' Therefore, there are 12 travel behavior parameters such as the number of cars owned by families before EV carsharing (N_b) in the calculation model.

Apart from those, there are also three energy consumption parameters and three emission parameters—gasoline consumption per 100 km of ICEVs (C_{ICE}), energy consumption per 100 km of HEVs (C_{HEV}), electricity consumption per 100 km of EVs (C_{EV}), life cycle emissions of ICEVs (GHG_{ICE}), life cycle emissions of HEVs (GHG_{HEV}), and life cycle emissions of EVs (GHG_{EV}).

Before joining EV carsharing, driving private cars produces GHG emissions. Meanwhile, there are also potential emissions from purchasing ICEVs, HEVs, or EVs in the future. After joining EV carsharing, households abandon their purchasing plans, so the potential emissions are avoided in fact; however, driving remained private cars and using EV carsharing still bring about emissions. In particular, no-car families drive more due to EV carsharing, which is the increasing impact of EV carsharing on GHG emissions, whereas in contrast, the decreasing impact is in two aspects: First, the VKT of driving ICEVs declines; second, the potential emissions brought by purchasing plans are avoided. The total GHG emission impacts are the combination of increasing impact and decreasing impact.

After acquiring the data of every household's travel behavior parameters by conducting questionnaire surveys or recording with instruments, the GHG emission impacts can be calculated with Eqs. (1)–(3).

However, there are three major limitations in this research. First, there is no empirical calculation. Since there have not been large-scale carsharing programs in China, we are not able to conduct surveys among carsharing members. Besides, using instruments such as GPS to record members' travel behaviors may invade their privacy, so the related data are difficult to acquire. Second, the annual VKT of plan-to-buy cars is just estimated by the respondents; therefore, the data are not accurate enough and we need better prediction methods. Third, the values of energy consumption parameters and emission parameters are different in different research, so a reasonable range is needed.

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References

Autolib' [EN/OL]. WIKIPEDIA (2014-8-10) [2014-8-20]. http://en.wikipedia.org/wiki/Autolib%27

BYD new-energy vehicles had been sold from January to July (EN/OL). (2014-8-11) [2014-8-20]. d1ev.com. http://www.d1ev.com/news/company/2014081133538.html (in Chinese)

Carsharing (EN/OL). Innovative Mobility Research (2014-8-6) [2014-8-20]. http://www.innovativemobility.org/carsharing/index.shtml

Cervero R, Tsai YS (2004) City Carshare in San Francisco, California: second-year travel demand and car ownership impacts. Transp Res Rec: J Transp Res Board 1887:117–127

Cervero R, Golub A, Nee B (2007) City CarShare: longer-term travel demand and car ownership impacts. Transp Res Rec 1992:70–80

EV Beijing [EN/OL] [2014-8-20]. http://www.evbeijing.cn (in Chinese)

Glotz-Richter M (2012) Car-Sharing—Car-on-call for reclaiming street space. In: Conference on transport research arena. Athens, pp 1454–1463

Introduction to Edoauto carsharing (EN/OL) (2014-8-20). http://www.eduoauto.com/guanyugongsi.php (in Chinese)

Liu H, Wang H-w, Luo Q, Wang Y, Ou Yang M-g (2007) Energy, environment and economic assessment of life cycle for electric vehicle. Technol Econ Areas Commun 6:45–48 (in Chinese)

Martin EW, Shaheen SA (2011) Greenhouse gas emission impacts of carsharing in North America. IEEE Trans Intell Transp Syst 12(4):1074–1086

Mineta NY, Jackson MP et al (2003) Highlights of the 2001 National Household Travel Survey. US Department of Transportation, Washington, DC

National Bureau of Statistics of China (2013) China Statistical Yearbook 2013. China Statistics Press, Beijing (in Chinese)

Standardization Administration of the People's Republic of China (2004) GB 19578-2004 Limits of fuel consumption for passenger cars. Standards Press of China, Beijing (in Chinese)

Vehicle information of EV CARD [EN/OL] [2014-8-20]. http://www.evcardchina.com/car_rental/vehicle_Information.aspx (in Chinese)

Wang M (1996) Development and use of the GREET model to estimate fuel-cycle energy use and emission of various transportation technologies and fuels, Center for Transportation Research. Argonne National Laboratory, ANL/ESD-31

Wang M (2002) Fuel choices for fuel-cell vehicles: well-to-wheels energy and emission impacts. J Power Sources 112(1):307–321

Wu W-h (2007) Comparisons of energy consumption and emission in transport field between China and typical countries. Energy China 29(10):19–22 (in Chinese)

Wu L-w (2013) A GPS-based research on the driving patterns of private passenger vehicle in Beijing. MS program, Tsinghua University Beijing, China (in Chinese)

Xia K-x, He M-s, Zhang H (2007) Study on car sharing service based on theory of economic ecological efficiency. Manag World 11:152–153 (in Chinese)

Zhang M, Hui Y, Wang M-q (2012) Urban greenhouse gas emission of car sharing. China Popul Resour Environ 22(9):48–53 (in Chinese)