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Carbon Value Analysis of Taxi Electrification in Beijing

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Abstract: As an important part of urban transportation, the economic value of carbon emission reduction in the process of electrification of taxis is of concern in academic field. With the help of empirical data and considering the direct and indirect carbon emission of taxis, we study the economic value of taxi electrification's carbon footprint in the annual and operational lifecycle. First, the theory and method for the carbon value of taxi electrification are presented and carbon value of the transition from fossil fuel-powered taxis to battery electric taxis (CVTFE) in the annual and operational life cycle is calculated. Secondly, the various influencing factors determining the carbon value are analyzed. Third, the magnitude of the various influencing factors on CVTFE is quantified. The calculation results show that: (1) the positive and negative value of CVTFE represents a carbon asset or carbon debt, and the results may vary under different situations; (2) the influencing factors include carbon emission price, annual driving distance, fuel / energy, fuel / electricity consumption level, discount rate and operating life period; (3) the indirect carbon emission coefficient of electric energy has the greatest impact on CVTFE and the minimum impact of taxi annual driving distance on CVTFE.

Keywords Carbon footprint, Economic value, Electrification

INTRODUCTION

In recent years, rapid development of transportation industry is accompanied by the discharge of pollutants, contributing 22 percent of global carbon dioxide emissions, 35 percent of nitrogen oxides and 30 percent of chlorofluorocarbon compounds and becoming an important factor affecting urban air quality. Cruise taxis are an important part of urban transport. Since annual mileages of cruise taxis are far greater than that of ordinary vehicles, carbon emissions of cruise taxis have attracted widespread attention[António P. et. al., 2015]. One possible way for cruise taxis to reduce carbon emissions is to replace fossil fuel-powered taxis (FFTS) with battery electric taxis (BETS). Although BETs rarely produce direct carbon emissions while driving, but BETs need to consume electricity[Jinlei Zhang, et. al., 2018]. Carbon dioxide is emitted during electricity production and resulting in indirect carbon emission from BETs[Cooney, G, et. al.,2013]. Therefore, in evaluating emission reduction effect and corresponding economic value of taxi electrification, a life cycle perspective of taxis need to be considered[Ribau, J, et. al., 2014]. Since carbon emissions associated with fuel consumption of taxis account for the largest share of life-cycle carbon emissions, in comparing battery electric taxis with fossil fuel-powered taxis, more and more researches have focused on carbon emissions studies for different fuel types of taxis, including production of fossil fuels and electricity for charging and assessment time span[Xylia, M, et. al., 2019]. Therefore, the paper also focuses on the life cycle carbon emissions related to taxis operation[Chan, S, et. al., 2013].

The paper studies direct and indirect carbon emissions in taxi electrification process from perspective of urban cruise taxis, considers carbon emissions of operation life cycle of taxis and calculates carbon value of operating life cycle of taxi electrification to evaluate economic value of carbon emission reduction of taxi electrification.The rest of this paper is set as follows: Section 2 reviews the literature related to CVTFE. Section 3 introduces the theory and methodology to evaluate annual CVTFE and operation life cycle CVTFE and deduces the influencing factors of CVTFE. Section 4 presents datas and variables used in this paper. Section 5 analyzes and discusses empirical results. Section 6 is summarized.

THEORY AND METHODOLOGY

According above researches [Hong Zhao, et. al., 2021], the value of carbon assets in transportation industry is mainly determined by standard carbon emission level[Zhou, B, et. al., 2016], carbon emission reduction and carbon price. As a result, the CVTFE of replacing fossil fuel-powered taxis with battery electric taxis is determined by carbon emissions of battery-powered taxis, carbon emissions of fossil fuel-powered taxis and carbon exchange price. For calculating CVTFE, we use value of carbon assets of battery electric taxis minus value of carbon assets (or debt) of fossil fuel-powered taxis[Rupp, M, et. al., 2019], which can be written as:

$$V_t = (CF_t - CE_t) \times P_t \tag{1}$$

Since the service life of BET and FFT is not the same at present, in order to facilitate analysis and comparison, we assume that BET and FFT have same service life T, and the discount rate r is constant over the life period. Life cycle value of CVTFE can be written as follows:

$$V = \sum_{t=0}^{T} (FU \times CPF - EU \times CPE) \times P_t \times L_t \times (1+r)^{-t} \quad (2)$$

where FU is the carbon emission coefficient of fossil fuel (unit: kg CO2eq/kg), EU is the indirect carbon emission coefficient of electric power (unit:kg CO2eq/kWh), CPF is the distance-specific fossil fuel consumption of FFT (kg/km), CPE is the distance-specific electric power consumption of BET (kWh/km) and L_t is the average annual driving distance of FFT (km).

We further assume carbon exchange price is constant and annual driving distance is also constant for both FFTs and BETs in whole service life, i.e.,

$$P_t = P \quad (3)$$

$$L_t = L \quad (4)$$

Then, Formula (2) can be written as:

$$V = \sum_{t=0}^{T} (FU \times CPF - EU \times CPE) \times P \times L \times (1+r)^{-t} \quad (5)$$

DATA AND VARIABLES

According to formula (2), it is necessary to determine annual driving distance of FFT, distance-specific fossil fuel consumption of FFT and carbon emission coefficient of FFT respectively for calculating annual carbon emissions of FFT. According to statistics from the Beijing Municipal Bureau of Statistics, By the end of 2018, there are about 70035 taxis in Beijing and about 60,000 fossil fuel - powered taxis[Harris, A, et. al., 2019]. Average annual mileage of FFT is 120,000 kilometers. Considering traffic congestion in the city, the fuel consumption of gasoline cars is 10L±2L/100km. Carbon emission factor for gasoline No .92 is 2.36 kg CO2eq/kg.

Similarly, annual carbon emission of BET is calculated according to formula (3). It is also necessary to determine annual driving distance of BET, distance-specific electricity consumption of FFT and the indirect carbon emission coefficient of FFT. For comparison, average annual driving distance of BET is also calculated at 120000 km. In addition, due to heating demand, power consumption of 100 km of pure electric taxis in winter is obviously higher than that of other seasons, which is about 30% higher. In summer, power consumption of 100 km is slightly higher than that of spring and autumn, which is about 10% higher than that of other seasons. Basic information of BETS in Beijing is showed in Table 1.

Annual electricity consumption in Beijing reached 114.2 billion kWh in 2018. Of these, 43.7 billion kWh (94 percent of gas-fired power, 2.5 percent of hydropower, 0.68 percent of wind power, 0.16 percent of photovoltaic, 2.66% percent of biomass energy) was generated in Beijing. 70.5 billion kWh (83% percent of coal-fired power, 2.5 percent of hydropower, 0.68 percent of wind power, 0.16 percent of photovoltaic, 2.66% percent of biomass energy) was external power supply. Therefore, the source of annual electricity consumption in Beijing including: Coal-fired power accounts for 51%, Gas-fired power accounts for 36%, Hydropower accounts for 1.4%, Wind power accounted for 8.3%, Solar energy accounts for 1.6%, Biomass energy accounts for 1.7%. Electricity power from different types of power plants has completely different indirect carbon emission coefficients[Xu, X, et. al., 2018]. Different indirect carbon emission coefficients lead to different annual carbon emissions or service life carbon emissions of BETs.

Table 1.Basic information and electricity consumption of the battery electric Taxis (BETs)

Vehicle number	Electricity taxis	Gross vehicle weight(kg)	capacity (kWh)	Electrcity consumption(kWh/100km)		
				min	max	mean
EU	EU220	1587	37.8	17	22	19.5
EU	EU260	1587	41.4	16	21	18.5
EU	EU300	1587	45	15	19	17

According to formulas (4) and (5), In addition to reducing carbon emissions, carbon price are another factor in the transition from FFTs to BETs. Carbon price come from price data[Xinkuo Xu, et. al., 2021] by Beijing's carbon emissions distribution electronic trading platform. According to 145 transactions on the Beijing trading platform in 2018, Maximum value $74.6/ tCO2, Minimum $30.32/ tCO2, Average price 55.64 yuan/ tCO2, The standard deviation is 10.84 yuan, as shown in Figure 1. When calculating carbon value, average value of carbon price is adopted.

The yield rate of a 5-year treasury bond was approximately 4.75% in China in February, 2019, and this value is used to represent the discount rate of the carbon value in this paper. The service life of FFTs is usually 6 years. For convenience of comparison, the service life of BETs is also set to 6 years.

EMPIRICAL RESULTS AND ANALYSIS

Annual CVTFE Value in Beijing

The annual CVTFE is determined by reduction of relative carbon emissions of BET replacing FFT, annual travel distance of taxis and carbon price. According to formula (4), calculate annual CVTFE of Beijing taxi every year. Where annual driving distance of BETs or FFTs is 120,000 kilometers, carbon price is average value 55.64 Yuan/tCO2. The results are shown in Table 2.

Table 2.Annual CVTFE with the changes of electric power sources or electricity consumption levels of BETs in Beijing (Yuan/Year)

Taxi	Electric source	Min	Max	Mean	Mean+sd
EU220	average	465.04	268.08	366.56	593.51

	Power plants	181.28	-99.15	41.07	268.01
	Natural gas	658	517.79	587.90	814.84
	Hydro electricity	1100.67	1090.66	1095.67	1322.61
	Wind energy	1100.67	1090.66	1095.67	1322.61
	Solar energy	1032.57	1002.53	1017.55	1244.49
	Biomass energy	862.31	782.19	822.25	1049.20
EU260	average	504.44	307.47	405.95	632.90
	Power plants	237.36	-43.06	97.15	324.10
	Natural gas	686.04	545.83	615.94	842.88
	Hydro electricity	1102.68	1092.66	1097.67	1324.61
	Wind energy	1102.68	1092.66	1097.67	1324.61
	Solar energy	1038.58	1008.53	1023.56	1250.50
	Biomass energy	878.34	798.21	838.28	1065.22
EU300	average	543.83	386.26	465.04	691.99
	Power plants	293.44	69.11	181.28	408.22
	Natural gas	714.09	601.92	658	884.95
	Hydro electricity	1104.68	1096.67	1100.67	1327.62
	Wind energy	1104.68	1096.67	1100.67	1327.62
	Solar energy	1044.59	1020.55	1032.57	1259.52
	Biomass energy	894.36	830.26	862.31	1089.26

Table 2 shows that CVTFE fluctuates with the change of different power sources or power consumption level of BETs and the value is positive or negative. The higher indirect carbon emission coefficients of electric power are, the smaller annual CVTFE is, and the smaller carbon emission reduction capacity of BETs replacing FFTs. The annual CVTFE also fluctuates with electric power consumption level of BETs. The annual CVTFE of EU220、EU260 or EU300 will change if electric power consumption level fluctuates. The lower electric power consumption of BETs are, the greater annual CVTFE are, and the greater carbon emission reduction capacity of BETs replacing FFTs are.

Service-Life CATFE Value in Beijing

According to formulas (5) and (6), we can calculate CVTFE of service life. The results are shown in Table 4. According to table 3, When FFTs' fuel consumption is 10L/100km, electric power consumption of BETs is average value and indirect carbon emission coefficient is average value, service life CVTFE of three types of BETs are 1964.60, 2175.71 and 2492.41 Yuan respectively. If power source changes, service life CVTFE of three types of BETs will change from 220.12 to 5899.11 Yuan. When electric power consumption is minimum, service life CVTFE of three types of BETs will change from 971.58 to 5920.60 Yuan. When electric power consumption is maximum, service life CVTFE of three types of BETs will change from -531.40 to 5877.67 Yuan. When FFBs' fuel consumption is 10L+2L/100km, service life CVTFE will change from 1436.42 to 7115.46 Yuan. When FFBs' fuel consumption is 10L-2L/100km, service life CVTFE will change from -996.24 to 4682.81 Yuan. Above, the service life CVTFE will fluctuate with the FFTs' fuel consumption or carbon emission level, electric power consumption level of BETs and indirect carbon emission coefficients of power sources.

Table 3.Service-Life CVTFE of BETs in Beijing (Yuan)

Taxi	Electric source	Min	Max	Mean	Mean+sd
EU220	average	2492.41	1436.79	1964.60	3180.95
	Power plants	971.58	-531.40	220.12	1436.42
	Natural gas	3526.59	2775.13	3150.89	4367.18
	Hydro electricity	5899.11	5845.46	5872.31	7088.61
	Wind energy	5899.11	5845.46	5872.31	7088.61
	Solar energy	5534.12	5373.12	5453.62	6669.92
	Biomass energy	4621.60	4192.19	4406.90	5623.25
EU260	average	2703.58	1647.90	2175.71	3392.07
	Power plants	1272.15	-230.78	520.68	1737.03
	Natural gas	3676.87	2925.41	3301.17	4517.47
	Hydro electricity	5909.88	5856.18	5883.03	7099.33
	Wind energy	5909.88	5856.18	5883.03	7099.33
	Solar energy	5566.33	5405.28	5485.83	6702.13
	Biomass energy	4707.52	4278.06	4492.81	5709.11
EU300	average	2914.69	2070.18	2492.41	3708.76
	Power plants	1572.71	370.40	971.58	2187.88
	Natural gas	3827.21	3226.03	3526.59	4742.94
	Hydro electricity	5920.60	5877.67	5899.11	7115.46

	Wind energy	**5920.60**	**5877.67**	**5899.11**	**7115.46**
	Solar energy	**5598.54**	**5469.70**	**5534.12**	**6750.47**
	Biomass energy	**4793.38**	**4449.83**	**4621.60**	**5837.96**

RESULTS AND CONCLUSIONS

This paper provides a reference for the government to formulate policies to realize the transition of taxi electrification by using the calculation of annual CVTFE and service life CVTFE. Because of the diversity of power sources used in BETs, there is more or less a certain level of carbon emissions in the production process of electric power. Therefore, the influence of indirect carbon emission coefficient of different power sources on the CATFE is considered in the paper. It can be seen from the results:

First, both annual CVTFE and service life CVTFE, due to the consideration of indirect carbon emissions during electric power production, the analysis results are more accurate and persuasive when analyzing environmental and economic advantages of battery electric taxi (BETs) replacing fossil fuel-powered taxi (FFTs). If all electric power comes from coal-fired power, positive carbon assets may become negative carbon debt. Second, annual CVTFE and service life CVTFE depend on the indirect carbon emission coefficients, carbon price, electric power consumption of BETs and annual driving distance. At the same time, service life CVTFE also depends on discount rate of carbon value and service life of taxis. Finally, among the influencing factors of annual CVTFE and service life CVTFE, indirect carbon emission coefficients has the greatest effect on the CVTFE, while annual driving distance has the least effect on the CVTFE.

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