Economic Benefits Analysis of Battery Charging and Swapping Station for Pure Electric Bus in Public Transportation Field

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Abstract: As a breakthrough for the development of new energy automobile industry in China, pure electric buses have made great achievements. From the perspective of the development of pure electric buses, the construction of BCSS plays a crucial role. The economic benefits of BCSS, as one of the most important problems in the process of industrialization, has received lots of attention. After analyzing constructing and operating status, this paper builds up economic benefits model founded on cost-benefit model and chooses NPV as the assessing indexes of economic benefits. The uncertainty of economic benefits is also analyzed by using the break-even analysis and sensitivity analysis. At the end of the paper, the economic benefits of BCSS in Xue Jiadao, Qingdao, was analyzed through utilizing the economic benefits model. Results show that China's BCSS for pure electric buses under current stage has limited profitability, which is not conducive to commercialization. Results of Break-even analysis will provide references for the design of charging price and for the prediction of service scale. In addition, after sensitivity analysis, we found that the key factors influencing economic benefit of BCSS were charging price, battery renting price, power purchasing price and state subsidies in the descending order of importance. The established economic model and the analyzing results could provide references for economic benefits assessment and decision-making for the commercial development of BCSS of electric buses.

Introduction

Nowadays, as the problem of energy shortage and environmental pollution become increasingly serious, electric vehicle, as a green and energy saving transportation, gradually gets national attention and is vigorously promoted in many countries. At present, China mainly focus on the demonstration and operation of electric cars in public transportation and have achieved good grades. In order to meet the growing demand for electric vehicle charging and promote the development of electric vehicle industry, large-scale construction of charging infrastructure is imperative. In this context, charging/swapping market was opened by the State Grid in May 2014 to encourage the investment of social capital. In order to improve the return on investment and promote the commercialization of charging infrastructure, domestic and foreign scholars are dedicated to research economic benefit of electric vehicle charging infrastructure. Existing researches are mainly focus on the following three aspects.

Some scholars make comparative analysis of economic benefit for different kinds of electric vehicle charging infrastructure. Xu(2015)comparatively analyzed the investment evaluation and economic benefit of different kinds of electric vehicle charging infrastructure. Wang et al.(2015) make contrast analysis of economic benefit between the network of "centralized charging, scattered battery swapping" and "scattered charging and battery swapping" by cost-benefit method. Part of scholars focus on economic benefit evaluation of electric vehicle charging infrastructure. Considering construction of charging/swapping infrastructure, operation of charging station and battery swapping station, monitoring and intelligent scheduling system, Chen et al.(2016)make a systematic cost-benefit model for charging/swapping station and put forward the method of
cost-benefit evaluation based on life-cycle theory. Xue(2012) build a dynamic cost-benefit assessment framework to evaluate the impact of electric vehicle scale development on the cost and benefit of transportation department and power grid enterprise. In addition, other scholars research one factor that affects the economic benefit of electric vehicle charging infrastructure. Lu et al.(2014) research the setting of charging price using cost-benefit method. Niu et al.(2014) calculate the power battery operating price of electric sanitation trucks in public domain by ROI.

In conclusion, the existing research on the economic benefits of electric vehicle charging infrastructure mainly focus on the building of economic benefits model, while few researches are combining calculation and evaluation of economic benefits. The recent research mainly focus on operating return but few take carbon emission return into consideration; in addition, the analysis of charging infrastructure operating mode is the foundation of the economic benefit research but some scholars ignore the analysis of operating mode.

In this paper, the economic benefits model is built based on analysis of constructing and operating status. It is based on cost-benefit mode and chooses NPV as assessment criteria of economic benefit and uses the method of break-even analysis and sensitivity analysis to analyze uncertainty of economic benefits. Finally, the article analyzes economic benefits of BCSS of Xuejiadao in Qingdao by using the economic benefits model. The analysis results will provide reference of economic benefits assessment and reference of decision-making for commercial development of BCSS.

**Construction and operation status of BCSS for electric bus**

**Construction situation.** In order to reduce energy consumption and environmental pollution, in recent years, the state vigorously promote the application of new energy vehicles and take the lead in promoting in the field of public transportation. As shown in Figure1 and Figure2, from 2013 to August 2015, the cumulative promoting number of new energy vehicles in 39 demonstration cities in the field of public transportation is 89775, accounting for 56.26% of the total amount of promotion, among them the promoting number of electric bus is 30528, accounting for 50% of the total amount of promotion in the field of public transportation, which shows that, at present, Chinese promotion of new energy automobile focuses on the field of public transportation and the promotion of new energy bus have been the focus of promotion in the field of public transportation.

![Figure 1. The promoting state of new energy vehicles in 39 demonstration cities about public and private transportation from 2013 to August 2015.](image)

![Figure 2. The promoting state of different new energy vehicles in 39 demonstration cities in the field of public transportation from 2013 to August 2015.](image)
With the developing of new energy bus, the charging infrastructure is being constructed vigorously. Because of the large capacity of electric bus vehicle battery, the unified battery specification and its fixed operating routes/time, battery swapping mode, as a way of energy supply is often applied into electric bus and BCSS is often constructed at start-stop station of the routes. In China, the construction of the charging infrastructure is dominated by the state grid. Figure 3 is the constructing state of BCSS by national power grid from 2010 to 2015, which shows that from 2010 to 2015, its constructing quantity has been increasing in BCSS and the increasing speed is faster. By the end of 2015, the cumulative number of completed BCSS is 1537. The amount of completed BCSS only in 2015 is far more than the accumulative number over the past four years. This shows that in order to meet the growing charging demand of electric vehicle, the constructing speed of charging infrastructure is accelerating and the scale expands unceasingly.

![Figure 3. The constructing state of BCSS by national power grid from 2010 to 2015.](image)

From the point of constructing mode, at present, there are mainly two kinds of constructing mode for battery swapping network. One kind is “centralized charging, scattered battery swapping” which consists of a large charging stations and many battery distribution stations, charging station is responsible for a concentrated charging of power batteries that are switched down, then delivered fully charged battery to the distribution station which are specialized in battery swapping services. Another kind is “scattered charging and battery swapping” which means that BCSS have both ability of charging and replace for battery, according to the capacity of the battery allowance, it is able to choose concentrated charging or timely charging. Wang et al.(2015) have done some related research and found that economic benefit of “scattered charging and battery swapping” mode is better than “centralized charging, scattered battery swapping” mode and suggest to choose “scattered charging and battery swapping” mode at present stage. In view of that, this article mainly studies the economic benefit of “scattered charging and battery swapping” model.

**Operation situation.** At present, the main operating subject of charging/swapping facilities is power grid enterprise, the government plays a positive role in promoting and supporting charging/swapping facilities. By the end of 2015, 1537 BCSS have been built by the State Grid. At the national level, the government constantly introduced the relevant support policies, encouraging the construction of battery swapping model. For example, in 2012, the state council issued *the energy conservation and new energy vehicle development plan for 2012-2020* which explicitly pointed out that it is necessary to explore a variety of business models such as the battery in leasing and battery swapping service, and encourage the establishment of independent operating charging/swapping enterprises.

For operating mode, the cost of power battery is a major component of operating costs and the cost of power battery is expensive. So in order to save operating cost, battery lease mode is widely applied. As shown in figure 2, operators of BCSS rent power battery from upstream battery manufacturers and lease them to downstream users. The operator business behavior is purchasing electric energy from power supplying company and providing the service of battery swapping and maintenance to users. Users buy naked car from car manufacturers, which can save the consumers’ expense on buying cars. This paper mainly studies the economic benefits of BCSS based on the battery lease mode.
In this section, economic benefit model of BCSS is based on cost-benefit model and the NPV is chosen as evaluation index of economic benefit. Because in the process of analysis and evaluation, many factors which affect the economic benefits derived from prediction and estimation and are constantly changing, it is necessary to analyze their influence on the uncertainty of economic benefit. This article chooses break-even analysis and sensitivity analysis as the main method of economic uncertainty analysis.

**Cost model.**

(1) Initial investment cost model. Initial investment cost $C_1$ is mainly composed of land cost, constructing cost of buildings, purchasing cost of charging/swapping equipment and other expense. So, there is

$$C_1 = C_L + C_C + C_D + C_O$$

where $C_L$ in Eq. 1 denotes land cost which is an important part of BCSS construction and can be expressed as

$$C_L = L_P L_S$$

where $L_P$ and $L_S$ in Eq. 2 respectively denote unite land price and the land area.

Where $C_C$ in Eq. 1 denotes constructing cost of buildings in BCSS, which can be expressed as

$$C_C = C_Y + C_F$$

where $C_Y$ and $C_F$ in Eq. 3 respectively denote construction fee of office and park area and construction fee of charging/swapping room and transformer room.

Where $C_D$ in Eq. 1 denote the purchase cost of charging/swapping equipment which can be expressed as

$$C_D = \sum_{i=1}^{n} P_i N_i$$

where $P_i$ in Eq. 4 denotes the unit price of charging/swapping equipment, $N_i$ denotes the number of equipment and $n$ denote the total number of types.

Where $C_O$ in Eq. 1 denotes other expense, for example, construction management fees, architectural design and land exploration fees, which can be estimated according to industry standards.

(2) Annual operation cost model. The annual operation cost $C_{2,n}$ mainly concludes the power purchasing cost, battery leasing cost, labor cost and maintenance cost for charging/swapping equipment. So, there is

$$C_{2,n} = C_{P,n} + C_{B,n} + C_{H,n} + C_{M,n}$$
Where $C_{P,n}$ in Eq.5 denotes the power purchasing cost that is used to meet the demand of daily operation and charging, which can be expressed as

$$C_{P,n} = P_p N_p$$  \hspace{1cm} (6)

Where $P_p$ in Eq.6 denotes unite power purchasing price, $N_p$ denotes the amount of power demand.

Where $C_{B,n}$ in Eq.5 denotes battery leasing cost which can be expressed as

$$C_{B,n} = \frac{P_B N_B}{T}$$  \hspace{1cm} (7)

Where $P_B$ in Eq.7 denotes unite battery leasing price, $N_B$ denotes the number of leasing battery pack, $T$ denotes leasing term that is assumed as project operating cycle.

Where $C_{H,n}$ in Eq.5 includes the basic salary, bonus, social security, accumulation fund and other benefits.

Where $C_{M,n}$ in Eq.5 denotes maintenance cost of charging/swapping equipment, which usually is calculated by certain proportion of purchasing cost of charging/swapping equipment.

**Revenue model.** The annual revenue of BCSS $R_n$ mainly is consisted of charging/swapping service income, income of carbon emission, the salvage value income and state subsidies. So, there is

$$R_n = R_{s,n} + R_{c,n} + R_{v,n} + R_{Subsidies,n}$$  \hspace{1cm} (8)

Where $R_{s,n}$ in Eq.8 denotes charging/swapping service income, which can be expressed as

$$R_{s,n} = PDME \times \frac{NL}{100}$$  \hspace{1cm} (9)

Where $P$ in Eq.9 denotes the unite charging price which includes charging service fee, $D$ denotes the annual operating days of electric bus, $M$ denotes daily number of serviced vehicles, $E$ denotes power consumption per hundred kilometers for each electric bus, $N$ denotes the average times of charging everyday for each electric bus, $L$ denotes the average mileage of each electric bus after being fully charged.

Where $R_{c,n}$ in Eq.8 denotes the annual income of carbon emission which make the reduced CO$_2$ emission by electric cars instead of traditional fuel vehicles into benefit and can be expressed as

$$R_{c,n} = VW$$  \hspace{1cm} (10)

Where $W$ in Eq.10 denotes the reduced CO$_2$ emission, $V$ denotes carbon emission trading price.

Where $R_{v,n}$ in Eq.8 denotes the salvage value income which is decided by the purchasing cost of fixed assets and salvage value percent.

Where $R_{Subsidies,n}$ in Eq.8 denotes the state subsidies, which accounts for 30% of charging/swapping equipment investment.

**The evaluation model of economic benefits.** The financial evaluating indicators of economic benefits mainly include static and dynamic indicators. The former mainly refers to the T (dynamic payback period), NPV(net present value) and IRR (internal rate of return) which all are based on the time value of money, the latter is directly calculated by the project cash flow, including static payback period and investment profit margins$^{[1]}$. Considering that dynamic indicators can better reflect the dynamic changes of economic benefits, NPV is selected by this paper, if NPV>0, the project is feasible, if NPV<0, the project is not feasible. Computational formula is as follows.

$$NPV = \sum_{n=1}^{T} \frac{(R_n - C_{2,n})}{(1 + i_o)^n}$$  \hspace{1cm} (11)

**Uncertain analysis of economic benefits.** In the process of analysis and evaluation for economic benefits of BCSS, many data that is from prediction and estimation is uncertain, some adequate objective information are not sufficient and all situation cannot be fully considered.
Therefore, it is necessary to analyze the uncertainty of economic benefits. This paper chooses the methods of Break-even analysis and Sensitivity analysis.

(1) Break-even analysis. This paper analyzes the influence of different charging price to surplus-deficit status of BCSS under the condition of considering the carbon emission return and unconsidering the carbon emission return by the method of break-even analysis. Because the income of BCSS mainly comes from charging/swapping service, the average daily number of electric bus served by BCSS is regarded as the break-even point. Break-even model is as follows.

\[ TR_n - C_{1} - TC_{2, n} = 0 \]  \hspace{1cm} (12)

So, when the carbon emission return is taken into account, according to Eq.11, there is

\[ M_1^* = \frac{(C_1 + TC_{2, n} - TrC_D - TWV)100}{T(PDE)NL} \]  \hspace{1cm} (13)

When the carbon emission return is not taken into account, according to Eq.11, there is

\[ M_2^* = \frac{(C_1 + TC_{2, n} - TrC_D)100}{T(PDE)NL} \]  \hspace{1cm} (14)

(2) Sensitive analysis. Based on the certain analysis of economic benefit, sensitivity analysis is further analysis about influence of uncertain factors on the economic benefit. This article selects NPV as the indicator of sensitivity analysis. Along with the advance of battery technology and the development of new materials, the future battery costs will drop, so battery renting cost will produce certain effect on the total cost of BCSS. Among the operating costs, power purchase costs accounted for 25% to 30%, if the power supply enterprise adjust power purchasing price, it will influence the economic benefits of BCSS. At the same time, because BCSS’ revenue mainly comes from charging service income, so the charging price will affect its economic benefits. In addition, the state subsidies play an important role in the early construction. So this paper selected battery rental costs, power purchasing price, charging price and state subsidies as uncertain factors. Sensitive factor \( e_i \) means the sensitive degree of NPV to uncertain factors. The calculative formula is as follow:

\[ e_i = \left| \frac{\Delta NPV \left( x_i \right)}{NPV \left( x_i \right)} \right| \]  \hspace{1cm} (15)

Where \( x_i \) in Eq.15 means some factor, \( \Delta x_i \) is the change value of \( x_i \), \( \Delta NPV(x_i) \) is the change value of NPV.

The case study: BCSS for electric bus of Xue Jiadao in Qingdao

The project of Xue Jiadao BCSS for electric bus started construction in April 10, 2011 and completed the construction in June 30, 2011. It began to provide charging/swapping service to Qingdao bus company, Huangdao district bus company and Qingdao transportation group in July 1, 2011.

According to the survey, this project operating cycle is 20 years; the depreciation life of housing construction is 30 years. According to the notice concerning the adjustment of the fixed assets directory of State grid corporation (Treasury [2011] 12), the depreciation life of charging/swapping equipment is 10 years. According to related regulation of Chinese industry benchmark yield, take the industry benchmark yield as 10%. At the early construction stage of BCSS, the government subsidies accounts for 30% of charging/swapping equipment investment. The carbon emission trading price is \( 0.227 \text{ ¥}/\text{kg} \). This paper assumes that the salvage value yield is 10% and power purchasing amount is equal to the charging amount By entering the evaluating formulation of economic benefits with parameters, the NPV is calculated. NPV is -15839.39 million Yuan, which means the current project's investment return rate is less than the capital cost, projects are losing money and is not suitable for commercialization. In view of the above analysis results, it is
necessary to further analyze the main factors affecting economic benefit of BCSS. Because the project's main revenue comes from charging/swapping services and charging price is the key factor influencing the revenue, this paper will further analyze the influence of the charging price to the average daily number of electric bus served and predict the surplus-deficit status of the project. Break-even points under two different conditions are drawn by figure 7.

It can be seen from the above figure that under the condition of without considering carbon yield, when charging price $P$ is 3.1, the BCSS stays in the state of profit and loss balance with the current daily service volume $M = 250$. Given the current charging price $1.38 \leq P \leq 1.8$, if average daily service capacity is $517 \leq M \leq 849$, BCSS will make a profit. Under the condition of considering the carbon yield, when charging price $P$ is 2.95, BCSS can be profitable by the current service ability. If average daily service capacity is $567 \leq M \leq 931$, corresponding to the current charging price $1.38 \leq P \leq 1.8$, BCSS will be profitable. In order to future study the influencing extent of uncertain factors to economic benefits, then the paper will use sensitivity analysis method to analyze the influence of battery renting price, power purchasing price, charging price and state subsidies to NPV. Concrete results are shown in the figure 8 below.

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In the figure 8, you can see that NPV and battery lease price and electricity purchasing price are negatively correlated, NPV and charging price and subsidies are positively correlated. Battery renting price and charging price have larger influence on NPV, the sensitive coefficient respectively are 1.512 and 1.55, electricity purchasing price and state subsidies have less effect on NPV, the sensitive coefficient respectively are 0.625 and 0.333. Under the condition of other factors being constant, when the battery renting price drops to RMB155100 /set, NPV= 0, the project can be profitable within the operating cycle. When the charging price rises to RMB2.96 /KW.h, NPV = 0, projects can be profitable within the operation cycle.

Summary

(1) At present, the popularization and application in the field of electric buses in China have made great achievements. In order to promote the construction of BCSS, government encourages
the social capital investment to prompt its commercialization by opening the charging and swapping market. But, according to the current calculation, because of the high upfront capital, limited state subsidies and less charging income, the overall profitability of BCSS is limited, which will affect its commercial development.

(2) This paper predicts the charging price and service scale under the condition of considering the carbon emission return and unconsidering the carbon emission return by the method of break-even analysis. The results can draw a conclusion that when the carbon emission return is taken into account, if charging price $P>$2.95, the project will be profitable within the operating cycle by the current average daily service ability and if the number of average daily service bus is $517\leq M \leq 849$, the project will be profitable within the operating cycle under the current charging price which is $1.38\leq P \leq 1.8$; when the carbon emission return is not taken into account, if charging price is $P>$3.1, the project will be profitable and if the number of average daily service bus is $567\leq M \leq 931$, the project will be profitable.

(3) Though sensitivity analysis, can we find that the key factors influencing economic benefit of BCSS was followed by charging price, battery renting price, power purchasing price and state subsidies. We further find that if other factors are constant, after battery technology achieving breakthrough, the battery renting price falls to 29% of the original price, BCSS will realize the balance of payments. On the premise of other factors being constant, if charging price rises to 64%, BCSS will realize the balance of payments.

(4) In view of the above analysis, at present, the commercial improvement of BCSS in China need various efforts including battery manufacturers, power supply company, state and charging station operators. Battery manufacturers must make a breakthrough in technology to reduce the battery cost. BCSS can ask power supply company for a discount price to reduce the electricity purchasing cost. Government subsidies play an important role in the early construction of BCSS, in addition to the one-time subsidies in early construction, the government can provide discount loans or fixed tax exempted to BCSS.

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