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The development pattern design of Chinese electric vehicles based on the analysis of the critical price of the life cycle cost

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A B S T R A C T

In recent years more and more people have been paying attention to the development of electric vehicles. At the same time, due to the lack of innovation in business models, the promotion of electric vehicles has been relatively slow. The development model of electric vehicles is in urgent need of innovation. Considering the initial investment cost, operating costs, fuel cost and other expenses of electric vehicles, this paper designed a critical price model of alternative fuel vehicles in the whole life cycle from the consumers' point of view. The results showed that users can use the electric vehicles when the selling price is lower than the critical price. And the rise of oil prices, the reduction of the initial investment of electric vehicles and the imposition of carbon tax will help to improve the critical price and promote the development of electric vehicles. Four kinds of promotion models for the electric vehicle from three angles of risk transfer, risk reduction and risk sharing have been designed. The point of difference between critical price and current electricity price will be the expected per kWh for the promotion of electric vehicles has been put.

1. Introduction

Faced with increasingly severe environmental pollution and a progressively tight energy supply, the need to develop a low-carbon economics has become the basic consensus of the world. Low-carbon traffic is undoubtedly one of the core contents of a low-carbon economics. From a global point of view, the transportation system consumes about one-third of the world's energy. This amount is still rising.

From the total energy consumption point of view, the total amount of traffic energy consumption is continuing to grow. From a variety of forms of energy consumption, the energy consumption in the transportation sector mainly includes oil, coal, electricity, natural gas and so on. In recent years the energy consumption of transportation has mainly been based on petroleum products. The consumption of other energy sources, such as natural gas and electricity, has gradually increased. Obviously, regardless of the total energy consumption or growth rate, transportation is one of the key areas of national energy conservation and emission reduction. Although in recent years the structure of transportation energy consumption has changed, it is still mainly based on petroleum products. At the same time, China's oil resources are scarce and mainly rely on imports (Ao et al., 2008). An effective method to solve the contradiction between increasing oil consumption and strengthening environmental protection is to develop clean electric transportation in the traffic domain.

Along with the development of electric vehicles, scholars have conducted research on the promotion and development of electric vehicles from the aspects of technology, policy and business models and market promotion in recent years. Shenzhen has succeeded in fostering a distinct government-enterprise cooperation model that not only reduces the financial pressure on the local government to promote electric vehicle use, but also gives enterprises significant leeway to experiment with various innovative business models. The joint result of these efforts is that the commercialization of electric vehicles has become feasible for delivering the public transport service (buses and taxis) in Shenzhen (Li et al., 2015). A real-time charge pricing (RCP) mechanism of electric vehicles was developed based on the system dynamics model (Zhang et al., 2017). Through a comprehensive analysis of the development of electric vehicles in Sweden, the obstacles to the development of electric vehicles were obtained (Vassileva and Campillo, 2016). The impact of policy interventions on the adoption of plug-in electric vehicles was assessed by an agent-based model (Silvia and Krause, 2016; Lakatos et al., 2014). Scenario analysis of the basic principles and procedures was employed, as well as including science and technological development, government policies and laws, consumer consciousness, firm behaviours and other variables in the consideration, to analyse the possibilities for electric vehicles in the future development. It also specifically investigated feasible strategy

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development suggestions using the scenario analysis method (Hsueh, 2013). The domestic conditions of electric vehicles have been introduced (Weinert et al., 2008; Wei et al., 2012). Further, many topics regarding electric vehicles, such as the prospect, industrial policies, key technologies and domestic charging network, have been analysed. Some thoughts and suggestions relating to the development of electric vehicles have been put forward. The potential economic and environmental benefits available from the provision of renewable energy for charging electric vehicles using public electric vehicle service equipment (EVSE) was evaluated (Nienhueser and Qiu, 2016; Daina et al., 2017). Total cost of ownership (TCO) calculations was conducted to study how costs and sales of electric vehicles relate to each other and the role of fiscal incentives in reducing TCO and increasing electric vehicle sales were examined (Lévay et al., 2017). A multiple regression model was developed to explore which factors influence the likelihood of deciding to purchase an electric vehicle. Findings suggest that, controlling for brand, the key success factors were a salesperson's positive attitude and the availability of an electric vehicle on site (Lynes et al., 2017). Based on a stated-choice experiment, the effect of several potential policy incentives on electric vehicle adoption, as well as the influence of socio-psychological determinants were investigated, using constructs of the Trans Theoretical Model of Change (TTM) and the Protection Motivation Theory (PMT) (Langbroek et al., 2016). The development prospect and operation mode of electric vehicle charging facilities have been discussed (Madina et al., 2016). The development model and application prospect of electric vehicles were discussed in the energy Internet environment (Ren et al., 2009; Nezamoddini and Wang, 2016).

At present, the research on the calculation and analysis of the electric vehicle based on the life cycle theory is few. A study from the perspective of life-cycle energy consumption and greenhouse gas emissions based on the GREET platform has been made (Zhou et al., 2013). From the point of view of the consumer, the cost of the life cycle of the electric vehicle has been analysed and the life cycle cost model of electric vehicles has been established (Hu et al., 2016). The opportunities and challenges brought by the development of electric vehicles to the Power Grid Corp have been introduced (Li et al., 2013). By comparing the regional differences in charging and discharging electric vehicles in Japan, the influence of electric vehicles on the environmental load was evaluated (Nansai et al., 2002).

Based on the previous research, this paper puts forward the concept of the life cycle critical price of electric vehicles instead of traditional cars. From the point of view of the life cycle cost, the critical price of electric vehicles as an alternative to traditional vehicles is calculated and analysed in this paper. Finally, the crux of the development of electric vehicles was identified through the analysis of critical price combined.

2. A brief introduction to the theory of the critical electricity price and life cycle cost

The life cycle cost (LCC) refers to the sum of all the costs incurred in the process of demonstration, development, production, operation, maintenance, protection and retirement in the life cycle of an object. It quantifies the various technologies, materials, man-power and organization management measures involved in its life cycle. It can adopt the system engineering point of view, a certain number of methods and computer technology to provide a reliable basis for scientific management and decision making. The life cycle cost theory method, which is widely used in the military equipment industry, was born in the United States and introduced into China in the early 1980s. Since then it has gradually received attention and application in various industries. After nearly 30 years of continuous development, the LCC theory has been widely used in the military, aerospace, construction, logistics and other fields.

To undertake a comprehensive economic evaluation of electric vehicles, the critical electricity price is analysed and evaluated from the consumer point of view, which is equal to the total cost of ownership (TCO) in this paper. Assuming the life cycle cost (LCC) of electric vehicles equals to that of fuel vehicles, this paper uses the current fuel price to calculate the corresponding electricity price which is the critical electricity price. Under the assumption that the cost of electric vehicles is consistent with the cost of fuel vehicles, the critical price is the highest price that consumers can accept. After that, the critical price is compared with the existing electric vehicles' charging electricity price. If the critical price is higher than the sales price, it indicates that it is economic for users to use electric vehicles; conversely, it means electric vehicles are not economic relative to fuel vehicles.

3. A model of the critical electricity price of electric vehicles based on the life cycle cost

In this paper the LCC theory is applied to the analysis of the critical electricity price of electric vehicles. The life cycle cost of electric vehicles can be analysed from two angles: the producer's point of view – the life cycle cost of electric vehicles is composed of the research and development cost, production cost, operation and maintenance cost and disposal cost – and the consumer's point of view – the life cycle cost consists of the purchase cost, use and maintenance cost, fuel cost, carbon tax expenditure and disposal cost. This paper calculates the critical price from the perspective of consumers. When users pay for the scrap disposal costs, they also recover costs from the salvaged equipment. Therefore, the proportion of the cost of scrap processing in the life cycle cost of electric vehicles is very small and will not be considered in this paper.

According to Fig. 1, the life cycle of the vehicle consists of investment stage, use and maintenance stage and recovery stage. In the investment stage, the purchase cost will be paid if one buys cars; in the use and maintenance phase, the maintain cost, fuel cost and carbon tax need be paid. There has not a mature carbon tax system in China, and the carbon taxes don't be existed in the fuel cost. Considering the increasing demand for environmental protection in the future, this paper takes the carbon tax which is independent of fuel price in the use stage. In the recovery stage, the scrap disposal cost need to be paid.

In this section, by considering the cost of purchasing, driving and maintenance and so on, the life cycle critical price model of electric vehicles is constructed. The critical price calculation model is shown below:

$$I_O + N_1 \times \frac{(1+i)^{L_O} - 1}{i(1+i)^{L_O}} = I_E + N_2 \times \frac{(1+i)^{L_E} - 1}{i(1+i)^{L_E}} \tag{1}$$

$$\begin{cases} N_1 = D \times C_O \times (P_O + T_O \times E_O) \\ N_2 = D \times C_E \times P_{E/O} \end{cases} \tag{2}$$

where N_1 and N_2 respectively represent the annual operating costs of fuel vehicles and electric vehicles; i indicates the discount rate; D

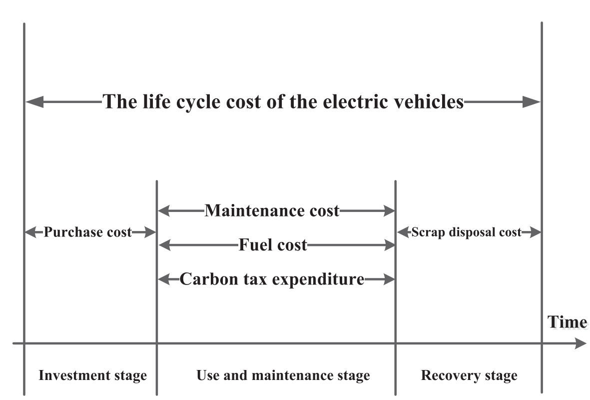

Fig. 1. The composition of the life cycle cost based on the consumer's point of view.