Applied Energy 178 (2016) 567–578

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Life-cycle private-cost-based competitiveness analysis of electric vehicles in China considering the intangible cost of traffic policies

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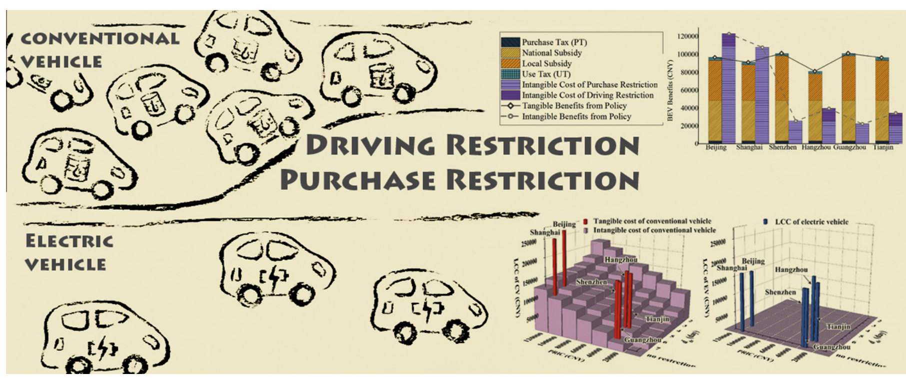
HIGHLIGHTS

- LCCs of BEVs and CVs are compared, considering the effects of traffic policy.
- BEVs are economically competitive with both national and local subsidies.
- Traffic policies have a significant impact on the competitiveness of BEVs.
- The promotion of electric vehicles should prioritize mega-cities.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 February 2016
Received in revised form 18 May 2016
Accepted 20 May 2016

Keywords:
Life-cycle cost (LCC)
Electric vehicle (EV)
Purchase restriction
Driving restriction
Intangible cost
Policy benefits

ABSTRACT

Electric vehicles produce zero tailpipe emissions during operation and have thus been considered a most promising method for providing mobility while reducing the greenhouse gas emissions of the transportation sector in the future. The life-cycle cost of electric vehicles has been widely studied to evaluate their competitiveness compared to conventional vehicles. However, the competitiveness of electric vehicles is highly dependent on government promotion policies, and the effects of non-economic incentive policies are currently difficult to include in life-cycle cost analysis. These non-economic effects are usually measured by the intangible cost. Traffic policies represent typical non-economic incentive policies. In China, electric vehicles are exempted from purchase restrictions (license plate control policy) and driving restrictions; thus, the intangible cost of traffic policies has significant effects on the comparison of electric vehicles and conventional vehicles. In this paper, from the consumers' perspective, the intangible cost of purchase and driving restrictions is modeled and expressed in monetary terms; then, the impact of these non-economic incentive policies are compared with subsidies and other costs of vehicles. Thus, a more comprehensive comparison between electric and conventional vehicles can be provided. Using three selected typical battery electric vehicles and three correspondingly similarly sized conventional vehicles in China, the private life-cycle costs of battery electric vehicles and conventional vehicles are calculated and compared, a parametric variation analysis is performed, and the effects of economic and non-economic incentive policies in different cities are discussed. The comparison shows that, considering the tangible costs of vehicles, battery electric vehicles are not currently economically competitive compared with conventional vehicles, and both national and local subsidies are necessary for battery electric vehicles to compensate the cost gap between battery electric vehicles and conventional vehicles in the short term. However, considering the intangible costs, the advantages of traffic policies are very

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http://dx.doi.org/10.1016/j.apenergy.2016.05.116

prominent in mega-cities but are significantly smaller in second-tier cities. With the increasingly worse traffic and environmental problems China facing, it is suggested that the promotion of electric vehicles in mega-cities be prioritized and that electric vehicle promotion policies based on taxes, subsidies and traffic control be balanced.

1. Introduction

The Paris Agreement – the first-ever universal, legally binding global climate deal – was adopted by 195 countries at the Paris Climate Conference (COP21) in December 2015, wherein it was determined that plans that greatly reduce greenhouse gas (GHG) emissions should be executed by all of the signatory countries. Its strong socio-economic development establishes China as a leading contributor of GHG emissions worldwide; therefore, the reduction of the GHG emissions in China has attracted substantial international attention. The energy consumption of the transportation sector accounts for 20% of the total energy consumption in China [1] and is responsible for 8% of the total GHG emissions nationwide [2]. Because this ratio would be significantly higher in large cities and has become the primary cause of pollution haze [3], the reduction of GHG emissions in the transportation sector is a top priority of the government [4,5]. Because battery electric vehicles (BEVs) produce zero emissions during operation, they have been considered a most promising means of mobility toward reducing the GHG emissions of the transportation sector in the future. The Chinese government believes that the total production and sales of electric vehicles (EVs) will reach 5 million units in 2020 [6]; however, the adoption of BEVs is highly dependent on the consumers. Therefore, the life-cycle cost (LCC) of BEVs from a consumer's perspective (also referred to as the total cost of ownership) is a very important factor influencing the adoption of BEVs.

The LCC analysis and comparison of conventional vehicles (CVs), hybrid electric vehicles (HEVs) and BEVs has been extensively studied [7–12]. The AFLEET (Alternative Fuel Life-cycle Environmental and Economic Transportation) tool was developed by Argonne National Laboratory (ANL) to examine both the environmental and economic costs and benefits of alternative fuel and advanced vehicles [13]; moreover, based on AFLEET, comparisons and optimizations of the combination of different vehicle types have been proposed [14]. Analysis results indicate that, for consumers, EVs do not currently represent a cost-effective mobility option compared to CVs [8,15]. However, policies play a key role in EV penetration; therefore, the impact of government subsidies has been widely discussed [16,17]. Zhao et al. [11] indicated that the LCC of BEVs with central government subsidies is approximately 1.4 times higher than that of comparable CVs, and it is forecasted that BEVs without subsidies likely will not be competitive in China's market before 2031. Similarly, Hao et al. [18] concluded that China's subsidy is quite necessary for BEVs to ensure that they are cost competitive in the short term; in the mid-term of approximately 2015–2020, BEVs could become less or not reliant on subsidies to maintain their cost competitiveness. However, policies do not only include subsidies, but the impacts of non-economic incentive policies are also important and could significantly affect the total cost of the ownership of vehicles.

Traffic policies represent one of the most important policy types among non-economic incentive policies in China [18]. Vehicle purchase restrictions (license plate control policy) and driving restrictions have been adopted in many cities to directly mitigate traffic congestion. To promote BEVs in China, the government announced that BEVs are exempt from purchase and driving restrictions [19]. The impact of purchase restrictions [20,21] and driving restrictions [22–25] has been widely discussed [26]; however, such studies mainly focus on the macro impact of traffic policies such as the growth in the volume of vehicles, traffic congestion mitigation, pollution and fuel consumption reduction. Jiayi and Jianxiao [27] mentioned that, from a consumer's perspective, the marginal benefits of vehicles will be reduced after driving restrictions are implemented; however, the economic intangible costs of traffic policies for personal car users have not been fully studied and are usually omitted in conventional LCC methods because the effects of these non-economic incentive policies cannot be easily quantified.

In this paper, the effects of purchase and driving restrictions are calculated in monetary terms, and a novel LCC model considering these traffic policies is proposed. BEVs are selected for comparison with CVs because BEVs are typical and representative of new energy vehicles and because the promotion policies for HEVs are complex. Six cities, including two mega-cities, namely, Beijing and Shanghai, and four second-tier cities, namely, Shenzhen, Hangzhou, Guangzhou and Tianjin, are selected for our analysis. By using the proposed intangible cost model, the LCCs of EVs are compared with those of CVs considering the traffic policy impact in the six cities, parametric variation analysis is conducted, and the policy benefits for BEVs are better evaluated and compared. This study is expected to provide a more realistic assessment of the competitiveness of BEVs and CVs in the Chinese market and establish a framework for more comprehensive policy analysis toward promoting electric vehicles.

The remainder of the paper is organized as follows. Section 2 elaborates upon the methodology of conventional LCC analysis and proposes a model for the intangible costs incurred by vehicle purchase and driving restrictions. In Section 3, the LCC analysis of BEVs and CVs in China is given, the policy benefits for EVs in different cities are compared and discussed. Parametric analysis of the proposed LCC model is conducted in Section 4. Section 5 contains some concluding remarks, and finally, limitations and future work are presented in Section 6.

2. Methodology

2.1. Vehicle model selection

Three of the best-selling BEVs in China, the BAIC EV200, JAC iEV5 and BYD e6, are selected for our analysis, and corresponding similarly sized conventional models, the BAIC SHENBAO D50, JAC HEYUE A30 and BYD M6, are used as their counterparts. The specifications of the six vehicles are shown in Table 1. The parameters in the table are the official values, and the energy consumption rates are tested under the new European driving cycle (NEDC).

2.2. Framework

The framework of our analysis is shown in Fig. 1. The tangible cost (TC) includes the purchase cost (PC), operating cost (OC) and resale value (RV), and the intangible cost includes the intangible cost of purchase restrictions (PRIC) and the intangible cost of driving restrictions (DRIC). Compared with previous life-cycle private cost models [11], non-economic impacts on the competitiveness evaluation of EVs and CVs are measured by intangible cost in our analysis. The intangible cost of CVs includes the effects of traffic