Transportation Research Part D 56 (2017) 68–84

Contents lists available at ScienceDirect

Transportation Research Part D

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

Electric vehicles for greenhouse gas reduction in China: A cost-effectiveness analysis

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ARTICLE INFO

Keywords:
Battery electric vehicle
Greenhouse gas emissions
Cost-effectiveness analysis
Life cycle assessment
China

ABSTRACT

There have been ongoing debates over whether battery electric vehicles contribute to reducing greenhouse gas emissions in China's context, and if yes, whether the greenhouse gas emissions reduction compensates the cost increment. This study informs such debate by examining the life-cycle cost and greenhouse gas emissions of conventional vehicles, hybrid electric vehicles and battery electric vehicles, and comparing their cost-effectiveness for reducing greenhouse gas emissions. The results indicate that under a wide range of vehicle and driving configurations (range capacity, vehicle use intensity, etc.), battery electric vehicles contribute to reducing greenhouse gas emissions compared with conventional vehicles, although their current cost-effectiveness is not comparable with hybrid electric vehicles. Driven by grid mix optimization, power generation efficiency improvement, and battery cost reduction, the cost-effectiveness of battery electric vehicles is expected to improve significantly over the coming decade and surpass hybrid electric vehicles. However, considerable uncertainty exists due to the potential impacts from factors such as gasoline price. Based on the analysis, it is recommended that the deployment of battery electric vehicles should be prioritized in intensively-used fleets such as taxis to realize high cost-effectiveness. Technology improvements both in terms of power generation and vehicle electrification are essential in improving the cost-effectiveness of battery electric vehicles.

1. Introduction

With rapid economic and population growth, China's vehicle market scale has been increasing dramatically over the past decade, from 2.09 million in 2000 to 23.49 million in 2014, accounting for about 26% of global vehicle sales (State Council, 2000). However, as the vehicle ownership in China is relatively low (125 vehicles/1000 people in 2015) compared with developed countries (300–500 vehicles/1000 people), great growth potential is expected for China's vehicle market.

The rapid growth of China's vehicle market leads to considerable increases of oil consumption, pollutant emissions and greenhouse gas (GHG) emissions (Wang et al., 2015). China's dependence on oil import increased from 30.0% in 2000 to 59.6% in 2014 (National Bureau of Statistics of PRC, 2000). According to McKinsey, China's dependence on oil import will be higher than 70% in 2020, raising concerns about China's national energy security (Krieger et al., 2012). Hundreds of pollutants exist in the emissions of vehicles, threatening the health of urban residents (Pathak et al., 2016). Vehicles are considered to be the primary sources of particulate matter (PM) in most densely populated cities in China. In addition, China was responsible for 27.5% of the world's CO_2 emissions in 2014, ranking the highest globally (Amoco, 2015). GHG emissions from passenger vehicles accounted for roughly 5% of China's total GHG emissions in 2014 (Hao et al., 2015). However, as the growth rate of the vehicle industry is faster than the national

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http://dx.doi.org/10.1016/j.trd.2017.07.025

economy, this proportion will increase as a result of the growth of China's vehicle ownership in the future.

To cope with the issues of national energy security and emissions caused by passenger vehicles, China's policy makers have been seeking alternatives to conventional vehicles, including hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and battery electric vehicles (BEV). Among the alternative technologies, BEVs are generally considered to be a promising option (Yuan et al., 2015). BEVs offer the benefits of replacing oil consumption and there is no emission during the use stage (Zhang and Yao, 2015). Therefore, BEV deployment contributes to addressing the energy security issue from the national level and reducing pollutant emissions in densely populated cities (Wu et al., 2015). With the aim of promoting BEV penetration, the Chinese government has launched a series of policy initiatives, including financial subsidies and tax exemptions. Besides, China has established an ambitious target of 5 million cumulative BEV sales by 2020, implying great growth potential for China's BEV market (State Council, 2012).

Regarding the impact of BEV deployment on GHG emissions in China, extensive studies have been conducted. However, no consensus has been reached yet. Most studies concluded that BEVs have the benefit of reducing GHG emissions in China. However, their results are scattered. Ou et al. estimated GHG emissions of BEVs charged from China's coal electricity, concluding that even if coal electricity is used, BEVs can still reduce life-cycle GHG emissions compared with conventional gasoline vehicles (Ou et al., 2010). Under China's current generation mix, the GHG emissions reduction effect of BEVs is believed to be higher. Zhou et al. compared CO_2 emissions of BEVs in the contexts of several regional power grids in China (Zhou et al., 2013). Their results showed that BEVs reduce GHG emissions by 17.1% at the national level in 2009. On the regional level, the reduction depends heavily on the regional power grids. Huo et al. studied CO_2 emissions of BEVs in 2008 and 2030 (Huo et al., 2010). Their results showed that BEVs do not promise much benefit in reducing CO_2 emissions in China in 2008. In the future, the CO_2 reduction effect of BEVs is expected to be improved. Shi et al. estimated potential of BEVs in reducing GHG emissions in China (Shi et al., 2013). They concluded that from the life cycle perspective, BEVs can reduce GHG emissions by 56% in China. However, a certain studies reached an opposite conclusion that BEVs will increase GHG emissions. Wang et al. conducted a life cycle assessment of internal combustion engine and BEVs in China (Wang et al., 2013). According to their results, BEVs increase GHG emissions by 16.5% in 2009 compared with conventional vehicles. In 2020, they estimated that BEVs will still increase GHG emissions by 11.3%.

In contrast, the GHG reduction potential of BEVs in many developed countries is larger than that in China, mostly because of the domination of coal electricity in China. For instance, Huo et al. compared the GHG emissions of BEVs between China and the U.S. (Huo et al., 2015). According to their results, EVs in California and the northeast states in the U.S. have 30–60% lower GHG emissions than EVs in China. JongRoul Woo et al. estimated the GHG emissions of BEVs in different countries (Woo et al., 2017). Their results showed that BEVs in China have 30% higher GHG emissions than global average.

In spite of the different conclusions from existing studies, it is widely accepted that BEVs have the potential of reducing GHG emissions under cleaner electricity generation. However, the evaluation of GHG emissions reduction needs to be balanced from the economic point of view. Although BEVs may reduce GHG emissions with a cleaner power grid, it probably have higher total cost than conventional vehicles. As there are numerous technologies in reducing GHG emission, it is still in doubt whether BEV is the most economic technology pathway (Ruan et al., 2016; Rezvani et al., 2015). Therefore, total cost analysis of the vehicles is also essential in providing a comprehensive evaluation. Several studies have been conducted on the total cost of BEVs. Wu et al. estimated the total cost of BEV ownership in China from the consumer perspective under nine cases (Wu et al., 2015). The results indicated that the total cost of BEV ownership is highly influenced by driving distance and vehicle class. Under the long driving distance case, BEVs cost less than gasoline vehicles for all vehicle classes. Hao et al. used real-world data to compare the levelized costs of conventional vehicles and BEVs in Beijing (Hao et al., 2015). They concluded that with average driving profiles and an assumed 8-year vehicle lifetime, the levelized cost for conventional vehicles is 1.40 yuan/km while 1.44 yuan/km for BEVs. Zhao et al. estimated the cost of BEVs from both the consumers and society perspectives in China (Zhao et al., 2015). Their results indicated that even with subsidies from the government, the life-cycle cost of BEVs is still about 40% higher than comparable internal combustion engine vehicles. They also predicted that BEVs will not become economically competitive in China until around 2030.

Based on the literature review, it is widely believed that currently the total cost of BEVs is higher than conventional vehicles. The basic rationale behind BEV deployment is realizing lower GHG emissions than conventional gasoline vehicles with higher cost. Under such a circumstance, cost-effectiveness analysis is required to assess BEV's GHG emissions reduction effect more comprehensively. However, few studies have covered this topic. Bickert et al. estimated both the GHG emissions and total private cost of BEVs in Germany (Bickert et al., 2015). According to their study, total GHG emissions can be reduced by BEV deployment in Germany, but the total private cost of BEVs exceeds the cost of conventional vehicles in 2015. Their study is a valuable reference for this study for China. Vliet et al. studied the cost-effectiveness of BEVs in Europe and concluded that the cost in reducing GHG emissions is currently above 1900 €/ton and will drop below 300–800 €/ton in the future (Van Vliet et al., 2011). Their research provided the method framework for conducting cost-effectiveness analysis for BEVs. However, their conclusions can not reflect China's specific situation.

With the aim of filling such a gap, the cost-effectiveness of deploying BEVs for reducing GHG emissions in China's context is estimated. Due to the nonconformity of existing researches on BEVs' GHG emissions, the GHG emissions of BEVs are evaluated from the life-cycle perspective. Afterwards, the life-cycle costs and cost-effectiveness of different vehicles are evaluated under China's localized situation. Moreover, single factor analysis is conducted to get a better understanding of the impacts from the influencing factors. These influencing factors include the coal power share, coal power efficiency, energy density of the battery, learning rate of the battery, vehicle use intensity and gasoline price. Afterwards, three scenarios are defined and compared to present the uncertainty of the results. This paper is organized as follows. The next section describes the research method and data. Following that, the cost-effectiveness estimations under the reference scenario and multiple scenarios are presented. The subsequent section proposes the policy implications for BEV deployment. The final section provides the conclusive remarks.