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The economic competitiveness and emissions of battery electric vehicles in China

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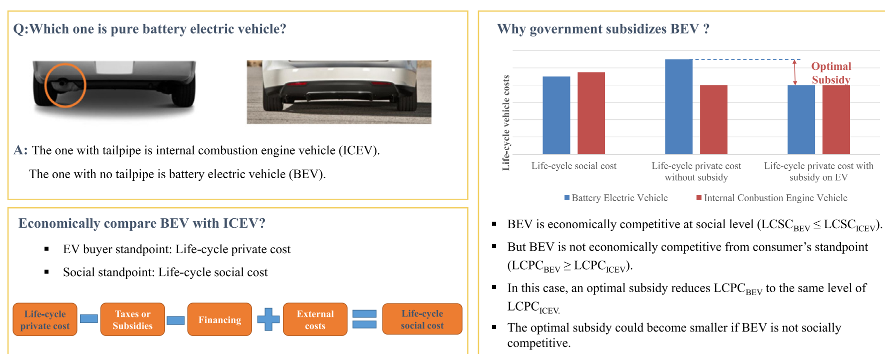
HIGHLIGHTS

- We evaluate the life-cycle cost and emissions of BEVs in China.
- BEVs are not economically competitive compared with ICEVs in the Chinese market.
- The value of emission reductions is small compared with the subsidy on BEVs.
- The CO_2 emission reduction from BEVs is relatively constant over the time.
- BEVs likely will not be economically competitive in China before 2031.

GRAPHICAL ABSTRACT



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ABSTRACT

Electric vehicles (EVs) have high energy efficiency and low pollutant and greenhouse gas (GHG) emissions compared with conventional internal combustion engine vehicles (ICEVs). This study examines the economic competitiveness of battery electric vehicles (BEVs) in the Chinese market. BEVs are compared with ICEVs using benefit-cost analyses from the perspectives of consumers, society and GHG emissions. A life-cycle cost model is developed to evaluate the lifetime cost of a vehicle. The results show that, with central government subsidies, the BEV life-cycle private cost (LCPC) is about 1.4 times higher than comparable ICEVs. Central government subsidies on BEVs will not be cost effective and efficient unless the annual external cost reduction from using BEV reaches $2500 for a compact vehicle or $3600 for a multi-purpose vehicle. That total cost level would imply a carbon cost of more than $2100 per ton. The current life-cycle external cost reductions from using BEV are around $2000–$2300, which are smaller than government subsidies or LCPC differences between BEV and ICEV. Further projections show that BEVs likely will not be economically competitive in the Chinese market before 2031.

1. Introduction

Increasing concerns about high oil prices, energy security, air pollution and greenhouse gas (GHG) emissions in China have led policymakers and the automobile industry to seek alternative fuels for transportation. The electric vehicle (EV) is considered to be one of the most promising technologies to improve energy efficiency and reduce carbon dioxide (CO_2) emissions in the transportation sector [1]. There are three kinds of EVs in the current market, the pure battery electric vehicle[1] (BEV), the conventional hybrid electric

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[1] Pure battery electric vehicles (BEVs) are propelled by an electric motor powered by rechargeable battery packs.

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vehicle[2] (HEV) and the plug-in hybrid electric vehicle[3] (PHEV). Compared with conventional internal combustion engine vehicles[4] (ICEVs), EVs are more advantageous in terms of powertrain efficiency, motor performance, and tailpipe emissions [2].

With the growth of Chinese residents' income and the acceleration of urbanization driven by China's rapidly growing economy, vehicle demand is rising dramatically. The estimated annual average vehicle growth rate for China from 2009 to 2024 is around 13–17% [3]. This rapidly increasing vehicle population is leading to a considerable increase in oil consumption and air pollution. In 2013, China's oil consumption rose by 4%, reaching 10.5 million barrels per day (bbl./d), of which about 6 million bbl./d (about 57% of oil consumption in China) was imported [4]. According to a recent projection from McKinsey, more than 70% of the oil consumed in China will need to be imported in 2020 [5]. Thus, energy security is a growing problem for China, for which, the development of EVs could present a partial solution.

Tailpipe emissions of conventional ICEVs comprise carbon dioxide (CO_2), volatile organic compounds (VOC), total hydrocarbons (THC), carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM). Air pollution is a growing problem in most cities in China. In 2013, there were 58 days of heavy air pollution in Beijing; only 52 days were considered "good" in terms air quality in Shanghai [6]. Transportation vehicles accounted for significant air pollution and zero-tailpipe-gas EVs may considerably contribute to reducing urban air pollution relative to ICEVs. China's GHG emissions are growing rapidly. In 2012, China accounted for 26% of total carbon dioxide emissions in the world [4]. In 2009, the central government announced that it would reduce its carbon intensity by 40–45 percent by 2020 from the 2005 level. Furthermore, it set a target in its 12th Five-Year Plan (2011–2015) to cut energy consumption per unit of GDP by 16 percent while slashing carbon emissions by 17 percent [7]. Around 75% of the electricity in China is generated by coal, an energy resource with low efficiency and high emissions. The "emission factor" of coal is about 30% higher than crude oil and 70% higher than natural gas [8]. Nevertheless, once electricity is generated, the efficiency of the electric motor in terms of propelling a vehicle is much higher than the gasoline or diesel internal combustion engine, which is the reason why EVs can still help reduce carbon dioxide emissions even with coal fired electricity.

The impacts of using EVs on GHG emissions and energy consumption have been investigated and discussed widely. Zhou et al. and Shen et al. examined carbon dioxide emissions of BEVs through a life-cycle analysis [9,10]. The studies demonstrated that BEVs could reduce CO_2 emission by 17–34% compared with ICEVs. Ou et al. [11–13] conducted several studies applying life-cycle analysis on vehicle emissions in China and, like Zhou et al. and Shen et al., concluded that EV development would significantly contribute to CO_2 emission reductions, and that the benefits would be magnified in the future with increasing weight for renewable energy (wind, hydroelectric, etc.) in the electricity generation mix. Hawkins et al. [14] developed a life cycle analysis to assess the global warming potential (GWP) of using EV and ICEV. The study compared existing model Mercedes A-series ICEV with the Nissan Leaf EV under European conditions. The study found that EVs powered by the present European electricity mix offer a 10–24% decrease in GWP relative to conventional diesel or gasoline vehicles assuming lifetimes of 150,000 km. In addition, Donateo et al. [15] compared CO_2 emissions as well as pollutant emissions, including CO, NO_x, VOC, THC and particulate, from EVs and ICEVs based on the analysis on the recharging habits of Italian electric vehicle drivers using data from public recharging infrastructure in Rome. An hourly electricity generation mix was used to obtain the corresponding GHG and pollutant emissions from EVs. The study demonstrated that the seasonal and periodic variation of electricity generation mixes could have significant impacts on emissions and pollution reduction from using EVs. Onat et al. [16] did a similar analysis comparing GHG emissions from EVs, PHEVs and HEVs across 50 states in the U.S., taking into consideration regional electricity generation mixes, driving pattern and vehicle manufacturing impacts. The results indicated that there could be considerable variation of carbon-intensive vehicle rank across states.

In 2009, the central government launched a pilot program for EV deployment in 13 Chinese cities and set the national goal of manufacturing 0.5 million alternative fuel vehicles (AFVs) in three years. However, due to the slow market development and global economic depression, this ambitious goal was not achieved. In 2012, the central government issued a plan that aims for cumulative production and sales of BEVs and PHEVs to reach 0.5 million units by 2015 and 2 million by 2020 [17]. That target represents a fairly large leap given that there were only around 13,500 EVs and PHEVs sold in 2012 [18]. In 2014, the central government is also providing a subsidy up to 60,000 CHY ($9767) to EV consumers.

The motivation of this study is to examine whether BEVs are economically competitive in the Chinese vehicle market and whether current government incentives are cost effective from the perspective of emissions reduction in fostering development of the Chinese electric vehicle market. Two similar studies, Clinton et al. [19] and Sierzchula et al. [20], employed multiple linear regression analysis to model the relationship between government financial incentives and EV adoption. Clinton et al. concentrated on BEVs in the U.S. using state-level data while Sierzchula et al. used 2012 cross-sectional data for 30 countries. Both studies discovered that EV adoption is positively related to government incentives. Other studies have considered the economic competitiveness of EVs from the consumer perspective. Huang et al. [21] assessed PHEV competitiveness in the California market. The study compared several existing vehicle models including a regular gasoline vehicle (Chevrolet Cobalt), a conventional hybrid vehicle (Toyota Prius) and a plug-in hybrid electric vehicle (GM Volt). The results indicated that, even with a $7500 tax incentive, PHEV will not be economically competitive with conventional or hybrid vehicles until the gasoline price increases to $6.26 per gallon. Cai et al. [22] analyzed the lifetime cost of BEVs, PHEVs and fuel cell electric vehicles (FCEVs) in China in the near future. The study used Cruze GM as the base model and applied an additional cost method with a number of assumptions to estimate the costs of BEVs, PHEVs and FCEVs. The study found that compared with the ICEVs, the full lifetime cost of the BEVs, PHEVs and FCEVs are approximately 1.5, 0.5 and 2.3 times more expensive than the base model respectively with an 8 year vehicle lifetime. Several more studies [23–25] analyzed and discussed the economic impacts of using EVs from the perspective of consumers, but most studies in the literature focused on developed regions like the U.S. or Europe. Lin et al. [26] developed a consumer-based vehicle life-cycle private cost (LCPC) model to comprehensively evaluate the cost of owning a vehicle in China. The study examined the market feasibility of HEVs by comparing the LCPCs of a HEV model (Kluger HV) and an ICEV (Highlander SUV) model. The results of the study indicated that the LCPC of the HEV model was roughly the same (about 1.06 times) as that of its comparable ICEV. The

[2] Conventional hybrid electric vehicles (HEVs) can be propelled by both electric motor powered by an on-board generator and internal combustion engine.

[3] Plug-in hybrid electric vehicles (PHEVs) share the characteristics of both conventional hybrid electric vehicles and pure battery electric vehicles allowing them to be propelled by electricity or gasoline.

[4] Internal combustion engine vehicles (ICEVs) are propelled by energy from the burning of fossil fuels (gasoline or diesel) in combustion chambers.