Transportation Research Part D 53 (2017) 334–353

Contents lists available at ScienceDirect

Transportation Research Part D

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

# Projected pathways and environmental impact of China's electrified passenger vehicles

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ARTICLE INFO

*Article history:*
Available online 4 May 2017

*Keywords:*
Electric vehicle
Energy consumption
Renewable electricity generation
GHG emissions
China's in-use fleet
Model forecasting

ABSTRACT

China's rapidly rising number of light-duty vehicles (LDVs) on the road is resulting in serious environmental, energy security, and health problems. This paper examines how electrified vehicles (EVs) can help reduce China's energy demand and greenhouse gas (GHG) emissions in the future. Here EVs include hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and battery electric vehicle (BEV). First, this study uses an Electricity Supply and Emissions Model to forecast the GHG emissions intensity factors of China's electric grid under three renewable generation adoption scenarios. Then, it uses a China FLEET model to project the stock, energy demand, and GHG emissions of the LDV fleet for different scenarios out to 2050.

Results show that there is significant potential for electrification to reduce the energy demand, oil dependence, and GHG emissions of the LDV fleet, because of the high efficiency of EVs, and especially BEVs. Compared to growing the renewable energy contribution to the electricity supply system, expanding EVs in the fleet can occur faster, provided that they become more attractive relative to conventional gasoline vehicles. To help China reverse the rising trajectory of $CO_2$ emissions by 2030, the *aggressive* EV scenario and the *more-renewables* electricity scenario will likely be needed.



## 1. Introduction

As China becomes the largest economy in the world, it has also become the largest market for car sales. However, the tremendous growth of China's vehicle fleet has led to serious air pollution, increasing $CO_2$ emissions, traffic congestion, and energy insecurity. To address these problems, China has taken actions such as raising the fuel economy standards, limiting the number of vehicles on the road, improving the energy efficiency of vehicles, and adopting alternative energy-source vehicles.

This paper focuses on electrified vehicles (EVs) as a way to help reduce the fuel consumption and greenhouse gas emissions of China's light-duty vehicle fleet (LDV), investigating this fleet within the time frame of now to 2050. LDV typically includes cars, SUVs, crossovers, vans (mini-bus), and pick-up trucks. EVs in this study include hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs); our study puts a main focus on PHEVs and BEVs, which together, we designate as plug-in electric vehicles (PEVs). Our study quantifies how various levels of PEV penetration into the in-use LDV fleet, and of renewable electricity in the grid mix impact, over time, China's transportation energy use and greenhouse gas (GHG) emissions rates. In addition, because China aims to reverse the rising trajectory of $CO_2$ emissions

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http://dx.doi.org/10.1016/j.trd.2017.04.007
1361-9209/

by 2030,[1] this paper uses this GHG emissions objective as a benchmark to determine the extent to which EV expansion and renewable electricity adoption could contribute to reaching this $CO_2$ peaking goal.

This paper uses a model of the China in-use LDV fleet (China FLEET model) that adopts a bottom-up approach to forecast the vehicle stock, fuel use, and emissions of the fleet, by tracking vehicle sales, scrappage rates, vehicle distance traveled, vehicle technology improvements, fuel consumption, and emission intensity factors of fuel sources, comparing results among three EV penetration scenarios: *plausible*, *aggressive*, and *passive*.

An Electricity Supply and Emissions Model (ESEM) is used to forecast the electricity generation mix and the average GHG emissions intensity factors of the grid in China out to 2050. To reflect the different levels of aggressiveness in incorporating renewables in the grid, this model adopts three different electricity scenarios: *planned*, *more-renewables* and *less-renewables*. The major output from this model, the emission intensity factor of the grid, is used as an input for the China FLEET model described above.

The contribution of this study is combining the vehicle fleet model together with the electricity supply model, developing different scenarios for both models and assessing their relative importance. This paper evaluates the impact of vehicle electrification on total LDV fleet's energy demand and GHG emissions, by varying the aggressiveness of EV penetration in the fleet and renewables adoption in the grid. Three electricity scenarios with different levels of renewable generation are analyzed with ESEM, and the results, combined with the three EV scenarios, are used as inputs for the China FLEET model. Results from these two models for combinations of these two sets of scenarios show the relative impact, importance and inter-dependency of expanding EV use and cleaning up the grid. Such combined analysis has not been performed previously for China's LDV fleet on a national scale.

This paper also makes detailed assumptions about aspects of the LDV fleet, which have not been captured by previous studies. For example, it divides the BEV category into regular-BEV and micro-BEV to reflect the current trend of strong micro-BEV growth in China's EV industry. It also makes different assumptions for vehicle types categorized into private, non-private, mini-bus and mini-trucks. It tailors assumptions such as vehicle distance traveled and fuel consumption to the different powertrains, for example, micro-BEVs. The China FLEET model allows us to see what assumptions are most critical to achieving significant energy and emissions reductions, and through identifying the year when emissions peak, and at what magnitude, in the different scenarios. This enables us to draw policy implications for the Chinese government.

Several studies have forecast the potential for EVs to reduce the environmental impact of the transportation system. Most of the studies used models that forecast the growth of either the transportation sector as a whole or the LDV fleet, and then they make assumptions about the level of EV penetration in the fleet and forecast its environmental impact. For example, Ou et al. (2010) designed a scenario with high EV penetration, using a bottom-up model to analyze the energy demand and GHG emissions impact for the entire transportation sector under each scenario until 2050. The China Automotive Energy Research Center at Tsinghua University built the Tsinghua Center of Automotive Energy Model (TCAEM) that forecasts the development of the entire automotive sector, and it specifically designed an EV scenario to evaluate how EV penetration changes the energy usage and emissions of the transportation sector (Zhang et al., 2012). They found that EV penetration could greatly improve the efficiency of the automotive energy system and reduce the country's reliance on foreign oil.

Instead of working at the national level, Wu et al. (2012) focused on several regions in China, developing different scenarios of EV penetration and analyzing grid emissions intensities for the regions, to evaluate the impact of EVs' reduction of $CO_2$ emissions from the LDV between 2010 and 2030. They found that in the southern part of China, EVs are more effective in mitigating emissions, while in northern China, due to a high share of coal power in the electricity mix, HEV might be a better option than pure EVs to reduce emissions. Similarly, Zhou et al. (2013) used the GREET-based Tsinghua_LCAM model to forecast the emissions saving per km for PHEV and BEV on regional-level grids, comparing them with that of conventional vehicles in the time period of 2012–2020. They found a difference in emissions savings for EVs powered by different regional grids and, in the future, those reductions due to EV deployment are expected to be larger.

Similar international studies also emphasized the importance of the electricity generation mix. Canals et al. (2016) calculated the global warming potential for EVs in European countries and found that while the current power generation mix in most of these countries is able to accommodate higher EV penetration, the power plants in some top EV selling countries, such as UK and Germany, are such high GHG emitters that an increase of the EVs on the road would not reduce the global warming potential. Jochem et al.'s (2015) study, focused on Germany, also found that the emissions of marginal electricity mix tend to be higher than those of average electricity mix, and therefore controlled recharging is better than uncontrolled recharging for reducing EV emissions.

A small number of studies directly analyzed the growth of EV in China, including a study using the Bass model to forecast the stock of EV from 2011 to 2020, taking into account oil prices, innovation and imitation effects (Zeng et al., 2013). Another study used a dynamic segmentation approach to forecast the market share development of EV in China, capturing patterns distinct from those observed in developed countries through 2050 (Qian and Soopramanien, 2014).

The study conducted by Hao et al. (2011b) is closer to our analysis in terms of its scope as it also focused on the national level, but it did not analyze the different scenarios of EV penetration and grid's renewable energy adoption. They forecast the fuel consumption and emissions of the LDV fleet between 2010 and 2050 with scenarios such as *promoting EVs*. They found

[1] In 2014, President Obama and President Xi signed a U.S.-China joint statement together, in which China announced that it will enable the $CO_2$ emissions to peak by 2030.