Fuel Cycle Environmental Assessment for Electric Vehicles in China

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Abstract. Electric vehicles (EVs) offer the potential for substantial reductions in energy consumption and emissions during the vehicle traveling stage. In considering these benefits, it is important to address concerns of environmental problem-shifting. In addition, while praise has focused on the use phase in comparing transportation options, the power source production is also significant when comparing conventional and EVs. This study develops and provides a life cycle inventory of EVs and applies the inventory to assess the fuel cycle energy consumption and greenhouse gas emissions of the EVs and the internal combustion engine vehicles (ICEVs). The results show that EVs powered by the present China electricity mix offer a 48% decrease in energy use and a 38% decrease in global warming potential (GWP) relative to conventional gasoline vehicles.

1. Introduction

Since 2009, China has become the world’s largest new car producing and consuming countries for three consecutive years, which leads the consumption of road transportation fuel and oil to rise continually. New vehicles annual sales grew from 2.1 million in 2000 to 18.5 million in 2010 in China[1]. The rapid increase of vehicle population aggravates serious energy shortage and air pollution. China imported 240 million barrels of oil in 2010, which is about 55% of oil import dependence[1, 2]. Above 52% of China oil consumption is consumed in transportation sector from 2005, the number reaches 54.4% in 2010[3]. Road transport accounted for 86.32% carbon dioxide emissions of the transport sector in 2008, and the share is rising[4]. From the energy saving trends of the automotive industry, developing the electric vehicles is an inevitable choice for the automotive technology progress and industry upgrading.

As the low energy saving and emission reduction during the electric vehicles (EVs) operation, countries are making effort to carry out the research and development of EVs. China attaches great importance to the development of electric vehicle technologies, and has introduced many policies to support and guide the rapid development of the electric car industry. Under the China EVs development roadmap, the Chinese government hopes to see 0.5 million electric vehicles on the road by 2015 and 5 million by 2020[1]. If the development target materializes, it will account for 5-10% of the domestic new car purchase by 2020[5].

Different from conventional internal combustion engine vehicle (ICEV), the fuel of EVs is electricity and/or conventional fuels. In order to illustrate the fuel cycle and/or Well-to-Wheel
(WTW)[6, 7] environmental impacts of the EVs, the related energy use and emissions from raw resources recovery through fuel production until fuel consumption must be taken into consideration[8, 9]. Many fuel cycle assessment studies have been done in China[10-15]. For instance, Xiaoyu Yan et al.[11] compared the fuel cycle energy use and greenhouse gases (GHG) emissions for ICEVs powered by crude oil based fossil fuels and biomass based biofuels in China. In Ou Xunmin et al. [13], the fuel cycle GHG emissions of coal-to-liquid (CTL) fuel and EVs powered with coal-to-electricity in China are analyzed and compared. However, these studies only analyze the fuels for ICEVs and coal based fuels for EVs. None of these studies includes a detailed quantitative analysis of energy use and GHG emissions from the full fuel life cycle perspective for EVs in China.

Therefore, to assess the full fuel cycle environmental impacts for EVs in China should be performed. This work attempts to indentify the fuel cycle energy use and GHG emissions for EVs in China with the life cycle assessment (LCA) methodology[16, 17].

2. Methodology

2.1. Life cycle assessment
Life cycle assessment is an attempt to address the environmental burden throughout a product's or system's life time (i.e. cradle-to-grave) [16-21]. The LCA identifies energy and material used and wastes and emissions released to the environment, as well as environmental improvements if feasible[22, 23]. This study focuses on the fuel cycle energy consumption and GHG emissions of EVs. This analysis adopts the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) Model[6, 23]. Data and information from 2010 in China are used wherever possible.

Fuel cycle analysis is requisite when comparing different vehicle technologies powered by different fuels, because the energy use and emissions associated with fuel production and distribution can be significantly different[24]. The fuel cycle of vehicle technologies in this study is divided into the Well-to-Tank (WTT) stage and the Tank-to-Wheel (TTW) stage[7, 25], as shown in figure 1. The WTT stage refers to feedstock acquisition and transportation, and fuel production and delivery to the vehicle tank. The TTW stage refers to the fuel usage during vehicle operation.

2.2. Research objective and scope
The objectives of this study are to evaluate the fuel cycle energy consumption and GHG emission effects of a sedan-type EVs, and to compare the impacts of EVs with those of ICEV. Three key types of GHG emissions (CO2, CH4 and N2O) are taken into consideration and the global warming potentials (GWP) for CO2 equivalent (CO2-eq) were calculated assuming a 100-year time horizon according to the IPCC 2007[26]. For CO2, CH4 and N2O, the IPCC factors are 1, 25, and 298 respectively.

The sedan-type EVs technologies assessed in this study include battery electric vehicle (BEV) with a range of 150 km, grid independent (GI) hybrid electric vehicle (HEV), and grid connected (GC) or plug-in hybrid electric vehicle (PHEV) powered with gasoline and electricity from grid. The PHEV considered have an electric range of 30 km and drive afterwards with its ICE fueled with gasoline. For comparison we also consider a sedan-type ICEV fueled with gasoline. The dotted line as shown in figure 1 represents the research system boundary under study. The functional unit of this study is 1 kilometer of vehicle travel in China.
2.3. **Inventory analysis**

2.3.1. **Vehicle assumptions**

In the process of building our data inventory, we made several assumptions. First, we assumed the design of the cars to be exactly the same, excluding the ICEV engine and the EV battery. The total weight of the ICEV used in this LCA study is 1405 kg. The HEV assumed weight is 1460 kg. The PHEV assumed weight is 1679 kg. For the BEV, it is assumed a total weight of 1940 kg, including the vehicle body and the battery. The effective vehicle life assumed for the four vehicles is 250000km based.

The fuel economy of the ICEV is 9.0 L/100km under the New European Drive Cycle (NEDC), corresponding to 26.1 miles per gallon gasoline (MPG), which is comparable to a First Automobile Workshop (FAW) Besturn B70, 6.0 L/100km under the NEDC for the GI hybrid (or HEV) [27], corresponding to 39.2 MPG, which is comparable to a FAW Besturn B70 Hybrid, 16 kWh/100km (132.2 miles per gallon gasoline equivalent (MPGe)) in electric mode and a combined city/highway rating of 6.0 L/100km (39.2 MPG) in hybrid mode for the GC hybrid (or PHEV) [27], which is comparable to a FAW Besturn B50 Plug-in Hybrid, and 16 kWh/100km (132.2 MPGe) for the BEV[27], which is comparable to a FAW Besturn B50 Electric. The PHEV is assumed to operate 60% of its overall operational range in charge-depleting mode and 40% of its overall operational range in charge-sustaining mode. The charging efficiency for the PHEV and the BEV is 80%. The charging energy of the BEV and the PHEV is the China power plant mix in 2010. A final assumption used was the IPCC conversions rates[26] for carbon dioxide (CO2), methane (CH4), and nitrous oxides (N2O) to carbon dioxide equivalents (CO2eq) in our final calculations of total GHG or CO2eq emitted.

2.3.2. **Gasoline assumption**

Life cycle impacts from gasoline include crude oil extraction and transportation, refining and distribution, and combustion to power the vehicle.

Crude oil extraction efficiency is found from National Statistic Bureau of China (NSBC) and is 95.7%[30]. And the process fuel mix of crude oil extraction contains: electricity (22.7%), crude oil (52.6%), coal (6.0%), diesel (14.4%), residual oil (2.5%) and gasoline (1.9%)[28]. Gasoline refining efficiency is assumed to be 90.6%. And the process fuel mix of oil refinery compromises of crude oil (3.5%), coal (24.9%), natural gas (NG) (1.9%), liquefied petroleum gas (LPG) (5.7%), electricity (17.2%), refinery still gas (38.6%), residual oil (6.1%), diesel (0.8%) and gasoline (1.3%)[30].

2.3.3. **Electricity mix assumptions**

This study assumed all charging will be done in China, therefore the current China electricity mix is used for our calculations. Data of the electricity production mix was found from the China Electricity Council[29]. This mix contains: coal (76.9%), hydropower (16.2%), nuclear (1.8%), natural gas (1.8%), wind (1.2%), oil (0.4%), biomass (0.2%) and others (1.5%)[29]. The efficiency of the average
electricity production is 35.9%[29]. There is transmission and distribution loss in the grid. The actual loss as stated in Statistical Bulletin of China National Electric Power Industry was 6.53%[29].

2.3.4. Transportation assumptions
According to China Traffic and Transportation Association (CTTA)[30], the five methods of transportation assumed in the movement of the fuels and raw materials are sea tanker, rail, waterway, pipeline and truck. The sea tanker and waterway utilize residual oil fuel. The rail and truck utilize diesel fuel. The process fuel mix of pipelining contains diesel (20%), residual oil (50%), natural gas (24%) and electricity (6%). We assumed the energy intensities of 25 kJ/(ton•km) for sea tanker, 243 kJ/(ton•km) for rail, 264 kJ/(ton•km) for waterway, 166 kJ/(ton•km) for pipeline, 673 kJ/(ton•km) for truck.

The transportation mode mix and distance of the crude oil are taken from NSBC[28], CTTA[30] and China Communication and Transportation Association (CCTA) [31], and consists of: sea tanker (59.0%, 11000 km), rail (14.7%, 917 km), waterway (52.0%, 250 km) and pipeline (33.4%, 428 km). The transportation mode mix and distance of gasoline transportation are sea tanker (65%, 7000km), rail (39%, 913km), waterway (50%, 1940 km), pipeline (11%, 78km) and truck (100%, 50km) [28, 29, 31]. Since crude oil / gasoline from one source may involve more than one mode for transport, the mode shares defined here are not to be summed across the different modes. Energy consumption and emissions of these modes of transportation were calculated using the GREET model.

3. Results and discussion
Both of the results of the WTT (the production and distribution of feedstock and fuel) and TTW stages (fuel consumed during vehicle operation) are combined to obtain the fuel cycle results for the selected vehicle technologies. The fuel cycle energy use and GHG emission of the evaluated vehicles are presented in figure 2 and figure 3.

As illustrated in figure 2, the fuel cycle energy consumption of the ICEV is about 3841kJ per vehicle traveled kilometer. From the fuel cycle perspective, the HEV, PHEV and BEV respectively have a 33%, 23% and 48% reduction in the energy consumption compared to that of the ICEV.

![Fig. 2. Fuel cycle energy consumption of EVs compared to that of ICEV in China](image_url)

Though the analysis above, we get the following results. The total energy consumption for the whole electric vehicles lifetime decrease obviously comparing with the ICEV. And advanced technology vehicles substantially reduce fuel consumption during vehicle operation. However, the energy consumption of BEV is slightly higher than PHEV during WTP stage, as the electricity of China is dominated by coal-fired electricity and its low efficiency.
Fig. 3. Fuel cycle GHG emission (g CO2-eq / km traveled) of EVs compared to that of ICEV in China

As illustrated in Figure, the fuel cycle GHG emission of the ICEV is about 304 gram per vehicle traveled kilometer. From the fuel cycle perspective, the HEV, PHEV and BEV respectively have a 33%, 17% and 38% reduction in the GHG emission compared to that of the ICEV. And advanced technology vehicles substantially reduce GHG emission during vehicle operation. The GHG emission over the VO is transmitted to the WTT stage.

4. Conclusion
The study shows that EVs powered by China electricity mix offer a 48% decrease in energy use and a 38% decrease in global warming potential (GWP) relative to conventional gasoline vehicles. The energy consumption and GHG emission during the charging for BEV is more than the operation of HEV and PHEV, due to a large percentage of coal-fired electricity, the low electricity generation efficiency and the loss of power transmission in China. In order to promote the energy and emission benefits of EVs in China, environment friendly electricity should be considered by Chinese government. The study indicates that replacing ICEVs with EVs may result in shifting the downstream environmental impacts toward the upstream.

Acknowledgments
This work was supported by the National High Technology Program of China (2011AA11A288) and the Fundamental Research Funds for the Central Universities (JZ2014HGBZ0364).

References
[1] State Council of China. "Twelve Five" national strategic emerging industry development plan. 2012 (in Chinese).
[2] EIA (Energy Information Administration), 2011. International energy outlook 2011. Available from: http://www.eia.gov/forecasts/ieo/index.cfm
[3] China energy statistic yearbook. Beijing: China Statistics Press; 2009.
[4] Cai Bofeng, Feng xiangzhao. China’s low carbon policies and actions for transport sector [J]. Environmental Economy, 2011(10): 38-45.
[5] Chinese Electric Vehicle Market 2020 Outlook. http://www.energytrend.com/China_EV_08042011.
[6] Wang, M.Q., GREET 1.5 — Transportation Fuel-Cycle Model, Volume 1: Methodology, Development, Use, and Results, Volume 1, ANL/ESD-39, Center for Transportation Research, Argonne National Laboratory, Aug. 1999.
[7] JEC (JRC, EUCAR, CONCAWE). Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context. Version 3, Oct 2008
[8] Tom Beera, Tim Grant, David Williams, et al. Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles. Atmospheric Environment 36 (2002) 753-763.
[9] Nada Zamel, Xianguo Li. Life cycle analysis of vehicles powered by a fuel cell and by internal combustion engine for Canada. Journal of Power Sources 155 (2006) 297–310.
[10] Ou Xunmin, Xiaoyu Yan, Zhang Xiliang. Using coal for transportation in China: Life cycle GHG of coal-based fuel and electric vehicle, and policy implications. Int. J. Greenh. Gas Con. 2010, 4(5), 878-887.

[11] Xiaoyu Yan, Roy J. Crookes. Life cycle analysis of energy use and greenhouse gas emissions for road transportation fuels in China. Renewable and Sustainable Energy Reviews. 2009, 12(9), 2505-2514.

[12] Zhang Liang. Study of life cycle energy consumption, environmental emission and economics of coal-based dimethyl ether as vehicle fuel. Shanghai Jiao Tong University, 2007. (in Chinese).

[13] Ou Xunmin, Zhang Xiliang, Chang Shiyan, Guo Qingfang. Energy consumption and GHG emissions of six biofuel pathways by LCA in (the) People’s Republic of China. Applied Energy. 86 (2009) S197-S208.

[14] Zhang Zhishan. Thermodynamic Analysis of Corn Fuel Ethanol Life Cycle System. Tianjin University, 2005, May.

[15] Wei Shen, Weijian Han, David Chock, Qinhu Chai, Aling Zhang. Well-to-wheels life-cycle analysis of alternative fuels and vehicle technologies in China. Energy Policy 49 (2012) 296-307

[16] International Organization for Standardization (ISO). Environmental Management: Life Cycle Assessment — Principle and Framework; ISO 14040-14043, 1997.

[17] International Organization for Standardization (ISO). Environmental Management: Life Cycle Assessments — Goal and Scope Definition and Inventory Analysis; ISO 14041, 1998.

[18] Shuhua LI, Nannan LI, Ying GAO, Jun LI. Vehicle Cycle Environmental Impacts Assessment of a China Passenger Car. 2012 International Conference on Biomedical Engineering and Biotechnology

[19] Hsien H. Khoo, Reginald B. H. Tan. Environmental Impact Evaluation of Conventional Fossil Fuel Production (Oil and Natural Gas) and Enhanced Resource Recovery with Potential CO2 Sequestration. Energy & Fuels 2006, 20, 1914-1924.

[20] Jeroen B. Guinee, Reinout Heijungs, Gjalt Huppes. Life Cycle Assessment: Past, Present, and Future. Environ. Sci. Technol. 2011, 45, 90-96.

[21] Anne-Christine Aycaguer, Miriam Lev-On, Arthur M. Winer. Reducing Carbon Dioxide Emissions with Enhanced Oil Recovery Projects: A Life Cycle Assessment Approach. Energy & Fuels 2001, 15, 303-308.

[22] James A. Fava. A Technical Framework for Life-Cycle Assessment. Society of Environmental Toxicology and Chemistry (SETAC): Pensacola, FL, 1991, 09.

[23] Wang, M., Wu, Y., Elgowainy, A., Operating Manual for GREET: Version 1.7, Argonne National Laboratory. November, 2005.

[24] Michael WANG. Fuel Cycle Analysis of Conventional and Alternative Fuel Vehicles. Encyclopedia of Energy. 2004(2): 771-789.

[25] Adam R. Brandt, Stefan Unnasch. Energy Intensity and Greenhouse Gas Emissions from Thermal Enhanced Oil Recovery. Energy & Fuels 2010, 24, 4581–4589.

[26] S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M. M.B. Tigonr, et al.. Working Groups I: IPCC Fourth Assessment Report-Climate Change 2007. USA, 2007.

[27] China Automotive Information Net. http://www.autoinfo.gov.cn/zhuanti/news/lsay/ayzs/webinfo/2008/08/1217463583290230.htm

[28] NSBC (National Statistic Bureau of China). China Energy Statistic Yearbook 2011. Beijing (China): China Statistic Press; 2011 [in Chinese].

[29] China Electricity Council (CEC). Statistical Bulletin of China National Electric Power Industry 2010. Beijing, 2011-02-23. [in Chinese]

[30] CTTA (China Traffic and Transportation Association). China TransportationStatistic Yearbook 2011. Beijing (China): China Transportation Press; 2011 [in Chinese].

[31] China Communication and Transportation Association (CCTA). China Transportation Statistical
Yearbook. Beijing (China): China Transportation Statistics Press, 2011 [in Chinese].