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A hybrid life cycle and multi-criteria decision analysis approach for identifying sustainable development strategies of Beijing's taxi fleet

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HIGHLIGHTS

- An hybrid approach was proposed for evaluating sustainable strategies of Beijing's taxi fleet.
- This approach was based on the combination of multi-criteria decision analysis methods and life-cycle assessment.
- Environmental, economic and policy performances of multiple strategies were compared.
- Detailed responses of taxi drivers and local residents were interviewed.
- The electric vehicle would be the ideal solution for Beijing Taxi fleet.

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ABSTRACT

To identify and evaluate sustainable strategies of taxi fleet in Beijing in terms of economic, policy, and environmental implications, a hybrid approach was developed through incorporating multi-criteria decision analysis (MCDA) methods within a general life-cycle analysis (LCA) framework. The approach can (a) help comprehensive evaluate environmental impacts of multiple types of vehicles, (b) facilitate analysis of environmental, economic and policy features of such vehicles, and (c) identify desirable taxi fleet development strategies for the city. The developed approach represented an improvement of the decision-making capability for taxi implementation based on multiple available technologies and their performance that can be specifically tailored to Beijing. The results demonstrated that the proposed approach could comprehensively reflect multiple implications of strategies for the taxi fleet in Beijing to reduce air pollution in the city. The results also indicated that the electric vehicle powered with the year 2020 electricity projections would be the ideal solution, outranking the other alternatives. The conventional vehicle ranked the lowest among the alternatives. The plug-in hybrid vehicle powered by 2020 electricity projects ranked the third, followed by the plug-in hybrid vehicle ranking the fourth, and the hybrid vehicle ranking the fifth.

1. Introduction

Across the entire world, few cities have attracted so much attention due to notorious air pollution as Beijing which is the second largest city in China by population (BMBS, 2015). In this city, air pollution is a well-known and multi-faceted problem (Cai et al., 2009; Dong et al., 2012; Hao et al., 2006; Zhang et al., 2007; Zeng et al., 2011). The automotive sector in the city will continue to be an increasingly important part of the economy, posing threats to the air quality in the coming years. It was estimated that automobiles were responsible for approximately 30% of the total air pollutant in Beijing (MEP, 2013). Thus, the potential effects of air pollution will increase along with the constant growth in production and utilization of vehicles within the city. Efforts have been considered in several governmental plans within Beijing, ranging from limiting the total number of vehicles in the city, to limiting the number of days on which the vehicles can operate (Hao et al., 2006). However, much more is needed if there is any chance of reducing the number of the city's smog days without causing too much disturbances on its normal economic

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conditions. Also, considering the large number of taxis in Beijing, efforts including technologies and policies to reduce the emissions of the fleet are highly desired. Moreover, multiple indicators such as those are related to economic, environmental and social conditions need to be considered for identifying and evaluating vehicle mixes and policies. Therefore, it is desired to propose effective approaches for help facilitate decision making regarding the mixes of taxi fleet in Beijing city.

The transportation sector was responsible for more than 40% of the total greenhouse gas (GHG) emission in cities and was identified by the Kyoto Protocol to fulfill global GHG emission reduction targets (Chaturvedi and Kim, 2015; Zhu et al., 2016). To reduce on-road pollution and GHG emissions, many key strategies discussed in the previous literatures lied in the following aspects: (i) urban transportation management for reducing travel demands by passengers (Chen and Haynes, 2015), (ii) vehicle electrification transformation for promoting new technologies of vehicles (e.g., hybrid-, plug-in hybrid-, and electric vehicles) (Zhu et al., 2016), and (iii) fuel efficiency improvement for decreasing energy consumption intensity in vehicles (Chaturvedi and Kim, 2015). For example, Ustaoglu et al. (2016) combined scenario analysis and cost-benefit analysis to assess the potential investments on transportation. Tseng et al. (2013) compared the economic and environmental benefits between hybrid and conventional vehicles.

Although new technologies of the vehicles could effectively reduce GHG emissions in operation, initial investment costs and major battery expenses of the vehicles were found to be major setbacks in limiting the widespread adoption of electric vehicles (EVs) (Cai and Xu, 2013; Gao and Kitirattragarn, 2008; Karabasoglu and Michalek, 2013; Wu et al., 2012). For example, a report in 2012 implied that less than 1% of total number Beijing's taxi fleet was utilizing new technologies (Qiu, 2012). Concurrently, the electricity, the new technology based vehicles consumed, was primarily generated from coal-fired power plants with high GHG emissions in China (Gallagher et al., 2015). As Karabasoglu and Michalek (2013) stated, operational costs and GHG emissions throughout the life-cycle stages of new-technology vehicles could be major factors regarding their sustainable development. Thus, it is important to consider the environmental and economic policies associated with new technology based vehicles in a life cycle perspective (Kelly et al., 2012; Traut et al., 2012). Many studies were thus undertaken for sustainable development and environmental impact assessment of multiple vehicles in the framework of life cycle analysis (LCA) (Cooney et al., 2013). For example, Abdul-Manan (2015) analyzed GHG emission features between electric vehicle and internal combustion engine vehicles based on Monte Carlo stochastic simulation in the life cycle analysis (LCA) framework. In terms of taxi fleet, a few studies were performed by LCA in comparison with different technologies (Baptista et al., 2011; Vedrenne et al., 2014). For instance, Baptista et al. (2011) assessed energy consumption and CO_2 emission of London taxi fleet based on multiple vehicle technologies in a LCA perspective. Also, as the Society for Environmental Toxicology and Chemistry (SETAC) argued, effective tools should be combined with the LCA framework in order to facilitate environmental decision making in competing decision objectives (Yue et al., 2014). In detail, the adoption of many multi-criteria decision analysis (MCDA) methods in the LCA framework can facilitate the comparison of new-technology vehicles with conventional ones in consideration of environmental impacts and operational costs. Among many MCDA methods, technique for order of preference by similarity to ideal solution (TOPSIS), simple additive weighting (SAW), and elimination and choice expressing reality III (ELECTRE III) were widely used by many researchers (Cavallaro, 2010; Milakis and Athanasopoulos, 2014; Tan et al., 2011; Xu et al., 2011). However, there was a lack of research that could bring multiple MCDA methods into an LCA framework to help comprehensively evaluate environmental and economic features of Taxi fleets.

Therefore, the objective of this research is to analyze multiple scenarios for sustainable taxi implementation based on evaluation of their life-cycle environmental effects and economic costs as well as current and future policies pertaining to the taxi fleet in Beijing. Environmental impacts of multiple vehicles (i.e., conventional, hybrid, plug-in hybrid, and electric vehicles) will be assessed in the framework of life-cycle analysis (LCA). Environmental, economic and policy reviews for each vehicle type will be conducted, detailing the costs of ownership and operation as well as future traffic policy and regulation in Beijing. Moreover, taxi drivers and local residents will be interviewed for collecting information and data. Such information and data will be coupled with LCA results and be analyzed through the adoption of several multi-criteria decisions analysis methods to identify the best-case scenarios for facilitating sustainable taxi technology in Beijing. The results will provide support for decision making in taxi implementation based on multiple available technologies and their performances specifically tailored to Beijing. In essence, it will provide a comprehensive evaluation for environmental sustainability of each vehicle type, as well as the major economic and relevant policy for analyzing the adoption of hybrid, plug-in hybrid and electric vehicles in Beijing.

2. Overview of Beijing's taxi fleet

Recently, there have been over 69,000 registered taxicabs in Beijing. The taxi fleet in the city accounts for a substantial percent of the operating vehicles in the city (Cai and Xu, 2013). Taxi companies rapidly opened and expanded in the late 1980s (Geng and Mozur, 2013). Within the past ten years, the number of taxis operating in Beijing has stayed relatively stable (Table S1 of the Supporting material).

Currently, the taxi fleet in Beijing mainly consists of conventional fossil-fueled vehicles. The most popular model is Hyundai Elantra according to governmental reports and survey of this research (see Section 3.1 and Supporting material). The model is manufactured in Beijing, and is the third generation's body style (international production years 2001–2006), which only remains in production for the Chinese and Venezuelan markets (Feijter, 2012). The vehicles are powered by a 1.6–1.8 liter gas engine and have a curb weight of 1,200 kg. Fuel consumption of the vehicles is 7.69 L/100 km according to the survey (Cai and Xu, 2013). With gasoline producing 2.3 kg of CO_2 per liter of fuel burned (Samaras and Meisterling, 2008), a single vehicle can produce more than 85 kg CO_2 in one day's driving. When considering the total emissions of taxis together as a fleet, the scale of the pollutants becomes so large as to warrant substantial environmental improvement through implementation of existing and developing technologies (Anwar et al., 2013; Rahman and Kim, 2012).

Because new-technology vehicles have not yet widely adopted in Beijing's taxi fleet, their environmental impact and economic cost assessment should be conducted based on average level of the typical vehicles in China for future decision-making support. In this study, the typical new-technology vehicles are described as following: (a) a late model Toyota Prius is chosen as a typical hybrid vehicle. The battery pack weighs 55 kg, and its electric motor is capable of producing 27 kW of auxiliary power. It is coupled with a 73 kW, 1.8-liter gasoline motor. Its average fuel consumption is 4.76 L/100 km, under similar driving conditions in New York City (Cai and Xu, 2013; Karabasoglu and Michalek, 2013); (b) the model of BYD Qin is chosen as a typical plug-in hybrid vehicle. The vehicle contains an 80 kg lithium-ion battery, which is capable of producing 60 kW of power. Meanwhile, the vehicle also has a 1.8-