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Battery electric vehicles in Japan: Human mobile behavior based adoption potential analysis and policy target response

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HIGHLIGHTS

- BEV adoption analysis with 1.6 millon people for 3 years travel behavior data is developed.
- Human travel mode detection model and travel habit clustering model are proposed.
- Diverse consumption attitudes are taken into consideration.
- A novel weighted vehicle adoption potential metric is introduced.
- The detailed advises for policy target response are presented.

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ABSTRACT

With the pressing demand of climate change mitigation, the rapid technological development and market adoption of battery electric vehicles are imperative. However, the diverse consumption attitudes and their interactions, which are rarely considered, can significantly affect the adoption potential of battery electric vehicles. On the basis of three years of global positioning system data of 1.6 million people, we estimated the travel and adoption demands of battery electric vehicles in Japan considering diverse consumption attitudes. Under the current construction conditions for public charging systems and charging technologies, the adoption potential of battery electric vehicles may not be as promising as previously expected, and the government still faces great pressure to respond to the market share target. Given the current level of battery technology, technical and policy improvements such as fast charging, reducing the production cost, perfecting the public charging infrastructure, and increasing purchasing subsidies were found to be more effective than improving the battery capacity at increasing the adoption potential of battery electric vehicles.

1. Introduction

The current global energy market is in a transition period. Driven by technological advances and environmental needs, energy consumption is taking a turn towards clean and low-carbon energy [1]. Many countries are preparing to set a time at which internal combustion engine vehicles (ICEVs) will exit the market. As the world's third-largest economy, Japan has a high demand for energy. The annual demand for primary energy is 445.3 million tons of oil equivalent, and transportation accounts for 24.1% of the total energy consumption [2]. After the Fukushima Daiichi nuclear disaster, Japan increased its imports of natural gas and crude oil in the short term to make up for the power shortage. However, this resulted in more carbon emissions and increased the price of fossil fuels [3]. At present, Japan is restarting some of its nuclear power plants and readjusting its energy structure to reduce carbon emissions and balance its energy self-sufficiency [4]. These factors offer new opportunities for the development of the market for battery electric vehicles (BEVs) [5]. Meanwhile, the Japanese government is also vigorously promoting the development of new energy vehicles [6]. The promotion of BEVs would satisfy the requirements for reducing carbon emissions and relieve Japan's dependence on fossil fuels [7].

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Nomenclature

BEV	battery electric vehicle
CI	charging interval
DAP	daily vehicle adoption potential
DCA	diverse consumption attitude
ELVT	extremely low-frequency vehicle traveler
GPS	global positioning system
HHVT	holiday high-frequency vehicle traveler
ICEV	internal combustion engine vehicle
LVT	low-frequency vehicle traveler
HVT	high-frequency vehicle traveler
OHVT	overall high-frequency vehicle traveler
SR	satisfaction rate of the daily driving travel demand
VCR	velocity change rate
WAP	weighting vehicle adoption potential

However, at present, most BEVs have been designed with a focus on specific uses such as short-distance low-speed use, urban public transport, and tourism purposes [8]. The widespread use of BEVs is still hindered by insufficient technological advancements [9], infrastructure facilities [10], and policy support, and they do not meet the expectations of consumers [11]. The key technologies restricting the marketization of BEVs are those for efficient battery energy storage [12] and quick charging at a low temperature [13]. In addition, the high prices of electric motors, batteries, and motor control systems increase the production cost of BEVs compared to ICEVs, which limits the market potential of BEVs to a certain extent [14]. To promote the electrification of BEVs, the charging and maintenance infrastructure systems need to be improved [15]. The sophistication of these support service systems will directly affect the demand for BEVs [16]. Meanwhile, the BEV market is still immature, and the government has been investigating policies related to the usage, market, and subsidy of BEVs [17]. Further, the promotion of BEVs will impact the development and operational efficiency of urban areas [18]. Thus, the development of BEVs is a challenging sociotechnical issue [19].

Conducting an adoption-potential analysis based on BEV technical indexes is key to connecting the social and technical aspects of this issue. This analysis contributes to the determination of the sensibilities of the technical and economic indicators of BEVs, which can guide BEV companies and the government for the planning of the construction of infrastructure facilities and the creation of policies based on the current demand and technical level.

Many scholars have conducted studies on this issue and provided new research perspectives and experimental methods for analyzing the market potential and policy-making of BEVs [20]. For example, on the basis of GPS data from 744,788 driver trips, Needell et al. [21] analyzed the impact factors for automotive energy consumption by considering the second-by-second velocity and ambient temperature. From the perspectives of the daily vehicle adoption potential (DAP) and gasoline substitution potential, they analyzed the potential for the widespread electrification of personal vehicle travel in the United States. They concluded that affordable BEVs can replace 87% of vehicles driven on a given day without recharging. Li et al. [20] introduced choice experiment to analyze the impact of personal carbon trading on BEVs adopting decision and compared this incentive with other policies. The results showed that except for government subsidy, the personal carbon trading was more powerful than other policies. Zhao et al. [22] proposed a life-cycle cost and emissions model for BEVs in China. The results showed that until 2031, BEVs are not economically competitive compared with ICEVs in the Chinese market. Palencia et al. [23] took japan as an example, proposed a ‘two-step’ approach to estimate the optimum market penetration of lightweight and electric-drive vehicles in the long-term and the impact on the light-duty vehicle fleet. They found ICEVs and hybrid electric vehicles dominate in the Base scenario, fuel cell hybrid electric vehicles dominate when low cost is prioritized and BEVs occurs when low CO2 emissions are prioritized. Neaimeh et al. [24] analyzed 90,000 fast charge events in the UK and the US and 12,700 driving days collected from 35 BEVs in the UK. The found that fast chargers could help overcome perceived and actual range barriers, and greatly increase the adoption rate of BEVs. Current studies have mainly just chosen one aspect of consumption attitudes to make the comparison between BEVs and ICEVs. Nevertheless, the interactions between those aspects are usually ignored. Due to technical, travel cost, and policy differences (such as restricting the travel time and area of ICEVs, increasing the taxes of ICEVs and fuel, financial subsidies for BEV purchases, and government guidance), BEVs and ICEVs have multiple differences regarding the economy, convenience, traveling comfort, environmental protection, and personal subjective evaluation [25]. Strong interplay will exist between the promotion process for BEVs and the diverse consumption attitudes (DCAs) [26], making adoption analyses and policy planning for BEVs more complex. Therefore, some new questions are worth discussing further. Which factors mainly affect the adoption potential of BEVs? What are the sensitivities and interaction of such factors to the adoption potential of BEVs? And based on those, what effective policies should be put forward by the government to respond to the proposed target?

Here, on the basis of smartphone GPS data from approximately 1.6 million people in Japan over a three-year period, we analyzed the characteristics of human mobile and travel mode preferences during different periods (working days and holidays). We quantitatively derived a statistical classification for vehicle travel behavior. For each classified group, we performed an analysis of the adoption potential of BEVs with multiple dimensions. Finally, policy measures are suggested for the Japanese government to respond to the proposed target.

The contributions of this work are shown as following:

(1) On the basis of three years of GPS data of 1.6 million people, we estimated the travel and adoption demands of BEVs in Japan;
(2) Diverse consumption attitudes of BEVs are taken into the consideration which are also proved to have great impact on the conclusion;
(3) Human travel mode detection model and travel habit clustering model are design to reveal the multiple energy consumption behaviors in human travel;
(4) A new metric, weighted vehicle adoption potential, is proposed to indicate the expectation of satisfying the driving travel demand;
(5) The results show that the adoption potential of BEVs may not be as promising as previously expected, and the government still faces great pressure to respond to the market share target for BEVs.

The remainder of this paper is organized as follows. In Section 2, the data sources of our study are introduced. The two main data-mining methods for travel behaviors—human travel mode detection and travel habit clustering—are proposed in Sections 3 and 4. Section 5 describes the metric definitions used in the future discussion. Section 6 presents the final results solved by proposed methods and metrics. The conclusion is provided in Section 7.

2. Data sources

To address the problem of real-world human mobility, in Japan, NTT DOCOMO INC collected data for an anonymous GPS log dataset, called “Konzatsu-Tokei (R)”, from about 1.6 million mobile-phone users, totaling 30 billion GPS records, over a three-year period from August 1, 2010 to July 31, 2013. “Konzatsu-Tokei (R)” Data refers to people flows data collected by individual location data sent from