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Forecasting electricity demand of electric vehicles by analyzing consumers' charging patterns

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ABSTRACT

The spread of electric vehicles (EVs) and their increasing demand for electricity has placed a greater burden on electricity generation and the power grid. In particular, the problem of whether to expand the electricity power stations and distribution facilities due to the construction of EV charging stations is emerging as an immediate issue. To effectively meet the demand for additional electricity while ensuring the stability of the power grid, there is a need to accurately predict the charging demands for EVs. Therefore, this study estimates the changes in electricity charging demand based on consumer preferences for EVs, charging time of day, and types of electric vehicle supply equipment (EVSE) and elucidates the matters to be considered for constructing EV infrastructure. The results show that consumers mainly preferred charging during the evening. However, when we considered different types of EVSEs (public and private) in the analysis, people preferred to charge at public EVSEs during the day. During peak load time, people tended to prefer charging using fast public EVSEs, which shows that consumers considered the tradeoffs between the full charge time and the price for charging. Based on these findings, this study provides key political implications for policy makers to consider in taking preemptive measures to adjust the electricity supply infrastructure.

1. Introduction

Since the Paris Agreement, countries around the world have started making various efforts to reduce greenhouse gas emissions; in particular, by expanding the supply of electric vehicles (EVs). An EV is defined as a vehicle that has a battery and uses electricity supplied from an external power source to operate.[1] As of 2015, 1.26 million EVs were in use worldwide, about 100 times more than in 2010. In Norway, the Netherlands, Sweden, Denmark, France, China, and the United Kingdom, the market share of EVs has exceeded 1% (IEA, 2016).

With the expansion of EVs, their demand for electricity has increased rapidly, augmenting their influence on the nation's electric

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[1] The types of EVs are categorized into all-electric vehicles (AEVs) and plug-in hybrid electric vehicles (PHEVs). AEVs run only on electricity and store electric energy in a battery. AEVs include battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs). BEVs receive electricity by connecting to the power grid and storing it in batteries, while FCEVs produce electricity using a fuel cell powered by hydrogen. PHEVs run on both electricity and petroleum-based fuel. PHEVs use electricity to power an electric motor and petroleum-based fuel to power the internal combustion engine. They plug into the power grid to charge batteries (U.S. Department of Energy, 2017).

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power generation system and the power grid.[2] In particular, governments are especially concerned about the effect of the additional electricity demand from EVs on peak load. Depending on the size of the power load from EV charging, there may be a need to expand or transform the existing power generation portfolio.

In the case of Korea, EVs currently account for only 0.2% of the automobile market (IEA, 2016). However, the Korean government is currently encouraging ownership of EVs by providing subsidies, tax exemptions, and other monetary incentives for individual consumers. As of 2016, the Korean government was providing up to $21,900 in subsidies to individual EV buyers, which is four times higher than those provided by the French, British, and German governments (IEA, 2016; Ministry of Environment, 2016). The main goal of the Korean government is to significantly expand the EV market by 2020. To improve the public charging infrastructure, the Korean government plans to install various types of electric vehicle supply equipment (EVSE) in public locations such as apartment complexes, restaurants, and cafés, with the ultimate goal of constructing a charging infrastructure to enable EVs to operate nationwide[3] (KEMRI, 2015).

Under these circumstances, the diffusion rate of EVs in Korea will gradually increase, leading to greater demand for electricity and the charging infrastructure. However, there is a possibility that the existing power grid will not be able to manage the increased electricity demand when there are additional EVSEs and EVs. In particular, the current power grids in areas that experience a considerable amount of traffic but have no significant electricity demand will have difficulties coping with the increase in demand. As a result, the government may have to expand transmission lines or transform the current power generation portfolio to ensure the stability of the power grid.

It is essential for policy makers to grasp the magnitude of potential electricity demand resulting from EV usage to effectively cope with changes in grid systems caused by EVs. To accurately predict the effects of the new demand on the grid constraint, consumers' preferred charging patterns should be taken into consideration. A charging pattern represents each consumer's preferred time, location, and type of EVSE for their EV. It is possible to evaluate how the additional electricity demand will be distributed throughout the day by analyzing consumers' preferred charging time. Moreover, analyzing consumers' preferred types of EVSE allows to identify the electricity demand on each type of EVSE at a particular time of day.[4] Hence, analyzing consumers' charging patterns is crucial for accurately estimating the additional grid constraint from EVs, and providing a guideline for future energy policies.

Thus, this study analyzed consumers' preferences of EVs, charging locations, types of EVSEs, and charging times of day to estimate the potential size of additional electricity demand derived from expansion of EVs. In addition, we discussed impacts of the additional electricity demand on energy systems in Korea and derived policy implications associated with EV expansion. To this end, we conducted a survey that included two discrete choice experiments[5]. By analyzing the results from the first discrete choice experiment, we were able to construct viable EV expansion scenarios and estimate their electricity demands. From the results of the second experiment and responses from the multiple choice questions, we were able to identify changes in charging demands by time of day and type of EVSEs. By combining the analyses and applying different scenarios of EV expansion, we predicted how additional electricity demands from EV usage change throughout the day for the different types of EVSEs.

The remainder of this paper is organized as follows. Section 2 reviews previous research on the effects of diffusion of EVs on the power grid, and research analyzing consumers' EV charging patterns. Section 3 provides an overview of the research model and explains the design of the discrete choice experiments. Section 4 describes the survey data used in the analysis, and presents the estimated electricity demand from EV charging by time of day and type of EVSEs. Finally, Section 5 summarizes the study, emphasizing its key findings and significance, discusses its limitations, and provides future research directions in the field.

2. Literature review

Many of the previous studies related to EV focus on the diffusion of EVs and its economic and environmental impacts. Some recent studies analyze the impact of the growing EV market on the power grid, and these studies can be categorized into two types: those that analyze the total impact of additional electricity demand from expanding the EV market on the power grid, and those that analyze the charging patterns of consumers to analyze the effect of EVs on the power grid.

The studies that analyzed the impacts of the EV market on the power grid used different estimation methods to simulate the diffusion rate of EVs and the additional electricity demand. Based on the simulated demand of EVs, these studies applied consumers' electricity demand data, the average voltage capacity of EV batteries, or assumed changes in the total electricity consumption level to estimate electricity demand of the EV market. The resulting electricity demand's impact on the national, or state-wide, power grid was analyzed to derive the ideal, efficient, and optimal power generation portfolios (Cho et al., 2004; Heinrichs and Jochem, 2016; Jenkins et al., 2008; Mets et al., 2010; Putrus et al., 2009; Qian et al., 2011; Sundstrom and Binding, 2011; Yilmaz and Krein, 2013).

[2] Qian et al. (2011) estimated that if the market share of EVs exceeds 10%, daily peak demand for electricity increases by 17.9%.

[3] In 2015, there were about 26 public EVSEs installed for every 100,000 people in Korea. This is much smaller than 246, the figure used in other countries (IEA, 2016). Also, current EVSEs are mainly concentrated in metropolitan areas or islands, and, as a result, the actual availability at the national level is even lower.

[4] EVSEs are categorized into two types: public and private. Public EVSEs are usually open to the public (can be shared with others) and installed in public locations, such as apartment complexes, restaurants, stores, cafés, public parking lots and commercial buildings. On the other hand, private EVSEs are usually owned by individuals or families (cannot be shared with others) and installed in private locations, such as homes and personal spaces. Under this criteria, EVSEs in parking lots of commercial buildings (working places) can be classified as public EVSEs like EVSEs in public parking lots. For EV drivers, charging their EVs at public and private EVSEs will feel entirely different since most countries including Korea have different electricity pricing systems on commercial (public) and residential (private) regions.

[5] Consumers' stated preferences can be analyzed by conducting discrete choice experiments that enable researchers to quantitatively estimate the part-worth of consumers for attributes of products or services (Shin et al., 2014; Woo et al., 2017a).