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Evaluating a business model for vehicle-grid integration: Evidence from Germany

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ABSTRACT

Intelligently managing the charging processes of electric vehicles is generally considered to be a promising method of supporting the integration of volatile renewable energy sources into the power grid. We analyze this concept from an economic perspective by developing and evaluating a business model for vehicle-grid integration. Specifically, we investigate the case of parking garage operators using the electric vehicles located at their facilities to provide reserve energy for frequency regulation. We evaluate revenues and cost structures using extensive real-world data sets on the German market for frequency regulation, on battery states of charge at different times of day, and on occupancy rates of parking facilities. We find that possible revenues, given current market conditions, are inferior to investment costs for charging and IT infrastructure. Even if the operator installs these features to enable customers to charge their vehicles for a fee, it would be more profitable to focus on this service and charge batteries immediately when the vehicles enter the garage instead of delaying charging for frequency regulation. Overall, our results illustrate that studies on the relationship between electric vehicles and the integration of renewable energy sources require a closer look at the associated business models to derive robust economic and policy implications.

1. Introduction

During the past decade, electric mobility has received attention as a promising way to reduce transportation-related carbon emissions. However, actual sales figures are only slowly increasing, often depending on national subsidy schemes to bridge the price difference between electric and conventional vehicles. A proposed strategy to soften the financial strain on prospective customers is to use electric vehicles to buffer energy generated by intermittent renewable sources through intelligent charging and discharging. The idea is intriguing since their dependence on exogenous factors, such as wind or sun, is a crucial drawback of many renewable energy sources. Furthermore, cars are generally only used during a small portion of the day, such that electric cars could be used to store energy and return it to the grid as needed during the remaining hours. Similarly, EVs could be charged primarily during times of high supply of renewable energy within the power grid. In either case, the owners of these electric vehicles (EVs) would receive a monetary compensation for this grid-stabilizing service. Thus, the financial burden for prospective buyers is decreased. At the same time, the grid integration of renewable energy sources is improved, resulting in a win-win situation for vehicle owners and grid operators.

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In this paper, we investigate the question of why the concept of vehicle-grid integration (*VGI*, California ISO, 2014) that includes such grid services has not yet taken root in the real world, despite these optimistic prospects, political support, and extensive research efforts (e.g. Brooks, 2002; Kempton and Tomić, 2005a,b). While most past research thoroughly analyzes the technical feasibility of such a scheme, economic analyses are often based on extensive assumptions. This reliance on assumptions results in a high variance of expected revenues, ranging from a few dollars (Vattenfall Europe Innovation GmbH et al., 2011) to several thousand dollars (Kamboj et al., 2011) per car and year—differences that cannot be explained by variations in market design and degree of competition alone. By contrast, we approach the topic by considering a business model that is deemed *viable for VGI* within the literature. In that context, various studies have used parking garage operators as intermediaries in VGI schemes (e.g. Tulpule et al., 2011; Chen et al., 2012, 2013; Sanchez-Martin and Sanchez, 2011). We extensively draw on literature concerning business models to further investigate this proposal (e.g. Osterwalder, 2004; Alt and Zimmermann, 2014; Veit et al., 2014). In a second step, we discuss the associated costs and simulate the revenue streams for such a VGI implementation based on real-world data. We conclude our analysis by discussing the managerial and policy implications of the results.

2. Background and related work

During the past decade, the transportation sector has been undergoing a steady but, nonetheless, radical shift as combustion engines are increasingly replaced by electric motors. This development is particularly evident for privately-owned vehicles, where a switch to electric mobility is often subsidized by the government. The reasons for the appeal of electric mobility can be found in decreased emissions of pollutants and noise, resulting in an improved quality of life in urban centers around the world. Naturally, the increasing electrification of mobility, along with the necessary preconditions and resulting impacts, has been accompanied by research efforts in a wide variety of disciplines. These include engineering (e.g. Lopes et al., 2011; Clement-Nyns et al., 2010; Sortomme et al., 2011; Tomić and Kempton, 2007; Saxena et al., 2015), management and operations research (e.g. Mak et al., 2013; Avci et al., 2014; Glerum et al., 2014; Chung and Kwon, 2015; Flath et al., 2014), policy research (e.g. Galus et al., 2012; Lemoine et al., 2008; Andersen et al., 2009; Sovacool and Hirsh, 2009; Wan et al., 2015), and research on the environmental benefit (e.g. Hromádko and Miler, 2012; Gould and Golob, 1998; Zhang et al., 2013; Tarroja et al., 2014).

In the studies on electric mobility, the link to renewable energy sources is particularly noteworthy. On the one hand, electric vehicles substantially contribute to a reduction in CO_2 emissions only if the energy used to power the vehicles is largely generated by renewables (Faria et al., 2012, 2013; He and Chen, 2013). Faria et al. (2012), for instance, conduct a well-to-wheel life cycle analysis and calculate that battery-electric vehicles create only half the emissions of internal combustion engine vehicles, even with the current EU energy mix. On the other hand, many renewable energy sources, such as solar and wind power, are subject to exogenous factors and intermittent generation. As a result, they are difficult to align with energy demand. Intelligently charging and discharging plugged-in electric vehicles may contribute to a solution of this problem by using them as energy storage devices (Richardson, 2013; Ekman, 2011). Furthermore, providing grid services may open additional revenue streams to EV owners that help compensate for the initial cost difference between conventional and electric vehicles (Lave and MacLean, 2002; Peterson et al., 2010). These synergies between electric mobility and renewable energy generation have resulted in extensive research on VGI concepts.

VGI generally assumes that the storage capacity of multiple electric vehicles is aggregated by some intermediary entity and offered on an energy market. One of the first pilot projects on this topic was realized by Brooks (2002). He found that EVs are well suited to frequency regulation due to their short ramp-up time and negligible costs during periods of idleness. Frequency control (or regulation) is a perpetual process that seeks to negate demand or supply shocks in the power system (Beck and Scherer, 2010). It also refers to the energy market where reserve energy used for this process is traded. Brooks (2002) calculates annual gross revenues per EV from USD 1000 to USD 5000, depending on individual driving activities.

Kempton and Tomić (2005a,b) build upon Brooks' work and lay the theoretical and conceptual foundations for the work on VGI developed during the following decade. They particularly focus on vehicle-to-grid (V2G) applications, which allow for a bidirectional energy flow between the power grid and electric vehicles. In a study of Californian energy markets, they identify the markets for frequency regulation and spinning reserves as the most profitable. However, they note that they would be saturated if just three percent of the vehicle fleet in California would switch to electric and offer their storage capacity to those markets. Given the low current adoption rates of electric mobility, frequency control is nonetheless still the most appealing market and will be the focus of this paper.

In a pilot study, Kempton et al. (2008) use a single EV to support frequency regulation in the PJM market. They find that V2G-capable electric vehicles can provide valuable ancillary services. This is confirmed by Kamboj et al. (2011), who further highlight the short response time of EVs as the main advantage over traditional regulation mechanisms. They estimate annual revenues ranging between USD 1200 and USD 2400 per vehicle. However, they assume that vehicles participate in regulation for 15 h a day on average and set the price of regulation energy to be twice the normal value. The impact of these assumptions becomes evident when contrasted to the results from the *Mini E Berlin* field test (Vattenfall Europe Innovation GmbH et al., 2011). In this study, a fleet of 50 EVs is investigated, with the authors assuming that vehicles only contribute to regulation for four hours a day. The calculated revenues are, at EUR 34 (about USD 40) per vehicle and year, substantially lower. Evidently, Kamboj et al. (2011) follow substantially more optimistic assumptions regarding clearing price levels