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Quantitative analysis of the public charging-point evolution: A demand-driven spatial modeling approach

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ABSTRACT

The coverage standard of the current publicly accessible charging infrastructure is insufficient and considered as a major obstacle in the introduction to the market of plug-in electric vehicles (PEVs). Therefore, it is necessary to establish a publicly accessible charging infrastructure that features an appropriate coverage standard. The aim of this study is to support a spatially differentiated and demand-driven infrastructure development that ensures a desired coverage standard. For this purpose, we developed a calculation model which is applied to cumulated PEV sales and the inventory of publicly accessible charging points, in Germany with the spatial resolution of administrative districts. The required public charging-point evolution until 2040 is calculated for a given PEV market diffusion. In 2015, an appropriate coverage standard was achieved in only some regions of Germany; this means that the probability of finding access to a free public charging point at the desired time of charging is at least 90%. When one considers the entire country, however, it becomes clear that an additional 3600 publicly available charging points are needed. By 2040, the provision of approximately 730,000 public charging points could ensure an appropriate coverage standard for an estimated 17.8 million PEVs. The study results show that the rate of public charging-point deployment can decrease once PEV sales increase. The economically feasible operation of public charging infrastructure highly depends on the average utilization rate and it appears to be challenging to reach profitability by only selling the electricity.

1. Introduction

The market ramp-up of plug-in electric vehicles (PEVs) in Germany is progressing, albeit slowly. About 55,000 PEVs were registered in Germany in 2017, accounting for 0.1% of all passenger car stock (KBA, 2017a). The lack of an adequate publicly accessible charging infrastructure is considered a major obstacle to market growth (European Commission, 2013; Rudolph, 2015; Vogt and Bongard, 2015; Vogt and Fels, 2017). Furthermore, a lack of customer knowledge of and experience with PEV technology, as well as high upfront costs, are seen as further barriers to widespread customer adoption (Egbue and Long, 2012; National Research Council, 2013; Bailey et al., 2015). Nevertheless, user-convenient public charging infrastructure that is available nationwide is considered crucial to a faster PEV market ramp-up (Achtnicht et al., 2012; NPE, 2014; Vogt and Bongard, 2015). Charging behavior varies widely among users (Corchero et al., 2015), thus increasing the complexity of deploying a public charging infrastructure network. For this reason, spatially balanced and demand-driven publicly accessible charging infrastructure development is needed to facilitate the economical operation of electric vehicle supply equipment (EVSE) (European Union, 2014; NPE, 2014).

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Several approaches with different perspectives and underlying datasets exist in addressing the challenge of providing an adequate public charging infrastructure for PEVs. Optimization routines are used to resolve charging station location, allocation, or deployment problems (Ip et al., 2010; Meng and Kai, 2011, Feng et al., 2012a; Feng et al., 2012b; Ge et al., 2012; He et al., 2013; Sharaki et al., 2015). Potential demand is calculated through models that use stated preferences data (Hackbarth and Madlener, 2013; Ito et al., 2013). Additionally, PEV market diffusion scenarios and travel surveys are used to determine public charging-point demand (Wirges et al., 2012; Gnann et al., 2013; Traut et al., 2013; Dong et al., 2014; Funke et al., 2015; Anderson et al., 2016).

The described approach supplements the literature by undertaking a spatial determination of the publicly available charging infrastructure that is needed, aggregated to a national level; it does so while considering a fine-grained data resolution. In addition, this study addresses the issue of PEV users making use of publicly accessible charging points only when they are accessible at a desired time. Currently, this latter issue is insufficiently addressed in the literature whenever attempts are made to calculate public charging-point demand. Furthermore, the relation of the desired coverage standard to the profitability of public charging points has also been insufficiently investigated. Hence, this study aims to investigate spatial charging-point allocation based on a demand-driven approach, while concurrently considering the aforementioned desired coverage standard, daily charging behavior, and related utilization rates. For this purpose, we developed a model by which to investigate and quantify the publicly available charging points needed, on a spatially differentiated basis. This model works at different spatial resolutions and distinguishes various PEV concepts in different segments. The model is designed to use scenario time-series produced by PEV market diffusion models. Through the use of this model, we can answer the following questions:

I. What is the availability of a public charging-point infrastructure that meets user demand at all times, based on an exogenously given number of public charging points?
II. What is the number of public charging points needed to meet a predefined availability of public charging infrastructure?

Therefore, this model can calculate the number of public charging points needed to achieve a predefined coverage standard, or calculate the coverage standard for a given public charging-point inventory. In the presented paper, the model is applied while assuming the current public charging-point inventory and a certain future PEV scenario for Germany. Additionally, costs and the profitable operation of public charging points are discussed. The model's main influencing factors are identified by undertaking sensitivity analyses.

2. Method and data

2.1. Model approach

The aforementioned questions illustrate that the *availability* parameter is a key element in analyzing the public charging infrastructure. We define *availability* as the probability of finding access to a free public charging point at the time when charging is desired. Therefore, this parameter represents a requested coverage standard.

In general, three different types of charging infrastructure can be distinguished, in terms of accessibility—namely, public, semipublic, and private charging infrastructure. While the accessibility of public charging points is assumed to be given at any time to everyone, that of semipublic charging points is more restrictive (i.e., fleet membership, opening hours). Private charging points are assumed to be accessible only to the owners or users themselves (e.g., home charging). Workplace charging is usually restricted to a very limited group of people (e.g., employees) and their vehicles; hence, in the following, workplace charging points are considered private. To preclude precise distinctions between public and semipublic charging points, the analyses in this study refer to all publicly accessible charging points at a given time. Unless otherwise specified, the term "charging infrastructure" connotes publicly accessible charging points.

Fig. 1 illustrates the model approach. The model follows a three-step approach. In the first step, the total public charging demand of PEVs is determined. Charging infrastructure characteristics, vehicle characteristics, and regional driving behavior are used to derive a requested plug-in time. In the second step, the availability of the given public charging network (I.) or the number of required public charging points (II.) is calculated, depending on the use case and while considering both a daily distribution of occupation probability and various regional characteristics. Both steps are undertaken at a regional level for each time interval (i.e., year). In the third step, the aggregation on a national level takes place.

2.1.1. Determination of total public charging demand

The total public charging demand based on vehicle specifications, charging infrastructure specifications, and driving behavior. It is defined as the total number of public charging processes needed, and is specified as the total electricity-powered distance driven until a recharge becomes necessary. In the following, this distance is called the "charging distance." The equivalent time-based measure for each charging process is specified as the plug-in time, to consider an additional occupation time of a charging point.

Two different PEVs—namely, battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV)—are considered in the course of determining total public charging demand. In addition, PEVs are categorized into different segments (i.e., small, medium, and large)[1] due to there being different vehicle specifications in terms of energy consumption, battery capacity (both nominal and

[1] Aggregation is based on the segmentation of the German Federal Motor Vehicle Office. Small: mini and small cars; medium: compact and mid-size; and large: full