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Large-scale deployment of electric vehicles in Germany by 2030: An analysis of grid-to-vehicle and vehicle-to-grid concepts

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HIGHLIGHTS

- Optimal strategies for charging/discharging battery electric vehicles are assessed.
- G2V scheme improves the stability of the future German power system.
- V2G scheme would increase the capacity factors of base and mid-load power plants.
- V2G scheme is not a viable economic option due to high batteries investment cost.
- Further incentives are necessary to make the business model attractive to car owners.

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ABSTRACT

This study analyses battery electric vehicles (BEVs) in the future German power system and makes projections of the BEVs hourly load profile by car size (‘mini’, ‘small’, ‘compact’ and ‘large’). By means of a power plant dispatching optimisation model, the study assesses the optimal BEV charging/discharging strategies in grid-to-vehicle (G2V) and vehicle-to-grid (V2G) schemes. The results show that the 2% rise in power demand required to power these BEVs does not hamper system stability provided an optimal G2V scheme is applied. Moreover, such BEV deployment can contribute to further integrating wind and solar power generation. Applying a V2G scheme would increase the capacity factors of base and mid-load power plants, leading to a higher integration of intermittent renewables and resulting in a decrease in system costs. However, the evaluation of the profitability of BEVs shows that applying a V2G scheme is not a viable economic option due to the high cost of investing in batteries. Some BEV owners would make modest profits (€6 a year), but a higher number would sustain losses, for reasons of scale. For BEVs to become part of the power system, further incentives are necessary to make the business model attractive to car owners.

1. Introduction

The European Union (EU) has agreed ambitious targets for renewable energy and reducing carbon emissions (European Commission (EC), 2010). This would require a significant transformation of the electricity system, including electrifying the transportation sector (EC, 2011, 2013a). The deployment of renewable energy has led to substantial wind and solar power generation, but has also increased concerns about their intermittent nature. Germany has the largest installed capacity of wind and photovoltaic power in the EU, and it is planning to increase this from 27.2 GW for wind power and 17.3 GW for photovoltaic power in 2010, to 46 GW and 52 GW respectively by 2020 (ECN, 2011). Germany's current power system is undergoing major changes, driven by strong social and political pressure to phase out nuclear power and to reduce demand through energy efficiency.

Recent announcements and launches of battery electric vehicles (BEVs) and plug-in hybrid vehicles suggest that a larger number of electric vehicles could be deployed in the coming years. It remains uncertain whether the current momentum regarding electro-mobility can be sustained in the future. Many challenges remain to a larger uptake of BEVs, notably their relatively higher investment costs over conventional internal combustion engine vehicles, and the need to deploy charging infrastructure on a large scale (Thiel et al., 2010; Pasaoglu et al., 2012). Several countries

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have established roadmaps for deploying a larger number of electric vehicles, indicating future market penetration targets. Germany has set itself a penetration target of 1 million electric vehicles by 2020 (German Federal Ministry of Economics and Technology, 2009).

Currently, BEVs have rather low penetration, and there is no well-developed practice or strategy for planning the time of charging, e.g., during the night, or during periods of high wind inflows. Rather, this is performed on an individual basis which depends on personal behaviour, preferences and economics, such as the propensity for electricity consumption and the price elasticity of income. This paper projects a future with significant diffusion of BEVs in which an aggregator of all electric cars implements smart strategies for recharging batteries. These smart actions need perfect information, as well as coordination between drivers and system operators through smart metering.

This paper builds BEV loads by 2030 using a rich database of car driving patterns in Germany for four different sizes of car, corresponding to ‘mini’, ‘small’, ‘compact’ and ‘large’ car types. By means of a power plant dispatching model, the research endogenously assesses the battery charging profile for each car category. The programme of minimising system costs is set within a highly detailed time formulation over 1 year, i.e., 8760 h. The power price is the output of the dispatching model, which links the decision to recharge a battery with the planning and operation of the power system.

The main contributions to the field are (1) an estimate of the loads induced by BEVs in the German car fleet by 2030 based on current patterns of driving behaviour, (2) an analysis of the impact of electric road transport on the power system, (3) the use of a methodology which describes the hourly profile of the power demand and of hydro, wind and solar power generation. Based on these analyses and calculations, the study points out cases in which V2G could be an optimal solution justifying further incentives, while other cases reveal—for reasons of scale—costs which outweigh the benefits to the system. Other studies have made a partial representation of the German power system with representative weeks, such as Schill (2011), thus ignoring important fluctuations over the year in resources which cannot be dispatched. Göransson et al. (2010) present recharging opportunities as a function of off-peak periods only. By contrast, our methodology also considers the possibility of recharging batteries during conventional peak times when suitable meteorological conditions (with large inflows of wind and solar energy) allow efficient use of resources.

This paper is organised as follows. Section 2 describes the methodology for the BEV load projections for 2030 and the recharging optimisation applied to the German power system. Section 3 discusses the relevant results and impacts of large-scale BEV deployment. Section 4 summarises the main findings of the work.

2. Methodology

2.1. Electricity demand of battery electric vehicles: a projection for Germany by 2030

The load profiles induced by BEVs depend on the charging patterns of the cars, which are directly influenced by driving and parking patterns. It is assumed that these patterns will not change with the introduction of BEVs. This work applies current parking and driving patterns of passenger cars in Germany, which are analysed by car size (Section 2.1.1) and extrapolated to obtain the load profiles of BEVs by 2030 (Section 2.1.2).

2.1.1. Building potential BEV driving patterns for the base year (2008/2009)

The driving pattern for passenger cars has been extracted from Mobilität in Deutschland (MiD) (2008), which is the most recent German mobility survey, consisting of 25,992 households and 60,713 individuals. MiD (2008) contains detailed information on the key characteristics of each participating household and each vehicle to which they have access. Each individual within the household is interviewed and asked to complete a 1-day trip diary. The MiD (2008) database is structured in three main files. The ‘Cars’ file documents the size and model of car, along with the fuel type, engine size, power of the car and other car-specific data. The ‘Trips’ file consists of data related to trips made by individuals, such as the mode of transport used, departure and arrival times, the duration of the trip, usage of a household vehicle and the class of the vehicle, as well as the points of departure and arrival. The ‘Households’ file describes vehicle ownership, household size, socio-economic situation and residential area.

In this study, it is assumed that BEVs have a range limit of 160 km, as presented in Perujo and Ciuffo (2010). Therefore, only the driving and parking patterns of passenger cars with short daily travel distances (less than 160 km) are analysed—a total of around 19,000 passenger cars.

The driving and parking patterns of each passenger car are aggregated from one-minute time intervals to hourly time periods in order to match the time formulation of the power plant dispatching model, described in Section 2.2.

The preliminary analysis reveals that the driving patterns, fuel consumption per kilometre and total daily travel distances of the passenger cars differ between car segments. Therefore, in this study, passenger cars are categorised into four segments based on the detailed car information provided by MiD: mini; small; compact and large (see Table 1).

2.1.2. Projections of electricity demand of BEV fleet in Germany by 2030

The projected demand for electricity of BEVs by 2030 is the input to the power plant dispatching model: the demand for power from BEVs is fixed for the power generation system and is fulfilled every hour by optimally dispatching the power plants. Re-charging batteries is, instead, endogenous to the model of the power system.

The BEV fleet size projections for Germany in 2030 are based on two of the BEV deployment scenarios described by Pasaoglu et al. (2012). The first scenario is a ‘highly decarbonised’ scenario, with high oil and natural gas prices and large development of alternative vehicles and refuelling infrastructure. The second scenario is a ‘slightly decarbonised’ scenario, with low oil and gas prices and low consumer acceptance of changes.

In the ‘highly decarbonised’ scenario, the projected size of the passenger car fleet of BEVs by 2030 is estimated to be 4.8 million passenger cars and 1.1 million cars in the ‘slightly decarbonised’ scenario.

Table 1
Main features of BEVs.
Sources: Perujo and Ciuffo (2010), German Federation for Motor Trades and Repairs (2011).

Passenger car segment	Capacity (kWh)	Range (km)	Electricity consumption (kWh/100 km)	Share in the fleet (%)
Mini	15	160	11	11.35
Small	20		15	23.38
Compact	24		18	35.81
Large	30		23	29.46

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