BEHAVIOUR-DRIVEN ELECTRIC VEHICLE CHARGING DECISIONS AND ITS IMPLICATIONS ON DEMAND RESPONSE FLEXIBILITY FOR THE INTEGRATION OF RENEWABLE ENERGIES IN GERMANY

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Overview

The expected increase in battery electric vehicles poses both, opportunities and risks for the decarbonisation of future power systems. While electric mobility may technically serve as a source of flexibility, it increases the overall power demand and may as well increase the demand for power in peak load hours. While electric mobility in national and continental scale energy system optimization is often treated ***in an aggregated fleet***, user behaviour and charging decisions play a crucial role in the availability of vehicles' batteries for balancing electric load and renewable energy feed-in. Michaelis, Gnann & Klingler (2018) find that reduction of peak load and RE surplus electricity stemming from plug-in vehicles in Germany may be as high as 2.2 GW and 1.8 TWh respectively for 2030. However, they assume constant charging stations' power of 3.7 kW that seem conservative. Also, the authors don't explicitly describe to what effect user behaviour limits vehicle charging.

By linking the modular energy system optimization model REMix with the vehicle stock model VECTOR21 and the charging decision simulation tool CURRENT, we aim to determine a more realistic demand response potential for future electric vehicles compared to previous studies. All three models are developed at the German Aerospace Center (DLR) and have been applied and validated in different project contexts. We for the first time integrate hourly profiles determined by individual charging decisions as input for an energy system optimization model. We determine the reduction potential of peak load, renewable energy (RE) curtailment as well as RE capacity expansion for the different cases of controlled charging versus uncontrolled charging for Germany for 2030. Thus, we provide both methodological and quantitative insights into the effects of coupling power and transport sector that are of value to the scientific discussion.

Methods

REMix is a flexible modular Linear Programming (LP) energy system optimization model that minimizes overall system cost under specified boundary constraints such as RE targets or CO2 emission reduction targets. In contrast to most other energy system models it explicitly models different flexibility options on the supply, demand and transmission side in great detail. Thus, different options for balancing variable renewable energy feed-in can be assessed in competition to each other. For grid expansion vs. electric mobility this is demonstrated in Luca de Tena & Pregger (2018). REMix models the load shifting potential of flexibility by treating electric mobility as one aggregated energy storage with five hourly profiles for each model node: Two state-of-charge (SOC) profiles giving the minimum and maximum constraints of the battery charging level, an electric driving demand profile describing the mobility demand, a charging infrastructure availability profile and an uncontrolled charging profile quantifying inflexible power demand.

CURRENT is an agent-based simulation focusing on the charging decisions of transport agents. Maximizing the utility of each agent it takes into account preferences such as location, costs and mobility demand. Input data such as trip and vehicle data are taken from a study of mobility behaviour in Germany (Mobilität in Deutschland, infas & DIW (2008)) and different charging infrastructure classes and respective availability profiles are considered. As output, CURRENT provides information about uncontrolled charging demand and controlled charging flexibility potential.

VECTOR21 simulates the market diffusion of electric vehicles on an annual basis based on agent distributions in annual mileage, area class and income. An individual value set of preferences is assigned to each agent in the preferences purchasing price, operating cost, CO2-emissions, range and acceleration. It considers 6 different drivetrain designs also taking into account internal combustion and compressed natural gas drivetrains. Outputs of the vehicle fleet of VECTOR21 for 2030 are taken as boundary conditions for the calculations in CURRENT and REMix.

We apply an hourly resolution to REMix and CURRENT and calculate power system effects in Germany with two model nodes, a northern region and a southern region, describing two different load profile characteristics plus adjacent neighbors. Basic model properties are listed below.

	Mathematical Implementation	Geographical Scope	Geographical resolution	Temporal resolution	Objective
REMix	Linear Programming	Germany plus neighbors	Discrete, Germany in two regions, neighbors as one model node each	Hourly	Minimize overall system cost
VECTOR21	Agent based modelling	Germany	Continuous, Statistical distribution	Annual	Maximize individual utility in car ownership
CURRENT	Agent based modelling	Germany	Discrete, individual agent's mobility profiles	Hourly	Maximize individual utility in electric vehicle operation

Results

There are two cases that surround user-behaviour based flexibility potentials of battery electric vehicles: The uncontrolled charging case and the availability of the complete battery under the condition that trips can be fulfilled. Compared to the first case, higher potentials of load shifting especially in the night time and to some degree during the day for public and company charging exist. In the summer, the daytime flexibility is used to charge whereas load and wind feed-in characteristics supply only limited potential for night load-shifting. This situation is expected to change in winter where night load shifting balances especially wind feed-in.

Compared to the second cased where user behaviour is neglected and the whole aggregated fleet battery is assumed to have an exploitation potential for renewable energies, this potential is significantly limited by user-preferences. The main reasons for this difference are that users are prone to having a battery state-of-charge of above 60% so that minimum SOC seems to be significantly over-estimated by neglecting user-behaviour. The second reason is expected to stem from the method of aggregating individual charging profiles to the input for REMix.

Conclusions

The results of our research suggests that energy system modellers should apply scrutiny in estimating load-shifting potential from future battery electric vehicle fleets as means of balancing RE feed-in. When models that explicitly take user-behaviour into account are not at hand as in most cases, modellers should apply relatively high security margins to prohibit unrealistic charging profiles.

At the same time, our research shows, that user charging decisions do rely on boundary conditions that may affect user preferences. In order to tap the high load-shifting potentials of future electric vehicle fleet, decision-makers should form incentive-based policy regimes that make controlled charging possible, taking into account power system-friendliness of charging decisions.

While we assess controlled charging as mean to balance RE feed-in, the potential could be largely increased when a feeding-back to the grid (vehicle-to-grid) is allowed. However, also here, this potential may be limited by user preferences. These topics remain objects of further research.

References

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