ENERGY DEMAND VERSUS FLEXIBILITY SUPPLY – DISENTANGLING EFFECTS OF ELECTRIC VEHICLES IN A RENEWABLE ENERGY SYSTEM

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Overview

The market introduction of electric vehicles entails different power system effects: on the one hand, electric vehicles constitute an additional demand for electricity. On the other, electric vehicles can constitute an additional flexibility supply. If their batteries are charged flexibly in times when variable renewables are abundant, they can help to integrate such renewable energy sources. If vehicle-to-grid discharging is available, electric vehicles may not only serve as flexible demand-side resources, but may provide additional flexibility as distributed electricity storage devices.

This paper aims to disentangle both, potentially opposing, system effects of electric vehicles within a renewable dominated electricity system. To this end, we extend the open-source electricity system model DIETER. We study varying levels of system interaction of electric vehicles, including uncontrolled charging, that is vehicles start charging whenever they are connected to the grid, controlled charging, that is charging is optimized within hours of grid connection, additional vehicle-to-grid discharging, and further provision of balancing reserves. At the same time, we implement varying fleet sizes, from zero to full electrification of the passenger vehicle fleet, and varying shares of renewable electricity sources. We apply the model to the German setting, both with an endogenous power plant park (greenfield) and based on future projections (brownfield).

Preliminary results show that the positive flexibility effect may dominate for very small vehicle fleets, such that total system costs decrease compared to a setting without electric vehicles. For greater fleets, additional power demand dominates and total electricity system costs rise. The magnitude of this increase crucially depends on the degree of system integration. While uncontrolled charging can lead to substantially higher costs, controlled charging with additional vehicle-to-grid interaction and provision of balancing reserves generally mitigates the costs of providing charging electricity and also leads to the lowest system costs.

Methods

We use an extended version of the open-source electricity system model DIETER (Dispatch and Investment Evaluation Tool with Endogenous Renewables) (cf. Schill et al 2016, Zerrahn and Schill 2017). DIETER minimizes the total system costs by deciding on optimal investment and dispatch over one year in hourly resolution. The model comprises multiple conventional and renewable generation technologies, flexibility options such as different storage and demand-side management technologies as well as balancing reserves. Electric vehicles are implemented with 28 different vehicle profiles, which were derived from a European research project (Schill and Gerbaulet 2015). Code and input data for previous model versions as well as documentation are available under www.diw.de/dieter under open-source MIT and Creative Commons licenses. In this application, DIETER is loosely calibrated to Germany where assumptions on costs and availability of technologies lean on established projections for 2035 and 2050, both in a brownfield setting with exogenous capacities and in a greenfield setting with fully endogenous capacities.

For electric vehicles, we analyze four different operational modes: (i) *uncontrolled charging*, where vehicles follow an exogenous charging pattern and charge until the battery is filled whenever they are connected to the grid; (ii) *controlled charging*, where vehicle charging is endogenously optimized concerning timing and level; (iii) *controlled charging with V2G*, where vehicles can additionally discharge to the grid to serve as storage for the electricity system; and (iv) *controlled charging with V2G and reserve provision*, where vehicles can be additionally used to provide and deliver balancing reserves. We vary the size of the electric vehicle fleet between zero and full electrification of all passenger vehicles. We further distinguish different constraints on the charging energy. We either impose no restriction, prescribe the same renewables share as for the entire system, or require vehicles to be charged with 100 percent renewables.

Results

We analyze total system costs as well as dispatch and capacities of technologies. Preliminary results show that the flexibility benefit may dominate for very small fleets of electric vehicles, such that overall system costs decrease despite additional power demand. For greater fleets, overall costs increase compared to a case without electric vehicles because of simultaneity issues with the vehicles' flexibility potential. Yet system cost increases are moderate up to four million electric vehicles compared to a baseline without electric vehicles; total system costs are higher by between 2 and 9%. Beyond eight million electric vehicles, total system costs rise exponentially. Specifically, two findings stand out: first, the relative cost increase tends to be lower for higher overall renewables shares; second, the cost increase is lower the higher the degree of system integration of electric vehicles.

In this respect, controlled charging and vehicle-to-grid interactions yield a substantial cost advantage compared to uncontrolled charging. The value of flexibility supply from electric vehicles mitigates cost increases from additional demand by around 10% for controlled charging, and around an additional 10% for vehicle-to-grid interactions according to preliminary results. In relation to total system costs, this amounts to more than 200 Euro per vehicle and year.

Further results will shed light on the impact of charging energy restrictions, that is whether fully renewable or not, and relevant sensitivities, especially on costs and availabilities of other flexibility options. Moreover, contrasting a legacy system with exogenously given capacities and an endogenously optimized system suggests the assumption that flexible electric vehicles will unfold a greater beneficial effect in the short-term when other flexibility options are scarcer.

Conclusions

Both electric vehicles and renewable electricity sources are often regarded as important building blocks to de-carbonizing the energy sector. As electric vehicles constitute a new energy demand but also a new flexibility supply, understanding the interaction between the two is key. Our preliminary results, based on analyses with the open-source electricity system model DIETER, suggest that a flexible system integration of electric vehicles can substantially mitigate the cost increases of additional energy demand. Both controlled charging and vehicle-to-grid interactions can lower additional system cost by roughly 10% compared to a baseline of uncontrolled charging. Therefore, the design of policies and the regulatory framework should aim at fostering a system-friendly design and operation of electric vehicles. Moreover, owners of electric cars should receive price signals that appropriately embody scarcity information.

References

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