IS IT PLUGGED IN? IMPACT OF VEHICLE-TO-GRID AND THE CONNECTING BEHAVIOR ON THE EUROPEAN POWER SYSTEM

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Overview

Electric vehicles (EVs) are becoming increasingly important in the energy transition. Utilizing the batteries in EVs for bidirectional charging (i.e., vehicle-to-grid) has been the subject of numerous studies (e.g., [1], [2], [3], [4]). Yet, due to a lack of empirical knowledge, it is usually assumed that EVs are available to charge or discharge whenever they are not in use. This implicitly assumes that EV owners always connect their cars to the charging infrastructure when they park them and agree to external access. Against this background, the research question is twofold: When do EV owners plug in their EVs, and are they willing to participate in grid integration? What is the impact of improved modeling of the connecting behavior on the European power system?

Methods

We implement a three-step approach to address the research questions raised. **(I.)** Based on an online survey using an incentivized consumer panel (n = 2,240), we analyze the behavior of EV owners in terms of daily driving, connecting, and charging behavior. **(II.)** The *availability* (or plug-in probability) of EVs for charging and discharging is quantified using the Markov Chain Monte Carlo (MCMC) method. The approach considers the hourly connection status, individual battery capacity, and willingness to provide battery capacity for grid integration. **(III.)** The obtained *availability* of EVs is implemented into an optimization model covering the European energy system, including the electricity, heating, transport, and hydrogen sectors ([5], [6]). The E2M2s model covers a time horizon until 2050 and is formulated as a linear problem with recursive optimization across yearly stages. The objective function minimizes investment and operational costs. EVs are modeled as battery storage with a specific temporal *availability* and usually a higher state of charge when leaving than arriving. Moreover, EVs are aggregated into clusters that share certain driving characteristics.

Results

The empirical results of the online survey reveal three key insights (n = 327). **Connection frequency**: In the status quo, more than 60 % of the EVs are only connected to the grid once every three days, which fits a typical commuter profile with an average daily journey of around 35 km or up to two driving hours. **Willingness**: On average, EV owners are willing to make about 46 % of their battery capacity available for grid integration. **Temporal patterns**: On weekdays, the availability reaches 10-15 % during the day and up to 23.9 % in the late evening hours. At weekends, the differences between the times of day are less pronounced, and availability varies between 12 % and 18 %. Overall, grid connection frequencies remain below 25 %, indicating that a significant portion of the battery capacity installed in EVs is not consistently available for grid integration due to limited connection times. Figure 1 shows the results of the *availability* of EVs based on the MCMC simulation, mirroring the temporal patterns described above (step II.).

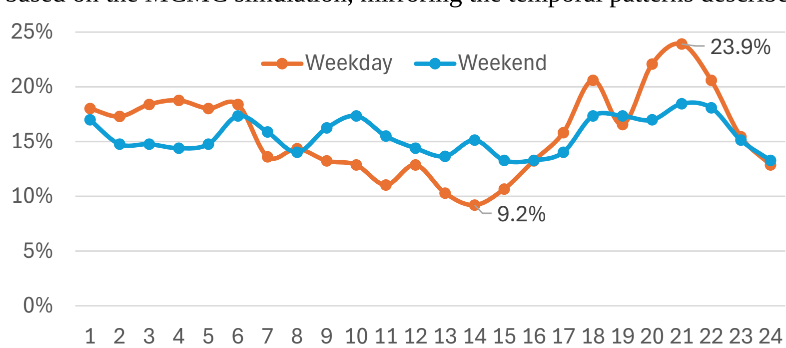

*Figure 1: Frequency of grid connection on **weekdays** and **weekends***

To gain insights into system effects, the simulated *availabilities* are implemented into the E2M2s model (step III.). The results are compared to a reference case with 100 % availability of EVs, i.e., EVs are always plugged in when parked. According to Figure 2, the lower *availability* limits the contribution of EVs to balancing supply and demand leading to lower synergies with solar power generation. Further, the lower *availability* in the morning and evening reduces the contribution of vehicle-to-grid to peak shaving. This induces higher additions and utilization of other storage and peak load technologies, such as gas and hydrogen plants, leading to higher system costs of 1.8 to 5.7 bn. € per year at the European level.

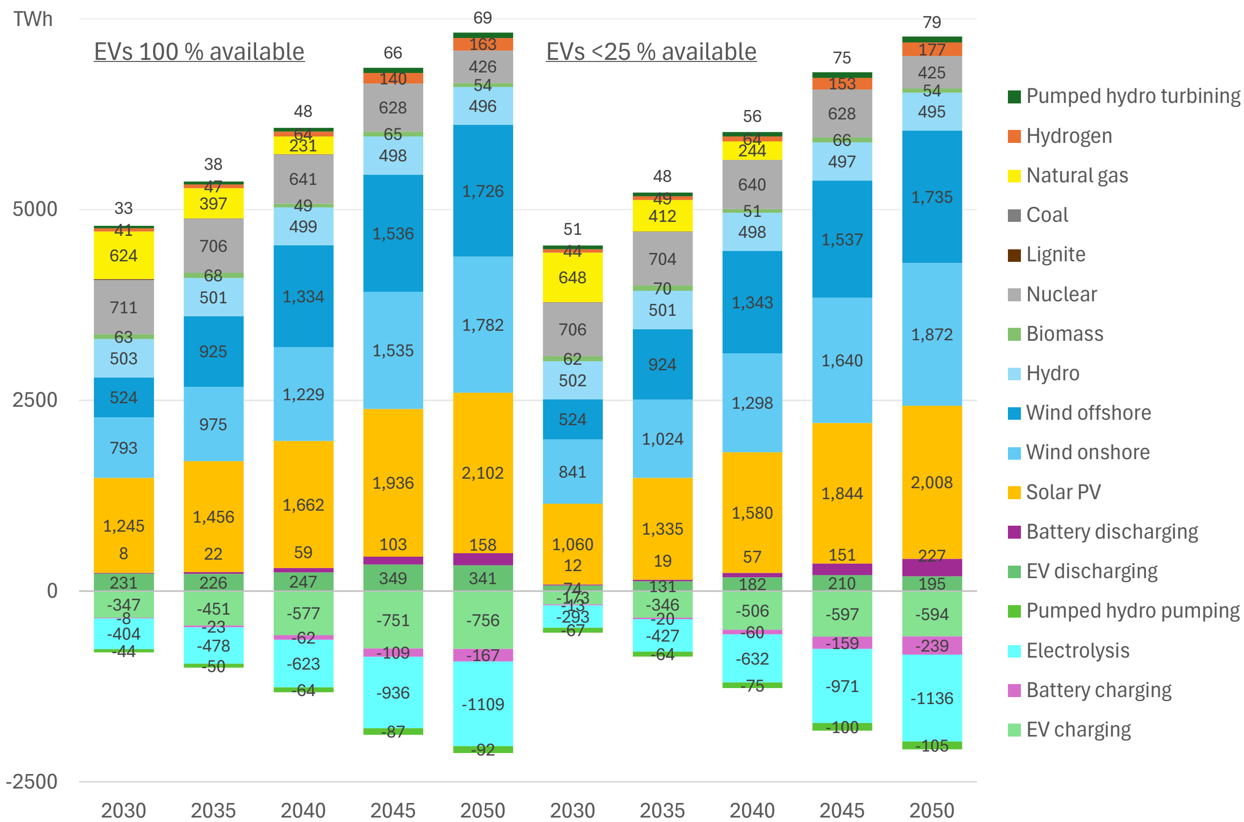

*Figure 2: Annual generation and consumption of flexibility options in TWh with **high (left)** and **low (right)** availability of EVs*

Conclusions

The results provide first insights into the system effects. Accordingly, the low *availability* of EVs on weekdays limits synergies with solar power generation, increasing the role of wind energy in the future generation mix. Moreover, the lower contribution of vehicle-to-grid to balancing supply and demand leads to a higher need for stationary battery storage and utilization of pumped storage, gas, and hydrogen plants. This effect drives system costs mirroring the opportunity costs of not plugged-in EVs. Future work will focus on implementing further scenarios with higher *availabilities* of EVs and differentiating between smart charging and vehicle-to-grid.

References

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