# Intermittent electricity supply and vehicle-to-grid: A desirable match?

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Electric vehicles (EVs) are dependent on electricity supply from the grid and will increase total electricity demand. However, since an EV with a large battery only needs charging for driving occasionally, the EV battery may also be used to smooth out short run variability in the supply of electricity due to intermittent renewables. Using the EV to supply electricity is referred to as vehicle-to-grid, or for short V2G.

Participation in V2G involves costs for the EV owner, first and foremost, because a two-way charger is more expensive than a one-way charger. All the same, the extra cost may be worthwhile since the EV owner can earn on the short run price differences in the electricity market. Such price differences will likely become more prevalent as the market share of intermittent renewable electricity supply increases. The research questions in the paper are thus: i) Who loses and who gains among the electricity market actors on V2G adoption and ii) Will free market adoption of V2G by EV owners lead to the socially efficient adoption rate?

The research questions are first analyzed within a theoretical model of the electricity market augmented with EV owners who may adopt V2G and start to supply electricity based on market incentives. EV owners differ by how much they use they use their EV for driving, and only those who drive less frequently or mainly shorter distances will tend to adopt V2G. Adoption is also affected by electricity price differences and the additional cost of a two-way charger.

Further components of the model are a stochastic supply of electricity from renewables and residual demand of electricity from all other sectors. At the start of each period, an EV owner with V2G decides to charge her battery fully if weather conditions are good for renewable electricity production, or only charge the daily need if weather conditions are bad for renewable electricity production. This follows from the market prices of electricity which are high if conditions are bad and *vice versa*. Moreover, an owner with

V2G will decide to sell her surplus charge if she has a full battery and weather conditions are bad in the coming period.

We use the theoretical model to show the following results: Increasing the share of EV owners with V2G tends to lower the expected price of electricity, which is good for all consumers of electricity. Still, even if the expected price of electricity decreases, the investment in renewable energy is spurred. This counter intuitive result is due the fact that electricity prices increase when weather conditions are good (for renewable energy), and since production in these periods are higher, the profitability of renewable investments improve with V2G. In other words, lower prices in bad periods do not hurt as much because production is then also low. Finally, incumbent producers of base load electricity will loose on the decline in the expected price. They may therefore not be particularly interested in promoting up-take of two-way chargers.

The theoretical model is then calibrated to a simplified numerical model of the EU electricity market. We show that V2G may significantly lower the cost of owning an EV, which, all other things equal, could increase the sales of EVs in general. Preliminary results also suggest that adoption will not be socially efficient, but lower than desirable. Thus, there may be unrealized gains to V2G in a free market solution. The reason is that V2G owners cannot fully appropriate all the benefits for the electricity market of V2G: the need for investment in conventional back-up power capacity decreases and low value electricity in periods with good conditions may be exchanged with high value electricity in periods with bad conditions. Governments should therefore consider subsidizing investments in two-way chargers.

Clearly, uptake of V2G among EV owners requires more than buying a two-way charger. We conjecture that the administrative burden of selling and charging from day to day will be too much for the average EV owner. V2G therefore also likely requires that electricity providers engage and offer automated systems. The government may again need to engage to coordinate a common system for all local electricity suppliers. V2G also implies some caveats. First, as far as we understand from the engineering literature, daily charging and recharging of the EV battery must be tightly controlled in order not to accelerate the depreciation of the battery. Also, V2G will only succeed in realizing its social benefits if there is true peak load pricing in the electricity sector.