Competition between vehicle-to-grid (V2G), second life electric vehicle batteries, and new stationary batteries in providing decentralized storage

Background and Motivation

The electrification of the transport sector is a major step in moving towards a sustainable society, since the deployment of electric vehicles (EV) promises to reduce noise and air pollution in cities. If – as should be the case in a sustainable society – all electricity is generated from renewable, emission-free sources, electrifying the transport sector will also result in reducing its overall greenhouse gas emissions. The additional demand of electric power for EV charging is likely to strain the power system. This strain may even be reinforced by the growing integration of intermittent renewable energies such as wind and solar.

Vehicle-to-grid (V2G) has been proposed as a measure to relieve some of this strain. The V2G concept is for EV batteries to offer charging or discharging capacity to the grid while the EVs are connected to the power grid. As explained in [1], the central idea behind V2G is that the EV battery is purchased for the transportation function, yet is idle about 96% of the time. The down side of V2G might be that the battery of electric vehicles may deteriorate faster due to the charging and discharging for grid support, thus accelerating the value loss of the vehicle.

Once the EV battery capacity drops below a certain threshold (about 80% of its nominal capacity), it is considered unfit to fulfill its transportation function. In such a case, the battery may still be used for stationary grid support [2,3],in which case it is referred to as Second Life Battery (SLB).

As opposed to EVs, stationary batteries are always connected to the grid, implying that they may be more competitive than EVs in providing grid services. As a consequence, it is unclear what role V2G will have, once a significant number of EV batteries will have reached their end of life for electric mobility and will be used as stationary grid support [4]. This may severely impact the business case of V2G, which thus cast a significant investment risk on the deployment of this technology. However, depending on the level of demand for distributed storage, V2G and SLB might actually complement each other rather than compete against each other.

Research Questions

Our overarching research question reads "what is the level of competition or complementarity between V2G and SLB to the 2050 horizon in Europe". This question breaks down into the following sub-questions:

- How will the availability of second-life batteries (SLB) evolve over time?
- Which grid services will V2G and SLB offer ?
- Under what conditions can SLB capture an important share of the grid balancing services in a given region, e.g. in Switzerland?
- How does the demand for distributed storage and for ancillary services compare to the potential supply from V2G and SLB ?
- How will SLB compete against V2G and against new stationary battery installations (e.g. Powerwall)?

References

[1] W. Kempton and J. Tomić, 'Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy', J. Power Sources, vol. 144, no. 1, pp. 280–294, June 2005.

[2] S. Beer et al., 'An Economic Analysis of Used Electric Vehicle Batteries Integrated Into Commercial Building Microgrids', IEEE Trans. Smart Grid, vol. 3, no. 1, pp. 517–525, Mar. 2012.

[3] A. Kirmas and R. Madlener, ‘Economic Viability of Second-Life Electric Vehicle Batteries for Energy Storage in Private Households’, Social Science Research Network, Rochester, NY, SSRN Scholarly Paper ID 2954629, Apr. 2017.
[4] D. Lauinger et al., ‘A review of the state of research on vehicle-to-grid (V2G): Progress and barriers to deployment’, European Battery, Hybrid and Fuel Cell Electric Vehicle Congress, Mar. 2017

Approach and Phasing

The project will have five main phases:

1. **Data collection**. The typical energy and power capacity, availability, cost and lifetime of V2G, SLB, and new decentralized batteries will be gathered. As there is a range of these parameters for each storage solution and since the future evolution of these parameters is uncertain, we will provide a realistic value range for each parameter based on a literature review and data provided by PSA. Furthermore, the grid services that each of the three storage solutions can provide will be identified and assessed in terms of complementarity.
2. **Demand-side scenarios**. Scenarios for the temporal evolution of the need for decentralized storage are to be defined. These scenarios are to be based on the available literature and possibly be refined through interviews with selected stakeholders. Given the large uncertainty on the future demand for decentralized storage, considering that this solution competes with many others (e.g. demand response, electricity highways, standing reserves, etc.), these scenarios should reflect best, worst and mid-cases.
3. **Supply-side potential**. Employing principles of dynamic material flow analysis the temporal evolution of the cumulative capacity of decentralized storage in V2G and SLB will be estimated for a set of scenarios pertaining to EV penetration rates, the evolution of the absolute number of road vehicles, and EV battery lifetime. The scenarios build on the data collection step in phase 1.More information about the model used for estimating V2G and SLB cumulative capacities is provided below.
4. **Supply-demand analysis**. Based on the need for decentralized storage, and cumulative availability of V2G and second-life EV batteries, supply and demand curves will be compared, and conclusion drawn on the technical potential for V2G and second-life EV batteries to meet the demand for distributed storage.
5. **Competitiveness and market prospects**. The market prospects of V2G, SLB, and new batteries will be compared based on their costs and the supply-demand analysis carried out under 4. The project will conclude with a projection of how their cumulative capacity may evolve in the medium-term.

The dynamic material flow analysis model that yields the cumulative capacities or *stocks*, of installed decentralized storage works as follows:
In a first stage, the temporal evolution of the stock of second-life EV batteries is calculated based on EV production and an assumed lifetime distribution for each cohort of EV batteries. It may be necessary to assume a different lifetime distribution for the EVs that take part in V2G.
In a second stage, the lifetime costs of V2G, SLB, and new batteries will be considered to determine the share each of them should contribute to meet the total need for decentralized storage. These considerations need to take into account the interlinkages between the different storage resources.

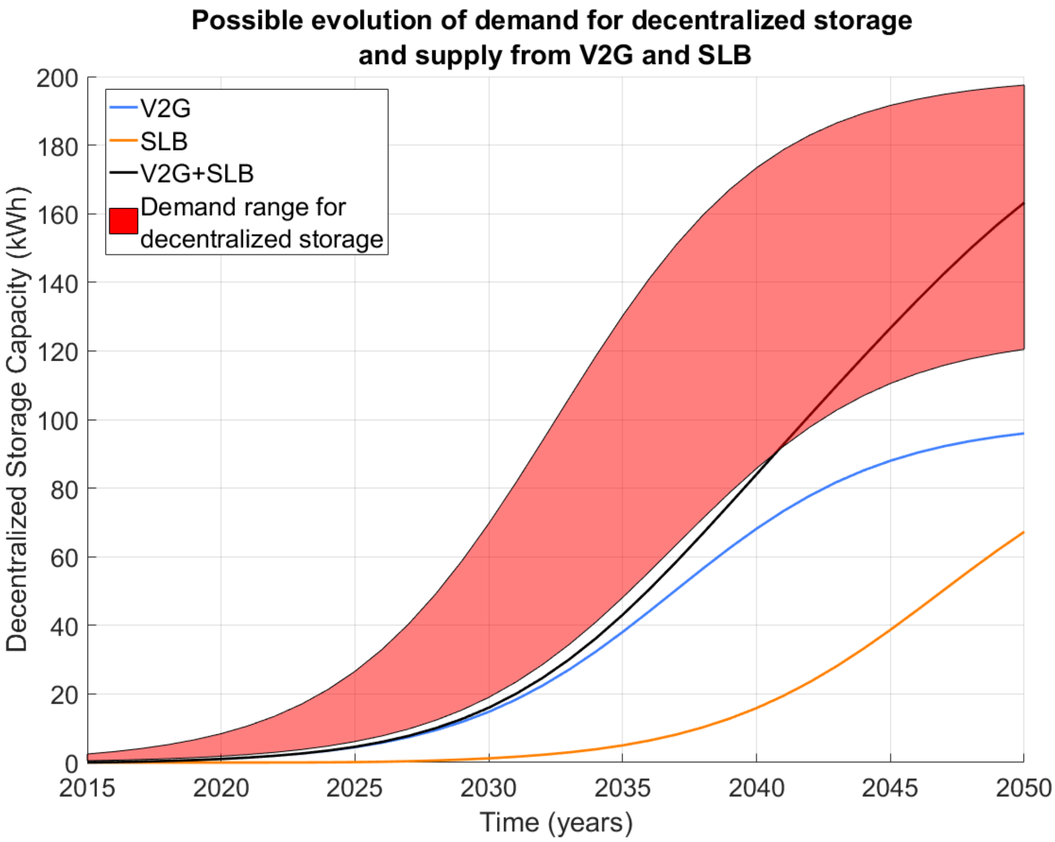
Expected Outcomes

Based on the 5 project phases, the expected outcomes are:

1. A table characterizing and comparing the three decentralized storage technologies (V2G, SLB, new batteries)
2. Scenarios for the temporal evolution of decentralized storage demand and the parameters determining the supply of the three decentralized storage technologies

3. A scenario-based MFA-type parametric model that calculates the evolution of the medium-term capacity of each technology.
4. A cost model that compares the three decentralized storage technologies
5. A final report, which, depending on the project outcome, could lay the foundation for a conference presentation or a scientific publication.

The conclusion on the temporal evolution of the cumulative capacity of V2G and second-life EV batteries based on the projected demand for decentralized storage should be summarized as in the graph below. The shape of the three curves and the values of the absolute amount of decentralized storage on the y-axis are to be determined by this project.



Scope

The geographic scope is to be determined. It may be for a single European country (France or Switzerland preferably) or for the European Union. The granularity will be adapted accordingly so that the overall project size remains the same.

The time horizon for this project is 2050 with yearly resolution.
Concerning the level of detail for each of the storage technologies, since this the project aims at a broad analysis, they will be treated on a very general level only.
For the analysis of V2G and second-life EV batteries, the vehicles to be considered are battery electric vehicles, plug-in hybrid electric vehicles and extended range electric vehicles. Non-plug-in hybrids may be considered if time allows. Since the time horizon is limited to 2050, it is not planned to consider fuel cell electric vehicles.
Concerning the sizes of the decentralized storage technologies, one may consider V2G batteries to come in blocks ranging from 24 to 100 kWh. If recycled after the end of their first life, these batteries may then be used as stationary storage in their second-life. They may be dissembled into smaller units. This possibility should be briefly examined in phase 1 of the project. For new decentralized stationary battery installations, we will consider typical ranges between 2 and 20 kWh. If time permits, we will

consider container-size solutions for stationary decentralized storage. These solutions may benefit from lower costs due to economies of scale.

Data & Assumptions

Input data to the model will be mainly sourced from:

- Primary literature
- Internal knowledge at EPFL and PSA
- Possible interview with external stakeholders
- Expert judgment in the last instance

It is important that the data that PSA could provide be explicitly indicated in the project contract.

Particularly, data concerning the following will be needed:

1. EV penetration and overall number of vehicles
2. Battery lifetime (distribution if possible), Re-Use Rate, Recycling Rate of First- and Second-Life Batteries
3. V2G impact on battery state-of-health
4. Costs of the three decentralized storage solutions
    a. V2G: battery cost, (perceived) vehicle value, battery lifetime, potentially aggregation
    b. SL: collection and refurbishing, lifetime, potentially aggregation
    c. New: capital cost, lifetime, potentially aggregation
5. Need for decentralized storage or the parameters influencing this need

Resources

The project is to be hosted by the Energy Center. The involved persons are:

- Head of Project: Francois Vuille
- Investigator: Dirk Lauinger
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Timeline

- Start 15.09.2017, Deliver 22.12.2017