Power grid batteries

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Renewable energy and electric vehicle technologies are essential to decarbonizing both the energy and transportation sectors. In Europe, most additional renewable electricity generation is expected to come from wind and solar since its geography limits the potential of other sources, such as hydropower and geothermal energy. A wide deployment of renewable electricity generation and electric transportation thus requires sufficient storage to (1) balance the intermittent production of wind and solar energy with electricity demand and (2) power the electric vehicles2. Within storage technologies, the industry is expected to largely remain committed to lithium-ion batteries (LIBs) for the foreseeable future because of their technological maturity and rapid cost decrease3.

Potential capacity that can be offered by (a) V2G and (b) SLBs under a baseline and an accelerated EV penetration scenario.The EV penetration scenarios were defined according to scenarios proposed by the European Commission, ENTSOE, and the IEA (see SI 1.4). The expected demand for short-term stationary storage is based on scenarios by the ENTSOE and the European Commission (see SI 1.9).

The total demand for battery materials will depend on the combination of V2G, SLBs, and NSBs used for grid storage. We first compare the yearly demand for battery materials from 2020-2050 of scenarios using exclusively NSBs, V2G, or SLBs (single technology scenarios). The goal is to estimate the maximum potential material savings of using V2G and SLBs compared to using NSBs. We thus consider a favorable context for each technology individually based on 1) a high storage demand scenario, 2) a V2G mandate scenario, and 3) the full reuse of EV batteries (see SI 1.3, 1.6, and 1.9 for a full description of the scenarios).

Battery reuse reduces the recycled content, i.e., the share of recycled materials from battery scrap in new batteries, during the growth phase in storage demand between 2020 and 2040. Regardless of battery reuse, the recycled content ranges from 25% to 45% by 2050, depending on the scenarios considered for EV and V2G adoption (see SI 3 for a breakdown per battery material). For lithium specifically, the recycled content ranges from 0.6-5% for hydrometallurgical recycling and 1-10% for direct recycling. This value overlaps with previous findings of 5.2-6.2% by Kastanaki and Giannis (2023)16. We attribute our wider range to the larger solution space we explored by including more parameters, such as stationary batteries and vehicle-to-grid.

We explore more closely the potential for SLBs and V2G to compete or complement each other in providing stationary storage by analyzing more conservative scenarios of battery reuse (only LFP chemistries are reused) and V2G adoption. Figure 3b, h show that low adoption of V2G (10% of vehicle sales by 2030 and 20% by 2040) can significantly reduce the need for new batteries while reducing the demand for SLBs by about half in 2050. A medium V2G adoption (25% by 2030 and 70% by 2040) almost eliminates the need for second-life batteries and penetrates the stationary storage market to a similar extent as the mandate scenario.

Considering the potential excess capacity of V2G and SLBs, the two technologies may compete for grid services both with each other and with NSBs. Table 1 compares the three technologies. The colors indicate whether a specific technology has an advantage (green), a neutral position (orange), or a disadvantage (red) on a particular point.

Throughout this study, we compared aggregate storage demand with aggregate storage availability without considering bottlenecks in the electricity grids that connect centers of storage demand with centers of storage supply. We thus overestimated the effective storage demand that V2G may supply. However, since V2G has the potential to supply more than twice the anticipated demand for stationary battery storage in the long term (see Fig. 1), it seems likely that V2G could fully supply the storage demand in the long term, even when accounting for bottlenecks. Future work could combine our material flow analysis with spatially explicit energy system models2 that compute storage needs at various points throughout Europe.

Overall, our study showed the importance of considering the demand for both electric transportation and grid storage when assessing future resource needs for lithium-ion batteries. Securing a stable supply of these resources is a strategic concern for Europe. On the one hand, we found that policies that were designed to increase self-sufficiency, such as the proposed EU regulation on battery recycled content, may backfire because they disincentivize battery reuse and thus increase the demand for primary battery materials. On the other hand, considering the interplay of recycling along with multifunctional battery use technologies reveals opportunities to reduce total primary material needs and bolster both Europe''s energy and material security.

We investigate the LIB system related to the passenger vehicle fleet and stationary energy storage in the European Union (including the European Free Trade Association) using a yearly resolution from 1950 to 2050 (Fig. 4).

The top part shows the main processes in squared boxes and system parameters in hexagonal boxes. Energy and material parameters are marked in green and black, respectively. The bottom part shows the layers included in the model, which can be balanced for the processes marked in parenthesis.