The social and environmental values of energy storage in the presence of renewables

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Overview

To achieve carbon neutrality by 2050, many countries rely on increasing the share of renewable energy sources (RES) in their power mix. This cannot be achieved without considerably increasing the amount of energy flexibility in electricity markets. One of the most promising sources of flexibility is energy storage and in particular, battery energy storage (BES). While from the system's point of view, BES could be a perfect enabler for renewable integration and their development is encouraged by authoritees[1], we still do not see its proliferation in the market. This is mostly attributed to the lack of economic incentives for BES operators, as the cost of storage has proven to be larger than the revenue in electricity markets. The revenue obtained in electricity markets is governed by the market mechanisms and pricing, which often deviate from the true values of the traded assets. For this reason, in this study, we tend to quantify the value of BES in electricity markets in terms of total cost reduction and total curtailment reduction. These valuations can be further used to adjust market mechanisms and pricing to remunerate BES operators and boost their revenues.

There are few prior studies that relate to the impact of storage for the market. Sioshansi (2010) investigates the impact of BES on social welfare depending on the storage ownership. Sioshansi (2014) does a similar study looking at the impact depending on market power. Similarly, Shahomohammadi et al. (2018) simulate different market equilibra depending on the market structure. In terms of environmental impact, some studies have shown that BES can either increase or decrease emissions depending on their efficiency (Hittinger et al., 2015), the market energy mix (Gotteti et al., 2019), the Co2 tax (Arcinieras et al, 2019) and the market structure (Shiosanshi, 2011). While these prior studies are insightful, the question of the true value of BES in terms of both cost and curtailment reduction in the market remains open, especially as a function of RES power share.

Among all market stages, in this study, we focus on the wholesale day-ahead market, which is the largest market stage by far. Participation of battery energy storage (BES) in this market is very limited. A reason for this is the limited profitability of price arbitrage with BES compared to participation in other markets such as ancillary services (Dong, 2021). Historically, on various markets, the price spread was not large enough to compensate for the high capital investment cost. However, in a relatively inflexible market increasing the share of renewable increases the number of events of extreme high and low prices (Huisman et al, 2020) which in turn increases the value of BES. This study aims to evaluate the impact of BES on reducing the total cost of procurement as well as reducing the total renewable curtailment as the share of RES increases.

Method

We envisage an electricity market with inelastic demand, some renewable energy sources, some conventional fossil-based energy resources, and some BES operators. The model is built in a centralized perspective with an omniscient system operator that organizes the schedule of each resource. We assume a zero marginal cost for renewables and BES, and a quadratic cost function for fossil-based generators. We formulate an ex-post cost minimization dispatch, subject to serving the inelastic demand. We cast this problem as a Mixed Integer Linear Programming (MILP). The objective function is to minimize the total cost of energy procurement. As a constraint, we force the exogeneous demand to be satisfied and that all the analysis including time-shifting of the load is restricted to a daily horizon, while the total cost is aggregated over all days.

To evaluate the role of BES, we compare the cost reduction and curtailment reduction under two scenarios, with and without BES. We evaluate the result on data using loads and RES production on the Dutch market from 2019 to 2021. The cost of the gas plant is estimated taking the past average Dutch Title Transfer Facility Natural Gas price,

[1] Order No. 841, Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System, 162 FERC 61,127 (2018).

an average heat-rate and Co2 allowance cost. In this study, we look at the impact of a Lithium–ion battery with a capacity that represents 10% of the demand and which also has a zero marginal cost.

Results

Our preliminary results show that the value of batteries experiences a sharp rise when the share of RES keeps increasing in terms of both cost and curtailment reduction. In particular, we observe that the battery starts having a significant effect when the daily share of RES exceeds 40%. Figure 1. shows that the decrease in the overall cost of procurement can reach to 2-6% as the share of renewables increases. Similarly, we observe that BES prevents 41 GWh of renewable curtailment over the course of the 3-year period we analyzed. Figure 2 shows the overall curtailment reduction percentage as a function of renewable shares. It is worth mentioning here that these high impacts are made only with a relatively small BES capacity (10% of market capacity). Of course, these positive impacts scale as the size of BES compared to market capacity increases.

Figure 1 - Reduction in cost scenario with battery/ without battery

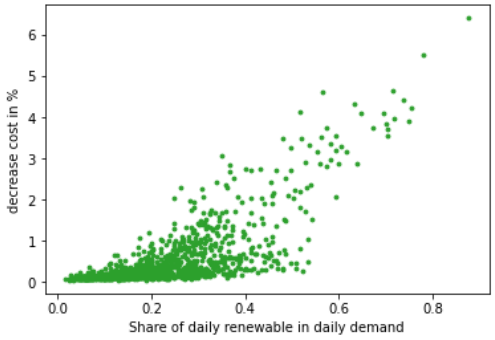
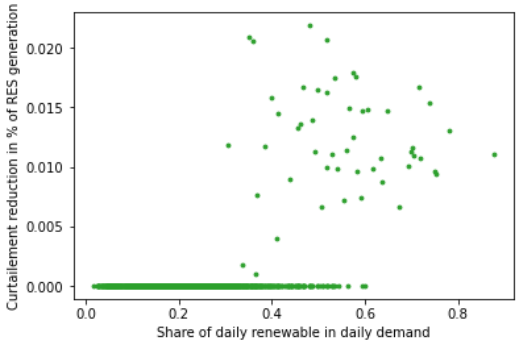


Figure 2 - Reduction in curtailement of scenario with battery/ without battery



Conclusion

This study shows us that the value of BES is linked to the share of RES in the power mix. With the increasing share of RES, there is a steep rise in the social and environmental values of BES. These social and environmental valuations can be further used in the next steps as guidelines to design proper market mechanisms and bidding structures to efficiently transsfer the additional gains as economical incentives to attract BES in the electricity market.

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