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LIFE CYCLE EMISSIONS AND LIFE CYCLE COST ANALYSIS FOR STATIONARY BATTERIES IN DIFFERENT GEOGRAPHIES

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Motivation

In the last decade, renewable energy (RE) technologies have experienced enormous growth and cost reductions. However, key renewables (wind, PV) are intermittent, hence, with growing RE shares, measures to counter-balance intermittency and provide grid stabilization are needed. To this end, energy storage technologies are one important lever. Battery storage technologies are particularly interesting as they can be deployed in several different applications across the electricity supply chain (from generation, in the transmission and distribution grids, to the consumer's sites) [1] [2] [3].

Several battery chemistries compete, with different technologies possessing different comparative advantages [4]. In order to understand how these alternatives compare in their potential to provide important grid balancing services, and thereby enable high-RE low-carbon electricity systems, two important variables need to be analyzed:

- Their life-cycle cost (LCC): important to ensure economic efficiency
- Their life-cycle carbon emissions (LCE): important for deep decarbonization

Importantly, both indicators ought to be analyzed simultaneously to be able to balance private and social cost of different technologies.

Extant literature has thus far: analyzed LCC in different stationary applications and found significant differences between technologies across applications [5] and looked at LCE but primarily in mobile applications, where it was shown that the life-cycle emissions strongly vary with the grid emission factor. Only very recently, first papers were published that combine LCC and LCE of stationary systems, based on consistent definitions of technologies, applications, and system boundaries along both dimensions [6] [7]. However, both studies omit the role of geographical factors for LCC and LCE as they focus on just one region. This is interesting given the role of grid-emission factors identified in the studies of batteries in e-mobility applications (see above). Besides this variation, it would be interesting to understand the role of geography on LCC. Finally, neither study translates the LCE into social cost and thereby allows a direct comparison between private and social cost and highlight potential economic trade-offs.In this study, we aim to address this gap by analyzing to which extent geography, and particularly the grid's CO_2-emissions intensity, influence the performance of battery systems regarding their LCC and LCE across different applications.

Methodology

To this end, we perform a LCC and LCE analysis of three battery types, namely Vanadium-Redox-Flow (VRF), Lead-acid (PB), and Lithium-ion (LI). Within LI we differentiate four different chemistries: nickel manganese cobalt oxide (NMC), nickel cobalt aluminum oxide (NCA), titanate oxide (LTO) and iron phosphate (LFP). We compute their performance in three exemplary European countries, which each represent a different CO_2-emissions intensity: Switzerland (low), Germany (medium), and Poland (high). Five applications are defined according to Malhotra and colleagues [2], reflecting different locations in the electricity value chain (residential consumer, commercial & industrial consumer, transmission or distribution grid) as well as various ways of generating value (increasing power quality and power reliability, increasing the utilization of existing assets and utilizing price differences through arbitrage).

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The system boundary in this study includes the manufacturing of battery systems, international transport of the systems from manufacturing to application country, installing the systems up to the point of grid integration and operating them during the use phase. We do not consider the end-of-life disposal and recycling of batteries in this analysis due to limited data availability [8]. To ensure robustness of our results, we conduct an integrated Monte-Carlo-Simulation, varying parameters with high uncertainty and/or difference between settings that effect both LCE as well as LCC results (efficiency, battery lifetime). In addition, we vary the energy consumption for manufacturing batteries (LCE) and capital cost of the fully installed battery system (LCC). To enable analysis of trade-offs between social and private cost, we recalculate LCE using the concept of social cost of carbon.

Results

Based on the conducted analyses we find that for the LCE, the use phase is of highest importance across all technologies and applications under study. The more the electricity supply to the battery is decarbonized (either via a low CO_2-intensity in the electricity grid, as in Switzerland, or via direct supply from a RE source, as in self-consumption of PV generation), the more the relevance shifts to battery manufacturing. For the LCC, the choice of technology is of highest importance. It is crucial to fit the technological characteristics to the application at hand. In general, LI batteries seem to perform best in most settings. Recent cost and technological improvements, driven mostly by the automotive industry, have led to this new reality. The geography has only limited influence, since the cost occurring during the use phase of the battery systems is rather small, compared to the initial capital expenditure. Therefore, both cost for operating and maintaining the system as well as for recharging the batteries due to efficiency losses is of limited influence. Combining LCE and LCC analyses, we find that there is a limited trade-off between social and private cost of battery technologies, when decarbonizing the electricity sector in a given geography. Battery storage systems are therefore a great example of how private and social welfare may go hand in hand.

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