Comparative Life Cycle Assessment of Battery Storage Systems for Stationary Applications

Mitavachan Hiremath[a,b], Karen Derendorf[a] and Thomas Vogt[a]**

[a]NEXT ENERGY – EWE Research Centre for Energy Technology at the University of Oldenburg, Carl-von-Ossietzky-Str. 15, 26129 Oldenburg, Germany.

[b]FluxGen Engineering Technologies Pvt. Ltd., #1064, BTM Layout, 560076 Bengaluru, India.

Motivation: The key challenge in highly renewable electricity scenarios is going to be the matching of demand and supply due to intermittent and non-deterministic nature of renewable sources, especially wind and solar, which are expected to dominate the renewable electricity-mix in the future. This, in-turn, leads to a series of technical challenges at various levels in the electricity grid network. For instance, the network operators in Germany are already facing problems of reverse power flows, high local voltage magnitudes and voltage violations during peak hours of solar PV generation. These issues not only induce instabilities in the grid, but also limit further penetration of renewables into it.

Because of their ability to decouple demand and supply, energy storage systems are considered to be promising candidates to address some of the major issues caused by the integration of large proportions of renewables into the future grid. Within the portfolio of available energy storage technologies, it is projected that batteries will play a promising role in future highly renewable electricity scenarios, especially for storages at distribution grid level (see Supporting Information (SI), Figure S1). In addition, there exists a potential synergy between battery applications for automotive and for stationary purposes. It is for these reasons that there is renewed interest within the industry, R&D institutions and academia alike to develop and deploy advanced environmentally friendly batteries for stationary applications.

This study compares four promising batteries– lead-acid (PbA), lithium-ion (Li-Ion), sodium-sulfur (NaS) and vanadium-redox-flow (V-Redox) – for near future stationary applications from an environmental life cycle assessment (LCA) perspective, keeping its focus on distribution grids. Based on the results of comparative analysis of the four batteries, a qualitative LCA of Li-Ion was carried out for more environmental indicators in order to identify the key impact categories affected by Li-Ion process chains. The results of our study can guide the battery industry by pointing out the key battery parameters that boost their environmental sustainability as well as aid decision makers in developing sustainable energy storage policies based on a comprehensive environmental understanding of battery systems.

Present State of Research: Various LCA studies on different kinds of batteries can be found in the literature, and most of the recent LCA studies on batteries focus on their application for automotive purposes. However, there is still a significant lack of detailed LCA studies that account for all the life cycle stages of batteries, as noted by Sullivan and Gaines. Furthermore, there have been very few LCA studies when it comes to stationary applications of batteries. Rydh compared V-Redox with PbA for stationary applications by accounting for five environmental impact categories. Denholm and Kulcinski compared flow batteries with other energy storage systems for utility scale applications in terms of life cycle energy requirements and GHG emissions. Rydh and Sandén evaluated life cycle energy requirements for eight batteries for their application in stand-alone PV systems. Recently, Longo et al. assessed the energy and environmental impacts of sodium/nickel chloride batteries for stationary uses, while Spanos et al. assessed the same for PbA and other batteries. However, there have been no studies that carry out a comparative life cycle assessment of battery systems for different stationary applications, taking into account the impacts arising from their stationary use phase.

In this paper, we address this research gap and complement the scientific literature by providing a transparent comparative LCA of the four promising batteries that covers two impact categories for seven stationary applications; in addition, we also provide a qualitative LCA of Li-Ion covering 17 mid-point impact categories. Contribution and sensitivity analyses of key parameters, including the influence of power-grid mix, are also presented. Our work thus adds a considerable level of environmental specificity to the ongoing discussion on stationary batteries and links earlier battery manufacturing and automotive based LCA literature to upcoming LCA studies in the context of stationary storage systems.

The complete publication is available here

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