Renewable and Sustainable Energy Reviews 78 (2017) 46–60

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Environmental impacts of Lithium Metal Polymer and Lithium-ion stationary batteries

Laurent Vandepaer[a,*], Julie Cloutier[b], Ben Amor[a,*]

[a] Interdisciplinary Research Laboratory on Sustainable Engineering and Ecodesign (LIRIDE), Civil Engineering Department, Université de Sherbrooke, 2500, boul. de l'université, Sherbrooke, QC, Canada J1K 2R1

[b] Hydro-Québec, Institut de recherche d'Hydro-Québec, 1800, boul. Lionel-Boulet, Varennes, QC, Canada J3X 1S1

ARTICLE INFO

Keywords:
Life Cycle Assessment (LCA)
Electrical energy storage
Stationary battery
Solid-state, Lithium Metal Polymer (LMP)
Lithium-ion (Li-ion)

ABSTRACT

The installed capacity of stationary batteries is expected to grow rapidly in the coming years. This deployment will have impacts on the environment that must be investigated to guide our policy and technology choices. A large variety of stationary battery technologies exists, however previous studies have failed to assess the environmental implications of several of them. In this study, the environmental performance of Lithium Metal Polymer (LMP) stationary batteries is quantified through the life cycle assessment methodology and compared to Lithium-ion (Li-ion) units. LMP is a promising technology which is advocated as more stable, safe and simple to manufacture than batteries with liquid electrolytes. Models with a storage capacity of 6 MWh and 75 kWh are examined, corresponding respectively to batteries designed for a centralized and a distributed grid configuration. The assessments cover the entire life cycle of the batteries and evaluate their impacts in fifteen different environmental categories.

The results show that the battery manufacturing stage drives the majority of environmental impacts in the different investigated batteries. Li-ion batteries cause significantly more impacts than LMP units in terms of global warming and ozone depletion. The effects on global warming come mainly from the production of components in countries where fossil fuel dominates electricity mixes. The production of polytetrafluoroethylene, used only in Li-ion batteries, is the main contributor to the ozone layer depletion category and also an important source of global warming emissions. Conversely, LMP batteries are responsible for a bigger impact in terms of aquatic eutrophication originating from sulfidic tailings linked to mining activities. An additional finding of this study is that centralized battery system configurations bring smaller environmental impacts than distributed systems with more but smaller storage units.

1. Introduction

Stationary batteries grew from a global power capacity of 800 MW in 2014–1720 MW in 2016 [1–3]. According to different prospective studies [4–6], this deployment is likely to continue and could reach 4000 MW in 2022. This current and forecasted expansion is largely driven by the ability of stationary batteries to bring flexibility to electricity systems with increasing shares of variable renewables [7,8]. Additionally, in comparison to alternative flexibility measures,[1] stationary batteries feature several important attributes. They are highly efficient, they have a fast response time and their modularity makes them scalable to an extensive set of applications and locations [9,10]. In addition to renewable energy output shifting, they can provide different grid services which are increasingly demanded such as frequency response and voltage regulation [10–12]. Finally, they are experiencing a sustained reduction in technology costs and a favorable regulatory framework [11]. The growth of stationary batteries is likely to have environmental implications. It is, therefore, essential to assess carefully the environmental performance of the technologies available to guide our technological and policy choices.

Life Cycle Assessment (LCA) has been used to quantify the environmental performance of batteries in several studies [13,14]. This framework is adopted because of its comprehensiveness: covering all the life cycle stages of the studied products and quantifying their impacts and damages among a wide range of environmental categories [15]. Among the current assessments on batteries, it is possible to

* Corresponding authors.
E-mail addresses: Laurent.vandepaer@usherbrooke.ca (L. Vandepaer), ben.amor@usherbrooke.ca (B. Amor).

[1] The following measures are frequently mentioned as a potential solution to increase flexibility: increased demand response, enabling trading close to real time, installation of dispatchable power sources, greater interconnection between markets, combination of complementary renewables, and improved forecasting of variable renewables and energy storage technologies [10,74].

http://dx.doi.org/10.1016/j.rser.2017.04.057
Received 17 February 2016; Received in revised form 18 February 2017; Accepted 20 April 2017
1364-0321/

identify several lines of research and methodological choices that have been favored by the research community. For example, a majority of studies conduct cradle-to-grave assessments, but these assessments only focus on a small set of impact categories: namely climate change and cumulative energy demand [14]. This limited coverage increases the risk of shifting environmental problems from the assessed environmental classes to areas that are not covered (e.g. ozone depletion or toxicity). With regards to the type of applications investigated, an important effort can be noted for the assessment of batteries with mobility purposes, also referred as traction batteries, where the following references [16–30] are relevant examples. In comparison, stationary batteries have been investigated with less dedication. Studies [31,32] focus on the assessment of micro-storage stationary solutions coupled with household solar photovoltaic installation. Study [30] evaluates a plug-in hybrid electric vehicle Lithium-ion (Li-ion) battery of 30 Ah with a second life application as a stationary battery of 20 Ah. A comparative LCA of a different type of stationary batteries is carried out in [33] where the following technologies are investigated: Li-ion, lead-acid, sodium-sulfur, and vanadium-redox-flow. Similarly, study [9] assesses different technologies used for stationary purposes, namely valve-regulated lead-acid, flow-assisted nickel-zinc, and non-flow manganese dioxide-zinc. A comparison of a stationary battery using vanadium and sodium polysulphide electrolytes to pumped hydro storage and compressed air energy units was conducted in [34]. In a recent work, study [35] compares redox flow stationary batteries to technologies with various power-to-X technologies. Despite the intensification of the LCA work in the field, the assessment of solid-state batteries is limited to technologies at an experimental level which are examined in the following studies [36,37]. Moreover, to the best of our knowledge, no research about the environmental impacts of Lithium Metal Polymer (LMP) batteries could be identified in the literature. LMP is a promising solid-state battery technology which is available at a commercial scale for stationary applications. Similarly to other solid-state technologies, it is advocated as less toxic, more environmentally friendly, more stable and simpler to manufacture than other types of batteries [38]. Finally, there are no published studies comparing batteries installed on the grid according to a centralized and a distributed configuration.[2] The increase in the distribution of technologies composing power systems also applies to storage and is considered as an important trend to take into account [39].

In this paper, the environmental impacts of LMP and Li-ion stationary batteries are quantified and compared through the LCA methodology. A set of fifteen impact categories and four damage categories are evaluated. Both chemistries investigated use lithium iron phosphate (LFP) at the positive electrode while at the negative electrode, the Li-ion unit uses graphite and the LMP a metallic lithium. LMP batteries are manufactured by a battery producer located in the province of Quebec, Canada. The Li-ion batteries are considered to be produced in Asia where the majority of the production of this technology is taking place [40,41]. Each technology is then modeled according to a use and subsequent life cycle stages occurring in Quebec or Canada. The models with storage capacity of 6 MWh and 75 kW h are examined corresponding respectively to batteries designed for a centralized and a distributed grid-configuration.

This work closes the gap with regards to the environmental assessment of LMP and solid-state batteries available at a commercial scale. Even though Li-ion units have been extensively studied, their assessment has not been realized according to a use stage in Quebec. Moreover, Li-ion is the most utilized battery technology for grid-scale stationary application and is expected to be an important player in the battery market of Quebec [36,42,43]. This study also highlights the difference in environmental performance between stationary batteries installed in centralized and distributed configurations. Finally, the environmental assessments realized investigate a broader set of impact and damage categories than in the current literature.

This article is organized into the following three sections. First, the LCA approach and the methodological choices made for this study are introduced. Thereafter, the results are presented, discussed and their robustness is tested. Finally, different outlooks are identified, including a conclusion at the end of the paper.

2. Methodology

Life Cycle Assessment (LCA) is a methodology used to assess the environmental impacts of products.[3] The ISO 14040-44 standard defines it as the *compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system*[4] *throughout its life cycle* [44,45]. The term life cycle usually covers the following stages of a product life: the extraction of raw material, the production and processing of materials, the distribution, the use phase, the final disposal at the end of its life, and the transport during and between the different phases [44]. LCAs are comprehensive and reduce the risk of problem-shifting by considering the product entire life cycle and a large set of potential environmental impacts [46,47].

2.1. Goal and scope

The goal of this study is to measure and compare from a life cycle perspective the environmental performance of two stationary LFP battery technologies: Li-ion and LMP. For each technology, models of batteries of 75 kWh and 6 MWh capacities are considered corresponding respectively to models used in a distributed and a centralized battery system configuration. In total, four models of batteries are evaluated. The function of these units is to store electricity from an intermittent electricity production source at one point in time to deliver it at a later time.

2.1.1. Functional unit

The functional unit is defined as *the quantified performance of a product system for use as a reference unit* [44]. It is used to define the studied product according to its function formally and allows comparison of several products according to a functionally equivalent basis [48]. The functional unit used in this study is one megawatt-hour (MWh) of electricity delivery. The environmental performance of a battery can be significantly influenced by its lifetime, its efficiency and its maximum depth of discharge [14]. This functional unit allows capturing the influence of these key parameters on the amount of battery required per output delivered. Furthermore, when considering the production and delivery of electricity, it also enables the study to take account of the efficiency loss of electricity occurring at each charge and discharge cycle.

2.1.2. System boundaries

Fig. 1 shows the boundary of the foreground system analyzed in this study. A cradle-to-grave approach is adopted. The product system includes the extraction of raw materials, the manufacture of the battery and its components, the installation on site, the maintenance and use phase, the production and delivery of the stored electricity, the transport and the end of life treatments.

[2] A distributed configuration consists of small energy storage systems located close to the load and spread across the grid [75]. On the other hand, a centralized battery system is composed of units with bigger capacity and installed on the grid in a smaller number.

[3] Product refers to any goods or service [44].

[4] Product system collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product [44].