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Primary control provided by large-scale battery energy storage systems or fossil power plants in Germany and related environmental impacts☆

Peter Stenzel*, Jan Christian Koj, Andrea Schreiber, Wilfried Hennings, Petra Zapp

Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research—Systems Analysis and Technology Evaluation (IEK-STE), D-52425 Jülich, Germany

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ABSTRACT

Increasing renewable energy generation influences the reliability of electric power grids. Thus, there is a demand for new technical units providing ancillary services. Non-dispatchable renewable energy sources can be balanced by energy storage devices. By large-scale battery energy storage systems (BESSs) grid efficiency and reliability as well as power quality can be increased. A further characteristic of BESSs is the ability to respond rapidly and precisely to frequency deviations, making them technical ideal candidates for primary control provision (PCP).

In this paper environmental impacts of PCP by novel Li-ion BESSs are compared to impacts of PCP by state-of-the-art coal power plants (CPPs) using a Life Cycle Assessment (LCA) approach and considering German control market conditions. The coal power plant stock is characterized by varying properties. Thus, different scenarios of CPP operation are analyzed by varying sensitive parameters like efficiency loss and required must-run capacity. Finally, PCP by BESSs and CPPs are compared in terms of environmental performance. The more must-run electricity generation is attributable to PCP of CPPs, the higher are the environmental impacts of these CPPs. This leads to a better relative environmental performance of BESSs in most scenarios. Contrary, comparative or even better environmental performance of CPPs compared to state-of-the-art BESSs can solely be achieved if power plants without load restrictions for provision of primary control and with extreme low efficiency losses caused by PCP are applied. Consequently, the results of this paper indicate that BESSs are a promising option to reduce environmental impacts of primary control provision.

1. Introduction

The energy system transformation towards more sustainable energy systems incorporates a growing electricity generation from non-dispatchable renewable energy sources. This increasing renewable energy generation influences the reliability of electric power grids [1]. Thus, there is an demand for new technical units providing ancillary services to secure system stability [2].

In literature, different definitions of ancillary services are used. According to [3] they can be divided in four sections: frequency control, coordination and operation, system backup, and restoration. Control power as a measure for frequency control is required if the amount of generated electricity varies from current load which results in grid frequency deviations. Positive frequency control is used to compensate drops of the frequency while negative control energy supports a decrease of frequency [4].

Regarding to the speed of activation there is a subdivision of control power in three types in Germany and further countries belonging to the interconnected European Network of Transmission System Operators for Electricity (ENTSO-E network) [5]:

- Primary frequency control reserves,
- secondary frequency control reserves, and
- tertiary frequency control reserves

Primary frequency control reserves, also denominated as primary control has to be activated entirely within 30 s to stabilize the frequency [5]. Up to now primary control power is mostly provided by fossil power plants [6]. The ability to respond rapidly and precisely to frequency deviations is a main characteristic of battery systems, making them ideal candidates for primary control provision (PCP) [7]. PCP by battery systems occurs in form of positive (discharge mode) and negative control (charge mode) and can reduce must-run electricity generation of fossil power plants.

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* Corresponding author. Fax: +49 2461 61 1560.
E-mail address: p.stenzel@fz-juelich.de (P. Stenzel).

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There are already numerous assessments of PCP by large-scale battery energy storage systems (BESSs) considering non-environmental aspects. Essential topics are techno-economic assessment, system operation and sizing of BESSs or PCP by BESSs in small island systems [8–10]. However, environmental impact assessments and LCAs of large-scale Li-ion energy storage battery systems especially for PCP provided by such BESSs are missing in previous scientific literature. Although there are already miscellaneous LCAs of batteries, these studies are primary limited to batteries within mobility applications [11]. In recent years also battery systems combined with photovoltaic systems were assessed from an environmental perspective [12,13]. However, even in these assessments of stationary battery systems, systems with significantly smaller capacities (110 kWh in maximum) than those of BESSs for frequency control, are considered [13]. In contrast to these former assessed small or medium sized battery systems, a recently published overview of realized and planned BESSs for ancillary service provision shows an average capacity of more than 4 MWh per BESS in Germany [14]. Beside the battery related publications, there are diverse scientific papers and reports including LCAs of CPPs [15]. In particular there are several papers about environmental impacts of CPPs combined with carbon capture and storage [16]. However, so far no detailed environmental assessment of PCP by CPPs has been conducted.

Thus, this paper fills a knowledge gap by presenting an assessment of environmental impacts of primary control provided by Li-ion BESSs in comparison to state-of-the-art coal power plants (CPPs). The framework of the German electricity market is considered within this research work. The environmental assessment of BESSs is based on data from a 5 MW/5 MWh BESS in Germany. In contrast, the environmental assessment of PCP by CPPs is more complex. An essential contribution to environmental impacts of CPPs is induced if there is a must-run electricity generation attributable to PCP. The extent of this must-run electricity generation attributable to PCP depends on provided ancillary services and further operation characteristics of CPPs. Thus, this paper presents scenarios of ancillary service provision by CPPs and calculates the resulting must-run electricity generation ranges. Finally, the environmental impacts of these scenarios are compared to the environmental performance of BESSs.

2. Methodology

2.1. Environmental assessment using LCA method

LCA is an adequate method for a holistic evaluation of environmental effects. It is well-established, internationally acknowledged, and defined in the ISO standards 14040 [17] and 14044 [18]. Within LCA environmental impacts along the whole life cycle of products are assessed. These assessments typically include construction, operation, and end of life of technical products or systems. Data from Younicos AG from an 5 MW/5 MWh Li-ion BESS, launched on 16th September 2014 in Schwerin, Germany [19], are applied as central data source. Where data from Younicos AG or own calculations could not be used, generic data were taken from the LCA databases GaBi 6.0 and ecoinvent 2.2. In this paper end of life of Li-ion BESSs is not taken into consideration due to non-established recycling infrastructures. However, first operation experiences with pilot installations exist (e.g. [20,21]) and results from studies on recycling of batteries for electric vehicles [22–27]. show that especially for resource depletion and acidification a high reduction can be expected, while for energy savings the chosen recycling process is crucial.

2.2. Goal and scope definition

This LCA paper compares the environmental performances of PCP provision by BESSs and by CPPs according to German primary control power market framework. The control power demand of 551 MW represents the average demand in Germany for the year 2013 [28] and is assumed to be constant in the period of 2015-2034. Environmental impacts of BESSs and CPPs are compared by means of the functional unit (FU). In this context the FU is defined by the total primary control power demand of 551 MW which has to be provided permanently for the period of 20 years. The period of 20 years is considered as time frame within the calculations

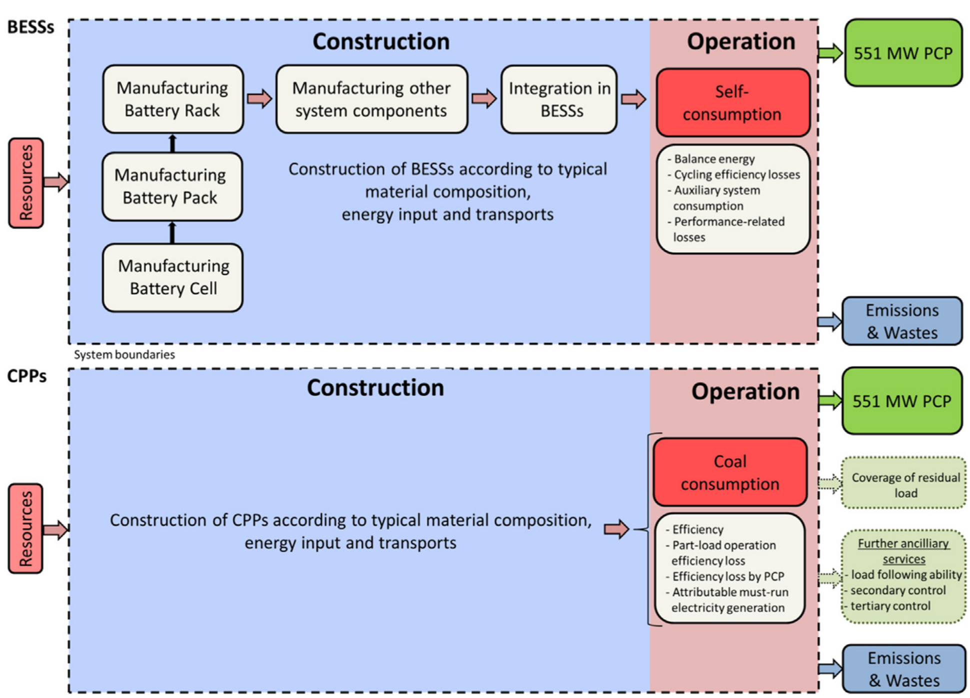

Fig. 1. System boundaries of CPPs and BESSs.