A REVIEW ON REVIEWS OF ENERGY STORAGE SYSTEMS: DO WE KNOW ENOUGH TO MAKE A SUSTAINABLE DECISION?

[Dominik Huber, Vrije Universiteit Brussel (VUB), Flanders Make, Belgium, +32 (0)2 629 28 00, Dominik.Huber@vub.be]
[Maarten Messagie, Vrije Universiteit Brussel (VUB), Flanders Make, Belgium, +32 2 629 38 30, Maarten.Messagie@vub.be]
[Thierry Coosemans, Vrije Universiteit Brussel (VUB), Flanders Make, Belgium, +32 2 629 37 67, Thierry.Coosemans@vub.be]
[Luis Ramirez Camargo, Vrije Universiteit Brussel (VUB), Flanders Make, Belgium, +32 (0)2 629 28 00, Luis.Ramirez.Camargo@vub.be]

Overview

Until recently, storage technologies for energy systems are mainly selected based on their technological and economic parameters. Though, every energy storage technology (EST) bears different environmental impacts even before being commissioned due to various structure and material composition. Therefore, choosing the right storage technology should no longer be only of financial interest, but should at the same time expose less harm to the environment. Numerous studies quantify potential environmental impacts of individual storage technologies in terms of global warming potential, acidification potential, eutrophication potential or others. Even though the quantification of ESTs is broadly available in literature, overviews of ESTs fail to include such impacts. This study presents a review of current parameters of various ESTs considered in overview documents and assesses the frequency of appearance of parameters and the transparency in reporting. A literature research was carried out, followed by a frequency analysis to identify relevant studies and most frequently reported parameters. In total, 14 studies are chosen, reporting values for 18 different parameters of 62 ESTs. It was found that technological and economic parameters are well-integrated in the reviewed studies while environmental impacts are assessed qualitatively and less frequently. A general issue that affects studies collecting and comparing parameters of multiple storage systems is the lack of explanation on how parameters where exactly calculated.

Methods

We conducted a literature review of commercial and scientific publications reporting on multiple storage technologies. Scopus and google (scholar) search engines were used to explore publications related to the search string "energy storage technologies overview". This exploratory study concentrates on overview publications reporting on multiple storage systems that already gather data from thousands of publications on individual storage types and technologies. We kept studies reporting, in a structured form, on various storage technologies and constructed a data base of parameters based on these. Afterwards, the parameters in the selected studies were observed and fed into a frequency analysis. Parameters were considered if three or more studies reported values for the same parameter. Furthermore, the technologies were classified into mechanical, electrochemical, electromagnetic and thermal technologies. Even though studies entail the same parameter, it did not necessarily allow direct comparison as they have used different units. Wherever possible, units were converted (e.g. from MWh to kWh or from hours into minutes). USD were translated into Euros utilizing an exchange rate of 1,13 USD/EUR (European Central Bank, URL). However, unit conversion was not possible for all parameters. For instance (Kousksou et al., 2014) and (Mahlia et al., 2014) report energy density values in Wh/kg and (Sabihuddin et al., 2015) provides energy density data in kWh/m^3 while the majority reports values on a Wh/l unit. In such cases, values of the three studies for energy density were excluded from the overview. Furthermore, all values are assessed quantitatively except for technology maturity and environmental impact, which were reported in text-form.

Results

In total, 14 studies have been selected. Eight of the publications are scientific papers, four are reports of research institutes or universities and two are reports from industry. These report on 62 different technologies, which are classified as following: 17 mechanical, 31 electrochemical, four electromagnetic and 10 thermal ESTs. The studies present values for about 80 different parameters of ESTs. Out of these 80 different parameters, 18 parameters are presented by at least three or more studies. Figure 1 shows, that the three most reported parameters are lifetime, energy density and life cycles. The first six parameters are technological parameters, whereas economic parameters are observed to be less frequently reported. Included technological parameters are lifetime, energy density, life cycles, efficiency, power rating, response time, power density, round-trip efficiency, daily self-discharge rate, storage time and discharge time. Considered economic parameters are energy costs, power costs, CAPEX and fixed and variable OPEX. Other parameters that are found to be relevant are technology maturity and, concluding the frequency list, environmental impacts (see Figure 1). One first finding was that only three out of 14 studies report on environmental impacts (Connolly, 2010; Kousksou et al., 2014; Sabihuddin et al., 2015). However, these studies conducted only a qualitative assessment of this parameter. (Connolly, 2010) for example described the environmental impact of pumped hydro energy storage as "reservoir", but without providing clear numbers about how much resources are being used by installing the required reservoirs. In the same report environmental impacts of compressed air energy storages are described as "gas emission". Without providing numbers about the same impacts, e.g. how much resources are being used or how much CO_2 emissions are issued by a particular technology, readers will find it impossible to select the most sustainable storage technology. Moreover, some studies lack a proper definition of the parameters, for example when talking about efficiency. Eight studies report data on efficiency, but only (Kousksou et al., 2014) and (Connolly, 2010) defined efficiency. Similar observations can be found when analysing the power rating. Eight studies present data about power rating of different storage technologies, none of them providing a definition of the parameter. Such fundamental definitions provide the readers with information whether the comparability of the same parameter is possible or not. Another result was encountered when describing the dimension of ESTs. For the description of the dimension, three different parameters are utilized: power rating, capacity and scale. Out of all considered studies, only (Kousksou et al., 2014) defines capacity to describe the dimension of the storage technology before reporting values about it. Besides analyzing the qualitative assessment of the covered environmental impacts, further details including a comprehensive analysis of parameters and recommendations are presented in the full paper.

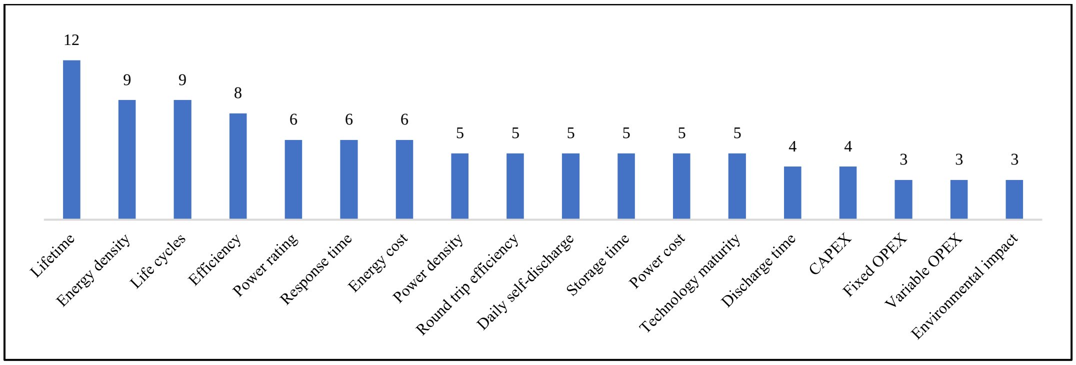

Figure 1: Number of reports providing data per parameters

Conclusions

A thorough review of overviews on storage systems has shown that there is a concerning lack of standardization on reporting about parameters of storage systems. There is little transparency on how parameters are calculated, and environmental impacts seem to play a secondary role. As a consequence, further studies should start their work with well-defined metrics in order to provide readers with highest transparency. Additionally, the qualitatively assessed environmental impacts do not provide sufficient information in order to identify the most sustainable EST. As a result, environmental impacts of ESTs by itself but also from a system perspective should be quantified and included into future overviews. Moreover, most parameters of the reviewed studies address more technological than economic or other parameters. On one hand, this is reasonable as these values are used to describe the system under study and give the reader an idea about it. On the other hand, sustainability is gaining more and more importance nowadays, particularly in an energy system that is designed to prevent climate change. Therefore, when choosing an EST for an energy system, technological, economic and environmental parameters should be considered equally. Furthermore, future authors of EST overviews are asked to include besides technological and economic parameters also quantifiable and reproducible environmental impacts, such as carbon dioxide, sulphur dioxide, methane and other emissions.

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