Environmental Impact of Alternative Energy Sources, Batteries, and BMSs

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

In an increasingly mobile and environmentally aware time, batteries have become much more widely used than ever before. From electric bikes – or E-bikes – and scooters to electric vehicles – or EVs – and even our homes, batteries have started to dominate as our main source of energy. With all the benefits that batteries provide as energy storage devices, it can be easy to overlook some of the potential risks they bring. For example, Lithium-ion – or Li-ion – cells are high performance but can also present great danger to the user if not handled correctly. Without proper protection, they may even explode, which has led to many car fires in EVs. Thus, the Battery Management System – or BMS – was developed (Balasingam, Ahmed, & Pattipati, 2020). Its main goal is to provide safety for users of battery cells, typically for more volatile batteries such as Li-ion cells. However, BMSs have expanded to provide more features such as measuring the state-of-charge – or SOC – and state-of-health – or SOH – of battery packs.

BMSs today often use a centralized system where a single device monitors all the data and provides all outputs, for both the individual cells and the pack as a whole. This typically ends up becoming rather disorganized and complicated, both within the BMS itself and for the user of the BMS. Therefore, a solution is to move toward a modular design for a BMS, where there are two components: a main node and multiple cell nodes. The main node handles all inputs/outputs regarding the overall pack while each cell node handles all inputs/outputs regarding one individual cell. The cell nodes then communicate the data they gathered individually to the main node, which can then make decisions regarding the overall pack. This structure greatly simplifies the designs of both the BMS and battery pack layout, as wiring the BMS to the pack can now be done around the pack rather than throughout it.

The research question I hope to answer in this paper is two-fold: first, should batteries be used as our primary energy storage devices in the first place? Many new technologies allow energy storage with less negative consequences than batteries, although they are typically more expensive or harder to use. Second, if we continue to use batteries at the current rate, what can BMSs do to reduce the environmental impact of battery usage? Most BMSs today only accurately model the cell's charge levels for first-time use since most batteries are replaced by the time they reach 80% of their original capacity anyway (Balasingam et al., 2020). However, there is some ongoing research into the reuse of cells from EVs as renewable energy storage systems, in which case a new BMS would be required to ensure the safety of those systems.

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Literature Review

All the articles used in this paper are rather recent, published in either 2019 or 2020. All the authors are affiliated with well-known universities. The only potential issue with these sources lies in the article by Ouyang, Ou, Zhang, & Dong, as it is studying the purchase of electric vehicles in China, which may not translate very well to the purchase of electric vehicles in the US or Europe. This is especially true due to the policy differences between China and the US: the paper by Ouyang et al. specifically talks about the differences between license plate-controlled (LPC) cities and cities with no license plate-controlled (NLPC), a policy that does not exist in the US.

There is also currently a gap in the research of the second use characteristics of batteries, described later in this paper. Without a full understanding of the SOC and SOH characteristics of batteries after their first use (in EVs, for example), it is difficult to develop a BMS to ensure the safety, efficiency, and reliability of the second use of batteries.

Methodology

The methods employed to pursue these research questions can be split into three main steps: gathering, analyzing and concluding. In the first step, data as well as various views and commentaries that have been made in past articles are gathered from many sources. In the second step, the gathered data and commentaries are analyzed for trends common among many sources, or for certain points that vary among the different sources. All of these similarities and differences are taken into account and summed up in the third step, making conclusions from the information gained from the various sources.

These methods proved beneficial in making concrete and well-supported conclusions rather than cherry-picking data that supports an initial claim. They were easily used to compare and contrast various energy storage technologies to answer the first research question. These methods were also used to discover many different ways BMSs can be used to reduce the environmental impacts of battery usage, thus answering the second research question.

Part 1: Social and Environmental Impacts of Batteries

Currently, batteries do not make up the largest portion of global electric storage capacity: pumped-storage hydropower facilities claim that title at 99 percent (Russo & Kim, 2019). However, battery usage is growing, particularly Li-ion batteries, due to their use in EVs. In fact, EV sales are expected to grow 500% in the next decade (Balasingam et al., 2020), thus leading to a 32% annual growth in Li-ion battery demand (Russo & Kim, 2019). However, does this increase in battery use equate to a better outcome for the environment? This is an important question to answer, since many consumers purchase new battery-powered technologies, such as EVs, with the expectation that they are helping the environment by switching to renewable sources of energy. In reality, the harm caused by using batteries in these alternative technologies may outweigh the benefits of using renewable sources of energy, something many consumers easily overlook. This is especially important as many consumers do consider environmental impacts when purchasing electric vehicles, even if it comes after cost and performance (Ouyang, Ou, Zhang, & Dong, 2020).

At first glance, this increased growth of battery usage in EVs seems to be a good thing for the environment, since EVs would not cause as much pollution as traditional internal combustion engine cars. However, there are many aspects of the battery's life cycle that could negatively affect the environment, from mining, manufacturing, and usage to storage, disposal, and recycling (Dehghani-Sanij, Tharumalingam, Dusseault, & Fraser, 2019).

To manufacture Li-ion batteries, many natural elements are required. While most of these are rather abundant and sustainable, there are a few rare or depletable elements such as cobalt that involve high-risk work environments with little protection or even child labor (Russo & Kim, 2019). Even for abundant elements, such as lithium, nickel, and graphite, the process of mining the material generates large amounts of CO_2 or other harmful materials that could pollute the environment and contaminate the surrounding food and water supplies. Not many regulations are in place to control the mining process, so it is up to private companies to keep their supply chains clean. Some have already taken steps to ensure this, such as LG Chem not sourcing cobalt from high-risk work areas like the Democratic Republic of Congo or Apple adhering to standards set by the Organisation for Economic Co-operation and Development (Russo & Kim, 2019).

Usage of batteries can also play an important role in how sustainable they are. Simply using a battery-powered EV does not mean that there will be less carbon emissions than using an internal combustion engine car: if the batteries themselves were charged using power generated from coal or fossil fuels, then the use of batteries has not reduced carbon emissions, it has only offset the time of carbon emissions (Russo & Kim, 2019). In order for EVs to be more sustainable than combustion engines, the electric grid that powers the batteries must have a cleaner energy mix, with more reliance on solar, wind, hydro, etc. rather than coal and fossil fuels.

Disposal of used batteries is also a problem. Typically, batteries for EVs are replaced by the time they reach 70-80% of their initial capacity (Balasingam et. al., 2020; Russo & Kim, 2019). These used batteries can still be used for less intensive applications, such as storing excess energy generated by solar and wind farms, or for residential applications, and often times are. Either way, once batteries are completely used up, they are typically disposed of in landfills, which is an issue for Li-ion batteries since the metals inside them can leach out and contaminate the environment (Russo & Kim, 2019). Furthermore, Li-ion batteries could still explode and cause fires in landfills. Despite these risks, very few batteries are recycled, with only 5% of Li-ion batteries in the European Union being recycled (Russo & Kim, 2019). Some other battery types, such as Zn-air and Ni-MH batteries, can be easily recycled, but recycling Li-ion is more difficult as it has higher energy requirements (Dehghani-Sanij et al., 2019). The lack of investments in recycling Li-ion cells is concerning, as the large expected growth of its use means there will necessarily be more Li-ion cells that need to be recycled or disposed, and re-using the elements in them, especially the rarer elements such as cobalt, could be very beneficial.

Part 2: Comparisons to Alternative Energy Storage Devices

Plenty of alternative energy storage devices are available for use such as pumped hydroelectric storage (PHS), compressed air energy storage (CAES), flywheel energy storage (FES), hydrogen fuel cells, capacitors, super capacitors, and superconducting magnetic energy storage (SMES), etc., but none of them are as distributable as batteries (Dehghani-Sanij et. al., 2019). Thus, at least for the near future, Li-ion batteries do seem to be what will be commonly used. A couple of alternative energy sources could be promising in the future, such as hydrogen fuel cells, where hydrogen is used to generate electrical power and water, but obtaining hydrogen typically requires the use of fossil fuels (Dehghani-Sanij et al., 2019), which then defeats the purpose of using the fuel cells in the first place. However, as long as hydrogen can be obtained sustainably, the fuel cell itself only produces water, heat, and electrical power, and should be rather sustainable. There are other similar examples where at present, there is simply not enough research done yet to efficiently and sustainably use alternative energy storage devices. With more research in these devices, there will likely be better solutions than batteries in the future.

For now though, batteries are the most effective energy storage devices we have. However, different types of batteries also have different environmental impacts. Li-ion batteries have one of the highest carbon footprints just for production, at about 12.5 kg CO_2 per kg of battery produced (Dehghani-Sanij et al., 2019). Lead acid – or Pb-A – batteries have the lowest carbon footprint, at about 3.2 kg CO_2 per kg of battery, but the lead used in them is toxic. However, Pb-A batteries, along with most other batteries, can easily be recycled as opposed to Li-ion batteries, which require a larger energy investment in recycling. Thus, from a purely environmental standpoint, other battery types than Li-ion would be better to use, but the performance of Li-ion is what has drawn most people to use it, especially in EVs (Dehghani-Sanij et al., 2019).

Part 3: How BMSs can Reduce Environmental Impact of Batteries

BMSs are used to ensure three things: safety, efficiency, and reliability (Balasingam et. al., 2020). The improved efficiency gained by using a BMS allows longer lifetimes for the batteries used, thus reducing environmental impact by reducing the number of new batteries that need to be produced, since Li-ion batteries have a high carbon footprint in production. Furthermore, batteries in EVs (the major use of batteries) tend to be replaced by the time they reach 70-80% of their initial capacity (Balasingam et. al., 2020; Russo & Kim, 2019), with the used batteries either being disposed, recycled, or re-used in second use cases such as storing excess energy produced by renewable energy sources or in residential applications.

However, this second use comes at a certain risk: currently we know that different usages and environments do affect batteries' SOC and SOH characteristics, but we do not know how the SOC and SOH characteristics are affected (Balasingam et al., 2020). Thus, it is imperative that we invest in more research on the second use of batteries, so that we can accurately model the behavior of batteries during their second use (possibly with prior knowledge of their first use). With this knowledge, we can develop new BMSs that can improve the safety, efficiency, and reliability of batteries during their second use, and further reduce the environmental impacts of batteries.

Conclusion

Batteries have become a widely used technology that we constantly rely on in everyday life. With each new piece of technology that is released for consumer use comes a set of batteries for powering it. Batteries of all sizes surround us. We have larger and larger battery packs capable of delivering more power in an instant – and of failing catastrophically. Therefore, BMSs are needed now more than ever to ensure safety while using these high-performance cells. The Modular BMS I described is better suited for handling this increasing size of battery packs. It can theoretically handle any number of cells, from an E-bike or scooter to a full EV made up of hundreds of cells. However, in this entire process of using batteries and BMSs to provide safe and efficient forms of energy, it is important to keep in mind the environmental impacts of batteries, from manufacturing and using them to disposing and recycling them.

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