The Impact of Battery Systems on Society and the Environment

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Dipesh Manandhar
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On my honor as a University Student, I have neither given nor received
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Signature Dipesh M Date 4/23/2021
Dipesh Manandhar
Approved Date
Richard D. Jacques, Department of Engineering and Society

Introduction

With the rise in technology available for consumer use, many more people are constantly exposed to interacting with electronic equipment than ever before. In every person's pocket is a battery-powered mobile device, in every building are several mains-powered lighting systems, in every vehicle is a battery-powered display, in every laptop used for Zoom meetings is a battery, all of which, most people would agree, are improvements to living standards (perhaps with the exception of Zoom meetings over in-person ones). The modern world as we know it would not exist without electricity. Of course, not all of this progress comes without its downsides. It is not uncommon to hear about cases of battery-powered devices catching fire or broken power lines shocking bystanders in the news. The increase in such cases is strongly correlated with the fact that it has become much more commonplace for the public to be near or using high-power electronic devices, as they are much more readily available on the market.

My technical work was to design a modular battery management system (BMS) that not only actively works to prevent battery failures but is also configurable for a wide range of application sizes, from electric scooters and bicycles (E-bikes) to electric vehicles (EVs). Many BMSs today are built for a specific battery pack size, such as those built for small E-bike battery packs or those built for a specific number of cells in a large EV. Though modular BMSs have already been designed, they are often too expensive or consume too much space for both boards and complex wiring (Turgut, Bayir, & Duran, 2018). This project attempts to overcome these issues by developing a modular BMS that is small enough to use in E-bike and electric scooter applications, while also being expandable to fit the needs of larger battery packs for EVs.

My STS work covers the social and environmental effects of developing such technology for widespread public use in high-powered electric applications. This includes, perhaps most notably, in the use of EVs. I hope to answer what the implications of designing this modular BMS are not only on the environment, but also society as a whole. This question is important because of the many unseen and hidden risks, both environmental and social, that continue to not only persist but also grow bigger and bigger every day. Even if they may not affect us immediately, these growing problems will come back to haunt us in the near future.

I would like to thank the Solar Car Team at the University of Virginia for providing all of the batteries, battery holders, battery charger, power supply, and other miscellaneous electronic components needed to test our Modular BMS.

Literature Review

There has been much research done on the environmental impacts of batteries, particularly as many EV manufacturers and other proponents of new renewable energy sources and applications continue to promote their new technology as more “clean” than traditional technology, such as traditional gasoline-fueled vehicles. Thus, it is not too difficult to find credible research papers that compare the environmental impact of such new technology to traditional ones (Russo & Kim, 2019). However, it is much more difficult to find any information on the social impacts of such technology. For example, though I was able to find research on the social risks of different supply chain configurations for batteries, I was not able to find any research that compared the supply chain of batteries to that of fossil fuels (Thies, Kieckhäfer, Spengler, & Sodhi, 2019). In addition, it should be noted that though many of these research papers are from credible sources, they often focus on a case study or analysis of a specific country or location, which may introduce some amount of bias or results that may only apply to that specific location (Ding, Zhao, & Li, 2020).

Methodology

The environmental impacts of designing a modular BMS will be evaluated by collecting and analyzing data from past research on how high-powered consumer applications such as EVs affect the environment. The social impacts will be accessed by analyzing a Social Life Cycle Assessment (S-LCA) of current battery systems to determine the parts of the batteries’ lifetime that present high social risk.

The impacts EVs have on the environment have already been thoroughly researched, so there are already large amounts of data on this topic. Thus, it makes sense to utilize this vast amount of data to determine how a modular BMS would affect the environment. There is not as much data on the social impacts of EVs and battery systems, so a thorough case study of one specific EV will provide insight on common problems in the life cycle of the batteries used. This study will cover the entire lifetime of the batteries, from the sourcing of raw materials, to the manufacturing process, then finally the disposal of the batteries.

Part I: Motivation

I started this project because of my experience as the Power Lead in the Solar Car Team at the University of Virginia, a student organization whose goal is to provide engineering and business students hands-on learning experience working on a competition-ready solar-powered electric vehicle. As a part of this role, it is my responsibility to ensure the battery pack remains not only safe and functional throughout active driving and charging times, but also in top condition to extend lifetime and increase efficiency. To achieve this, we currently use the Orion BMS, which has a built-in maximum capacity for the number of battery cells it can support (which is over the size of our battery pack) (*Orion li-ion battery management system | affordable & reliable ev li-ion bms*, n.d.).

However, in the future, we would like to switch over to using a custom-designed BMS built by the team in order to give ourselves more flexibility in configuration options and to provide more learning opportunities for our members. Thus, this technical project would serve as the basis for our team to design our future BMS off of. I decided to make this BMS focus on a modular structure not only to ensure flexibility of the BMS to potentially different future battery pack layouts, but also to ease the design process of the BMS. In our previous version of the electrical system for the Solar Car Team, we experienced many difficulties due to its highly monolithic structure, so starting with this year's new iteration, we decided to use a modular structure for the entire car's electrical system. Thus, it made sense to use a similar structure for our BMS as well.

Part II: Supply Chain

The production of all lithium-ion batteries, regardless of what the end application is for, starts with the raw materials. The four most important elements that go into a lithium-ion battery are lithium, cobalt, nickel, and graphite, all of which are rare earth metals found largely outside of the United States (Russo & Kim, 2019). On top of the mining process being a very environmentally dirty process, with heavy machinery that releases large amounts of greenhouse gases pollutants into the surrounding air and water, there are often many social implications associated with the mining of each of these rare earth metals.

Most of the world's total supply of lithium is produced in Australia or Chile, which combined make up 75 percent of the world's total supply (Russo & Kim, 2019). While the extraction process used in these two countries differs greatly, they both pose their own risks. The heavy machinery used in Australia requires large amounts of energy and releases pollutants, such as CO_2 emissions and sulfuric acid, which contaminate the surrounding air and water. On the other hand, the brine pumping process used in Chile requires large volumes of water, which often leads to disputes with local communities over the scarce resource. Additionally, because the stakeholder engagement by mining company representatives and government officials has been very poor, many of these affected communities feel that "their ancestral lands are being exploited by outsiders, with not much for them to gain from the bargain" (Russo & Kim, 2019).

The Democratic Republic of Congo (DRC) produces about two-thirds of the global supply of cobalt, but about a fifth of that comes from "small-scale (informal) miners, who have no equipment other than very basic tools such as headlights, hammers, and chisels" (Russo & Kim, 2019). This means many miners have to working risky environments unprotected, which often leads to fatal accidents and many health hazards, such as metal poisoning, birth defects, and sulfuric acid contamination. On top of these harsh working environments, many of these informal mining practices in the DRC include child labor practices.

Nickel and graphite mining face more problems with long-term negative environmental impacts than with any social issues (Russo & Kim, 2019). A common theme with these rare minerals is that the countries which have lower mining costs often “[come] at the price of low environmental standards and enforcement” (Russo & Kim, 2019).

In one study, the social hotspots database (SHDB) was used to calculate the total number of social risk hours for three different theoretical supply chain configurations needed to produce a state-of-the-art EV battery pack (Thies et al., 2019). These three configurations were a China-focused production with raw materials being sourced from the top three producing countries in 2017, a similar German-focused production using the same raw materials sourcing, and finally a China-focused production with more responsible raw material sourcing using one of the top three countries that exposes the lowest social risk for raw material sourcing. The results of the experiment are shown in Figure 1, which plots the total risk hours for each of these three supply chain configurations for four different social risk categories: child labor, corruption, occupational toxics and hazards, and poverty.

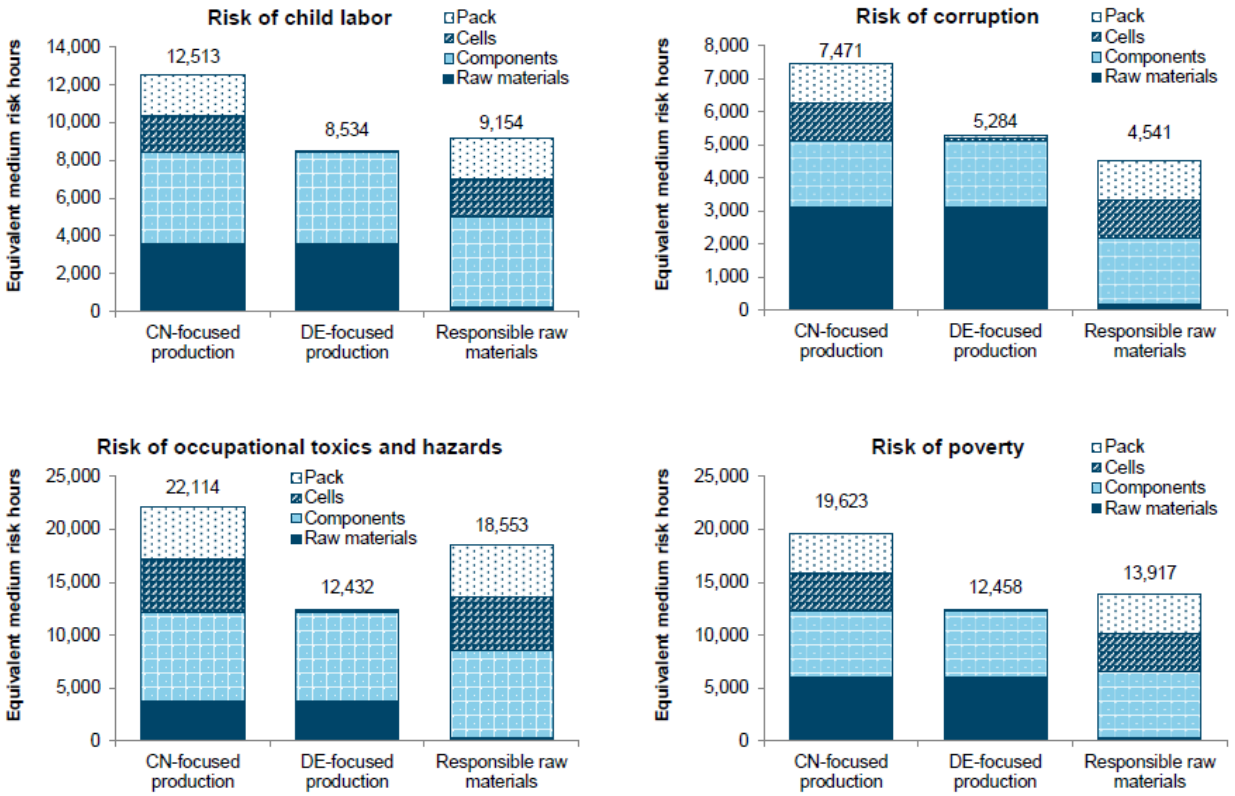

Figure 1: S-LCA Assessment Results

The major takeaway from these results is that manufacturers should carefully consider where to locate production and raw material sourcing facilities. Simply moving production from China to Germany, for example, significantly reduced the social risk in all four of these categories. In addition, simply choosing to source all raw materials from countries with lower social risk also reduces the social risk in all four categories, most notably in the corruption category, where raw material sourcing accounted for the largest part of the social risk.

Part III: Degradation and Disposal

Though governments worldwide have prioritized the development of EVs in response to the impacts of climate change, it remains unclear who is responsible for properly disposing the waste batteries these EVs generate (Ding et al., 2020). This is an imminent problem, as the average lifetime of many battery packs used in EVs is 5-8 years, which means a surge in EV waste batteries is expected to occur within the next two years. In China alone, the accumulative amount of decommissioned batteries is already about 25 GWh, or approximately 200,000 tons. If left in landfills, the metals contained in batteries can leach out into the environment and into the surrounding soil and water supply (Russo & Kim, 2019). The nickel and cadmium in these batteries are known to be carcinogens, and lithium-ion batteries specifically risk exploding or starting fires in landfills. Despite this, only a shocking 5 percent of lithium-ion batteries in the European Union are recycled, mainly due to high investment costs, and in China, currently, no recycling system exists for waste batteries, and manufacturers lack an incentive to do so (Ding et al., 2020).

Instead, the common solution now is for manufacturers to place this burden on third-party professional recycling agencies because the collection process is a low-profit industry in comparison to automotive and battery industries (Ding et al., 2020). Collected batteries face one of two fates: reuse or dismantling for raw materials. Currently, most batteries are dismantled at the end of their lifetime because of three major reasons: (1) reuse is difficult because of the vastly different battery models, specifications, and technical approaches used by different car companies, (2) battery manufacturers do not want to bear the risk of reused batteries and would lose profits if retired batteries were to re-enter the market, and (3) the rise in lithium-ion battery demand has lead to shortages of the rare earth metals needed to make them and thus it is increasingly necessary to extract these metal materials from used batteries.

An important stakeholder in this growing problem is the government. One study from China analyzes the effectiveness of two different types of government subsidies in the power battery recycling industry: collection subsidies and dismantling subsidies (Ding et al., 2020). The study has shown several key insights for how EV manufacturers and third-party recycling agencies make decisions on whether or not to recycle used batteries. First, the fixed collection cost is the key basis for choosing collection strategies. That is, even without any collection or dismantling subsidies, if the fixed collection cost is low, then even EV manufacturers would choose to collect used batteries. However, too high of a fixed cost led EV manufacturers and third-party agencies both to not collect used batteries.

Second, both collection subsidies and dismantling subsidies are effective in persuading EV manufacturers to collect used batteries (Ding et al., 2020). The key factor used by EV manufacturers and third-party agencies when choosing to accept collection subsidies or dismantling subsidies is the dismantling efficiency. With a higher dismantling efficiency, dismantling subsidies provide more profits to both manufacturers and third parties, but with a lower dismantling efficiency, collection subsidies are more utilized. This information is not only relevant to the manufactures and third parties, but also to policymakers, as they can use the insights from this study to help make more informed decisions on how to make effective subsidies that will reduce environmental impact of the power battery industry, rather than only focusing on increasing the battery collection rate. Simply focusing on collection subsidies is not enough to incentivize manufacturers to play an active role in used battery recycling. Instead, policymakers will need a better understanding of key factors such as dismantling efficiency in order to decide what type of subsidy (collection or dismantling in this case) would be most effective.

Part IV: How BMSs can Help

The purpose of a BMS is two-fold: to protect batteries from operating in unsafe conditions (which many include too high of current, too low of voltage, or temperatures outside of the operating range of the batteries) and to extend the batteries' lifetime by ensuring they are use efficiently. Thus, simply the use of BMSs can help reduce the demand for new batteries by ensuring each battery can be used to its maximum lifespan. In addition, the modular structure of my BMS means it will be much easier to integrate with a wide range of applications, from single-cell applications, to large EV battery packs. That said, it should be noted that EVs and other high-power applications often only use batteries until their capacity drops to about 70 to 80 percent (Russo & Kim, 2019). After this point, they must be replaced with new batteries, but the used batteries, though they may not be powerful enough to use in high-power applications, they still can be used in many second-use applications.

These second-use applications primarily include acting as a long-term energy storage device for certain renewable energy sources that only provide intermittent energy, such as solar or wind, which can only provide energy during certain times of day or weather conditions. Here, again, the BMS can be used to help alleviate this problem. BMSs are often designed to work most effectively with brand new batteries and not used ones, as this makes the modeling of the batteries' lifetime and state of charge easier. However, this makes them not as effective when used for second-use applications, where the batteries do not start at 100 percent capacity. Thus, second-use applications will often need their own BMSs specifically designed for their used batteries, which is very difficult to design because of the vastly different models and specifications used by different battery manufacturers (Ding et al., 2020). However, because of the modular structure of my BMS, it is much easier to set specific parameters based on the battery specifications provided by the manufacturer. This means it will be much easier to design a system based on my modular BMS that could be used in second-use applications.

The diagram in Figure 2 from the U.S. Department of Energy shows the lithium-ion battery recycling options currently available, and clearly marks in red the worst possible path for the environment that batteries could take in this cycle: disposal in a landfill. BMSs can help by extending the lifetime of batteries to slow down their progression through this cycle, and by being specifically developed for more effective second-use applications.

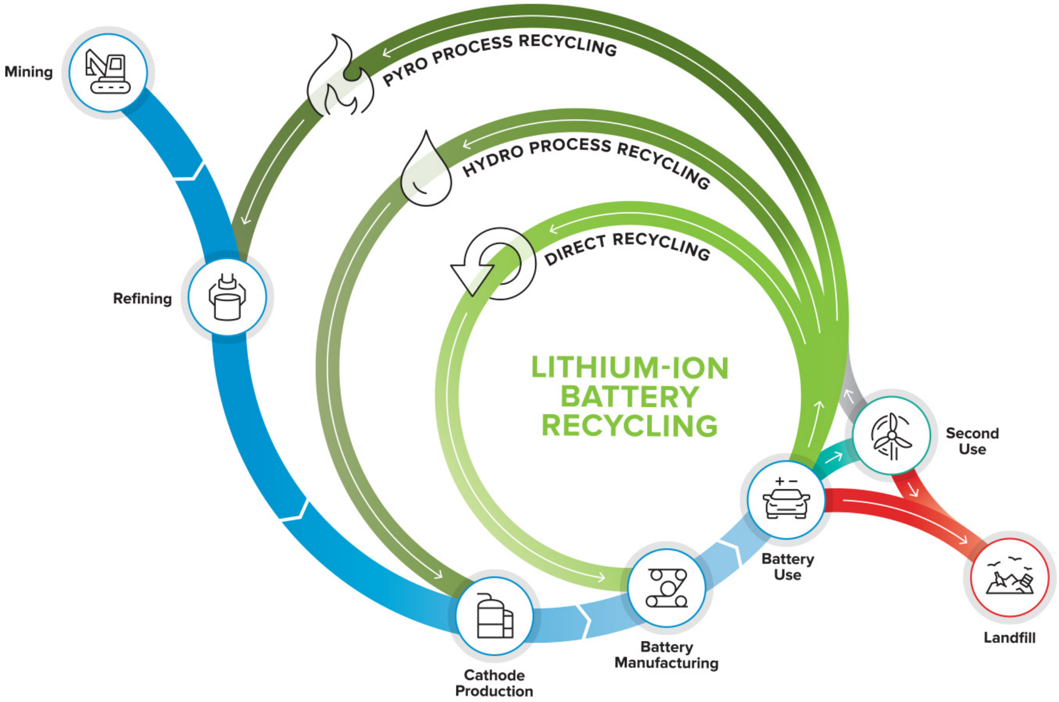

Figure 2: Lithium-ion Battery Recycling

Conclusion

The modern world has become, and will only continue to grow, dependent on “clean” energy storage devices such as the battery. These energy solutions are not always as optimal as they may seem. The disposal of batteries continues to be an easily overlooked problem globally, and battery failure continues to prevail as an obstacle to widespread acceptance of these “green” electrical systems. The supply chain of the raw materials used in the production of these batteries introduces many social risks, which are often overlooked in the mass production of battery packs for EVs and other high-power applications. My technical project introduced a modular BMS that is usable in various applications, from the smallest battery-powered consumer electronics to full-scale EVs. The small size and low cost of this project ensures that it can be used even in the smallest applications, and takes less space for EV battery packs. The modularity of the BMS also lends itself as more useful to solve some of the common problems with battery use, both in high-powered applications and in second-use storage applications. Some areas of future research would be an investigation into several overlooked factors in my STS research, such as how the demand for lithium-ion batteries may fluctuate, or how competition between used battery collectors may affect the market, or even consumer environmental and social awareness which may influence manufacturers to choose more responsible supply chains and recycling versus disposal methods.

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