Systematic Investigation of Environmental Impact between Lithium-ion Battery and Sodium-ion Battery

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Abstract

This paper provides significant new insights into Sodium-ion and Lithium-ion batteries' environmental impact. Lithium-ion batteries are used in commercials on a large scale. However, lithium-ion batteries are used less than sodium batteries. Considering that Sodium-ion batteries technology is not as advanced as Lithium. Sodium-ion batteries may have the potential to replace Lithium-ion batteries. According to commercial data, batteries are widely used in different areas because of their significant use in the renewable field, such as electric cars or energy storage projects. The battery has become a significant component in the renewable area. In that case, we will discuss which kind of battery will be better, especially the environmental impact. If the public cloud analyzes which battery is better, we will benefit from replacing batteries. First, the paper will discuss the environmental impact of five aspects: water pollution, Solid pollution, Raw material, Recycling, and Gas emissions. Second, according to the five aspects, we will use method AHP to analyze which battery is better. After AHP, the conclusion of which batteries are better regarding environmental impact will be given.

Keywords: sodium battery, lithium battery, environmental impact, recycle, analytic hierarchy process

1. Introduction

The Paris Agreement in Dec. 2015 set new goal for 196 nations. Every nation is working for reducing the emission of gases that contribute to global warming. Growing renewable energy become an option to accomplish the goal. Using Electric vehicle occupied a significant role in reducing the emission. Nowadays, According to Electric selling data, Global EV sales reached 6,75 million units in 2021, 108 % more than in 2020.This volume includes passenger vehicles, light trucks and light commercial vehicles [1]. Battery as the heart of the EV, power whole EV systems. According to the Data, the global EV battery usage in June 2022 was 45.2GWh, more than 1.7 times higher compared to the same month last year. With huge usage, if we could analyze different kind of battery, we could save the energy and get more benefit.

2. Methods and Materials

2.1 Water Pollution

2.1.1 About LIB

Due to the unstable output of lithium batteries, the complexity of raw materials, the intermittent discharge of wastewater and the semi-automatic production, the water quantity control is not accurate in the process of lithium battery production, and the water quality and quantity of wastewater are volatile. According to the above analysis of the characteristics of wastewater, we know that the conventional single treatment method cannot reach the standard in the treatment of wastewater from lithium battery production, and the targeted treatment process must be adopted.

2.1.2 *About SIB*

Wastewater needs to be pretreated by physical and chemical methods (coagulation and precipitation process) to ensure the stability of subsequent biochemical treatment, and to deal with biodegradable substances and heavy metal substances. and biochemical treatment (anaerobic + aerobic process) is used to further degrade pollutants such as COD and ammonia nitrogen in the water. Treatment of the wastewater requires pretreatment of harmful pollutants such as heavy metals. So, generally, SIB cost less money and is easier to be treated compared to LIB considering the complexity of pollutants in wastewater.

2.2 *Gas Emission*

When manufacture sodium-ion battery or Lithium-ion battery. It will definitely have gas emission. Waste gas will have terrible impact to the environment. According to the research. Lithium-ion battery will emit waste gas, including Phosphorus trifluoride (PF3), Hydrogen fluoride (HF), diethyl carbonate, ethyl methyl carbonate. These waste gases will damage human's health. PF3 is strongly corrosive and highly toxic. Harming the skin when human confront this gas. Diethyl carbonate and ethyl methyl carbonate are organic compounds. They will cause headache, dizziness, weakness, nausea, dyspnea after inhalation. Sodium-ion battery electrolyte is similar to the Lithium-ion battery. However, there is a different between them. SIB electrolyte will combine salts of similar nature and concentration – usually 1 M $NaPF_6$. LIB electrolyte will combine salts which include bis(trifluoromethanesulfonic)imide (TFSI) anion. Comparingly, TFSI anion have the characteristic that have chemical and thermal stability than PF_6^- anion and does not lead to the formation of hazardous hydrogen fluoride (HF) in the same situation [2]. In that case, LIB is safer than SIB.

Another aspect of emission is GWP, GWP stand for global warming potential. We could divide SIB into different components. Fig 1 shows the composition of the modelled SIB.

After modeling the SIB, we could analyze different components' GWP. Fig.2 shows different composition of SIB GWP.

After analyzing the data, we could see that manufacturing anode is the main driver to the GWP, especially producing the hard carbon active material. Battery components occupy the highest emission in the GWP (24%). Another process, producing the sugar from the sugar beet, which is used as a precursor for the hard carbon preparation. This process occupies 16% whole GWP. Another electro is cathode, cathode production occupies 20% of the total GWP.

Figure 3 compares SIB and LIB components and process's GWP. In this figure, we could parentally see that LIB have lower GWP. The reason why the LIB has lower GWP is that SIB have lower energy density, which require increasingly larger battery cells in the same situation of storage capacity.

Also, we could analyze the process that will have GWP when companies recycle these batteries in Figure 4. During the recycle process, we could have a conclusion that LIB still has a lower GWP. Aluminum is a significant driver for GWP impacts. What's more, the SIB cells with lower energy density and higher aluminum content. Therefore, SIB show higher benefits from the mechanical recycling.

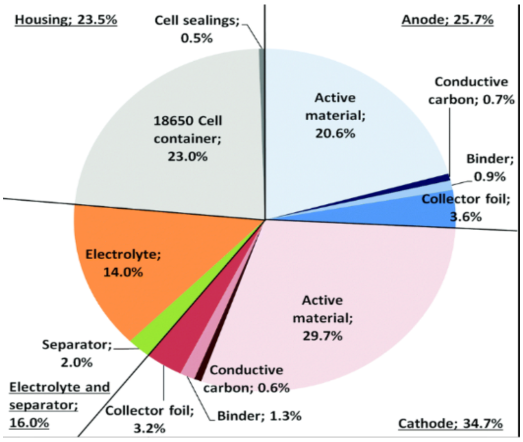

Figure 1. The composition of the modelled SIB [3]

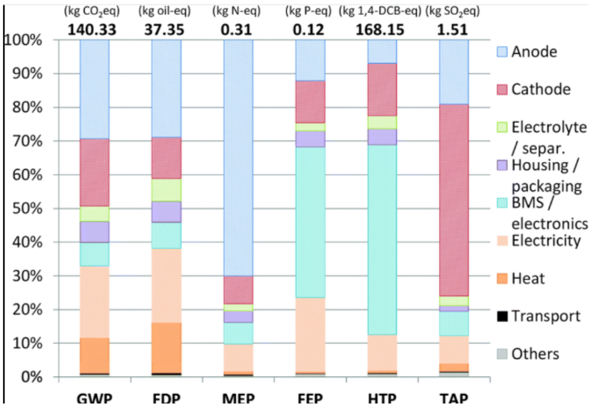

Figure 2. Different composition of SIB GWP [3]

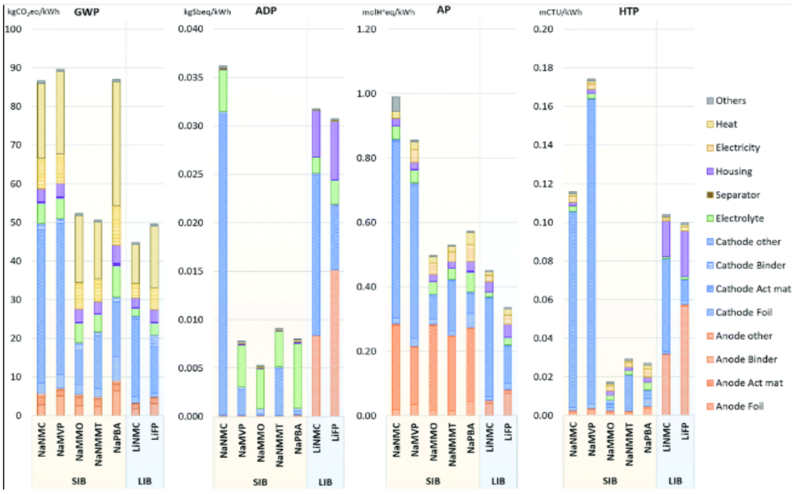

Figure 3. Comparison between SIB and LIB processing GWP [4]

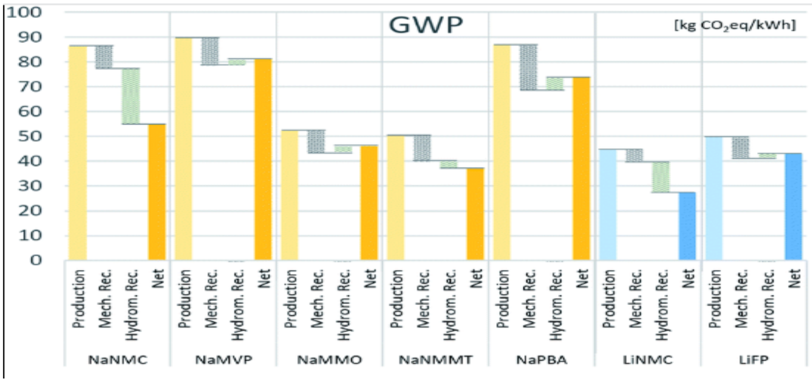

Figure 4. Recycling GWP Between SIB And LIB [4]

2.3 *Raw Material and Consumption of Resources*

As for the raw material of lithium iron phosphate battery, lithium is very rare in the Earth's crust. It is a soft silvery-white alkali metal, containing about 20 parts per million lithium in the Earth's crust, 0.17 parts per million lithium in the ocean, and basically negligible lithium in the atmosphere [5]. The distribution of lithium is extremely uneven, with most of the lithium resources located in South America and Australia. As a result, the price of lithium is extremely high, reaching 49.1W yuan per ton. For sodium-ion batteries, sodium is much more available than lithium, with the fourth highest metal content in the Earth's crust, at 2.36 percent [6]. This means that once lithium metal is overused to make a large number of lithium-ion batteries, and when lithium-ion batteries are in use and lithium cannot be recycled, lithium becomes excessively deficient. But with huge reserves of sodium metal, this is not a problem [7].

Energy density is also an important parameter in the environment. Because the high energy density reduces the number of batteries that need to be produced to provide a given storage capacity, the corresponding environmental impact is reduced. With the increase of battery energy density, the pollution to the environment will be smaller. Because life cycle assessment of a battery, the fewer batteries are produced, the less electricity are used and the less carbon dioxide are emitted.

The Table 1 shows the carbon dioxide equivalents of most sodium ion and lithium-ion batteries on the market based on different energy densities.

We can see that as the energy density of the battery increases, carbon dioxide emissions decrease. However, there is a very important point here. The average energy density of lithium iron phosphate batteries produced by Guoxuan High-tech Company can reach 175WH/Kg, but the limit energy density of sodium ion batteries can only reach 160WH/Kg, which is less than the average level of lithium iron phosphate batteries. In other words, to make a battery with a given storage capacity, making it from a sodium-ion battery releases more carbon dioxide than making it from a lithium-iron phosphate battery.

Table 1. CO2. equivalents of SIB and LIB on the market based on energy densities [4].

En. Dens.	NaNMC	NAMVP	NaMMO	NaNMMT	NaPBA	LiNMC	LiFP
WH/Kg			GWP	KgCO2	Eq/KWh		
100	74.6	124.0	72.3	64.1	91.8	74.6	85.0
110	67.8	112.7	65.7	58.2	83.4	67.8	77.3
120	62.2	103.3	60.2	53.4	76.5	62.2	70.8
130	57.4	95.4	55.6	49.3	70.6	57.4	65.4
140	53.3	88.6	51.6	45.8	65.5	53.3	60.7
150	49.8	82.7	58.2	42.7	61.2	49.7	56.7
160	46.6	77.5	45.2	40.0	57.3	46.6	53.1
170	43.9	72.9	42.5	37.7	54.0	43.9	50.0
180	41.5	68.9	40.1	35.6	51.0	41.5	47.2
190	39.3	65.3	38.0	33.7	48.3	39.3	44.7
200	37.3	62.0	36.1	32.0	45.6	37.3	42.5

2.4 *Disposal of Waste*

The electrification of automobile comes faster than we have ever thought of. It is estimated that two thirds of the passenger-vehicles in 2040 will be electric vehicles, as different large carmakers claim that they will gradually stop selling gasoline-powered cars. One major problem that may greatly harm the environment is that it is rather hard to recycle and reuse the lithium batteries. One of the main reasons is that the recycle technology which is currently used for lead-acid batteries does not apply to lithium batteries. What's more, lithium batteries are larger, heavier and more sophisticated than the traditional batteries. The most common method of recycling batteries is simply grinding everything and extract refined complex mixtures. Such method is expensive which outweighs the output. In fact, the cost of recycling lithium batteries is larger than exploiting more lithium metal to produce new lithium batteries.

Additionally, because of the lack of a highly sufficient recycling way, only 5% of lithium batteries can be recycled. Although electric vehicles can help to decrease the emission of carbon dioxide, the huge environmental impact of battery material requires us to come up with a standardized and environmentally-friendly method.

Currently, there is three methods to recycle the used lithium battery. The first common method is pyrometallurgy technology. The method will burn the electrode at extreme high temperature to burn the carbon and organic compound. Then generate new alloys through reduction. In the following process, precious metal (Lithium, Iron) is separated and reproduced by high temperature solid state method. However, such method still has several impacts on the environment. Firstly, during the smelting operation, large amount of carbon dioxide is emitted and a great deal of energy is consumed.

The second method is hydrometallurgy. By dissolving metal ions in lithium-ion battery using acid and base solution, people are able to extract dissolved metal ions by precipitation and adsorption in the form of oxide and other compounds. The reaction mainly uses $H2SO4$, $NaOH$ and $H2O2$. Such method is comparatively easy to carry out and does not require a high standard of equipment. It is suitable for industrial large-scale production and currently the most mainstream recycling method. One of the products of the recycling is $Li2CO3$.

This method has a low cost but the main ingredient ferric phosphate is not fully recycled, which causes waste of resources. But by using the wet method to preferentially extract lithium, the recovery rate of lithium in ternary materials can reach 95%. $LiCO3$ and $FePO4$ produced during recycling can be directly used in battery manufacturing system. Compared to pyrometallurgy, hydrometallurgy can produce material with high purity and emits less carbon dioxide. However, such method requires large storage space and thus increase the cost and complexity. Due to the similarity of these elements, it is rather difficult to separate them. Additionally, it is inevitable that hydrometallurgy will produce waste water which might cause secondary pollution.

The third way is direct recycling. The used batteries will be dismantled, crushed and sieved. Then the material will go through the re-lithiation processes, which consists of solid-state synthesis, hydrothermal, electrochemical and chemical processes. This method has a relatively easy process and the active material can be directly used after regeneration. Also, the carbon dioxide emission is greatly reduced.

Although there are several ways to recycle the lithium batteries, none of them are able to provide a perfect solution. Lots of problem along with these different ways are especially harmful to the environment, such as the secondary waste.

On the other hand, for lithium-ion batteries, it is hard for researchers to acquire precise and efficient data for the recycling process. Information of sodium-ion batteries is less available. The hydrometallurgical facility that is currently used in lithium batteries is not suitable for the low-value containing batteries like sodium-ion batteries. A specific recycling model for sodium ion batteries is required so as to evaluate the recycling performance of the considered batteries.

The recycling process model is dependent on the past researches which offered data for various recycling processes. The process will increase load by the hydrometallurgical treatment of lithium-ion batteries and sodium-ion batteries The preliminary model has been upgraded and incorporated into the excel-calculation tool which is based upon the stoichiometric calculations and other information obtained from patents and secondary publications on the recycling process. The currently most advanced hydrometallurgical technology consists of a mechanical treatment: the battery cells are dismantled and shredded, then recovers all these metals from the cell. Plastics as well as other organic compounds are separated at this stage. What's more, the electrolyte is also recovered and then recycled after the previous steps. A subsequent recycling stage will process the remailing black mass, which will recover all the metals and active material involved.

2.5 *Solid pollution*

The concentrations of these metals, together with those of lithium and manganese, are often higher in many types of Li-ion batteries than they are in natural ores, making wasted batteries like highly enriched ore. If those metals can be economically and on a big scale extracted from old batteries as opposed to natural ore. According to Zhi Sun, a specialist in pollution control at the Chinese Academy of Sciences, cobalt, nickel, manganese, and other metals contained in batteries can easily escape through the casing of underground batteries and contaminate soil and groundwater, endangering ecosystems, and human health.

An essential component of the lithium-ion battery is the electrolyte. All battery systems have an electrolyte solution, which has a significant impact on both power and energy densities (thermodynamic qualities like Gibbs energy, enthalpy, and ionic activity) (nonhemodynamic properties such as viscosity, conductivity, and transference). The electrolyte solution is made up of an ionizable material, such as a salt or an acid, which is referred to as the electrolyte, and a liquid or solid phase that contains at least one component, such as water. [8,9].

The design of batteries makes recycling efforts more difficult. Li-ion batteries are compact, complex, and impossible to remove. They come in a variety of sizes and forms as well. A cell's constituent parts include the separator, electrolyte, cathode, and anode. A polymeric substance like poly (vinylidene fluoride) is typically used to glue an electrochemically active powder (LCO, NMC, etc.) to an aluminum-foil current collector on cathodes (PVDF). Typically, copper foil, PVDF, and graphite are used to create anodes. Separators are thin, porous plastic sheets that segregate the electrodes to prevent short circuits. They are commonly constructed of polyethylene or polypropylene. To create the electrolyte, $LiPF_6$ is typically dissolved in a solution of ethylene carbonate and dimethyl carbonate. The parts are tightly wrapped or stacked, then placed in an aluminum or plastic shell. The same is true for the electrolyte, which is a solution of lithium fluoride salts ($LiPF_6$ is typical) in organic solvents [10].

These batteries leach nickel, cobalt, and manganese into the environment when they are disposed of in landfills. Figure 5 shows different component of different type of batteries. Not to mention dangerous polymers and lithium salts. Lithium-ion batteries have the potential to spark underground fires that burn slowly over extended periods of time, releasing harmful compounds into the nearby garbage. Underground fires can leave the landfill with significant voids and are difficult to detect. The landfill surface may collapse as a result, burying flammable electrolytes even deeper [11].

The lithium-ion battery recovery technique now in use, which is primarily focused on the recovery of electrode components, does not address graphite or electrolyte. When li-ion batteries degrade, some of their metal components, even in relatively small amounts, can cause significant harm.

Lithium ions in a lithium battery settle between the graphite crystal's layers without significantly altering the structure. Brennhagen must substitute different materials for graphite in the anode while working with sodium batteries. The issue is that when these materials are exposed to ions, their structural makeup changes. "Sodium-ion batteries can become a more environmentally friendly alternative to lithium-ion batteries. They can also become cheaper and more sustainable," Brennhagen says.

More than a thousand times more sodium than lithium can be found in the crust of the earth. You don't get reliant on the few nations with abundant lithium. Sodium batteries may provide advantages in some applications, but they won't likely replace lithium. "Lithium-ion batteries will in all likelihood always have higher energy density than sodium-ion batteries, but you may not always need the very best. Sometimes price has a lot more to say, and then sodium-ion batteries can be better," Brennhagen says. "For now, lithium-ion batteries are so cheap, and that technology is well developed, so it's easier to go for it."[12].

According to all included before, Sodium-ion battery is a better choice to choose on the effect of environment during recycling than Lithium-ion battery.

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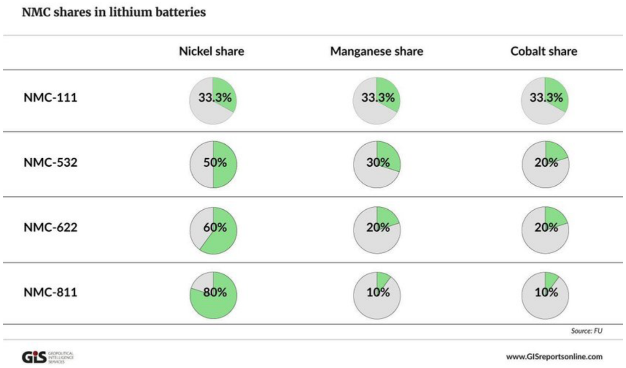

Figure 5. NMC shares in Lithium batteries [13]

3. Quantitative Research

Analytic hierarchy process model is a simple, flexible and practical multi-criteria. decision-making method for quantitative analysis of qualitative problems. It allows the analyzer to combine both of objective factors as well as the subjective opinions together to form a finalized result. It is not accurate enough to give weights to each element manually. Instead, during the process, the model will quantitatively describe the importance of comparing two of the elements of a level. After, the model will use mathematical methods to calculate the weights that reflect the relative importance of the elements of each level and calculate the relative weights of all elements.

In that aij represents the relative importance of the ith evaluating indicators to the. jth. evaluation target, (i= 1,2, ..., m; j= 1,2, ..., n).

For instance, using index of battery performances:

Step 1: We have normalized the data beforehand to ensure the relative. importance. Of each indicator is the same.

Step 2: We can get the results from the code, which is Table 2 showing.

So, we can take index of environment again, we evaluate the relative importance of the index in a battery as shown in Table 3.

Table 2. weights of index of a battery

Factors	Weights
Cost	0.3
Usable capacity	0.25
Dimension	0.02
Continuous power rating	0.09
Instantaneous power rating	0.03
Depth of discharge	0.13
Round-trip efficiency	0.11
Battery type	0.16

Table 3. Relative importance of the index in a battery

	Water pollution	Solid pollution	Raw material & consumption of resources	Gas emission	Disposal of waste
Water pollution	1.000	1.000	3.000	9.000	7.000
Solid pollution	1.000	1.000	4.000	7.000	5.000
Raw material & consumption of resources	0.333	0.250	1.000	5.000	2.500
Gas emission	0.111	0.143	0.200	1.000	0.250
Disposal of waste	0.143	0.200	0.400	4.000	1.000

We can get the Eigenvector, weight, maximum eigenvalue in Table 4.

Table 4. Maximum eigenvalue

	Eigenvector	Weight	Maximum Eigenvalue	CI		
Water pollution	1.912	38.232%	5.210	0.053		
Solid pollution	1.824	36.480%				
Raw material & consumption of resources	0.693	13.851%				
Gas emission	0.176	3.513%				
Disposal of waste	0.396	7.924%				

N	3	4	5	6	7	8	9	10	11	12	13	14	15	16
RI	0.56	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59	1.5943
N	17	18	19	20	21	22	23	24	25	26	27	28	29	30
RI	1.6064	1.6133	1.6207	1.6292	1.6358	1.6403	1.6462	1.6497	1.6556	1.6587	1.6630	1.6670	1.6693	1.6724

Then we are able to get the RI value under different steps as Table 4.

Using above data, the consistency test result shown as in Table 5 has passed:

Table 5. Consistency Test Result

Maximum	CI	RI	CR	Consistency Test Result
5.210	0.053	1.120	0.047	Pass

So, we can use AHP to get the weighting of these different index:

We find that gas emission is the least important factor and water pollution is the most important factor. Figure 6 shows the final result, which is used to describe or evaluate the which factors is more important in these factors.

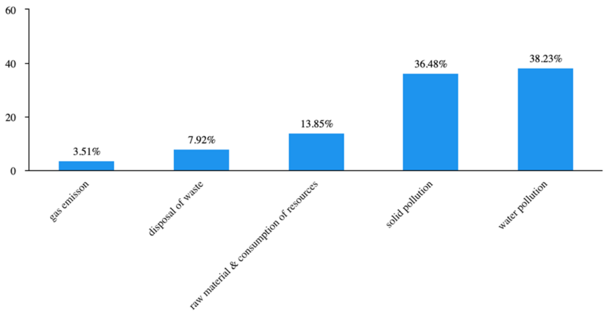

Figure 6. Results of the AHP

4. Results and Discussion

After analyzing the different aspects of environment impact, we have a result that these all five aspects show different influence to the environment. From the perspective of water pollution, SIB cost less money and is easier to be treated, especially the complexity of pollutants in waste water. When it comes to the gas emission, we compare two kind of parameters, waste gas and global worming potential (GWP). LIB have more stable anion in electrolyte, which makes it safer than SIB. In different process, such as manufacture, recycle, LIB also have lower GWP than SIB because of the lower energy density. In that case, from the aspect of gas emission, LIB is better than SIB.

Thirdly, when it comes to the raw materials, lithium is rarer than sodium. There is abundance sodium in the ocean. From this raw material aspects, SIB is better than LIB. Energy density also is a main parameter of the environment impact. The higher energy density, the lower number of batteries public need. LIB is 175WH/Kg, SIB is 160 WH/Kg, from this aspect, LIB is better than SIB. Fourthly, in terms of the disposal of waste, there are 3 methods to recycle battery, lithium-ion battery. Because of the SIB aren't manufacture as large as LIB, the data about SIB recycling isn't as reliable as LIB. However, institution estimated that LIB may easier recycle than SIB. In terms of solid pollution aspect, after using and recycling batteries, some batteries will come to the landfills. They have large probability to leak environmental contaminants like cobalt, manganese, and nickel. What's worse, it will also leak hazardous lithium salts and plastics. In that case, in the solid pollution area, SIB is better than LIB.

After analyzing five aspects, we model 5 aspects with AHP method. We get different index among different parameters. Water pollution and Sloid pollution get higher score in the index, SIB is better than LIB in two factors, solid pollution and raw materials. These two factors occupy main index. SIB index added to (36.48%+13.85%)50.33%, higher than LIB. In that case, we have a whole conclusion that SIB have less environmental impact than LIB.

In this paper, we just analyze one specific area, environment impact between two kinds of batteries. Actually, we still lack of some specific data, which means we need to assume this kind of data. In that case, there is a disparity between real comparison. Even if we use AHP to balance and reduce subjectivity.

5. Conclusion

This work provides new insights into the environmental performance between sodium-ion battery and lithium-ion battery. We first research into the five aspects that may have an environmental effect. After investigating the five aspects, we then prioritize the five aspects based upon our research into them. According to the research from 5 aspects, we analyze the data and use AHP method to figure out which battery have less environment impact. After comparing 5 aspects, we can have a conclusion that SIB is better than LIB in terms of the environment impact.

6. Acknowledgement

Chengtong Li, Hai Zhu, Juehao Wang, Shengwei Lei, Zhaotong Li contributed equally to this work and should be considered co-first authors.

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