

Assessing and Comparing Different Policies Regarding Recycling Lithium-ion Batteries

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Abstract. As renewable energy resources become more and more popular in the energy market, the application of lithium-ion batteries (LIBs) in EV cars and other portable electronic devices has been stimulated. As a result of that, the demand for recycling lithium-ion batteries has increased. This paper discusses the technological developments, recycling methods, and historical background of LIBs to emphasize the need for recycling LIBs. Meanwhile, this paper analyzes different recycling policies in some countries from the past to now, including East Asia, Europe, and Australia. Moreover, the paper overviews the challenges of those recycling policies and makes predictions about those policies, which also provide solutions and suggestions based on current situations. The assessment and analysis in this paper of the recycling policies regarding the LIBs help people solve current problems of those policies and better understand the future development and trends of recycling LIBs, especially on the fields and aspects that the policies could improve and promote in the implementations.

Keywords: Lithium-ion Battery, Lithium-ion Battery Recycling policies, Policy Prediction

1. Introduction

Since an increasing number of spent LIBs need to be recycled properly and efficiently because of environmental and economic benefits, different countries have provided many policies to increase recycling rates over the past fifteen years. This research is meaningful to human society since the benefits of promoting the recycling process through improving policies and collecting mechanisms are significant. There are a lot of papers and research regarding the policies of recycling LIBs, so this paper provides a critical review of the development of those policies from the past to now and analyzes the different policies' advantages and drawbacks for future improvements. A comparatively completed and well-organized recycling policy can avoid safety issues and waste of reusable products in spent LIBs and provide opportunities for secondary use of scarce resources in a circular economy. Therefore, this paper also suggests advice based on the assessment of different recycling mechanisms, which helps provide guidance for future use. The importance of researching LIBs recycling policies is that lithium-ion battery takes an important place in our society, and solving the challenges of recycling useable resources can also improve economic and environmental development for the whole society.

2. LIBs technology development analysis

LIBs have been used in the energy market for many years, and it has significant roles in the energy market and environment partly because of the recycling process. LIBs were first developed in the 1970s and awarded by Nobel Prize in 2019 for their significant achievements and contributions to the living environment and social society [1]. An increasing number of different types of LIBs have been developed for the energy market and have become available for commercial use. Considering the characteristics of performance functions of these LIBs, including cost benefits, safety issues, and chemistry aspects, LIB have become the most widely used portable electronic goods in the world. As the technological advantages of LIB are being discovered by industries and environmental scientists, LIB has been defined to be a vital element in achieving the goals of carbon emission reduction.

However, the increasing use of LIB has created a burden on the environment, although it promotes the use and generation of electronic power since the source of LIB comes from natural mineral metals, which requires a lot of exploitations that accelerate the environmental footprint [2]. 95% of the LIBs produced globally are thought to remain untreated in homes [2], which did conflict with the original intention of using environmentally friendly energies. Furthermore, as the use of EV cars increases, the LIBs' retirement time is approaching soon as well; the rise of EVs poses a significant problem to the proper disposal of waste LIBs (LIBs). Globally speaking, it is predicted that by 2030, the amount of annual energy produced by retired EV LIBs will be 275 GWh [3]. The importance of LIB in our society cannot be ignored because it is good for industrial and technological use. In comparison to other battery types (such as NiMH and Pb-acid), LIBs have a longer lifespan, a more compact design, superior self-discharge resistance, stronger resistance to high temperatures, and a higher voltage output (3.7 V for a LIB vs. 1.2 V for a Pb-acid battery, for example) [2].

The massive using of LIB in the energy market causes the demand for recycling to stimulate, so the attention of the LIB has been moved to the technological investment for recycling. The most complex and difficult part of Recycling LIB is the recovery process, including repair and reuse, since recovery has some safety issues regarding the possibility of explosion because of the Li metal. The pretreatment process is crucial to the later recycling process since metal materials in LIB have different physical and chemical properties to be separated out. At the same time, many factors affect the recycling rate, making the recycling rate low and executed inefficiently. There are three methods to use in the recycling process: Direct method, pyrometallurgy, and Hydrometallurgical. The direct method requires disassembly battery to get the useful materials inside it, as the spent LIB needs to replace components in the battery. After that, adding Li source and calcination it to regenerate the active material for the new battery. Pyrometallurgy transformed metal oxide, one of the processed battery components, into cobalt, nickel, copper, iron, and slag containing lithium and aluminum [1]. While hydrometallurgical requires more procedures in separation and acid leaching and mainly uses aqueous solutions to separate some precious metals from LIBs such as cobalt. The combination of pyrometallurgy and hydrometallurgical to deal with Recycling LIB is widely used in nowadays society because pyrometallurgy allows the raw materials for batteries to be flexible, and hydrometallurgical has a lower cost to implement [1].

3. Analyzation of policies regarding recycling LIBs

3.1. The social and economic benefits of recycling LIBs

People are concerned about recycling technology for LIB because it significantly pushed economic and environmental development. Recycling LIB is a method used in the circular economy that offers a practical way to reintroduce LIB compounds into the market while lowering the demand for basic raw materials [2]. A key component of the circular economy (CE) is recycling operations since they allow for internal material flows and cut down on the number of resources needed for the manufacture of original raw materials [2]. Applying recycling LIBs theory to the circular economy means easing the environmental impacts that human activities made on the earth by saving raw materials and avoiding overexploitation. Recycling process performance is one of the stages in the circular economy by rearranging the spent materials back to the original position and decreasing the demands of exploiting the raw materials to get economic benefits. The circular economy seeks to reduce resource waste; hence inputs and losses must be managed when implementing policies based on this idea.

Additionally, collecting valuable sources and shortening the process of producing new products decrease footprints and carbon emissions which meet the expectations of the world on sustainable development goals. LIBs recycling performance is a significant achievement in saving natural resources in the mining and refining process [4]. Moreover, recycling provides better control of the toxic waste contained in LIBs, possibly damaging the environment seriously if not disposed of as instructed [4]. However, lacking regulated implementations of recycling policies can cause LIB to become a useless and dangerous energy resource.

3.2. Challenges regarding LIB recycling

Recycling LIB is beneficial to society in both economic and environmental aspects, but the challenges do exist and are expected to be solved to promote recycling rates. Disassembly and pretreatment are the most necessary parts of recycling, and they encounter difficulties since EV-signed companies have developed new types of LIBs to promote efficiency while using them. While the change in the cell, module, and pack designs has made the separation of components part more challenging and less effective [5]. To solve this, manufacturers should consider recycling demand when designing different battery types. Secondly, the need to close material cycles is also crucial for recycling LIBs since this allows people to change carbon-based energy resources to sustainable energy sources. According to statistics from the Circular Economy Initiative Deutschland of acatech, 85 percent of Li, 90 percent of Co, Ni, and Cu, and 90 percent of used lithium battery systems should be recycled by 2030 [6].

However, a large number of nations, including the US, did not have well-regulated restrictions on returning the materials of recovered LIBs, which made it difficult to meet this recycling aim and caused the recycling rate to decline. Besides that, the hydrometallurgical process also experiences challenges during its three recycling steps: leaching, purification, and recovery. The hydrometallurgy approach cannot separate remaining fluorine without the help of pyrometallurgy [6], so this method's main challenge is accelerating its demanded recovery rate and purified materials with high qualities. While pyrometallurgy uses high temperatures to separate different metals, this method generally has low quality of recovered materials with a high recovery rate. Therefore, the best way is to combine hydrometallurgy and pyrometallurgy, so the recovered metals can be further purified by the hydrometallurgy method [6]. The recycling procedures in pyrometallurgy and hydrometallurgy approaches, including disassembly and pretreatment methods, need to be improved to accelerate the recycling rate to lower the recycling cost when the concentrations of the recyclable materials are low. Moreover, various hazards could happen during the recycling process, including electrical, thermal, and chemical hazards. Electrical hazards may occur as electrical shock and skin burns during the handling of the batteries recycling process. Thermal hazards could happen since the LIB contains flammable carbonate, which could be easily activated at a moderate temperature to cause an explosion and fire. The small size of toxic materials such as heavy metal nickels and cobalt can enter the human respiratory system and damage their body health [6]. Therefore, it is important that companies and industries restrict their recycling regulations based on temperature, transaction and handling process, and safety protection of their careers.

4. Policy analysis

4.1. The past policies regarding Recycling LIBs

Overviewing China's situation in the past related to Recycling LIBs, it's not hard to see the significantly increased number of used EVs cars and electronic devices accelerated the economic development of China. While at the same year, The Policy on Pollution Prevention Techniques from Waste Batteries was co-issued by the State Environmental Protection Agency of China and nine other government organizations [7]. This policy focused on lowering the exposure and potential hazards to people and the public, which left out the important and essential intention of recycling. It did not mention the specific instructions based on who is responsible for collecting the spent materials and recovering them for the next use, and it did not assign who needs to regulate the transportation and reassign those materials. Although this policy lacks details or specific instructions that support recycling LIBs, this is just the beginning of China to start its recycling journey.

Similar to China, Australia was at a similar stage of development, and according to the Australian Battery Recycling Initiative, there are 6 organizations in Australia overall, which account for 43% of the country's whole LIB recycling and collecting business [8]. Both countries implemented policies

regarding the Recycling of LIBs, but the efficiency and impact were not obvious since the policies need to be improved.

4.2. Analysis of recent policy about recycling LIBs

China's announcement in 2017 of a general prohibition on the importation of waste goods from abroad marked the transitory point for the worldwide recycling of LIBs [8], since China then published policies regarding their strict regulations on reusable energy resources, waste products, and LIBs recycling restrictions. Australia, Brazil, and the US start implement recycling waste products policies in their own countries. As for now, the current global situation of LIB recycling has changed significantly. East Asia has achieved huge progress in recycling batteries, with five existing operations in China totaling 188,000 tons. Additionally, Brunp Recycling Technologies in China's Hunan Province has the world's biggest battery recycling factory, with a capacity of 100,000 tons [1]. The collecting capacity for Europe and Asia has been expanded a lot, and those countries have started to implement the reward-penalty mechanism policy to increase the recycling rate for LIBs. Reward-penalty mechanism's working principle is choosing manufacturers to be the controller and making them pay for the fines while the collecting rate is lower than the targeted level or awarding them subsidies when the collecting rates exceed the goal. The deposit and refund mechanism is an efficient recycling policy, especially when in an EV battery life cycle system. The framework starts by having EV manufacturers wholesale batteries to the EV retailer. After that, the retailers are responsible for collecting back spent batteries and sending them to material extraction industries for remanufacturing [9]. Under this system, the deposit and refund policy has been implemented in EU countries and China showing a great effect, but there are still some problems that need to be considered regarding this mechanism, such as recycling's dangers to the soil, water, and earthly life [10], collection efficiency, and the disposal of used LIBs [10].

4.3. Trends and suggestions for future recycling policies

It is acknowledgeable that the technology development regarding LIBs' applications and recycling is growing so fast, and the world has been working hard on dealing with the recycling issue. The past policies are different from current policies since people converted the volunteering collection mechanism to a reward and penalty policy to increase motivation and improve recycling rates. Furthermore, people care more about the environment and society impact that sustainable energy brings to us, which means the policies have been improving residents' awareness of recycling LIBs. The reward-penalty mechanism's assessment helps these achievements as it's implementable and efficient, but it still needs more regulations based on the country's development goals and government's demand since they have different situations based on storing and transporting spent LIBs.

However, the problem of implementing a reward and penalty policy still exists. The welfare and total economic situation of each company are closely related to three things: the public educational awareness of people and the partnership between manufacturer and retailer. Thus, the regulation department should not forget this important factor while generating policies which is to increase public attention on recycling since the average real collection rate and total welfare rise by 12.27 percent and 1.62 percent, respectively, as the number of the free collection increases from 0 to 2000. [3]. The partnership, on the other hand, is important to this system because, in the absence of policy intervention, they achieve 46.56 percent and 4.71 billion RMB, respectively, which are roughly 86.82 percent and 12.06 percent more than the average of the other five collecting techniques [3].

More importantly, the government should balance the total welfare while approaching the actual collection rate since as the rate increase, the welfare tends to rise and fall again. While the strict collection rate target is also likely to promote then restrain the situation of welfare growth.

From those changes that countries made to recycling policies about LIBs, the benefits of using efficient policy have been revealed as well. The useful policy helps people get balanced by achieving sustainable development goals on energy savings and carbon emission reductions. Meanwhile, using lithium batteries to support EV cars also promotes economic development. For instance, according to

the International Energy Agency, the production of electric cars alone resulted in the creation of 500,000 tons of LIB waste in 2019, and the entire quantity by 2040 may reach 8 million tons [1]. Therefore, in the future, the number of recycled energy sources from LIBs can save a huge number of natural resources in an economic cycle.

5. Conclusions

The development of LIBs has provided society with many advantages for the environment and economy since it was invented. However, as a growing amount of EV cars and renewable energy resources were used, a significant number of retired LIBs occurred and were not recycled and collected well in past years. Thus, many countries have implemented different policies aimed at stimulating the recycling rates of LIBs. Several methods include combining different technologies to better promote the quality and efficiency of recycling valuable metals, which can still be enhanced and improved in leaching and pretreatment procedures. The challenges of recycling LIBs also affect the collecting rates and results because there are safety issues regarding toxic chemicals in LIBs that might damage human health during transporting the spent LIBs. Therefore, different policies must consider temperature regulation and safety instructions while implemented. Compared to the past years, China and Australia did not have restricted policies regarding recycling LIBs. While recently, East Asia and the EU used a reward-penalty mechanism that significantly stimulated the rate of recycled LIBs and policy effectiveness. From the change of policies, the importance of educating public awareness regarding recycling LIBs should be considered in future policy improvements. Moreover, the balance of welfare and collecting rate of recycling policies should be considered more while implementing regulations, which should also be adjusted based on local government situations.

Recycling LIBs can help the world achieve sustainable development goals sooner because of saving sources and energy; meanwhile, recycling is considered a circular economy that benefits economic development.

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