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OPTIMISATION OF THE COLLECTION SYSTEM FOR WASTE BATTERIES

Abstract. *Currently, developing countries like China or Ukraine lack effective waste batteries collection. The purpose of this study is to analyse the waste battery collection systems in developed countries and suggest the improvements for the waste battery collection systems in developing countries. Relevant literature on waste batteries management through academic databases, government reports, and industry research channels was analysed. Several developed countries were selected as case studies for in-depth comparative analysis, focusing on the current situation of waste battery collection, including management policies, market size, technological level, etc.*

The differences in waste battery collection models between developing and developed countries have been compared. By analysing successful cases, some best practices were summarized and used for improving the collection of waste batteries in developing countries.

The advices for waste batteries collection system in China have been suggested (including collection points, logistics, etc.) in order to provide reference for the standardization and revision of waste batteries collection in China. The recommendations on separate collection of different types of waste batteries were also developed. This has great practical significance since can help developing countries to achieve waste management goals.

The scientific novelty of this study is that waste batteries collection system has been optimised based on the suggestions for developing countries, while providing efficient waste management. Through a sound pricing strategy and a reasonable logistics system, the collection system for waste batteries has been standardized, facilitating macro level management at the national level, avoiding environmental pollution, and increasing user enthusiasm.

As a next step, the development of relevant recommendations for local authorities and business can be suggested.

Key words: *waste batteries; collection; environmental protection; waste management; optimisation.*

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Introduction

With the development of technology, our lives are increasingly inseparable from batteries. However, the disposal of waste batteries has always troubled us. Batteries contain harmful substances such as heavy metals and acids, which can cause serious environmental pollution if discarded. Therefore, the recycling and treatment of waste batteries has become particularly important.

At present, the current situation of waste batteries management is not ideal. Many people do not know how to dispose of waste batteries, or choose to dispose of them randomly due to various reasons (such as inconvenience and high costs). Besides, the imperfect recycling channels and the lack of effective recycling mechanisms are also important reasons [1].

Batteries have different uses, different specifications and models, different components, which contain heavy metals such as lead, zinc, cadmium, nickel and many other substances harmful to the environment and human body. Waste batteries, if discarded in large quantities in the environment, cause serious harm. Heavy metals cannot be degraded naturally and gradually accumulate through the food chain after being absorbed by organisms. And finally, endangering our own health [2].

European countries are the earliest countries and regions in the world to recycle and manage used batteries. The EU's management of used batteries began in the 1990s, with the first directive on the management of used batteries issued in 1991. This regulation focuses on batteries and accessories containing harmful substances and stipulates that waste batteries should be separated from household waste and collected separately. In some countries, the collection rate of used batteries is as high as 60% (such as Austria, Denmark, and Switzerland). Although there were minor adjustments to the regulations in 2008, 2010, and 2013, the basic provisions are still based on the 2006 regulations [3]. The 2013 survey report [3] by the European Portable Battery Association showed that almost all countries in the European Economic Area had established laws related to battery recycling in accordance with the 2006 regulations. The management of waste batteries in Europe is based on the extended producer responsibility system, and the recycling of waste batteries also extends to all types of batteries. The regulations issued in 2006 greatly promoted the management of waste batteries in Europe, but some problems still exist, such as a large number of waste lead-acid batteries mixed with portable batteries, which means that the recycling rate of portable batteries is very low.

For efficient waste batteries management, a proper collection system must exist. In fact, developing countries like China or Ukraine lack effective waste batteries collection. Therefore, this paper is aimed to suggest some mechanisms and recommendations to improve waste batteries collection based on the experience of developed countries.

Methodology of research

When studying waste batteries collection, a systematic literature review and comparative analysis method were used. The specific steps were as follows:

1. Literature review. First, relevant literature data on waste batteries management were collected throughout academic databases, government reports, and industry research channels. Special attention was paid to the current situation in developing countries, including waste batteries management policies, market size, technological level, and challenges they face. Then, the collected data have been classified with a focus on analysing the policies, practices, and effectiveness of countries at different stages of waste batteries collection, as well as the gaps in technology and infrastructure compared to developed countries.

2. Comparative analysis. Several developed countries (EU, Japan, New Zealand, Australia) were selected as cases studies for in-depth analysis. We compared the differences in the models of waste batteries collection between developing and

developed countries. For example, developed countries typically adopt a combination of voluntary and mandatory policies, while developing countries may rely more on informal collection mechanisms. By analysing successful cases in developed countries, some best practices and lessons learned can be summarized, such as technological innovation, public awareness enhancement, and business participation, which can provide reference for improving waste batteries collection in developing countries.

Through the above steps, it was possible to comprehensively understand and analyse the differences in waste battery collection schemes in different countries, as well as how to learn from the experience of developed countries to promote the progress of waste batteries collection in developing countries.

Research results

Waste batteries collection in developed countries

Waste batteries in the United States are divided into two categories: hazardous waste and non-hazardous waste. The former includes manganese batteries and lithium-ion batteries, while the latter includes button batteries, silver oxide batteries, closed lead-acid batteries, and lead-acid batteries for motor vehicles. According to the regulations of the US Environmental Protection Agency, hazardous waste batteries must be collected according to standardized collection procedures, while non-hazardous waste batteries can be disposed of as household waste. In fact, lead-acid batteries for motor vehicles are collected by motor vehicle dealers or local waste management agencies, while other harmful waste batteries are collected by hazardous substance recycling points near residents [4]. The example is RBRC Corporation, which has established over 25000 battery collection points in the United States and Canada, including every postal district. The company has designed and produced battery collection bins, plastic bags with zippers and specialized battery recycling logos, which are distributed to battery retailers and community waste collection stations in various regions.

In Australia, batteries are divided into two categories: portable batteries and large lead-acid batteries (weight over 5 kg). Large lead-acid batteries are treated as hazardous waste and collected by car repair shops, transfer stations, and waste management agencies, while there is no regulation on the recycling and reuse of portable batteries. The collection and utilization of portable batteries are generally provided by non-profit organizations such as the Australian Battery Recycling Campaign. The generation of discarded portable batteries in 2012 was 14700 tons, with a collection of 403 tons (approximately 2.7% of those generated) [4].

In New Zealand, lead-acid batteries are collected at gas stations, car repair shops, and municipal recycling points. Secondary batteries can be collected and recycled through municipal waste facilities. In fact, all batteries in New Zealand are recycled, but that requires consumers to pay. After battery collection, lead-acid batteries are recycled domestically, while other batteries are either landfilled or transported to other countries for recycling. The focus of battery recycling is still lead-acid batteries, and portable batteries are mostly recycled through voluntary activities, but most of them are landfilled along with household waste [5].

Japan does not have mandatory recycling of secondary batteries, and policies formulated by different local governments vary. However, most secondary batteries are recycled, and the collected batteries are either recycled by companies or stored

as non-combustible waste. Lead-acid batteries are collected and recycled by producers. Since 2001, the collection and recycling of embedded batteries have adopted an extended producer responsibility system [5]. As a member of the Organization for Economic Cooperation and Development and a contracting party to the Basel Convention, Japan complies with the Basel Convention and does not allow the export of waste (including waste batteries) to countries that are unable to process waste, especially developing countries.

In South Korea, the recycling and disposal of waste batteries is based on the extended producer responsibility system, where the government requires battery manufacturers to set recycling targets and impose fines on companies that do not meet the standards. The management of secondary batteries in South Korea is based on the extended producer responsibility system, while the collection of disposable batteries has not been well organized and practiced [5].

Optimization of waste batteries collection system

After studying the waste batteries management system, it has been concluded that it is based on the actual situation of each country and needs to have certain characteristics, such as reasonable pricing, targeting densely populated cities, and closely integrating with logistics management, in order to form a circular and long-term effective recycling system. Combining these factors, optimize the waste batteries management system. Below are some recommendations for optimization of waste batteries collection system.

1. Paid collection of waste batteries.

The paid collection system for waste batteries in Europe, America, and Japan is mainly aimed at the battery production industry. The cost of collection and treating waste batteries is directly deducted from the income of companies, otherwise the cost waste batteries collection is added to the retail sale prices. By gradually phasing out waste batteries through market regulation, the collection rate is increased.

While this strategy can be used in Ukraine (relevant regulations are submitted to Ukrainian Parliament), it is not suitable for China due to the national conditions, and there have been many studies on the paid collection system for waste batteries, which has not been implemented [6]. Unlike developed countries, the Chinese waste trading industry has been preserved for a long time in Chinese consumer awareness. The paid collection system that directly converts waste batteries in users' hands into currency through the sale of waste products is more suitable for China's national conditions.

Direct paid collection of waste batteries is not in line with the actual situation in China, and the specific reasons are as follows:

- direct offsetting the price of waste batteries requires a large amount of investment from companies, which can be described as a risk investment, but the return rate is unknow;
- converting waste batteries into currency will accumulate a large amount of waste batteries in a short period of time, suddenly increasing the difficulty of disposing of waste batteries;
- converting waste batteries into currency will make it difficult for a small number of users to pass them off as real, making collection work more difficult and causing economic losses for companies;
- sudden emergence of a large number of waste batteries that cannot be processed can cause environmental pollution and harm;
- setting up collection stations requires a large amount of human resources.

2. Exchange of waste batteries for other items.

Battery manufacturers implement the practice of exchanging old batteries for new ones for customers who purchase batteries. Each old battery can be offset by a certain amount, mainly in supermarkets or large stores. This has achieved certain results, but still cannot comprehensively solve the problem [7].

The strategy of old batteries exchanging for new ones has achieved some success because companies do not require prior investment and reduce risks. Employees at battery sales points can take on the role of sorting and collection. In addition, the policy of replacing old batteries with new ones ensures a balance between used and new batteries, without causing short-term compression or vacancies. However, due to the widespread generation of waste batteries, exchanging them for new ones still cannot increase the level of waste batteries collection. The collection of waste batteries requires a balanced system that can continuously provide a certain amount of waste batteries, while reducing investment risks for enterprises and facilitating national policy adjustments. Reasonably offsetting waste batteries is suitable for the current situation in China.

If waste batteries are converted into a convenient way of life, it will be much better. For example, if 4 waste batteries have a collection value of 1 USD, it means that 4 batteries can be converted into 1 USD for convenience. For students, it can be converted to washing clothes and taking the school bus, for city citizens – taking a bus once, subscribing to some magazines, purchasing drinks from vending machines. Unmanned vending machines do not require big investments and management efforts, but the collection of waste batteries is not directly converted into profits. Therefore, the waste batteries collection industry can provide more convenience and public welfare, decreasing citizens' awareness. Converting waste into a convenient way of life is not yet common, including both China and Ukraine, but users have expressed recognition and support for this method.

Optimization of waste battery logistics system

The logistics of waste battery collection cannot rely on traditional waste management logistics. Providing such a logistics system requires a many efforts and financial resources, and needs the use of other logistics systems. In traditional logistics systems, waste batteries are sent through distributors to manufacturers and finally arrive at plants. Many developed countries also adopt this method to form a certain standardized process, but it is not suitable for the current situation in developing countries like China or Ukraine due to the lack of extended producer responsibility. There is no standardization and that may cause environmental pollution in local areas. After waste battery collection bins are installed in the community, that can provide initial results. However, such waste battery collection channels take too much time and may encounter resistance from unknown factors at any time, such as community administrators and a few residential users. These logistics methods have their own advantages and disadvantages [8].

There is no unified standard transportation vehicle or standard storage conditions for waste batteries in China and Ukraine. There is an example of Sichuan province in China, where amount of waste batteries generated is about 4000 tons per year. Due to the lack of a disposal site, the city of Chengdu alone currently accounts for nearly 400 tons of waste batteries, which have been stored for 9 years and still cannot be disposed of. This is a typical situation for developing countries, where no standardized collection system is established and no logistic chain is built up.

In Ukraine, there is also some amount of waste batteries collected by non-governmental organisations, which still are not recycled due to the lack of financing and appropriate facilities. Establishing a waste battery disposal factory can solve the issue. This means that there will be a logistics endpoint for waste batteries, and the selection of logistics key points (hubs) will affect the entire logistics cost. The waste batteries collected in various areas will be transported to logistics hubs for accumulation. After reaching a certain quantity, they will be transferred to the logistics endpoint, which is the waste battery recycling factory, which forms a logistics network for waste battery recycling. Waste batteries collection bins can be installed in schools, communities, and streets, encouraging citizens to collect and transfer waste batteries through publicity. Through this method, a certain amount of waste batteries can be accumulated in a short period of time.

The flow chart of battery collection logistics system optimization is shown in Fig. 1.

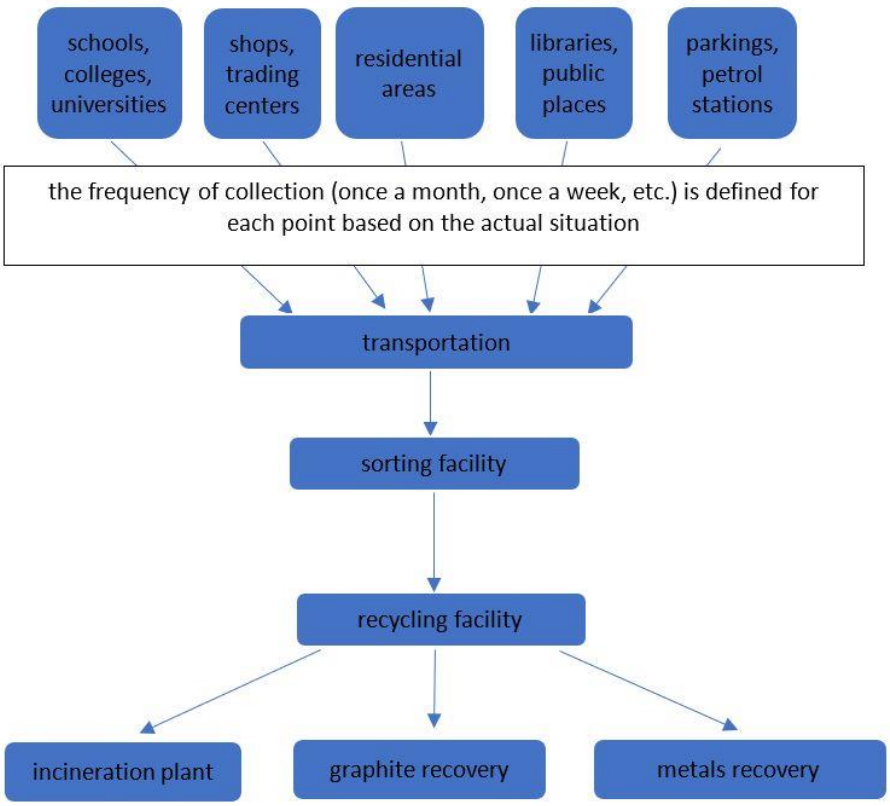

Figure 1. The flow chart of battery collection logistics system optimization

Overall, the main issue in the current waste battery management industry is the lack of smooth circulation and the inability to form an effective resource loop. In the case of China, that includes the following.

1. The destination of the waste batteries collected is unknown, and the market is irregular. Currently, other business models such as battery banks and battery swapping in China are still at the stage of small-scale application. In the on-board sales model, the ultimate right to use and ownership of the battery belongs to the consumer. Consumers can sell waste batteries to companies through trade in or

directly dispose of them. But the reality is that a large number of used batteries flow into illegal channels, even causing a phenomenon of "inverted" prices for new and old batteries. It is understood that according to current policies, sellers have the main responsibility for collection, and battery manufacturing and recycling companies have corresponding responsibilities. However, due to the high prices of upstream raw materials in recent years, the high profit margins have driven informal market entities to purchase scrapped batteries in a form similar to "auctions". At the same time, Chinese regulations have not clearly defined the responsibility of consumers for collection, and consumers have no responsibility or obligation to dispose of waste batteries, lacking effective binding force. According to market estimates, only about 30% of waste batteries enter formal recycling channels.

2. Poor domestic transportation and circulation. The transportation requirements and packaging costs of waste batteries are high, and the phenomenon of non-standard transportation often occurs. In terms of regulatory standards of China, the "List of Dangerous Goods" classifies waste batteries as Class 9 dangerous goods and requires Class II packaging, which has high requirements for packaging strength and cost. According to the "Regulations on Road Transport of the People's Republic of China" and the "Regulations on the Administration of Road Transport of Dangerous Goods", transport units and vehicles are required to have corresponding licenses, the condition of the vehicles must meet the first level standards, and vehicle drivers, loading and unloading management personnel, and escort personnel must obtain corresponding professional qualification certificates. The "Management Regulations for Battery Recycling and Utilization Part 1: Packaging and Transportation" also requires that if there are dangerous situations such as leakage, deformation, fire, and water immersion in batteries (Class B batteries), special protective measures should be taken for their packaging and transportation. At present, professional battery transportation vehicles are not only rare, but also quite expensive. In the absence of strict supervision, companies lack the willingness to seek compliant transportation. Besides, the procedures for waste batteries transportation across provinces are cumbersome and costly. According to the "Management Measures for the Transfer of Hazardous Waste", the cross-provincial transfer of hazardous waste requires joint approval from environmental authorities of the two provinces where the hazardous waste is transferred and received, and can only be transferred after approval. The procedures are complicate and the cost is high. At the same time, based on the current industrial situation, some provinces and regions in China have not yet established strong recycling bases, making it difficult to effectively dispose of waste batteries in their own provinces. This has led to a large number of waste batteries having to be processed into powder before transportation, further reducing production efficiency and increasing costs.

3. Overseas waste batteries cannot be recycled. Currently, there are certain policy barriers to the transportation of waste batteries from abroad, and China's import policies are becoming increasingly strict. In November 2017, the European Commission passed the proposal for a new regulation on the transportation of waste in Europe, which, in conjunction with the requirements of the New Battery Law, clarifies that waste batteries can be transported out of the EU if permitted by the receiving country and provided that they can be proven to be non-toxic after import and meet relevant safety requirements. Currently, the vast majority of countries comply with the Basel Convention, allowing the export of waste batteries to countries with processing capabilities. In contrast, in recent years, China has become increasingly strict in its import policies for waste batteries, gradually tightening the import of all solid waste.

Waste batteries collection is crucial for environmental protection and resource recovery. Here are some additional suggestions for effective battery collection:

1. Public awareness campaigns

Educational programs: inform the public about the importance of waste batteries collection and the environmental hazards of improper disposal.

Social media outreach: use social media platforms to share information, tips, and updates about waste batteries collection initiatives.

2. Convenient collection points

Retail locations: partnership with electronics and automotive retailers to set up collection bins for used batteries.

Community centres: place collection bins in easily accessible public places like community centres, libraries, and schools.

3. Mobile collection points

Scheduled events: organize periodic collection events in neighbourhoods or at community festivals to encourage residents to bring in their used batteries.

Mobile collection units: use vehicles equipped to collect waste batteries from various locations.

Recommendations on separate collection of different types of waste batteries

Waste batteries should be separated from other waste in the collection process. If it is put together with other household waste, there will be numerous issues. The fermentation will be affected by the metal and mercury contained in the waste composting treatment [9]. If waste is incinerated, the high mercury content in the flue gas will affect the quality of the air treatment and pollute the air. If waste is landfilled, heavy metals in the battery will penetrate into the underground and pollute the soil and groundwater.

Waste batteries must be collected separately, so that the battery can be recycled and prevented the spread of harmful substances.

For common dry batteries, one should put them directly into the official garbage bin and does not collect them in a centralized manner (along with alkaline batteries, lithium batteries, and nickel hydrogen batteries).

For batteries with high levels of harmful substances, including most button batteries, nickel cadmium batteries (old-fashioned rechargeable batteries), etc., if there is a waste battery recycling agency nearby, one should deliver it there (such as some neighbourhood committees, environmental protection associations, etc.); if there are no recycling agencies for waste batteries nearby (like in most cities and rural areas), one should contact the local environmental protection department or send waste batteries to recycling agencies in other cities.

Specifically, if a large number of waste batteries have been collected, one should classify them first and then dispose of separately according to the aforementioned suggestions. All types of waste batteries should not be managed together [10]. In the absence of effective recycling technology and economic conditions, the government does not encourage centralized collection of waste batteries that have not met the national low mercury or mercury free requirements. But, in many cases, if the primary technology for waste batteries treatment is shredding followed by pyrometallurgy or hydrometallurgy, no classification is needed since all the batteries will be processed together.

Recommendations for the efficient management of waste batteries:

1. Strengthen the classification, collection and management of waste batteries.

In the engineering analysis of environmental impact assessment for newly built, renovated, and expanded battery manufacturers, not only should the raw materials, processes, and finished products containing heavy metals and harmful substances meet the emission standards, but also the after-sales recycling and utilization of products should be evaluated and analysed. Manufacturers should achieve clean production to facilitate the recycling and utilization of their products. Environmental protection and relevant departments should increase their supervision and management efforts, regularly or irregularly monitor the recycling and utilization situation. In the environmental impact assessment, based on the production scale, it is recommended to establish a production line for the treatment of old battery renewable resources, effectively promoting the recycling and utilization of renewable resources.

2. Encourage the production of environmentally friendly batteries.

Batteries containing heavy metals and mercury should have relevant labels for easy recycling and classification. The government should relax policies in tax or other areas to encourage the production of green and environmentally friendly batteries. Adopting computer network control and utilizing system functional module data transmission technology to sort waste batteries [11]. Extracting and recycling metal substances such as zinc, manganese, silver, mercury, cadmium, and iron, and using furnace slag to make building materials, environmentally friendly treatment of unusable substances can be carried out. This overcomes the shortcomings of the previous complex processes, long process flows, and high treatment costs, and achieves a comprehensive utilization of harmless, resourceful, and stable waste battery treatment.

3. Improve the awareness of all people on the separation and collection of waste batteries.

Environmental awareness of the entire society must be enhanced through education on environmental protection from kindergarten onwards, and making the collection of waste batteries habitual and standardized. Besides, research efforts on the harmless treatment process of waste batteries must be increased, and authorities should provide policy or financial support for treatment processes and achievements that are pollution-free, low-cost, less energy consuming, and have quick results, so that discarded waste batteries can enter a virtuous cycle of production – consumption – regeneration.

Conclusions

This paper proposes an optimization plan for the waste battery collection system. Through improved pricing strategies and reasonable logistics systems, the waste batteries collection system is standardized, which is easy to be managed by the national macro level, forms an industrial scale, avoids environmental pollution, and can increase user enthusiasm. In order to improve the current situation of waste batteries recycling, the following aspects can be taken into consideration:

1. Enhance public awareness: through various means such as publicity, lectures, community activities, etc., raise public awareness of the importance of waste batteries collection. Let everyone understand that protecting the environment is protecting ourselves.

2. Establish collection channels: the government can establish specialized collection points or cooperate with relevant companies to establish effective waste batteries management mechanisms. At the same time, encourage communities, schools, companies and institutions to establish their own collection systems and form a collection network that covers the entire society.

3. Promote reusable batteries: encourage companies to develop and produce reusable batteries to reduce environmental pollution. At the same time, rewards will be given to users who use reusable batteries to increase their enthusiasm for recycling.

4. Technological innovation: increase research and development efforts on waste batteries treatment technology, and find more environmentally friendly and efficient recycling methods. For example, developing an intelligent collection system to achieve automatic battery classification and recycling through IoT technology.

5. Strengthen the laws and regulations: develop and improve relevant laws and regulations to regulate the collection and disposal of waste batteries. Violations of regulations should be punished in accordance with the law to form an effective deterrent force.

It is necessary to enhance the environmental awareness of the entire society, improve people's comprehensive quality, constantly change people's attitudes, and let environmental protection concepts gradually enter people's daily lives, becoming a habitual behaviour of the people, thus making the collection of waste batteries a part of people's daily lives.

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ОПТИМІЗАЦІЯ СИСТЕМИ ЗБОРУ ВІДПРАЦЬОВАНИХ БАТАРЕЙ

Анотація. Зараз у країнах, що розвиваються, – таких як Китай чи Україна, – немає ефективного збору відпрацьованих батарейок. Метою цього дослідження є проаналізувати системи збору відпрацьованих батарейок у розвинених країнах і запропонувати вдосконалення систем збору відпрацьованих батарейок для країн, що розвиваються. Було проведено літературний огляд управління відпрацьованими батареями шляхом аналізу наукових баз даних, урядових звітів та промислових дослідницьких матеріалів. Кілька розвинених країн було обрано, як приклад, для поглибленого порівняльного аналізу, із фокусом на поточну ситуацію зі збором відпрацьованих батарей, включаючи політику управління, обсяг ринку, технологічний рівень тощо.

У роботі порівняні відмінності в моделях збору відпрацьованих батарей між розвиненими країнами та тими, що розвиваються. Аналізуючи успішні приклади, деякі кращі практики були узагальнені та використані для оптимізації збору відпрацьованих батарей у країнах, що розвиваються.

Було запропоновано поради щодо системи збору відпрацьованих батарей у Китаї (включаючи пункти збору, логістику тощо), щоб забезпечити стандартизацію та перегляд збору відпрацьованих батарей. Також розроблені рекомендації щодо роздільного збору різних видів відпрацьованих батарей. Це має велике практичне значення, оскільки може допомогти країнам, що розвиваються, досягти цілей управління відходами.

Наукова новизна цього дослідження полягає в тому, що систему збору відпрацьованих батарей оптимізовано на основі пропозицій для країн, що розвиваються, для забезпечення ефективного управління відходами. Завдяки обґрунтованій стратегії ціноутворення та розумній системі логістики систему збору відпрацьованих батарей було стандартизовано, що полегшує управління на національному рівні, запобігає забрудненню навколишнього середовища та підвищує залученість населення.

В якості наступного кроку пропонується розробка відповідних рекомендацій для місцевої влади та бізнесу.

Ключові слова: відпрацьовані батарейки; збір; захист довкілля; управління відходами; оптимізація.

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