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Optimization of Waste Power Battery Recycling Process from the Perspective of Supply Chain

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Abstract

With the rapid popularization of electric vehicles, the recycling of used power batteries has become an increasingly prominent issue. Recycling of used power batteries not only involves environmental protection, but also relates to the efficient utilization of resources. The current recycling system faces problems such as low recycling efficiency, high cost and resource waste. From the perspective of supply chain management, this paper analyzes the current situation and problems in the recycling process of used power batteries, and puts forward a series of optimization strategies, including recycling network optimization, logistics management improvement and inventory control strategies. This paper aims to provide theoretical support and practical guidance for the optimization of waste power battery recycling supply chain, and promote the sustainable development of recycling industry.

Keywords

Supply Chain Management; Recycling Process; Waste Power Battery; Optimization Strategy.

1. Introduction

With the rapid development of the global electric vehicle market, the recycling and disposal of used power batteries has become a major environmental issue and resource challenge that needs to be urgently addressed. Electric vehicles play an important role in improving energy efficiency and reducing carbon emissions, but the ensuing problem of disposal of used power batteries is becoming increasingly serious. These batteries not only contain hazardous substances such as heavy metals and chemical compositions, which will cause serious pollution to the environment if they are not handled properly, but also contain a large amount of reusable resources such as lithium, cobalt and nickel, which are of great strategic value for electronic products and other high-tech industries. Therefore, how to effectively recycle and dispose of used power batteries has become an urgent problem.

Most of the existing research focuses on the recycling technology and policies and regulations of used power batteries. For example, Wang Kunqiang et al [1] explored different recycling technologies in depth, investigated the current status of key technology development of the recycling process of used batteries, compared the advantages and disadvantages between the various technological processes, and briefly analyzed and summarized the current status of the gradient utilization of retired power batteries, and provided a reference for the subsequent research on recycling and utilization of batteries. Zhang Chuan and Chen Yuxiao [2] studied a retailer-led closed-loop supply chain of power batteries considering government subsidies and scale effect, and the results showed that government subsidies can reduce the retail price and increase the recycling rate as well as the profits of each member. In the study of power battery recycling, Jia Junxiu and Zhao Kexue [3] investigated the optimal decision-making problem of

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supply chain members under three strategies: no government subsidy, battery producer subsidy and new energy vehicle manufacturer subsidy, and found that both government subsidy to battery producers and new energy vehicle manufacturers can improve the range of power batteries and the recycling rate of used batteries. The incentives of national policies for battery recycling enterprises, including financial subsidies and regulatory policies, are analyzed, emphasizing the key role of policies in promoting the development of the recycling industry. However, most of these studies focus on a single aspect of recycling technology and policy, failing to fully explore the full impact of the supply chain management perspective on the recycling of used power batteries.

In the field of supply chain management, scholars have conducted preliminary exploration on the optimization of resource recovery systems. Liu Mingjing and Chen Xuan [4] proposed that the overall efficiency of the resource recovery system can be significantly improved by optimizing the design and configuration of the recycling network. Their study pointed out that the rational layout of the recycling network and the effective allocation of resources are the key factors to improve the recycling efficiency. Zhou Xingjian et al [5], on the other hand, investigated the impact of the optimization of the information flow in the supply chain on the recycling process, and concluded that the rationalization of information sharing and resource allocation can significantly improve the recycling efficiency and reduce costs. They emphasized the importance of achieving information transparency and optimal resource allocation in the recycling process.

Nevertheless, the application of supply chain management on the recycling of used power batteries is still relatively limited, especially the research on specific practices such as recycling network design, logistics management and inventory control is still insufficient. Existing literature is less concerned with how to systematically optimize the recycling process of used power batteries from the overall perspective of supply chain management. In particular, there is still a lack of in-depth discussion and empirical research on how to apply supply chain theory to the design of recycling network, logistics optimization and inventory management of waste batteries. Therefore, this study will systematically analyze the current situation and bottlenecks in the recycling process of waste power batteries from the perspective of supply chain management and propose optimization strategies. The research focus of this paper is to analyze the current situation of waste power battery recycling network layout, logistics management and inventory control from the perspective of supply chain, and to propose optimization strategies based on supply chain theory and the latest technological development. This not only helps to reduce recycling costs and improve recycling efficiency, but also promotes the sustainable development of the recycling industry.

2. Analysis of the Current Situation of the Supply Chain of Waste Power Battery Recycling

With the widespread use of electric vehicles, the large number of retired power batteries has created a significant demand for recycling. Power batteries are rich in valuable metal resources, such as lithium, cobalt, nickel, etc. However, if not handled properly, the hazardous substances in these batteries can also pose a significant threat to the environment. Therefore, it is crucial to build an efficient recycling supply chain for used power batteries. However, the current recycling supply chain for used power batteries faces multiple challenges, involving core issues such as recycling network layout, logistics management, information flow and inventory control.

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2.1. Recycling Network Layout Issues

The layout of the recycling network for used power batteries is one of the key factors determining the efficiency of recycling. Currently, most of the recycling networks in China rely on EV manufacturers, third-party recycling companies and recycling points set up by the government. However, there are some obvious structural imbalances in this recycling network.

Foremost, the distribution of recycling points is uneven. Existing recycling points are mainly concentrated in economically developed and densely populated urban areas, especially in the eastern coastal cities, while in the central and western regions and remote areas, the layout of the recycling network is seriously lagging behind. This leads to insufficient recycling coverage of used power batteries, limiting the effective recycling and treatment capacity of used batteries. The lack of sufficient recycling points in economically underdeveloped areas leads to high recycling costs, and recycling companies are therefore not motivated to invest in these areas.

In the second place, there is a lack of synergistic management of the recycling network. Currently, the various nodes in the recycling network (e.g., manufacturers, recycling companies, treatment plants, etc.) work in isolation and lack a unified and coordinated management mechanism, resulting in a poor flow of information and resources in the recycling chain. For example, the degree of sharing of information on the quantity and quality of used batteries between manufacturers and third-party recycling companies is low, and there is often duplication of efforts or waste of resources in the recycling process. This not only increases the overall cost of recycling, but also reduces the efficiency of resource utilization.

Finally, there is insufficient legal and policy support for recycling networks. Although the government has introduced a series of policies to encourage the recycling of power batteries, there are still problems such as insufficient policy implementation and ineffective supervision by local governments in the concrete implementation process. Some regions have not yet established a perfect incentive mechanism for power battery recycling, resulting in a lack of sufficient power to expand the recycling network of recycling enterprises..

2.2. Inadequate Logistics Management

Logistics management plays a crucial role in the supply chain of waste power battery recycling, because the transportation of waste batteries is not only related to the flow of resources, but also involves the handling of hazardous materials and environmental protection. However, the current logistics management system has multiple problems in the process of waste power battery recycling.

First, high transportation cost. Waste power batteries are dangerous goods, and there are strict requirements for safety and environmental protection in the transportation process. Since the batteries contain hazardous substances, such as heavy metals and electrolyte, special equipment and strict protective measures are required during transportation, resulting in a significant increase in logistics costs. Especially in long-distance transportation, the existing logistics system does not realize the optimal planning of the path and cost control, resulting in low transportation efficiency and high costs.

Secondly, the lack of intelligent logistics management. The traditional logistics management model in the recycling of waste batteries shows a certain lag. The existing logistics system mostly relies on manual scheduling and experience management, and cannot realize real-time monitoring and dynamic adjustment of the transportation process. This makes it difficult to respond quickly and adjust the logistics plan when encountering transportation delays, traffic jams or other unexpected conditions. Especially in large-scale recycling tasks, the traditional logistics model is difficult to effectively manage and optimize the allocation of resources, resulting in a waste of time and cost in the transportation process.

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Finally, the inadequacy of green logistics. With the promotion of the concept of sustainable development, green logistics has become an important part of the future recycling supply chain. However, the current application of green logistics technology in the recycling supply chain of used power batteries is relatively small. Most recycling enterprises still rely on traditional fuel transportation means and fail to effectively introduce new energy logistics technology to reduce carbon emissions and environmental impact. In addition, the reverse logistics of used power batteries, i.e., recycling the batteries from consumers to recycling and processing centers, has not yet been fully optimized, resulting in the waste of resources in the logistics link is still prominent.

2.3. Poor Flow of Information

Information flow is an important part of supply chain management, and in the recycling supply chain of used power batteries, the circulation and transparency of information directly affects the recycling efficiency. At present, the information management and sharing mechanism in the recycling process is not perfect, which is reflected in the following aspects.

Firstly, upstream and downstream information sharing is insufficient. In the existing recycling supply chain, the information sharing mechanism among manufacturers, recycling enterprises, logistics companies and reuse treatment plants is not sound. Upstream manufacturers have difficulty in grasping specific recycling data on used batteries, while downstream recycling companies have difficulty in obtaining key information from battery manufacturers on battery design, service life, and so on. This information asymmetry leads to the inability of each link in the supply chain to realize efficient synergy, increasing decision-making uncertainty and operating costs.

Secondly, the application of informationization management technology is insufficient. Although some enterprises have begun to adopt information management tools, such as big data analysis and cloud computing, to optimize the recycling process, the overall application is still relatively limited. The traditional information management model relies on manual data entry and paper document delivery, which is inefficient, has a high error rate, and is unable to adapt to large-scale, multi-link recycling operations. Especially in terms of tracking and monitoring of recycled materials, existing information technology means are difficult to realize the full tracking of the entire supply chain.

Finally, the lack of emerging technologies such as blockchain. Although blockchain technology has shown great potential in supply chain management, such as improving information transparency and ensuring data immutability, the application of this technology in the supply chain of used power battery recycling is still in its infancy. The introduction of blockchain technology can effectively solve the problem of information asymmetry and trust, promote synergistic cooperation between the upstream and downstream of the supply chain, and improve the traceability and utilization efficiency of resources.

2.4. Inventory Control Challenges

Inventory management of used power batteries is a part of the supply chain that cannot be ignored. As used batteries may produce safety hazards due to chemical changes during storage, their inventory management requirements are more stringent, while the current inventory control system has some common problems.

First of all, there is an excessive backlog of inventory. Due to the volatility of market demand and the insufficiency of recycling network layout, recycling enterprises often face the problem of inventory backlog. Storage of used batteries not only takes up a lot of space, but also increases management costs. In addition, safety issues such as performance decline, corrosion and even liquid leakage may occur during long-term storage of used batteries, which puts higher requirements on inventory management.

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Secondly, the inventory management method is lagging behind. At present, most enterprises still use the traditional static inventory management, unable to dynamically adjust the inventory according to market demand and supply chain. This static management method leads to the lagging of inventory management, which can not respond to changes in demand in a timely manner, thus affecting the operational efficiency of the entire supply chain.

Finally, the lack of environmental and safety management measures. Used power batteries in inventory may produce chemical reactions, release harmful substances, and even cause safety accidents such as fire or explosion. However, at present, many recycling enterprises have not yet established a perfect environmental and safety management system in the storage process, especially in the areas of fire and explosion prevention, exhaust gas emission and wastewater treatment and other aspects of the protection measures are relatively weak, there are potential environmental and safety hazards.

3. The Optimization Strategy of Supply Chain of Waste Power Battery Recycling

Based on the previous in-depth analysis of the current situation of the supply chain of waste power battery recycling, it can be seen that the current recycling system still has obvious deficiencies in terms of network layout, logistics management, informationization level and policy support. In order to solve these problems and realize efficient recovery and recycling of resources, system optimization is needed from multiple levels of the supply chain. In the following, specific optimization strategies will be proposed in terms of recycling network layout, logistics management and informationization construction, with a view to improving the efficiency and sustainability of the overall supply chain.

3.1. Optimization of Recycling Network Layout

At the starting point of the supply chain, the layout and coverage of the recycling network directly affects the recycling rate and efficiency of used power batteries. The uneven distribution of the existing recycling network, especially the difficulty of recycling in remote areas, has become an important bottleneck restricting the efficient operation of the recycling system. Therefore, it is necessary to optimize the design of the existing recycling network to improve the overall coverage and operational efficiency.

3.1.1. Increased Coverage of Recycling Points

The current recycling network is concentrated in urban areas, leading to difficulties in recycling in some remote areas and the problem of unbalanced network layout. In order to improve the overall recycling efficiency of used power batteries, it is first necessary to reasonably expand the coverage of recycling points and take some powerful measures. For example, the construction of recycling facilities in remote areas should be strengthened. According to the use of regional electric vehicles, population density, transportation conditions and other factors, additional recycling outlets should be set up in remote areas. Flexible methods such as mobile recycling stations and regular door-to-door recycling can be used to cover areas where it is difficult to set up fixed points to ensure a wide coverage of the waste battery recycling network. In addition, establish a hierarchical recycling network. Large centralized treatment centers are set up in big cities to undertake the main tasks of waste battery treatment, while small collection points are set up in the surrounding areas and communities to build a multi-level recycling network system. By combining this centralized and decentralized network design, the recycling rate of waste batteries can be effectively increased, and the transportation and treatment costs can be optimized. In addition, it is necessary to strengthen the synergistic cooperation between the government and enterprises. The government can promote EV manufacturers and third-party recycling companies to enhance the expansion of the recycling

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network through policy support and subsidies. Recycling companies, on the other hand, should cooperate with manufacturers to share recycling channels and resources, avoid duplicating the construction of recycling facilities, and create synergistic effects.

3.1.2. Increased Efficiency of Recycling Point Operations

In order to improve the operational efficiency of existing recycling points, measures can be taken to optimize the recycling process. For example, standardize the recycling process. Formulate unified recycling standards and operational specifications for used power batteries to ensure the efficient operation of recycling points in the collection, classification, storage and transportation of batteries. Through standardized processes, reduce safety risks and resource wastage caused by improper operation. In addition, introduce automated equipment. Introduce automated equipment in recycling points, such as automatic detection systems for used batteries, automatic sorting and packaging equipment, etc., to reduce the error rate and time cost of manual operation and improve the processing efficiency of recycling points. In addition, it is also necessary to improve the level of personnel training. Regularly provide professional training for the staff of recycling points to ensure that they master the safe operation norms and the latest technological developments in the recycling process of waste batteries. In particular, the awareness and capacity building of personnel should be strengthened in terms of safe battery handling and environmental protection.

3.2. Optimization of Logistics Management

In the recycling system, logistics management is the key to connecting various links. The logistics of waste power batteries involves multiple factors such as safety, cost and environmental protection, so the transportation efficiency and sustainability of the recycling chain can be significantly improved by introducing intelligent logistics technology and green transportation means.

3.2.1. Introduction of Intelligent Logistics System

Logistics management of used power batteries is a key link in the whole supply chain, especially important in ensuring safety and controlling transportation costs. For this reason, the overall efficiency of logistics management can be improved by introducing an intelligent logistics system. First of all, intelligent scheduling and path optimization, using big data, artificial intelligence and other technologies to carry out intelligent planning of transport paths, combining traffic conditions, transport volume and time and other elements to dynamically optimize transport routes. The intelligent scheduling system can also adjust the allocation of vehicles and personnel in real time, reducing transportation time and cost. Secondly, IoT monitoring and tracking, the application of IoT technology can realize real-time monitoring of the whole process of waste battery transportation. By installing sensors on transportation vehicles and battery packages, the status of batteries (such as temperature, humidity, vibration, etc.) can be monitored to ensure the safety of the transportation process. Once an accident occurs (such as battery overheating, liquid leakage, etc.), the system can provide timely warning and take appropriate measures to prevent accidents. Finally, intensive transportation. In order to reduce logistics costs, it is recommended to adopt intensive transportation. For example, the waste battery transportation needs of different enterprises can be integrated through a logistics sharing platform to optimize the load capacity of vehicles and reduce the idling rate and energy consumption. At the same time, multimodal transportation (such as railroad + road transportation) can also be used to improve the efficiency of long-distance transportation.

3.2.2. Application of Green Logistics Technology

In order to reduce the negative impact on the environment during the recycling of used power batteries, the application of green logistics technologies should be further promoted. First, enterprises are encouraged to adopt new energy transportation vehicles, such as electric trucks

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and hydrogen fuel cell trucks, to reduce carbon emissions during transportation. Meanwhile, the government should promote the popularization of green logistics technology through policy support and financial subsidies. Secondly, promote green packaging materials. At present, most enterprises still use traditional plastic packaging, which is easy to cause secondary pollution. It is recommended to promote the use of recyclable or biodegradable environmental protection packaging materials to reduce the environmental burden in the logistics link. In addition, optimize the reverse logistics of waste batteries. The reverse logistics of waste batteries, i.e. the logistics link from consumers or end-users to recycling enterprises, is usually the weak link in the supply chain. For this reason, it is possible to simplify the logistics process and reduce the recycling time and logistics costs by setting up a dedicated channel for reverse logistics.

3.3. Construction of Information Flow and Sharing Mechanisms

In the recycling supply chain, the smoothness of information flow directly affects the efficiency of recycling and the effect of synergy among all parties. At present, the information transparency in the recycling chain of waste power batteries is relatively low, and the information asymmetry and insufficient sharing mechanism seriously hinder the rational allocation of resources and the overall optimization of the supply chain. Therefore, promoting the construction of informationization and establishing an efficient information sharing mechanism has become an important part of enhancing the efficiency of the waste power battery recycling supply chain. Through the construction of a unified information platform, the application of big data and blockchain technology and other means, it can effectively promote the synergy of all parties, reduce the operating costs, and enhance the overall transparency of the supply chain.

3.3.1. Supply Chain Informatization Management

Information management is one of the core means to improve the efficiency of the waste power battery recycling supply chain. Through the introduction of information technology, information sharing and transparent management of each link in the supply chain can be realized, which in turn optimizes the whole recycling process. For example, build a unified information management platform. Establish a unified information management platform covering recycling enterprises, logistics companies, recycling enterprises and government regulators to realize information sharing in the whole process of waste battery recycling. Through this platform, all parties can grasp key information such as the quantity, quality and transportation status of recycled batteries in real time, so as to optimize resource scheduling and decision-making. Secondly, big data analysis and prediction, using big data analysis technology, analyzing and predicting data such as market demand, the amount of waste batteries generated, logistics costs, etc., to help enterprises develop more scientific recycling and treatment plans. At the same time, predictive analysis can also help enterprises optimize inventory management and reduce the risk of inventory backlog. In addition, blockchain-based supply chain management is conducted. Blockchain technology can ensure the non-tamperability and traceability of information in each link of the supply chain. In the waste power battery recycling supply chain, the introduction of blockchain technology can ensure that the whole process of data transparency from the production of batteries to recycling and reuse, and that the authenticity of the data can be verified in each link. This will effectively improve the synergistic efficiency of the supply chain and enhance the trust of all parties in the supply chain information.

3.3.2. Enhancing Information Transparency

Information asymmetry and lack of transparency are currently a major problem in the supply chain of used power battery recycling. For this reason, each link in the supply chain should promote the openness and transparency of information, for example, real-time information release mechanism. The establishment of an information release mechanism ensures that all

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parties in the supply chain can obtain relevant information in real time, such as the quantity, type, quality and price of recycled batteries. This not only helps all parties make more rational decisions, but also improves the overall transparency of the recycling process and reduces operational risks. In addition, attention is paid to consumer information guidance. Through tools such as smartphone apps, provide consumers with convenient waste battery recycling information inquiry and recycling reservation services. Consumers can check information such as nearby recycling points, recycling time, process and incentive policies through the apps, thus increasing the motivation to participate in recycling.

3.4. Optimization of Inventory Management

In the recycling supply chain of used power batteries, inventory management, as an important link connecting recycling, treatment and reuse, directly affects the operational efficiency and safety of the supply chain. There are potential environmental and safety risks in the storage process of waste batteries, which can lead to resource waste and environmental pollution if not handled properly. Therefore, improving the dynamics and safety of inventory management and establishing a more efficient and environmentally friendly inventory management system are key steps to optimize the supply chain process.

3.4.1. Dynamic Inventory Management

The traditional static inventory management model can no longer meet the changing market demand, so dynamic inventory management strategies should be promoted. Through real-time monitoring of the recycling volume of used batteries and market demand, the inventory level can be dynamically adjusted to avoid inventory backlog and resource waste. Dynamic inventory management system can track inventory changes in real time with the help of IoT technology and quickly adjust the inventory strategy according to demand changes.

3.4.2. Security and Environmental Management

Waste power batteries may generate safety hazards during storage, such as chemical reaction, liquid leakage, combustion, etc. Therefore, safety and environmental management measures must be strengthened in inventory management. For example, establish strict storage safety standards. According to the characteristics of waste power batteries, establish strict storage safety standards, including temperature, humidity, ventilation, isolation and other requirements, to ensure the safety of batteries in the storage process. In addition, carry out green inventory management. The impact on the environment should be minimized in the storage process, especially in preventing the leakage of hazardous substances and environmental pollution by taking effective measures. Build a green inventory management system through the use of environmentally friendly materials, reduce energy consumption and other means.

4. Conclusion

Optimization of the supply chain of waste power battery recycling is not only a key path to achieve sustainable use of resources, but also an important means to promote the development of green economy. Through the analysis of the current situation of the existing supply chain, it can be found that there is still a large optimization space in the recycling network layout, logistics management, information construction, inventory management and other aspects. From the perspective of supply chain, this paper proposes multi-dimensional optimization strategies such as optimizing the recycling network layout, introducing intelligent logistics system, establishing information circulation and sharing mechanism and improving inventory management, aiming at enhancing the overall efficiency of the waste power battery recycling supply chain.

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First, optimizing the recycling network layout can improve the coverage and operational efficiency of recycling points, thus significantly increasing the battery recycling rate, especially in remote areas. Secondly, intelligent and green logistics management can help reduce transportation costs and enhance environmental benefits, and the logistics efficiency of used batteries can be improved through the application of intelligent scheduling and green packaging. The construction of informatization and sharing mechanism can strengthen the synergy and transparency among various links in the supply chain, especially through the introduction of big data and blockchain technology, which improves the information transmission and decision-making efficiency of the supply chain. Finally, the optimization of inventory management is able to improve the security and dynamic deployment of battery storage, thus reducing inventory backlog and potential environmental risks.

In conclusion, through the systematic optimization of each link in the supply chain, the recycling and reuse efficiency of used power batteries will be significantly improved, which will reduce resource waste and environmental pollution, and provide strong support for the development of China's recycling economy and the realization of the goal of carbon neutrality. However, the optimization of the recycling supply chain is a systematic project, which requires the cooperation of all parties, as well as the continuous promotion of policy, technology and market environment. In the future, with technological progress and further improvement of policies, the used power battery recycling supply chain will be more intelligent and efficient, and make greater contributions to sustainable development.

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