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Research on Recycling Benefits and Environmental Impacts of New Energy Vehicle Batteries

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ABSTRACT

China's fast industrial expansion has resulted in substantial environmental contamination, limiting the economy's long-term growth potential. In this setting, the low-carbon economy has emerged as an essential development strategy followed by all countries. The electric vehicle sector, which is a key pillar of the low-carbon economy, is quickly expanding. However, the linked battery recycling business has a lot of space for development. This study looks into the recycling benefits and environmental consequences of NEV batteries. The research methodologies used include literature review, theoretical analysis, and case studies of prominent firms. The findings emphasize the economic, environmental, and social benefits of battery recycling, including considerable reductions in carbon emissions and resource consumption. The conclusions highlight the importance of battery recycling to promote sustainable development and achieve low carbon goals.

KEYWORDS

Battery Recycling, Environmental Impact, New Energy Vehicles, Sustainable, Development, Carbon Emissions.

1. INTRODUCTION

The issue of environmental pollution is becoming increasingly noticeable these days due to China's industry's rapid expansion, and it is now a major barrier to the sustainable growth of the national economy. In this regard, pursuing a low-carbon economy has emerged as a key global development strategy.

As one of the important pillars of the low-carbon economy, the new energy industry has developed rapidly in recent years, in which the development of the electric vehicle industry is more complete, but the development of its related battery recycling industry still has a greater room for improvement. With the rising volume of power battery decommissioning and the soaring prices of metal resources such as lithium nickel manganese cobalt, the market size of China's power battery recycling industry has been expanding, rising from 5.83 billion yuan in 2018 to 20.4 billion yuan in 2022, and is expected to grow to 55 billion yuan by 2027.

Reusing power batteries can help achieve the "dual-carbon" objective of lowering emissions and saving energy. The production of power batteries is a high-energy business that emits a lot of greenhouse gases throughout the process.

The rapid rise of the electric vehicle industry provides strong support for the realization of China's low-carbon economic goals, and its battery recycling is not only directly related to environmental protection, to avoid the leakage of hazardous substances and waste of resources, but also has important economic significance, and has an important impact on the healthy development of the electric vehicle industry chain. Under the conditions of environmental protection demand, technological progress and policy support, the electric vehicle industry is emerging. However, as this market grows, the issue of battery recycling becomes increasingly important. Battery recycling is not only about environmental protection, avoiding the leakage of hazardous substances and the waste of resources, but also has a significant economic impact.

2. LITERATURE REVIEW

2.1. Domestic

According to Chen Bingyue (2023), new and renewable energy sources have been developing in recent years, but fossil fuels are still the main source of energy used by human beings, and global carbon emissions are huge and cause serious pollution to the environment. As an alternative to traditional fuel vehicles, new energy vehicles play an important role in energy saving and emission reduction and in realizing the goal of "carbon neutrality". However, although new energy vehicles are the key to future development, battery recycling still faces many challenges.

According to Peng Zhun, Liu Shaokui, Liu Yongqi, and Gong Qinxue (2022), the new energy vehicle industry is tasked with the important mission of promoting "carbon neutrality and carbon peaking", and its explosive growth, sustainable development, and huge development space constitute the current status of the new energy vehicle industry. As a key component of new energy vehicles, power batteries have a fixed life cycle, and the first batch of power batteries in service have gradually reached their end-of-life, thus promoting the first development of the power battery recycling industry.

In reality, as material demand rises, EV recycling is becoming more significant. The advantages are computed based on the technology used by prominent firms, including overall revenue, reduced energy usage, and greenhouse gas emissions. Life Cycle of Recycling Equipment Life Cycle of Recycling Equipment Economic and environmental implications are not considered. Researchers from Xie Xiangyang estimated that while energy consumption and greenhouse gas emissions are reduced by 25.6 GJ and 4.1 t CO2eq, respectively, the total income per recycled EV is around $473.9 USD. Furthermore, the environmental advantages are estimated to be 36.3 kg CO2eq/USD and 241.3 MJ/USD per technology cost. Currently, the major source of advantages for the environment and economy is the vast amount of recovered metal; but, with the development of traction batteries, the recovered cathode active material will become more valuable.

2.2. Foreign

Several studies conducted abroad indicate that approximately 5 million tons of lithium-ion batteries are anticipated to reach the end of their useful lives by 2030.

The widespread use of electric vehicles will yield long-term strategic and environmental benefits, as shown by Cheng et al. (2017), Høyer (2008), and Pistoia and Liaw (2018).

Emissions from the use of fossil fuels to produce electricity are concentrated along the chain of energy production rather than, as is now the case, in main hubs. Although lithium-ion batteries are widely utilized in residential and industrial equipment, electric automobiles, and portable devices, they still include components that pose safety and environmental concerns. These comprise graphite, Nb, Li, and Ti in the anode, iron in the casing, Li, Mn, Co, and Ni in the cathode, and organic compounds in the electrolyte. Al and Cu are found in the anode collector. These materials may adversely affect the survival, growth and reproduction of living organisms and are toxic, persistent and bio accumulative. Recycling is crucial from an economic and environmental perspective, as certain raw resources are seen as essential in certain nations or areas.

To summaries, substantial progress in the non-recycling value chain can only be made through extensive development if high recycling rates for lithium-ion batteries, competitive raw material costs, and decreased energy and environmental footprints are attained. As lithium-ion battery recycling for electric cars is still in its early stages (particularly outside of China), there are possibilities and difficulties for those who are ready to take on the increasingly important strategic problem of sustainable battery manufacture.

In summary, a large number of studies at home and abroad have shown that battery recycling for electric vehicles has attracted the attention of multiple stakeholders and has shown a trend of gradual expansion in scope. However, most of the studies and applications still focus on the estimation of recycling, lack of practical estimation guidelines for the environmental impact effect, less quantitative research on design, more subjective judgments, and too formalized.

In this study, with the help of the development research of electric vehicle recycling at home and abroad, we conduct an overall overview and compare the data on the effect of enterprise battery recycling before and after, so as to reflect the final recycling benefits with the data.

3. THEORETICAL BASIS

3.1. Battery recycling process

The secondary utilization of waste electric vehicle batteries mainly includes gradient utilization and recycling. Graduated utilization is mainly oriented to low-speed electric vehicles, energy storage and other fields, the main object for the lithium iron phosphate battery, because of its stable, long-life characteristics. Batteries are classified according to the conditions and then utilized in different fields for graded utilization, and when the power is less than 20%, they are recycled to extract key metals such as copper, nickel, cobalt and manganese, so as to realize resource recycling. Regenerative utilization is based on ternary material batteries, which are recovered through mature pyrometallurgical, hydrometallurgical and bio metallurgical processes, of which hydrometallurgy has become the mainstream due to its high recycling rate and specific metal recovery capability. This kind of utilization is not only economically efficient, but also environmentally friendly and energy-saving.

3.2. Theory of Sustainable Development

The theory of sustainable development aims to ensure that the needs of the present are met without jeopardizing the development potential of future generations. Governments should develop and implement plans and regulations related to EV battery recycling in order to drive the industry's strong growth while emphasizing sustainability. This will help maintain the balance between the commercial benefits of EV battery recycling and environmental protection and social responsibility.

3.3. Life Cycle Assessment (LCA)

Throughout the lifecycle of a product, life cycle assessment (LCA) is a vital tool for a comprehensive assessment of its environmental impact. For the electric vehicle battery recycling business, the application of LCA is particularly critical, which can help us identify the key links in the battery recycling process, so as to strengthen and optimize the recycling process. In addition, through LCA, we can provide a scientific basis for the formulation of environmental protection laws and promote the industry to develop in a more sustainable direction.

3.4. Environmental cost-benefit analysis

Environmental cost-benefit analysis (CEA), on the other hand, is a method that focuses on assessing the environmental costs and benefits of recycling processes. With CEA, we aim to identify recycling technologies and policies that are most effective in protecting the environment. For the EV motor recycling sector, the use of CEA findings will allow it to make informed decisions on the choice of technologies and policies that will both protect the environment and generate economic benefits.

The first step in implementing CEA is to identify and quantify the environmental costs and advantages of the recycling process. On this basis, we will conduct a comparative cost-benefit analysis. This analysis will provide us with a strong basis to support the development of environmental regulations and the choice of recycling technology, ensuring that the battery recycling process has positive results at both economic and environmental levels. This method necessitates a comparative cost-benefit analysis once we first determine and quantify the environmental costs and advantages of the recycling process. With the use of this analysis, we can firmly advocate for the creation of environmental regulations and the choice of recycling techniques in order to guarantee a scenario in which the battery recycling process helps the economy and the environment.

3.5. Theoretical Analysis of Battery Recycling Benefits

Battery recycling benefits can be explored from three aspects: economic, environmental and social:

(1)Economic benefits: Recycling batteries can bring about efficient utilization of resources, cost reduction and profit enhancement, while creating new business opportunities and job opportunities.

(2)Environmental benefits: Recycling reduces the emission of hazardous substances and waste of resources, reduces environmental impacts and realizes resource recycling.

(3)Social benefits: Enterprises participating in recycling activities enhance their social image and market competitiveness, and demonstrate social responsibility.

4. CASE STUDY

4.1. Company Profile

The power automobile battery recycling industry chain covers the upper, middle and lower parts, the power battery recycling industry upstream channels are many and relatively messy, battery factory is the main supply channel, accounting for about 50%; the middle reaches involved in the main body of the type of miscellaneous, the market competition is fragmented, and is currently dominated by the third-party enterprises; the downstream application includes two types of laddering utilization and recycling. This study focuses on Greenman, a leading battery recycling company, which is located in the midstream of the market.

Grammy’s main business is recycling waste batteries, electronic waste and other waste resources recycling high-tech products, is one of China's leading enterprises in the economic and large-scale recycling of electronic waste and waste batteries.

4.2. Battery Recycling Status

Grammy has formed a new energy full life cycle value chain recycling model of waste battery recycling, raw material remanufacturing, material remanufacturing, battery pack remanufacturing and reuse and gradient utilization, which maximizes the utilization of new energy materials.

4.3. Financial Analysis

According to Grammy's financial report, the revenue of Grammy's new energy battery materials business has reached RMB 23 billion in 2023, accounting for 75.23% of its total revenue. Among them, the revenue of ternary precursor business accounted for 57.59%, which is one of the most core modules on the power battery, accounting for a quarter of the total cost of the battery. The annual shipments of Grammy is one quarter of the total installed capacity of domestic new energy vehicles, which is equivalent to every four cars at least one of the raw materials provided by Grimme. Therefore, this study takes Grimme as the research object.

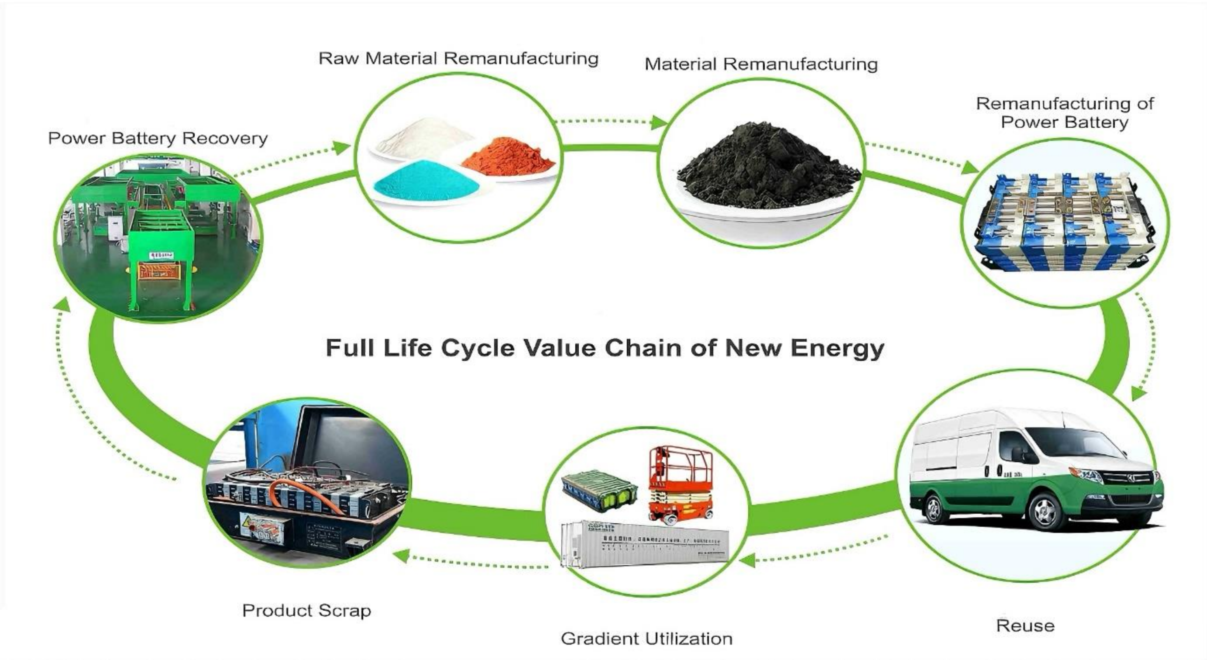

Figure 1 Full Life Cycle Value Chain of New Energy

4.4. Environmental impact analysis

Through the battery recycling process in the process of carbon footprint accounting and review of relevant literature can be seen, each recovery of 1kg of nickel, cobalt, aluminum will achieve emissions reduction of 3-6kg CO2-eq. From 2017 onwards, Grammy increased the new energy battery recycling business, which is recycled through the waste. From Grammy 2020 through waste recycling (including battery recycling), the carbon dioxide emission reduction will be realized about 63,500 tons (equivalent), which is equivalent to the carbon emission reduction brought by planting 6.35 million trees in a year. The Chinese government-initiated policies related to the recycling of new energy vehicle batteries in 2017, and has subsequently released a series of reports detailing the environmental impact of recycling policies. In a report released by China's Ministry of Industry and Information Technology (MIIT), it was noted that battery recycling not only reduces environmental pollution from waste, but also significantly lowers carbon dioxide emissions (China Daily).

5. RESEARCH METHODOLOGY

5.1. Case selection and assumptions

China's power battery recycling industry is in the beginning stage of development, and the market shows a fully competitive pattern, Grammy, Bump Cycle and Huayu Cobalt have strong existing recycling and processing capacity, and Grammy, Bump Cycle, Camelot, and Tianqi are actively planning to expand production. In this study, Grammy, Huayu Cobalt and Bump Circulation, the leading EV battery recycling companies, were selected for the study in view of data availability. Given that electric vehicle battery recycling began to formally develop in 2017, and the policy "Interim Measures for the Administration of Power Battery Recycling for New Energy Vehicles" began to be implemented in 2018, the data of the three companies for the period 2017-2022 was selected for analysis and research.

Hypothesis: battery recycling of new energy vehicles will reduce environmental pollution.

5.2. Variable selection:

(1) According to studies by the International Council on Clean Transportation (ICCT): From the perspective of the whole life cycle, the carbon dioxide emissions per kilometer of new energy vehicles are about 13g/km. However, if the used power batteries can be used in a gradient application and regeneration application, the corresponding carbon emissions per kilometer of new energy vehicles will be reduced by 22g and 4g, respectively, which will significantly reduce the carbon emissions of the new energy vehicle's whole life cycle. As a result, the dependent variable is selected to be the reduction in CO2 emissions. As a result, the dependent variable chosen is the reduction in carbon dioxide emissions. Carbon dioxide reduction is calculated as the difference between this year's carbon dioxide emissions and the previous year's.

(2) Recycling advantages are difficult to quantify directly due to the intricacy of the electrical remittance recovery process. The Royal Society of Chemistry released an essay on the development of novel recycling processes and the critical role of R&D in making these approaches commercially feasible. The report emphasizes that R&D investment is crucial for enhancing the recovery rate of valued The report emphasizes the need of R&D investment in raising the recovery rate of valuable materials and lowering the environmental impact of battery recycling (RSC Publishing, 2023). Thus, the battery recycling R&D expenditure is employed to assess the recycling advantages. Battery recycling research & development utilizes the company's investment capital in battery recycling for the current year.

(3) Control variables are selected as firm size, financial leverage, GDP growth rate, and further control of

Firm Size: Large firms usually have more resources for environmental investment and technology R&D, which may have a positive impact on CO2 reduction (King and Lenox, 2021). Firm size is represented by taking the natural logarithm of total assets plus one.

Financial Leverage: Firms with high leverage may face more financial pressure and may invest less in environmental protection and recycling programs (Jensen, 1986). Calculated by dividing the company's total assets by its total liabilities.

GDP Growth Rate: the rate of economic growth can affect a firm's overall economic environment and market demand, which in turn can affect a firm's environmental investments and performance (Grossman and Krueger, 1995). It is calculated by dividing the current year's GDP index by the previous year's GDP index.

ROA: Profitability ratio in order to generate profit efficiency. Improved ROA means improved company management and profitability. This may be related to the company's initiatives and investments in exchange construction and the reduction in nitrogen dioxide emissions from battery recycling. Calculated as net income divided by total assets.

5.3. Formula of hypothesis

H1: $$CO_2\ Reduction = \beta_1\ Battery\ R\&D\ Investment + \beta_2 Firm\ Size + \beta_3 GDP\ Growth\ Rate + \beta_4 ROA + \beta_5 Leverage + \epsilon$$

5.4. Data Collection

All data were obtained from the official financial reports of each company as well as publicly available financial data platforms. Specific sources include: Official company reports: Annual reports and financial statements of companies, such as GEM, Bumper and Huayu Cobalt, usually publish annual financial data and environmental performance reports. Public financial data platforms: Use financial data platforms such as Wind and Bloomberg to obtain detailed corporate financial data and market performance.

6. RESULTS

This research adopts the descriptive statistical method to find the characteristics of the variable, and use multiple regression models to find new energy battery recycling effect impact on the environment.

6.1. The result of descriptive statistic

Table 1 Descriptive Table

Variable	Obs	Mean	Std. Dev.	Min	Max
GDP Growth Rate	18	0.055167	0.0217465	0.0235	0.081
Battery R&D Investment	18	6.721111	2.903493	2.8	14.76
Firm Size	18	25.09252	1.755512	22	29
Leverage	18	0.559231	0.0480587	0.48	0.65
ROA	18	0.032918	0.0093826	0.0151	0.05
CO2 Reduction	18	6.380556	1.106284	4.5	8

Descriptive statistics are shown below:

GDP Growth Rate:

The average GDP growth rate is approximately 0.0552 with a standard deviation of 0.0217. This suggests that the GDP growth rate varies moderately around the mean, indicating some variability but not extreme differences. The range is from 0.0235 to 0.081, showing that while there is variation, the values do not deviate drastically from the mean.

Battery R&D Investment:

The mean Battery R&D Investment is about 6.7211 with a standard deviation of 2.9035. The relatively high standard deviation indicates a significant variation around the mean, suggesting that the investment amounts differ considerably among observations. The extreme difference, ranging from 2.8 to 14.76, highlights that some companies invest much more heavily in R&D compared to others, indicating the data is influenced by high values.

Firm Size:

Firm size has an average value of 25.0925 and a standard deviation of 1.7555. This relatively low standard deviation suggests that most firms have sizes close to the average, with minimal variation. The range, spanning from 22 to 29, shows that while there is some variability, firm sizes do not differ drastically, implying a relatively consistent firm size among the observations.

Leverage (lev):

The average leverage is 0.5592 with a standard deviation of 0.0481. The small standard deviation indicates that leverage values are closely clustered around the mean. The range from 0.48 to 0.65 demonstrates minimal dispersion, suggesting that most firms have similar leverage ratios and the data is not significantly affected by extreme values.

Return on Assets (Roa):

The mean Return on Assets is 0.0329 with a standard deviation of 0.0094. This small standard deviation indicates that the Roa values are tightly grouped around the mean, implying low variability. The range is from 0.0151 to 0.05, showing that most firms have similar returns on assets with little deviation.

CO_2 Reduction:

The average CO2 reduction is 6.3806 with a standard deviation of 1.1063. This suggests moderate variability around the mean, indicating some differences in CO2 reduction efforts among firms. The range from 4.5 to 8 points out that while there is some variation, the values do not deviate extremely from the mean, implying that most firms have similar CO2 reduction levels but with a few exceptions.

6.2. The result of linear regression

Table 3 Model Regression Table

	-1 CO2 reduction
Battery R&D Investment	0.152***
	-4.42
Firm Size	0.218***
	-3.93
GDP Growth Rate	0.064
	-0.02
Roa	-1.97
	(-0.22)
lev	-9.296***
	(-3.84)
_cons	5.138**
	-2.2
N	18
r2_a	0.93

t statistics in parentheses
* p < 0.1, ** p < 0.05, *** p < 0.01

According to the results, firstly, in Table 2, the R-square value of the model is 0.93, indicating that the regression line has a high degree of fit. Second, the significance of the interaction between battery R&D investment and CO 2 emission reduction is less than 0.01, while the significance of the interaction between firm size and CO 2 emission reduction is also less than 0.01. In addition, the significance of urbanization rate and GDP growth rate both exceeds 0.05. Therefore, these variables will affect CO 2 emission reduction to a certain extent and have an impact on the results of this study.

Finally, we analyze the β values of the regression coefficients in Table 2. The coefficient of battery R&D investment is 0.152, and the significance is less than 0.01, which indicates that battery R&D investment has a significantly positive impact on carbon dioxide emission reduction. The coefficient of enterprise size is 0.218, and the significance is also less than 0.01, indicating that enterprise size has a significantly positive impact on carbon dioxide emission reduction. The coefficient of lev is −9.296 with a significance less than 0.01, indicating that lev has a significantly negative impact on carbon dioxide emission reduction.

7. CONCLUSION AND RECOMMENDATIONS

7.1. Summary of Major Findings

Through the above regression. It confirms the existence of the hypothesis that battery recycling of new energy vehicles will reduce environmental pollution.

Meanwhile, power battery, as the core component of new energy vehicles, contains lithium, cobalt, manganese, nickel and other metal elements, which take up a significant proportion of the raw material cost, usually between 50% and 70%. Particularly noteworthy is that lithium and cobalt salts consumed by power batteries account for the largest share of all applications of lithium and cobalt. With the rapid expansion of the new energy vehicle market, the rate of consumption of these primary resources is accelerating.

However, the finite nature of resources requires us to focus not only on resource extraction, but also on resource recycling. Recycling of secondary resources, especially the recovery of metal elements in power batteries, is crucial to maintaining the sustainable utilization of resources. China has designated rare earth metal minerals as strategic resources since the publication of the National Mineral Resources Plan (2016-2020), emphasizing the significance of power battery recycling. (Ministry of Land and Resources, PRC, 2016).

The advantages of power battery recycling are numerous. First, it improves resource utilization and reduces the need for primary resource extraction, thereby reducing the risk of environmental damage and resource depletion. In addition, power battery recycling not only helps to alleviate the pressure of China's long-standing external dependence on rare metal resources, thereby strengthening the country's resource security, but more importantly, by reducing the extraction and processing of virgin resources, this initiative significantly reduces carbon emissions and the release of other pollutants, resulting in a positive emission reduction effect on the environment.

In summary, the recycling of power batteries for new energy vehicles is not only in line with the development concept of circular economy, but also an effective way to reduce environmental pollution and improve the efficiency of resource utilization. Therefore, we can be sure that the recycling of new energy vehicle power batteries will have a positive impact on the environment, confirming our hypothesis.

7.2. Theoretical and Practical Implications of Findings

Theoretical significance:

By exploring in depth the benefits of new energy vehicle battery recycling and its impact on the environment, this study not only enriches the theoretical system in the new energy field, especially in the battery recycling industry, but also provides a systematic theoretical guidance and analytical methodology for related fields. In terms of theoretical construction, this study integrates multiple theoretical frameworks, such as sustainable development theory, life cycle evaluation, and environmental cost-benefit analysis, to provide a comprehensive theoretical perspective on the benefits and environmental impacts of battery recycling. In addition, the multidimensional analysis method of this study will be able to evaluate the effectiveness of battery recycling policies and provide a certain theoretical basis for subsequent policy formulation and industry guidance.

Relevance:

This study thoroughly analyzes the benefits and environmental impacts of new energy vehicle battery recycling from the perspective of practical application, which not only helps the government and enterprises to understand the dual economic and environmental values of battery recycling, but also promotes the innovation of environmentally friendly battery recycling technologies and the improvement of policies. The successful implementation of battery recycling is expected to reduce the pollution of hazardous substances to the environment, extend the life cycle of resources, reduce the waste of resources, and lead to the development of related industries, such as the recycling treatment and material reuse industries. In addition, by exploring the best practices of battery recycling, this study will help to promote the healthy development of the new energy vehicle industry chain, promote the realization of a green and low-carbon economy, and contribute to the realization of China's "dual-carbon" goal.

7.3. Limitations of the Study

The development of electric vehicle battery recycling is relatively short, and the development of the industry is not yet perfect. In view of this, data availability is very limited, and the experimental results are only indicative and not convincing enough to fully validate the conclusions. After further development of the industry, further research can be conducted. At that time, a large amount of relevant data can be obtained, while adding more control variables, regulating variables, and refining the measurement criteria of battery recycling benefits, so as to obtain more accurate and more powerful research results.

7.4. Recommendation

Based on the results and analysis of the research on the benefits and environmental impacts of battery recycling for new energy vehicles, recommendations are made to improve the sustainability and effectiveness of the battery recycling process:

(1)Stricter laws should be created and implemented by governments to promote and enable the recycling of batteries used in new energy vehicles. To promote compliance and efficiency in battery recycling, it may be necessary to set mandatory recycling goals for businesses, offer tax breaks or subsidies to those who recycle batteries, and create a uniform framework for the recycling procedure.

(2)Companies that are relevant can spend more on research and development to create and enhance battery recycling technology. It is important to investigate and improve cutting-edge techniques like hydrometallurgy and bio metallurgy in order to boost recycling rates and more effectively recover precious materials.

(3)It is crucial for parties in the value chain to work together, including battery producers, recyclers, and legislators. Together, they can create integrated recycling programs, exchange best practices, and guarantee that battery management is sustainable throughout the battery's life cycle.

(4)Stress the need for circular economy models to be developed in order to guarantee resource sustainability. This include employing recyclable components, designing batteries with recycling in mind, and developing a closed-loop system.

(5)Encouraging the growth of secondary markets for repurposed materials can enhance battery recycling's financial sustainability. Businesses may offset the expenses of the recycling process and support the sustainability of resources by generating demand for recycled metals and other components recovered from batteries.

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