Journal of Cleaner Production 486 (2025) 144591

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Collaborative management of battery manufacturer responsibility in electric vehicle production with ESG due diligence

Senlin Zhao [a], Yue Han [a], Qin Zhou [b,*], Xiqiang Xia [c,**]

[a] School of Economics and Management, Shanghai Maritime University, 1550 Haigang Ave, 201306, Shanghai, PR China
[b] Department of Decision Analytics and Risk, Southampton Business School, University of Southampton, UK
[c] Business School, Zhengzhou University, Zhengzhou, PR China

ARTICLE INFO

Handling Editor: Yutao Wang

Keywords:
Due diligence
ESG
Echelon utilization
Battery manufacturer
EV manufacturer

ABSTRACT

Precious elements within used electric vehicle (EV) batteries can be utilized through echelon utilization. However, the current echelon utilization system for retired batteries remains immature, exposing numerous issues in environmental, social, and governance (ESG) aspects. This paper seeks to enhance and regulate ESG issues throughout the lifecycle of EV batteries and explore the balanced decisions of battery manufacturers (BMs) and electric vehicle manufacturers (EVMs) in a supply chain. Using the Stackelberg game model, we explore ESG-related cost-sharing contracts across three distinct supply chain models, influenced by BM's ESG improvements and EVM's due diligence efforts. Our analysis reveals that prioritizing ESG considerations enhances mutual benefits, with centralized systems consistently outperforming decentralized ones. Notably, as consumer sensitivity to recycling prices increases, BMs tend to lower their recycling prices, which can reduce battery recycling rates and hinder the sustainable development of the closed-loop battery supply chain. To better align the interests of supply chain members, we propose a two-way cost-sharing contract, with EVMs favoring moderate arrangements to avoid profit loss for both parties. This paper contributes to a more responsible, transparent, and sustainable battery recycling system by integrating ESG improvements and due diligence into the closed-loop supply chain for EV waste batteries.

1. Introduction

The intensification of climate impacts coincides with soaring greenhouse gas emissions and escalating temperature records. The United Nations Environment Program urges nations to expedite the transition to low-carbon development across all sectors to align with the Paris Agreement's objective of capping global warming at 1.5 °C (Programme, 2023). Notably, sectoral decarbonization efforts, particularly within transportation, have spurred the rapid expansion of the electric vehicle industry and a corresponding surge in EV demand (Agency, 2024). However, this growth has engendered a new challenge: the proliferation of retired power batteries. Projections by the China Society of Automotive Engineers indicate that retired power battery volume in China will soar to 1.04 million tons by 2023 and is projected to escalate to 3.5 million tons by 2030. Consequently, the management of retired batteries has become a focal point of societal concern.

Currently, the primary approach for handling decommissioned power batteries is echelon utilization. Following prolonged usage in EVs, the capacity of power batteries gradually diminishes. Typically, when the capacity decreases to between 70% and 80%, it becomes insufficient to meet the demands of EVs. Consequently, the power battery is retired from EVs (Wang et al., 2020). Diverging from conventional products, the power battery recycling value chain follows a trajectory of "recycling-echelon utilization-metal recycling". The residual capacity serves as the criterion for determining whether a used power battery can be repurposed within the echelon. In particular, when the remaining capacity of a power battery is between 60% and 80% of its original capacity, it can find applications in fields such as energy storage, communication base stations, power conditioning, and low-speed EVs following disassembly and reorganization (Zhang et al., 2022). As the remaining capacity declines to 20%–60%, the battery can be utilized either by end-users or within microgrids. These application scenarios fall under the echelon utilization category, representing a methodical approach to resource allocation and utilization. However, when the

* Corresponding author.
** Corresponding author.
E-mail addresses: slzhao@shmtu.edu.cn (S. Zhao), 202330710071@stu.shmtu.edu.cn (Y. Han), Q.Zhou@soton.ac.uk (Q. Zhou), xqxia@zzu.edu.cn (X. Xia).

https://doi.org/10.1016/j.jclepro.2024.144591
Received 29 May 2024; Received in revised form 6 November 2024; Accepted 26 December 2024
Available online 27 December 2024

residual capacity dwindles below 20%, the power battery becomes unsuitable for stepwise utilization and must undergo direct scrappage and disassembly to extract internal battery components and refine rare metal materials (Zhang et al., 2022).

Electric car sales continue to rise and are projected to reach approximately 17 million in 2024, making up over one in five cars sold worldwide. By 2030, nearly one in three cars on the roads in China could be electric, with the United States and the European Union each seeing nearly one in five cars being electric (Agency, 2024). The battery recycling industry needs to get ready for the 2030s. Global battery recycling capacity reached 300 GW-hours in 2023 and is projected to exceed 1500 GW-hours by 2030, of which 70% would be in China (Agency, 2024). The strategic and efficient echelon utilization of retired batteries presents significant economic advantages. Nonetheless, the current echelon utilization system for retired batteries remains nascent, exposing challenges in environmental, social, and governance (ESG) domains. These challenges, coupled with substantial economic stakes and societal pressures, have prompted battery manufacturers (BMs) and electric vehicle manufacturers (EVMs) to enhance and oversee the entire lifecycle of automotive batteries. Addressing these issues necessitates not only ESG enhancements by BMs based on retired battery utilization but also requires EVMs to exercise due diligence (DD) concerning the conduct of upstream suppliers to meet societal demands.

For BMs, numerous ESG challenges within the battery echelon recycling process significantly impede the enhancement of retired battery utilization rates. Environmental concerns arise from inefficiencies in material utilization, particularly regarding vital raw minerals, like cobalt and lithium, resulting in the over-exploitation of related ores (Murdock et al., 2021). Additionally, the inability to effectively recover nickel, cobalt, and manganese from decommissioned batteries results in irreversible environmental damage (Jiang et al., 2021). On the social front, urgent attention is required to address human rights violations, such as unethical mining practices in Congo, the world's largest cobalt producer (Murdock et al., 2021). In terms of governance, BMs are actively implementing measures to establish and enhance health status assessment and management systems throughout the battery's lifecycle (Chen et al., 2022; Lai et al., 2021). They are also employing innovative clustering (Chen et al., 2022) and recombination methods (Chang et al., 2022) to improve the battery echelon utilization's efficiency and safety (Chen et al., 2022).

Collaboration with other companies further strengthens BMs' efforts to enhance battery echelon utilization rates. To construct the world's largest lithium-ion battery energy storage system, Tesla partnered with the South Australian government. British MG Motor's cooperation with India's Exicom Tele-Systems to manufacture energy storage products using decommissioned LIBs from MG electric vehicles. Similarly, BYD's collaboration with Itochu Corporation has led to the establishment of a joint venture for the echelon utilization and energy storage business of lithium-ion batteries. These partnerships contribute to the improvement of retired battery utilization rates. Currently, the significance of ESG factors for societal and corporate development surpasses traditional corporate social responsibility considerations (Cucari et al., 2018). Consequently, BMs are actively addressing ESG challenges in retired battery echelon utilization, aligning with societal expectations and enhancing retired battery utilization rates.

Indeed, BMs may tend to conceal their true ESG situation, as revealing unfavorable information could potentially hinder their ability to attract investment from investors. However, with the introduction of regulations like Germany's Supply Chain Due Diligence Act, manufacturers are mandated to conduct due diligence on suppliers' ESG factors, including those within the battery closed-loop supply chain. This necessitates EVMs to perform due diligence on BMs, given the hidden behavior of suppliers.

Supplier ESG due diligence entails the systematic assessment, management, and reporting of environmental and social issues to upstream suppliers (Cao et al., 2023). EVMs conducting ESG due diligence on BMs not only contribute to the improvement of BMs' ESG performance but also align with public expectations. Moreover, it enhances consumers' purchasing desire by demonstrating a commitment to sustainable and ethical practices throughout the supply chain (Cao et al., 2023). A notable example is Tesla's ESG due diligence on its battery supplier CATL. Prior to the collaboration, Tesla conducted a thorough assessment of CATL's ESG practices. This evaluation encompassed CATL's production processes, including material procurement, energy consumption, and waste disposal, to ensure alignment with Tesla's sustainability objectives. Furthermore, Tesla scrutinized CATL's labor standards and employee welfare policies to ensure adherence to Tesla's social responsibility standards. Additionally, CATL's governance structure and compliance practices, such as financial transparency and board diversity, were evaluated. Through this rigorous ESG due diligence process, Tesla determined that CATL met its sustainability criteria and subsequently designated CATL as one of its primary battery suppliers. The outcome of this assessment not only reinforced consumer confidence in Tesla's commitment to product quality and performance but also underscored its dedication to sustainable supply chain practices and social responsibility. As a result, consumers are increasingly inclined to purchase Tesla products, knowing that the company prioritizes both excellence and sustainability across its operations (Easto, 2017).

Numerous ESG challenges have surfaced in the supervision of power batteries throughout their lifecycle. Due to inadequate oversight, a significant number of retired EV batteries are underutilized, leading to wasted precious metals and increased environmental pollution. The European Union's recent Battery Law (EU, 2023/1542) mandates that BMs strengthen lifecycle management, track battery health and history through "battery passports," and enhance cascade utilization rates. Despite growing regulatory pressures for better ESG practices, few BMs voluntarily disclose their true ESG performance. Some may embellish ESG data to attract investors or conceal issues to protect their reputation. On July 5, 2024, the European Union introduced the Directive on Due Diligence for Sustainable Development of Enterprises, which requires companies to perform due diligence on ESG risks across their supply chains. Failing to meet this requirement can lead to fines of up to 5% of global net turnover. Additionally, consumers are increasingly concerned with the sustainability of the supply chain, as higher levels of "ESG due diligence" (ESG DD) boost consumer trust and purchasing intent. Consequently, EVMs are incentivized to conduct ESG DD on their upstream suppliers to align with market demand and regulatory expectations. Establishing a more responsible, transparent, and sustainable battery recycling system has thus become a critical challenge for all members of the closed-loop supply chain.

To solve ESG issues within the battery recycling closed-loop supply chain, collaboration between BMs and EVMs is imperative. However, existing research has largely overlooked the joint consideration of ESG improvement and DD within closed-loop supply chains, making it a noteworthy contribution of this paper. Despite increasing focus on corporate ESG, little research has explored ESG improvements and due diligence within battery recycling closed-loop supply chains. This study aims to address this gap. Unlike standard reverse supply chains, where second-hand products are often restored to new condition, hazardous waste automotive batteries cannot meet new battery standards through remanufacturing. Instead, they undergo cascade utilization or are processed for raw material recovery. Thus, we structure the battery recycling chain as "recycling – echelon utilization – metal recovery." By introducing ESG improvements and DD to capture shifts in sustainability performance, this study advances sustainable practices beyond the fixed cascade utilization rates assumed in previous research.

Moreover, batteries are not recycled like conventional second-hand products; instead, they undergo a series of steps before being dismantled by BMs to recover precious metals. Therefore, this article centers on the unique nature of used batteries as second-hand products and addresses ESG improvement and due diligence throughout their lifecycle. The premise of this article is that EVMs are responsible for recycling used batteries and will conduct due diligence on BMs' ESG issues to meet societal demands. In the meanwhile, in order to increase the rate at which waste batteries are utilized, BMs address ESG concerns in the overall usage process and assist in the manufacturing and disassembly of recycled batteries. This collaborative approach is essential for achieving sustainable outcomes.

This study extends beyond mere profit maximization for supply chain members; it aims to address ESG issues throughout the battery lifecycle. By strengthening the improvement and due diligence of ESG issues, the goal is to establish a more responsible, transparent, and sustainable battery lifecycle supply chain system. To achieve this objective, the article proposes a supply chain framework that involves BMs determining the level of improvement in ESG issues related to battery echelon utilization, while EVMs are responsible for both recycling and echelon utilization of used batteries, as well as conducting due diligence on BMs' ESG issues to meet societal demands. This paper establishes three closed-loop supply chain models. In the first model, BM and EVM operate independently: BM produces and sells new batteries to EVM, who assembles and sells the vehicles to consumers. In the reverse supply chain, EVM manages the recycling of retired EV batteries through cascade utilization and ultimately returns fully used batteries to BM for metal recovery. In the second model, BM and EVM also make independent decisions but with a focus on ESG improvements. BM introduces technological innovations for ESG compliance to enhance battery sustainability, and EVM performs due diligence on BM's ESG practices, influencing consumer demand. EVM manages recycling as in Model 1, while BM recovers metals from fully utilized batteries for resale. In the third model, BM and EVM make joint, centralized decisions with integrated ESG improvements and due diligence, ensuring responsible battery lifecycle management similar to Model 2.

This study uses the Stackelberg game model to analyze how battery ESG improvements and due diligence affect the equilibrium decisions and profits of BM and EVM. In this game, BM is positioned as the leader in the closed-loop supply chain, given that battery performance directly influences vehicle competitiveness in the technology-driven EV industry (Fan et al., 2021). Accordingly, BM first determines the investment level in ESG improvements, battery wholesale pricing, and the repurchase price of used batteries based on market and policy factors. EVM, as the follower, then sets the electric vehicle sales price, the recycling price for used batteries, and the level of ESG due diligence for battery manufacturers (Tsao and Ai, 2024). The main research questions of this article include:

(1) How do equilibrium decisions and profits change for BMs and EVMs before and after opting for ESG improvements and due diligence?
(2) How will the recycling cost and price sensitivity of old batteries affect the balanced decision-making of supply chain players, especially in terms of ESG improvements and due diligence?
(3) Have any supply chain contracts that allow BMs and EVMs to achieve Pareto improvements and optimize ESG issues throughout the battery life cycle?

In this study, both BM and EVM contribute to improving the battery closed-loop supply chain. BM's investment in ESG improvements not only fulfills extended producer responsibility but also enhances revenues from battery cascading. EVM's ESG due diligence (DD), meanwhile, meets regulatory and social demands and increases consumer purchase intent, boosting the supply chain's overall profitability. Joint decision-making between BM and EVM, such as the collaborations between BYD and FAW Group and between Ford and CATL, aligns with investor interests and strengthens closed-loop operations.

As both BM and EVM are now motivated to invest in improving the EV battery closed-loop supply chain, each party's investment benefits the overall performance of both. However, this also introduces the risk of free-riding, where members might benefit without contributing to costs—undermining fairness and sustainable battery practices. To address this, we propose a two-way cost-sharing contract to foster a more transparent, responsible, and sustainable closed-loop system. The two-way cost-sharing agreement involves multiple supply chain members sharing costs, achieving better optimization and efficiency than one-way contracts by discouraging free-riding and enabling a fairer profit distribution. This flexible approach supports long-term cooperation and joint investments among members, leading to Pareto improvements in the supply chain. Compared to decentralized models, the proposed contract enhances battery recovery rates and overall performance, offering a new pathway to a sustainable and accountable battery closed-loop supply chain.

Our counter-intuitive finding is that, when considering ESG improvements and the DD dispersion model, an increase in consumer sensitivity to recycling prices prompts BM to lower its recycling price, which actually reduces battery recycling—hindering sustainable closed-loop supply chain development. By introducing a two-way cost-sharing contract, both the number of batteries recycled and the recovery rate improve. This contract supports Pareto improvement. Interestingly, EVM prefers BM to share a balanced portion of the costs; if BM bears too much, it may reduce ESG investments, lowering EVM's benefits from repurposing batteries and ultimately impacting profits for both parties.

The rest is organized as follows. Section 2 conducts a literature review. Section 3 introduces the modeling framework and model setup. In Section 4, an equilibrium analysis is performed and a mutual cost-sharing agreement is proposed. Section 5 uses statistical methods to verify the research outcomes. The conclusions, consequences for management, and future research directions are outlined in Section 6.

2. Literature review

To build a more responsible, transparent, and sustainable system for recycling retired power batteries, it is essential to focus on both the BM's ESG improvements in battery echelon utilization and the EVM's due diligence on BM's ESG level. Furthermore, cooperation between BM, EVM, and consumers is crucial. Therefore, we divide it into three sections: ESG improvement on battery echelon utilization, due diligence research, and supply chain coordination research.

2.1. ESG improvement on battery echelon utilization

Governments and financial regulators were first exposed to the idea of ESG in 2004 when the United Nations suggested the global compact "Who Cares Who Wins" (Group, 2004; Li et al., 2024). ESG consists of three dimensions, i.e., environmental, social, and governance. The environmental dimension (E) refers to aspects of a company's environmental footprint and sustainability practices, such as carbon emissions, raw material development and procurement, and waste recycling (Jayachandran et al., 2013). The social dimension (G) refers to supply chain coordination and the impact of corporate behavior on consumers. It is worth noting that profitability is now widely recognized as one of the indicators of corporate social responsibility. The more profitable a company is, the more resources it can have, and the more social responsibility it has (Zeng et al., 2022). The governance dimension (G) refers to the company's compliance with regulatory obligations and the avoidance of bribery, corruption and so on within the organization (Dai and Tang, 2022). Improving the ESG level of enterprises is conducive to the establishment of a more responsible and sustainable closed-loop supply chain system (Shakil, 2021; Whitelock, 2019).

For the closed-loop power battery recycling system, retired batteries are a special second-hand product, and more companies will use them in echelon utilization to maximize their residual value (Shafique et al., 2023). Most articles on the closed-loop power battery recycling system assume that the recycled batteries can be recycled or only partially recycled. For example, Tang et al. (2018) studied different recycling channels and incentives and found that manufacturers and retailers have obvious advantages in joint recycling. Zhao et al. (2024) examined the impact of the external environment on the equilibrium decisions of supply chain members when BM considers the disassembly design, and found that the profitability of both manufacturers and retailers increases when cost-sharing contracts are proposed. Zhang et al. (2022) studied that when considering both channel selection and carbon emission reduction decision, the intensity of competition between channels will affect the optimal channel selection.

Many scholars are aware of the huge profits hidden behind the echelon utilization of retired batteries, and BM has conducted many studies to improve ESG issues in the echelon utilization process to improve the echelon utilization rate (Shafique et al., 2023). To improve the environmental dimension (E), Jiang et al. (2021) found that low utilization of retired batteries and low recycling efficiency contribute to over-mining of related ores. In the social dimension (S), Murdock et al. (2021) think that human rights issues such as unethical mining in the Democratic Republic of the Congo (the world's top cobalt producer) must be addressed immediately. In response to the above problems, BM actively explores solutions in the governance dimension (G), such as Lai et al. (2021) set the health state assessment and management system involving the whole life cycle of batteries has been actively established and improved, with a commitment to testing the entire life cycle of batteries. Chen (2022) expanded the definition of battery state of health and enhanced the battery state of health assessment index, thereby proposing a multiple habitats, multifaceted and multi-physics analysis technique for battery state of health. Chang et al. (2022) evaluated the discharge characteristics of multiple categorys of retired lithium-ion batteries from the perspective of parallel configuration, and obtained a recombination criterion that can increase the utilization rate of old batteries.

The literature reviewed above primarily highlights that BM is enhancing ESG practices in the echelon utilization of retired batteries and increasing utilization efficiency in response to societal demands (Cucari et al., 2018; Li et al., 2024). However, at present, most of the proportion of retired batteries that can be used in echelon is fixed or considered to be fully echelon used. This study applies a dynamic perspective to analyze the impact of BM's ESG improvement on the equilibrium decision-making of members in the closed-loop supply chain. This approach differs from previous studies and provides a new perspective on the field.Fig. 1

2.2. Due diligence

With the issuance of regulations such as the Supply Chain Due Diligence Act in Germany, manufacturers are required to conduct due diligence on the ESG elements of their suppliers (Cao et al., 2023; Okpechi, 2021). In the closed-loop power batteries recycling system, BM will hide some ESG information that is not conducive to obtaining investment from investors, which requires EVM to conduct due diligence on BM's ESG information and disclose relevant information to consumers. To establish a more transparent closed-loop supply chain system, due diligence has become a common behavior of downstream suppliers. For example, Dai and Tang (2022) showed that a company's due diligence behavior has become the most widely accepted standard for measuring corporate sustainability and governance. Chen and Dagestani (2023) showed that countries are promoting transparency in ESG matters and combating greenwashing, requiring downstream manufacturers to conduct ESG due diligence on suppliers. Elbel et al. (2023) showed that the implementation of the EU Corporate Due Diligence Law, context-specific reforms, can stably enhance the conditions under which small-scale and artisanal cobalt workers in the Democratic nation of the Congo labor.

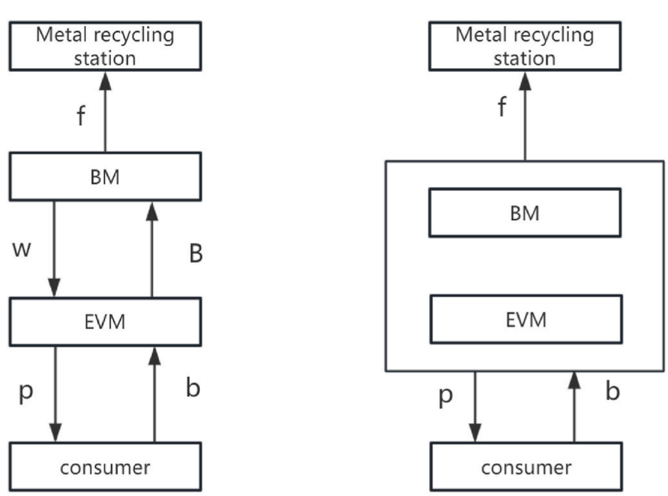

Fig. 1. Decentralized and Centralized decision-making models.

The term "ESG DD" on suppliers describes the methodical evaluation, handling, and disclosure of primary suppliers' environmental and social concerns (Cao et al., 2023; Farnham, 2022). There are costs associated with EVM conducting ESG due diligence on BMs, but at the same time, the disclosure of ESG information is conducive to increasing consumer enthusiasm for purchasing (Schleper et al., 2022). For example, Huang et al. (2022) found that as consumers focus on sustainable supply chains, downstream manufacturers can leverage ESG data disclosures to improve consumer awareness of products. Lee et al. (2022) discovered that customers' purchasing decisions might be influenced by a product's ESG features since they are aware of the supply chain's attempts to detect and mitigate ESG risks (Cao et al., 2023). Cao et al. (2023) showed that there are many unsustainable behaviors hidden in upstream supply chains, and downstream supply chain members undergo ESG due diligence to assess, manage, and report on the ESG practices of upstream suppliers, which can strengthen consumer trust. Fang and Cho (2020) showed that downstream supplier surveys of upstream suppliers will affect consumers' purchase intentions and that retailers are best able to manage their co-supplier environmental and social responsibility under competitive conditions.

All of the above studies show that EVM's ESG due diligence on BM can increase consumers' desire to buy. Given the changing market factors such as the booming EV battery industry and the uncertainty of the ESG level of upstream companies, the optimal level of due diligence on ESG by EVM is still fuzzy. This paper addresses the research gap through a comprehensive analysis of market factors.

2.3. Supply chain coordination

Relevant studies show that vicious competition in the supply chain often harms the interests of each supply chain member, and is not conducive to the establishment of a more responsible, transparent, and sustainable closed-loop supply chain system (Terzi and Cavalieri, 2004). As a result, an increasing number of academics have focused on studying supply chain coordination agreements and have put forth coordination contracts for various decentralized decision-making models that can better serve the interests of each supply chain participant (Xiao et al., 2017).

Current discussions on supply chain contracts mainly focus on two areas: the impact of contractual clauses on supply chain parameters and the relationship between the demand function and these contractual clauses (Wu, 2013; Zhao et al., 2022). Palsule-Desai (2013) found that through contract parameter adjustments in the revenue-sharing mode, the benefits of each member of the supply chain can be improved, and then the supply chain coordination can be realized. Cachon and Lariviere (2005) also conducted a study on revenue-sharing agreements, demonstrating that profit-sharing agreements can reconcile the relationship between the supply chain and individual retailers, and distribute the profits of the supply chain arbitrarily. Mukhopadhyay et al. (2008) considered the contract design problem of eliminating channel conflicts when service cost information is asymmetrical. Chao et al. (2009) researched recovery-related cost-sharing arrangements to support initiatives for quality enhancement. Bai et al. (2016) utilized numerical tests and computational modeling to demonstrate that revenue-sharing plans, contracts with rewards and penalties, and franchise agreements can all lead to supply chain coordination under the linear demand model. Qiu et al. (2022) concentrated on the issue under variable standards, contrasting outcomes agreements and two-part agreements, and demonstrating that supply chain coordination may be accomplished by two-part agreements.

The study of supply chain agreements has been expanded to various industries because of its applicability. Li et al. (2024) applied ESG cost-sharing contracts to the apparel industry and sought a contract model that incentivizes the overall sustainability of the apparel industry in the supply chain. Chang et al. (2022) implemented the revenue sharing agreement to the new supply chain, they discovered that the supply chain's loss rate rose and its profit fell in the presence of complete information. Gao et al. (2020) integrated profit-sharing contracts in medical services and offered managerial suggestions for the hierarchical diagnosis and treatment service model. Heydari et al. (2021) investigated how to accomplish supply chain coordination while enhancing the quality of environmentally friendly products. For the fashion supply chain, Zhao et al. (2020) investigated the application of revenue-sharing and linear quantity discount contracts to address supply chain coordination issues, finding that the latter effectively achieve supply chain coordination within certain limits. In addition, the application of supply chain coordination agreements to the power battery supply chain is also the focus of scholars' attention, Rajaeifar et al. (2022) study showed that more cooperation between BM and EVM will be conducive to the establishment of a more efficient closed-loop supply chain coordination system. Zhao and Ma (2022) found that combining profit-sharing and cost-sharing agreements in a closed-loop supply chain for power battery outsourcing and recycling results in more efficient battery recycling and echelon utilization. As more and more ESG issues are exposed in the closed-loop supply chain of EV batteries, BM and EVM have begun to carry out targeted improvements and due diligence to meet societal needs.

2.4. Research gap

Most existing research focuses on recycling and remanufacturing waste products to create closed-loop supply chains, often assuming that used products can be repaired and transformed to meet the quality of new products (Wang et al., 2019; Wei et al., 2018). However, waste automotive power batteries, as hazardous materials, cannot meet the quality standards of new batteries through remanufacturing alone; they must instead be cascaded or processed to extract raw materials for new batteries. For example, researchers have simulated residential energy distribution to assess the feasibility of using EV batteries for energy storage, finding it cost-effective and beneficial for grid management (Heymans et al., 2014). Xu et al. (2019) demonstrated that most retired power batteries maintain around 77% of their capacity, making them suitable for secondary applications like energy storage. Therefore, we define the power battery recycling value chain as "recycling-cascade utilization-metal recycling."

In prior studies on cascade utilization, some assumptions suggest that all collected cells are suitable for cascade use (Sun et al., 2022; Tang et al., 2018), or that all batteries are directly disassembled for new battery production (Li, 2022), overlooking the distinctions between used batteries and other second-hand products. Other papers recognize the varying quality of retired batteries but fix the proportion of batteries eligible for cascade use (Zhang et al., 2022; Zhao et al., 2024), failing to address the sustainable development of the closed-loop battery supply chain. We introduce ESG improvements and DD to account for changes in sustainable performance, addressing these research gaps. With the introduction of the 'New Battery Law' (EU, 2023/1542) and the German Supply Chain Due Diligence Law, the ESG performance of companies has garnered significant attention from consumers, investors, and regulators. As companies are increasingly required to enhance their ESG standards, downstream ESG DD towards upstream supply chain members is essential for fostering a responsible and transparent supply chain (Cao et al., 2023).

Thus, this paper provides guidance for optimizing decision-making in the closed-loop supply chain and aims to establish a more responsible, transparent, and sustainable battery recycling system. In this context, we make three key contributions to existing research. First, building on Raza (2018), we utilize the ESG performance of BMs to depict sustainable performance in the battery supply chain, thereby addressing shortcomings in the current literature. Second, drawing from Cao et al. (2023), we highlight the role of ESG DD in consumer decision-making; unlike traditional DD, which focuses solely on supplier behavior, ESG DD assesses and manages supplier actions while providing consumers with reliable ESG information about upstream members. This enriches the research on ESG DD within the battery closed-loop supply chain. Finally, inspired by Zhu et al. (2018), we acknowledge that both BMs and electric vehicle manufacturers (EVMs) aim to invest in improving the closed-loop supply chain of EV batteries, suggesting that investments from either party benefit both. To mitigate the risk of free-riding by non-investing parties, we propose a two-way cost-sharing contract. Our study shows that introducing this contract fosters a more responsible, transparent, and sustainable closed-loop battery supply chain system. To clarify how this study differs from previous research, Table 1 highlights the gaps between our work and related studies.

3. The model

In a supply chain comprising BMs and EVMs, the BM assumes the game leader while the EVM is the follower. For the optimal usage of old batteries, the BMs first set the wholesale price of batteries, the

Table 1
A brief literature review.

Author	Disposal of retired batteries			Improve ESG performance	
	Battery recycling	Echelon utilization	The quality of retired batteries	Due diligence	Technological innovation
Tang et al. (2018) Sun et al. (2022)	✓	✓			
Zhang et al. (2022); Zhao et al. (2024)	✓	✓	✓		
Li (2022)	✓				
Chen (2022); Heymans et al. (2014); Lai et al. (2021); Xu et al. (2019)	✓	✓			✓
Li et al. (2024)					✓
Cao et al. (2023); Elbel et al. (2023)				✓	
This paper	✓	✓	✓	✓	✓

repurchase price of used batteries, and the degree of ESG upgrades. EVMs set the prices for selling electric vehicles, the cost of recycling spent batteries, and the extent of ESG due diligence on BMs. In this study, we position the BM as the leader of the closed-loop supply chain, with the EVM as the follower, reflecting real industry practices. For example, in their power battery project, BYD and its EVM partner, China First Automobile Works (FAW), invested 13.5 billion yuan in electric vehicle production, with ownership shares of 51% and 49%, respectively.

3.1. Problem description

In the closed-loop power batteries recycling system, EVMs bear the responsibility of recycling used electric vehicle batteries to comply with extended producer responsibility obligations. BMs produce batteries, improve battery utilization efficiency, and supply them to EVMs for integration into electric vehicle production, subsequently selling them to consumers. This model concentrates on the recycling and echelon use of used batteries by EVMs, as well as the compensation for consumers, without diving into specific consumer behavior (Zhao et al., 2024). Consumer behavior can be divided into two scenarios: battery replacement and electric vehicle replacement. EVMs recycle used batteries and sell them to BMs for processing, which are then further delivered to metal recycling facilities. The power battery recycling value chain discussed in this article follows the sequence of "recycling-echelon utilization-metal recycling" with the remaining capacity serving as the criterion for determining the suitability of used power batteries for echelon utilization.

In particular, after disassembly and reorganization, power batteries with between 60% and 80% of their initial capacity can be used for energy storage, communication base stations, power conditioning, and low-speed electric cars (Zhang et al., 2022). As the remaining capacity declines to between 20% and 60%, the battery can still find utility on the user side or within microgrid systems. These applications fall under the category of echelon utilization, which entails the rational allocation and reuse of resources. However, once the remaining capacity of the power battery falls below 20%, it becomes unsuitable for further use and must be directly scrapped and disassembled to recover internal battery components and refine rare metal materials (Zhang et al., 2022). In this article, batteries that are suitable for recycling are classified as the second category of used batteries, while batteries that undergo dismantling and recycling for metals are categorized as the third category which is called scrap battery as well (Zhao et al., 2024; Zhao and Ma, 2022). To enhance the sustainable development of the closed-loop supply chain, we incorporate ESG improvements and DD to better capture changes in sustainable performance, addressing the gaps present in existing research on sustainable practices.

We present three models: 1) The first one explores decentralized decision-making, where both BMs and EVMs operate independently. Here, the BM does not focus on ESG improvements for battery echelon utilization, and the EVM does not conduct ESG due diligence on BMs. 2) The second one also delves into decentralized decision-making but emphasizes ESG considerations. In this scenario, the BM implements ESG improvements for battery echelon utilization, and the EVM conducts ESG due diligence on the BM. 3) The third one investigates joint decision-making between EVMs and BMs. Here, both parties collaborate to integrate ESG considerations into their decisions. The BM implements ESG improvements for battery echelon utilization, while the EVM conducts ESG due diligence on the BM. Flow charts illustrating both centered and distributed systems are provided below.

Below are the main assumptions:

Assumption 1. Demand is influenced by product prices and manufacturers' sales efforts (Ma et al., 2013). According to Cao et al. (2023), manufacturers conducting DD to assess, manage, and report on the ESG practices of their upstream suppliers can attract more consumers in the end market. This is because EVM's ESG DD behavior reflects their commitment to social responsibility, leading to increased consumers' willingness to buy (Naeeni et al., 2023). Therefore, in the demand function, we take into account that consumers are inclined to buy products that are priced lower and have higher levels of ESG disclosure. Specifically, when the EVMs do not conduct due diligence, the demand function is D, while when they do conduct ESG due diligence, the demand function is d.

The amount of used batteries recycled by EVMs q is related to the recycling price b. It is possible to obtain the demand function by consulting the pertinent literature (Zhao et al., 2024; Zhao and Ma, 2022).

$$D = a - \phi p$$

$$d = a - \phi p + \alpha k$$

$$q = s + \lambda b$$

Assumption 2. The percentage of batteries that can be used in echelons is the sole factor impacted by ESG enhancements made by BMs to battery echelon usage. The cost of ESG improvement in the echelon utilization of new batteries is an improvement investment, and the function is ηe^2 (Li et al., 2024). Among them, e is the ESG improvement level of battery echelon utilization by BMs, and the η is investment cost coefficient of ESG improvement level of battery echelon utilization by BMs.

Assumption 3. ESG due diligence of EVMs on BMs can influence consumer demand. The cost as an improvement investment for an EVM, the cost function is rk^2. Among them, k is the battery manufacturing of EVMs' level of ESG due diligence of a businessman, r is its investment cost coefficient (Cao et al., 2023).

Assumption 4. The market demand for new electric vehicles exceeds the amount of used batteries that EVMs recycle (Zhao et al., 2024).

$$q < d$$

Assumption 5. Examining and disassembling old batteries is less expensive than producing new batteries (Zhao et al., 2024).

$$g < c$$

Assumption 6. Assuming that δ represents the original proportion of used batteries that meets the standard of echelon utilization, and let x denotes the unit income (Zhang et al., 2022; Zhao et al., 2024). As BMs improve ESG issues in the process of battery echelon utilization, the proportion of waste batteries that can be used for echelon utilization has been effectively increased (Chang et al., 2022). Among them, e is the ESG improvement level of BMs for battery echelon utilization, and m is the influencing factor of ESG improvement level on the proportion of batteries that can be used for echelon utilization. And $\delta + me$ has a limited range, so that enables the existence of non-disposable and disposable batteries during the recycling process. For EVMs, the revenue from battery echelon utilization is $(\delta + me)x$ (Zhao et al., 2024; Zhao and Ma, 2022).

$$\delta + me \in (0, 1)$$

The notations are summarized in Table 2.

Table 2
Notations.

Parameter	Definition
d	EVs' demand
q	Used batteries' recycling quantity
a	The minimum demand in the new energy vehicle market
ϕ	Price sensitivity coefficient of new energy vehicle demand
s	Used batteries' basic quantity recycled
λ	Price sensitivity coefficient of recycling prices
w	Unit retail price of new battery
p	Unit retail price of new EV
c	The new battery's unit production cost
G	The unit cost of each battery dismantled by BMs
g	Unit cost of inspecting and disassembling used batteries by EVM
B	Unit recycling price of used batteries by BMs
b	Unit recycling price of batteries by EVM
f	Unit price for the third category of battery
e	Level of ESG improvements
r	Influence factor of ESG due diligence on ESG due diligence costs
k	Level of ESG due diligence on BMs
η	Influence factor of ESG improvements on improvements costs
δ	Used batteries proportion that meets echelon utilization standard
m	Influence factor of improvements on a proportion of used batteries which meets echelon utilization standard by BM ESG improvements
α	Consumers' preference coefficient for ESG
ρ	BMs' cost-sharing factor
θ	EVMs' cost-sharing factor
π_B π_E π	BM profits, EVM profits, the total supply chain profits

3.2. Model formulations

In the first model, decentralized decision-making by BMs and EVMs is considered, with BMs not making ESG improvements to battery echelon utilization and EVMs not conducting ESG due diligence on BMs. The profit function for EVMs and BMs are below:

$$\text{Max } \pi_E = (p-w)d + (B+\delta x - g - b)q \tag{1}$$

$$\text{Max } \pi_B = (w-c)d + (f-G-B)q \tag{2}$$

$$s.t. x > b+g, f > B+G, w > c, p > w$$

In the second model, BMs and EVMs are considered to make decentralized decisions, with BMs making ESG improvements to battery echelon utilization, and EVMs conducting ESG due diligence on BMs.

$$\text{Max } \pi_E = (p-w)d + (B+(\delta+me)x - g - b)q - rk^2 \tag{3}$$

$$\text{Max } \pi_B = (w-c)d + (f-G-B)q - \eta e^2 \tag{4}$$

$$s.t. x > b+g, f > B+G, w > c, p > w$$

The third model involves a collaborative decision-making process between an EVM and a BM, with the BM making ESG improvements to the battery echelon utilization, and the EVM conducting ESG due diligence on the BM.

$$\text{Max } \pi c = (p-c)d + (f+(\delta+me)x - g - G - b)q - rk^2 - \eta e^2 \tag{5}$$

$$s.t. x > b+g, f > B+G$$

4. The equilibrium

4.1. The model without ESG improvements and due diligence

This section analyzes the fragmented decision-making of BMs and EVMs, with BMs not making ESG improvements to battery echelon utilization, and EVMs not conducting ESG due diligence on BMs. By applying backward induction, the expression p^* and b^* can be derived. Subsequently, substitute the obtained expressions into equation (2). Due to the negative definiteness of the Hessian Matrix, it can be concluded that π_B is a concave function relative to w and B. At last, the optimal w^* and B^* can be obtained. The equilibriums are presented in Lemma 1.

Lemma 1. *The equilibriums without ESG improvements and due diligence are*:

$$w^* = \frac{a+c\phi}{2\phi}$$

$$p^* = \frac{1}{4}\left(c + \frac{3a}{\phi}\right)$$

$$d^* = \frac{1}{4}(a - c\phi)$$

$$q^* = \frac{1}{4}(s + (f-g-G+x\delta)\lambda)$$

$$b^* = \frac{-3s + (f-g-G+x\delta)\lambda}{4\lambda}$$

$$B^* = \frac{-s + (f+g-G-x\delta)\lambda}{2\lambda}$$

$$\pi_B{}^* = \frac{1}{8\lambda\phi}\left(a^2\lambda - 2ac\lambda\phi + \phi\left((s+(f-g-G+x\delta)\lambda)^2 + c^2\lambda\phi\right)\right)$$

$$\pi_E{}^* = \frac{1}{16\lambda\phi}\left(a^2\lambda - 2ac\lambda\phi + \phi\left((s+(f-g-G+x\delta)\lambda)^2 + c^2\lambda\phi\right)\right)$$

Propositions 1 and 2 *can be gotten from* Lemma 1.

Proposition 1. *If BMs do not make ESG improvements to battery echelon utilization, and EVMs do not conduct ESG due diligence, the BM's unit reusing price of old batteries raise with the increase of the old batteries price or increase prices sensitivity, i.e.,* $\frac{\partial B^*}{\partial f} = \frac{1}{2} > 0$ *and* $\frac{\partial B^*}{\partial \lambda} = \frac{s}{2\lambda^2} > 0$

Proposition 1 demonstrates that as the batteries increases, prices sensitivity increases, leading to a higher recycling batteries price. Consequently, prompting BMs to elevate the price of battery recycling by raising the third category of used batteries price or enhancing price sensitivity will incentivize EVMs to recycle a greater number of used batteries.

Proposition 2. *If BMs do not make ESG improvements to battery echelon utilization, and EVMs do not conduct ESG due diligence, the used batteries price by EVMs rises with the scrap battery price or the price sensitivity increase,* $\frac{\partial b^*}{\partial f} = \frac{1}{4} > 0$ *and* $\frac{\partial b^*}{\partial \lambda} = \frac{3s}{4\lambda^2} > 0$

Proposition 2 indicates that as the used batteries price in the third category increases, customers are becoming increasingly cost-conscious of recycling, resulting in higher unit prices for waste battery recycling by EVMs. Consequently, prompting BMs to raise battery recycling price by increasing the third category used batteries price or enhancing price sensitivity will encourage consumers to supply a larger quantity of old batteries.

4.2. Decentralized model

Analysis of independent decision-making is done in this section, with BMs making ESG improvements to battery echelon utilization, and EVMs also conducting ESG due diligence on BMs. By employing backward induction, we can obtain p^{**}, b^{**} and k^{**}. Subsequently, substitute it into equation (4). Due to the negative definiteness of the Hessian Matrix, it can be concluded that π_B is a concave function with respect to w, B, and e. At last, the optimal w^*, B^* and e^{**} can be derived. The equilibriums are presented in Lemma 2:

Lemma 2. *The equilibrium with ESG improvements and due diligence are*:

$$w^{**} = \frac{a + c\phi}{2\phi}$$

$$p^{**} = \frac{a\alpha^2 - 6ar\phi + c\alpha^2\phi - 2cr\phi^2}{2\alpha^2\phi - 8r\phi^2}$$

$$d^{**} = \frac{r\phi(a - c\phi)}{-\alpha^2 + 4r\phi}$$

$$q^{**} = -\frac{2\eta(s + (f - g - G + x\delta)\lambda)}{-8\eta + m^2x^2\lambda}$$

$$b^{**} = \frac{2(-f + g + G - x\delta)\eta\lambda + s(6\eta - m^2x^2\lambda)}{\lambda(-8\eta + m^2x^2\lambda)}$$

$$B^{**} = \frac{4s\eta + \lambda(-4(f + g - G - x\delta)\eta + (f - G)m^2x^2\lambda)}{\lambda(-8\eta + m^2x^2\lambda)}$$

$$e^{**} = -\frac{mx(s + (f - g - G + x\delta)\lambda)}{-8\eta + m^2x^2\lambda}$$

$$k^{**} = \frac{\alpha(a - c\phi)}{-2\alpha^2 + 8r\phi}$$

$$\pi_B^{**} = \frac{1}{2\lambda(-8\eta + m^2x^2\lambda)(\alpha^2 - 4r\phi)}\Big(-2s^2\eta(\alpha^2 - 4r\phi) - 4s(f - g - G + x\delta)\eta\lambda(\alpha^2 - 4r\phi) + \lambda\big(-2\alpha^2(-f + g + G - x\delta)^2\eta\lambda + a^2r(8\eta - m^2x^2\lambda) + 8r(-f + g + G - x\delta)^2\eta\lambda\phi + 2acr(-8\eta + m^2x^2\lambda)\phi + c^2r(8\eta - m^2x^2\lambda)\phi^2\big)\Big)$$

$$\pi_E^{**} = \frac{1}{4\lambda(-8\eta + m^2x^2\lambda)^2(\alpha^2 - 4r\phi)}\Big(16s^2\eta^2(\alpha^2 - 4r\phi) + 32s(f - g - G + x\delta)\eta^2\lambda(\alpha^2 - 4r\phi) + \lambda\Big(16\alpha^2(-f + g + G - x\delta)^2\eta^2\lambda - a^2r(-8\eta + m^2x^2\lambda)^2 - 64r(-f + g + G - x\delta)^2\eta^2\lambda\phi + 2acr(-8\eta + m^2x^2\lambda)^2\phi - c^2r(-8\eta + m^2x^2\lambda)^2\phi^2\Big)\Big)$$

By deriving the equilibrium results, Propositions 3–6 can be obtained.

Proposition 3. *When BMs make ESG improvements to battery echelon utilization, and EVMs also conduct ESG due diligence, the level of ESG improvement of BMs increases with the scrap battery prices and price sensitivity increase, i.e.,* $\frac{\partial e^{**}}{\partial f} = \frac{mx\lambda}{8\eta - m^2x^2\lambda} > 0$, $\frac{\partial e^{**}}{\partial \lambda} = \frac{m^3sx^3 + 8mx(f - g - G + x\delta)\eta}{(-8\eta + m^2x^2\lambda)^2} > 0$

Proposition 3 indicates that as the third category of old batteries price increases, and customers start to pay greater attention to recycling price. This, in turn, leads to a higher level of ESG improvement for the BM in terms of echelon use of old batteries. The increase in recycling batteries quantity through the reverse channel, accompanied by the increase in the scrap battery prices and price sensitivity to old batteries cost, results in BMs further improving ESG improvement level of the battery echelon utilization process. The improvement intends to enhance the echelon use of old batteries, which ultimately contributes to improving the BM's profit.

Proposition 4. *When BMs make ESG improvements to battery echelon utilization, and EVMs also conduct ESG due diligence, the ESG due diligence of EVMs on BMs is not related to the scrap battery prices and price sensitivity, but will increase as consumers preference coefficient for ESG increases, i.e.,* $\frac{\partial k^{**}}{\partial \alpha} = \frac{(a - c\phi)(\alpha^2 + 4r\phi)}{2(\alpha^2 - 4r\phi)^2} > 0$

Proposition 4 shows that neither the scrap battery prices nor price sensitivity will have an impact on the level of ESG due diligence of EVMs, and only when the ESG preference coefficient of consumers increases, it will have an impact on the ESG due diligence efforts of EVMs. This is because EVMs will increase their ESG due diligence efforts to cater to consumer demand, as EVMs move closer to consumers, as consumers ESG preferences translate into greater demand.

Proposition 5. *When BMs undertake ESG improvements on battery echelon utilization, and EVMs also conduct ESG due diligence, the recycling price from BM rises as the third category of used batteries price increases. However, it decreases as consumers sensitivity to recycling prices raise. Importantly, the recycling price is not influenced by consumers preference coefficient for ESG. i.e.,* $\frac{\partial B^{**}}{\partial f} = 1 + \frac{4\eta}{-8\eta + m^2x^2\lambda} > 0$, $\frac{\partial B^{**}}{\partial \lambda} = \frac{4\eta\left(8s\eta - 2m^2sx^2\lambda + m^2x^2(-f + g + G - x\delta)\lambda^2\right)}{\lambda^2(-8\eta + m^2x^2\lambda)^2} < 0$

Proposition 5 demonstrates that an increase in the unit price of the third category of used batteries will motivate the BM to increase its battery recycling price. This is because BM aims to recycle more used batteries in response to the higher third category batteries price. However, the increase in price sensitivity coefficient to the recycling price will decrease the recycling price of BM's used batteries. This is because the higher price sensitivity coefficient from Proposition 3 results in an increased ESG improvement level for BM in terms of echelon utilization of used batteries, which in turn raises costs. To maintain profits, BM reduces recycling price of used batteries. However, this action reduces the quantity of batteries being recycled, which is not conducive to forming a sustainable supply chain. Therefore, we propose implementing a two-way cost-sharing agreement later to improve this situation.

Proposition 6. *When BMs make ESG improvements to battery echelon utilization, and EVMs also conduct ESG due diligence, EVM's unit spent battery recycling price increases with the third category used batteries price and price sensitivity increase, i.e.,* $\frac{\partial b^{**}}{\partial f} = -\frac{2\eta}{-8\eta + m^2x^2\lambda} > 0$, $\frac{\partial b^{**}}{\partial \lambda} = \frac{48s\eta^2 - 12m^2sx^2\eta\lambda + m^2x^2\left(m^2sx^2 + 2(f - g - G + x\delta)\eta\right)\lambda^2}{\lambda^2(-8\eta + m^2x^2\lambda)^2} > 0$

Proposition 6 demonstrates that as the third category of used batteries price increases and customers start to pay greater attention to recycling price, recycling price from the EVM also increases. It can be seen from Proposition 3 that the increase in the third category used batteries price will prompt the BM to make ESG improvements to the used batteries, which will increase the echelon use rate of EVM recycled old batteries and increase profit of EVM units to recycle used batteries, so this action will increase the recycling price. Analogously, higher recycling prices encourage the recycling of more batteries in situations where consumers are more price-conscious.

Proposition 7. *Comparing the differences in outcomes between scenarios where the BM undertakes ESG improvements in battery echelon utilization versus no improvement, and where the EVM conducts ESG due diligence versus not, we have* $p^{**} > p^{*}, d^{**} > d^{*}, q^{**} > q^{*}, B^{**} < B^{*}, b^{**} > b^{*}$

Propositions 1, 3, and 5 together reveal that for BM, the increase in the unit price of category 3 used batteries is conducive to increasing the battery recycling price of BM and improving the level of ESG improvement in the echelon utilization of used batteries. At this time, increasing the recycling price can enable BM to recycle more used batteries, which in turn will increase profits. At this time, BM tends to assume more social responsibility and improve the ESG improvement level of the echelon utilization of waste batteries, which is conducive to the establishment of a more responsible and sustainable closed-loop supply chain.

Propositions 2, 4, and 6 together reveal that higher unit prices of category third used batteries and consumers sensitivity to recycling prices are conducive to higher unit recycling prices from EVMs. From Proposition 7, we conclude that when BMs make ESG improvements to battery echelon utilization, and EVMs also conduct ESG due diligence, the total amount of used batteries recycled will be higher. This means that EVMs should be encouraged to conduct ESG due diligence on BMs, and that the more sensitive consumers are to ESG preferences, the higher the EVM's due diligence efforts will be. However, the cost of ESG due diligence for BM is shifted to the price of EVM's recycled batteries, so the two-way cost-sharing contract we proposed later is conducive to effective cooperation between BM and EVM to jointly build a more transparent closed loop power batteries recycling system.

Proposition 8. *Comparing the differences in outcomes between scenarios where the BM undertakes ESG improvements in battery echelon utilization versus no improvement, and where the EVM conducts ESG due diligence versus not, we find that BMs and EVMs tend to conduct ESG improvement and due diligence under certain conditions, and if* $0 < r < \alpha^2 \left(\frac{a^2(-8\eta + m^2x^2\lambda) + 16ac\eta\phi + m^2x^2\left(-2ac\lambda + (s + (f - g - G + x\delta)\lambda)^2\right)\phi + c^2\left(-8\eta + m^2x^2\lambda\right)\phi^2}{4m^2x^2(s+(f-g-G+x\delta)\lambda)^2\phi^2} \right)$ *and* $0 < \eta < \frac{m^2x^2\left(a^2\alpha^2\lambda + \alpha^2\left(-2ac\lambda + (s + (f - g - G + x\delta)\lambda)^2\right)\phi + \left(c^2\alpha^2\lambda - 4r(s+(f-g-G+x\delta)\lambda)^2\right)\phi^2\right)}{8\alpha^2(a-c\phi)^2}$*, then* $\pi_B^{**} > \pi_B^{*}$ *and* $\pi_E^{**} > \pi_E^{*}$.

Proposition 8 shows that both BMs and EVMs tend to proceed when the cost factor for ESG improvement and due diligence is within a certain range. This indicates that ESG improvement and DD enhance the sustainability of the battery closed-loop supply chain while boosting the profits of its members. However, excessive investment costs can impede both the enhancement efforts of supply chain members and their willingness to engage in DD. Therefore, when fostering a more responsible, transparent, and sustainable battery recycling system, it is crucial to consider the investment costs borne by supply chain members. Externally, society can provide greater support to help enterprises in their transformation efforts. Internally, supply chain members can achieve cost-sharing through closer collaboration.

4.3. Centralized model

We explored the centralized decision-making model for BMs to make ESG improvements to battery echelon utilization, and for electric car manufacturers to conduct ESG due diligence, and analyzes the equilibrium results. It can be concluded that π is a concave function with respect to p, b, k, and e. Eventually, the optimal value is obtained as p^{***}, b^{***}, k^{***} and e^{***}, as presented below.

Lemma 3. *The equilibriums under the centralized model when BM conducts ESG improvements and EVM conducts ESG due diligence are*:

$$p^{***} = \frac{c\alpha^2 - 2r(a + c\phi)}{\alpha^2 - 4r\phi}$$

$$d^{***} = \frac{2r\phi(a - c\phi)}{-\alpha^2 + 4r\phi}$$

$$q^{***} = -\frac{2\eta(s + (f - g - G + x\delta)\lambda)}{-4\eta + m^2x^2\lambda}$$

$$b^{***} = \frac{2(-f + g + G - x\delta)\eta\lambda + s(2\eta - m^2x^2\lambda)}{\lambda(-4\eta + m^2x^2\lambda)}$$

$$e^{***} = -\frac{mx(s + (f - g - G + x\delta)\lambda)}{-4\eta + m^2x^2\lambda}$$

$$k^{***} = -\frac{\alpha(a - c\phi)}{\alpha^2 - 4r\phi}$$

$$\pi^{***} = \left(-s^2\eta(\alpha^2 - 4r\phi) - 2s(f - g - G + x\delta)\eta\lambda(\alpha^2 - 4r\phi) + \lambda\left(-\alpha^2(-f + g + G - x\delta)^2\eta\lambda + a^2r(4\eta - m^2x^2\lambda) + 4r(-f + g + G - x\delta)^2\eta\lambda\phi + 2acr(-4\eta + m^2x^2\lambda)\phi + c^2r(4\eta - m^2x^2\lambda)\phi^2\right)\right) / \left(\lambda(-4\eta + m^2x^2\lambda)(\alpha^2 - 4r\phi)\right)$$

From Lemma 2 and 3, we get Proposition 9.

Proposition 9. *When BMs implement ESG improvements in battery echelon consumption, and EVMs conduct ESG due diligence, it can be concluded that*: $\pi^{***} > \pi_B^{**} + \pi_E^{**}$, $d^{***} > d^{**}$, $q^{***} > q^{**}$, $b^{***} > b^{**}$, $k^{***} > k^{**}$, $e^{***} > e^{**}$.

Proposition 9 demonstrates that in a scenario where the BM enhances ESG improvements in the battery echelon utilization rate, and EVM also carries out ESG due diligence. The centralized system has a higher price for recycling spent batteries. Thus, in the centralized system, the total amount of old batteries recycled exceeds that in the decentralized system. Furthermore, centrally managed decision-making approach exhibits an increased level of ESG enhancement and due diligence, hence augmenting the demand for new batteries and enhancing the supply chain's profitability. This demonstrates how improving supply chain coordination helps to create a win-win scenario for all involved and work together to create a closed-loop supply chain that is more accountable and transparent.

Based on the above conclusions, joint decision-making by BMs and EVMs promotes both the recycling of waste batteries and the resolution of ESG challenges. To create a sustainable electric vehicle system and build a more accountable and transparent closed-loop supply chain, BMs and EVMs should strengthen their collaboration. In the following section, we propose a contract to address this need.

4.4. A cost-sharing contract

Comparing the third model to the second model in this paper reveals that the pricing decisions and profit levels of the node enterprises in the closed-loop supply chain are optimized under the centralized model, maximizing overall benefits. In contrast, under the decentralized decision-making model, each node enterprise aims to maximize its own profits. This misalignment of goals can lead to double marginality and channel conflicts within the closed-loop supply chain. In this section, where responsibilities and costs are shared between the parties involved (Zhao et al., 2024). Inside the contract, BM shares the cost of the EVM's ESG due diligence ρ $(0<\rho<1)$ and EVM shares the cost of the BM's ESG improvement of the battery echelon utilization θ (0 < θ < 1) (Zhu et al., 2018).

$$\text{Max } \pi_{\text{ES}} = (p-w)d + (B + (\delta + me)x - g - (1-\rho)b)q - rk^2 - \theta\eta e^2 \tag{3}$$

$$\text{Max } \pi_{\text{BS}} = (w-c)d + (f - G - B)q - (1-\theta)\eta e^2 - \rho b q \tag{4}$$

$$\pi_B^{****} = \left(2s^2\eta(-1+\theta)(\alpha^2-4r\phi) + 4s(f-g-G+x\delta)\eta(-1+\theta)\lambda(\alpha^2-4r\phi) - \lambda\left(-2\alpha^2(-f+g+G-x\delta)^2\eta(-1+\theta)\lambda + a^2r(m^2x^2\lambda - 4\eta(-1+\theta)(-2+\rho)) + 8r(-f+g+G-x\delta)^2\eta(-1+\theta)\lambda\phi - 2acr(m^2x^2\lambda - 4\eta(-1+\theta)(-2+\rho))\phi + c^2r(m^2x^2\lambda - 4\eta(-1+\theta)(-2+\rho))\phi^2\right)\right) / \left(2\lambda(m^2x^2\lambda - 4\eta(-1+\theta)(-2+\rho))(\alpha^2-4r\phi)\right)$$

$s.t. x > b + g, f > B + G, w > c, p > w$

Theorem 1. *the equilibriums consider cost-sharing contract are determined as follows*:

$$w^{****} = \frac{a + c\phi}{2\phi}$$

$$p^{****} = \frac{a\alpha^2 - 6ar\phi + c\alpha^2\phi - 2cr\phi^2}{2\alpha^2\phi - 8r\phi^2}$$

$$d^{****} = \frac{r\phi(a - c\phi)}{-\alpha^2 + 4r\phi}$$

$$q^{****} = \frac{2\eta(-1+\theta)(s + (f-g-G+x\delta)\lambda)}{m^2x^2\lambda - 4\eta(-1+\theta)(-2+\rho)}$$

$$b^{****} = \frac{-m^2sx^2\lambda + 2(f-g-G+x\delta)\eta(-1+\theta)\lambda + 2s\eta(-1+\theta)(-3+2\rho)}{\lambda(m^2x^2\lambda - 4\eta(-1+\theta)(-2+\rho))}$$

$$B^{****} = f - G - \frac{4\eta(-1+\theta)(s + (f-g-G+x\delta)\lambda)}{\lambda(m^2x^2\lambda - 4\eta(-1+\theta)(-2+\rho))} + \frac{s\rho}{\lambda}$$

$$e^{****} = -\frac{mx(s + (f-g-G+x\delta)\lambda)}{m^2x^2\lambda - 4\eta(-1+\theta)(-2+\rho)}$$

$$k^{****} = \frac{\alpha(a - c\phi)}{-2\alpha^2 + 8r\phi}$$

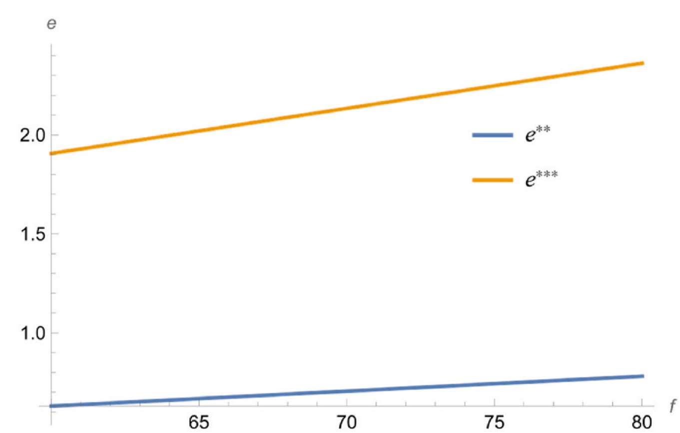

Fig. 3. The impact of f on the level of ESG improvement.

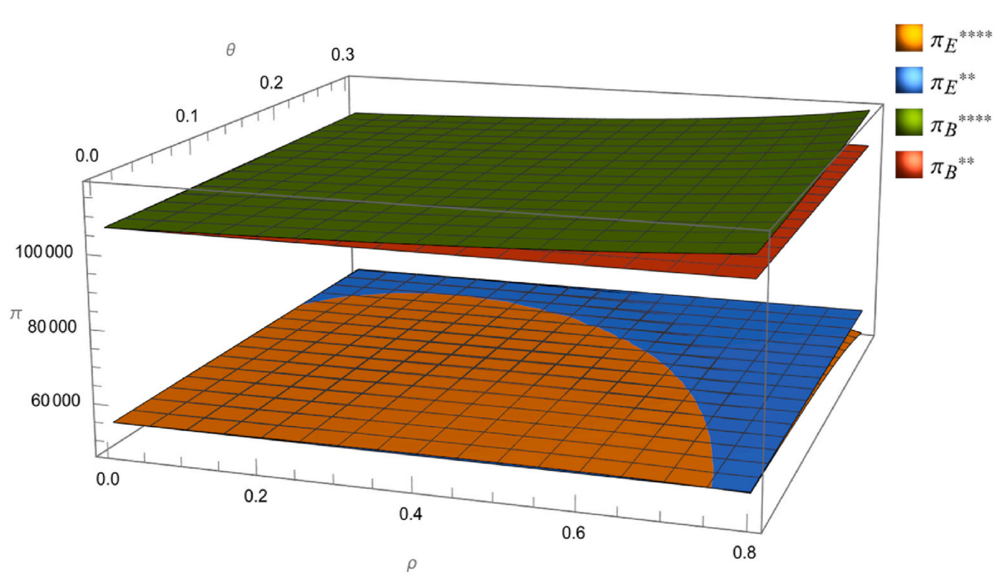

Fig. 2. Supply chain implementation Pareto improvement scope.

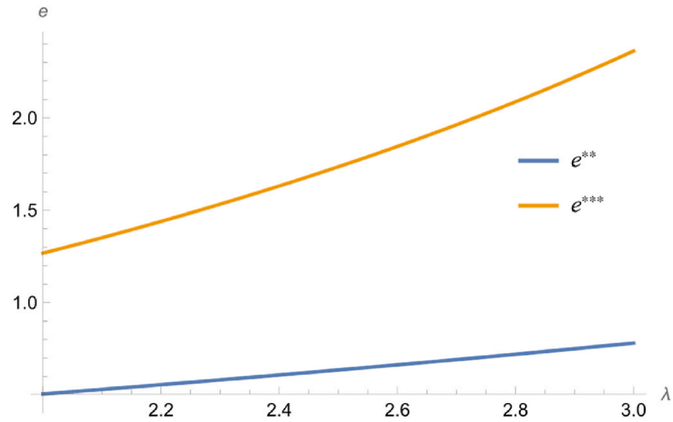

Fig. 4. The impact of λ on the level of ESG improvement.

$$\pi_E{}^{****} = -\frac{\eta(s+(f-g-G+x\delta)\lambda)^2(m^2x^2\theta\lambda+4\eta(-1+\theta)^2(-1+\rho))}{\lambda(m^2x^2\lambda-4\eta(-1+\theta)(-2+\rho))^2} - \frac{r(a-c\phi)^2}{4(\alpha^2-4r\phi)}$$

By comparing the equilibriums with and without the contract, Proposition 10-11 are obtained.

Proposition 10. *The comparison can be illustrated by examining the equilibrium decision with and without a cost-sharing agreement, we have*: $q^{****} > q^{**}, e^{****} > e^{**}, b^{****} > b^{**}$.

Proposition 10 indicates that BM will enhance ESG advancements pertaining to battery echelon use when sharing costs agreements are implemented. This is due to the fact that the EVM amortizes the cost of ESG improvement for the BM, thereby incentivizing the BM's improvement behavior. Simultaneously, BM contributes to the cost of recyclable used batteries for EVM, allowing EVM to recycle more old batteries overall and at a higher recycling price on the market. It can be observed that the cost-sharing contract not only enhances the recycled used batteries number but also improves the echelon utilization rate of the recycled used batteries.

Proposition 11. *Pareto improvements are achieved by the two-way cost-sharing, when*

$0 < \rho < \frac{15}{128}\left(m^2\lambda(16-15m^2\lambda)+\frac{\sqrt{m^4\lambda^2(16-15m^2\lambda)^2(10+(11+30\delta)\lambda)^4}}{(10+(11+30\delta)\lambda)^2}\right)$ *an* $0 < \theta < \Big(\sqrt{15}\sqrt{\big(m^2\lambda(16-15m^2\lambda)^2(10+(11+30\delta)\lambda)^4(3375m^6\lambda^3 + 480m^2\lambda(16-15m^2\lambda)\rho-2048\rho^2\big)} - (10+(11+30\delta)\lambda)^2\big(3375m^6\lambda^3 + 5760m^2\lambda\rho - 1024\rho^2 - 3600m^4\lambda^2(1+\rho)\big)\Big)/\big(16(10+(11+30\delta)\lambda)^2(-480m^2\lambda(-1+\rho)+225m^4\lambda^2(-1+\rho)+64\rho^2\big)$, *we have* $\pi_B{}^{****} > \pi_B{}^{**}$ *and* $\pi_E{}^{****} > \pi_E{}^{**}$.

Proposition 11 and Fig. 2 show that when the above conditions are met, both BM and EVM profits will increase, and bi-directional cost-sharing agreements can help supply chains accomplish Pareto improvements.

5. Numerical study

The following initial parameter settings were established for this article: $a = 1000, s = 50, \delta = 0.2, x = 150, g = 20, G = 5, \phi = 1, c = 100, \eta = 3000, r = 200, \lambda = 3, m = 0.3$ and $\alpha = 1.1$ (Zhao et al., 2024).

There are three main parts. First of all, the effect on equilibrium decisions scrap battery prices and price sensitivity coefficient are explored. The effect of the third-category batteries unit recycling price and customer response to the recycling price on the supply chains overall profit under two styles of centralized and decentralized system are examined in Section 5.2. Last but not least, this paper focuses on how cost-sharing agreements affect the closed loop supply chain.

5.1. The exogenous variables

The impact of exogenous variables on BM equilibrium decisions is analyzed.

Figs. 3 and 4 show an interesting trend: when the unit recycling cost of the third category of used batteries rises and customer response to recycling pricing rises, BM tends to raise the level of ESG improvements in the tiered usage of batteries. In real-world situations, if BM notices an increase in the cost per unit of recycling used third-category batteries and increased consumer awareness of recycling costs, they are inclined to intensify ESG improvements. This strategic response aims to augment the proportion of used batteries utilized in echelon applications, thereby incentivizing EVMs to recycle more used batteries.

Furthermore, we find that under the central decision-making model for battery echelon use, the ESG improvement level of BM continuously outperforms that of the distributed decision-making model. This indicates that strengthened cooperation between BM and EVM leads to higher levels of ESG improvements. Not only does this foster the collection of more used batteries, but by enhancing ESG practices throughout the echelon utilization process, it also boosts the overall utilization rate of used batteries. Consequently, this collaborative approach contributes significantly to the establishment of a sustainable closed-loop supply chain.

Fig. 5 illustrates that for BMs that enhance their ESG practices, an

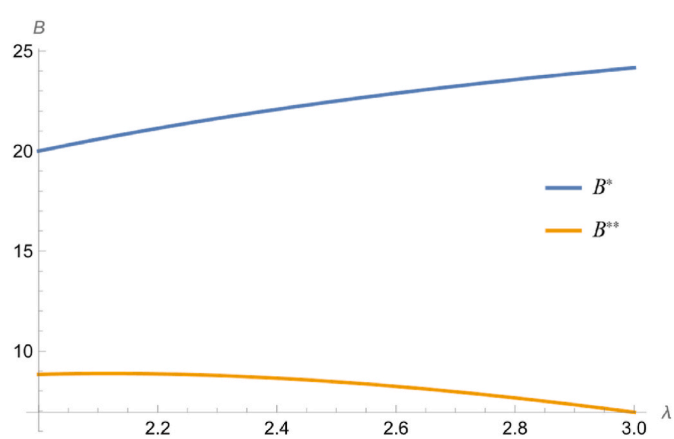

Fig. 5. The effect of λ on BM recycling price.

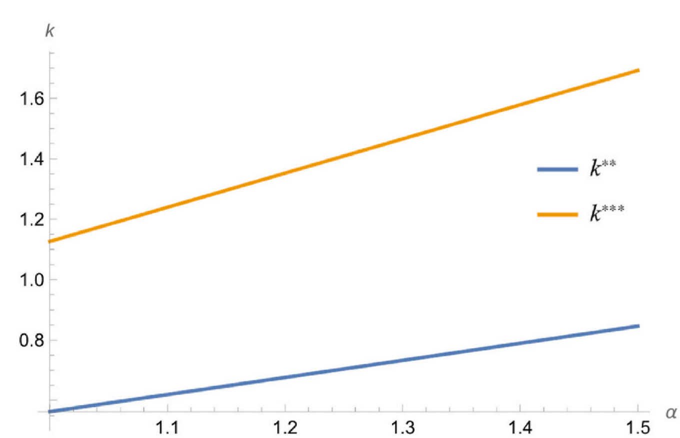

Fig. 6. The effect of α on the EVM ESG due diligence level.

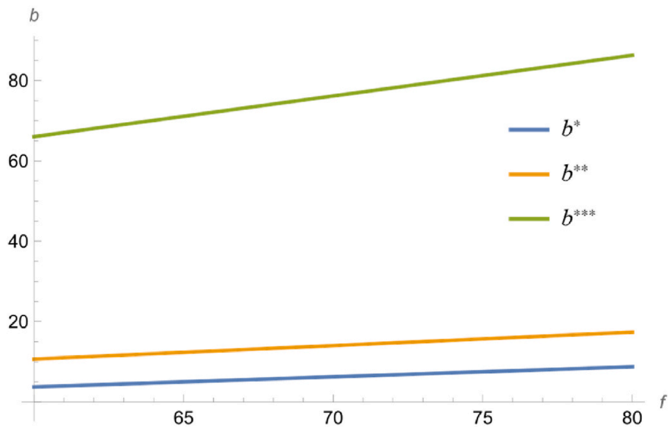

Fig. 7. The effect of f on the EVM ESG due diligence level.

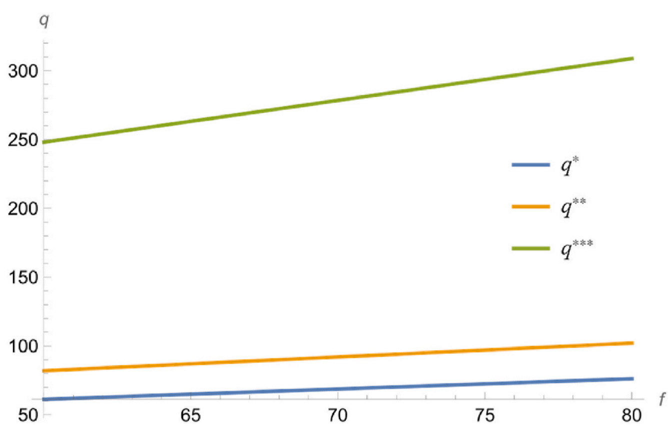

Fig. 8. The effect of f on recycling number of used batteries.

increase in consumer sensitivity to recycling prices leads them to lower the transfer payment price for recycling used batteries. In practical scenarios, when BMs do not prioritize improving ESG issues in battery echelon utilization, when observed increase in the scrap battery prices and heightened price sensitivity should prompt BM to enhance the transfer free price for recycling used batteries. This strategic adjustment is expected to bolster the quantity of recycled batteries by BM and enhance profitability. Conversely, when BM actively addresses ESG issues in battery echelon utilization, encountering an upsurge in the

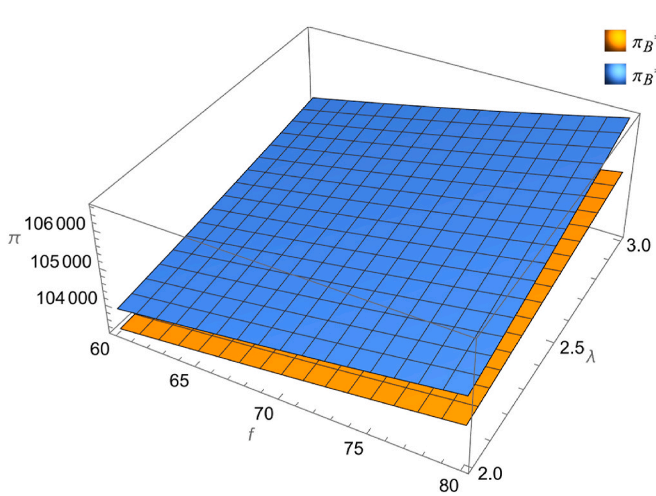

Fig. 9. The effect of exogenous variables on BM's profit.

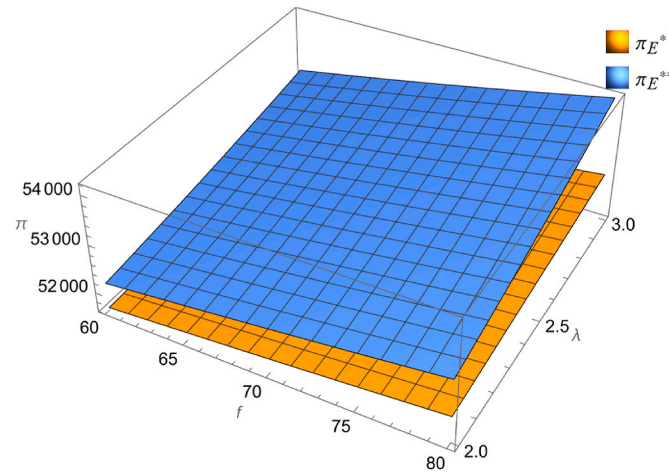

Fig. 10. The effect of exogenous variables on EVM's profit.

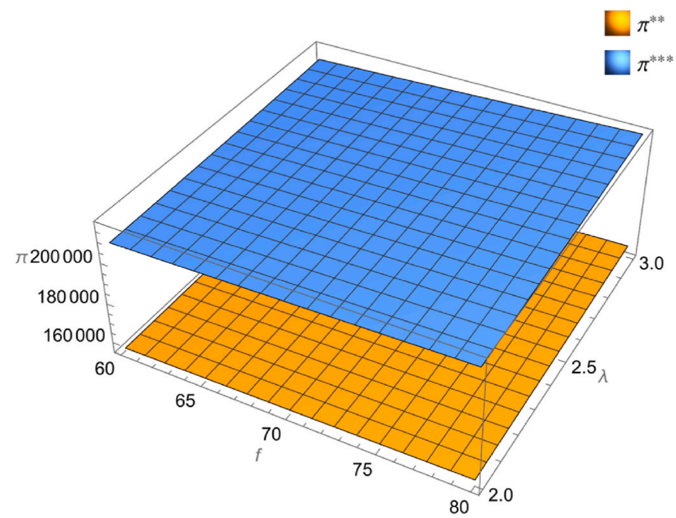

Fig. 11. The effect of exogenous variables on supply chain profit.

recycling price of used battery units should prompt a similar response as when ESG improvements are not considered. Furthermore, when price sensitivity rises, BM should adjust their strategy by lowering the used batteries price to maximize profits.

We next delve into the analysis of how exogenous variables influence the equilibrium system of EVMs.

Fig. 6 illustrates that when corporate ESG standards significantly influence consumer purchasing behavior, the level of EVM's ESG due diligence consistently surpasses that of the decentralized model when employing centralized models involving both BMs and EVMs. This observation underscores the beneficial impact of collaboration between BM and EVM in fostering EVM's assumption of social responsibility and alignment with consumer preferences.

Fig. 7 demonstrates that EVMs adjust the scrap battery prices upwards to facilitate increased recycling as scrap battery prices rise. Notably, across all three models, the recycling price set by the centralized model EVM, which incorporates considerations of ESG improvements and due diligence, is the highest, while the recycling price set by the decentralized model EVM, which does not consider ESG improvements and due diligence, is the lowest.

Fig. 8 suggests that a centralized supply chain that incorporates ESG improvements and due diligence demonstrates an enhanced capacity to recycle more used batteries as the third category of used batteries price increase. Conversely, a decentralized supply chain that lacks

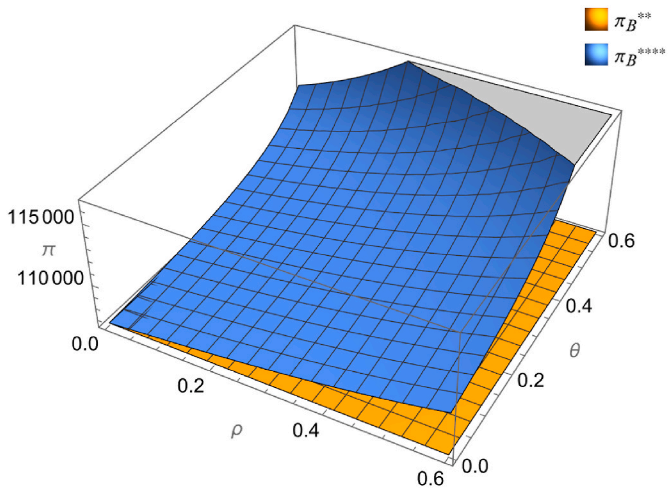

Fig. 12. The effect of the contract on BM's profit.

consideration of ESG improvements and due diligence exhibits minimal recycling capacity, posing challenges to environmental sustainability.

Therefore, bolstering ESG improvement and due diligence efforts not only contributes to the establishment of a transparent and information-sharing closed-loop supply chain but also fosters the development of a more sustainable closed-loop supply chain. The conclusions are summarized in Observation 1.

Observation 1.

1) In response to increases in the third category of used battery price units and heightened price sensitivity, BMs are inclined to elevate the level of ESG improvements in battery echelon utilization. However, for BM actively engaged in ESG improvements, heightened price sensitivity tends to result in lower transfer payment prices for used batteries.
2) In the face of increases in scrap battery prices and heightened price sensitivity, EVMs adjust the recycling price of old batteries upwards. Moreover, EVM also enhances the level of ESG due diligence to align with consumer preferences as consumers increasingly prioritize corporate ESG standards.
3) An raise in the volume of old batteries is facilitated by reinforcing improvements and due diligence on ESG issues within the supply chain.

5.2. *Profit analysis*

Initially, we assess the impact of ESG improvements by BMs in battery echelon utilization and ESG due diligence conducted by EVMs under decentralized conditions on their respective profits.

The implementation of ESG improvements by BM in battery echelon utilization and EVM's ESG due diligence on BM consistently outperforms the absence of such initiatives, when the price sensitivity and scrap battery prices increase, as illustrated by Figs. 9 and 10. Notably, ESG improvements and due diligence yield substantial profitability gains.

Next, we compare the profits of centralized and decentralized model supply chains when BMs implement ESG improvements and EVMs conduct ESG due diligence.

Fig. 11 illustrates that the profits of the centralized supply chain consistently surpass those of the decentralized model, irrespective of fluctuations in the recycling unit price of category-third batteries and consumer sensitivity. This superiority arises from the centralized supply chain's enhanced transparency of information between BM and EVM, as well as the shared costs associated with recycling and utilizing used batteries. Consequently, the centralized model enhances the recycling and utilization rates of used batteries, thus maximizing supply chain profitability.

Therefore, fostering collaboration among supply chain members can effectively address ESG issues in the closed-loop supply chain, fostering transparency and sustainability. The two-way cost sharing model proposed later is specifically designed to achieve this objective.

5.3. *The cost-sharing contract*

The cost sharing coefficient effect on BM and EVM profits is shown in

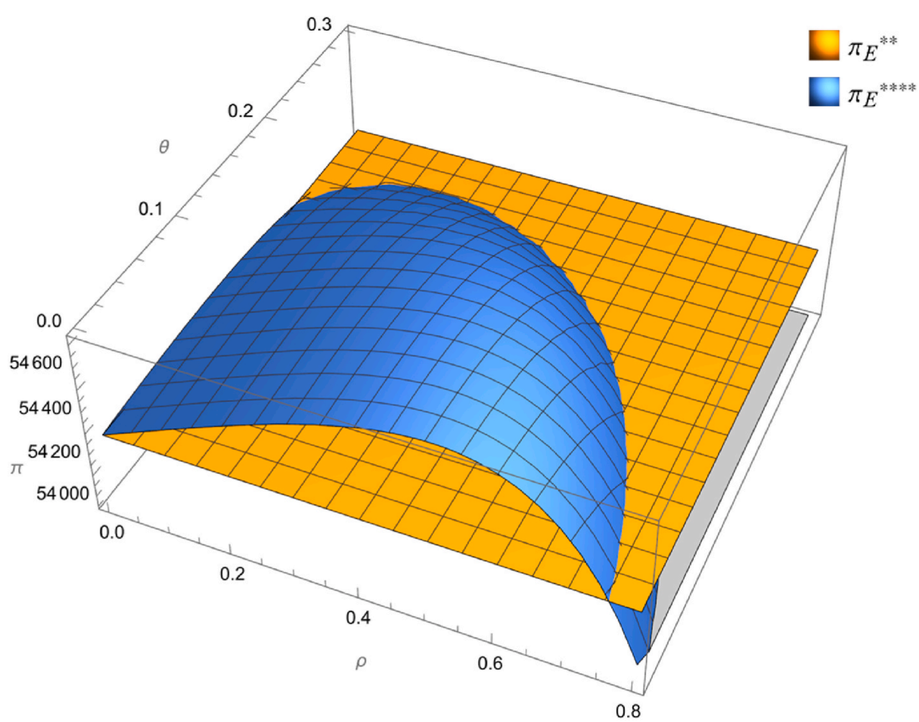

Fig. 13. The effect of the contract on EVM's profit.

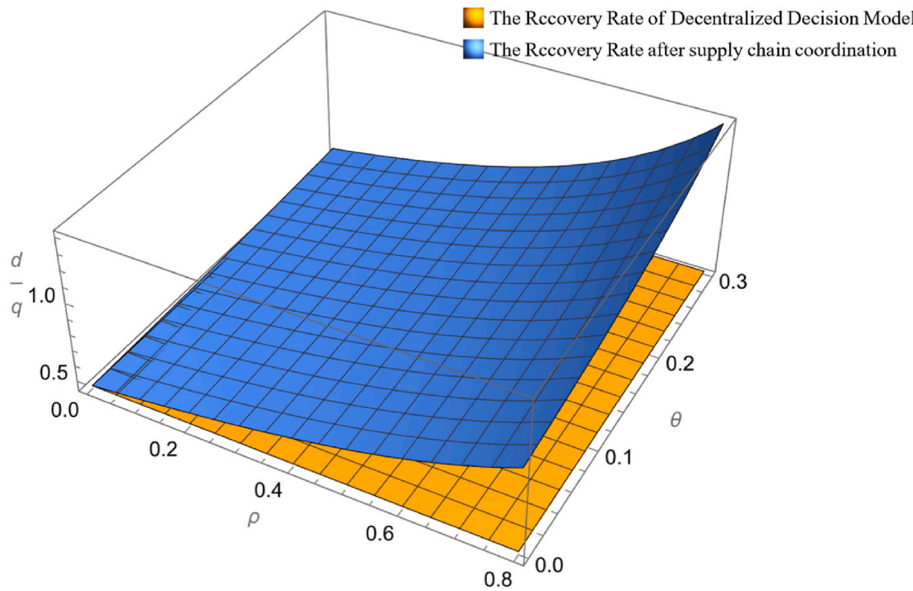

Fig. 14. The recycling rate under the contract.

Figs. 12 and 13. In fact, for BM, increasing the cost sharing coefficients θ and ρ will always be beneficial to increasing its profits. This is because, on the one hand, as θ increases, EVM shares more ESG improvement costs for BM, directly increasing BM's profits. On the other hand, as ρ increases, BM shares the cost of recycling used batteries for EVM, increasing the amount of used batteries recycled, which is beneficial to BM's later dismantling and recycling of metals, and indirectly increases BM's profits.

For EVM, when θ is kept at a small value, its profits can be increased. This shows that helping BM share an appropriate amount of ESG improvement costs can not only increase its profits from the echelon utilization of recycled batteries but also help promote BM's ESG improvements. However, we unexpectedly noticed that when the value of ρ is too large, it is not conducive to the improvement of EVM profits. This is because, when BM shares an appropriate amount of the cost of recycling used batteries with EVM, it will help increase the profits of both parties. However, when the apportionment coefficient ρ increases to a certain level, BM will reduce ESG improvements to protect profits, which is not conducive to the increase in profits of both parties. Therefore, EVM prefers to only let BM share an appropriate amount of waste battery recycling costs.

As we can see in Fig. 14, the closed-loop supply chain recycling efficiency will be effectively increased by the increases in ρ and θ when the two-way cost-share contract is implemented. Thus, it is possible to draw the conclusion that a closed-loop supply network managed by a two-way sharing of costs model can contribute to the creation of a more responsible, transparent, and long-lasting closed-loop supply chain system in addition to helping the supply chain achieve Pareto improvement.

Observation 2.

1) If the coefficients (ρ and θ) are not too large, the profits of both BM and EVM will be improved.
2) The two-way cost-sharing contracts increase the recycling rate.

However, the two-way cost-sharing coefficient is not large. On the one hand, it can increase the profits of BM and EVM at the same time and encourage them to cooperate. On the other hand, it can improve the recycling rate of waste batteries in the closed-loop supply chain. It illustrates that the application of two-way cost-sharing contracts not only helps improve the ESG issues of closed-loop supply chains but also constructs a more responsible, transparent, and sustainable closed-loop supply chain.

6. Conclusions

A closed-loop supply chain model that includes BMs, EVMs, consumers, and valuable metal recycling facilities is presented in this paper. Utilizing the Stackelberg game model, led by BMs, it investigates the equilibrium decision-making under centralized and decentralized systems, focusing on BM's ESG improvements in battery echelon utilization and EVMs' ESG due diligence.

The innovation of this study lies in integrating ESG improvement and due diligence into the closed-loop supply chain of electric vehicle waste battery recycling. The proposed methodology increases the recycling and use rates of used batteries while increasing the revenues of BM and EVM. It also suggests a two-way cost-sharing agreement to improve coordination. Ultimately, it facilitates the establishment of a more responsible, transparent, and sustainable waste battery recycling framework.

6.1. Concluding remarks

Below are the key research findings:

The recycling price of old batteries fluctuates in reaction to variations in the recycling value of the scrap battery prices and price sensitivity in circumstances where BMs and EVMs do not solve ESG issues in used battery consumption. Notably, when BM and EVM do not undertake ESG improvements and due diligence, the recycling price of old batteries tends to be higher, whereas it decreases when these initiatives are implemented by either part.

Upon implementation of ESG improvements by BM and ESG due diligence by EVM, the level of ESG improvement by BM increases with price sensitivity and the recycling price of the third category of used batteries. Similarly, EVM's ESG due diligence level on BM rises with increasing consumer preference for ESG. Moreover, under the centralized model, the levels of ESG improvement and due diligence consistently surpass those under the decentralized model. Furthermore, EVM's recycling price for used batteries escalates in tandem with the third-category used batteries recycling price and price sensitivity, whereas BM's recycling price for used batteries rises in tandem with the third-category used batteries recycling price nonetheless falls as customers sensitivity to recycling prices increases.

The implementation of ESG improvements and due diligence results in higher profits for both BM and EVM compared to scenarios without such initiatives. This is attributed to the enhanced utilization and recycling rates of used batteries, which align with market demand.

Higher profits for supply chain members are revealed in the centralized model, as comparisons between centralized and decentralized models indicate. Additionally, the levels of ESG improvement and due diligence by BM and EVM are consistently higher under the centralized model compared to the decentralized model. Moreover, greater used battery collection is exhibited by the centralized model.

The two-way cost sharing model proves beneficial in enhancing the profits of supply chain members and increasing the recycling rate of old batteries. Notably, when apportionment coefficient is moderate, it yields optimal improvements in supply chain member profits.

6.2. Managerial suggestions

The study findings presented in this paper offer both practical and theoretical insights for BM and EVM, fostering commercial success while addressing social concerns.

For BMs like CATL, enhancing ESG practices in the echelon utilization of used batteries can boost profitability in EVM's recycling units, incentivizing increased battery recycling and the development of a more sustainable closed-loop supply chain. BM should align ESG improvements with fluctuations in the third category of used batteries price, adjusting their level of improvement accordingly as price sensitivity evolves.

To meet consumer demands, EVM, responsible for recycling and reusing old batteries, should conduct ESG due diligence on BM. Ensuring a consistent supply of used batteries for recycling can be achieved by adjusting the recycling price in response to changes in consumer sensitivity and the third category of used batteries price. Likewise, EVM should conduct ESG due diligence on BM.

When BM and EVM embrace a two-way cost-sharing agreement, recycling supply chain could accomplish Pareto improvements. However, EVM tends not to burden BM with excessive costs, as the investment made by BM in ESG improvements benefits EVM by increasing profits from recycling used. Excessive cost-sharing could hinder BM's ongoing ESG efforts, harming the profits of both parties and impeding the establishment of a responsible, transparent, and sustainable closed-loop supply chain.

With ESG ranking high on business agendas and consumer priorities, fostering the electric vehicle waste battery recycling industry requires concerted efforts. Encouraging BM to enhance ESG practices, EVM to conduct due diligence, and facilitating practical contractual arrangements can drive this initiative forward. Moreover, BM and EVM may be encouraged to emphasize advancements in this area by raising the cost of recycling the third category of used batteries and boosting consumer preferences for ESG.

6.3. Future research directions

The following areas can be explored in future research: 1) Dynamic Coordination Mechanism: Market environments, supply, and demand are dynamic, and a coordination mechanism on a non-stable market environment is worth studying. 2) Government Subsidies: Researchers in the future can examine how the government can encourage the growth of used battery recycling and echelon usage. 3) Various Recycling Channel Options: Future research should explore the involvement of battery makers and third-party recyclers, as this paper assumes EVMs are accountable for recycling spent batteries.

CRediT authorship contribution statement

Senlin Zhao: Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Yue Han:** Writing – original draft, Data curation. **Qin Zhou:** Writing – review & editing, Supervision. **Xiqiang Xia:** Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors sincerely thank the Guest Editor, the Handling Co-Editor-in-Chief, and the three reviewers for their constructive and insightful comments during the review process, which have significantly enhanced the quality of this paper. This work is supported by the National Natural Science Foundation of China (Grant number: 72472142, 72072111, and 72472096).

Data availability

No data was used for the research described in the article.

References

Agency, I.E., 2024. Global ev outlook 2024. https://www.iea.org/events/global-ev-outlook-2024.

Bai, Q.G., Xu, X.H., Xu, J.T., Wang, D., 2016. Coordinating a supply chain for deteriorating items with multi-factor-dependent demand over a finite planning horizon. Appl. Math. Model. 40 (21–22), 9342–9361.

Cachon, G.P., Lariviere, M.A., 2005. Supply chain coordination with revenue-sharing contracts: strengths and limitations. Manag. Sci. 51 (1), 30–44.

Cao, Y., Li, Q., Shen, B., Wang, Y., 2023. Buyer collaboration in managing supplier responsibility with esg due diligence effort spillover and fairness concerns. Transport. Res. E Logist. Transport. Rev. 180, 103333.

Chang, L., Ma, C., Zhang, Y.L., Li, H.Y., Xiao, L.J., 2022. Experimental assessment of the discharge characteristics of multi-type retired lithium-ion batteries in parallel for echelon utilization. J. Energy Storage 55, 12.

Chao, G.H., Iravani, S.M.R., Savaskan, R.C., 2009. Quality improvement incentives and product recall cost sharing contracts. Manag. Sci. 55 (7), 1122–1138.

Chen, 2022. An efficient regrouping method of retired lithium-ion iron phosphate batteries based on incremental capacity curve feature extraction for echelon utilization. J. Energy Storage 56, 105917.

Chen, Deng, Y., Li, H., Liu, W., 2022. An efficient regrouping method of retired lithium-ion iron phosphate batteries based on incremental capacity curve feature extraction for echelon utilization. J. Energy Storage 56, 105917.

Chen, P.Y., Dagestani, A., 2023. Greenwashing behavior and firm value - from the perspective of board characteristics. Corp. Soc. Responsib. Environ. Manag. 30 (5), 2330–2343.

Cucari, N., De Falco, S.E., Orlando, B., 2018. Diversity of board of directors and environmental social governance: evidence from Italian listed companies. Corp. Soc. Responsib. Environ. Manag. 25 (3), 250–266.

Dai, T.L., Tang, C., 2022. Frontiers in service science: integrating esg measures and supply chain management: research opportunities in the postpandemic era. Serv. Sci. 14 (1), 1–12.

Easto, J., 2017. Rocket Man: Elon Musk in His Own Words. Agate Publishing.

Elbel, J., Bose O'Reilly, S., Hrzic, R., 2023. A European Union corporate due diligence act for whom? Considerations about the impact of a European Union due diligence act on artisanal and small-scale cobalt miners in the democratic republic of Congo. Resour. Pol. 81, 103241.

Fan, Z.-P., Huang, S., Wang, X., 2021. The vertical cooperation and pricing strategies of electric vehicle supply chain under brand competition. Comput. Ind. Eng. 152, 106968.

Fang, X., Cho, S.-H., 2020. Cooperative approaches to managing social responsibility in a market with externalities. M&Som-Manuf.Serv.Op 22 (6), 1215–1233.

Farnham, K., 2022. Esg due diligence: why it matters for your organization. https://www.diligent.com/resources/blog/due-diligence.

Gao, X.Q., Wen, J.P., Song, J., 2020. Capacity allocation and revenue sharing in healthcare alliances. Flex. Serv. Manuf. J. 32 (4), 829–851.

Group, W.B., 2004. Who cares wins : connecting financial markets to a changing world. http://documents.worldbank.org/curated/en/280911488968799581/Who-cares-wins-connecting-financial-markets-to-a-changing-world.

Heydari, J., Govindan, K., Basiri, Z., 2021. Balancing price and green quality in presence of consumer environmental awareness: a green supply chain coordination approach. Int. J. Prod. Res. 59 (7), 1957–1975.

Heymans, C., Walker, S.B., Young, S.B., Fowler, M., 2014. Economic analysis of second use electric vehicle batteries for residential energy storage and load-levelling. Energy Pol. 71, 22–30.

Huang, L., Song, J.S., Swinney, R., 2022. Managing social responsibility in multitier supply chains. M&Som-Manuf.Serv.Op 24 (6), 2843–2862.

Jayachandran, S., Kalaignanam, K., Eilert, M., 2013. Product and environmental social performance: varying effect on firm performance. Strat. mgmt. j. 34 (10), 1255–1264.
Jiang, S., Zhang, L., Hua, H., Liu, X., Wu, H., Yuan, Z., 2021. Assessment of end-of-life electric vehicle batteries in China: future scenarios and economic benefits. Waste Manage. (Tucson, Ariz.) 135, 70–78.
Lai, X., Huang, Y., Gu, H., Deng, C., Han, X., Feng, X., Zheng, Y., 2021. Turning waste into wealth: a systematic review on echelon utilization and material recycling of retired lithium-ion batteries. Energy Storage Mater. 40, 96–123.
Lee, M.T., Raschke, R.L., Krishen, A.S., 2022. Signaling green! Firm esg signals in an interconnected environment that promote brand valuation. J. Bus. Res. 138, 1–11.
Li, L., Liu, X., Hu, M., 2024. Textile and apparel supply chain coordination under esg related cost-sharing contract based on stochastic demand. J. Clean. Prod. 437, 140491.
Li, X., 2022. Collection mode choice of spent electric vehicle batteries: considering collection competition and third-party economies of scale. Sci. Rep. 12 (1).
Ma, P., Wang, H., Shang, J., 2013. Supply chain channel strategies with quality and marketing effort-dependent demand. Int. J. Prod. Econ. 144 (2), 572–581.
Mukhopadhyay, S.K., Zhu, X.W., Yue, X.H., 2008. Optimal contract design for mixed channels under information asymmetry. Prod. Oper. Manag. 17 (6), VIII. VIII.
Murdock, B.E., Toghill, K.E., Tapia-Ruiz, N., 2021. A perspective on the sustainability of cathode materials used in lithium-ion batteries. Adv. Energy Mater. 11 (39), 2102028.
Naeeni, H.S., Sahin, F., Robinson, E.P.R., 2023. Socially responsible product-positioning: impact of halo/horns spillover on product image. Eur. J. Oper. Res. 308 (2), 852–863.
Okpechi, D.A., 2021. Coming soon: the German supply chain due diligence act. https://www2.deloitte.com/ch/en/pages/operations/articles/coming-soon-the-german-supply-chain-due-diligence-act.html.
Palsule-Desai, O.D., 2013. Supply chain coordination using revenue-dependent revenue sharing contracts. Omega-Int.J.Manage.S 41 (4), 780–796.
Programme, U.E., 2023. Broken Record Temperatures Hit New Highs, yet World Fails to Cut Emissions (Again), pp. 4–30.
Qiu, R.Z., Yu, Y., Sun, M.H., 2022. Supply chain coordination by contracts considering dynamic reference quality effect under the o2o environment. Comput. Ind. Eng. 163.
Rajaeifar, M.A., Ghadimi, P., Raugei, M., Wu, Y.F., Heidrich, O., 2022. Challenges and recent developments in supply and value chains of electric vehicle batteries: a sustainability perspective. Resour.Conserv.Recy 180.
Raza, S.A., 2018. Supply chain coordination under a revenue-sharing contract with corporate social responsibility and partial demand information. Int. J. Prod. Econ. 205, 1–14.
Schleper, M.C., Blome, C., Stevenson, M., Thürer, M., Tusell, I., 2022. When it's the slaves that pay: in search of a fair due diligence cost distribution in conflict mineral supply chains. Transport. Res. E Logist. Transport. Rev. 164, 102801.
Shafique, M., Ateeq, M., Rafiq, M., Azam, A., Luo, X., 2023. Prospects of recycling from end-of-life of li-ion batteries on alleviating materials demand-supply gap in new electric vehicles in asia. Waste Manage. (Tucson, Ariz.) 171, 207–217.
Shakil, M.H., 2021. Environmental, social and governance performance and financial risk: moderating role of esg controversies and board gender diversity. Resour. Pol. 72.
Sun, Q., Chen, H., Long, R., Li, Q., Huang, H., 2022. Comparative evaluation for recycling waste power batteries with different collection modes based on stackelberg game. J. Environ. Manag. 312, 114892.
Tang, Y.Y., Zhang, Q., Li, Y.M., Wang, G., Li, Y., 2018. Recycling mechanisms and policy suggestions for spent electric vehicles' power battery -a case of beijing. J. Clean. Prod. 186, 388–406.
Terzi, S., Cavalieri, S., 2004. Simulation in the supply chain context: a survey. Comput. Ind. 53 (1), 3–16.
Tsao, Y.-C., Ai, H.T.T., 2024. Remanufacturing electric vehicle battery supply chain under government subsidies and carbon trading: optimal pricing and return policy. Appl. Energy 375, 124063.
Wang, L., Wang, X., Yang, W., 2020. Optimal design of electric vehicle battery recycling network – from the perspective of electric vehicle manufacturers. Appl. Energy 275, 115328.
Wang, N., He, Q., Jiang, B., 2019. Hybrid closed-loop supply chains with competition in recycling and product markets. Int. J. Prod. Econ. 217, 246–258.
Wei, J., Wang, Y., Zhao, J., 2018. Interaction between greening and remanufacturing strategies in a manufacturer-retailer supply chain. J. Clean. Prod. 189, 585–601.
Whitelock, V.G., 2019. Multidimensional environmental social governance sustainability framework: integration, using a purchasing, operations, and supply chain management context. Sustain. Dev. 27 (5), 923–931.
Wu, D.Y., 2013. The impact of repeated interactions on supply chain contracts: a laboratory study. Int. J. Prod. Econ. 142 (1), 3–15.
Xiao, F., Dong, M., Han, G.H., 2017. Coordinating a trust-embedded two-tier supply chain by options with multiple transaction periods. Int. J. Plant Prod. 55 (7), 2068–2082.
Xu, X., Mi, J., Fan, M., Yang, K., Wang, H., Liu, J., Yan, H., 2019. Study on the performance evaluation and echelon utilization of retired lifepo4 power battery for smart grid. J. Clean. Prod. 213, 1080–1086.
Zeng, H.L., Li, R.Y.M., Zeng, L.Y., 2022. Evaluating green supply chain performance based on esg and financial indicators. Front. Environ. Sci. 10.
Zhang, C., Tian, Y.-X., Han, M.-H., 2022. Recycling mode selection and carbon emission reduction decisions for a multi-channel closed-loop supply chain of electric vehicle power battery under cap-and-trade policy. J. Clean. Prod. 375, 134060.
Zhao, S., Liu, H., Zhou, Q., Xia, X., 2024. How the external environment affects the equilibrium decisions and profits of battery and ev manufacturers? J. Clean. Prod. 434, 139838.
Zhao, S., Ma, C., 2022. Research on the coordination of the power battery echelon utilization supply chain considering recycling outsourcing. J. Clean. Prod. 358, 131922.
Zhao, S.L., You, Z.Z., Zhu, Q.H., 2022. Effects of asymmetric cost information on collection outsourcing of used products for remanufacturing. Transport. Res. E Logist. Transport. Rev. 162.
Zhao, T.Y., Xu, X.P., Chen, Y., Liang, L., Yu, Y.G., Wang, K., 2020. Coordination of a fashion supply chain with demand disruptions. Transport. Res. E Logist. Transport. Rev. 134.
Zhu, Q., Li, X., Zhao, S., 2018. Cost-sharing models for green product production and marketing in a food supply chain. Ind.Manage.Data.Syst 118 (4), 654–682.