NEV Battery GU and Recycling

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Recycling and gradient utilization (GU) of new energy vehicle (NEV) power batteries plays a significant role in promoting the sustainable development of the economy. GU is an effective means to extend the life cycle of NEV batteries and recognize their value fully. GU refers to the retesting, screening, repairing, pairing, and reuse of power batteries that have been retired from NEV (their performance is reduced to less than 80% of initial performance) under relatively mild conditions. Batteries after GU can be disassembled, and they can be recycled (typically when the remaining capacity is less than 30%) to recover cobalt, lithium, and other precious metals to achieve the “win-win” of resource recovery and environmental protection.

Keywords: NEV battery recycling ; gradient utilization ; alliance cooperation mode

1. Environmental and Economic Benefits of NEV Power Battery Recycling and Utilization

NEV power batteries contain a large number of toxic substances that, if not properly handled, will cause serious harm to the ecological environment and human health [1][2][3]. Battery recycling involves primarily physical disassembly, dry and wet recovery, biological recovery, and other technologies to recover precious metals and degrade harmful substances in batteries [4][5][6]. However, there is an urgent need for more efficient recycling and treatment processes to improve the environment and the economic viability of recycling [7].

Some scholars proposed that although the recycling and reuse of NEV power batteries have significantly promoted environmental benefits, the economic benefits must be verified [8]. For example, Gu et al. analyzed the economic benefits of power battery recycling and reuse by establishing the pricing and decision-making model of a closed-loop supply chain. They demonstrated that battery recycling can reduce the consumption of new battery raw materials and reduce environmental impact, but it may not gain economic benefits [9]. Hao Han et al. compared the energy consumption and greenhouse gas (GHG) emissions of the production of electric vehicles with and without recycling according to the predicted data of China’s NEV recycling volume in 2025. The results revealed that recycling some materials, such as steel, aluminum, and battery cathode materials, could effectively reduce pollution emissions and have economic benefits [10].

Although the assessment of the lifecycle emissions of Lithium-Ion Batteries (LIB) manufacturing is complex, it is generally recognized that at least 30–50% of lifecycle GHG emissions from EVs are related to battery manufacturing and mineral extraction [11]. Raw materials account for up to 50% of the cost of a typical LIB. By substituting virgin materials with recycled materials, the total pack cost could be reduced by up to 30% [12]. It is an effective means to obtain economic benefits to prolong the life cycle of the used power battery of NEV and to make further reuse of non-violent scenes [13].

Studies have found that battery GU has certain commercial and environmental benefits and also social value. Moreover, battery cost, government subsidies, and electricity prices are three critical factors that affect the GU value of China’s NEV battery [14]. The development of essential technologies, such as battery screening and performance evaluation, and the further enrichment of application scenarios of GU, are the main factors of environmental and economic benefits [15].

2. Strategy Optimization of NEV Power Battery Recycling and Utilization

Effectively designing the layout strategy and pricing strategy of NEV power battery recycling sites and the means of utilization after recycling are essential to achieving efficient battery recycling and utilization [16][17]. From the perspective of NEV manufacturers, Lei et al. proposed the optimal design scheme of NEV waste power battery recycling sites and found that transportation cost, carbon tax, and the number of batteries to be recycled are the three major factors affecting the layout of recycling sites [18]. Tang et al. studied the optimal channel selection and battery capacity allocation strategy of EV manufacturers for battery recycling and explored the influence of critical parameters on the equilibrium capacity allocation strategy and the manufacturer's profit through numerical experiments [19]. Hong et al. built a manufacturer-led closed-loop supply chain battery recycling game model, compared the profit and loss of manufacturer recycling, retailer recycling, and third-party enterprise recycling, and found that the retailer recycling method is the optimal economic benefit strategy [20]. Cheng et al. proposed an optimization scheme of battery GU strategy from the perspective of the value chain and discussed the application of battery capacities in different GU scenarios, which is an important basis for gradient pricing [21]. In addition to the further development of critical technologies such as sorting and testing, GU of NEV power batteries should introduce cutting-edge information technology and other means, such as establishing a battery life cycle information storage chain with a consensus mechanism. Such an approach is effective for improving data security and economy, reducing transaction costs and testing costs, and increasing the residual value of batteries [22].

3. The Impact of Policies on the Recycling and Utilization of NEV Power Batteries

The enthusiasm among most enterprises for power battery recycling is related to supervision, subsidies, and other incentive measures, and the intensity of government rewards and punishments affects the choice of cooperative partners of manufacturers [23][24]. Wang et al. considered the impact of battery recycling with and without mandatory policies, finding that manufacturers and OEMs were unable to develop a unified plan for battery recycling with the effects of non-mandatory policies [25]. Based on game theory, Shao et al. found that exogenous and endogenous government subsidy policies differ significantly in their influence on the battery recycling strategies of EV manufacturers—environmental awareness by consumers is essential [26]. Gu et al. studied the optimal production decision of NEV manufacturers for government-subsidized battery recycling, revealing that for a small market, manufacturers may prefer a relatively small battery recovery rate. Moreover, battery recycling can offset the adverse effects of loss aversion on the optimal output and expected utility, with a positive impact on the output of NEV manufacturers [27]. Alexandre et al. studied the opportunities and challenges of EV battery recycling and proposed that it is necessary for the government to introduce research and development funds and establish pilot projects and some market-pull measures [28]. Jiang et al. studied the influence of government subsidies on the independent R&D and technology introduction strategy of NEV enterprises, demonstrating the positive effects of subsidy intensity and the success rate of the R&D and innovation environment on the independent R&D strategies of NEV enterprises [29].

According to existing studies, the recycling and utilization of NEV power batteries can extend the battery life cycle, weaken the negative externalities of the environment, and effectively alleviate the pressure on China's energy and environmental protection, which has significant social importance. However, there are still some problems with industrial development, such as core technology breakthroughs and refining and improving the policy system. Furthermore, retired batteries have not yet reached scale, leading to unclear economic benefits in the industry.

Most scholars focus on the optimization strategy of NEV power battery recycling, such as supply chain pricing and profit maximization. They also study how to effectively recycle power batteries from the perspective of NEV manufacturers and battery manufacturers based on the EPR system and how to regulate and subsidize to improve the recovery rate and recovery efficiency from the perspective of the government. The battery recycling subjects and the GU subjects have not been included in a research model, and the competition and cooperation relationship between these two strategies has not been discussed. Moreover, the vital role of the GU subjects in regulating the recycling channel, battery traceability, and secondary recycling of echelon products have not been fully considered.

In October 2020, China issued the New Energy Vehicle Power Battery Gradient Utilization Management Measures (draft), which encourages upstream and downstream enterprises to build cooperative ecological systems to build battery-recycling sites and GUEs to actively adopt business strategies, such as leasing batteries, large-scale utilization, and others to facilitate subsequent recycling [30]. The GUEs should also be included in the battery-recycling channel and undertake the extended responsibility of the producer of power battery recycling and the secondary recycling responsibility of the echelon products.

Therefore, under the guidance of relevant management policies in China, this paper focuses on power battery recycling and GU industry and constructs a game model of competition and cooperation between NEV enterprises and GUEs. Evolutionary game theory is used to explore the Pareto equilibrium for maximizing the benefits of these agents, and a stable cooperation mode of "win-win" was sought for the alliance of power battery recycling and GU. The results are expected to promote the rapid and sustainable development of the NEV power battery recycle and GU industry and also offer references for China's NEV industrial management policies.

References

1. Liu, S.; Gong, D. Modeling and simulation on recycling of electric vehicle batteries—Using agent approach. Int. J. Simul. Model 2014, 13, 79–92.
2. Thiel, C.; Perujo, A.; Mercier, A. Cost and CO2 aspects of future vehicle options in Europe under new energy policy scenarios. Energy Policy 2010, 38, 7142–7151.
3. Kang, D.H.P.; Chen, M.; Ogunseitan, O.A. Potential environmental and human health impacts of rechargeable lithium batteries in electronic waste. Environ. Sci. Technol. 2013, 47, 5495–5503.
4. Zhang, W.; Yang, J.; Wu, X.; Hu, Y.; Yu, W.; Wang, J.; Dong, J.; Li, M.; Liang, S.; Hu, J.; et al. A critical review on secondary lead recycling technology and its prospect. Renew. Sustain. Energy Rev. 2016, 61, 108–122.
5. Hung, Y.; Yin, L.; Wang, J.; Wang, C.; Tsai, C.; Kuo, Y. Recycling of spent nickel-cadmium battery using a thermal separation process. Environ. Prog. Sustain. Energy 2018, 37, 645–654.
6. Lee, J.; Kim, T.; Sung, M.; Vu, H.; Shin, K.N.; Ahn, J.W. An Integrative Approach to International Technology Transfer for Recycling Vietnam Coal Ash with Consideration of the Technological, Legal, and Network Perspectives. Sustainability 2020, 12, 771.
7. Harper, G.; Sommerville, R.; Kendrick, E.; Driscoll, L.; Anderson, P. Recycling lithium-ion batteries from electric vehicles. Nature 2019, 575, 75–86.
8. Miedema, J.H.; Moll, H.C. Lithium availability in the EU27 for battery-driven vehicles: The impact of recycling and substitution on the confrontation between supply and demand until2050. Resour. Policy 2013, 38, 204–211.
9. Gu, X.; Ieromonachou, P.; Zhou, L.; Tseng, M.L. Developing pricing strategy to optimise total profits in an electric vehicle battery closed loop supply chain. J. Clean. Prod. 2018, 203, 376–385.
10. Hao, H.; Qiao, Q.; Liu, Z.; Zhao, F. Impact of recycling on energy consumption and greenhouse gas emissions from electric vehicle production: The China 2025 case. Resour. Conserv. Recycl. 2017, 122, 114–125.
11. Ellingsen, L.A.; Hung, C.; Strømman, A.H. Identifying Key Assumptions and Differences in Life Cycle Assessment Studies of Lithium-Ion Traction Batteries with Focus on Greenhouse Gas Emissions. Transp. Res. Part D Transp. Environ. 2017, 55, 82–90.
12. Mayyas, A.; Steward, D.; Mann, M. The case for recycling: Overview and challenges in the material supply chain for automotive li-ion batteries. Sustain. Mater. Technol. 2019, 19, e00087.
13. Steward, D.; Mayyas, A.; Mann, M. Economics and Challenges of Li-Ion Battery Recycling from End-of-Life Vehicles. Proc. Manuf. 2019, 33, 272–279.
14. Zhang, L.; Liu, Y.; Pang, B.; Sun, B.; Kokko, A. Second Use Value of China's New Energy Vehicle Battery: A View Based on Multi-Scenario Simulation. Sustainability 2020, 12, 341.
15. Li, J.; Wang, Y.; Tan, X. Research on the Classification Method for the Secondary Uses of Retired Lithium-ion Traction Batteries. Energy Procedia 2017, 105, 2843–2849.
16. Zhang, Q. The Current Status on the Recycling of Lead-acid Batteries in China. Int. J. Electrochem. Sci. 2013, 8, 6457–6466.
17. Jung, M.; Wooyoung, J. The Impact of Electric Vehicle Demand and Battery Recycling on Price Dynamics of Lithium-Ion Battery Cathode Materials: A Vector Error Correction Model (VECM) Analysis. Sustainability 2018, 10, 2870.
18. Wang, L.; Wang, X.; Yang, W. Optimal design of electric vehicle battery recycling network—From the perspective of electric vehicle manufacturers. Appl. Energy 2020, 275, 115328.
19. Tang, Y.; Zhang, Q.; Li, Y.; Wang, G.; Li, Y. Recycling mechanisms and policy suggestions for spent electric vehicles' power battery—A case of beijing. J. Clean. Prod. 2018, 186, 388–406.
20. Hong, X.; Xu, L.; Du, P.; Wang, W. Joint advertising, pricing and collection decisions in a closed–loop supply chain. Int. J. Prod. Econ. 2015, 167, 12–22.
21. Cheng, D.; Zhou, J.; Li, J.; Du, C.; Zhang, H. Analysis in Power Battery Gradient Utilization of Electric Vehicle. Adv. Mater. Res. 2012, 347–353, 555–559.
22. Sun, B.; Su, X.; Wang, D.; Zhang, L.; Liu, Y.; Yang, Y.; Jiang, J. Economic analysis of lithium-ion batteries recycled from electric vehicles for secondary use in power load peak shaving in China. J. Clean. Prod. 2020, 276, 123327.
23. Zhang, S.; Zhang, M.; Yu, X.; Ren, H. What keeps chinese from recycling: Accessibility of recycling facilities and the behavior. Resour. Conserv. Recycl. 2016, 109, 176–186.

24. Chen, S.; Lian, Z.; Li, S.; Junbeum, K.; Li, Y.; Cao, L.; Liu, Z. The Environmental Burdens of Lead-Acid Batteries in China: Insights from an Integrated Material Flow Analysis and Life Cycle Assessment of Lead. Energies 2017, 10, 1969.
25. Wang, W.; Wu, Y. An overview of recycling and treatment of spent LiFePO4 batteries in China. Resour. Conserv. Recycl. 2017, 127, 233–243.
26. Shao, Y.; Deng, X.; Qing, Q.; Wang, Y. Optimal Battery Recycling Strategy for Electric Vehicle under Government Subsidy in China. Sustainability 2018, 10, 4855.
27. Gu, H.; Liu, Z.; Qing, Q. Optimal electric vehicle production strategy under subsidy and battery recycling. Energy Policy 2017, 109, 579–589.
28. Beaudet, A.; Larouche, F.; Amouzegar, K.; Bouchard, P.; Zaghib, K. Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials. Sustainability 2020, 12, 5837.
29. Jiang, C.; Zhang, Y.; Li, W.; Wu, C. Evolutionary Game Study between Government Subsidy and R&D Activities of New Energy Vehicle Enterprises. Oper. Res. Manag. Sci. 2020, 29, 22–28. (In Chinese)
30. To Solicit Public Opinions on the New Energy Vehicle Power Battery Gradient Utilization Management Measures (draft). Available online: (accessed on 15 December 2020).