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Review article

Sustainability of new energy vehicles from a battery recycling perspective: A bibliometric analysis

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ABSTRACT

In recent years, new energy vehicles (NEVs) have taken the world by storm. A large number of NEV batteries have been scrapped, and research on NEV battery recycling is important for promoting the sustainable development of NEVs. Battery recycling is an important aspect of the sustainable development of NEVs. In this study, we conducted an in-depth analysis of the current status of research on NEV battery recycling from a new perspective using bibliometric methods and visualization software. This study shows that research targeting the recycling of NEV batteries is growing rapidly, and collaborative networks exist among researchers from different countries, institutions, and fields. The focus of research has shifted from lead-acid batteries to lithium batteries, and the supply chain and circular economy related to NEV battery recycling is an emerging research hotspot. Based on our analysis, we propose that the government should establish policies to improve the recycling networks at the collection stage and provide subsidies to attract consumers. Enterprises should develop low-cobalt and cobalt-free technologies, utilize green solvents, and develop new battery swap modes. The establishment of an information platform is conducive to the further development of collaborative networks.

1. Introduction

With the rapid growth of the global population, air pollution and resource scarcity, which seriously affect human health, have had an increasing impact on the sustainable development of countries [1]. As an important sustainable strategy for alleviating resource shortages and environmental degradation, new energy vehicles (NEVs) have received widespread attention worldwide, and the related industries are flourishing [2,3]. NEVs are energy efficient and environmentally friendly, and many countries have developed incentive policies to promote the development of electric vehicles [4]. For example, the United States introduced a new bill, the Inflation Reduction Act, to encourage NEV companies to invest more in their country, promote the recycling industry, and enhance supply chain sustainability [5]. China's State Council issued the New Energy Vehicle Industry Development Plan (2021–2035) to provide direction for the development of the NEV industry in the new era, promoting innovation and depth in China's efforts to combat climate change,

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which in turn promote green development [6].

As a core component of NEVs, the cost of batteries accounts for 40 % of the cost of NEVs and can be as high as 60 % when the supply of raw materials is unstable [4]. The raw materials for NEV batteries are expensive and depend on foreign imports, leading to instability in the supply chain [7]. In addition, if used batteries are not handled in a timely and effective manner, the leakage of hazardous substances will lead to environmental pollution affecting soil and water quality and causing kidney damage, metal poisoning, and cancer [8,9]. Therefore, it is important to recycle these batteries. Considering the popularity of NEVs and the average life of NEV batteries of 5–10 years, many batteries will be retired shortly [10]. By 2025, the number of retired NEV batteries will reach 1.3 million tons [11]. After the recovery of NEV batteries, based on the remaining battery capacity, there are two main treatment methods: resourceful dismantling and gradient utilization. Resourceful dismantling refers to obtaining a large number of resources from the waste battery: lead-acid batteries can be recycled for copper, cadmium, and mercury, lithium-ion batteries can be recycled for lithium, nickel, and cobalt, sodium-ion batteries can be recycled for nickel, copper, and manganese, nickel-metal hydride batteries can be recycled for nickel and rare earth materials [12–14]. Waste batteries with high residual capacity can be gradient utilization, by still being applied in residential energy storage, low-speed electric vehicles, and other fields [15]. Used NEV batteries have high economic value, and their recycling can promote sustainable development.

In recent years, researchers have conducted extensive research on the recycling of used NEV batteries and have achieved great results. NEV battery recycling technologies vary. Wang et al. [16] developed an integrated system to quantitatively compare the technical, economic, and environmental impacts of the solvent metallurgy, pyrometallurgy, and hydrometallurgy of deep eutectic solvents (DESs) and design methods to improve the sustainability of DESs. Furthermore, the direct regeneration method is simpler and has higher economic efficiency than the traditional pyrometallurgy and hydrometallurgy, demonstrating the necessity for its development [17]. Numerous types of batteries are used in NEVs. Lead-acid, nickel-metal hydride, nickel-cadmium, and lithium-ion batteries have structural similarities but very different chemistries. The recycling of lithium-ion batteries is relatively mature, and lithium–iron phosphate batteries are widely used because of their cost-effectiveness. However, because lithium–iron phosphate batteries do not contain cobalt or nickel, their recycling is not economical [18]. Zhang et al. [19] pointed out that lead-acid batteries need to pay attention to lead contamination during recycling, and the recycling of rare earth elements in nickel-based batteries is attracting widespread attention.

Most of the current reviews reviewed the existing literature based on different types of NEV batteries, different technical approaches and their economic and environmental impacts. This study used the bibliometric method to systematically organize the published literature to provide new perspectives for research related to the recycling of NEV batteries. Bibliometrics combines statistical knowledge to study the characteristics of literature on related topics. Bibliometrics can analyze productivity as well as the influence of countries and fields, through objective data. Simultaneously, bibliometrics can help understand knowledge clusters and reveal social relations through scientific mapping [20]. Bibliometrics is widely used in various fields, such as medicine [21,22], business and economics [23], agriculture [24], forestry [25], and supply chain management [26].

This study focuses on NEV battery recycling using visual analysis software to identify developments in the research field. This study: (1) used bibliometrics to quantify the contributions of countries, fields, organizations, journals, and authors to the current development of NEV battery recycling research; (2) analyzed collaborative networks among countries, organizations, and authors for NEV battery recycling research; (3) explored the changes in research hotspots over time through keyword analysis and proposed future research directions.

2. Method and analytical tool

Bibliometrics is an interdisciplinary field that combines mathematics, statistics, and documentation. Based on bibliometrics, this study conducted a quantitative analysis of the literature in the database. We investigated the number of related articles, authors, institutions, and subject vocabularies to gain an understanding of the research status, research hotspots, and future development of a certain subject. We used a visualization map to intuitively and accurately demonstrate the knowledge development.

2.1. Data collection

To obtain internationally authoritative, influential, high-quality, and time-honored research data, we analyzed the status of research on NEV battery recycling published in the Web of Science Core Collection (WOSCC) database from January 1, 2009, to March 31, 2023 [27,28]. The specific retrieval keywords are: (new energy vehicle OR new energy automobile OR NEV OR plug-in hybrid car OR hybrid vehicle OR electric car OR hydrogen energy vehicle OR fuel cell vehicle OR Electric Vehicle) AND (battery) AND (retir* OR retrieve* OR recover* OR reclaim* OR recoup OR Remanufactur* OR recycle* OR reutilization OR recuperation OR retirement OR decommissioning OR treatment OR dismantling OR disassembly OR reuse OR echelon utilization OR gradient utilization OR cascade utilization).

2.2. Data cleanup and organization

A total of 2423 articles were obtained through precise search. The types of literature retrieved included articles (1616), proceedings papers (655), review articles (203), early access papers (51), and other types (16). To reduce errors and improve accuracy, we read the titles, keywords, and abstracts and excluded research papers that were inconsistent with the research topic and search theme, which resulted in 716 articles. Note that the data for China included Taiwan. Data for England, Wales, Scotland, and Northern Ireland were covered in the UK. Meanwhile, in the case of different author names, we queried more information in WOSCC and verified whether they referred to the same author by checking the official website of the author's affiliated organization and the authors' ORCID information. The data were reorganized based on multiple validations.

2.3. Data analysis and visualization

With the advent and development of bibliometrics, analysis and visualization tools such as the VOS viewer, CiteSpace, and Derwent Data Analyzer (DDA) have emerged. DDA and CiteSpace are Clarivate's text-mining softwares for data cleaning, multi-perspective data mining, and visualization. They improve the efficiency of data analysis and reduce labor costs, providing researchers with valuable insights into scientific and technological trends, identifying emerging technologies in the field/industry, finding partners, and determining research strategies and directions [29]. Therefore, DDA and CiteSpace were selected for literature analysis in this study. All articles related to NEV battery recycling were evaluated using bubble charts, matrix plots, and cluster plots for the country, institution, field of study, journal, and author keywords.

3. Result

3.1. Contribution of leading countries or regions

Researchers from different countries are working together to promote research progress. The published papers on NEV battery recycling are shown on a world map (Fig. 1).

The number of articles published annually on NEV battery recycling is shown in a histogram (Fig. 2), which shows that the relevant research literature has surged in recent years. Three months of data in 2023 are comparable to the total number of articles published in 2019, indicating that the field is beginning to receive widespread attention. This study provides an in-depth analysis of the top 20 countries that contributed the largest number of papers (Table 1), by analyzing the publication of papers in these countries from multiple perspectives. The corresponding contribution ratios were also visualized (Fig. 3). Of these 20 countries, European countries were the largest contributor with 12 countries. This is followed by the Americas with 3 countries, Asia with 4 countries and Oceania with 1 country. China ranked first with 344 publications, followed by the United States (114) and the United Kingdom (59). An excellent performance of France can be found in the analysis of the average number of citations per paper (ACPP; 64.88), which shows that France has a significant influence in the field. Among the top 20 countries, international cooperation was particularly significant in terms of paper contributions. Specifically, Denmark, the Netherlands, and Australia have 92.31 %, 84.62 %, and 72.73 % of international cooperation papers, respectively, reflecting the high degree of openness and international cooperation in scientific research in these countries. China has published the largest number of papers in this field; however, its average number of citations is not outstanding (20.26). To further expand their influence, researchers should improve the quality of their studies.

The cooperation between the 20 countries is illustrated through a matrix shown in Fig. 4. In the matrix, the countries are represented as nodes, and the number of articles published is proportional to the size of the country node, reflecting the productivity of each country. The lines between nodes represent the cooperative relationships between countries, and the width of the lines is directly proportional to the intensity of cooperation. The number of cooperating countries (nCC) represents a country's cooperation network. China has the widest cooperation network with 32 countries, including the United States, the UK, and Australia. This is followed by the USA (21) and Germany (21). The h-index is a significant indicator used to measure the impact of a research paper, representing the number of papers (h) that have received at least h citations [30]. For the h-index, China occupies the first place with an h-index of 46. This is followed by the United States (38) and the United Kingdom (24). Collaboration with international partners not only enhances the level of research but also provides an avenue for the global dissemination of relevant technologies and demonstrated practices.

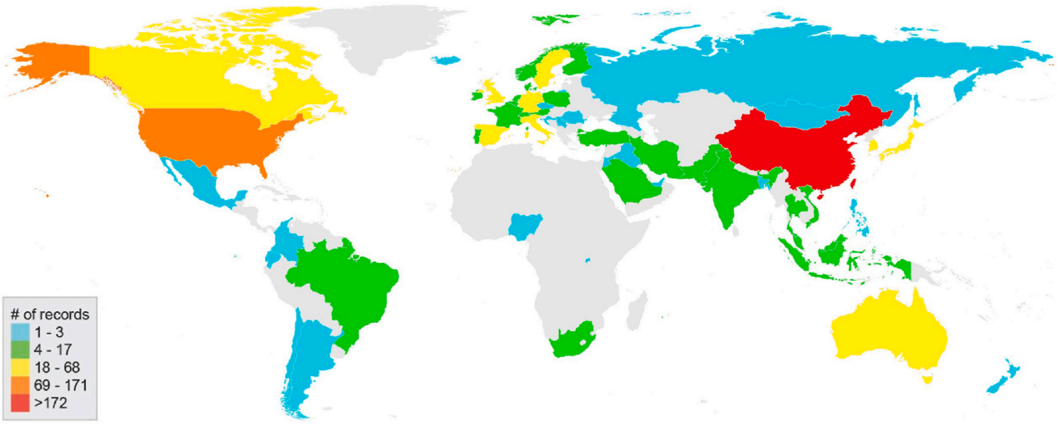


Fig. 1. World map showing the distribution of published papers on NEV battery recycling.

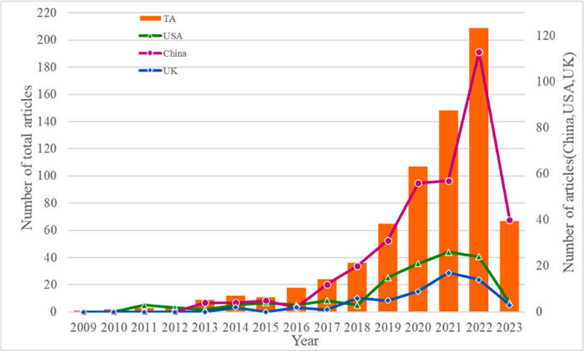


Fig. 2. Evolutionary trend in the annual number of articles.

Table 1

Top 20 countries in publishing papers on the recycling of NEV batteries.

Rank	Country	TA	TC	ACPP	H-index	SP(%)	nCC
1	China	344	6971	20.26	46	15.41 %	32
2	USA	114	5117	44.89	38	37.72 %	21
3	UK	59	1926	32.64	24	52.54 %	20
4	Germany	50	1677	33.54	19	50.00 %	21
5	Spain	44	1480	33.64	18	36.36 %	15
6	Japan	30	488	16.27	9	33.33 %	8
7	South Korea	26	651	25.04	12	38.46 %	10
8	Canada	23	810	35.22	13	60.87 %	13
9	Australia	22	352	16	9	72.73 %	13
10	Sweden	22	1208	54.91	15	54.55 %	12
11	Italy	18	609	33.83	11	44.44 %	9
12	France	17	1103	64.88	10	47.06 %	9
13	India	16	117	7.31	7	31.25 %	9
14	Norway	15	336	22.4	9	66.67 %	17
15	Denmark	13	260	20	7	92.31 %	10
16	Netherlands	13	432	33.23	9	84.62 %	9
17	Belgium	9	349	38.78	7	44.44 %	5
18	Brazil	9	324	36	8	22.22 %	8
19	Austria	7	84	12	5	42.86 %	4
20	Finland	7	251	35.86	7	57.14 %	4

TA: the total number of articles; TC: the total number of citations; ACPP: the average number of citations per publication; SP: the share of publications; and nCC: the number of collaborating countries.

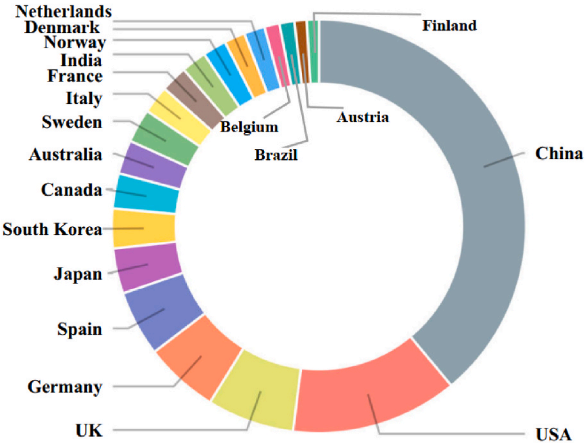


Fig. 3. Map showing the contributions to the number of national publications (Top 20).

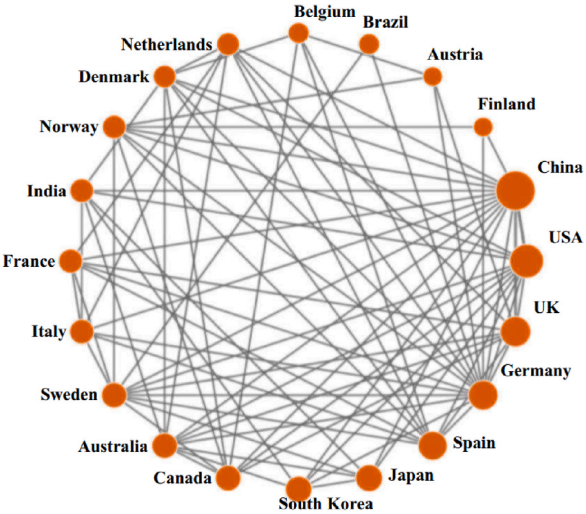


Fig. 4. Cooperation matrix for the Top 20 countries.

3.2. *Contribution of leading institutions*

We identified the top 20 institutions that contributed the most to the research on NEV battery recycling (Table 2). Tsinghua University (38) and the Chinese Academy of Sciences (25) ranked first and third, respectively, demonstrating the outstanding contributions of Chinese institutions to this field. In addition to the overall contribution of the institutions, we focused on the average number of citations and the h-index of each institution. The US Department of Energy (DOE) excelled in both metrics and ranked first in ACPP (68.44), indicating that its published papers have a high academic impact. The Chalmers University of Technology ranked second (53.3), while the Beijing Institute of Technology ranked third (47.29). For the h-index, Tsinghua University occupied first place, with an h-index of 20. Trailing closely behind are the U.S. DOE (15) and the University of California System (13), which are also influential in the field. As shown in the chart data, the institutions have been instrumental in the development and promotion of the field of NEV battery recycling. It is worth noting that 13 of the top 20 research institutions are from China, demonstrating the research activities of Chinese institutions in this field. However, the ACPP is generally low for Chinese institutions, implying that the quality or impact of their research must be improved. As the bubble chart shows, the top five institutions have had a steady output of articles in recent years (Fig. 5). The matrix map shows the collaboration between these institutions (Fig. 6). Tsinghua University and the U.S. DOE have the most extensive collaborative networks, each working with seven institutions. The Chinese Academy of Sciences collaborates with six institutions. Most institutions are not limited to domestic collaboration but actively collaborate with foreign institutions, reflecting the global nature of research on NEV battery recycling.

Table 2
Top 20 institutions in publishing papers on the recycling of new energy vehicle batteries.

Rank	Institutions	TA	TC	ACPP	H-index	Country
1	Tsinghua Univ	38	1447	38.08	20	China
2	US DOE	25	1711	68.44	15	USA
3	Chinese Acad Sci	25	489	19.56	12	China
4	Univ California System	18	838	46.56	13	USA
5	Cent South Univ	16	117	7.31	7	China
6	Shanghai Jiao Tong Univ	16	421	26.31	9	China
7	Beijing Inst Technol	14	662	47.29	9	China
8	Univ Birmingham	14	370	26.43	10	UK
9	Helmholtz Association	13	536	41.23	6	Germany
10	Beijing Univ Technol	11	181	16.45	8	China
11	Harbin Insti Technol	11	219	19.91	7	China
12	Huazhong Univ Sci & Technol	11	350	31.82	9	China
13	Newcastle Univ	11	442	40.18	7	UK
14	Univ Shanghai Sci & Technol	11	172	15.64	6	China
15	Aalborg Univ	10	173	17.3	6	Denmark
16	Beijing Jiaotong Univ	10	334	33.4	7	China
17	Chalmers Univ Technol	10	533	53.3	10	Sweden
18	Shandong Univ	10	409	40.9	7	China
19	Chongqing Univ	9	248	27.56	5	China
20	Nanjing Univ Information Sci & Technol	9	101	11.22	6	China

TA: the total number of articles; TC: the total number of citations; ACPP: the average number of citations per publication.

Fig. 5. Bubble chart showing annual trends for the top 20 most prolific institutions.

3.3. *Contribution of leading research areas*

NEV battery recycling is a comprehensive topic involving multiple disciplines. Through an in-depth analysis of the retrieved papers, we identified 20 research areas with the most focused discussions (Table 3). The most discussed field is engineering with 329 articles (45.95 %). This is followed by environmental science and ecology (244 articles) and energy fuels (204 articles). These are the main research areas in the field of NEV battery recycling.

The total number of papers published in the top 20 areas tends to increase year by year, indicating that this topic is attracting an increasing number of researchers (Fig. 7). The recycling of NEV batteries requires multi-disciplinary cooperative research. The recycling process involves multiple stages, including collection, testing, screening, disassembly, and disposal. Engineering, energy fuels, and materials science are the key disciplines in this field, and the three areas are the most closely linked (Fig. 8). Of these, the ACPP is the highest for mineralogy, indicating that much of the research is focused on metallic elements using mineralogy-related knowledge. After 2018, several research directions have begun to gain attention, diversifying the field of NEV battery recycling. These fields include computer science, thermodynamics, and operations research management science. The expanding focus on these areas reflects the increasing recognition of their relevance and potential contributions to advancing battery recycling technology and

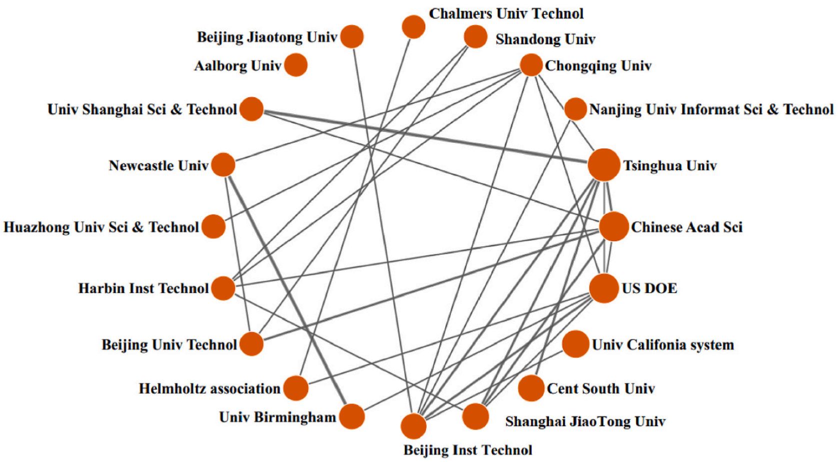


Fig. 6. Collaboration matrix of the top 20 prolific institutions.

Table 3
Top 20 most discussed research areas.

Rank	Research areas	Percent	TA	TC	ACPP	H-index
1	Engineering	45.95 %	329	10,463	31.8	56
2	Environmental Sciences Ecology	34.08 %	244	8936	36.62	53
3	Energy Fuels	28.49 %	204	5432	26.63	40
4	Science Technology Other Topics	26.12 %	187	5477	29.29	41
5	Materials Science	15.22 %	109	3226	29.6	28
6	Chemistry	14.66 %	105	3814	36.32	29
7	Electrochemistry	7.54 %	54	2040	37.78	20
8	Metallurgy Metallurgical Engineering	4.47 %	32	742	23.19	14
9	Physics	4.33 %	31	310	10	10
10	Computer Science	3.49 %	25	577	23.08	10
11	Thermodynamics	2.37 %	17	323	19	9
12	Business Economics	1.96 %	14	546	39	9
13	Mining Mineral Processing	1.96 %	14	560	40	8
14	Operations Research Management Science	1.96 %	14	225	16.08	8
15	Telecommunications	1.96 %	14	467	33.36	7
16	Mineralogy	1.54 %	11	524	47.64	6
17	Nuclear Science Technology	1.54 %	11	114	10.36	7
18	Transportation	1.54 %	11	300	27.27	7
19	Mathematics	1.26 %	9	19	2.11	3
20	Automation Control Systems	0.98 %	7	312	44.57	5

TA: the total number of articles; TC: the total number of citations; ACPP: the average number of citations per publication.

practices. The diversification of research directions indicates a broader and more interdisciplinary approach to tackling the challenges and exploring innovative solutions in the field.

3.4. Contribution of leading journals

The 716 articles compiled in this study were published in 198 journals. To gain insights into the research dynamics of the field, we conducted a comprehensive analysis of the top 20 journals with the most published articles (Table 4). *Journal of Cleaner Production* ranked first, with 57 articles on the subject. *Resource Conservation and Recycling* (47 articles) ranked second, while the *Journal of Energy Storage* (43 articles) ranked third. The top 20 journals published a total of 371 papers (51.82 %). *Journal of Hazardous Materials* holds the top position in ACPP (96.63). This is followed by the *Journal of Power Sources* (84.28) and *Environmental Science & Technology* (72.22). Renewable Sustainable & Energy Reviews boasts the highest impact factor (IF).

The bubble chart illustrates the trends for the top 20 journals in terms of the total number of papers published (Fig. 9). In recent years, the academic community has paid increasing attention to research on NEV battery recycling. Some influential journals, such as the Journal of Cleaner Production, have continuously published many relevant articles. This not only highlights the importance of the subject in the academic world but also emphasizes its practical significance. To promote the use of NEVs, multiple values of battery recycling in terms of economic benefits and environmental protection are considered. Establishing a management system for the full life cycle of NEV batteries should be promoted.

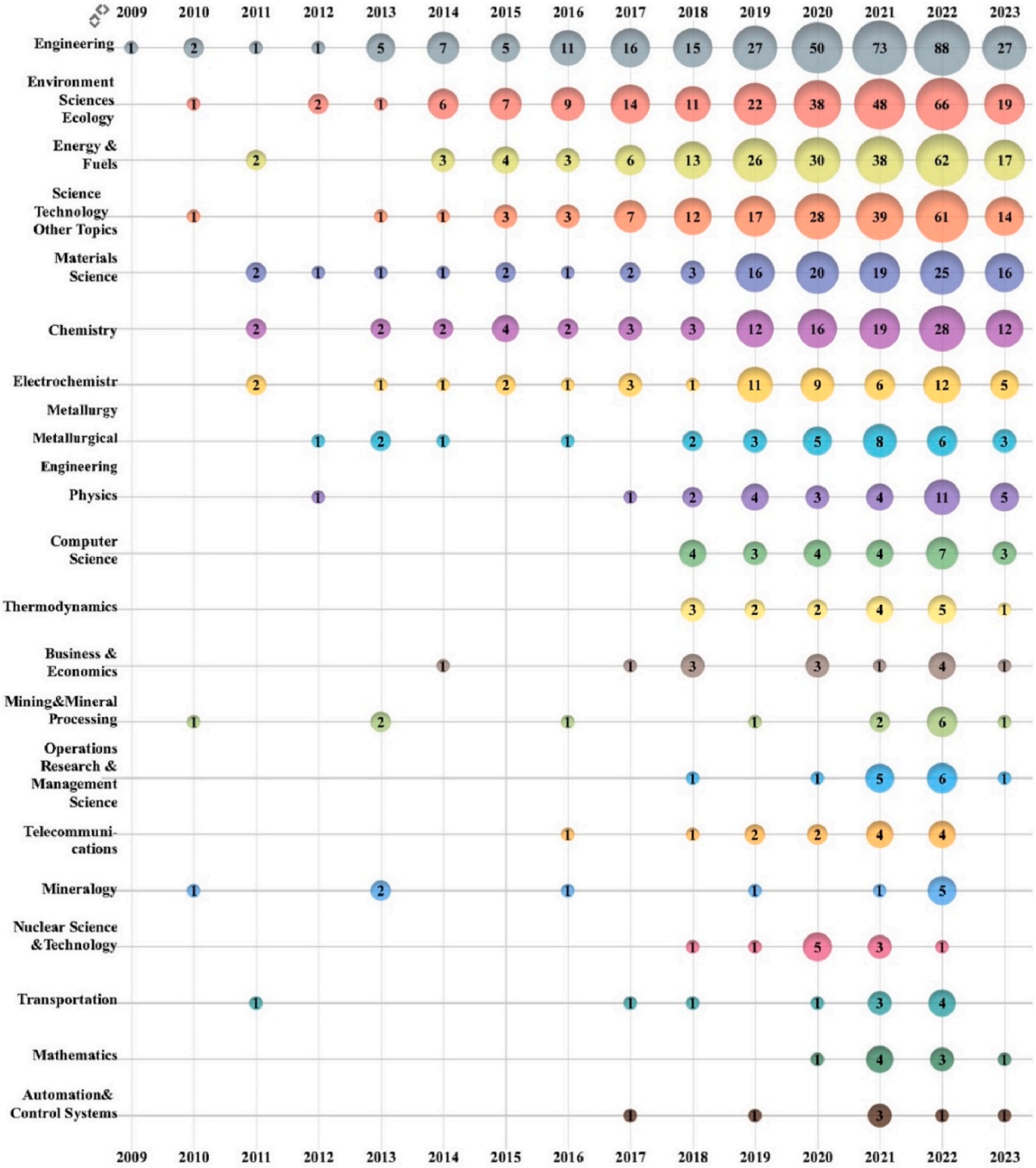


Fig. 7. Bubble chart showing annual trends for the top 20 most prolific research areas.

3.5. *Contribution of leading authors*

A total of 716 articles have been published by 2701 authors during the search period. We analyzed the top 20 researchers in terms of posting volume (Table 5). Garg, Akhil ranked first with a contribution of 10 articles, followed by Lai, Xin (8) and Zheng, Yuejiu (8). In terms of ACPP, Linda L Gaines ranked highest (116.17), followed by Babbitt, Callie W. (113.83). Garg, Akhil had the highest h-index score of 8. These results indicate that Garg, Akhil dominates in research on NEV battery recycling. There are mutual collaborations between these authors, such as Garg, Akhil and Gao liang; Park, Sanghyuk and Kwon, Kyungjung; Lai, Xin and Zheng, Yuejiu (Fig. 10). Meanwhile, the number of papers published by the top 20 authors accounts for 12.15 % of the total. This data demonstrates that many people are involved in research in the field of NEV battery recycling. An increasing number of researchers are actively engaged in this field, injecting strong vitality into the long-term development of this field. With the addition of more talents from different fields and the strengthening of collaborative research, more breakthroughs and progress are expected in the field of NEV battery recycling. This diversified mode of collaboration and research participation will further promote knowledge exchange and cooperation and drive continuous innovation and improvement in the field.

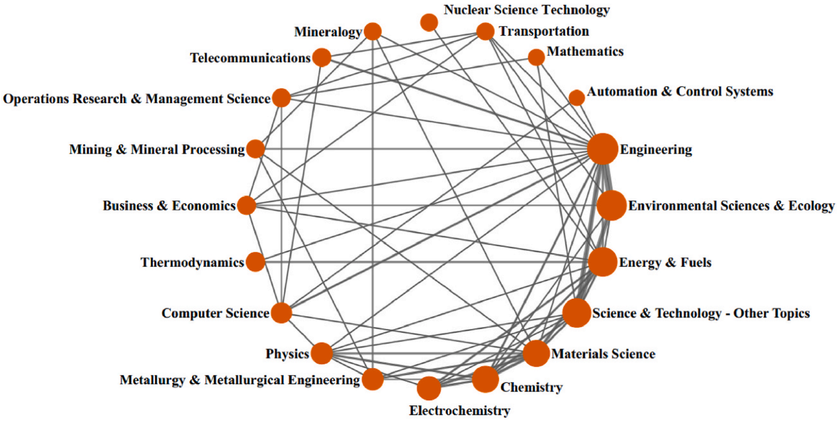


Fig. 8. Collaboration matrix of the top 20 prolific research areas.

Table 4
Top 20 journals in publications.

Rank	Journal title	TA	Percent	TC	ACPP	H-index	IF
1	Journal of Cleaner Production	57	7.961	2188	38.39	24	11.1
2	Resources Conservation and Recycling	47	6.564	1778	37.83	24	13.2
3	Journal of Energy Storage	43	6.006	898	20.88	16	9.4
4	Energies	29	4.05	259	8.93	10	3.2
5	Sustainability	22	3.073	189	8.59	9	3.9
6	Journal of Power Sources	18	2.514	1517	84.28	15	9.2
7	Acs Sustainable Chemistry Engineering	17	2.374	359	21.12	11	8.4
8	Applied Energy	14	1.955	446	31.86	9	11.2
9	Waste Management	13	1.816	444	34.15	10	8.1
10	Renewable Sustainable & Energy Reviews	12	1.676	261	21.75	9	15.9
11	Batteries Basel	11	1.536	54	4.91	5	4.0
12	Energy	11	1.536	210	19.09	6	8.9
13	IEEE Access	11	1.536	430	39.09	6	3.9
14	International Journal of Energy Research	11	1.536	115	10.45	7	4.6
15	Journal of Industrial Ecology	11	1.536	286	26	6	5.9
16	Environmental Science & Technology	9	1.257	650	72.22	6	11.4
17	International Journal of Life Cycle Assessment	9	1.257	546	60.67	8	4.8
18	Metals	9	1.257	107	11.89	6	2.9
19	Separation and Purification Technology	9	1.257	37	4.11	4	8.6
20	Journal of Hazardous Materials	8	1.117	773	96.63	6	13.6

TA: total number of articles; TC: total number of citations; ACPP: average number of citations per publication; IF: impact factor.

3.6. Research hotspots and trends

Important information about dissertation research is usually summarized using keywords [31–33]. Keyword analysis is an indispensable part of researching future trends in the field. We extracted keywords from 716 articles and organized them with the same meaning as in the original data, resulting in 1692 keywords. The size of the bubbles in the bubble chart and the numbers they contain indicate the number of occurrences of the keyword during the year. The horizontal comparison of bubbles shows the changes in keywords in different years, while the comparison between vertical bubbles can be used for the attention heat of keywords of different authors in the same year [34]. The top 20 keywords are shown in Fig. 11. As the most widely used NEV battery type, lithium-ion batteries have the highest frequency of occurrence (196). This is followed by new energy vehicles and recycling, with 176 and 122 occurrences respectively.

As the bubble chart shows, keywords such as closed-loop supply chain, circular economy, material flow analysis, and sustainability have been increasingly discussed since 2018. This trend signals a growing recognition among researchers regarding the importance of establishing effective management modes. The combination of new technologies and efficient recycling methods will help to alleviate the scarcity of raw materials. Governments and businesses must develop circular economy strategies from a long-term perspective to address the problems that arise in the supply chain [35]. This work involves collaboration and competition among multiple stakeholders in a closed-loop supply chain. Battery manufacturers, vehicle companies, recycling companies, and gradient utilization companies are all involved. Their collective efforts are required to establish a comprehensive battery recycling network and value chain, facilitating the efficient recycling and remanufacturing of used batteries. By establishing an effective circular economy model, the sustainability of battery resources can be improved, waste can be reduced, and the efficient use of materials can be promoted.

Fig. 9. Bubble chart showing annual trends for the top 20 journals in publications.

Collaboration among stakeholders is essential to achieve these goals and move the industry forward.

To obtain a more comprehensive understanding of the hotspots in the field, we used a clustering algorithm to cluster the keywords in the literature (Fig. 12) and analyze the development of each cluster (Fig. 13). The interrelationships between the keywords are shown in the clustering diagram. The size of the keyword nodes is positively correlated with the frequency of keywords appearing in the study. The clustering diagram shows that the clusters are closely related.

Cluster 1 represents state of health, Cluster 2 represents life cycle assessment, and Cluster 3 represents energy storage. Batteries are the core components of NEVs, and their environmental impacts throughout their life cycle, from production to recycling, have been widely discussed. Life cycle assessment (LCA) is an effective tool for fully understanding this impact. Some used NEV batteries retain 70%–80 % of their original capacity, and people can still utilize this surplus energy. This is not only conducive to easing the pressure of decommissioning tide and reducing environmental pollution but can also improve economic efficiency and support the development of renewable energy [36,37]. The physical form of the end-of-life battery was first examined (e.g., bulging packs and leakage) to determine whether the battery met the conditions for reuse or disassembly for recycling. The performance of the end-of-life battery was also examined in terms of weight, size, and sealing [38]. Combined with machine learning algorithms, LCA can help estimate the capacity of used batteries quickly and efficiently [39–42]. Subsequently, the used batteries can be screened, sorted, and reorganized by

Table 5
Contributions of the top 20 authors.

Rank	Author	TA	TC	ACPP	H-index
1	Garg, Akhil	10	272	27.2	8
2	Lai, Xin	8	167	20.88	6
3	Zheng, Yuejiu	8	167	20.88	6
4	Wang, Yan	7	622	88.86	6
5	Tang, Yanyan	7	228	32.57	5
6	Casals, Lluc Canals	7	362	51.71	5
7	Gao, Liang	7	113	16.14	6
8	Li, Jinhui	6	659	109.83	6
9	Babbitt, Callie W.	6	683	113.83	6
10	Gabrielle Gaustad	6	651	108.5	5
11	Hao, Han	6	266	44.33	6
12	Gaines, Linda L.	6	697	116.17	6
13	Park, Sanghyuk	6	244	40.67	5
14	Kwon, Kyungjung	6	244	40.67	5
15	Lambert, Simon	6	79	13.17	5
16	Li,baohua	5	69	13.8	4
17	Cusenza, Maria Anna	5	361	72.2	5
18	Heidrich, Oliver	5	326	65.2	5
19	Kendrick, Emma	5	142	28.4	4
20	Ahmeid, Mohamed	5	37	7.4	5

TA: total number of articles; TC: total number of citations; ACPP: average number of citations per publication.

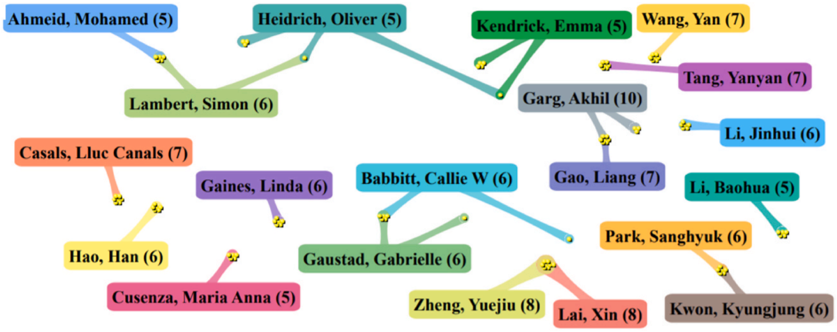


Fig. 10. Collaborations among the top 20 prolific authors charted.

model algorithms to improve efficiency while avoiding the impact of the short-board effect on the secondary use of the battery pack [43,44]. From an energy storage perspective, used batteries can be used secondarily for stationary energy storage in residential buildings, saving homeowners between 24 % and 77 % of the cost and extending the life of electric vehicle batteries by 3–5 years [45,46]. Using used batteries for residential energy storage can effectively reduce carbon emissions and promote a rational energy layout compared to new batteries [47,48]. Used batteries have great potential to open up new markets and reduce environmental impacts, with secondary battery laddering seen as a long-term strategy to effectively reduce the cost of energy systems [49].

Clusters 0 and 6 represent cobalt and electrode materials, respectively. NEV batteries contain large amounts of metals and have high recycling potential [50]. Lithium is a strategic resource in the new energy era and a key material for batteries [51,52]. Improper disposal of lithium in NEV waste batteries can cause serious pollution of water sources and soil [53]. In addition to lithium, cobalt is an important metal component in NEV batteries [54]. Cobalt is expensive, limited, and highly concentrated. Supply chain security issues affect access to cobalt resources [55,56]. The rapid rise of NEVs has also led to a significant increase in nickel demand; the nickel industry chain is booming, and the nickel resource trade has attracted widespread attention [57]. The rapid growth in demand for NEVs is driving the development of the NEV battery recycling chain [58]. Recovering metal resources from a large number of discarded NEV batteries not only protects the environment but is also an effective way to cope with resource shortages and ensure economic benefits [59,60]. Recycling methods that are both environmentally friendly and economical can increase the recovery rate of metallic elements and promote sustainable development [61–63]. Therefore, it is imperative to improve the leaching efficiency and promote the recycling of metallic elements.

Circular economy is represented by Cluster 4. The circular economy is an important means of sustainable development that can maximize the value of batteries, extend their service life, and reduce the waste of resources as well as the impact on the environment. This is an important method to solve environmental problems and resource shortages [64]. Utilizing used batteries for energy storage is an effective way to extend battery life and promote the circular economy [65]. Establishing an efficient closed-loop supply chain for NEV batteries can create a multi-win situation that benefits the environment, society, and people [66]. The rapid development of the NEV market has led to the development of waste battery recycling. Positive and effective incentive policies can promote the recycling

Fig. 11. Bubble chart showing annual trends in the top 20 keywords in publications.

of NEV batteries [67]. The government should encourage relevant enterprises in the market to establish a comprehensive recycling system while attracting consumers to actively participate in battery recycling. Globally, countries have proposed a series of regulations based on the principle of extended producer responsibility to promote the implementation of specific responsibilities by enterprises in the market [68–70]. Currently, the main government incentive is to grant subsidies. In China, there are two types of subsidies: one-time quota subsidies based on the number of batteries and range subsidies based on battery capacity [71]. Subsidies can also be divided into subsidies for consumers and subsidies for NEV manufacturers. The social benefits of subsidy policies vary for different subsidy targets [72]. Penalty mechanism also has an important impact on the recycling of used batteries, and penalizing enterprises that fail to fulfill their responsibilities can play a positive role [73]. The selection of recycling channels is an important aspect of NEV battery recycling. The battery recycling rate is a key factor affecting the competitive position of NEV manufacturers [74]. Battery endurance and advertising effects within the supply chain also affect the choice of recycling channels and recycling prices [75]. In combination with system dynamics studies, recycling subsidies can increase recycling rates, while technological advances can increase the incentives for retailers and third-party recyclers to recycle batteries [76]. Enhanced communication and cooperation between upstream and downstream enterprises within the supply chain system and information sharing will help establish a recycling system [77].

We performed a keyword burst analysis, as shown in Fig. 14. Keyword burst analysis means that keywords appear more frequently

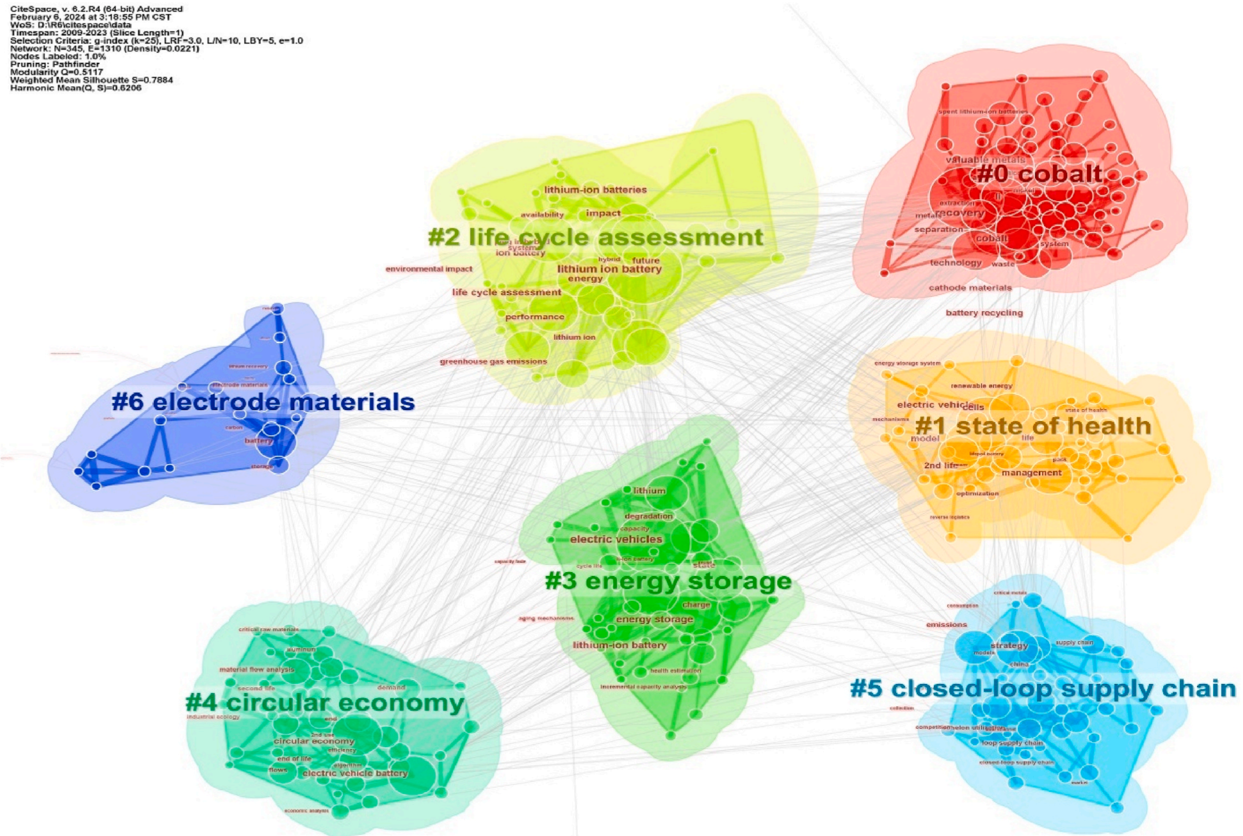


Fig. 12. Keywords clustering map.

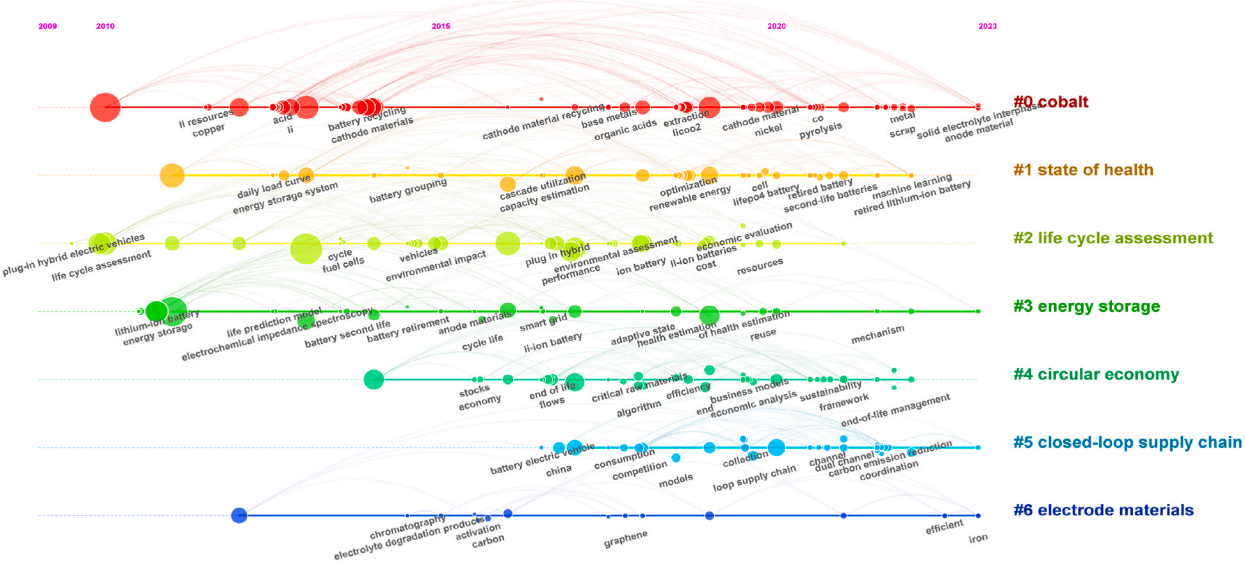
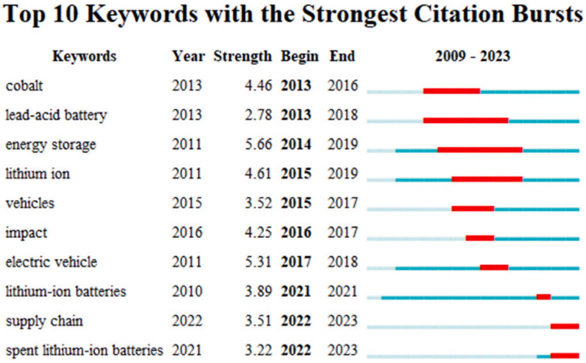


Fig. 13. Keywords clustering timeline map.

over a period and become a hot research topic. The red line segment indicates the time span from the starting year to the ending year of the keyword occurrence, from which the change in the research hotspot can be analyzed [78]. In the early stages of research on NEV battery recycling, studies mainly focused on lead-acid batteries. Later, researchers began to focus on lithium batteries, which showed


Top 10 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End
cobalt	2013	4.46	**2013**	2016
lead-acid battery	2013	2.78	**2013**	2018
energy storage	2011	5.66	**2014**	2019
lithium ion	2011	4.61	**2015**	2019
vehicles	2015	3.52	**2015**	2017
impact	2016	4.25	**2016**	2017
electric vehicle	2011	5.31	**2017**	2018
lithium-ion batteries	2010	3.89	**2021**	2021
supply chain	2022	3.51	**2022**	2023
spent lithium-ion batteries	2021	3.22	**2022**	2023

Fig. 14. Keywords burst analysis.

better performance. Compared with lead-acid batteries, Li-ion batteries have a higher energy density and better energy storage performance and cause less environmental pollution [79]. The keyword with the highest burst intensity is energy storage (5.66), which lasts for 5 years; NEV battery recycling is inextricably linked to energy storage. The keyword emergence analysis shows that since 2014, a large number of studies have focused on the energy storage properties of used NEV batteries, and the batteries removed from NEVs can be used in the grid as well as residential photovoltaic and other energy storage systems [80,81]. This not only extends the service life of batteries but also creates a high economic value. Cobalt is the most studied battery metal resource, with the highest intensity of 4.46. In 2021, 72 % of the global cobalt supply came from the Congo. Such a concentrated supply makes the world highly concerned about the security and stability of the cobalt supply chain, testing its robustness and quantitatively tracking its flow [82,83]. Since 2022, researchers have begun to pay attention to the importance of the supply chain of NEV batteries, which includes battery, automobile, and energy storage companies. To promote the development of a circular economy, it is necessary to strengthen the cooperation between upstream and downstream companies and realize the responsibility of each subject [84,85].

4. Discussion

4.1. National policy development

Battery recycling is a crucial component in the sustainable development of NEV supply chains. The volume of research literature is one of the most important indicators of the importance that countries worldwide attach to a particular area. Scientific research is closely related to national behavioral policies. As a major NEV manufacturing country, China has introduced several laws to regulate the recycling of used NEV batteries, clearly establishing that NEV manufacturers hold the primary responsibility for recycling. In parallel, China is also promoting pilot recycling programs [86]. The U.S., which is one of the top three NEV markets in the world, has established a deposit system as well as a regulatory system to alleviate the pressure of unstable raw material supply and promote the reuse of NEV batteries [87]. The EU Battery and Waste Battery Regulations require manufacturers to specify recyclable materials and set targets for recycling rates to regulate the use of batteries throughout their life cycle [88]. Closed-loop management of NEV batteries requires government guidance, corporate management, and the active participation of all market participants to establish a circular value chain for NEVs [89]. The formulation of relevant policies by governments, such as subsidies and reward and punishment systems, can provide incentives to market players [90]. India's Waste Battery Management Rules 2022 requires producers to take extended producer responsibility for collecting waste batteries for recycling or refurbishment [91]. However, most current policies focus on the technology and testing stages at the enterprise end. To standardize the development of the recycling industry, the government must adopt policies to promote the collection stage [92]. The construction of a recycling network is an important factor influencing the recycling of NEV batteries [93]. The government should adopt policies to incentivize the construction of high-level recycling networks. Education and training guidance for battery recycling should be strengthened to improve the quality and skill levels of practitioners. Simultaneously, the government should support enterprises in adopting subsidies and incentives to encourage consumers to participate in recycling activities.

4.2. Research network expansion

NEV battery recycling is a complex, multi-disciplinary industry that requires an ever-expanding research network. As there are limitations to recovery processes, with pyrometallurgical processes being ineffective and energy intensive for some metals and hydrometallurgical techniques being costly, the expansion of process technology is of great importance [94,95]. The emergence of new recycling processes, such as selective leaching and direct recycling, has provided new opportunities for the industry. Current research mainly focuses on the recycling of lithium-ion batteries; universal technologies for the recycling of nickel-metal hydrides and sodium-ion batteries must be explored further [96,97]. Researchers should consider both the economic feasibility and environmental friendliness of recycling technologies during technology development [98]. The use of green solvents for recycling is a future trend; green solvents, such as organic acids and deep eutectic solvents, can further improve the economic sustainability of NEV battery recycling. Applying emerging detection and dismantling technologies to NEV battery recycling is also important. The screening process of used NEV batteries can be accelerated using machine learning parameter clustering methods [41]. Combined with artificial intelligence technology, manual battery dismantling can be gradually decreased to improve labor efficiency and enhance the overall safety of the recycling process [99]. To further improve the closed-loop supply chain, the introduction of blockchain technology is necessary; the information on the battery can be used during the entire life cycle of NEV batteries, and the development of a battery passport facilitates the development of the recycling industry. Simultaneously, the development of low-cobalt and cobalt-free battery technologies is also important to alleviate the impact of unstable raw material supply [100]. Additionally, collaborative networks among researchers from different countries, institutions, and fields should be further developed. Encouraging cooperation among countries will help identify universal and unique challenges in the recycling of NEV batteries. Institutions should actively engage in exchanges with other institutions at home and abroad. Cooperation among researchers in different fields can help innovate research technologies. In addition, fostering cooperation among universities, research institutions, and enterprises is essential for addressing the practical challenges encountered in this field. Building an information-sharing platform is an effective way to promote cooperation and development.

4.3. Circular economy promotion

From the research hotspots, it is clear that the circular economy is an important factor to research in this field. The circular economy aims to maximize resource utilization and minimize environmental pollution. With the wave of NEV battery retirement, gradient utilization has become an important initiative to promote the development of a circular economy within the industry [101]. Gradient utilization involves reusing batteries in areas that do not require high battery performance. To maximize the economic benefits, it is important to classify the usage criteria according to the specific needs of different usage scenarios and allocate the secondary-use batteries accordingly [102]. The current circular economy focuses on application scenarios in which batteries are recycled for secondary use, such as energy storage or low-speed electric vehicles. A circular economy should run throughout the life cycle of batteries, and new modes must be developed. The vehicle-electricity separation battery-swap mode of NEVs is an important initiative that facilitates the development of new business modes for the circular economy. This battery-swap mode significantly reduces the waiting time for energy replenishment, thus enhancing the consumer experience [103,104]. The swap mode extends battery life by centralizing battery management and charging in an optimal environment [103,105]. The potential damage to the battery can be minimized using a unified approach for charging and management [106]. This mode further supports gradient development, resource utilization maximization, and closed-loop management. Using advanced machine learning techniques to detect battery health and focus on battery life, batteries can be recycled uniformly. The battery swap mode is still in the early stages of development and requires further infrastructure development and diffusion.

5. Conclusion

Recycling of used NEV batteries has become an urgent need to achieve a multi-win situation for individuals, industries, and the environment. An increasing number of researchers are recognizing the importance of NEV battery recycling and are trying to find comprehensive solutions from different perspectives. This study analyzes the current publication status of NEV recycling literature from a new perspective with the help of bibliometrics and provides a systematic review of the synergistic networks and knowledge development of related research. By analyzing the collected data and conducting related analyses, we explored future trends and research directions for NEV battery recycling. Through this study, we hope to provide valuable insights to researchers, industry stakeholders, and policymakers. We hope to introduce new research perspectives into the evolving field of NEV battery recycling and contribute to sustainable global development. The analysis shows that China and the United States, two prominent NEV manufacturing countries, play pivotal roles in driving progress in the field. Tsinghua University is the leading university in terms of publications. NEV battery recycling includes several knowledge areas, among which engineering has the highest number of research papers. The scale of researcher cooperation must be further developed. Keyword analysis shows that the research focus has shifted from lead-acid batteries to the more advantageous lithium batteries. Supply chain research related to NEV battery recycling has also been emphasized. The closed-loop supply chain and circular economy of NEV batteries have received considerable attention in recent years.

The development of NEV battery recycling requires the active participation of governments, enterprises, and researchers. The government should introduce active policies to support the development of the recycling and collection phases of enterprises, assist enterprises in improving their recycling networks, and provide subsidies to attract consumers to participate in recycling. Enterprises should actively adopt new technologies using low-cobalt and cobalt-free technologies to solve the raw material problem and utilize green solvents to improve sustainability. We introduce blockchain technology to focus on the entire lifecycle information of NEV batteries. Simultaneously, enterprises should explore new business modes, such as the battery swap mode. Researchers from different countries, organizations, and fields can further exchange and cooperate by building an information-sharing platform.

There are some limitations to this study. Only the literature in the WOSCC database was collected, and the literature in other databases, such as Google and Scopus, was not included. In the future, literature related to NEV battery recycling should be collected from all databases to provide a more comprehensive picture of developments in the field.

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Data availability statement

The datasets used in this research are available upon request from the corresponding author.

CRediT authorship contribution statement

Xiuyan Ma: Writing – review & editing, Funding acquisition, Conceptualization. **Chunxia Lu:** Writing – original draft, Formal analysis, Data curation. **Jiawei Gao:** Writing – review & editing, Conceptualization. **Jian Cao:** Investigation, Funding acquisition. **Yuehua Wan:** Visualization. **Hui Fang:** Writing – review & editing, Visualization, 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.

References

[1] R.D. Arias-Perez, N.A. Taborda, D.M. Gomez, J.F. Narvaez, J. Porras, J.C. Hernandez, Inflammatory effects of particulate matter air pollution, Environ. Sci. Pollut. Res. 27 (2020) 42390–42404.

[2] S.H. Sun, W.C. Wang, Analysis on the market evolution of new energy vehicle based on population competition model, Transport. Res. Part D-Transport, Environ. Times 65 (2018) 36–50.

[3] B.W. Cai, Deep learning-based economic forecasting for the new energy vehicle industry, J. Math. 2021 (2021) 10.

[4] Y.Y. Xu, X.Y. Ma, G.G. Zhou, Coordination of automobile supply chain considering relative endurance level under the dual-credit policy, Sustainability 14 (2022) 20.

[5] J.N. Trost, J.B. Dunn, Assessing the feasibility of the Inflation Reduction Act's EV critical mineral targets, Nat. Sustain. 6 (2023) 639. +.

[6] C.Y.L. Hsiao, R. Yang, X. Zheng, Y.B. Chiu, Evaluations of policy contagion for new energy vehicle industry in China, Energy Pol. 173 (2023).

[7] M. Shahjalal, P.K. Roy, T. Shams, A. Fly, J.I. Chowdhury, M.R. Ahmed, K.L. Liu, A review on second-life of Li-ion batteries: prospects, challenges, and issues, Energy 241 (2022).

[8] J.N. Yi, J.Z. Liao, T. Bai, B.L. Wang, C. Yangzom, Z. Ahmed, K. Mehmood, R.Z. Abbas, Y. Li, Z.X. Tang, H. Zhang, Battery wastewater induces nephrotoxicity via disordering the mitochondrial dynamics, Chemosphere 303 (2022).

[9] P. Haefliger, M. Mathieu-Nolf, S. Lociciro, C. Ndiaye, M. Coly, A. Diouf, A.L. Faye, A. Sow, J. Tempowski, J. Pronczuk, A.P. Filipe, R. Bertollini, M. Neira, Mass lead intoxication from informal used lead-acid battery recycling in Dakar, Senegal, Environ. Health Perspect. 117 (2009) 1535–1540.

[10] S.Q. Sun, C.X. Jin, W.Z. He, G.M. Li, H.C. Zhu, J.W. Huang, Management status of waste lithium-ion batteries in China and a complete closed-circuit recycling process, Sci. Total Environ. 776 (2021) 11.

[11] Q.Q. Sun, H. Chen, R.Y. Long, Q.W. Li, H. Huang, Comparative evaluation for recycling waste power batteries with different collection modes based on Stackelberg game, J. Environ. Manag. 312 (2022).

[12] L. Cassayre, B. Guzhov, M. Zielinski, B. Biscans, Chemical processes for the recovery of valuable metals from spent nickel metal hydride batteries: a review, Renewable Sustainable Energy Rev. 170 (2022).

[13] Y. Zhao, Y.Q. Kang, J. Wozny, J. Lu, H. Du, C.L. Li, T. Li, F.Y. Kang, N. Tavajohi, B.H. Li, Recycling of sodium-ion batteries, Nat. Rev. Mater. 8 (2023) 623–634.

[14] S. Kala, A. Mishra, Battery recycling opportunity and challenges in India, Mater. Today: Proc. 46 (2021) 1543–1556.

[15] Y. Al-Wreikat, E.K. Attfield, J.R. Sodré, Model for payback time of using retired electric vehicle batteries in residential energy storage systems, Energy 259 (2022).

[16] M.M. Wang, Z.B. Xu, S. Dutta, K. Liu, C. Labianca, J.H. Clark, J.B. Zimmerman, D.C.W. Tsang, Integrated assessment of deep eutectic solvents questions solvometallurgy as a sustainable recycling approach for lithium-ion batteries, One Earth 6 (2023) 1400–1413.

[17] J.X. Wang, J. Ma, Z.F. Zhuang, Z. Liang, K. Jia, G.J. Ji, G.M. Zhou, H.M. Cheng, Toward direct regeneration of spent lithium-ion batteries: a next-generation recycling method, Chem. Rev. 124 (2024) 2839–2887.

[18] M.M. Wang, K. Liu, S. Dutta, D.S. Alessi, J. Rinklebe, Y.S. Ok, D.C.W. Tsang, Recycling of lithium iron phosphate batteries: status, technologies, challenges, and prospects, Renewable Sustainable Energy Rev. 163 (2022).

[19] X.X. Zhang, L. Li, E.S. Fan, Q. Xue, Y.F. Bian, F. Wu, R.J. Chen, Toward sustainable and systematic recycling of spent rechargeable batteries, Chem. Soc. Rev. 47 (2018).

[20] D. Mukherjee, W.M. Lim, S. Kumar, N. Donthu, Guidelines for advancing theory and practice through bibliometric research, J. Bus. Res. 148 (2022) 101–115.

[21] H. Liu, C.E. Song, B.Z. Zhang, R. Luo, J.J. Yang, Research trends and areas of focus on cryoablation and oncology: a bibliometric analysis from 2001 to 2020, Medicine 101 (2022) 13.

[22] L.G. He, X.L. Wang, C.J. Li, Y.H. Wan, H. Fang, Bibliometric analysis of the 100 top-cited articles on immunotherapy of urological cancer, Hum. Vaccines Immunother. 18 (2022).

[23] L. Murillo-Ramos, I. Huertas-Valdivia, F.E. Garcia-Muina, Exploring the cornerstones of green, sustainable and socially responsible human resource management, Int. J. Manpow. 44 (2023) 524–542.

[24] Y.X. Xu, J. Lyu, H.B. Liu, Y. Xue, A bibliometric and visualized analysis of the global literature on black soil conservation from 1983-2022 based on CiteSpace and VOSviewer, Agron. Basel 12 (2022) 24.

[25] N.M. Ghazali, M.N.M. Said, W. Jaafar, A.M.M. Kamarulzaman, S.N.M. Saad, Research opportunity on fractional cover of forest: a bibliometric review, Forests 13 (2022) 17.

[26] H. Fang, F. Fang, Q. Hu, Y.H. Wan, Supply chain management: a review and bibliometric analysis, Processes 10 (2022).

[27] A.W. Harzing, S. Alakangas, Google scholar, Scopus and the Web of science: a longitudinal and cross-disciplinary comparison, Scientometrics 106 (2016) 787–804.

[28] P. Mongeon, A. Paul-Hus, The journal coverage of Web of Science and Scopus: a comparative analysis, Scientometrics 106 (2016) 213–228.

[29] W.H. Zuo, B.J. Mu, H. Fang, Y.H. Wan, User experience: a bibliometric review of the literature, IEEE Access 11 (2023) 12662–12675.

[30] J.E. Hirsch, Does the h index have predictive power? Proc. Natl. Acad. Sci. U.S.A. 104 (2007) 19193–19198.

[31] Y. Gao, L. Ge, S.Z. Shi, Y. Sun, M. Liu, B. Wang, Y. Shang, J.R. Wu, J.H. Tian, Global trends and future prospects of e-waste research: a bibliometric analysis, Environ. Sci. Pollut. Res. 26 (2019) 17809–17820.
[32] M.F. Bashir, B.J. Ma, Bilal, B. Komal, M.A. Bashir, Analysis of environmental taxes publications: a bibliometric and systematic literature review, Environ. Sci. Pollut. Res. 28 (2021) 20700–20716.
[33] H. Fang, Y. Jing, J. Chen, Y.Q. Wu, Y.H. Wan, Recent trends in sedentary time: a systematic literature review, Healthcare 9 (2021).
[34] Y. Chen, Q.X. Jin, H. Fang, H. Lei, J.R. Hu, Y.Q. Wu, J. Chen, C. Wang, Y.H. Wan, Analytic network process: academic insights and perspectives analysis, J. Clean. Prod. 235 (2019) 1276–1294.
[35] J. Baars, T. Domenech, R. Bleischwitz, H.E. Melin, O. Heidrich, Circular economy strategies for electric vehicle batteries reduce reliance on raw materials, Nat. Sustain. 4 (2021) 71–79.
[36] L. Chang, C.Y. Wang, C.H. Zhang, L.J. Xiao, N.X. Cui, H.Y. Li, J.F. Qiu, A novel fast capacity estimation method based on current curves of parallel-connected cells for retired lithium-ion batteries in second-use applications, J. Power Sources 459 (2020) 9.
[37] Y. Hua, S.D. Zhou, Y. Huang, X.H. Liu, H.P. Ling, X.N. Zhou, C. Zhang, S.C. Yang, Sustainable value chain of retired lithium-ion batteries for electric vehicles, J. Power Sources 478 (2020) 16.
[38] X.M. He, G. Zhang, X.N. Feng, L. Wang, G.Y. Tian, M.G. Ouyang, A facile consistency screening approach to select cells with better performance consistency for commercial 18650 lithium ion cells, Int. J. Electrochem. Sci. 12 (2017) 10239–10258.
[39] A. Garg, L. Yun, L. Gao, D.B. Putungan, Development of recycling strategy for large stacked systems: experimental and machine learning approach to form reuse battery packs for secondary applications, J. Clean. Prod. 275 (2020) 17.
[40] X. Lai, C. Deng, J.Q. Li, Z.W. Zhu, X.B. Han, Y.J. Zheng, Rapid sorting and regrouping of retired lithium-ion battery modules for echelon utilization based on partial charging curves, IEEE Trans. Veh. Technol. 70 (2021) 1246–1254.
[41] C.B. Li, N.B. Wang, W. Li, Y.S. Li, J.W. Zhang, Regrouping and echelon utilization of retired lithium-ion batteries based on a novel support vector clustering approach, IEEE Trans. Transp. Electrif. 8 (2022) 3648–3658.
[42] A.H. Ran, Z. Liang, S.X. Chen, M. Cheng, C.B. Sun, F.Y. Ma, K. Wang, B.H. Li, G.M. Zhou, X. Zhang, F.Y. Kang, G.D. Wei, Fast clustering of retired lithium-ion batteries for secondary life with a two-step learning method, ACS Energy Lett. 7 (2022) 3817–3825.
[43] X. Lai, D.D. Qiao, Y.J. Zheng, M.G. Ouyang, X.B. Han, L. Zhou, A rapid screening and regrouping approach based on neural networks for large-scale retired lithium-ion cells in second-use applications, J. Clean. Prod. 213 (2019) 776–791.
[44] A.H. Ran, S.X. Chen, S.W. Zhang, S.Y. Liu, Z.H. Zhou, P.B. Nie, K. Qian, L. Fang, S.X. Zhao, B.H. Li, F.Y. Kang, X. Zhou, H.B. Sun, X. Zhang, G.D. Wei, A gradient screening approach for retired lithium-ion batteries based on X-ray computed tomography images, RSC Adv. 10 (2020) 19117–19123.
[45] L.C. Casals, M. Barbero, C. Corchero, Reused second life batteries for aggregated demand response services, J. Clean. Prod. 212 (2019) 99–108.
[46] J. Thakur, A.G. Baskar, C.M.L. de Almeida, Electric vehicle batteries for a circular economy: second life batteries as residential stationary storage, J. Clean. Prod. 375 (2022) 18.
[47] M.M. Omrani, H. Jannesari, Economic and environmental assessment of reusing electric vehicle lithium-ion batteries for load leveling in the residential, industrial and photovoltaic power plants sectors, Renewable Sustainable Energy Rev. 116 (2019) 19.
[48] D. Kamath, S. Shukla, R. Arsenault, H.C. Kim, A. Anctil, Evaluating the cost and carbon footprint of second-life electric vehicle batteries in residential and utility-level applications, Waste Manage. (Tucson, Ariz.) 113 (2020) 497–507.
[49] Y. Yang, J. Qiu, C.X. Zhang, J.H. Zhao, G.B. Wang, Flexible integrated network planning considering echelon utilization of second life of used electric vehicle batteries, IEEE Trans. Transp. Electrif. 8 (2022) 263–276.
[50] H. Yang, X.L. Song, X.H. Zhang, B. Lu, D. Yang, B. Li, Uncovering the in-use metal stocks and implied recycling potential in electric vehicle batteries considering cascaded use: a case study of China, Environ. Sci. Pollut. Res. 28 (2021) 45867–45878.
[51] X. Sun, H. Hao, F.Q. Zhao, Z.W. Liu, Global lithium flow 1994-2015: implications for improving resource efficiency and security, Environ. Sci. Technol. 52 (2018) 2827–2834.
[52] B.Y. Liu, Q. Zhang, J.F. Liu, Y.W. Hao, Y.Y. Tang, Y.M. Li, The impacts of critical metal shortage on China's electric vehicle industry development and countermeasure policies, Energy 248 (2022) 10.
[53] N. Bolan, S.A. Hoang, M. Tanveer, L. Wang, S. Bolan, P. Sooriyakumar, B. Robinson, H. Wijesekara, M. Wijesooriya, S. Keerthanan, M. Vithanage, B. Markert, S. Fränzle, S. Wünschmann, B. Sarkar, A. Vinu, M.B. Kirkham, K.H.M. Siddique, J. Rinklebe, From mine to mind and mobiles - lithium contamination and its risk management, Environ. Pollut. 290 (2021).
[54] E.M. Harper, G. Kavlak, T.E. Graedel, Tracking the metal of the goblins: cobalt's cycle of use, Environ. Sci. Technol. 46 (2012) 1079–1086.
[55] M.F.G. Leon, G.A. Blengini, J. Dewulf, Analysis of long-term statistical data of cobalt flows in the EU, Resour. Conserv. Recycl. 173 (2021) 12.
[56] W. Liu, X. Li, C.Y. Liu, M.X. Wang, L.T. Liu, Resilience assessment of the cobalt supply chain in China under the impact of electric vehicles and geopolitical supply risks, Resour. Pol. 80 (2023) 18.
[57] P.F. Yao, X.H. Zhang, Z.L. Wang, L.F. Long, Y.B. Han, Z. Sun, J.W. Wang, The role of nickel recycling from nickel-bearing batteries on alleviating demand-supply gap in China's industry of new energy vehicles, Resour. Conserv. Recycl. 170 (2021) 7.
[58] A. Mayyas, D. Steward, M. Mann, The case for recycling: overview and challenges in the material supply chain for automotive li-ion batteries, Sustain. Mater. Technol. 19 (2019).
[59] J.F. Xiao, J. Li, Z.M. Xu, Novel approach for in situ recovery of lithium carbonate from spent lithium ion batteries using vacuum metallurgy, Environ. Sci. Technol. 51 (2017) 11960–11966.
[60] P.F. Yao, X.H. Zhang, Z.L. Wang, L.F. Long, Y.B. Han, Z. Sun, J.W. Wang, The role of nickel recycling from nickel-bearing batteries on alleviating demand-supply gap in China's industry of new energy vehicles, Resour. Conserv. Recycl. 170 (2021).
[61] H. Ku, Y. Jung, M. Jo, S. Park, S. Kim, D. Yang, K. Rhee, E.M. An, J. Sohn, K. Kwon, Recycling of spent lithium-ion battery cathode materials by ammoniacal leaching, J. Hazard Mater. 313 (2016) 138–146.
[62] Y. Luo, C.Z. Yin, L.M. Ou, C.Y. Zhang, Highly efficient dissolution of the cathode materials of spent Ni-Co-Mn lithium batteries using deep eutectic solvents, Green Chem. 24 (2022) 6562–6570.
[63] H. Jin, J.L. Zhang, C. Yang, L.L. Ma, Y.Q. Chen, C.Y. Wang, Selective recovery of lithium from spent LiFePO4 battery via a self-catalytic air oxidation method, Chem. Eng. J. 460 (2023) 10.
[64] L. Albertsen, J.L. Richter, P. Peck, C. Dalhammar, A. Plepys, Circular business models for electric vehicle lithium-ion batteries: an analysis of current practices of vehicle manufacturers and policies in the EU, Resour. Conserv. Recycl. 172 (2021) 15.
[65] H.Y.J. Lee, D. Lim, B.R. Lee, J.W. Gu, Y. Choi, H. Lim, What is the optimized cost for a used battery?: economic analysis in case of energy storage system as 2nd life of battery, J. Clean. Prod. 374 (2022) 10.
[66] J.B. Dunn, L. Gaines, J. Sullivan, M.Q. Wang, Impact of recycling on cradle-to-gate energy consumption and greenhouse gas emissions of automotive lithium-ion batteries, Environ. Sci. Technol. 46 (2012) 12704–12710.
[67] E.C. Wang, J.Y. Nie, Y.H. Wang, Government subsidy strategies for the new energy vehicle power battery recycling industry, Sustainability 15 (2023) 18.
[68] Y.Y. Tang, Q. Zhang, Y.M. Li, G. Wang, Y. Li, Recycling mechanisms and policy suggestions for spent electric vehicles' power battery -A case of Beijing, J. Clean. Prod. 186 (2018) 388–406.
[69] Y. Choi, S.W. Rhee, Current status and perspectives on recycling of end-of-life battery of electric vehicle in Korea (Republic of), Waste Manage. (Tucson, Ariz.) 106 (2020) 261–270.
[70] V. Noudeng, N. Van Quan, T.D. Xuan, A future perspective on waste management of lithium-ion batteries for electric vehicles in Lao PDR: current status and challenges, Int. J. Environ. Res. Publ. Health 19 (2022) 22.
[71] J.M. Chen, W. Zhang, B.A. Gong, X.Q. Zhang, H.P. Li, Optimal policy for the recycling of electric vehicle retired power batteries, Technol. Forecast. Soc. Change 183 (2022) 12.

[72] K. Liu, C.X. Wang, The impacts of subsidy policies and channel encroachment on the power battery recycling of new energy vehicles, Int. J. Low Carbon Technol. 16 (2021) 770–789.
[73] J.Z. Li, F.B. Liu, J.Z. Zhang, Z.P. Tong, Optimal configuration of electric vehicle battery recycling system under across-network cooperation, Appl. Energy 338 (2023).
[74] J.Z. Li, Y.Y. Ku, C.L. Liu, Y.P. Zhou, Dual credit policy: promoting new energy vehicles with battery recycling in a competitive environment? J. Clean. Prod. 243 (2020) 14.
[75] Q.Q. Sun, H. Chen, R.Y. Long, Q.W. Li, H. Huang, Comparative evaluation for recycling waste power batteries with different collection modes based on Stackelberg game, J. Environ. Manag. 312 (2022) 12.
[76] X. Li, J.B. Du, Y.W. Cheng, S. Hanif, D. Mu, Y.M. Cui, Electric vehicle battery recycling: system dynamics game based analysis for the influencing factors, Environ. Eng. Manag. J. 18 (2019) 1123–1136.
[77] X. Zhao, B.H. Peng, C.Y. Zheng, A.X. Wan, Closed-loop supply chain pricing strategy for electric vehicle batteries recycling in China, Environ. Dev. Sustain. 24 (2022) 7725–7752.
[78] L. Huang, M. Zhou, J. Lv, K. Chen, Trends in global research in forest carbon sequestration: a bibliometric analysis, J. Clean. Prod. 252 (2020).
[79] J. Yang, F. Gu, J.F. Guo, Environmental feasibility of secondary use of electric vehicle lithium-ion batteries in communication base stations, Resour. Conserv. Recycl. 156 (2020).
[80] D. Strickland, L. Chittock, D.A. Stone, M.P. Foster, B. Price, Estimation of transportation battery second life for use in electricity grid systems, IEEE Trans. Sustain. Energy 5 (2014) 795–803.
[81] A. Assunçao, P.S. Moura, A.T. de Almeida, Technical and economic assessment of the secondary use of repurposed electric vehicle batteries in the residential sector to support solar energy, Appl. Energy 181 (2016) 120–131.
[82] D.H. Qiao, T. Dai, G.S. Wang, Y.L. Ma, H.L. Fan, T.M. Gao, B.J. Wen, Exploring potential opportunities for the efficient development of the cobalt industry in China by quantitatively tracking cobalt flows during the entire life cycle from 2000 to 2021, J. Environ. Manag. 318 (2022).
[83] J.L. Yang, W. Chen, Unravelling the landscape of global cobalt trade: patterns, robustness, and supply chain security, Resour. Pol. 86 (2023).
[84] M.A. Rajaeifar, P. Ghadimi, M. Raugei, Y.F. Wu, O. Heidrich, Challenges and recent developments in supply and value chains of electric vehicle batteries: a sustainability perspective, Resour. Conserv. Recycl. 180 (2022).
[85] B. Atanu, T. Asit, R.K. Padhy, A. Gautam, Evaluating the lithium-ion battery recycling industry in an emerging economy: a multi-stakeholder and multi-criteria decision-making approach, J. Clean. Prod. 331 (2022).
[86] S.Q. Sun, C.X. Jin, W.Z. He, G.M. Li, H.C. Zhu, J.W. Huang, Management status of waste lithium-ion batteries in China and a complete closed-circuit recycling process, Sci. Total Environ. 776 (2021).
[87] F. Liu, J. Tang, A. Rustam, Z. Liu, Evaluation of the central and local power batteries recycling policies in China: a PMC-Index model approach, J. Clean. Prod. 427 (2023).
[88] J. Neumann, M. Petranikova, M. Meeus, J.D. Gamarra, R. Younesi, M. Winter, S. Nowak, Recycling of lithium-ion batteries-current state of the art, circular economy, and next generation recycling, Adv. Energy Mater. 12 (2022).
[89] A. Nurdiawati, T.K. Agrawal, Creating a circular EV battery value chain: end-of-life strategies and future perspective, Resour. Conserv. Recycl. 185 (2022) 14.
[90] Y.Y. Tang, Q. Zhang, Y.M. Li, H.L. Li, X.Z. Pan, B. McLellan, The social-economic-environmental impacts of recycling retired EV batteries under reward-penalty mechanism, Appl. Energy 251 (2019) 16.
[91] G.S. Jyoti, J., Lithium Ion Battery Manufacturers | Battery Recycling Companies India, JMK Research & Analytics, 2019.
[92] H.M. Zhang, J.Y. Huang, R.H. Hu, D.Q. Zhou, H.U.R. Khan, C.X. Ma, Echelon utilization of waste power batteries in new energy vehicles: review of Chinese policies, Energy 206 (2020).
[93] Y.Y. Tang, Q. Zhang, B.Y. Liu, Y. Li, R.Y. Ni, Y. Wang, What influences residents' intention to participate in the electric vehicle battery recycling? Evidence from China, Energy 276 (2023).
[94] M.Y. Chen, X.T. Ma, B. Chen, R. Arsenault, P. Karlson, N. Simon, Y. Wang, Recycling end-of-life electric vehicle lithium-ion batteries, Joule 3 (2019) 2622–2646.
[95] B. Makuza, Q.H. Tian, X.Y. Guo, K. Chattopadhyay, D.W. Yu, Pyrometallurgical options for recycling spent lithium-ion batteries: a comprehensive review, J. Power Sources 491 (2021) 21.
[96] W. Guo, T. Feng, W. Li, L. Hua, Z.H. Meng, K. Li, Comparative life cycle assessment of sodium-ion and lithium iron phosphate batteries in the context of carbon neutrality, J. Energy Storage 72 (2023).
[97] S. Trivedi, V. Pamidi, S.P. Bautista, F.N.A. Shamsudin, M. Weil, P. Barpanda, D. Bresser, M. Fichtner, Water-soluble inorganic binders for lithium-ion and sodium-ion batteries, Adv. Energy Mater. 14 (2024).
[98] M. Armand, P. Axmann, D. Bresser, M. Copley, K. Edström, C. Ekberg, D. Guyomard, B. Lestriez, P. Novák, M. Petranikova, W. Porcher, S. Trabesinger, M. Wohlfahrt-Mehrens, H. Zhang, Lithium-ion batteries - current state of the art and anticipated developments, J. Power Sources 479 (2020).
[99] K. Meng, G.Y. Xu, X.H. Peng, K. Youcef-Toumi, J. Li, Intelligent disassembly of electric-vehicle batteries: a forward-looking overview, Resour. Conserv. Recycl. 182 (2022) 26.
[100] J.R. Croy, B.R. Long, M. Balasubramanian, A path toward cobalt-free lithium-ion cathodes, J. Power Sources 440 (2019).
[101] J.L. Jiao, Z.T. Pan, J.J. Li, Effect of carbon trading scheme and technological advancement on the decision-making of power battery closed-loop supply chain, Environ. Sci. Pollut. Res. 30 (2023) 14770–14791.
[102] J. Neubauer, A. Pesaran, The ability of battery second use strategies to impact plug-in electric vehicle prices and serve utility energy storage applications, J. Power Sources 196 (2011) 10351–10358.
[103] W. Qi, Y.L. Zhang, N.W. Zhang, Scaling up electric-vehicle battery swapping services in cities: a joint location and repairable-inventory model, Manag. Sci. (2023) 22.
[104] X. Hu, Z.J. Yang, J. Sun, Y.L. Zhang, Optimal pricing strategy for electric vehicle battery swapping: pay-per-swap or subscription? Transp. Res. Pt. e-Logist. Transp. Rev. 171 (2023) 22.
[105] X. Yang, C.F. Shao, C.X. Zhuge, M.D. Sun, P.X. Wang, S.Q. Wang, Deploying battery swap stations for shared electric vehicles using trajectory data, Transport. Res. Part D-Transport, Environ. Times 97 (2021).
[106] G. Adu-Gyamfi, H.M. Song, B. Obuobi, E. Nketiah, H. Wang, D. Cudjoe, Who will adopt? Investigating the adoption intention for battery swap technology for electric vehicles, Renewable Sustainable Energy Rev. 156 (2022).