Circular economy strategy for waste management companies of electric vehicle batteries in Indonesia

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Abstract

Purpose – Electric vehicle (EV) battery waste is hazardous to human health and the environment. However, it also contains recoverable materials that can hold high value for the sustainability of the EV battery industry. Given the increasing sales of EVs and Indonesia's ambition to become an EV leader in Asia, proper management of EV battery waste becomes crucial. This study seeks to develop strategies for Indonesian-based EV battery waste management companies to support the country's growing EV adoption and advance the principles of a circular economy (CE).

Design/methodology/approach – Data collection combines semi-structured interviews, surveys and site visits. The research instruments are based on the conceptual framework of CE and strategic management. Data processing is conducted using strengths-weaknesses-opportunities-threats (SWOT) analysis, internal factor evaluation (IFE) and external factor evaluation (EFE) analysis.

Findings – The findings reveal that the Indonesian government has established regulations to classify and handle hazardous waste and published a roadmap for CE implementation. Three strategies have been formulated 1) joint ventures with foreign waste management companies, 2) cooperation with automakers as a third-party EV battery waste manager and 3) establish an EV battery repair shop. Waste management companies are encouraged to progressively enhance their battery repair, reuse, repurposing, refurbishing and recycling capabilities.

Research limitations/implications – This study offers strategic insights for waste management companies to optimize EV battery waste management.

Practical implications – This study offers practical implications for waste management companies and policymakers to enhance EV battery waste management, align with circular economic principles (particularly second-life applications) and create new revenue streams.

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Originality/value – This research contributes to environmental protection, employment opportunities and EV adoption by strengthening Indonesia's battery waste management industry and providing policy recommendations.

Keywords Circularity, Battery second life, Sustainability, Electric vehicle, Waste management

Paper type Research paper

1. Introduction

Environmental issues, especially air pollution, are the main driving factors behind the adoption of electric vehicle (EV) technology for transportation (Pamidimukkala *et al.*, 2024). Various countries are pushing for the accelerated adoption of EVs and banning internal combustion engine vehicles (ICEVs), as seen in regions like the EU and countries like Japan, the US, and China (Kito *et al.*, 2024; Wu *et al.*, 2021; European Commission, 2022). Currently, there are more than 40 million electric cars in use globally (Ritchie, 2024), and electric car sales are projected to keep rising, potentially reaching around 17 million sales in 2024, accounting for more than one in five cars sold worldwide (IEA, 2024a). This is undoubtedly good news for reducing air pollution. However, within the next 8–15 years, unused EV batteries will become waste, posing a new environmental problem (Abdelbaky *et al.*, 2020). An experiment even shows an even faster lifespan of batteries in EVs, ranging from only 3.5–7 years, depending on their usage (Makaramani *et al.*, 2023). Similarly, the IEA (2024a) predicts that EV battery waste is expected to grow rapidly in the 2030s, and the battery reuse and recycling industry must be ready to handle the emerging EV battery waste.

Proper EV battery waste management is essential in protecting the environment and human health and helping mitigate the demand for critical minerals. EV batteries contain hazardous and toxic chemicals that, without proper treatment, can pollute the air, water, and soil, disrupting ecosystems (Permatasari *et al.*, 2023). Based on calculations with the Ecoindicator 99 H/A, batteries have a negative impact of around 15% on human health, ecosystem quality, and resources during their life cycle (Setyoko *et al.*, 2023). For human health, materials in batteries can pose toxic risks (Noudeng *et al.*, 2022), including:

(1) Lithium: affects hematopoietic stem cell differentiation and glycogen synthesis during fetal development,

(2) Manganese: damage neurological systems and contribute to conditions such as Parkinson's disease,

(3) Nickel: induces lung fibrosis, renal dysfunction, cardiovascular ailments, and respiratory tract malignancies, and

(4) Cobalt: causes inflammatory lung responses and allergic skin reactions.

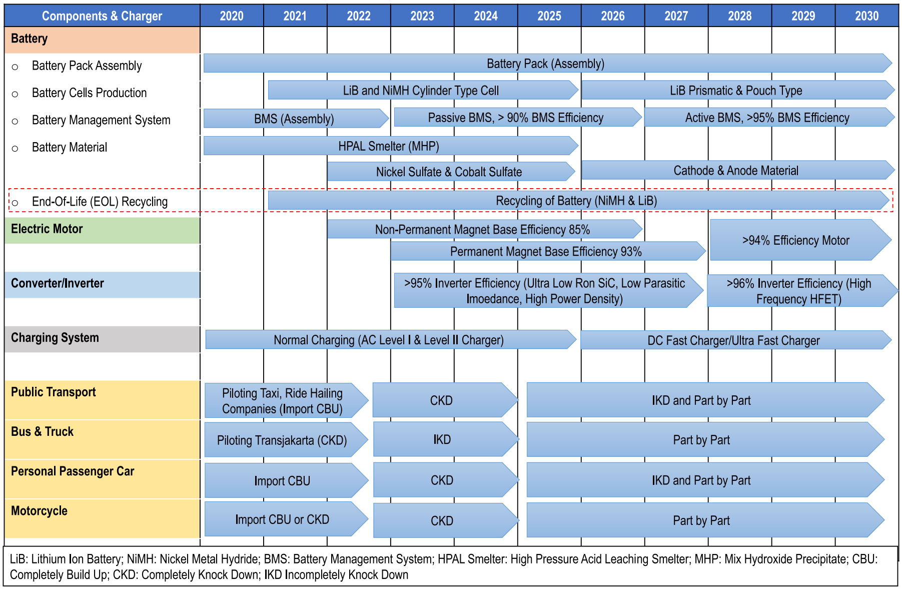
Moreover, according to Maisel *et al.* (2023), by 2040, the demand for lithium, cobalt, and nickel for lithium-ion batteries in EVs only, will exceed current raw material production, with lithium and cobalt demand potentially being up to eight times today's production.

Besides mining, effective end-of-life (EOL) strategies that encompass reuse and recycling must be put in place to make supply chains circular and help mitigate critical mineral demand (IEA, 2024b). After their retirement from EVs, available options for LIBs include battery second use, repair of electrode materials by direct regeneration, and material recovery through hydrometallurgical or pyrometallurgical processes (Maisel *et al.*, 2023). According to Cramer (2020), once a product has been used, it must consider all types of product reuse alternatives, including repurposing and refurbishing, called Circular Economy (CE). CE operationalization requires a paradigm shift where new value networks enable returned products to be reused, recycled, and repaired, as Awan *et al.* (2022) emphasize. The CE is a solution that can be applied to the problem of EV battery waste management. CE is an economic concept that aims to maximize resource utilization by reducing waste, extending the useful life of products, reusing and recycling materials (Morseletto, 2020). In this context, EV batteries are not used once and then thrown away, but batteries have second life through reused and recycled in a continuous cycle of use. The CE can help reduce the demand for limited raw materials, reduce environmental pollution, and extend the life of materials in the supply chain (Gaustad *et al.*, 2018). To support these EOL strategies, policymakers and companies must collaborate to integrate CE principles into the closed-loop supply chain. As Awan *et al*. (2021) highlight, companies should be actively involved in determining their role within the circular system, while policymakers should establish feedback mechanisms that facilitate resilient and adaptive CE strategies. Policymakers also need to incentivize the development of cost-effective and efficient technologies while endorsing standardization policies to mitigate technological barriers for second-use batteries (Gautam and Bolia, 2024).

Second-life batteries are batteries that are applied for a different use after their initial life cycle is over (Chirumalla *et al*., 2023; Meyer *et al*., 2024). Several studies have highlighted the potential of second-life EV batteries. For instance, reusing a single 20 kWh EV battery pack can be repurposed to produce 11 starter batteries for ICEVs (Chirumalla *et al*., 2023). Additionally, retired EV batteries can be utilized for stationary energy storage, providing reliable solutions for energy demand (Albertsen *et al*., 2021). In India, Chauhan *et al*. (2024) found that the lifespan of first-life batteries in EV applications ranges from 3.5 to 7 years, with an energy storage potential between 1,300 and 1870 GWh—equivalent to 17%–39% of the daily renewable energy generation in India projected for 2038. A study by Sarker *et al*. (2024) in Malaysia demonstrated that second-life EV batteries integrated into home photovoltaic (PV) systems have a lower total cost of ownership, achieving 12.62% savings and a CO2 emission reduction of at least 20% compared to new Lead–Acid Batteries. Reusing EV batteries in various applications can yield better economic and environmental benefits than recycling or disposing of them (Hua *et al*., 2021). If reuse is no longer viable, recycling to recover valuable materials becomes the next best alternative. Lithium, cobalt, and nickel have higher economic value than other battery materials (Hantanasirisakul and Sawangphruk, 2023). This recycling is also one of the measures to break down the excessive exploitation (mining) of nature, which causes environmental damage and can reduce the cost of producing raw materials by around 50–70% (Permatasari *et al*., 2023). Without proper waste management, there is potential harm to the environment and human health and a significant loss of valuable materials.

Indonesia is actively promoting the adoption and production of EVs and is committed to ensuring human health and environmental protection by establishing a battery reuse and recycling industry by 2030. The country is implementing various policies and incentives to foster the growth of eMobility (Habiburrahman *et al*., 2024; Lazuardy *et al*., 2024; Setyoko and Nurcahyo, 2023). The number of EVs in Indonesia has experienced a significant increase, with sales rising from 20,689 units in 2022 to 71,241 units in 2023 (Gaikindo, 2024). The adoption of EVs is expected to grow further as Indonesia plans to abandon the sales of ICE vehicles by 2040. In terms of production, Indonesia aims for alternative vehicles to account for 20% of total vehicle production by 2025 and aspires to become an EV manufacturing hub and leading battery producer in Asia (Doi *et al*., 2024). As EV sales continue to rise, the challenge of properly managing EV battery waste will become more pronounced in Indonesia (Nurdini *et al*., 2025; Santoso *et al*., 2024). According to Presidential Regulation 55/2019, to protect the environment, the handling of battery waste from EVs must be carried out by recycling and/or management by institutions, BEV industries, and/or domestic BEV component industries that have permits to manage battery waste from licensed BEVs in accordance with statutory regulations in the field of waste management. Furthermore, the roadmap for the development of the EV industry in Indonesia, as outlined in Minister of Industry Regulation 6/2022, targets the operation of the battery reuse and recycling industry by 2030 (Figure 1). Achieving this waste management target requires careful planning and preparation to ensure that the necessary infrastructure and regulations are in place.

Waste management in Indonesia currently faces numerous challenges. Sopha *et al*. (2022) identify three main issues: inefficient and inadequate government policy, lack of safety standards, and high recycling costs. Doi *et al*. (2024) also highlight that Indonesia has yet to formulate specific plans or regulations on battery waste management. While EV battery waste management is addressed in Presidential Regulation 55/2019, other technical and detailed regulations still categorize it under general hazardous waste (Mursalim and Susanto, 2022; Doi



Source(s): Minister of Industry Regulation No. 6/2022 concerning Technical Specifications, EV Roadmap, and Calculation of Domestic Local Content Levels

Figure 1. Roadmap for the development of the EV industry and its components in Indonesia

et al., 2024). The roadmap in Minister of Industry Regulation 6/2022 sets a target for the battery reuse and recycling industry to be operational by 2030, but it lacks detailed strategies for achieving this goal. Dewantoro *et al.* (2021) state that there are currently no standards related to the recycling of EV battery waste in Indonesia. While Automakers have not been transparent about how they handle EV battery waste (Putra *et al.*, 2024), no companies in Indonesia are specifically assigned to manage battery waste (Mursalim and Susanto, 2022). Furthermore, the technology also poses a significant challenge in managing EV battery waste (Satriadi *et al.*, 2024). To address these issues, it is essential to provide adequate battery waste treatment facilities and systems before increasing the use of EVs (Maghfiroh *et al.*, 2021).

Prior studies have examined various aspects of EV battery waste management in Indonesia. Sopha *et al.* (2022) compiled and analyzed the barriers, enablers, stakeholders, and business models associated with CE implementation in EV battery management. Other research also addresses policies (Doi *et al.*, 2024; Jamaluddin *et al.*, 2022), awareness among automakers and the public (Putra *et al.*, 2024), reuse applications (Arifidin, 2021), recycling technology (Satriadi *et al.*, 2024; Permatasari *et al.*, 2023; Wasesa *et al.*, 2022), and standardization (Dewantoro *et al.*, 2021). Researchers have also studied EV battery waste management, such as the study from Syahr and Putra (2023) on the role of the informal sector, Munawir *et al.* (2023) on the identification of related stakeholders and Basuki *et al.* (2022) on sustainable transportation routes. However, there is still limited research on the role of waste management companies in managing EV battery waste, particularly regarding the second use and circularity of EV batteries.

Previous research highlights the critical role of waste management companies in managing EV battery waste. Given that EV batteries are often returned to entities outside the OEM's control after the warranty period, external companies are becoming increasingly relevant in this process (Meyer *et al.*, 2024). Lee *et al.* (2024) assert that these companies play a central role in the circular governance of waste batteries, acting as key actors in promoting sustainable practices. With the growing adoption of EVs, more companies are expected to enter the recycling space, further emphasizing the need for enhanced collaboration and knowledge sharing to improve recycling efficiency and battery technology (Antony *et al.*, 2024). Establishing trusted partnerships is also essential to meet the high safety standards required by customers (Meyer *et al.*, 2024). While the recycling industry often garners significant attention, the reuse industry deserves greater focus to maximize the lifespan of batteries and promote a more sustainable approach to resource utilization (Lee *et al.*, 2024). In developing countries like Indonesia, the waste management landscape is shaped by the involvement of both formal and informal sectors, highlighting the critical need for effective oversight and regulation to ensure proper management practices (Sopha *et al.*, 2022). Therefore, studying the role of waste management companies in EV battery waste management is crucial to advancing CE practices and ensuring long-term sustainability.

With the rapid growth in EV adoption in Indonesia and the government's target to establish an EV battery reuse and recycling industry, as well as to become an EV battery hub in Southeast Asia, addressing the challenge of retired EV battery waste has become critical. The main research question in this study is: What strategies can waste management companies in Indonesia implement to manage emerging retired EV batteries and support the CE? This research aims to formulate strategies for Indonesian EV battery waste management companies, focusing on extending battery life through repair, reuse, repurpose, and refurbishment as steps toward advancing the implementation of a CE in Indonesia. The study employs qualitative methodologies using strategic management theory. By bridging the gap in understanding EV battery waste management in a developing country context, this study contributes theoretically to the literature on CE practices and waste management in emerging economies. Practically, it provides valuable insights for policymakers and industry practitioners aiming to enhance sustainability in the EV and waste management sectors.

The outline of this paper includes five sections. In Section 1, we explain the background of the study and identify the research gap. In section 2, we review the conceptual framework and relevant studies, providing context and grounding for our research. In section 3, we discuss the methodology. In Section 4, we present and discuss the findings, interpreting the results in the context of the existing literature and the research objectives. Finally, in Section 5, we offer conclusions, managerial and practical implications, discuss the limitations of the study, and suggest directions for future research.

2. Conceptual framework and relevant literature

2.1 Waste management and circular economy

Waste management is defined as controlling waste-related activities to protect the environment and human health and encourage resource conservation (Pongrácz and Pohjola, 2004). Poor waste management leads to soil, rivers, and air pollution, causing severe health impacts, particularly among those living close to waste sites (Ghosh, 2020). Waste management is also crucial for the secondary use of key materials in pursuing two objectives: prevention of resource depletion and security of supply (Di Maria, 2020). In this context, the concept of waste management has evolved to cover the entire scope of resource circulation and closed-loop systems, pollution reduction in water, air, and land, resource conservation, greening of manufacturing sectors, and many other activities, known as the Circular Economy (CE) (Ghosh, 2020).

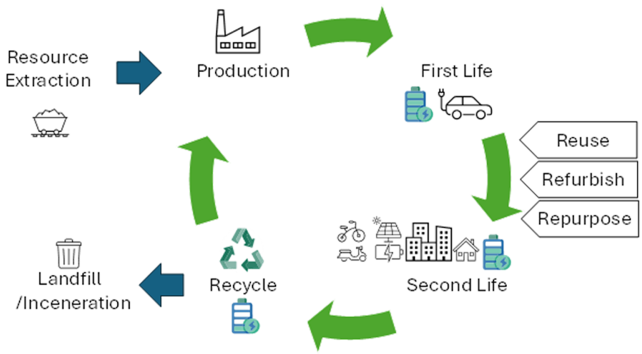
The CE is often referred to as a closed loop, as opposed to the "take-make-dispose" approach in a linear economy. According to Mitchell (2015), a CE is "an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extracting the maximum value from them while in use, then recovering and reusing products and materials." The European Commission (2015) defines a CE as "an economy where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste minimized. The transition to a more CE would make an essential contribution to the EU's efforts to develop a sustainable, low-carbon, resource-efficient, and competitive economy." A CE keeps products and materials in use, regenerates natural systems, and designs out waste and pollution through business and design principles (Ellen MacArthur Foundation, 2019). A CE goes beyond recycling and is based on a restorative industrial system focused on treating waste as a resource. Whenever a product reaches the end of its useful life, an attempt is made to keep the materials within the production boundary and use them productively enough to create further value (Ellen MacArthur Foundation, 2015).

The growing popularity of EVs has led to an increase in the use of lithium-ion batteries, which require proper disposal strategies (Ramoni and Zhang, 2013). Managing EV battery waste poses challenges due to its hazardous nature (Ordoñez *et al.*, 2016). Proper EV battery waste management is essential in protecting the environment and human health (IEA, 2019). A good waste management policy prevents the elements contained in batteries from being exposed to humans and the environment (Melin, 2018) and develops the automotive and battery raw material industries (Li *et al.*, 2020). According to Abdelbaky *et al.* (2020), the life stage model of EV batteries includes production, first-use in EV, second-use application, and recycling (Figure 2). Currently, waste management policies only emphasize recycling efforts, and questions linger regarding how upcoming policies will accommodate recycling and other CE strategies like reuse and repurpose (Albertsen *et al.*, 2021). As a result, there are increasing calls to prepare for implementing more CE strategies within this sector, necessitating systemic adaptations (Parchomenko *et al.*, 2021).

Prior research elucidates the prospects of implementing a CE within the automotive industry, particularly considering the increasing global adoption of EVs; such an implementation is paramount for addressing environmental concerns and ensuring a stable supply of battery raw materials (Duarte Castro *et al.*, 2021; Malinauskaite *et al.*, 2021). The widespread adoption of lithium-ion batteries in EVs will necessitate increased natural resource utilization by the automotive industry, and CE practices can mitigate primary resource requirements (Baars *et al.*, 2021; Valladares Montemayor and Chanda, 2023). Furthermore, Drabik and Rizos (2018) posit that CE practices also potentially enhance a country's trade in key materials for EV batteries and contribute to increased employment. A CE additionally generates diverse business prospects for EV battery manufacturers, waste management companies, and other stakeholders (Rönkkö *et al.*, 2023).

2.2 Strategic management

According to David (2011), strategic management is the art and science of formulating, implementing, and evaluating cross-functional decisions that enable an organization to achieve its objectives. The benefit of strategic management is that it allows an organization to be more proactive than reactive in shaping its future; it enables an organization to initiate and influence (rather than just respond to) activities—and thus to exert control over its destiny. One common method to develop strategies is analyzing internal and external factors using the Strengths-



Source(s): Authors' own work

Figure 2. EV battery lifecycle

Weaknesses-Opportunities-Threats (SWOT) Matrix. These evaluations are important in strategy formulation because they provide the necessary insights and information to design strategies that capitalize on strengths, address weaknesses, seize opportunities, and mitigate threats while aligning with the organization's vision, mission, and goals (David, 2011).

Strategic management and SWOT analysis have been applied in various studies on the CE in different countries. Stylianou *et al*. (2024) have outlined strategies for Cyprus's industrial and manufacturing sectors, while Usapein *et al*. (2022) focused on the palm oil industry in Thailand. Similarly, Tumuyu and Marthalia (2023) proposed strategies for the agro-industry in Indonesia. Díaz-López *et al*. (2021) devised strategies for constructing buildings in Zorpas (2020) developed approaches for waste management in Europe. SWOT analysis is widely recognized for its dual qualitative and quantitative capabilities, which support policymakers, facilitate future decision-making, and aid in planning and developing strategies (Zorpas, 2020). The primary advantage of SWOT analysis lies in its simplicity, enabling a thorough understanding of the internal and external factors that influence the adoption of CE practices (Díaz-López *et al*., 2021). Additionally, the insights from SWOT analysis can inform stakeholders, promoting a more informed and collaborative approach to advancing CE initiatives (Stylianou *et al*., 2024).

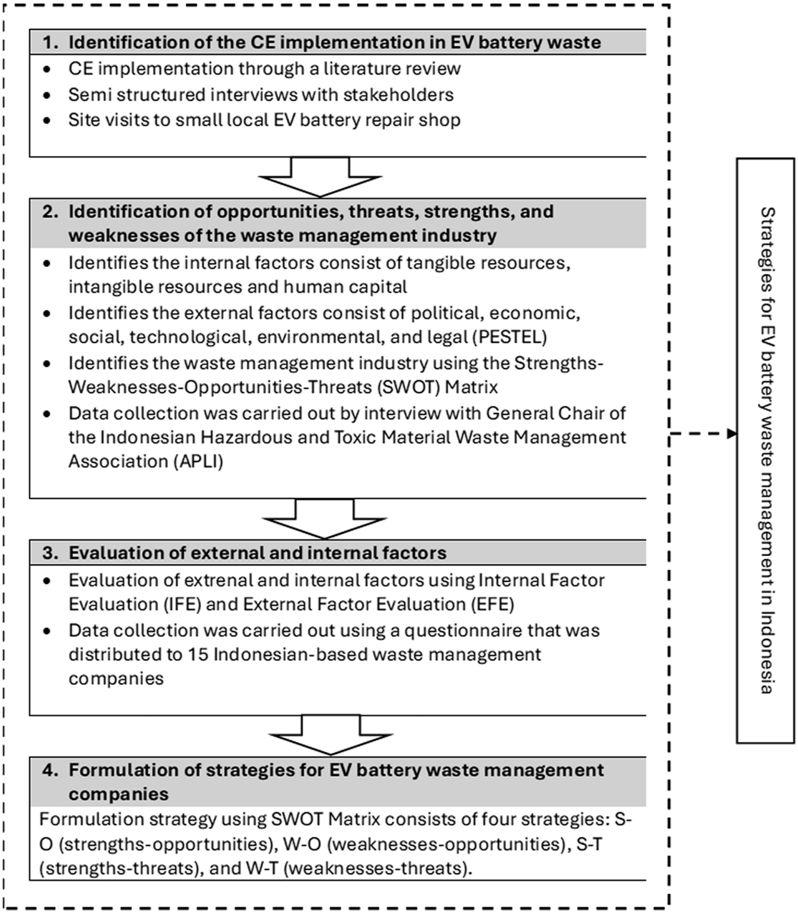
3. Methods

Data collection in this research combines semi-structured interviews, surveys with questionnaires, and site visits. The research instruments are based on the CE and strategic management conceptual framework. Data processing is conducted using SWOT analysis and quantification through Internal Factor Evaluation (IFE) and External Factor Evaluation (EFE) analysis. Figure 3 shows the research steps, and Table 1 shows the respondents and data collection process.

In step 1, we identified the CE implementation through a literature review, semi-structured interviews with stakeholders, and site visits. We visited a small, local EV battery repair shop to understand their repair process. Interviews and site visits were guided by instruments designed to achieve the expected goals.

Step 2 identifies the waste management industry by using the Strengths-Weaknesses-Opportunities-Threats (SWOT) Matrix, which helps develop strategies by analyzing internal and external factors (David, 2011). The internal factors consist of strengths and weaknesses, while the external factors consist of political, economic, social, technological, environmental, legal, cultural, demographic, governmental, and competitive factors. Interviews with the General Chair of the Indonesian Hazardous and Toxic Material Waste Management Association (APLI) were conducted to identify the external and internal factors. The analysis includes political, economic, social, technological, environmental, and legal (PESTEL) factors as external factors whereas tangible resources, intangible resources and human capital are internal factors. Data from the Ministry of Environment and Forestry's One Stop Service and APLI members were used.

In step 3, a questionnaire (supplementary material) was distributed to 15 Indonesian-based waste management companies to assess the priority level of SWOT factors. The external and internal factors in the scope of EV battery waste management was evaluated using the IFE and EFE. These evaluations are important in strategy formulation because they provide the necessary insights and information to design strategies that capitalize on strengths, address weaknesses, seize opportunities, and mitigate threats while aligning with organizations' vision, missions, and goals (David, 2011). The questionnaire was developed based on the results of the industrial factor analysis and included closed-ended questions with a 4-point Likert scale. It was sent to directors and operational managers of companies that hold permits for collecting, utilizing, and processing battery waste (the Republic of Indonesian Government Regulation Number 22/2021 lists battery waste as having the code B326-1).



Source(s): Authors' own work

Figure 3. The Research Steps

Lastly, for step 4, the identified strengths, weaknesses, opportunities, and threats form the foundation for strategy development. Balancing internal and external factors is crucial, and the SWOT Matrix is used for this purpose. The matrix consists of four strategies: S-O (strengths-opportunities), W-O (weaknesses-opportunities), S-T (strengths-threats), and W-T (weaknesses-threats). An S-O strategy uses internal strengths to capitalize on external opportunities; the W-O strategy focuses on leveraging external opportunities to address internal weaknesses; the S-T strategy utilizes strengths to mitigate external threats; and the W-T strategy addresses internal weaknesses and avoids external threats.

4. Results and discussion

4.1 CE implementation in EV battery waste in Indonesia

EV battery waste is classified as hazardous and toxic material waste according to President Regulation 55/2019 and Ministry of Environment and Forestry Regulation No. 6/2021; thus, management activities require permits. These activities encompass reduction, collection, transportation, utilization, processing, storage, and disposal. The government (Respondent

Table 1. List of respondents and data collection

Step	No	Type of organization	Means of data collection	Designation
Step 1	1	(R1) Government	Semi-structured interviews	Coordinator of Indonesia's Low Carbon Development and Circular Economy
	2	(R2) EV battery repair workshop	Site visit	Owner, technician
	3	(R3) Start-up EV conversion automotive company	Site visit	CEO and COO
	4	(R4) Vehicle research center at a university	Semi-structured interviews	Head of the research center
	5	(R5) Circular Economics Research Center, Government Research Agency	Semi-structured interviews	Head of the research center
	6	(R6) Waste management company	Semi-structured interviews	Business development manager
Step 2	7	Indonesian Hazardous and Toxic Waste Management Association	Semi-structured interviews	General Chair
Step 3	8	15 waste management companies	Questionnaire	Directors and operational managers

Source(s): Authors' own work

R1) recognizes the need for special attention to this type of waste due to its potential for environmental pollution, as highlighted in Government Regulation No. 27/2020. To promote awareness of CE practices, the government has published two books, one in 2021 detailing the benefits of CE in Indonesia and another in 2022 illustrating CE applications across various industries, including the automotive sector. Respondent R1 stated that no specific regulations exist for CE practices, which are currently integrated into existing hazardous waste management regulations. A roadmap for nationwide CE implementation was published in July 2024; however, the automotive sector was not included, and EV battery waste management was categorized under the electronics sector.

Producers are required to manage product waste under Government Regulation No. 81/2012, however, the implementation of Extended Producer Responsibility (EPR) remains voluntary. Producers of EVs in Indonesia are responsible for managing their battery waste either internally or by appointing third-party waste management companies. Some automakers have initiated partnerships with third-party waste management companies to address battery waste. For example, Hyundai collaborates with PT Arah Environmental Indonesia, a licensed hazardous waste management firm (Makmun, 2023). Suzuki Indonesia requires customers to return used batteries to authorized workshops, which are then sent to a third party with a permit for hazardous waste management (Suzuki Indonesia, 2022). Meanwhile, Toyota has established a dedicated team to handle EV battery waste and plans to build facilities in line with the growing volume of battery waste (Sukma, 2022). Another automaker, Wuling Indonesia, claimed that despite having EV battery storage facilities, they have not designated a location to manage used EV batteries (Sihombing, 2022). According to Respondent R6, a waste management company is currently studying the development of a new division dedicated to recycling EV batteries. The company is focused on establishing infrastructure for testing, dismantling, and recycling batteries but has no plans to explore reuse initiatives at this stage.

The adoption of CE principles among industry stakeholders remains limited. Respondent R3, representing an EV conversion startup, noted that there is currently no pressure or incentives to implement CE practices during EV assembly. They suggested that CE might only become a government program once EV battery waste becomes more prominent. Similarly, Respondent R4 from a university research center mentioned that CE is still largely conceptual and not widely understood by stakeholders. The respondent emphasized that waste management activities, especially CE initiatives, are often not seen as profitable, highlighting the need for government incentives to drive adoption.

Respondent R5, from a government research agency focusing on CE, explained that while the term “circular economy” has been adopted, its application is mostly limited to basic activities such as waste reduction, reuse, and recycling, with small-scale initiatives. For EV batteries specifically, practical implementation remains minimal, with most CE efforts being applied to other materials, such as transforming rice husks into briquettes. The respondent stressed the importance of creating a shared understanding of CE principles among all stakeholders to ensure effective implementation.

We conducted a site visit to a small, informal EV battery repair workshop to observe its operations (Figure 4). The workshop, located in a garage, is run by a single owner knowledgeable in electrical engineering. Through trial and error, the owner has acquired the necessary skills and equipment to repair EV batteries. Typically, he handles hybrid car batteries that have issues with one or two cells causing voltage drops and triggering sensor notifications. He identifies problematic cells and replaces them with functioning ones using his equipment. Customers are offered choices between new or used cell batteries in good condition or refurbished ones. Customers prefer this repair shop because of its lower prices than authorized repair shops, which require whole battery replacements costing 30–60 million IDR for a hybrid car compared to the workshop, only charging around 3–6 million IDR per damaged cell (Respondent R2).

In Indonesia, the waste management landscape reflects the findings of Sopha *et al.* (2022), where both formal and informal sectors play a significant role in waste management. The government is suggested to provide guidance and support for business development in the informal sector to ensure their operations align with safety standards, environmental protection measures, and product quality requirements.

4.2 Waste management companies' SWOT

In this research, external factors analysis was carried out using PESTEL analysis to identify industrial aspects through interviews with the General Chair of APLI. Each aspect has an influence on the battery waste management business. Internal factors analysis is classified into three categories: tangible resources, intangible resources, and human capital. Internal and external factors are provided in Table 2.

(a) **(b)**

Source(s): Authors' own work

Figure 4. The small EV battery repair shop. (a) Battery being repaired and (b) testing which modules and cells are malfunctioning

Table 2. Internal and external factors of the battery waste management industry

Strength (S)	Weakness (W)
Availability of investment in building a waste management business (S1)	Company profitability in running a waste management business (W1)
Capability of operating costs in running a waste management business (S2)	Waste management technology following the development of science and technology (W2)
Company legality following applicable laws (S3)	Workers with certificates of competence in waste management technology (W3)
Company internal policies regarding the fulfillment of waste management technical requirements (S4)	Cooperation with the Government (W4)
Condition of facilities and infrastructure (waste facilities, laboratories, equipment, materials, and transportation means) to support waste management (S5)	EPR Program or private cooperation in waste management (W5)
Location, layout, design, capacity, and coordinates of waste facilities according to waste management technical requirements (S6)	Cooperation with Nongovernmental Organizations (NGOs) or Community Organizations in waste management (W6)
Environmental Impact Analysis (S7)	

Opportunity (O)	Threat (T)
Support for licensing services and emergency management of hazardous and toxic material waste management (O1)	Financial support (either incentives or subsidies) from the government (T1)
Availability of regulations related to waste management (O2)	Company external investment support (T2)
Harmonization of central and regional regulations related to waste management (O3)	Waste management technology transfer from the government (T3)
National and international standards of waste management technology (O4)	Waste management technology transfer from universities (T4)
Private Corporate Social Responsibility (CSR) Program related to waste management (O5)	Waste management technology transfer from the private sector (T5)
Total battery waste generation rate (O6)	Public awareness regarding waste management (T6)
Public health conditions around the waste facility (O7)	Government socialization regarding waste management (T7)
Environmental quality around the waste facility (O8)	Dissemination of waste management information from print or electronic media (T8)

Source(s): Authors’ own work

4.3 Evaluation of external and internal factors

The evaluation of external and internal factors involves assigning weights to the identified factors and calculating their weighted scores. The ratings are: 4 representing superior, 3 representing above average, 2 representing average, and 1 representing poor. The questionnaire was administered by telephone to 15 respondents. The majority of respondents (46.7%) held operational management positions, followed by directors (40%). Most respondents (40%) had 11–15 years of experience, and 86.7% of the total respondents held bachelor’s degrees.

The EFE analysis findings indicate that the battery waste management industry has a strong external position to address the challenges associated with EV battery waste. The weighted score for the external factor evaluation was 3.426. Among the identified opportunities, the top-ranking opportunity is the favorable environmental quality around waste facilities (O8), as waste management facilities in Indonesia are situated in areas distant from residential zones. The second-ranked opportunity is the projected increase in the total battery waste generation rate (O6), suggesting a growing quantity of waste that presents a favorable opportunity for waste management companies. The rankings of external factors are shown in Table 3.

Table 3. Rankings of external factor

Rank	External factor (opportunity)	Weight	Rating	Weighted score
1	Environmental quality around the waste facility (O8)	0.072	4.000	0.288
2	Total battery waste generation rate (O6)	0.073	3.933	0.287
3	Public health conditions around the waste facility (O7)	0.071	3.933	0.279
4	Availability of regulations related to waste management (O2)	0.070	3.933	0.275
5	Harmonization of central regulations and regional regulations related to waste management (O3)	0.068	3.933	0.267
6	Support for licensing services and emergency management of hazardous and toxic materials waste (O1)	0.069	3.600	0.248
7	Private Corporate Social Responsibility (CSR) Program related to waste management (O5)	0.065	3.533	0.230
8	National and international standards of waste management technology (O4)	0.065	3.467	0.225
Rank	**External factor (threat)**	**Weight**	**Rating**	**Weighted score**
1	Company external investment support (T2)	0.060	3.267	0.196
2	Waste management technology transfer from the Government (T3)	0.062	3.133	0.194
3	Government socialization regarding waste management (T7)	0.060	3.133	0.188
4	Dissemination of waste management information either from print or electronic media (T8)	0.055	3.000	0.165
5	Waste management technology transfer from private sector (T5)	0.056	2.933	0.164
6	Waste management technology transfer from universities (T4)	0.052	2.800	0.146
7	Financial support (either incentives or subsidies) from the Government (T1)	0.052	2.800	0.146
8	Public awareness regarding waste management (T6)	0.050	2.533	0.127
	Total External Factor	*1*		*3.426*

Source(s): Authors' own work

The main threat to Indonesian waste management companies is the lack of external investment support (T2). These companies require significant financial resources to expand and stay updated with technological advancements. Unfortunately, they often struggle to secure investments from external sources. Additionally, in the second-ranked threat, respondents expressed concerns about the transfer of waste management technology, which hampers the effective management of EV battery waste.

The IFE score of 3.817 indicates that Indonesia's battery waste management industry has a strong internal condition and significant potential for future development. The key strengths of waste management companies are the availability of facilities and infrastructure to support waste management (S5) and adherence to waste management technical requirements (S6). The rankings of internal factors are shown in Table 4. Companies' main weakness is the EPR program or private cooperation in waste management (W5), which indicates that companies have not yet cooperated with other actors in waste management.

4.4 Strategy formulation

After obtaining the strengths, weaknesses, opportunities, and threats, the battery waste management industry's internal and external factors are matched into a SWOT matrix (Table 5).

This study focuses on real-world settings in Indonesia, where waste management companies with government permissions handle EV battery waste. Moreover, some automakers delegate

Table 4. Rankings of internal factors

Rank	Internal factor (strength)	Weight	Rating	Weighted score
1	Condition of facilities and infrastructure (waste facilities, laboratories, equipment, materials, and transportation means) in supporting waste management (S5)	0.084	4.000	0.336
2	Location, layout, design, capacity, and coordinates of waste facilities following waste management technical requirements (S6)	0.083	4.000	0.332
3	Company legality following applicable laws (S3)	0.082	4.000	0.328
4	Company's internal policies regarding the fulfillment of waste management technical requirements (S4)	0.080	4.000	0.320
5	Availability of investment in building a waste management business (S1)	0.079	4.000	0.316
6	Environmental Impact Analysis (S7)	0.078	4.000	0.312
7	The capability of operating costs in running a waste management business (S2)	0.080	3.867	0.309

Rank	Internal factor (weakness)	Weight	Rating	Weighted score
1	Extended producers responsibility (EPR) Program or private cooperation in waste management (W6)	0.077	3.800	0.293
2	Company profitability in running a waste management business (W1)	0.077	3.733	0.287
3	Cooperation with the Government in waste management (W5)	0.078	3.600	0.281
4	Workers who have a certificate of competence in waste management technology (W4)	0.078	3.533	0.276
5	Waste management technology following the development of science and technology (W2)	0.070	3.533	0.247
6	Cooperation with Non-Governmental Organizations (NGOs) or Community Organizations in waste management (W7)	0.054	3.333	0.180
	Total Internal Factor	*1*		*3.817*

Source(s): Authors' own work

Table 5. The Three developed strategies

S-O strategy	W-O strategy
Establish an EV battery repair workshop (S1, S3, S6; O1, O6)	Cooperation with automakers as third-party waste managers (W6, W1; O6)

S-T strategy	W-T strategy
Joint ventures with foreign companies (S2, S5, S6; T1, T2, T5)	–

Source(s): Authors' own work

the management of their waste to other companies. Therefore, this study provides recommended strategies for Indonesian-based waste management companies. This study highlights the importance of extending the lifespan of EV battery waste through circular strategies that prioritize reuse over recycling.

4.4.1 First thing first: increase company capability. Due to Indonesia's early adoption of EVs, batteries are in their initial use and the issue of EV battery waste recycling has not yet emerged. Large-scale recycling is not economically feasible because of the relatively small volume of waste. Instead of immediately focusing on recycling, exploring ways to extend battery life is recommended. Furthermore, recycling technology is experiencing rapid growth, allowing waste management companies to gradually build their expertise and determine which specific recycling technologies will be adopted in the future. Therefore, waste management organizations should progressively enhance their skills in repairing, reusing, repurposing, and refurbishing batteries.

A waste management company needs expertise in three key areas:

(1) Diagnosing Damaged Cell Batteries: investing in the necessary equipment and expertise for accurate diagnosis, which involves conducting various tests to identify specific issues, is required.

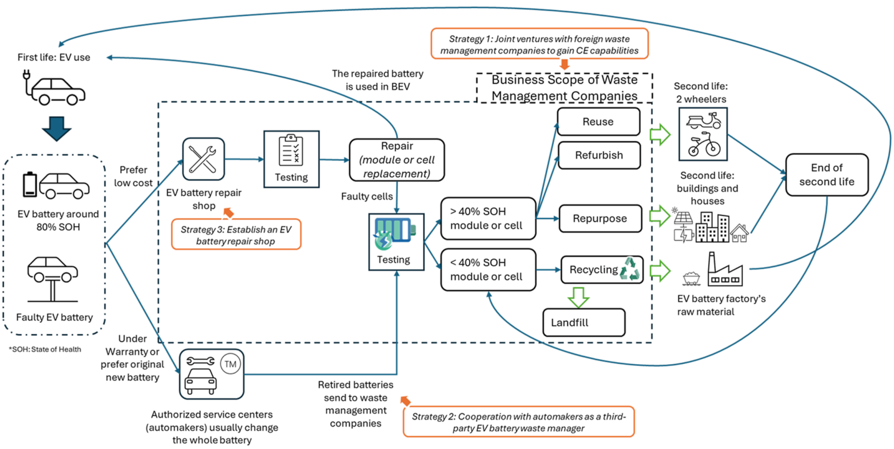
(2) Analyzing the State of Cell Batteries: experts should be employed to analyze the state of cell batteries and assess the severity of failures to determine the appropriate course of action for each cell battery.

(3) Developing Precise Procedures for Dealing with Each Cell Battery State: precise procedures for handling batteries based on diagnosis and analysis to determine the most suitable action (repair, reuse, repurpose, refurbish, or recycle) should be developed.

The company determines the fate of each battery cell, prioritizing extending battery life through repair, followed by evaluating options for reuse, repurpose, refurbish, or recycle if repair is not feasible. Figure 5 shows the business scope of waste management companies.

(1) Battery repair in EVs involves replacing damaged cells with new ones and restoring them to their original state (Potting *et al.*, 2017). Service providers like Spiers New Technologies and BatteriRetur cater to the growing demand for battery repair centers. This service offers comprehensive repair services, including battery disassembly, diagnostics, and repair processes, generating revenue through monthly service fees or one-time repair services Albertsen *et al.* (2021).

(2) Reuse refers to reusing discarded products in good condition, such as EV batteries, to fulfill their original function (Potting *et al.*, 2017). This practice offers cost reduction,



Source(s): Authors' own work

Figure 5. The business scope of waste management companies

making batteries more affordable and increasing their popularity. However, concerns remain about the reliability of used batteries. It is vital to establish standardized battery packs to ensure smooth operation and consistent size compatibility with individual cells across all batteries. The reuse value proposition targets EV users who require replacement batteries and prefer second-hand cells, with revenue generated by selling second-hand battery packs or modules Albertsen *et al*. (2021).

(3) Repurposing is using a discarded product or its parts in a new product with a different function (Potting *et al.*, 2017). Repurposing is a growing trend in the energy sector, particularly in the use of EV batteries for various applications (Azadnia *et al*., 2021). Although most wastes have less than 80% of their original capacity, they still retain sufficient energy for less demanding applications like backup energy sources in buildings (Azadnia *et al*., 2021), renewable energy storage (Munten *et al*., 2021), mobile/off-grid applications, and energy storage for hybrid and electric ships (Albertsen *et al*., 2021). Repurposing involves disassembly, diagnostics, technology development, and the repurposing process, with associated revenue flows through the sale of storage solutions and by offering battery packs or modules for sale or leasing purposes Albertsen *et al*. (2021).

(4) Refurbishing is the process of restoring old products, including diagnosing, replacing, or disassembling battery packs (Potting *et al.*, 2017). It targets price-sensitive customers who do not want to spend on new batteries. For example, Renault performs thorough diagnostics and integrates faulty modules into new EV modules. The process involves disassembly, diagnostics, and refurbishment, with revenue generated through sales or leasing contracts (Albertsen *et al*., 2021).

(5) Recycling is a process that processes materials to obtain lower quality materials (Potting *et al.*, 2017), such as cobalt and lithium, from EV battery waste (Xu *et al.*, 2017; Azadnia *et al*., 2021). Recycling techniques include mechanical, hydrometallurgical, and pyrometallurgical methods (Doose *et al*., 2021). However, challenges such as technical limitations and upgrading existing technologies still exist (Noudeng *et al*., 2022). Key resources include recycling machinery, skills, and storage facilities (Albertsen *et al*., 2021).

Efforts to enhance the management of EV battery waste include training existing staff and recruiting individuals with relevant qualifications, alongside fostering collaborations with government bodies, universities, and research institutions; the government's involvement can be through providing facilities, licensing incentives, capital access, and technical requirements guidance while competency can be elevated by fostering collaboration across the value chain and between established industry players and innovative firms. Noteworthy examples of successful collaborations are available in China and the EU, where projects focused on second-use and advanced recycling techniques have been undertaken. In China, BYD collaborated with GEM on a project that promoted, operated, and managed an energy storage station and photovoltaic power plant to facilitate the cascaded use of EV battery waste in stationary applications (Xu *et al.*, 2017). In the EU, Eramet, BASF, and SUEZ are collaborating to create an advanced closed-loop process specifically designed for recycling batteries (Azadnia *et al.*, 2021). Moreover, strategic partnerships between battery manufacturers, vehicle manufacturers, and recyclers will shape the future of EVs globally (Chizaryfard *et al.*, 2022).

4.4.2 Three developed strategies. Significant financial resources are needed to enhance capabilities, which presents challenges for companies in securing financing. Therefore, companies with limited financial capital should initially focus on implementing Strategy 1. Once the necessary capabilities mentioned in Section 4.4.1 are obtained, these companies can consider adopting Strategy 2 or 3.

4.4.2.1 Strategy 1: joint ventures with foreign waste management companies. The proposed strategy involves establishing joint ventures with foreign companies to facilitate technology transfer, joint investment, knowledge sharing, and market expansion opportunities within the global value chain for managing EV battery waste from reuse to recycling. This strategy stimulates collaboration among companies with a shared objective and contributes to achieving CE goals.

This strategy aligns with Lima *et al.* (2022), who discovered that joint ventures could facilitate a CE by addressing barriers to reusing and recycling batteries in Brazil, including logistics, transport, and disposal. A similar approach was observed in Germany, where Neometals formed a joint venture with Primobius based on pilot plant trials and studies using Neometals' proprietary hydrometallurgical flowsheet (Lima *et al.*, 2022). The joint venture strategy with foreign waste management companies is currently also being implemented in Thailand. DOWA ECO-SYSTEM Co., Ltd., by Japan Technology has stated that in 2019 it will start recycling and processing battery waste from HV and EV (Noudeng *et al.*, 2022). Joint ventures with foreign enterprises can enhance the growth of battery reuse and recycling, leading to increased profitability for companies throughout the value chain (Yang *et al.*, 2020).

4.4.2.2 Strategy 2: cooperation with automakers as a third-party EV battery waste manager. Waste management companies authorized by the Indonesian government are responsible for managing EV battery waste. While Hyundai is the only automaker that has been appointed the third party, there are potential to partner with other automakers. A third party handles existing EV battery waste obtained or collected by the automaker, and the third party determines the appropriate management approach. This strategy increases battery collections for economic value, allowing the waste company to receive batteries from automakers.

This collaboration has occurred in various countries. For example, Nissan and Ford outsourcing to Spiers New Technologies (Albertsen *et al.*, 2021), General Motors partnering with Cirba Solutions for battery recycling (Wang and Liu, 2023), Audi and Umicore joining forces for cobalt and nickel supply chain closure (Azadnia *et al.*, 2021), Renault selling second-life battery packs to external parties (Albertsen *et al.*, 2021), and BYD cooperating with GEM for the cascaded use of EV batteries in stationary applications (Xu *et al.*, 2017). In the EU, this cooperation is encouraged through EPR mechanisms for battery waste collection, which require manufacturers or designated third parties to finance collection, treatment, and recycling of EOL batteries (Richa *et al.*, 2017). In Asia, Tata Motors collaborates with Tata Chemicals to pave the way for EV battery recycling (Kumar and Sinha, 2023).

4.4.2.3 Strategy 3: establish an EV battery repair shop. The EV battery workshop specializes in providing repair services for EV batteries; diagnosing the condition of cells, identifying faulty cells, and replacing them. The tasks performed at the battery repair workshop, as outlined by Koriashkina *et al.* (2019), include:

(1) Diagnosing the overall condition of the EV system,

(2) Disassembling the relevant components to access the battery,

(3) Analyzing the battery to identify faulty cells,

(4) Replacing the faulty cells,

(5) Reinstalling the battery back into the EV and reassembling the body elements, and

(6) Conducting final evaluation and parameter adjustment of the EV battery.

This workshop offers EV users an alternative to authorized battery repair workshops at lower prices. Customers are attracted to the workshop because they can sell damaged battery cells at a reasonable price. Additionally, customers have the option to choose new, second-hand, or refurbished batteries for cell replacements, considering factors such as price and quality. Furthermore, the workshop serves as a collection point for EV battery waste for later reuse, refurbishment, and repurposing. Second-life battery technologies, including reuse, repurposing, and remanufacturing, are currently in a niche development stage, and innovative business models can facilitate their entry into and disruption of existing business models (Nurdiawati and Agrawal, 2022).

According to Eshtiaghi *et al.* (2021), economic factors, particularly the cost of battery replacement and accessibility of repair shops, largely influence the adoption of EVs. Battery replacement expenses over the next 8–10 years pose a significant barrier to EV adoption as they greatly affect the ownership costs of EVs and can hinder their cost competitiveness compared with ICEVs. Ensuring the longevity of EV batteries and reducing their prices to make them more affordable is crucial (Weldon *et al.*, 2018). Regarding accessibility, the availability of EV battery repair workshops is a significant barrier. Therefore, this strategy can help address the challenges related to high battery replacement costs and the limited availability of repair services, ultimately facilitating faster EV adoption.

4.5 Potential benefits for Indonesia

EV battery waste management offers several potential benefits. Indonesia aspires to become an EV leader in Asia by promoting the localization of battery and EV manufacturing (Schröder and Iwasaki, 2023). With domestic battery manufacturing, EV prices can become more affordable, as batteries are the most expensive component in EVs (Nykvist *et al.*, 2019), and a significant portion of that cost comes from importing batteries (Pandyaswargo *et al.*, 2021). Although Indonesia is the world's largest nickel ore producer (Konewka *et al.*, 2021), a key ingredient in lithium-ion batteries, and has around 25% of the nickel global reserve (Karali and Shah, 2022), the country lacks lithium (Pandyaswargo *et al.*, 2021). Implementing battery waste management, including battery recycling, can recover vital materials and ensure their availability for battery production (Shafique *et al.*, 2023; Sopha *et al.*, 2022). Furthermore, this initiative will likely create job opportunities in the waste management, battery manufacturing, and EV manufacturing sectors (Sopha *et al.*, 2022). The primary benefit of all these efforts is establishing Indonesia as a regional EV leader, and possibly even a global powerhouse (Suherman *et al.*, 2021).

5. Conclusions

With the rapid growth in EV adoption in Indonesia, addressing the challenge of retired EV battery waste has become critical. The main research question in this study is: What strategies can waste management companies in Indonesia implement to manage emerging retired EV batteries and support the circular economy? This research aims to formulate strategies for Indonesian EV battery waste management companies, focusing on extending battery life through repair, reuse, repurpose, and refurbishment as steps toward advancing the implementation of a CE in Indonesia. These strategies focus on prolonging battery life through repair, reuse, repurpose, and refurbishment approaches. The research follows a four-step process and incorporates semi-structured interviews, site visits, and questionnaire surveys to gather comprehensive data. As Indonesia's adoption of EVs continues to grow, the country has established regulations to categorize and manage hazardous and toxic battery waste. The government has also published books on the CE and a roadmap for its implementation in various industrial sectors. Although the implementation of EPR is still voluntary, Indonesian-based automakers are responsible for managing their EV battery waste, with Hyundai being the only one to officially appoint a third-party waste management company. Moreover, EV battery repair shops are emerging as an attractive option for customers, offering lower costs and the ability to replace individual cells. Three strategies have been developed based on SWOT analysis and evaluation of external and internal factors: joint ventures with foreign waste management companies, cooperation with automakers as third-party EV battery waste managers, and establishing EV battery repair workshops. This study emphasizes the importance of the CE approach, particularly in prioritizing second-life applications for batteries. Waste management companies need to gradually improve their repair, reuse, repurpose, refurbish, and recycle capabilities.

5.1 Practical implications

The practical implications of this study are substantial for waste management companies and policymakers. The study provides actionable strategies for waste management companies to enhance their capabilities in managing EV battery waste. To establish joint ventures with foreign waste management companies, local waste management companies can identify and approach global battery waste management companies such as Redwood Materials (US), Umicore (Belgium), Li-Cycle (Canada), Gem Co Ltd. (China), SungEel HiTech (South Korea) etc. Companies need to negotiate to form third-party partnerships with EV manufacturers in Indonesia such as Hyundai, Wuling, BYD etc. Companies also need to improve their technical and operational capacities, including the development of dedicated departments and facilities for testing, disassembly, long-term use through second-life batteries and recycling. Companies also need to provide training for their technicians to perform EV battery repairs and maintenance, including battery module replacement and system recalibration. Policymakers can use the findings to refine and develop regulations supporting circular economic principles, ensuring that company practices align with national standards and sustainability goals. Reusing and recycling battery materials can open new revenue streams and develop a new industry, namely the EV battery management industry. Developing this new industry and practices can create employment opportunities and support economic growth in Indonesia.

5.2 Managerial insights

The managerial insights derived from this study provide valuable guidance for leaders within waste management companies on optimizing their operations to handle EV battery waste more effectively. Managers can use these insights to develop strategic plans that incorporate battery repair, reuse, repurposing, refurbishing, and recycling into their core operations. By understanding the strengths, weaknesses, opportunities, and threats identified in the SWOT analysis, managers can make informed decisions on resource allocation, technology investments, and workforce training. Furthermore, aligning company strategies with the government's regulatory framework and CE roadmap will ensure compliance and enhance the company's reputation.

5.3 Research limitations and future research directions

There are several limitations in this research. Firstly, it relies solely on qualitative approaches. Additionally, EV contain numerous electronic components besides batteries that can also pose environmental and health risks. Therefore, future research should broaden its scope to include other critical components like electric motors and integrate quantitative methods such as econometric models that could effectively measure the impact of proposed strategies on waste reduction and resource efficiency. Moreover, future studies should comprehensively evaluate the benefits of implementing CE practices in Indonesia, and conduct comparative analysis with other countries particularly Southeast Asian countries. Lastly, there is a notable lack of official reports or research quantifying the volume of battery waste. Hence, future research efforts should focus on assessing the annual collection of EV battery waste and projecting future trends.

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Supplementary material
The supplementary material for this article can be found online.

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