A Reverse Logistics Framework of Swap Battery for Sustainable Supply Chain : A Preliminary Research

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Abstract

Worldwide are working to support the transition of internal combustion engine vehicles to electric (battery-based) vehicles. The electric vehicle program has faltered because the sales target for electric motorcycles until early 2022 reached only 60%. One reason is that investment in electric vehicles is still considered relatively high. The results of previous studies regarding the battery ownership model significantly reduce investment in electric vehicles. Swap batteries are expected to enter the end of life (EoL) phase after 5 - 10 years of use. End of life swap batteries have the potential to impact the environment. Studies related to the management and handling of EoL swap batteries are very open and relevant to be carried out. In this article, the study begins with a review of related literature. Then continues with a study of determining the technical criteria when it is appropriate for a swap battery to be declared EoL, and ends with a study of the EoL electric motorcycle swap battery (EMSB) management framework to be treated so that it can enter the second phase of life. Criteria are determined by considering technical and environmental aspects. The proposed treatment is reuse, repair, refurbishment, remanufacturing, and recycling. This systematic review of the reverse logistics framework is expected to create a sustainable supply chain.

Keywords
End of life, reverse logistics, second life, sustainable supply chain, swap battery

1. Introduction
Indonesia has also experienced dwindling fossil fuel reserves (Sitorus et al., 2014). Reduced reserves of fossil fuels impact the development of electric vehicle technology (electric vehicle = EV) to replace fossil fuel vehicles (internal combustion engine vehicle = ICEV). Indonesia was once the largest exporter of petroleum and played a very important role in the world organization OPEC (Organization of the Petroleum Exporting Countries). Since 2004 the situation has changed; the petroleum demand level has increased, and Indonesia has bought more than it has sold (Tondang,

2018). 30% of the needs of the Indonesian people come from imports. The petroleum shortage will gradually affect the country's economy. Data from the Central Bureau of Statistics in 2019 (CNN, 2021), the number of motorized vehicles in Indonesia has reached more than 133 million units, with an average increase of 5.6% each year. This situation is very much in line with Sitorus statement (2014) that the most significant consumption of fossil fuels is in the transportation sector, which reaches 88% of total consumption.

The presence of EV technology is a solution to the problem of limited fossil fuels. In addition to reducing fossil fuel consumption, EVs are more environmentally friendly, have smoother engine sounds, and have higher efficiency. The switch from ICEV to EV has the potential to reduce the use of fossil fuels by 12.243 million liters per year and reduce greenhouse gas emissions by 7.23 million tons of CO_2 (Meilanova, 2021). The support of government regulations reinforces this, Presidential Regulation Number 55 of 2019 (Regulation of the President of the Republic of Indonesia Number 55 of 2019 Concerning the Acceleration of the Battery Electric Vehicle Program for Road Transportation, 2019) concerning the Acceleration of the Battery-Based Electric Motor Vehicle Program (Battery Electric Vehicle/BEV) for Road Transportation and Regulation of the Minister of Industry Number 27 of 2020 (Regulation of the Minister of Industry of the Republic of Indonesia No 27 of 2020, 2020) regarding Technical Specifications, EV Roadmap and Calculation of Domestic Local Content Levels (TKDN).

EV manufacturers are adjusting to accelerate the production of electric motorized vehicles. Regulation of the Minister of Industry Number 27 of 2020 is a reference for manufacturers because it contains detailed TKDN targets for electric motorized vehicles and quantitative targets for development. Quantitative development targets are set to be more for two- and three-wheeled vehicles than four-wheeled vehicles (in 2035, it is targeted that two-wheeled vehicles will be 3.5 times that of four-wheeled vehicles). Thus the electric motor industry is a new ecosystem with cycles, as shown in Figure 1. The material industry and the main components of electric motors are entities that initiate the motor industry cycle. Then proceed with the battery-swap industry and charging stations, which are supporting components for the functioning of electric motors. The following entity is electric motorbike users to service providers for maintenance and waste management of electric motorbikes. They were starting from the material to the recycling process and postage.

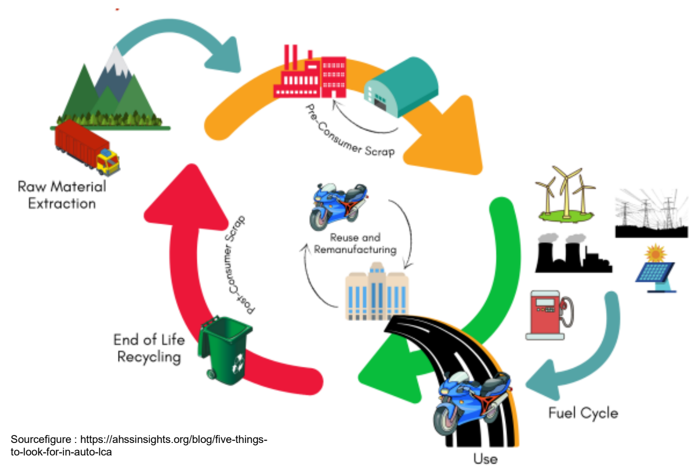

Figure 1. Electric Motorcycle Life Cycle

The government's optimism must be supported, especially in dealing with user convenience, so users genuinely accept it. Indonesia Battery Corporation (IBC) estimates that with the enactment of Presidential Regulation Number 55 of 2019, the peak demand for electric vehicles will occur in 2035 (Umah, 2021). According to Wenbo Li et al. (2017), the inhibiting factors for BEV adoption are grouped into three, demographic, situational, and psychological. The situational group is the most significant inhibiting factor with obstacles, including vehicle range, charging problems, battery life, after-sales maintenance, and the amount of investment (Li et al., 2017). The current condition of EV investment is still a higher investment than ICE (Anshori, 2022; Daina et al., 2017; Gulzari et al., 2022; Sanguesa et al., 2021). Furthermore, with incomplete after-sales support facilities (Ucer, 2019), so that most potential users choose to wait and see the attitude of the EV market (Browne et al., 2012; Egbue & Long, 2012). This situation makes manufacturers and academics continue researching to get the best technology and safety product at the investment price offered. In 2022, companies will start issuing electric cars at lower prices, even though they are small in size. Batteries are the most expensive part of an EV investment, 30-40% of the EV price (Cusenza et al., 2019; Li et al., 2017; Rossini et al., 2016). The high price is due to the high battery components, especially the cost of making cathode battery cells (Cusenza et al., 2019). Research by the International Council on Clean Transportation (ICCT) in 2019 stated that the cost of manufacturing battery cells reached up to 70 percent to 75 percent of the total cost of battery production as a whole (Widodo, 2022).

The battery industry comprises battery pack assembly, battery/cell production, battery management systems, battery materials, and end of life battery (EoL) recycling. Recent advances in battery technology have made Lithium-ion the preferred choice for traction batteries. Lithium-ion batteries are the most widely used storage element in electric vehicles (Venkatapathy et al., 2015; National Standardization Agency, 2020;). Lithium battery types, especially the LFP (lithium ferro phosphate) type, are estimated to have a service life of 5-8 years (Cusenza et al., 2019; Ioakimidis et al., 2019). If 500 thousand electric vehicles are sold in Indonesia in 2020, according to Gakindo's estimates (Kurniawan, 2022), five hundred thousand battery waste (EoL) will be produced in 2026. Meanwhile, the Indonesia Battery Corporation (IBC) estimates that with the enactment of Presidential Regulation Number 55 of 2019, the peak demand for electric vehicles will occur in 2035 (Umah, 2021). Batteries are part of EVs that contain hazardous materials (Nguyen et al., 2021). The EoL battery estimate in 2026, with a peak in 2035, is quite worrying if there is no anticipatory strategy.

Strategies for anticipating environmental impacts are of great concern at the United Nations. World leaders in September 2015 came together to support the Sustainable Development Goals (SDGs) (United Nations, 2020). Since then, research developments globally have been directed at issues of sustainable development programs. The SDGs program aims to end poverty, reduce inequality and protect the environment at the international level. This program involves all development actors: the government, civil society organizations, the private sector, and academics. The SDGs program is expected to have implications for manufacturing and the environment and indirectly for the economy and society. In its development, sustainable development then involves trends related to sustainable, green, and circular economies.

Various researches were developed to support the EV vehicle program, which is expected to reduce dependence on fuel oil but must also provide comfort to users to accept them truly. Among the solutions that make EVs more affordable are increasing the scale of battery production and developing new materials for batteries with greater energy density (Martinez-Laserna et al., 2018). Swap batteries are another solution that can also reduce EV investment costs apart from shortening the battery charging process. Battery charging time is fairly fast, only about three to eight minutes. EV investment costs can be reduced by offering EV sales without a battery or commonly known as a battery ownership model, a battery rental model; the battery belongs to a third party (Alamerew & Brissaud, 2020; Vu & Rahic, 2019; Yang et al., 2018; Zhao et al., 2021). The following solution, when the EV battery is declared EoL, still has a high enough remaining capacity that allows it to be used as a second-life battery. Second-life battery products include energy smart systems, electric heaters, stationary applications, and energy supply from photovoltaics (Alamerew & Brissaud, 2020; Ioakimidis et al., 2019; Kwade et al., 2018; Martinez-Laserna et al., 2018). Second life battery begins with the users' collection process, going through the necessary processes such as reuse, remanufacturing, and recycling. The management process focusing on product recovery is reverse logistics (Vu & Rahic, 2019).

End of life swap battery will be related to the sustainability issue and the reuse, recycling, and remanufacturing needed to become a second-life battery. It is considering that the cathode material has the most impact on the environment, research related to recycling has been carried out the most (Cusenza et al., 2019; Ioakimidis et al., 2019; Jumari et al., 2022; Kirkels et al., 2022; Kwade et al., 2018). When the first life enters the end of life of the battery and is about to enter the second life, several things need to be done, including battery health estimation, life cycle assessment, screening and regrouping, and safety management that must be faced (Hua et al., 2021).

This article consists of 6 sections: section 1, background; section 2, literature review; section 3, methodology; section 4, data collection; section 5, results and discussion; and section 6, conclusions. In section 1, current facts regarding EoL EMSB will be presented. Section 2 will present literature related to the general concept of the approach, namely RL. Section 3 tells the process steps in identifying the problem, finding relevant previous studies, and arriving at a conclusion. Section 4 is a combination of construct hypothesis and data-collecting steps. Section 5 analysis the steps for finding the continuation of this initial study. Furthermore, in closing, section 6 is the conclusion of the initial study.

1.1 Objectives
This study aims to support the program to accelerate the conversion of ICEV to EV to achieve a sustainable supply chain. This support is by building a reverse logistics end of life management framework for electric motor battery swaps to perform better and reduce environmental impact. It is also hoped that this study will reduce manufacturing costs, ultimately reducing EV investment costs. Low manufacturing costs will increase the competitiveness of EV products and their supporting components, including batteries.

Two research questions that will be carried out are:

RQ1 : How does the framework determine the technical criteria for cut-off EoL swap battery?

RQ2 : How does the reverse logistics framework for building sustainable supply chain management mechanisms to maximize industry sustainability?

2. Literature Review
The battery is a collection of cells packaged in construction (housing), equipped with an active cooling system, battery management system (BMS), and connectors. Figure 2. is a type of battery structure consisting of several cylindric battery cells that provide electric current through a reversible chemical redox reaction (Kirkels et al., 2022). The cell is held in place by a mechanical construction which also protects the cell from external influences. The cells are electrically connected, for example, via plates, to provide power at set voltages and currents and to allow charging of the cells. BMS is a very important component in the battery pack.

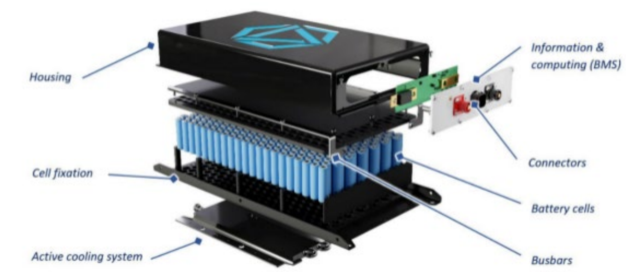

Figure 2. Archetypical structure of a battery system
(Kirkels et al., 2022)

Lithium battery cells are relatively more environmentally friendly because they can be recharged (Cusenza et al., 2019; Hossain et al., 2019; Koroma et al., 2022). The types of lithium batteries currently widely used are lithium ferro phosphate (LFP), lithium nickel manganese cobalt oxide (LNMC), lithium nickel cobalt aluminum oxide (LNCA), lithium titanate oxide (LTO), lithium manganese oxide (LMO), and lithium cobalt oxide (LCO). However, many electric vehicles currently use the LFP, LNMC, and LNCA. Table 1. compares the three types of batteries that are often used for electric vehicles. LFP type batteries are more widely used, with the main reasons being lightweight, non-flammable, and has a higher power density among the three types of batteries. The life span of an LFP battery swap is stated to be 2000-3000 cycles, or it can be said to be around 5 - 8 years.

The manufacturing-defined life cycle approximates the usage conditions according to the manufacturing scenario. The EoL swap battery is a discussion of the performance of the traction battery (Grandjean et al., 2019; Paolo Cicconi et al., 2012; Venkatapathy et al., 2015). Traction battery performance depends on the internal battery on electricity and chemical processes and is also influenced externally, in this case, the environment and usage. The swap battery cannot be used anymore or enters the EoL stage if it cannot meet the needs of EV traction or after it loses about 20%-30% of its initial capacity (Hua et al., 2021; Neubauer et al., 2015). Battery performance will be monitored by BMS, which consists of software and hardware. The BMS will monitor operating current, voltage, and temperature, estimate capacity, impedance and determine State Of Charge (SOC), State Of Health (SOH), and Remaining Useful Life (RUL) status at the system level (Sanguesa et al., 2021; Venkatapathy et al., 2015).

Increasing the production of electric motors means increasing the use of batteries (Koroma et al., 2022; Nguyen et al., 2021; Richa et al., 2014). All related parties need to increase their efforts to minimize their ecological impact, for example, those related to carbon dioxide footprint (Recycling of Lithium-Ion Batteries). End of life (EoL) battery is included in the category of hazardous and toxic materials. Although the main raw material, lithium is considered to have the least risk of burning, it reacts easily with oxygen or water (Arah, n.d.). Minister of Environment number 1 of 2021 - a replacement for Minister of Environment number 3 of 2014 (Ministry of Environment and Forestry, 2021), requires that every person in charge of a business must comply with environmental quality standards, monitor and report. This Ministerial Regulation regulates the Company Performance Rating Assessment Program in Environmental Management, commonly known as PROPER. One of the assessments in PROPER is a life cycle assessment. LCA is a method of analyzing and calculating the total environmental impact, both positive and negative, of a process or product so that a process or product that is more environmentally friendly is produced (Widiyanto et al., 2002). So that the value of the environmental impact is obtained from the start of production until the product cannot be reused (end of use/end of life) (Choi & Fthenakis, 2014; Christensen et al., 2021; Liu et al., 2022).

Table 1. Performance LFP, LNMC dan LNCA

Performance	LFP	LNMC	LNCA
Voltage (volt)	3,4	**3,8**	3,6
Current capacity (Ah/Kg)	160	150	**180**
Energy density/weight (Wh/Kg)	544	546	**648**
Energy density/volume (Wh/L)	1953	1915	**3110**
Power density (W/Kg)	**1800**	250 - 1000	150
Charge/discharge cycle	2000 - 3000	2000	**3000 - 3500**
Burn risk	**Small**	Risky	Risky
Environmental Impact : Lithium as main material : corrosive	Iron: corrosive heavy metal Phosphates : hazardous in large quantities in water	Nickel: corrosion resistant Manganese : safe Cobalt: heavy metal	Nickel: corrosion resistant Cobalt: heavy metal Aluminum : safe

Source : (Porzio & Scown, 2021), (Cusenza et al., 2019)

The anticipation of dealing with an increase in EoL batteries is Reverse Logistics (RL) concept. An approach defined by Fleischmann as a process of planning, implementing, and controlling the efficient and effective inflow and storage of used goods and related information in the opposite direction from the traditional supply chain, which aims to restore value and proper disposal (Fleischmann et al., 1997). RL for EoL battery management is expected to be sustainable, protect the environment and positively impact the economy and society.

Reverse logistics (RL) is a management process focusing on recovering products that users no longer want or can no longer use (Rubio & Jiménez-Parra, 2017). RL is part of supply chain management, which can involve several supply chain actors (Senthil & R.Sridharan, 2014). Awareness of the environment and increasing global competitiveness has made manufacturers implement RL (Mathiyazhagan et al., 2021). RL, in the beginning, was a purchase return with reasons, the goods were damaged, the product was not as requested, the product was damaged during delivery, the product was not performing, the exchange program, and the product recall by the manufacturer (Findlow, n.d.). RL is increasingly playing a role and is becoming very relevant to sustainable development that pays attention to the environment, society, and economy. The RL concept is the opposite of the forward logistics concept (Figure 3.). Based on the explanation in Figure 3. RL is not only about moving products that are no longer wanted or unusable but also related to evaluating the condition or performance of the product to be moved. Forward logistics is the process of raw material, manufacture, assembly, and distribution to the user. At the same time, RL is the user's movement that allows for reuse, repair, remanufacturing, or recycling with the aim of increasing product value and efficiency. The sustainability of the manufacturing business will be maintained, not burdening the environment and creating a circular economy.

RL will provide efficiencies for manufacturing. Only a few manufacturers do RL. The development of the RL system is carried out by first determining the value of the return, then finding the return mechanism or RL strategy for reuse, repair, remanufacturing, or recycling, also determining the allocation location, transportation costs, collection mechanism, effective return period. . The return mechanism will involve manufacturers, distributors, retailers and 3PL (third party logistics) companies.

The business has become very complex. The business is starting from a volatile business world of uncertainty, complex competition, and ambiguity. The description of the condition of this business situation by Warren Bennis and Burt Nanus in 1987 is called VUCA (Standarku.com, 2021). Organizations need to deal quickly with disruptions, market shifts, changes in consumer behavior, and increasingly fierce business competition. Peter Drucker (Morse & Babcock, 2014) introduced the term social responsibility. Every company has responsibilities as a corporate citizen that go beyond legal and economic requirements. Responsibilities include customers, employees, suppliers, communities, and society. Organizations that are not at least responsible for their impact on the environment deserve sanctions from society.

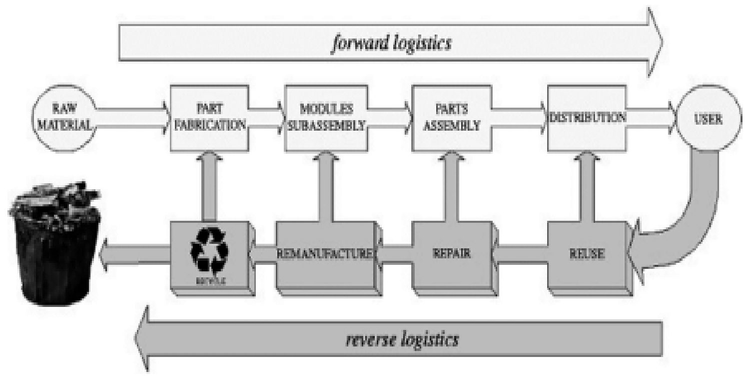

Figure 3. Forward and Reverse Logistics Process (Cerasis, n.d.)

3. Methods

This article is an initial study of the EoL EMSB which is the waste impact of the ICEV to EV transition program. This initial study was conducted to answer two research questions using a qualitative inductive scientific method approach that bases the science of logic on thinking and arguing (Kenaphoom, 2021; Suaedi, 2016). This study follows the body of knowledge approach framework from the Institute of Industrial and System Engineers 2021 which consists of fourteen fields of knowledge (Institute of Industrial and System Engineers, 2021).

Figure 4. represents the steps of this initial study. The learning steps consist of five steps:

3.1. Identify the problem and scope. Details of the problems are in section 1. There are two main issues raised in this article. The first is the problem with the target of the ICE transition program to EV that has not been achieved, one of which is due to the high investment in EV and allegedly due to battery prices. The two problems are the EoL swap battery EV which has an impact on the environment. The scope of the study is on the logistics network from first life swap batteries to second life which is expected to reduce investment value and environmental impact.

3.2. Research development. The study will refer to the IISE BoK and literature studies.

3.3. Data collection. Data collection traces body of knowledge IISE and previous research conducted between 2011 – 2022 related to the end of life of electric vehicle batteries (Section 4).

3.4. Results and Discussion. This step tells what has been obtained and will be considered for further studies (Section 5).

3.5. Conclusion. This step is the final step of the research which is closing.

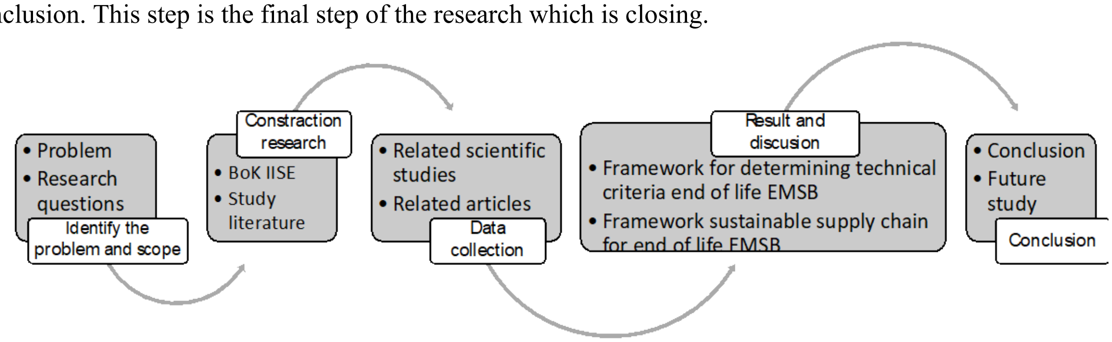

Figure 4. Research Schema

4. Data Collection

Section 4, is the result of searching the IISE body of knowledge and previous research. Based on section 2, RL is seen as the primary approach to overcoming the impact of the EoL SB EV. It will be seen from the point of view of industrial engineering education to strengthen this goal. As an initial study, the data collected is in the form of the results of previous research. Then it will be linked to the existing condition.

The quantitative development target in the Regulation of the Minister of Industry Number 27 of 2020 is more for two wheels. So the framework for the second-life battery development approach will be focused on the first-life swap battery from motorcycles. Considering the life cycle of the first life swap battery of five to eight years, with sales in 2018, 6 million EoL EMSB may begin to occur in 2023. As well as considering the world's demands to be able to carry out sustainable development, which involves the responsibilities of business people, government and all people at all levels. This statement means that it is essential to find solutions to problems by considering interdisciplinary and multilateral considerations. This article uses the point of view of industrial engineering education.

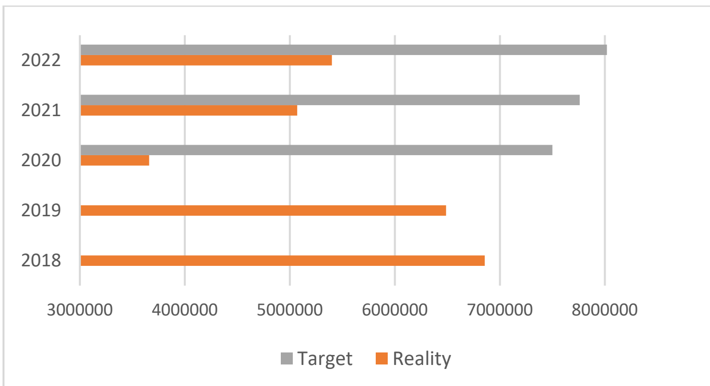

Figure 5. Comparison of Sales Targets and Reality

Based on data from AISI (Indonesian Motorcycle Industry Association) (Kompas.com, 2022), the development of the electric motorcycle industry in the last five years has not been as expected in the Minister of Industry Regulation Number 27 of 2020. In 2020 it was targeted to have as many as 7.5 million electric motorcycles based on sales data for 2018 and 2019. During the pandemic, only around 3.66 million electric motorbikes were sold. Likewise, in 2022 the target is 8.02 million, and only 5.4 million will be realized (Figure 5.). General AISI estimates this condition because battery prices are still very high, and there are no government subsidies for users.

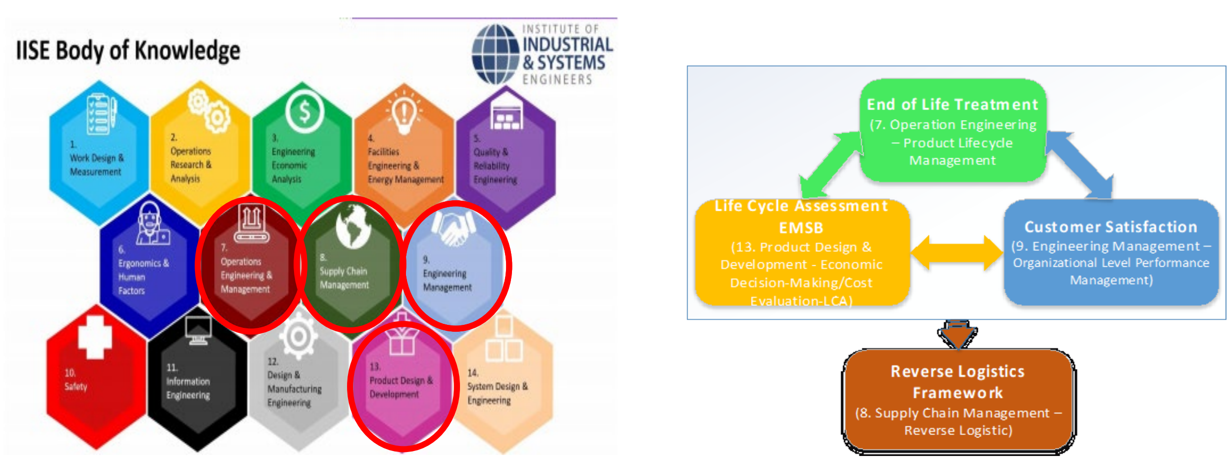

Figure 6. BoK IISE 2021

(Institute of Industrial and System Engineers, 2021)

The swap of batteries for electric motorbikes is expected to be a solution to reducing battery prices which are still high. Several studies have started to examine the issue; users do not need to buy a battery, just rent and recharge it or what is commonly known as the battery ownership model (Aqidawati et al., 2022; Sanguesa et al., 2021; Yang et al., 2018). The next problem is related to battery performance which is expected to enter the EoL in the next five to eight years battery swap providers will face.

4.1. IISE BoK Approach

The keyword used in this article is "end of life battery". These keywords are then used as the closest search key to knowledge. The search results from the fourteen IISE BoK obtained the four closest BoK, as shown in Figure 6. circled in red. The four BoK are (1) Product Design and Development, (2) Engineering Management, (3) Operation Engineering, and (4) Supply Chain Management.

4.1.1. BoK 7 : Operation Engineering and Management

Environmental issues change every aspect of supply chain operations and management, from product and service design to sourcing, manufacturing, and delivery (Russell & Taylor, 2011). Management is carried out with due regard to the environment and is sustainable. Innovation is always needed for manufacturing to be sustainable, and it is possible to experience changes to existing designs. The system for tracking design revisions is referred to as product life cycle management (PLM). PLM stores retrieves, and updates design data from product concepts through product creation, revision, service, and discontinuation.

4.1.2. BoK 8 : Supply Chain Management

The final integration design goal is life cycle support (Bowersox & Closs, 1996). Some items are sold without any guarantee that the product will perform as advertised. Product returns may occur due to increasingly stringent quality standards, product expiration dates, and liability for harmful consequences. A significant point regarding reverse logistics is maintaining maximum control when there is potential disruption. Companies that design efficient reverse logistics can often recover value by reducing the amount of products that might be discarded or sold at the same price.

4.1.3. BoK 13 : Product Design and Development

An excellent new product departs from integration design. It starts from an idea to a problem solution or user satisfaction. In addition to conducting studies on users considering future impact trends, it is necessary to do so (Ulrich & Eppinger, 2018). Growing environmental awareness creates a market for green products and services. Ideally, the product development phase begins by identifying the potential environmental impact of a product over its life cycle. The initial EoL SB study will begin by identifying potential environmental impacts using a life cycle assessment.

4.1.4. BoK 9 : Engineering Management

Since IE was born to answer problems that arose around the 18th century, between 1769 - 1800 or during the industrial revolution, finding solutions to problems was associated with decreased productivity and efficiency. Productivity can be defined as the output generated per unit of resources used. Efficiency is achieved using the least amount of input to produce a given output. This operational effectiveness is achieved when the organization pursues appropriate goals (Morse & Babcock, 2014). In a book entitled Principles of Scientific Management, Taylor's principle (Morse & Babcock, 2014) states that high productivity will be achieved, one of which is related to responsibility. At first, Taylor applies the responsibilities of each employee will cumulatively impact the organization. This responsibility issue was then strengthened by Max Weiber, who said that the basic organizational unit is an office or position, defined as a certain set of functions (based on the division of labor) with apparent authority and responsibilities. The proposed solution to the problem of the initial study of the EoL SB needs to review the efficiency of each stakeholder.

Figure 7. The linkage for the BoK IISE study, and the proposal for the management of RL EoL SB is a must in order to reduce environmental impact and provide more competitive value to the EV business in a sustainable manner. Sustainable development balances current and future needs for subsoil, energy, traditional and new materials, and transportation (Zhironkin & Cehlár, 2022). Management must have a vision, be able to understand the situation and make clear plans and strategies to adapt quickly to any changing situations (VUCA). Customer satisfaction, as BoK number 9, must be the main performance of a business. The focus on customer satisfaction is expected to reduce reluctance to buy because EV prices are still relatively high. The EV price is high because the battery is the component with the highest cost, with a life span of 5-8 years, and impacts the environment. RL management is expected to

provide convenience to customers without burdening manufacturers and other actors in the EV supply chain. To be able to provide convenience to customers, it is necessary to design management for each stage of the process in RL (reuse, repair, remanufacture, or recycle), especially the determining criteria for each stage of the process.

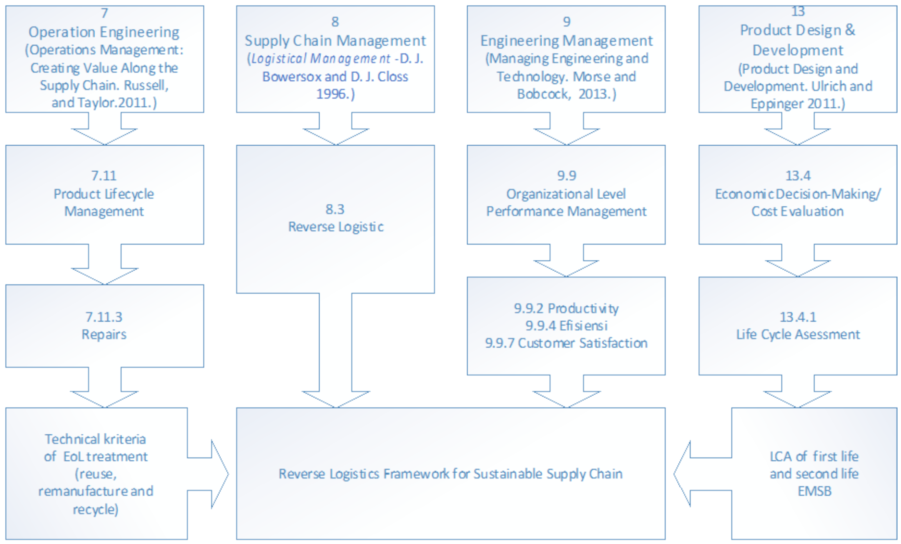

Figure 7. Linkage between BoK and Objective Research

4.2. Study literature

The initial study of EoL EMSB management conducted a search and collection of previous studies. The search was carried out through the Scopus database using the keywords "end of life", "battery", and "reverse logistics". The search process uses the Scopus database. Each topic keyword will be linked with an AND, meaning that the words are included in the topic. Articles are limited to those in the form of articles, journal publications in English between 2011 and 2022 obtained 116 articles. The search results were then limited to the subject area, engineering, environmental science, business management, and economics so that 25 articles in Table 2 were traceable. EoL treatment has 20 articles, 12 articles discussing LCA and 7 articles discussing reverse logistics. The point of view of previous researchers regarding the EoL battery looked more at the process that needed to be passed when entering the second life battery (EoL Treatment) than research on environmental impacts (LCA).

5. Results and Discussion

The section results and discussion will answer two research questions in Section 1.1., regarding the development of determining EMSB EoL criteria and developing a framework for developing a sustainable EMSB circular supply chain.

5.1 Determination of EMSB cut off end of life technical criteria in relation to EoL treatment

The swap battery is one solution that can apply the battery ownership model and make electric motorbikes affordable. Ownership of the battery is in the manufacture of electric motors or managed by a third party. Whoever owns the battery will bear the EMSB EoL. So for EMSB framework managers, the EoL treatment is needed. Apart from that, when EMSB is declared, EoL is also really needed. Cut-off EoL is the end of the degradation or aging process, which is influenced by environmental conditions that describe the traction battery's performance (Venkatapathy et al., 2015). The degradation measures are SoH and SoC, while environmental conditions are affected by temperature and mechanics, including user habits. Another measure of degradation uses capacity (Hua et al., 2021; Neubauer et al., 2015). Research needs to determine the appropriate cut-off size, which considers SoH, SoC, capacity, environmental impact, and the probability of EoL treatment occurring.

Table 2. Article end of life battery

Article	Battery	EoL Treatment	LCA	RL
2022-Junxi Liu., et al-Impact of recycling effect in comparative life cycle assessment for materials selection - A case study of light-weighting vehicles.	x	x	x	
2022- MichaelSamsuKoroma - Life cycle assessment of battery electric vehicles Implications of future electricity mix and different battery end-of-life management	x	x	x	
2022- MohammadShahjalal- A review on second-life of Li-ion batteries: prospects, challenges, and issues	x	x		
2022-Rajaeifar, M. A.- Challenges and recent developments in supply and value chains of electric vehicle batteries: A sustainability perspective.	x	x		x
2021-Christensen, P. A.,-Risk management over the life cycle of lithium-ion batteries in electric vehicles.	x			
2021-Hua, Y., et al-Toward Sustainable Reuse of Retired Lithium-ion Batteries from Electric Vehicles.	x	x		x
2021-MargaretSlattery-Transportation of electric vehicle lithium-ion batteries at end-of-life: A literature review	x	x	x	x
2021-MihaiMachedon-A methodological approach to assess the impact of energy and raw materials constraints on the sustainable deployment of light-duty vehicles by 2050	x			
2021-Porzio, Jason Scown, Corinne D.-Life-Cycle Assessment Considerations for Batteries and Battery Materials	x	x	x	
2021-Sanguesa, Julio A.-A review on electric vehicles: Technologies and challenges	x	x		
2020 - Andrea Temporelli - Life cycle assessment of electric vehicle batteries: An overview of recent literature	x	x	x	
2020-Karagoz, S., et al -End-of-life vehicle management: a comprehensive review.	x		x	
2020-Vanessa Gomes Silva-When part is too little: cutoff rules ' influence on LCA application to whole-building studies		x	x	x
2020-YohannesA.Alamerew-Modelling reverse supply chain through system dynamics for realizing the transition towards the circular economy: A case study on electric vehicle batteries	x	x		
2019-EklasHossain-A Comprehensive Review on Second-Life Batteries: Current State, Manufacturing Considerations, Applications, Impacts, Barriers & Potential Solutions, Business Strategies, and Policies	x	x	x	x
2019-Kurdve, M.-Considerations when modelling ev battery circularity systems	x	x		
2019-MariaAnnaCusenza-Energy and environmental assessment of a traction lithium-ion battery pack for plug-in hybrid electric vehicles	x	x	x	
2019 - Stefan Englberder - A techno-economic analysis of vehicle-to-building: Battery degradation and efficiency analysis in the context of coordinated electric vehicle charging	x			
2018 - E. Martinez - Battery second life: Hype, hope or reality? A critical review of the state of the art	x	x		
2018-PietroDeGiovanni-A joint maximization incentive in closed-loop supply chains with competing retailers: The case of spent-battery recycling	x	x		x
2015-Hendrickson, T. P., et al.-Life-cycle implications and supply chain logistics of electric vehicle battery recycling in California.	x	x	x	
2014-Ahmadi, L., et al -Environmental feasibility of re-use of electric vehicle batteries.	x	x	x	
2012-PaoloCicconi-Feasibility Analysis of Second Life Applications For Li-Ion Cells Used In Electric Powertrain Using Environmental Indicators	x	x	x	
2012-SajjadShokohyar-A model for integrating services and product EOL management in sustainable product service system (S-PSS)	x	x		x
2011-VilayanurV.Viswanathan-Second Use of Transportation Batteries: Maximizing the Value of Batteries for Transportation and Grid Services	x			

Observing the twenty articles in the EoL treatment column (Table 2.), most researchers stated that after EMSB entered EoL, it must be reused in a new application (Hossain et al., 2019; Hua et al., 2020; Shahjalal et al. ., 2022). Reinforced by Rajaeifar, et al., that reuse encompasses remanufacturing and repurposing (Rajaeifar et al., 2022). Sixteen of the twenty EoL treatment research articles focus more on treatment recycling. Recycling is reinforced by the value of the most significant potential global warming impact in material processing. Some EoL that still have high health values may still be used as EMSB. Efforts to maintain this as EMSB are then referred to as treatment repair (Kurdve et al., 2019; Shokohyar et al., 2014), treatment remanufacturing (De Giovanni, 2018; Kurdve et al., 2019; Shokohyar et al., 2014), and refurbishment treatment (Hossain et al., 2019; Koroma et al., 2022; Martinez-Laserna et al., 2018). Researchers have a point of view that defines treatment that is not uniform. European union regulations (Gustavsson et al., 2020) encourage manufacturers to allow reuse. Regulation of product reuse is focused on the concepts of reuse, repair, refurbishment, and remanufacture (Table 3.).

Table 3. Terminology EoL Treatment

Proses	Terminology Bessel Convention
Reuse	The using again of fully functional equipment that is not waste for the different purpose (another application) for which it was conceived, possibly after repair or refurbishment.
Repair	Fixing a specified fault in used equipment that is a waste or a product and/or replacing defective components of equipment in order to make the equipment a fully functional product to be used for its originally intended purpose.
Refurbishment	Refurbish is the process of returning a used product to a satisfactory working condition that may be inferior to the original specification. Generally the resultant product has a warranty that is less than that of newly manufactured equivalent. The warranty applies to all major wearing parts
Remanufacture	Modification of used equipment to increase or restore its performance and/or functionality or to meet applicable technical standards or regulatory requirements, with the result of making it a fully functional product to be used for a purpose that is at least the one for which it was originally intended, including through such activities as cleaning and data sanitization.
Recycle	Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations

The proposed framework for finding the EoL EMSB cut-off is linked to the EoL treatment, as shown in Figure 8. The stage begins with determining possible EoL treatments, which are in accordance with Table 3. Then the process of inspecting or testing the condition or degradation performance of the EoL EMSB is carried out. This step is to diagnose the level of damage from the EMSB and determine the possible treatment. After the treatment process, measurements are made again as a new performance from the second-life battery. Each event data will be considered as a state that will be simulated with various battery performance measures (SoH, SoC, capacity). The best cut-off size is obtained by considering technical decisions (EoL treatment) and environmental (global warming potential).

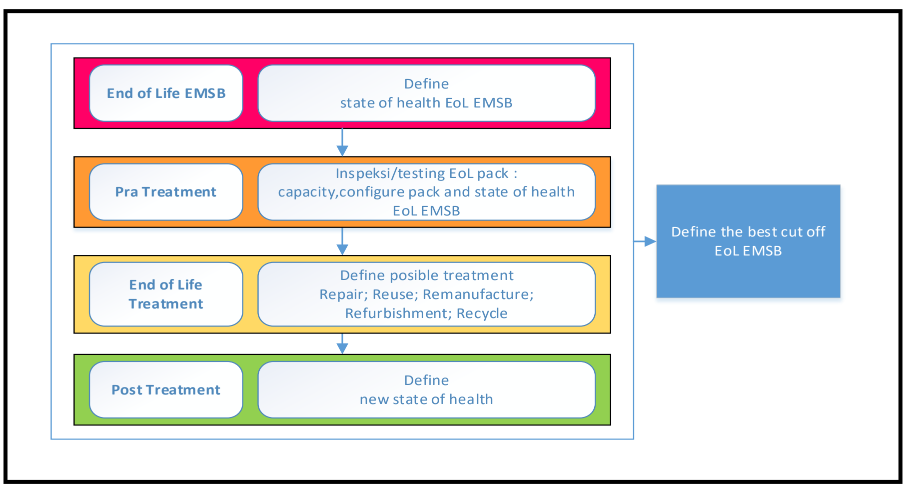

Figure 8. Framework determining technical criteria for end of life EMSB

5.2 Reverse logistics framework of sustainable supply chain for end of life EMSB

After developing the framework for determining the EoL EMSB cut-off criteria, the next step is to build a circular EMSB supply chain. Efforts to extend battery life with many EoL EMSB will not be practical if it is only the responsibility of the EMSB manufacturer. So this article offers the concept of a circular supply chain in EMSB, which will involve third parties in helping the EMSB EoL management to become a sustainable system.

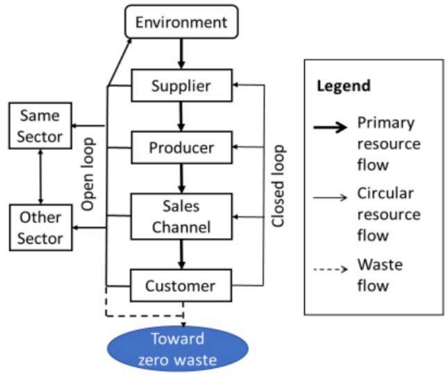

Figure 9. Circular supply chain
(Farooque et al., 2019)

The circular supply chain manages the supply chain and its surrounding industrial and natural ecosystems (Farooque et al., 2019). This concept systematically recovers technical materials and regenerates biological materials towards a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste. The framework combines two processes: the main process flow and the circular process flow. Figure 9. shows the basic concept of a circular supply chain. The main flow is the forward logistics flow (shown by the thick arrow) to process from material to finished product. At the same time, the circular flow is the return flow of products/materials/energy that have been recycled, retained, reused, repaired, remanufactured, refurbished, recovered, etc.

In this article, EoL treatment refers to the type of treatment and terminology in Table 3. The perpetrators of the five treatments are not just EMSB manufacturers. Only "remanufacture" must be carried out of the five treatments by the original EMSB manufacturer. For "reuse" and "repair", it can even be done by the customer or user. Thus, third parties can assist in the "reuse", "repair", "refurbish", and "recycle" treatments.

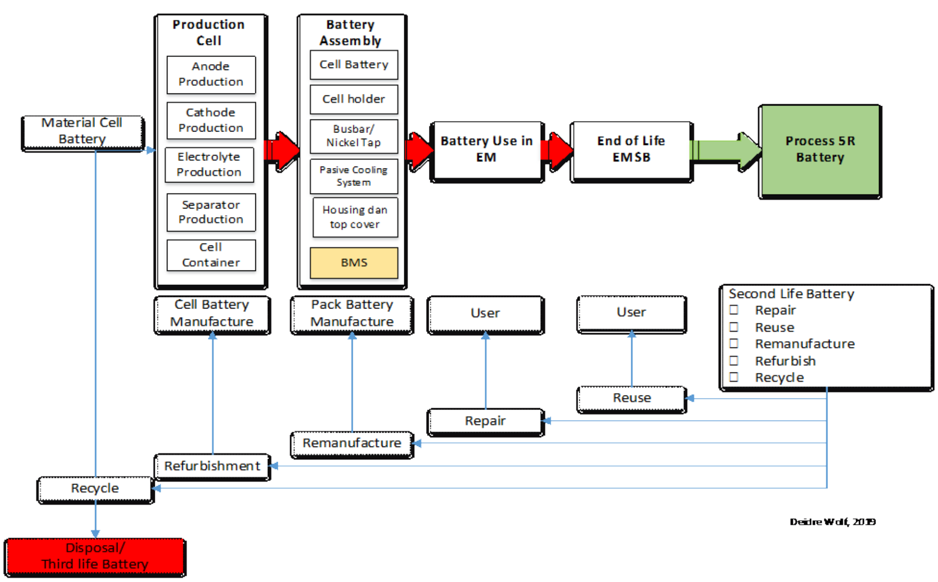

Figure 10. Reverse Logistics Framework for sustainable supply chain EMSB

These results can support manufacturers in designing future BEV batteries with battery improvements in EoL in mind. Similarly, the results can help stakeholders plan and develop a sustainable business model for refurbished EV batteries based on the useful life of both reusable cells for secondary use.

6. Conclusion

The framework of reverse logistics for sustainable supply chain for the EMSB (Figure 10) is the basic framework for managing the EMSB EoL to become a second life. This framework is not only a framework for manufacturers but also involves third parties in extending the service life of the swab battery. Five possible treatments can be carried out when the EMSB is declared end of life: reuse, repair, refurbish, remanufacturing, and/or recycling. The five possible EoL treatments provide a reduction in environmental impact. The possible treatment diagnostic framework can be seen in Figure 8.

The framework is expected to support the program to accelerate the conversion of ICEV to EV to achieve a sustainable supply chain. The two frameworks are also expected to reduce manufacturing costs, ultimately reducing EV investment costs. Low manufacturing costs will increase the competitiveness of EV products and their supporting components, including batteries.

Studies related RL and EMSB EoL management become even more helpful if supported by an EMSB redesign study. That considers the convenience of the EoL EMSB treatment, such as the mechanism for disassembling battery components and providing spare parts that facilitate installation, even though they come from different EV manufacturers. Another study still needed is a cooperation framework that provides added value to all actors in the circular supply chain at the EMSB.

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