Reverse Logistics of Electric Vehicle Battery in Indonesia: A Causal Loop Analysis

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Abstract

The Indonesian government continues to launch a battery-based electric vehicle acceleration program. It is estimated that there will be significant growth in sales of battery-based electric vehicle (EVB). The battery costs about 40% of the cost of an electric vehicle (EV). With a battery life of around 8 to 10 years, EV batteries will intensively face the retirement stage and have an impact on the environment in the form of unused battery waste. The target number of EVs in Indonesia in 2030 will reach 2 million units; hence, it is estimated that there will be 0.718 million tons of batteries that need to be recycled by 2040. There is a need for a study on the reverse logistics of the electric vehicle and electric vehicle battery industries. The causal loop diagram was utilized to examine the potential dynamics existing in the reverse logistics system of EV. The results could provide support the capacity planning of EVB remanufacturing as required by the potential regulation in the future.

Keywords
Reverse Logistics (RL), Electric Vehicle Battery, Remanufacturing Capacity, Collection Capacity, System Dynamics (SD).

1. Introduction
Along with the growth of world population, the need for energy continues to increase. Concurring to the International Energy Agency projections, global energy consumption will increment by 45% until 2030 or a normal increase of 1.6% each year. Approximately 80% of the global energy needs are provided from nonrenewable fuel source (IEA 2022). Indonesia is one of the countries with a continuously increasing amount of energy consumption, driven by the rate of population growth and GDP. Fuel consumption and emissions have received serious attention from the stakeholders in recent decades. The problems faced are global temperature change, climate change and side effects on human health (Sukarno et al. 2016). The transportation sector is expected to contribute 82% to the overall increment in liquid fuel use in 2035. Over the past three years, this segment has reached the highest yearly development percentage of 6.45% compared to other segments. 30% consumption comes from the transportation sector (Sukarno et al., 2016). Meanwhile in Indonesia more than 40% of the total energy consumption comes from the transportation sector (Ministry of Energy 2021).

At the 26th United Nations Climate Change Conference (COP 26) in 2021, the Indonesian government has outlined ambitions to accelerate the deployment achieving carbon neutral by 2060. It has already built this into the government's strategic plan to accommodate sustainability standards that can be realized with low carbon emission vehicles, electric cars and their components (Ministry of Industry 2018). The indicated target is to achieve 2 million electric cars in 2030. This number would relate to around 9% of the particular stocks, compared to well beneath 0.1% in 2021. To aid implementation, the Presidential Regulation on Battery Electric Vehicles and the Battery Electric Vehicle Guidelines set objectives for the share of low-carbon emission vehicles including battery electric vehicles, PHEV, flex-fuel motor, and low-cost green cars in domestic manufacturing. The guideline aims to fulfill 20% of local car manufacturing in 2025 and 30% in 2035 (Ministry of Industry 2018). The development of EV in Indonesia is heavily influenced by the simultaneous development of relevant stakeholders and growing is environmental concern to be an fundamental factor in adopting Electric Vehicle (Lonan and Ardi 2020), (Setiawan et al. 2022).

Global government agencies are very concerned about how EV battery recycling will be handled: EV batteries typically have a lifespan of 8-10 years (Li et al. 2020). More than 5 Kg EV batteries are categorized as harmful wastes in Australia (Sun et al. 2015). Without appropriate treatment, EV batteries contain plastics, mostly metals, and toxic electrolytes that can have irreversible and catastrophic consequences for the environment and human well-being (Li et al. 2019), (Yang et al. 2020). Electric vehicle batteries (EVB) can be recycled, repurposed, reused, and remanufactured at the end of life stage (Alamerew and Brissaud 2020), (Yang et al. 2020). With battery weight 359 kg per vehicle, Indonesia's EV battery volume will reach up to 718,000 tons by 2038-2040.

Table 1. Electric Vehicle Battery Specification and Weight adopted from Lima (2022)

Car	**Total battery capacity**	**Battery weight**	**Chemistry**	**Manufacturer**
Volkswagen e-Golf	35,8 kWh	349 kg	NCM 333, (also known as NCM 111)	Samsung, SDI
Volkswagen, e-up, SEAT Mii Electric, and Skoda CITIGOe iV	36,8 kWh	248 kg	NCM 622	LG Chem
Renault Twingo ZE	22 kWh	165 kg	NCM 712	LG Chem
Renault ZOE	44,1 kWh	305 kg	NCM 622	LG Chem
Renault ZOE ZE 50	54,66 kWh	326 kg	NCM 712	LG Chem
BMW i3	42,2 kWh	278 kg	NCM 622	Samsung SDI
Peugeot e-208 and Opel Corsa-e	50 kWh	356 kg	NCM 523	CATL
Nissan LEAF	62 kWh	410 kg (estimation)	NCM 523	Envision AESC
Chevrolet Bolt EV and Opel Ampera-e	62,2 kWh	435 kg	NCM 622	LG Chem
Hyundai Kona Electric	67,5 kWh	452 kg	NCM 622	LG Chem
Hyundai IONIQ Electric	**40,4 kWh**	**359 kg (without battery heater)**	**NCM 622**	**LG Chem**
Kia e-Soul	67,5 kWh	457 kg	NCM 622	SK Innovation
Kia e-Niro	67,5 kWh (estimation)	457 kg	NCM 622	SK Innovation
Jaguar I-PACE	90 kWh	603 kg	NCM 622	LG Chem
Mercedes-Benz EQC	85 kWh	652 kg	NCM. 622	LG Chem, or SK Innovation
Audi, e-tron 55 quattro	95 kWh	700 kg	NCM. 622	LG Chem
Porsche, Taycan Turbo S	93,4 kWh	630 kg	NCM 622	LG Chem
Tesla Model X	102,4 kWh	630 kg	NCA	Panasonic
Tesla Model S	102,4 kWh	630 kg	NCA	Panasonic
Tesla Model 3	80,5 kWh	478 kg	NCA	Panasonic

This study aims to investigate relationships of the complex dynamic among factors that influence battery remanufacturing capacity affecting the EV growth in Indonesia and determine capacity planning strategy to fulfill demand of remanufacturing and collection battery through a system diagram and a Causal Loop Diagram (CLD). This study will help the Indonesian government to define effective policies and regulations for EV battery waste management.

1.1 Objectives

Therefore, given the increasing waste challenges posed by EVB, the research objective of this study is to answer a set of research questions in a practical way:

- How to build a conceptual loop model of reverse logistics from complex system for retirement battery EV to simulate capacity expansion and remanufacturing capacity due to product collection in Indonesia?
- What are the influencing factors needed to be considered today and in the future regarding electric vehicle battery recovery in Indonesia?

2. Literature Review

2.1 Reverse Logistics

The study of recycling end-of-life products has appeared in any stream of literature: closed-loop supply chain (CLSC), reverse supply chain (RSC), green supply chain management (GrSCM), reverse logistics (RL), and environmental value chain management (EVCM) (Idjis et al. 2013). It characterizes as the method of arranging, executing, and controlling production process, cost efficiency of components or materials, line production stock, finish good products and related information, start from the point of usage until the point of original process for the reason of value added recovery, or appropriate scrapping (Rogers 1998).

Reverse logistics are more complex considering backflow may incorporate items or product, second process assemblies and/or components material that may step in the forward logistics in a few returns area. Fleischmann et al. (1997) give an curiously introduction to all process and potential streams in a circular logistics, that consist of forward and reverse logistics (Vlachos et al. 2007).

2.2 Remanufacturing, Recycle, and Reuse (3R)

Remanufacturing is a process in which utilized items or end-of-life product are receive the same minimum guarantee as recently fabricated products and returned to original equipment manufacturer (OEM) new condition (Alamerew and Brissaud 2020). From Foster (2014) cost comparison appears that batteries remanufacturing is financially attainable price difference up to 40% between new battery utilize.

Recycling is a process were materials disposed are collected, handled, then utilized within the new materials or products. Recycling may be a prevalent technique for recuperating important materials, such as cobalt and lithium, from retirement EV battery (Alamerew and Brissaud 2020).

Electric vehicles can reach the end-of-life stage due to vehicle accidents or breakdown and battery still not achieve 80% of its capacity. In some a scenario, vehicle with same specification can use as a replacement battery (Alamerew and Brissaud 2020).

2.3 System Dynamics (SD)

System Dynamics (SD) created initially within the 1950s by Professor Jay Forrester. SD is a viable strategy for analyzing and evaluating the dynamic behavior of large and complex frameworks. Today, SD is widely used by academic institutions, large corporations, consulting organizations, and government agencies to improve process development, policy planning, and decision-making within and across complex systems and dynamic spaces (Sterman 2000). System dynamics also empowered to deal with information feedback, time delay and dynamic complexity (Damayanti et al. 2020).

3. Methods

This work using causal loop diagrams (CLD) as the conceptual model. CLD is used to capture the EV forward and reverse logistics in Indonesia. A research review was established to distinguish variables influencing EV sales, spent EVB collection and remanufacturing capacity. Interactional connections among primary factors created based on the related theories, internal mechanisms of EV forward and reverse logistics, expert judgment. Effects of interactions between variables indicated by causality and polarity. Causality is indicated by an arrow from "cause" to "effect", and polarity is indicated by a balancing or reinforcing loop. (Damayanti et al. 2020), (Sterman 2000). the plus (+) sign implies that in case the cause increases, the impact increases, and vice versa. The minus (-) sign implies that the cause increases, the impact decreases, and vice versa (Sterman 2000), (Zahrina 2020).

The system diagram was at that point created to demonstrate EV reverse logistics issues comprehensively. A system diagram is used to represent the complete process of a framework to achieve a goal consistent with given parameters. A system diagram presents an organized picture of your system (Damayanti et al. 2020). The system diagram in this work describes the owner of the EV Reverse Logistics problem, the target parameters, and goals to be achieved, the stakeholders, how the inputs, processes, and outputs of the system work are defined, and what A comprehensive description of how the intervention will take place. influence the results.

4. Results and Discussion

4.1 Stakeholder analysis

A stakeholder analysis designates stakeholders' responsibility and authority, perception of the problem, and objectives. Stakeholders categorized by three types, specifically parties, (1) problem affected and results to be implemented, (2) mutually associated in regulation intervention and policy and (3) associated properly in solution application and implementation (Setiawan et al. 2022).

Table 2. Stakeholder Analysis

Stakeholder	Responsibility and Authority	Problem Perception	Objectives
Indonesian Government	EV implementation policy maker and Issuing policies regarding the EVB recycle and remanufacturing	Some of the challenges in implementing EV in Indonesia and 3R (Reuse, Recycle, Remanufacturing) activity	Provide regulations to bolster the successful EV adoption and 3R process EVB
EV and EVB Users	Determine the effectiveness and efficiency of using EV and EVB	EV adoption decisions are influenced by several factors (Internal and External)	Availability of vehicles that can meet consumer driving needs at affordable prices and provide driving comfort
EV and EVB Industries	Providing EV and EVB that fit the consumer needs in the market	Unclear regulatory and uncertainty EV demand affect the company strategy in production and pricing decisions	Profitability and Consumer satisfaction
BUMN (National Company) PLN	Supplying electricity for battery charging station	Costly electricity price leads to decreasing electricity demand	To produce an affordable price and place electricity supply
Waste Management Company	Battery collecting and recycling operation	Lack of battery to be collected & recycled	Operate a profitable battery recycling operation

4.2 Model Conceptualization

The system diagram includes system inputs, which are causal loop diagrams (CLDs) that outline the complex dynamics of the EV forward and reverse logistics processes, output of interests or government interventions, problem owner and his goal and stakeholders. Figure 1 describes the system diagram of conceptual model for this study adapted from Setiawan et al (2022); Vlachos et al (2007).

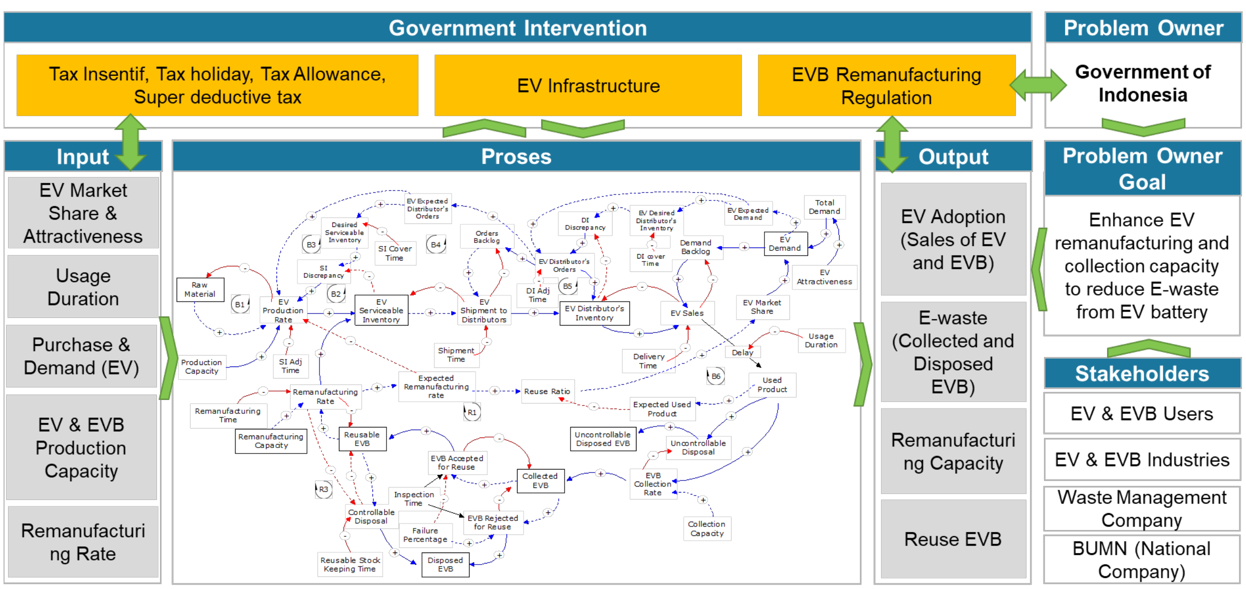

Figure 1. System diagram of EV Forward and Reverse Logistics in Indonesia

4.2.1 Forward Logistics Loop (B4)

Forward logistics consists of producers and distributors. This loop explains that the number of EV Distributor's Inventory are very dependent on the number of EV Shipment to Distributors. The more capacity means the more EV Production rate. Below is CLD Loop:

EV Production Rate (+) ➔ EV Serviceable Inventory (+) ➔ EV Shipment to Distributors (+) ➔ EV Distributor's Inventory (-) ➔ DI Discrepancy (+) ➔ EV Distributor's Orders (+) ➔ EV Expected Distributor's Orders (+) ➔ Desired Serviceable Inventory (+) ➔ SI Discrepancy (+) ➔ EV Production Rate.

4.2.2 EV Market Share and Reverse Logistics Loop (R1)

We expect remanufacturing to be the only reuse process within reverse logistics. Remanufacturing restores a part to " as good as new " condition by performing the necessary rebuilding, dismantle, and replacement processes (Vlachos et al., 2007). Below is CLD Loop:

EV Market Share (+) ➔ EV Demand (+) ➔ Demand Backlog (+) ➔ EV Sales (Delay +) ➔ Used Product ➔ EVB Collection Rate (+) ➔ Collected EVB (+) ➔ EVB Accepted for Reuse (+) ➔ Reusable EVB (+) ➔ Remanufacturing Rate (+) ➔ Expected Remanufacturing rate (+) ➔ Reuse Ratio (+) ➔ EV Market Share.

4.2.3 Remanufacturing and Collection Capacity Policy Loop (B7 and B8)

Government decision makers and regulators could use the created CLD to visualize the pathways of different behavior utilizing different levels of the model condition. In summary, models can be used to perform various operations "what-if" analyses. (Vlachos et al., 2007). Below is CLD Loop:

Collection Capacity (-) ➔ Collection Capacity Discrepancy (+) ➔ Collection Capacity Expansion Rate (+) ➔ Collection Capacity Adding Rate (Delay +) ➔ Collection Capacity

Remanufacturing Capacity (-) ➔ Remanufacturing Capacity Discrepancy (+) ➔ Remanufacturing Capacity Expansion Rate (+) ➔ Remanufacturing Capacity Adding Rate (Delay +) ➔ Remanufacturing Capacity

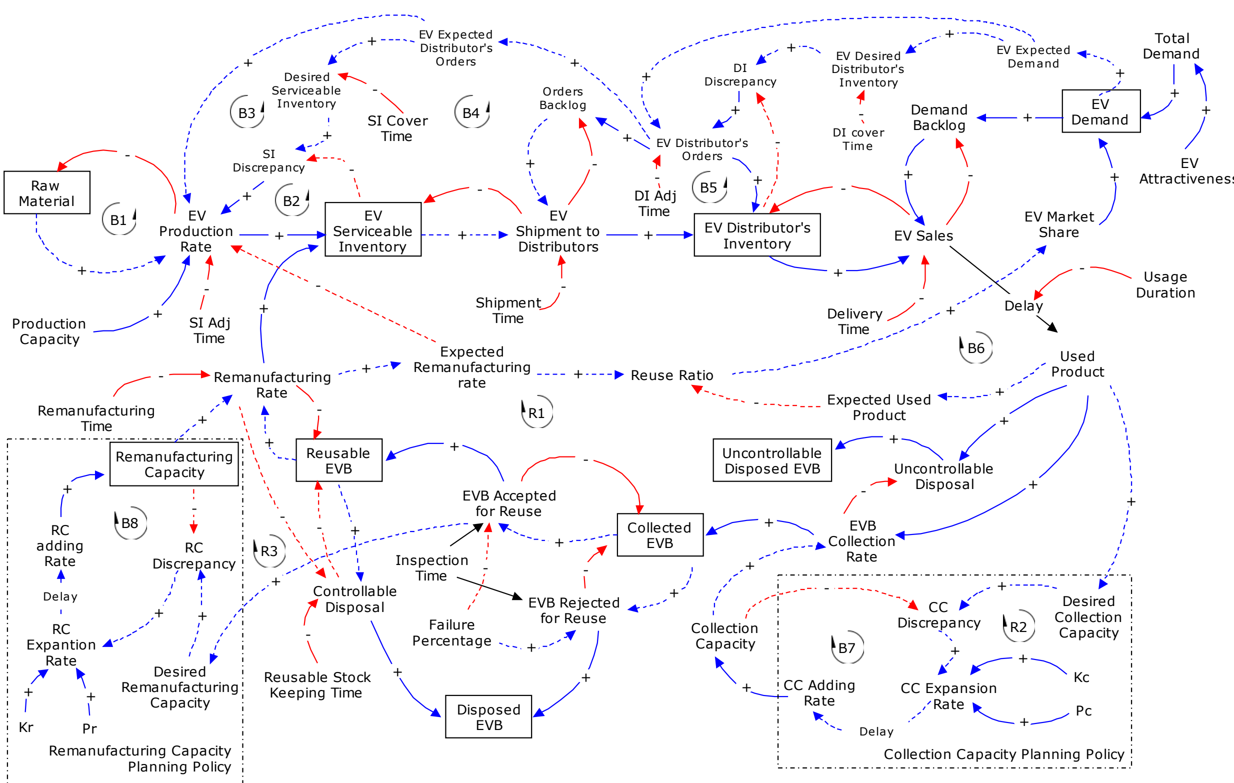

Figure 2. Causal Loop Diagram of EV Forward and Reverse Logistics in Indonesia

5. Conclusion

This study succeeded in explaining a conceptual model for the EV reverse logistics process and relates to the remanufacturing and collection capacity of EVB in Indonesia. The model is created by recognizing the factors included and distinguishing the connections between interrelated factors within the system boundaries. This conceptualization model was created utilizing system diagrams and causal loop diagram (CLD) that are the premises of the system dynamic path. A system diagram is developed for a comprehensive understanding of EV reverse logistics related to the problem owner's goals from the problem owner, the stakeholders involved, input systems, processes, and outputs, as well as intervention policies that can affect the output of the conceptual model.

Current study is limited to the build and develop of a reverse logistics EV conceptual model in Indonesia, while mathematical approach for this model have not been carried out. Subsequent research will consider a stock and flow diagram (SFD) refer to the conceptual model that has been developed and validated. Stock and flow diagrams can be utilized quantitatively and qualitatively to analyze the outcome of government interventions on the EV battery remanufacturing and collection systems.

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Biographies

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