
The Analysis of Formal and Informal Sector on Lead Acid Battery: A System Dynamics Approach

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ABSTRACT

With the increasing number of motor vehicles in Indonesia, it also increases the number of lead acid batteries (LAB) LAB one of electric powers used in motor vehicles. They can be recycled and reuse as again a battery of the vehicle. Therefore, it is interested to conduct research specially to see how a circular supply chain of LAB and how it affects the environment using a system dynamics approach. We use the causal loop diagrams to map the circular supply chain of LAB and design a simulation model using stock and flow diagrams. We also provide a discussion on how the formal and informal sectors competes in this very emerging market. It is expected that there will be regulations from the government to increase market share of the formal sector to support the informal sector so that it could carry out recycling processes like the formal one in order to reduce negative impacts on the environment. There are 5 scenarios used in the simulation model experiment, namely tax reduction on formal recycler, subsidy on formal recycler, subsidy or discount on LAB price, combination of tax reduction and subsidy on formal recycler and standardized price of LAB and lead in formal and informal sectors. Of the five scenarios, the best result is that subsidizing formal recycler can increase the formal old LAB market share to 64% from 47% and the excreted lead can decrease by approximately 1,200 kg/month.

Keywords:

Lead acid battery; formal sector; informal sector; circular supply chain; system dynamics

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1. Introduction

Along with the development of the number of motor vehicles in Indonesia, it is followed by an increasing in the number of one of the components that play an important role in the vehicle activation process, namely the lead acid battery (LAB). The battery used in motor vehicles—both cars and motorcycles—has a function as a store of electrical power which will then be flowed to other components in the vehicle. LAB, which has battery properties, is composed of lead metal, polypropylene polymer, and sulphuric acid. The hazardous characteristics of lead metal of the LAB waste for human health and the environment is one of the focuses in several developing and developed countries ([Joshi et al., 2021](#)).

LAB waste after life service is also a concern of many parties and several automobile companies which are currently aware of the environmental impact of the materials. Then they impose a trade-in system for used LAB officially (the formal sector); and also the informal sector, such as workshops or LAB collectors. The process of reusing lead materials of LAB in Indonesia is common in the informal sector because recycling LAB can provide a large benefit. However, the formal sector that applies good environmental regulations in the recycling stage is rarely found in Indonesia. The recycling process can produce waste which is very dangerous for the environment and health if it is not organized using proper technology. The air pollution resulting from combustion contains heavy metals (such as lead), sulphur, and plastic. The recycling process is intended to retrieve lead (Pb) and plastic boxes

that can be resold as raw materials for plastic recycling. The combustion process of this recycling process will produce CO₂, H₂O, and toxic gases, such as Co, HC, sulfuric acid liquid oxidation reaction which can damage solid objects (fabric, wood, paper) ([Kumaladewi, 2020](#)).

We then try to map the flow of LAB supply chain after it has been “consumed” by the consumers; the producers might accept the LABs for the use in other vehicles, or it can be reused as “a new” LAB after undergoing a reconditioning period, or can be used for other activities so that it will not disturb environment and human health, or even worse it will end up in landfills. We also attempt to map how consumers treat LAB after its lifetime and also where the role of the formal and informal sectors in the life cycle of this LAB in Indonesia.

Circular supply chain in LAB is very important to be discussed because the materials in LAB belong to the hazardous waste if they are not managed properly. There are a few researchers who pay attention to this discussion. [Daniel & Pappis \(2008\)](#) compared two scenarios that focus on the environmental impact caused by LAB, two alternative scenarios related to the end of life (EOL) of the battery and the supply chain process. The analysis used life cycle analysis impact assessment (LCIA) which includes environmental design of industrial products (EDIP). One of the results is that the circular supply chain process has an impact on global warming, especially in the collection process of batteries. The next aspect that plays a role in increasing the global warming is during the distribution process and the remanufacturing process of the battery.

[Ghalandari et al. \(2022\)](#) used data envelopment analysis (DEA) and life cycle assessment (LCA) using Simapro to analyse emissions in order to minimize the circular supply chain process of LAB. They then used the mixed integer linear programming (MILP) to minimize the process, transportation, and fixed costs in the circular supply chain process so as to produce a sustainable design for the circular supply chain process in the LAB industry which is not only used for vehicles but also in other uses. [Subulan et al. \(2015\)](#) combined the MILP with fuzzy number to develop a closed-loop supply chain (CLSC) model in the circular LAB supply chain process for models with multi-products, objects and echelons with the objectives of cost minimization, maximizing battery return facilities, and maximizing the number of LAB to be recycled.

While [Lashkari & Zhang \(2014\)](#) designed a CLSC in LAB on a multi-objective and multi-echelon basis using MILP which aims to minimize costs in the recycling process and minimize pollution caused by the circular supply chain process in the LAB recycling process. [Kamyabi et al. \(2022\)](#) used system dynamics and mathematical programming to optimize the CLSC model in LAB which aims to increase the economic value of LAB and reduce the adverse impact on the environment by purchasing raw materials from LAB. By using mathematical programming without dynamic systems, [Zan & Zhang \(2022\)](#) used extended producer responsibility (EPR) system that can solve the problem of recycling and utilization of waste use from LAB by using three channel modes, namely the recycling process which is only carried out by the manufacturer (Mode M), recycling by special facilities (Mode R) or recycling by third parties (Mode C). The aim is to minimizing costs in the recycling process and maximizing the amount of LAB recycled. Meanwhile, this paper conducts an analysis using dynamic systems to obtain the proportion of the number between the formal and informal sectors, and then several scenario options are made to reduce the extraction of hazardous waste from lead in the environment around the recycling process area.

2. Literature Review

2.1 Circular Supply Chain of Lead Acid Battery

Circular Supply Chain (CSC) is an activity that uses the concept of reusing end-of-life products to have a significant impact on environmental and economic aspects. One of the materials that are recycled after their useful life is lead acid batteries (LAB) or what is known as motor vehicle LAB ([Joshi et al., 2021](#)). In addition, some literature also discusses the Circular Supply Chain, one of which is [Fleischmann \(2000\)](#) who provides an understanding by summarizing the following three characteristics of the circular supply chain:

- a. First, the traditional supply chain system is a directional structure whose system consists of suppliers, manufacturers, distributors, retailers, and customers where the flow of materials flows from suppliers to customers and the flow of information flows downstream and upstream. While the supply chain

system that follows the development of the industry today has developed materials not only flow downstream but can return upstream as materials for the same product or different products. This system is now better known as forward supply chain and supply chain.

- b. The second, circular supply chain is related to secondary goods, which are goods that have finished using their original function. So that the circular supply chain is related to derivative goods from previous use, which can be reused as raw materials from the first item or into a product that is completely different from the previous one. Which has the aim of maximizing the economic value of the goods produced.
- c. Third, the circular supply chain is closely related to the view of the recipient of the material flow. From the three characteristics mentioned above, there is an understanding concluded by Fleischmann (2000) as follows:

“Circular Logistics is the process of planning, implementing, and controlling the efficient, effective inbound flow and storage of secondary goods and related information opposite to the traditional supply chain direction for the purpose of recovering value or proper disposal”

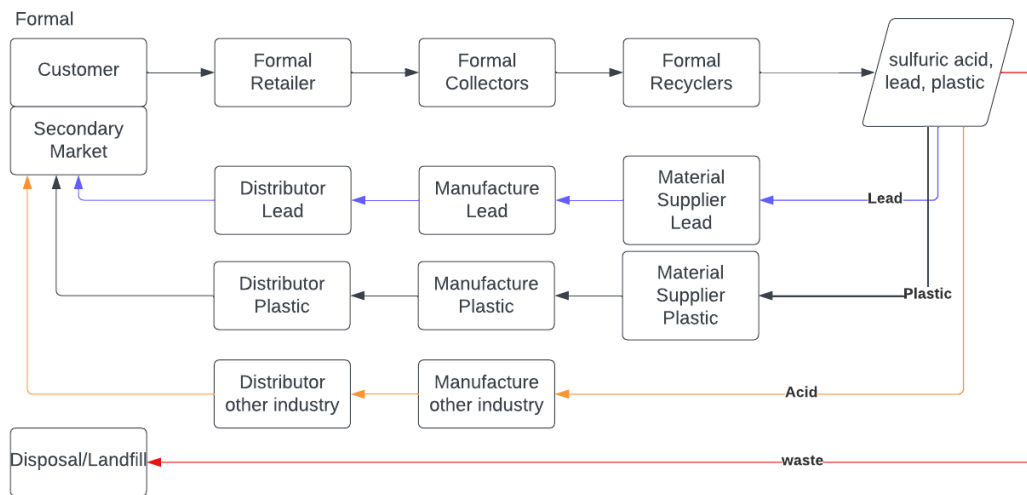


Figure 1. Circular Supply Chain Lead Acid Battery (LAB) formal sector

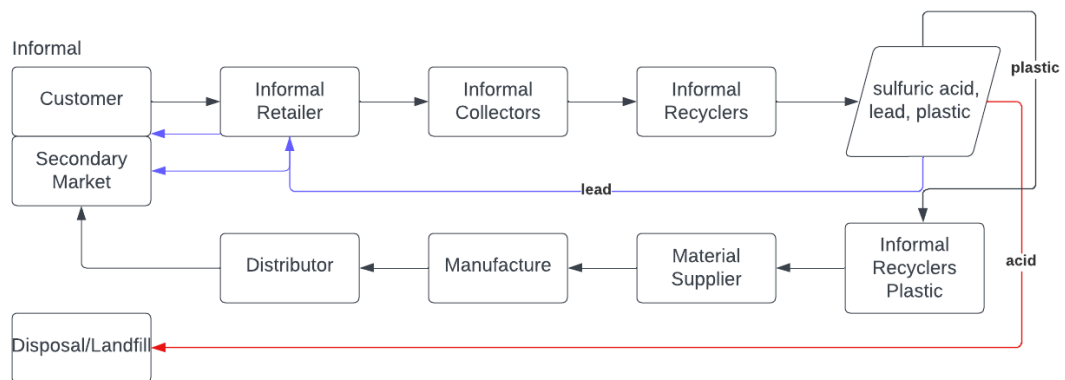


Figure 2. Circular Supply Chain Lead Acid Battery (LAB) informal sector

2.2 Lead Acid Battery

Lead Acid Battery (LAB) which is used as a source of electricity in motorized vehicles both motorcycles and cars is classified as hazardous waste because it contains reactive toxic materials and heavy metals such as lead ([Kamyabi et al., 2022](#)). According to Battery Council International (BCI), more than 97% of the lead content in LABs can be

recycled, which is greater than that of aluminium cans (55%), newspapers (45%), glass cups (26%) and tire rubber (26%) (Subulan et al., 2015). The structure of the lead-acid battery is a combination of chemicals, electrical components and mechanical formers. And generally consists of 4 parts, namely anode, cathode, electrolyte and separator. The anode is a positive plate or electrode that absorbs electrons during the discharge process, the chemical raw material that forms it is Lead Oxide (PbO_2). Then the negative plate or electrode that releases electrons during the discharge process is the cathode where the chemical that forms it is Lead (Pb). Both positive and negative poles are immersed in sulfuric acid (H_2SO_4) with a concentration of 25% to 60% and 40% to 75% is water (H_2O). The composition of both causes sulfuric acid to ionize into H^+ and HSO_4^- ions (Ghalandari et al., 2022).

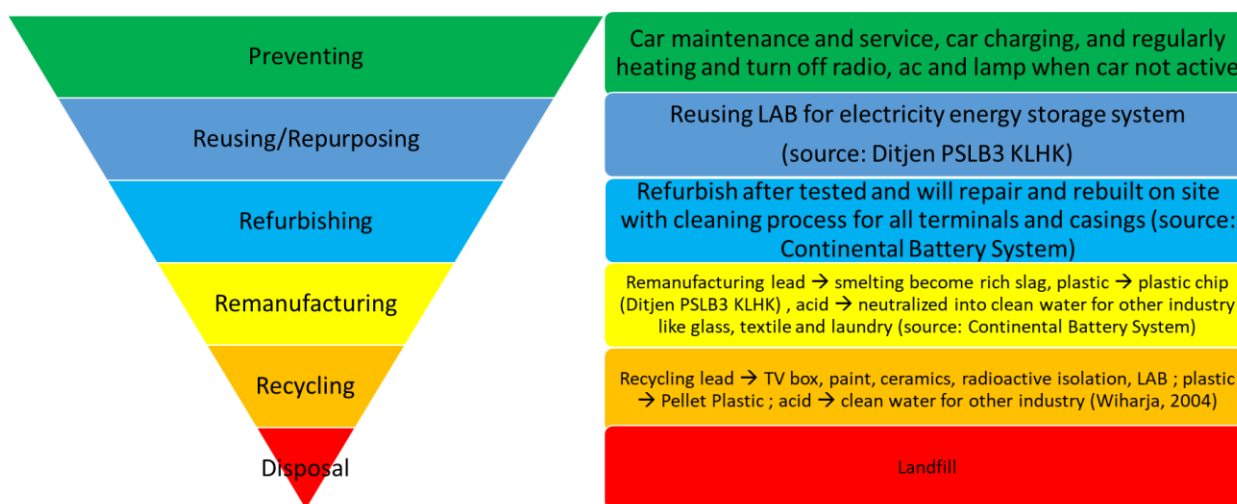


Figure 3. Waste Hierarchy Lead Acid Battery

Waste Hierarchy on LAB on Figure 3 from the safest and most frequently carried out stages to the stages where hazardous waste must be disposed of in landfills. The highest hierarchy is the preventing stage where to keep the car battery in good use is to carry out maintenance of the LAB properly as well as carry out routine services so that you can find out in advance if the LAB car battery must be replaced immediately or lacks power generation. In addition, if the motorized vehicle is no longer in use, do not forget to turn off the air conditioning, radio and car lights when used at night. After the preventing stage has been carried out to maintain car battery maintenance for the next LAB waste hierarchy is reusing or repurposing, namely reuse of its old function but not changing the form or carrying out other processes in transferring its function, according to the Directorate General of Waste Management, Waste and Hazardous Waste, Ministry of Environment and Forestry LAB can be utilized as an electrical energy storage system.

The next hierarchy is refurbishing where this stage is the process of repairing the old LAB which is no longer functioning properly as a power plant for motorized vehicles, after checking and repairing, it can be remade directly on the spot by cleaning first for the terminal parts and casing of the LAB (Continental Battery System). Then there is the next hierarchy, namely remanufacturing for each part, and what is conveyed in this study is remanufacturing lead with the smelting process into rich slag or ingot, then plastic for LAB boxes into plastic chips (Directorate General of Waste Management, Waste and Hazardous Waste, Ministry of Environment and Forestry) which can be used as LAB boxes again after the LAB box manufacturing process, while sulfuric acid liquid gets neutralized treatment into clean water which can be used for the glass, textile or laundry industry (Continental Battery System). Then the hierarchy that is close to the final hierarchy is recycling which changes the main function of LAB into secondary products such as lead which is used as a TV box, paint, ceramics or radioactive insulation, then plastic is recycled into plastic pellets and sulfuric acid liquid after going through the neutralization stage can be used by other industries (Wiharja, 2004).

2.3 System Dynamics

System Dynamics is a simulation method used to describe the dynamics of complex systems in a systematic way of thinking using real systems or systems that are modelled using mathematical equations. System modelling using the dynamic system method certainly has significant challenges because researchers must be able to convert the real system into a mathematical model or differential equation ([Sopha & Sakti, 2020](#)).

[Joshi et al. \(2021\)](#) developed a dynamic system model to analyse the LAB recycling process which focuses on the recycling and remanufacturing process of LAB in the formal and informal sectors. Where the model investigated the impact on regulatory decisions on performance in the motor vehicle LAB recycling process. In Brazil, [Ghisolfi et al. \(2017\)](#) analysed using a dynamic system for electronic waste in the form of laptops and desktop computers that looked at how the involvement of waste pickers in participating in being responsible for the life cycle of a product which here is electronic waste. Where this research aims to measure the impact of legal incentives and how much waste volume results from the participation of waste pickers in this circular supply chain system. Modelling with a dynamic system approach is also carried out in the case study of batteries for electric vehicles as stated in the research conducted by [Alamerew & Brissaud \(2020\)](#) where the model focuses on complex systems in the circular supply chain to recovery at the end of the LIB life in electric vehicles. And this model focuses on the costs incurred, income earned and strategic and regulatory decisions in the LIB circular supply chain process.

[Blumberga et al. \(2014\)](#) conducted research to look at changes from informal to formal collection of LAB waste based on social, economic and government regulatory factors using a dynamic system for collecting LAB waste in the Latvian region. The model was developed based on the decision supporting system of the developer's regulation which was used as a reference in the dynamic system for system management in the informal waste collection sector. [Papachristos \(2014\)](#) studied the relationship between capital goods supply chains and sociotechnical transition. This research focuses on sustainability, energy, and transportation systems and explores models of supply chain system dynamics. While the remanufacturing of used products by retailers and recycling by suppliers can reduce the environmental impact of the supply chain, competition in the market between new products and remanufactured products forces them into a situation where improving business and environmental performance is difficult. Based on these studies, dynamic systems are used in this study because dynamic systems are systems whose variables can continue to change due to changes in inputs and interactions between elements in a system as occurs in the circular supply chain LAB system. In addition, the problems associated with the circular supply chain are dynamic problems due to the interdependence, interaction and reciprocal relationship between entities in the LAB circular supply chain system. And in this condition, the dynamic system has the advantage that the costs incurred to carry out simulations with dynamic systems are cheaper, the calculations in the simulation are stronger, then being able to recognize system behaviour while evaluating policies and the results issued after simulation can be analysed easily.

3. Methodology

This research undertook the development of a Dynamic System model of the LAB recycling system in Indonesia that considers recyclers and remanufacturers in both the formal and informal sectors and the details of the model are given below:

3.1 Dynamic Hypothesis

- Problem Articulation

The problem articulation for this system is on the economic side: the LAB recycling process is already underway and generates added value in the supply chain process, because the formal and informal sectors have implemented a trade-in system for end-of-life vehicle; and the lead components in the LAB can still be used for LAB again or for other products. However, on the other hand, the government cannot supervise 100% of this recycling process: for the formal sector, they have carried out each stage in accordance with regulations; but for the informal sector there are still many processes that cause environmental pollution as well as can damage public health if the recycling process is not carried out in accordance with existing environmental regulations.

- Dynamic Problem Definition

The increase in the use of private vehicles, especially in Indonesia, is clear; it is also accompanied by an increasing in the use of LAB. LAB trade-in activities in both the formal and informal sectors will continue even though currently electric vehicles are starting to operate in Indonesia; but vehicles that use LABs as electricity storage will continue to be used as long as there is a need for motor vehicles. Therefore, the issue of the LAB trade-in and recycling supply chain deserves to be the focus of the government in implementing its regulations.

- Dynamic Hypothesis

Consumers have a preference to trade-in their LAB based on price, quality, and situation (emergency) in the formal and informal sectors. The exchanged LAB is then recycled and they can get the results of the lead recycler which can be reused as lead raw material for new LAB. The smaller the price of LAB in the formal and informal sectors, the demand in these sectors will increase. Supply will be inversely proportional to the demand. The model in this system is influenced by the price of the old LAB being exchanged (formal and informal sectors), the amount of lead generated from the LAB exchange process in both sectors, the price of lead before returning to LAB, and the price of new LAB with lead recycler raw materials.

- Reference Modes

Reference Modes for dynamic hypothesis in this system shows that historical data of total LAB demand from 2010 to 2022 has an increasing trend (see Figure 4) with oscillations. The oscillations are caused by economic factors that have increased and decreased from year to year and are most likely influenced by several other factors such as health, environment, and politics. When a straight line is drawn, a linear line is seen with a gradual and significant increase.

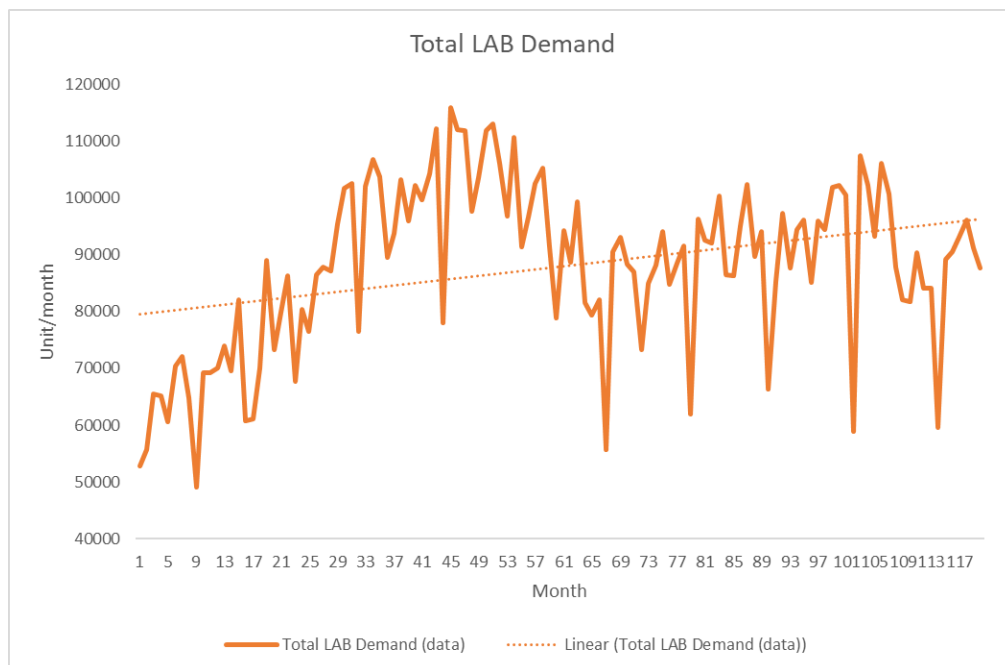


Figure 4. References Modes for Total LAB demand

the actual working model including the relationships between variables. Figure 6 represents the SFD of the model. The model was created and run in Vensim® PLE Software (Version 7.2a). In the SFD, rectangular boxes indicate stock variables. Flow governs the rate of change of the stock variable, represented by an arrow with a valve representing the flow rate. Causality is set by connecting the arrows. The model setting used in this simulation model is unit time in months, with initial time 0 and final time 120 months or 10 years with a time step of 1 month. The equations entered into the simulation model will be explained in detail at section 3.3.1 and 3.3.2 below:

3.3.1 Formal Remanufacturing System

The notation *Tot_LAB demand* is variable 'total LAB demand' here is modelled as a variable stock to get a dynamic total LAB demand. Each demand change in total LAB demand is driven by the flow variable 'increase in LAB demand' which notation *Inc_LAB demand* as per equation (1) and (2) below:

$$\text{Inc_LAB demand} = \text{Tot_LAB demand} \times \text{LAB demand_mgr} \quad (1)$$

$$\text{Tot_LAB demand} = \text{int_LAB demand} + \int_0^t \text{Inc_LAB demand} \times dt \quad (2)$$

'Formal LAB demand' with the notation *Form_LAB demand* is the market demand for LAB demand per month, where in this model the sum of formal and informal LAB demand is the total demand. 'Informal market share' with notation *Inf_LAB ms* is the percentage of informal LAB demand. The model in this system is described in accordance with economic theory where the higher the price, the smaller the demand. So when the formal LAB price is high, the greater the demand in the informal sector. 'Formal LAB demand' and 'Informal market share' are auxiliary variables that have a relationship with the 'formal LAB price' with notation *Form_LAB price*, where the 'formal LAB price' is a stock variable that can make dynamic price changes to the 'formal LAB price'. which then any changes to the 'formal LAB price' are driven by the flow variable 'formal LAB supply price relation' with notation *form_LAB sp_rel*.

$$\text{Form_LAB demand} = \text{Tot_LAB demand} \times ((100 - \text{Inf_LAB ms})/100) \quad (3)$$

$$\text{Inf_LAB market share} = \frac{\text{MAX}(\text{Form_LAB price}, 0)}{(\text{MAX}(\text{Form_LAB price}, 0) + \text{MAX}(\text{Inf_LAB price})) \times 100} \quad (4)$$

$$\text{Form_LAB price} = \text{int_form_LAB price} + \int_0^t \text{form_LAB sp_rel} \times dt \quad (5)$$

The 'formal manufacture rate' with notation *Form_mfg_rate* is the formal LAB remanufacture rate, where the output of the formal manufacture rate is the minimum value of raw material supply, manufacturing capacity and demand. The manufacturing capacity is the formal LAB manufacturing rate, then the demand for formal LAB is the formal LAB demand. The variable 'formal recycler lead supply' and 'mass of lead' with notation $\frac{\text{form_rec_lead supply}}{\text{mass of lead}}$ is the raw material required in a LAB. And variable 'Formal LAB supply' with notation *Form_LAB supply* is the monthly supply of LAB in the formal sector.

$$\text{Form_mfg_rate} = \text{MIN} \left(\frac{\text{form_rec_lead supply}}{\text{mass of lead}}, \text{MIN}(\text{form_LAB demand}, \text{form_LAB mfg_cap}) \right) \quad (6)$$

$$\text{Form_LAB supply} = \text{form_mfg rate} \quad (7)$$

$$\text{Prev_form_LAB supply} = \text{DELAY FIXED}(\text{form_LAB supply}, 60, \text{int_form_LAB supply}) \quad (8)$$

3.3.2 Formal Recycler System

The 'total old LAB rate' with notation *Tot_old LAB rate* here is modelled as a variable stock to get a dynamic total old LAB rate. Old LAB rate change in total old LAB rate is driven by the flow variable 'change in old LAB rate' with notation *Chg_old LAB rate*. Which details equation below:

$$\text{Inf_LAB ms} = \frac{\text{inf_rec_old LAB payment_ret}}{(\text{inf_rec_old LAB Payment_ret} + \text{form_rec_old LAB payment_ret}) \times 100} \quad (10)$$

$$\text{Tot_old LAB rate} = \text{int_old LAB} + \int_0^t \text{chg_old LAB rate} \times dt \quad (11)$$

$$\text{Chg_old LAB rate} = \text{Tot_Old LAB rate} \times \text{old LAB_mgr} \tag{12}$$

$$\text{Old LAB sold_form_rec} = \text{Tot_Old LAB rate} \times ((100 - \text{inf_old LAB ms}) / 100) \tag{13}$$

'Old LAB sold to formal recycler' with notation *Old LAB sold_form_rec* is auxiliary variables which are LABs that are exchanged by consumers and then sold by retailers to recyclers for recycling. The amount is determined by equation 13. The next is formal lead excretion which is a flow variable where the formal sector releases lead excretion for one month, if the lead recovery efficiency is x , then $(1-x)$ total lead is released to the environment. While total lead excretion is a stock variable which is the sum of formal and informal lead excretion affected by the time function.

$$\text{Form_lead excretion} = \text{mass of lead} \times \text{Old LAB sold_form_rec} \times (1 - \text{form_lead extraction etc}) \tag{14}$$

$$\text{Tot_lead excretion} = \int_0^t \text{form_lead excretion} + \text{inf_lead excretion} \times dt \tag{15}$$

4. Results

4.1 Model Validation

4.1.1 Validation with Historical Total Demand LAB data

The simulation results as shown in Figure 7 show a linear trend that increases from the initial year to 10 years according to the simulation time set. The historical data displays data with oscillating trends that experience many changes from year to year. If a straight line is drawn, it will produce a linear trend; After calculating errors for historical data and models, the standard error results for total LAB demand (model) = 503.90 and standard errors for total LAB demand (data) = 1335.07 mean that the sample data for total LAB demand (model) is more representative of the entire sample Compared to the total LAB demand (data), which has a higher error value. Meanwhile, when tested using the t test, the result is $t(238) = 8,708$, $p = 2.62e-16$, which states that the two data do not have a significant difference, so the data is the same or slightly different. So it can be concluded that the simulation results with historical data are in the same trend and with the results of errors and the t test it can be stated that this model is valid.

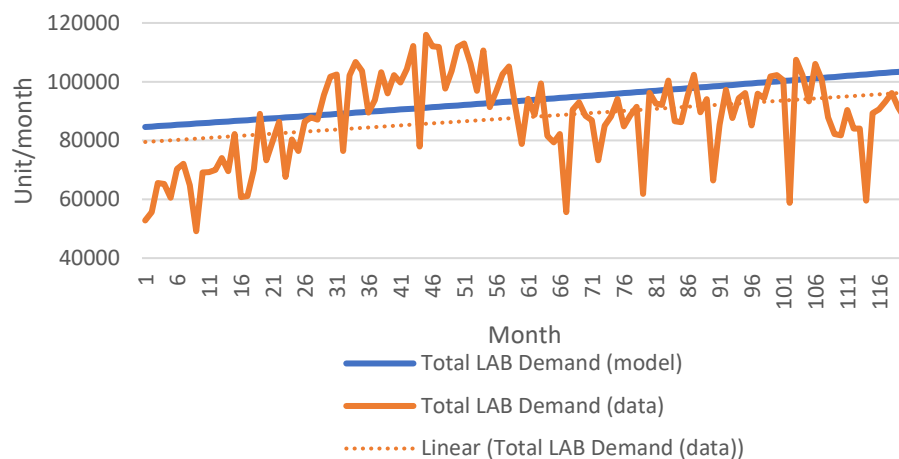


Figure 7. Model Validation Total LAB demand (model vs. historical data)

4.1.2 Validation with Historical data of Total Demand for LAB in formal and informal sectors

The second validation was carried out by comparing the simulation results of the formal and informal LAB demand models with historical data on the percentage of formal and informal workers in Indonesia from 2011 to 2021. Then the simulation runs for 10 years and shows simulation results with an increasing linear trend from the first month to the 120th month or 10th year, what looks different here is the comparison of the number in the formal and informal sectors which shows a greater demand value in the informal sector and the amount of demand in the

formal sector is below it. After calculating errors for historical data and models, the standard error results for formal LAB demand (model) = 488.94 and standard errors for formal LAB demand (data) = 58,387 mean that the sample data for formal LAB demand (data) are more representative of the entire sample. Compared to the formal LAB demand (model), which has a higher error value. While the results of the standard error for informal LAB demand (model) = 888.30 and the standard error for informal LAB demand (data) = 842.38 which means that the sample data for informal LAB demand (data) is more representative of the entire sample than the informal LAB demand (model) which the higher the error value. Then the t test was carried out for the formal LAB demand model and data and the results were obtained $t(239) = 4.003$, $p = 4.174e-05$, which stated that the two data did not have a significant difference, so the data was the same or slightly different. Meanwhile, the t test on the informal sector yielded results $t(240) = 13,530$, $p = 1.108e-31$ which also stated that the two data did not have a significant difference. Which can then be concluded that the simulation results with historical data are in the same trend on formal and informal LAB demand and with the results of errors and the t test it can be stated that this model is valid.

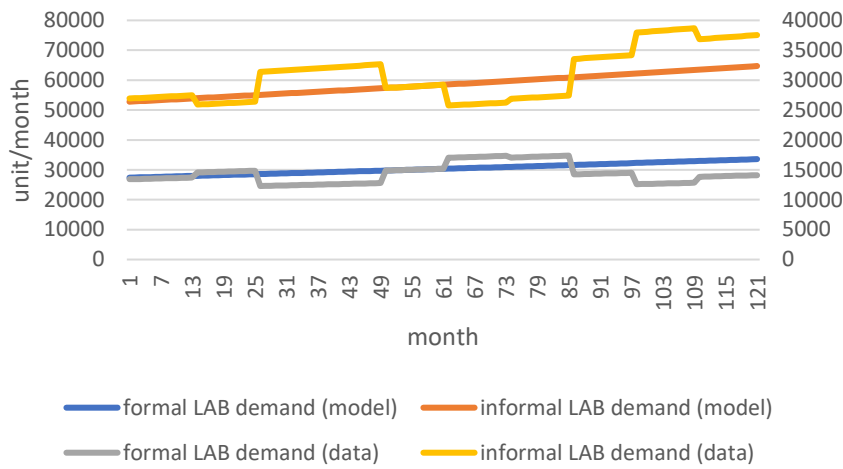


Figure 8. Formal & Informal Validation Model LAB demand (model vs data)

4.1.3 Validation with Extreme Condition

Validation model where an extreme condition is imposed on the price of LAB in the informal sector which results in no demand in the informal sector and demand is dominated in the formal sector. With validation like this, the model is declared valid because when the price of an item with the case here is LAB as the object is at a very high or expensive value, no consumer will buy the item so that the demand for the item does not exist.

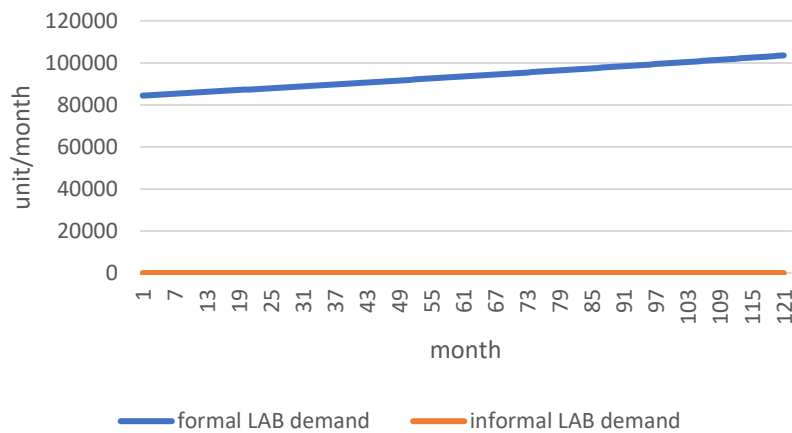


Figure 9. Formal & Informal Validation Model LAB demand (extremem condition)

4.1.4 Validation with economic theory

The economic theory of supply and demand is justified in the simulation model for this LAB circular supply chain, where when the price of LAB in the informal sector increases gradually over time, the amount of demand in the informal sector will decrease as shown in the Figure 10.

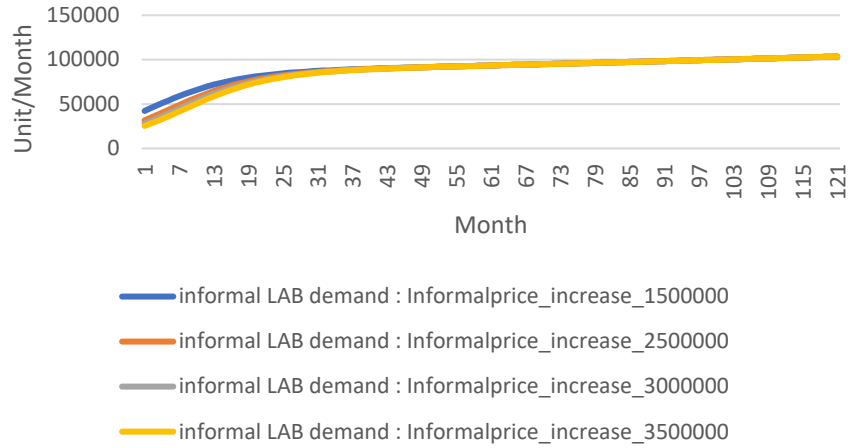


Figure 10. Informal LAB demand validation model with economic theory

4.2 Skenario Model

4.2.1 Tax Reduction on Formal Recycler

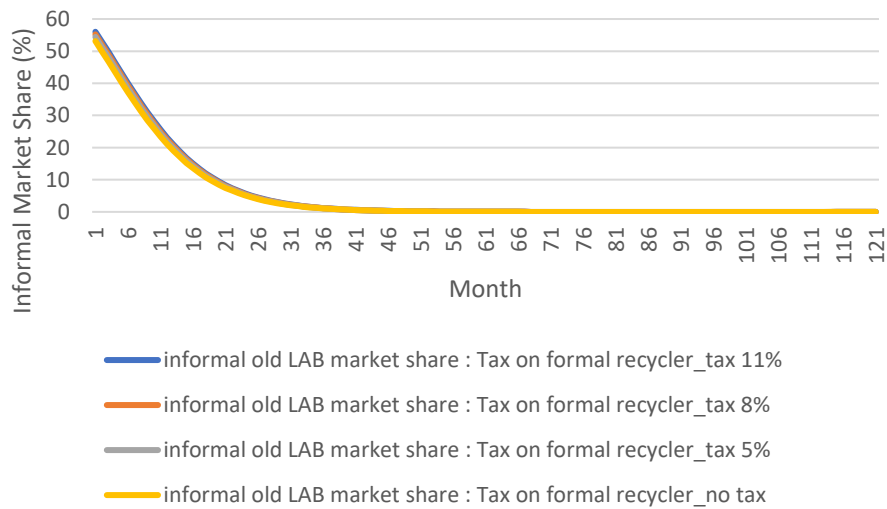


Figure 11. Impact of Tax Reduction on Informal old LAB market share

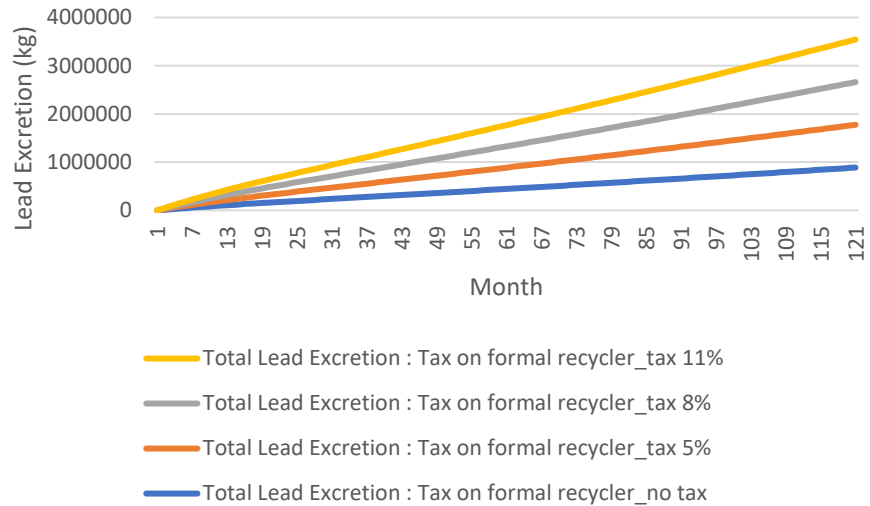


Figure 12. Impact of Tax Reduction on total lead excretion in the environment

Tax Reduction on formal recycler means a decrease in tax or VAT (Value Added Tax) from 11% to 5% is also simulated if there is no tax as an illustration to see how the value of market share in the informal sector when a tax reduction is carried out to 0%. So that the results obtained can be seen in Figure 11 below. In addition to economic factors, there is a resulting environmental impact as shown in Figure 12., namely the trend of the impact of tax reduction on total lead excretion in the environment, with a decrease in this tax where the resulting lead excretion is also decreasing, so it can be said that this tax reduction can also have a positive impact on the environment because the total lead polluted in the environment will be reduced by the tax reduction scenario.

4.2.2 Subsidizing Formal Recycler

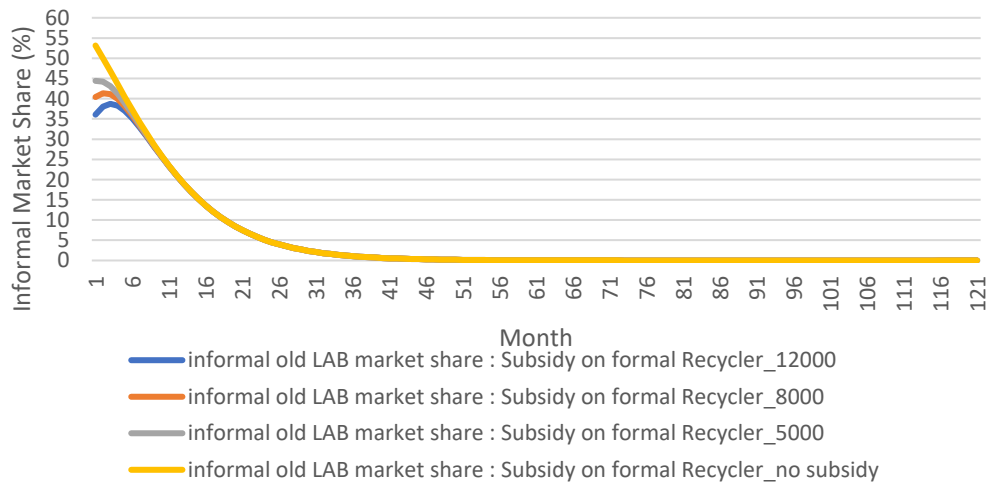


Figure 13. Impact of subsidizing formal recycler on informal old LAB market share

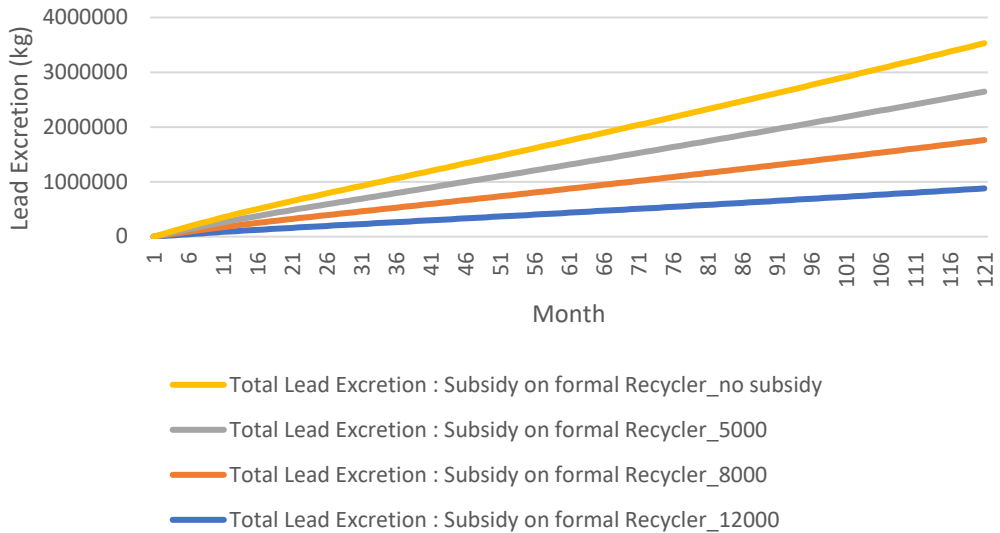


Figure 14. Impact of subsidies on total lead excretion in the environment

The provision of subsidies to formal recyclers intended in Figure 13 is the provision of subsidies to formal recyclers for material prices starting from IDR 5,000, - then IDR 8,000, - to IDR 12,000, - and also simulated if there is no subsidy at all in this system as an illustration of where the informal market share position is with subsidies or without subsidies. In addition to economic factors, there is a resulting environmental impact as shown in Figure 14, namely the trend of the impact of subsidies on total lead excretion in the environment, with this tax reduction where the resulting lead excretion is also decreasing, so it can be said that subsidizing the formal recycler sector can also have a positive impact on the environment because the total lead polluted in the environment will be reduced by the tax reduction scenario.

4.2.3 Subsidies or discounts by retailers

The provision of subsidies or discounts by retailers referred to in Figure 15 is the provision of subsidies on the price of LAB in the formal sector starting from Rp. 500,000, - then Rp. 800,000, - up to Rp. 1,000,000, - and also simulated if there is no subsidy at all in this system as an illustration of where the informal market shre position with subsidies or without subsidies for the price of LAB in the formal sector.

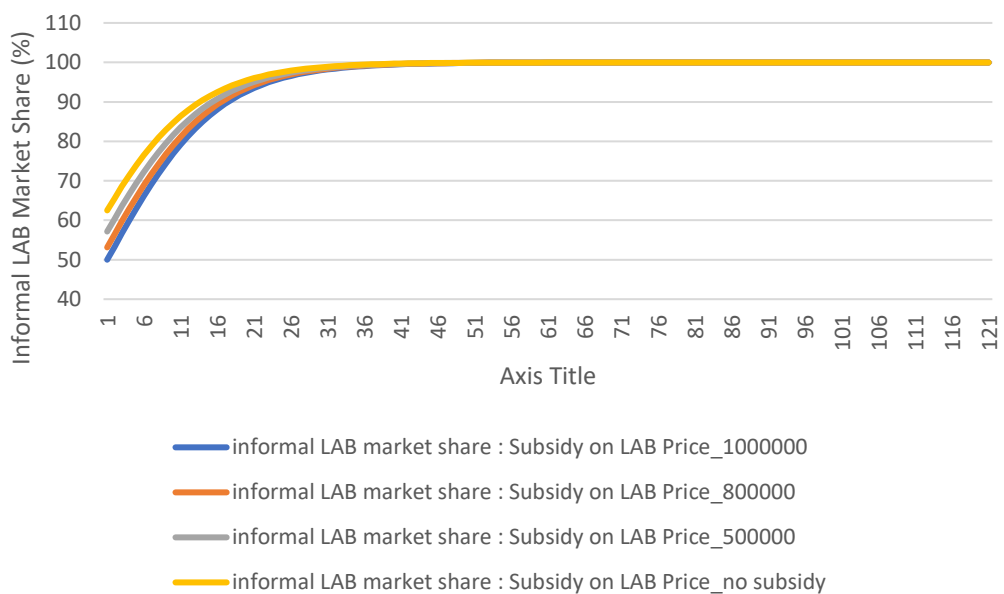


Figure 15. Impact of subsidizing formal LAB price on informal old LAB market share

5. Discussions

Tax reduction on formal recycler gives results of a decrease in informal market share when a tax reduction is imposed. The position of the informal market share when the tax is imposed at 11% (current condition) is 56%, while when the tax drops to 8%, the informal market share is 55%. When the tax is 5%, the informal market share is 54% and if there is no tax at all, the informal market share is 53%. It can be concluded that the reduction in tax from normal conditions to the absence of tax enforcement affects the market share in the informal sector which also affects the market share for the formal sector (even though a 3% tax reduction will only reduce market share by around 1%). The tax reduction scenario can be said to be effective as one of the scenarios in this circular supply chain system. Subsidizing formal recycler gives results of a decrease in informal market share. The position of the informal market share when there is no subsidy (current condition) is 53%, when there is a subsidy of Rp. 5,000, the informal market share is 44%. When the subsidy is increased to Rp. 8,000, the informal market share is 40% and with the highest subsidy of Rp. 12,000, the informal market share is 36%. It means that the formal market share is 64% which is higher when compared to the percentage of the informal recycler market share. It can be concluded that the provision of subsidies from a nominal value of IDR 5,000 to IDR 12,000 can reduce market share in the informal sector and increase market share in the formal sector. With the provision of subsidies, there is a significant decrease in percentage from the smallest nominal subsidy to a large subsidy to the informal market share, so it can be said that the provision of this subsidy is also one of the effective scenarios. Next scenario subsidies or discounts by retailers bring results of a decrease in informal market share when subsidies are given. The informal market share position when there is no subsidy (current condition) is 62.5%, while when there is a subsidy of Rp. 500,000, the informal market share is 57%. When the subsidy given is increased to Rp. 800,000, then the informal market share is 53%. With the highest subsidy of Rp 1,000,000, the informal market share is 50% (the formal market share is also 50%); it means that it is quite capable of balancing the market share because the price in the informal sector is cheaper when compared to the price of LAB in the formal sector. It can be concluded that the provision of subsidies from a nominal value of Rp. 500,000,- to Rp. 1,000,000,- can provide a decrease in market share for the informal sector and increase market share in the formal sector. By subsidizing the price of formal LAB, there is a significant percentage decrease from the smallest nominal subsidy to a large subsidy to the informal market share, so it can be said that subsidizing the price of LAB in the formal sector is also one of the effective scenarios.

In a study conducted by [Joshi et al. \(2021\)](#) with the subject of LAB and considering the formal and informal sectors in the tax reduction scenario, the results show that by reducing taxes on the formal sector, it also reduces the market share for the informal sector. This is due to reduced fluctuations in lead supply. Furthermore, the scenario of subsidizing the formal recycler resulted in the subsidy being able to inject money directly into the regulated system for the purchase of used batteries by the regulated sector. This will allow recyclers to pay more to retailers for used batteries. As retailers receive more payment per battery, the market share in the informal sector decreases. This causes businesses to gravitate towards the formal sector. For the last scenario adopted from [Joshi et al.'s \(2021\)](#) study, subsidizing the price of new batteries in the formal sector shows results where the informal market share increases with an increase in subsidies in the formal retailer sector because retailers are paid more by formal recyclers when compared to informal recyclers with subsidies on battery prices in the formal sector showing an increase in results.

6. Conclusion

The scenarios simulated for the formal sector, namely, tax reduction on formal recyclers, providing subsidies to formal recyclers and providing subsidies or discounts for the price of LAB in the formal sector. These scenarios are able to reduce market share in the informal sector meaning increasing market share in the formal sector or balancing them. The simulation is used to predict or provide an overview of how the formal and informal market share competes with prices that also continue to compete between the two sectors. It also pays attention to how the sectors affect the environment when the two sectors go hand in hand. With the consideration that the informal sector cannot be diminished at all, the government should be able to not only provide some regulations (that have been provided here) but also pays special attention to the informal sector. This informal sector can continue to provide benefits and improve the economy of the middle to lower class people but not ignore the impact of the recycling and

remanufacturing process on the environment. Providing assistance to the recycling process of the informal sector can be performed so that the informal sector can still exist and can pay attention to public health and the environment.

For the future, the conceptual model can be developed in more detail related to the environmental factors so that it can provide more information on the impact of hazardous waste pollution on the environment. The model on the recycling process of the formal and informal sectors can also be more developed so that how the regulation of providing the assistance should be carried out by the government.

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References

- Alamerew, Y. A., & Brissaud, D. (2020). Modelling reverse supply chain through system dynamics for realizing the transition towards the circular economy: A case study on electric vehicle batteries. *Journal of Cleaner Production*, 254, 120025. <https://doi.org/10.1016/j.jclepro.2020.120025>
- Blumberga, A., Timma, L., Vilgerts, J., & Blumberga, D. (2014). Assessment of sustainable collection and recycling policy of Lead-Acid accumulators from the perspective of system dynamics modelling. *Chemical Engineering Transactions*, 39(Special Issue), 649–654. <https://doi.org/10.3303/CET1439109>
- Daniel, S. E., & Pappis, C. P. (2008). Application of LCIA and comparison of different EOL scenarios: The case of used lead-acid batteries. *Resources, Conservation and Recycling*, 52(6), 883–895. <https://doi.org/10.1016/j.resconrec.2007.12.002>
- Fleischmann, M. (2000). *Quantitative Models for Reverse Logistics*. [Doctoral thesis, The Erasmus University Rotterdam]. doi:10.1007/978-3-642-56691-2
- Ghalandari, M., Amirkhan, M., & Amoozad, H. (2022). A hybrid model for robust design of sustainable closed - loop supply chain in lead - acid battery industry. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-022-21840-4>
- Ghisolfi, V., Diniz Chaves, G. de L., Ribeiro Siman, R., & Xavier, L. H. (2017). System dynamics applied to closed loop supply chains of desktops and laptops in Brazil: A perspective for social inclusion of waste pickers. *Waste Management*, 60, 14–31. <https://doi.org/10.1016/j.wasman.2016.12.018>
- Joshi, B. V., Vipin, B., Ramkumar, J., & Amit, R. K. (2021). Impact of policy instruments on lead-acid battery recycling: A system dynamics approach. *Resources, Conservation and Recycling*, 169(January), 105528. <https://doi.org/10.1016/j.resconrec.2021.105528>
- Kamyabi, E., Moazzez, H., & Husseinzadeh Kashan, A. (2022). A hybrid system dynamics and two-stage mixed integer stochastic programming approach for closed-loop battery supply chain optimization. *Applied Mathematical Modelling*, 106, 770–798. <https://doi.org/10.1016/j.apm.2022.02.009>
- Kumaladewi, R. A. (2020). Pengelolaan dan Dampak Limbah Elektronik di Indonesia (Studi Kasus Pengelolaan Limbah di Kampung Cinangka dan Kampung Curug). In *Prosiding Seminar Nasional Pascasarjana*, 1(1), 196–202.
- Lashkari, R. S., & Zhang, H. (2014). Modeling and Analysis of a Reverse Supply Chain Network for Lead-Acid Battery Manufacturing. *Operations and Supply Chain Management: An International Journal*, 1(1), 14–14. <https://doi.org/10.31387/oscm010006>
- Papachristos, G. (2014). Transition inertia due to competition in supply chains with remanufacturing and recycling: A systems dynamics model. *Environmental Innovation and Societal Transitions*, 12, 47–65. <https://doi.org/10.1016/j.eist.2014.01.005>
- Sopha, B. M., & Sakti, S. (2020). *Pemodelan dan Simulasi Berbasis Agen Untuk Sistem Kompleks Sosio-Teknikal: Konsep, Metode, dan Aplikasi*. Gadjah Mada University Press.
- Subulan, K., Taşan, A. S., & Baykasoğlu, A. (2015). A fuzzy goal programming model to strategic planning problem of a lead/acid battery closed-loop supply chain. *Journal of Manufacturing Systems*, 37, 243–264. <https://doi.org/10.1016/j.jmsy.2014.09.001>
- Wiharja. (2004). Kajian Teknologi Daur Ulang Timah Dari Aki Bekas Yang Ramah Lingkungan. *J.Tek.Ling.P3TL-BPPT*, 5(1), 69–74.
- Zan, X., & Zhang, D. (2022). Analysis on the Optimal Recycling Path of Chinese Lead-Acid Battery under the Extended Producer Responsibility System. *Sustainability (Switzerland)*, 14(9), 1–18. <https://doi.org/10.3390/su14094950>

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