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# Strategy Design Dynamic System-Based Circular Supply Chain Management on Waste Management in Sleman Regency, Yogyakarta

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**ABSTRACT:** This study aims to design a dynamic system-based Circular Supply Chain Management (CSCM) strategy for waste management in Sleman Regency, Yogyakarta. The increase in population and economic activity has led to a significant increase in waste volume, necessitating a sustainable and efficient management model. The CSCM approach is used because it integrates circular economy principles through the 5R concept (Reduce, Reuse, Recycle, Recover, and Redesign) to create a closed-loop supply chain system for waste management. The research method uses a system dynamics approach. Modeling with qualitative and quantitative analysis stages through the creation of Causal Loop Diagrams (CLD) and Stock and Flow Diagrams (SFD). Research data were obtained from field observations, interviews with the Environmental Agency, and supporting literature. Simulation results show that the existing waste management model in Sleman has implemented some CSCM principles but is still semi-linear. Through the development of four simulation scenarios, Scenario 4, which integrates the Organic Processing Center (OPC), the Plastic Shredding 3RWPS (Reduce, Reuse, Recycle (3R) Waste Processing Site), and the Compost IWPS (Integrated Waste Processing Site), is considered the most optimal in reducing waste generation and increasing management efficiency. This scenario successfully forms a multi-loop circular chain system that minimizes waste, maximizes resource utilization, and shifts the paradigm from waste management to resource management. The resulting model is expected to be a strategic reference for local governments in formulating long-term policies towards sustainable waste management.

**KEYWORDS:** Circular Supply Chain Management, Dynamic System, Waste Management, 3RWPS, IWPS, Scenario

## INTRODUCTION

Rapid economic growth and population growth at urban areas have led to a significant increase in waste generation, which has implications for various environmental and public health problems (Zhou et al., 2019; Tirkolaee et al., 2020). In developing countries, including Indonesia, waste management is a major challenge due to limited landfill space and a centralized management system (Azevedo et al., 2019; Kuznetsova et al., 2019). This situation demands a more efficient and sustainable management system that integrates all processes, from collection and transportation to waste processing (Mohammadi et al., 2019). Sleman Regency is one of the regions facing a waste management crisis due to the permanent closure of the Piyungan Landfill by the Yogyakarta Special Region Government (jogjaprov.go.id, 2024). The decentralized waste management policy encourages each district/city to be independent in managing its waste through a sorting and processing initiative at the source (SE No. 030 of 2022). However, the implementation of this policy still faces obstacles, such as low community participation, a lack of processing facilities, and suboptimal coordination between the local government and the community. The resulting impacts include the accumulation of waste in various locations and a decline in environmental quality around densely populated areas (prambanan.slemankab.go.id, 2024).

The implementation of decentralization in waste management in Yogyakarta, including in Sleman Regency, has not been running well. The closure of the Piyungan Landfill has had significant negative impacts, such as the accumulation of waste in various places and roads due to the lack of available final disposal sites. The participation of the Environmental Agency in providing adequate facilities and supervision also seems to be less than optimal, resulting in ineffective coordination and execution of waste management policies. So that disposal at the Piyungan Landfill is still carried out but is limited, waste disposal at the Piyungan Landfill is carried out because unprocessed waste still remains despite the Decentralization policy being established, waste disposal at the Piyungan Landfill is carried out according to policies and procedures by the DIY Provincial government, not the Regency government. The Piyungan Landfill is also undergoing a development process to become the Piyungan IWPS, this is certainly a very significant improvement in processing waste that was previously disposed of in landfills into a 3R waste site downstream.

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In a global context, the concepts of Circular Economy (CE) and Circular Supply Chain Management (CSCM) have emerged as strategic approaches to creating a sustainable waste management system. CE seeks to transform the linear "take-use-dispose" paradigm into a closed-loop system based on the 5R principles reduce, reuse, recycle, recover, and redesign to minimize waste and maximize resource value (Lacy et al., 2020;Zaenafi Ariani, 2022). CSCM is the application of CE principles in an integrated supply chain, from product design and reverse logistics to recycling processes, to simultaneously generate economic value and environmental efficiency (Genovese et al., 2017). Previous research has shown that a circular supply chain approach combined with system dynamics methods can be used to comprehensively evaluate the sustainability of waste management systems through simulations and policy scenarios (Theeraworawit et al., 2022; Vega et al., 2024; Vegter et al., 2023). Based on this, this study aims to design a system dynamics-based Circular Supply Chain Management strategy for waste management in Sleman Regency. This model is expected to provide a visual representation of interactions between variables, predict long-term policy impacts, and serve as a basis for strategic decision-making to improve the effectiveness and sustainability of the regional waste management system.

## METHOD

This research method section details the research workflow and its explanation. This section explains the methods used in the research to achieve the objectives of the problem formulation. This method includes a discussion of the research object and subject, research scope, population and sample, variables and operational definitions, research instruments, data collection, data analysis, and research procedures. Furthermore, there is a research flow, which systematically describes the steps taken by the researcher from the beginning to the end of the research process.

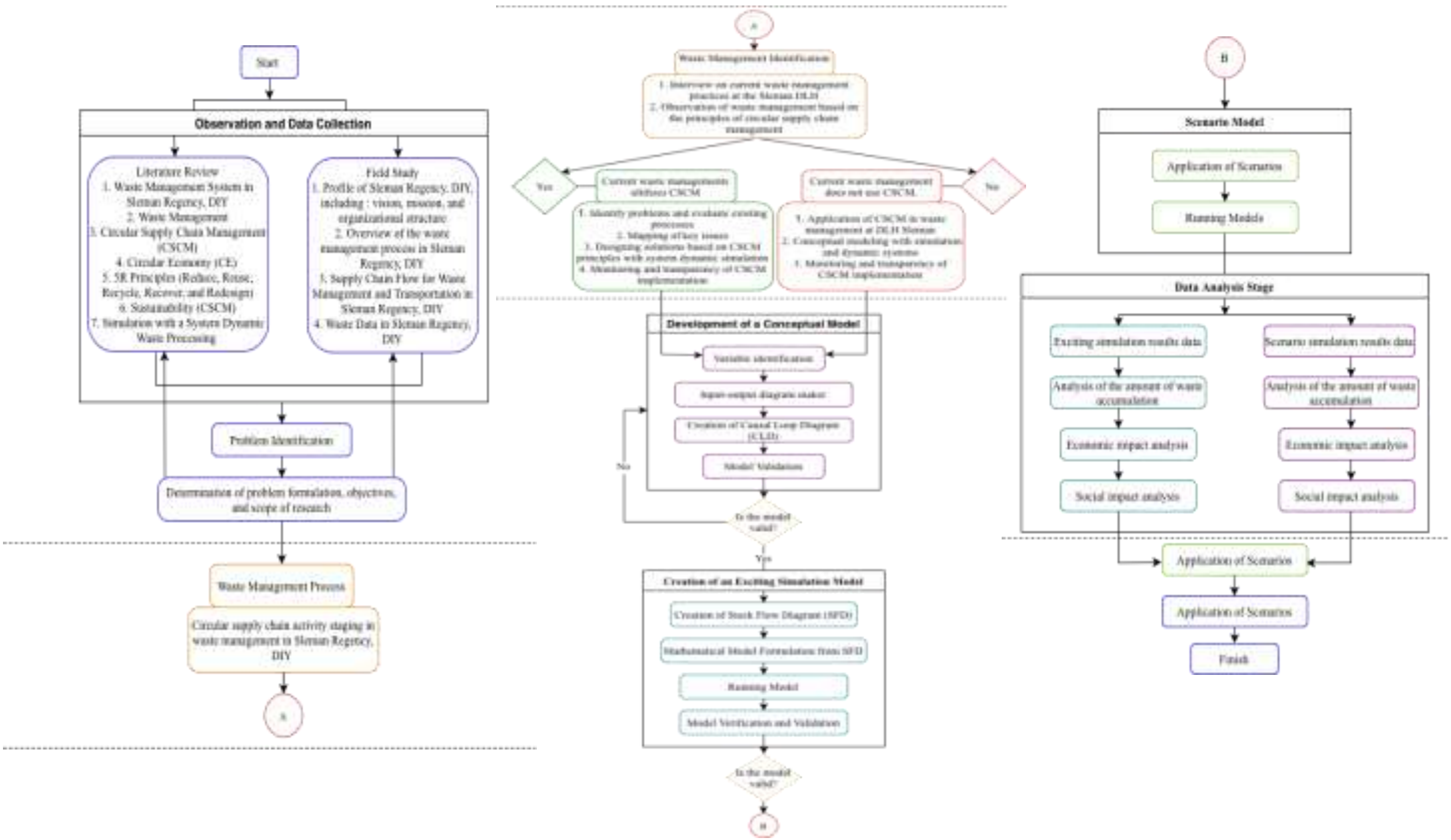


**Figure 1 Research Flow**

A. *Waste Management Concept*

The definition of waste management includes various human activities related to waste processing activities, namely participation in programs, both residential, institutional, industrial, with various collection methods, including door-to-door

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and selective waste collection from commercial areas, according to Fores et al., by optimizing economic and environmental aspects and the application of various network entities: municipal waste bins, curbside collection, self-delivery, and Contract or delegated services are fulfilled.

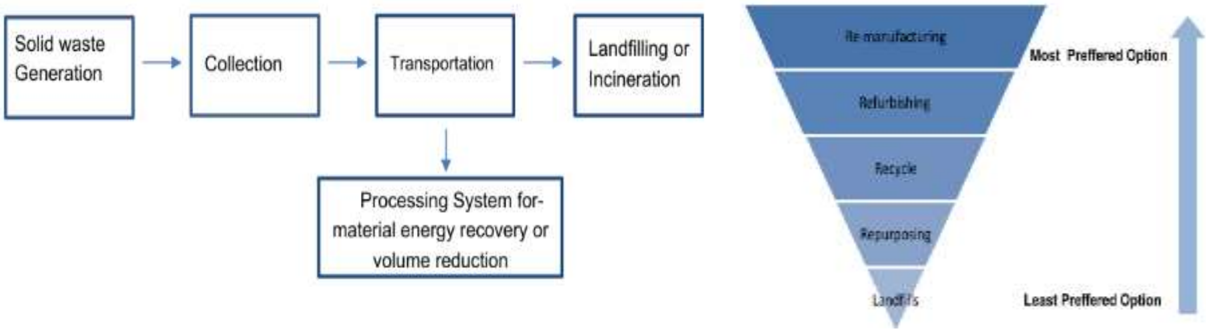


**Figure 2 General Waste Management & Waste Management Hierarchy**

B. *Supply Chain*

From a supply chain perspective, in municipal waste management, the supply chain is considered a strategic supply chain issue, because the supply chain includes the generation, collection, separation, distribution, processing, and disposal of waste. Therefore, it is very important to consider the entire supply chain when considering a waste management system, because the implementation of appropriate supply chain management techniques can improve the efficiency of municipal waste management (Ahmad et al., 2016).

C. *Circular Economy*

Circular Economy (CE) is identified as an alternative model to the linear economy (make, use, and dispose). The CE philosophy is based on effective driving forces that have great potential to support industrial performance in a sustainable and economical manner (Hobson 2018). CE is defined as a regenerative system as it is shown in the following Figure.


**Figure 3 Linear economy & Circular economy**

This idea has developed into a powerful driving force for sustainability both in practice and writing (Hobson et al,2016) and can help industry achieve innovation in sustainability.

D. *Circular Supply Chain Management*

The resources of the planet Earth are limited so the introduction of the term circular supply chain management (CSCM) is becoming increasingly important in this era, as well as environmental degradation a factor that shifts the economy and value chains towards sustainable and circular practices. In a linear supply chain, raw materials are taken from the environment and End of Life (EOL) waste materials are disposed of in landfills as shown in the figure.

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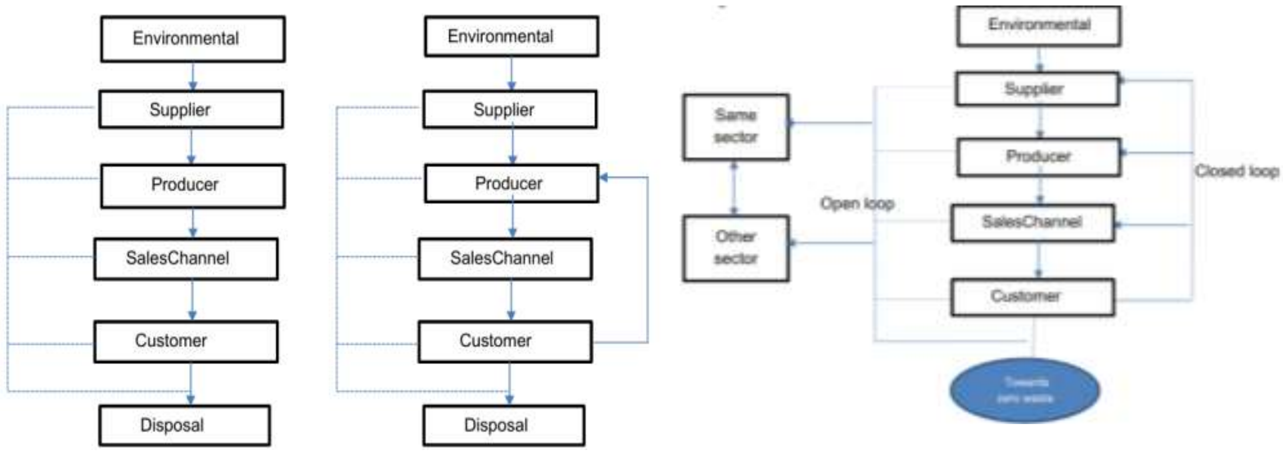


**Figure 4 Linear and Closed Supply Chain (Faroouqe et al)**

CSCM aims for a full reflection on environmental degradation and resource utilization. It helps minimize the impact of the supply chain on manufacturing industry management and resource utilization. It introduces new supply chain design from a sustainability perspective.

E. *Dynamic System*

System dynamics is a method for enhancing learning in complex systems, and in part, is a method for constructing a management flight simulator, a computer simulation model, to assist in studying dynamic complexity, understanding sources of policy resistance, and designing more effective policies (Sterman, 2000, p. 4).Shown a series of processes in system dynamics described by Jay Forrester in his journal, “System Dynamics, System Thinking and Soft OR ”:

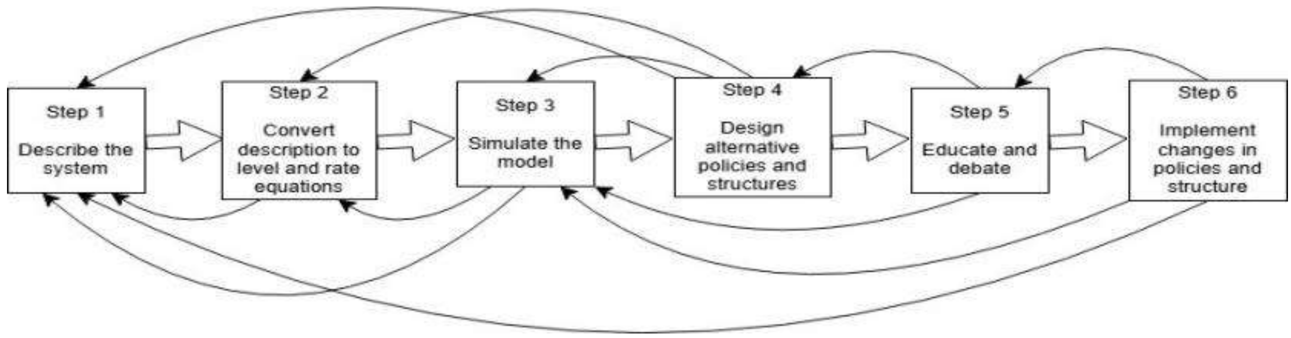


**Figure 5 Dynamic System Process (Forrester 1994)**

The main focus of dynamic systems methodology is gaining understanding of a system, so that problem solving steps provide feedback on system understanding.

a. *Causal Loop Diagram*

Loop diagrams are an important tool for representing the feedback structure of a system. They are useful for (Sterman, 2000, p. 137). This is shown in the figure below:

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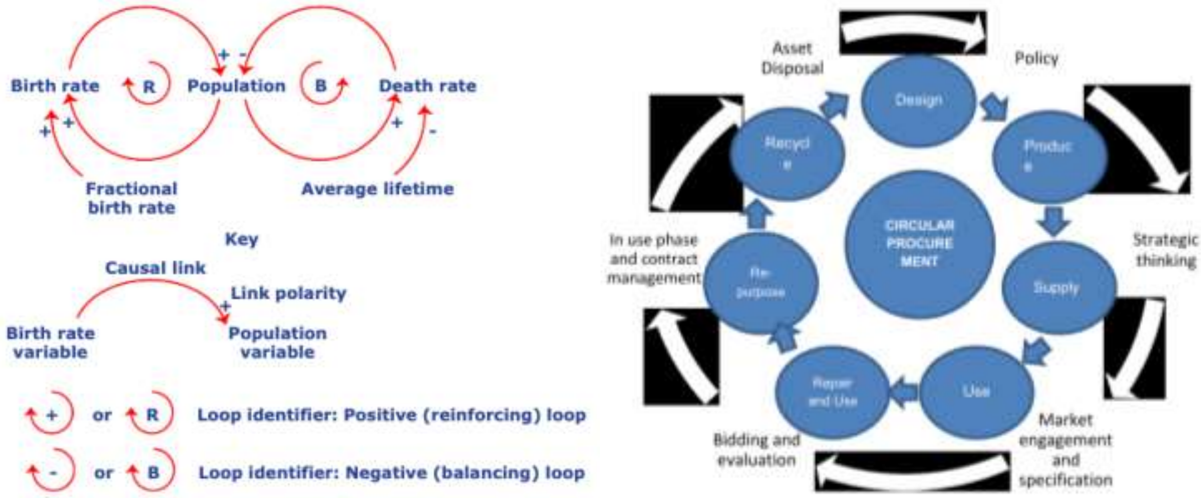


**Figure 6 How to Write a Cause-Effect Loop Diagram & Circular Procurement**

The variables are related in a causal way, as indicated by the arrows in the example above, the birth rate is determined by the population and the fractional birth rate. Each causal relationship is determined by a polarity, either positive (+) or negative (-) which indicates how variable A, which depends on variable B, changes when variable B changes.

b. *Flow Diagram ( Stock and Flow Diagram )*

Loop diagrams have several limitations and can easily be misused. One of the most important limitations of cause-and-effect diagrams is their inability to capture the stock and flow structure of the system.

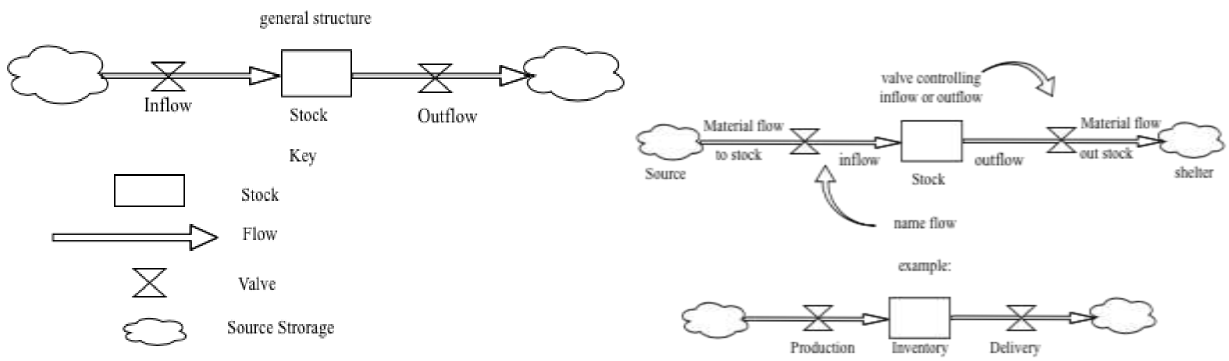


**Figure 7 How to Write a Flowchart (Sterman 2000)**

The image above illustrates how to write a flowchart in a dynamic system, with the following explanations. Stock is represented by a rectangle. Inflow is represented by a pipe with an arrow pointing toward the stock, meaning it increases stock. Outflow is represented by a pipe pointing away from the stock, meaning it decreases stock.

c. *Dynamic Structure and Behavior*

The behavior of a system emerges from its structure. A structure consists of feedback loops, stocks and flows, and nonlinearities created by the interaction of the physical and institutional structure of the system with the decision-making processes of the agents acting within it.

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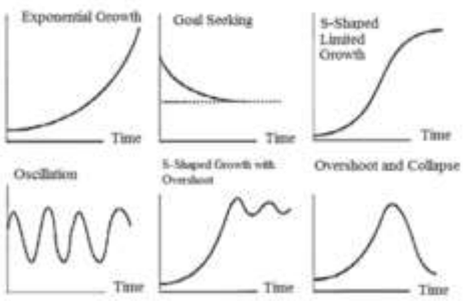


| Metric | Definition | Equation |
|---|---|---|
| MAE | Mean absolute error | $\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}\lvert y_i - y_i'\rvert$ |
| MAPE | Mean absolute percentage error | $\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left\lvert\frac{y_i - y_i'}{y_i}\right\rvert \times 100\%$ |
| RMSE | Root mean square error | $\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{y_i - y_i'}{y_i}\right)^2}$ |
| $R^2$ | Goodness of fit | $R^2 = 1 - \frac{\sum_{i=1}(y_i - y_i')^2}{\ldots}$ |

**Figure 8 General behavioral model (Sterman 2000) & Key Behavioral Validation formula**

The three basic forms of dynamical system behavior are exponential growth, goal seeking, and oscillation. Each of these three behaviors is shaped by a simple feedback structure: growth arises from positive feedback, goal seeking arises from negative feedback, and oscillation arises from negative feedback with a time delay in the loop.

## RESULT AND ANALYSIS

A. *Data collection*

The process of collecting data and information relevant to research is called data collection. The purpose of data collection is to gather data that can be used in the data processing process. Furthermore, as the basis for the study, data collection also serves as an initial foundation for the research to proceed to the next stage.

B. *Waste Management in Sleman Regency*

In managing waste, the people of Sleman Regency have implemented a Decentralized system of "reduce from source, sort, and process" which previously used a system of collecting, transporting, and disposing of waste from the source to the landfill. Waste sources come from community activities ranging from residential areas, schools, hospitals, markets and others. Some waste from the source is managed independently by the community and the rest is handled by the Environmental Agency (EA) and the Regional Technical Implementation Unit (RTIU) of Sleman Regency to be transported to the 3R Waste Processing Site (3RWPS), the Integrated Waste Processing Site (IWPS) and the Final Waste Disposal Site (Landfill).

C. *Existing Waste Management Model in Sleman Regency*

Existing model represents the actual condition of the waste management system in Sleman Regency, built on empirical data. This model serves to depict the actual situation before interventions or improvement simulations are implemented, and also serves as the basis for developing the proposed model.

a. *Causal Loop Diagram (CLD)&Stock Flow Diagram (SFD)of Existing Waste Management Model in Sleman Regency Describe cause-and-effect interactions in existing models waste management in Sleman Regency.*

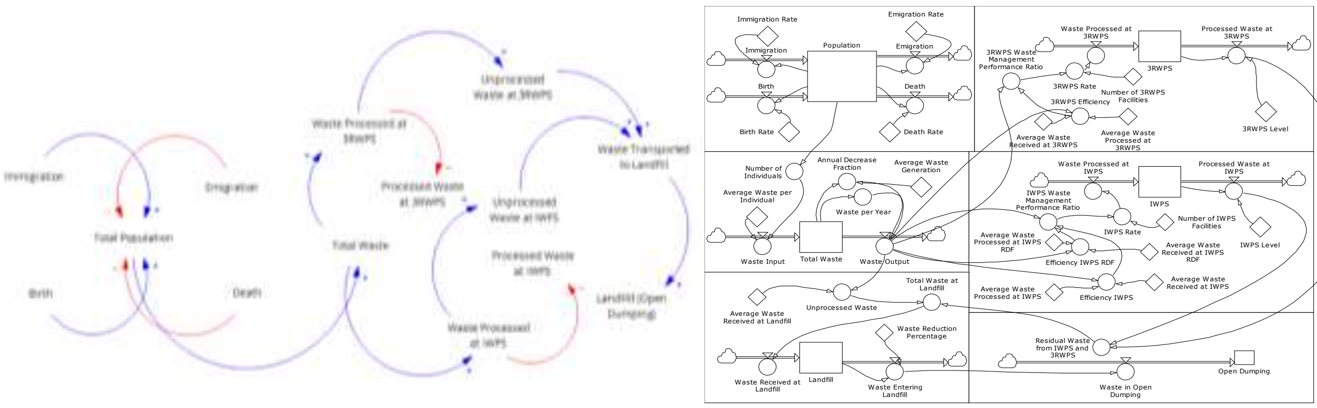


**Figure 9 Casual Loop Diagram (CLD) & Stock Flow Diagram (SFD) of the Existing Waste Management Model in Sleman Regency**

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The figure above shows a causal diagram depicting the relationship between variables in the population system and waste management in Sleman Regency. Population size is influenced by births, deaths, immigration, and emigration. Births and immigration have a positive effect on population size, while deaths and emigration have a negative effect. After designing a conceptual model using CLD, the existing system model was formulated using SFD.

b. *Exiting Simulation Results*

Based on the results of running the existing model, the results which can be seen in the image below.

| Time | Population (Individu) | Total Waste (Ton) | 3RWPS (Ton) | IWPS (Ton) | Landfill (Ton) | Open Dumping (Ton) |
|---|---|---|---|---|---|---|
| 01 Jan 2024 | 1.318.086,00 | 219.654,00 | 20.791,00 | 13.359,00 | 9.198,00 | 9.198,00 |
| 01 Jan 2025 | 1.346.293,00 | 226.133,55 | 21.608,05 | 14.361,54 | 13.092,76 | 9.657,90 |
| 01 Jan 2026 | 1.375.104,00 | 231.025,28 | 22.354,08 | 14.865,81 | 14.865,46 | 10.312,54 |
| 01 Jan 2027 | 1.404.531,00 | 235.970,83 | 22.986,17 | 15.213,04 | 15.618,54 | 11.055,81 |
| 01 Jan 2028 | 1.434.588,00 | 241.020,61 | 23.560,09 | 15.542,54 | 16.046,39 | 11.836,74 |
| 01 Jan 2029 | 1.465.288,00 | 246.178,46 | 24.108,00 | 15.875,68 | 16.341,04 | 12.639,06 |
| 01 Jan 2030 | 1.496.645,00 | 251.446,65 | 24.647,22 | 16.215,49 | 16.575,57 | 13.456,11 |
| 01 Jan 2031 | 1.528.674,00 | 256.827,58 | 25.187,10 | 16.562,51 | 16.784,75 | 14.284,89 |
| 01 Jan 2032 | 1.561.388,00 | 262.323,82 | 25.732,72 | 16.916,94 | 16.986,51 | 15.124,13 |
| 01 Jan 2033 | 1.594.801,00 | 267.937,62 | 26.286,94 | 17.278,97 | 17.190,30 | 15.973,45 |
| 01 Jan 2034 | 1.628.929,00 | 273.671,37 | 26.851,37 | 17.648,75 | 17.400,99 | 16.832,97 |

**Figure 10 Simulation Results of the Existing Waste Management Model in Sleman Regency**

The simulation results in the figure show the capacity of the landfill and landfill open dumping in 2034 is > 10,000 tons. The maximum waste capacity that can be accommodated by the Piyungan Landfill is 10,000 tons from Sleman Regency (After the regional waste decentralization policy was established). The population increases according to population growth data along with the increase in waste every year based on the results of existing simulations. 3RWPS is only able to handle 26,851 tons of waste in 2034, while IWPS can process 17,648 tons of waste in 2034, the remaining waste is processed by 1,144 unit waste banks spread throughout Sleman and 13,210 neighborhood unit/community unit scale composting throughout Sleman, not used in this research process. Anticipation needs to be done to prevent the full capacity of the Piyungan Landfill in 2034.

c. *Verification and Validation of Existing Models*

Model verification is carried out by identifying whether when running the model there are any discrepancies that cause errors in the coding or model formula.

Figure 10 Simulation Results of the Existing Waste Management Model in Sleman Regency

| ***Validation*** | ***Total population*** | ***Amount of Waste*** | ***3RWPS*** | ***IWPS*** | ***Landfill*** | ***Total Year 2024*** |
|---|---|---|---|---|---|---|
| Manual (Xm) | 1,318,086.00 | 219,653.64 | 21,822.57 | 13,359.00 | 91,198.00 | 1,664,119.21 |
| *Existing* Simulation (Xs) | 1,318,086.00 | 219,654.00 | 20,791.00 | 13,361.54 | 91,198.00 | 1,663,090.54 |
| *Error* (Xm-Xs) | 0 | −0.36 | 1,031.57 | -2.54 | 0 | 1,028.67 |
| *Absolute error* (\|Xm – Xs\|) | 0 | 0.36 | 1,031.57 | 2.54 | 0 | 1,028.67 |
| *Square of Error* $(Xm – Xs)^2$ | 0 | 0.1296 | 1,064,138.67 | 6.45 | 0 | 1,058,187.07 |
| *Relative error* (\|Xm – Xs\| / Xm) | 0 | 0.00000164 | 0.0473 | 0.00019 | 0 | 0.000618 |
| Total (Xm) = 3,328,238.4 | | | Total Error (Xm-Xs) = 2,057.34 | | | |
| Total (Xs) = 3,326,181.0 | | | Total Sq Err $(Xm – Xs)^2$ = 2,122,332.3 | | | |
| Total (\|Xm – Xs\|) / *absolute error* = 2,063.14 | | | Total Rl Er (\|Xm – Xs\|/Xm)= 0.04810 | | | |

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MAD (Mean Absolute Deviation) MAD calculates the average of the absolute differences between the predicted value and the actual value. $=\frac{1}{n}\sum_{t=1}^{n}|Xm - Xs|=\frac{1}{6}(2{,}057.34) = 342.89$ (MAD)

MSE (Mean Squared Error) MSE calculates the average of the squared differences between the predicted and actual values. $=\frac{1}{n}\sum_{t=1}^{n}(Xm - Xs)^2=\frac{1}{6}(2{,}122{,}332.3) = 353{,}722.05$ (MSE)

MAPE (Mean Absolute Percentage Error) MAPE calculates the average of the percentage difference between the predicted value and the actual value. $=\frac{1}{n}\left(\sum_{t=1}^{n}\frac{|Xm-XS|}{Xm}\right)x100=\frac{1}{6}\,(0{,}04810)x100= 0.0080$ (MAPE)

Existing system validation test where Xm is the average manual calculation data of the Number of Population, Number of Waste, 3RWPS, IWPS and Number of Waste in 2024 of 554,706.40, Xs is the capacity data of the simulation results of the average Number of Population, Number of Waste, 3RWPS, IWPS and Number of Waste in 2024 of 554,363.51. MAD (Mean Absolute Deviation) is the Average Absolute Deviation, based on the calculation results obtained the MAD value is 342.89 and the MSE (Mean Square Error) value is the average Square Error of the calculation results obtained is 353,722.05. While MAPE (Mean Absolute Percentage Error) is the Average Absolute Percentage Error, based on the calculation obtained the value is 0.80%, this value is below the limit of the validity provisions of the MAPE calculation. Where the MAPE value < 10% indicates very good forecasting model capability (Maricar2019).

D. *Waste Processing Scenario in Sleman Regency*

There are four alternative scenarios for waste management in the midstream and downstream areas to anticipate the Piyungan Landfill being filled by waste from Sleman Regency. The following are alternative scenarios for waste management in Sleman Regency.as follows:

a. *Scenario 1 : Addition of Organic Waste Processing Center (OPC)*

This scenario focuses on reducing the accumulation of unprocessed waste at the 3RWPS and IWPS by adding adaptive Organic Processing Center (OPC) units downstream based on need. This means that as population growth increases, so does waste generation.

Causal Loop Diagram (CLD) Scenario 1 POO Management and Stock Flow Diagram (SFD) Model Scenario 1 The causal interaction in scenario 1 is described as follows:

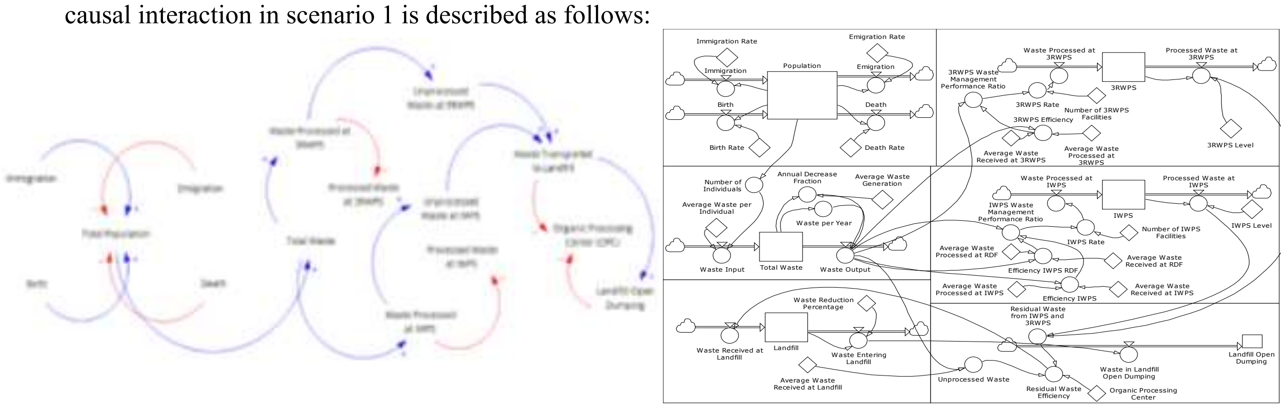


**Figure 11 Casual Loop Diagram (CLD) & Stock Flow Diagram (SFD) Model Scenario 1 Waste Management in Sleman Regency**

Overall, the CLD and SFD scenarios for Scenario 1 demonstrate a combination of a positive (reinforcing) loop that increases waste generation as population and waste flows to landfills grow, and a negative (balancing) loop that arises from the limited capacity of the 3RWPS and IWPS. If capacity is not increased, the reinforcing loop will dominate, increasing the burden on landfills.

The SFD model was developed from specific relationships between components in the CLD. The SFD model was built based on assumptions, limitations, and current data and conditions of waste management in Sleman Regency. After

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compiling and formulating the model, the model was run to examine any discrepancies that could cause errors in the coding or model formula.

| Time | Population (Individu) | Total Waste (Ton) | 3RWPS (Ton) | IWPS (Ton) | Landfill (Ton) | l Open Dumping |
|---|---|---|---|---|---|---|
| 01 Jan 2024 | 1.318.086,00 | 219.654,00 | 20.791,00 | 13.359,00 | 9.198,00 | 9.198,00 |
| 01 Jan 2025 | 1.346.293,00 | 226.133,55 | 21.608,05 | 14.361,54 | 9.892,40 | 9.442,67 |
| 01 Jan 2026 | 1.375.104,00 | 231.025,28 | 22.354,08 | 14.865,81 | 10.595,02 | 9.705,80 |
| 01 Jan 2027 | 1.404.531,00 | 235.970,83 | 22.986,17 | 15.213,04 | 11.291,43 | 9.987,63 |
| 01 Jan 2028 | 1.434.588,00 | 241.020,61 | 23.560,09 | 15.542,54 | 11.973,30 | 10.287,98 |
| 01 Jan 2029 | 1.465.288,00 | 246.178,46 | 24.108,00 | 15.875,68 | 12.638,71 | 10.606,47 |
| 01 Jan 2030 | 1.496.645,00 | 251.446,65 | 24.647,22 | 16.215,49 | 13.287,24 | 10.942,66 |
| 01 Jan 2031 | 1.528.674,00 | 256.827,58 | 25.187,10 | 16.562,51 | 13.918,94 | 11.296,10 |
| 01 Jan 2032 | 1.561.388,00 | 262.323,82 | 25.732,72 | 16.916,94 | 14.534,06 | 11.666,35 |
| 01 Jan 2033 | 1.594.801,00 | 267.937,62 | 26.286,94 | 17.278,97 | 15.132,93 | 12.052,95 |
| 01 Jan 2034 | 1.628.929,00 | 273.671,37 | 26.851,37 | 17.648,75 | 15.715,92 | 12.455,49 |

**Figure 12 Simulation results for Scenario 1**

The simulation results show that between 2024 and 2034, the population of Sleman will increase from 1.3 million to 1.6 million, resulting in an increase in waste generation from 219,000 tons to 273,000 tons. In the Organic Processing Center (OPC) scenario, most organic waste is processed at the end after processing at the 3RWPS and IWPS, thus reducing the waste load at the landfill and OD, from 20,000 to 26,000 tons and 13,000 to 17,000 tons, respectively.

b. *Scenario 2 : Addition of Organic Waste Processing Center (OPC) & plastic shredding 3RWPS*

Scenario 2 was developed with efforts to develop plastic waste management. The 3RWPS in scenario 2 was designed to handle inorganic waste, specifically shredded plastic.

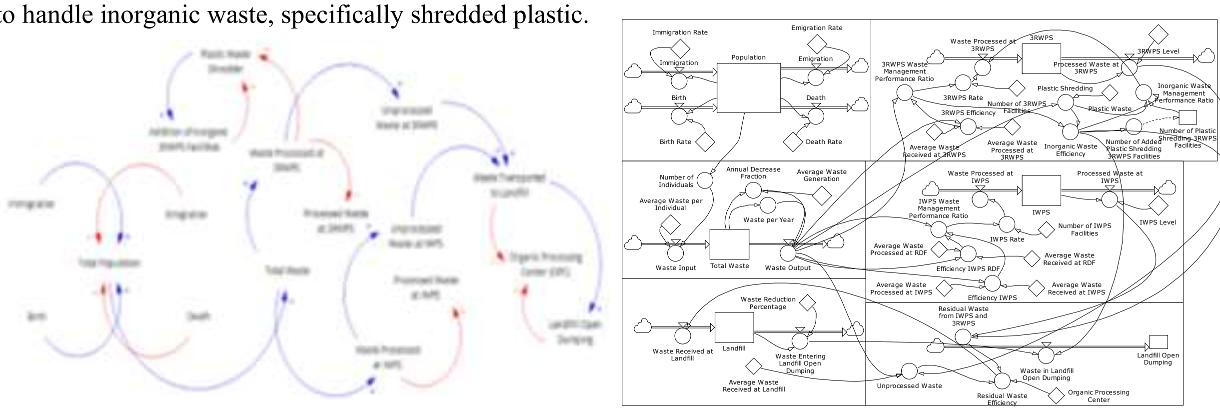


**Figure 13 Casual Loop Diagram (CLD) & Stock Flow Diagram (SFD) Model Scenario 2 Waste Management in Sleman Regency**

The presence of plastic shredding and the addition of inorganic 3RWPS units and OPC function as interventions that can reduce the residual load to IWPS and landfills, thereby slowing the rate of waste accumulation. The SFD model was developed from specific relationships between components in the CLD. The SFD model is built based on assumptions, limitations, and current data and conditions of waste management in Sleman Regency. The image above shows a waste processing system design that implements alternative plastic shredding and OPC strategies. After compiling and formulating the model, the model was run to examine whether there were any inconsistencies that caused errors in the coding or model formula. After ensuring there were no errors, the model was run. The following are the results of running the simulation model for scenario 2, which can be seen in the image below.

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| Time | Population (Individu) | Total Waste (Ton) | 3RWPS (Ton) | IWPS (Ton) | Landfill (Ton) | l Open Dumping |
|---|---|---|---|---|---|---|
| 01 Jan 2024 | 1.318.086,00 | 219.654,00 | 20.791,00 | 13.359,00 | 9.198,00 | 9.198,00 |
| 01 Jan 2025 | 1.346.293,00 | 226.133,55 | 24.314,32 | 14.361,54 | 9.402,20 | 9.170,64 |
| 01 Jan 2026 | 1.375.104,00 | 231.025,28 | 26.582,89 | 14.865,81 | 9.610,92 | 9.143,08 |
| 01 Jan 2027 | 1.404.531,00 | 235.970,83 | 28.086,91 | 15.213,04 | 9.824,29 | 9.115,19 |
| 01 Jan 2028 | 1.434.588,00 | 241.020,61 | 29.186,60 | 15.542,54 | 10.042,39 | 9.086,97 |
| 01 Jan 2029 | 1.465.288,00 | 246.178,46 | 30.077,01 | 15.875,68 | 10.265,33 | 9.058,38 |
| 01 Jan 2030 | 1.496.645,00 | 251.446,65 | 30.862,36 | 16.215,49 | 10.493,22 | 9.029,44 |
| 01 Jan 2031 | 1.528.674,00 | 256.827,58 | 31.598,36 | 16.562,51 | 10.726,17 | 9.000,11 |
| 01 Jan 2032 | 1.561.388,00 | 262.323,82 | 32.314,84 | 16.916,94 | 10.964,29 | 8.970,39 |
| 01 Jan 2033 | 1.594.801,00 | 267.937,62 | 33.027,85 | 17.278,97 | 11.207,69 | 8.940,27 |
| 01 Jan 2034 | 1.628.929,00 | 273.671,37 | 33.746,10 | 17.648,75 | 11.456,51 | 8.909,73 |
| | | | | | | |

**Figure 14 Simulation results for Scenario 2**

The results of this simulation show that the population is the same as the existing simulation and scenario 1, namely the population of Sleman increases from 1.3 million people (2024) to 1.6 million people (2034), and also waste generation increases from 219 thousand tons to 273 thousand tons per year. Without intervention, the data shows that 3RWPS increases from 20 thousand tons (2024) to 33 thousand tons (2034), or an increase of more than 60% compared to scenario 1, where 3RWPS waste processing (2024) is 20,791 tons and (2034) 26,851 tons, Meanwhile, landfills only received around 11,456 tons in 2034, and landfills OD even decreased significantly to 8,909 tons compared to scenario 1 which got the final result in 2034 at landfills of 15,715 tons and landfills open dumping of 12,455 tons.

c. *Scenario 3: Addition IWPS Compost Management and Organic Processing Center (OPC) Management*

Scenario 3 is a scenario developed as an effort to reduce the quantity of organic waste entering landfills and open dumping to maximize organic waste management, especially compost and biogas processing by adding a compost TPST and POO. The purpose of building a compost TPST is as a facility for processing organic food waste into high-value compost fertilizer for agriculture, then OPC functions as a refinement of organic waste processing downstream by producing biogas energy.

Causal Loop Diagram (CLD) Scenario 3 OPC management and organic compost waste management and Stock Flow Diagram (SFD) Model Scenario 3. The causal interaction in scenario 3 is described as follows:

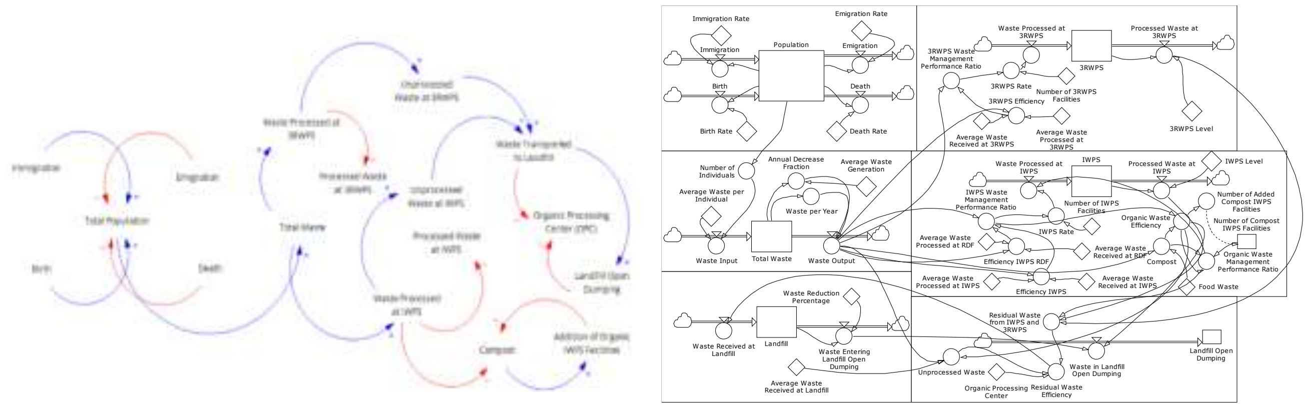



**Figure 15 Casual Loop Diagram (CLD) & Stock Flow Diagram (SFD) Model Scenario 3 Waste Management in Sleman Regency**

CLD Scenario 3 has a combination of (+) (which strengthens the organic processing drive) and (-) (which controls waste accumulation). The interaction of the two shows the dynamics of a complex system, where strengthening the capacity of organic IWPS and the utilization of OPC can reduce the burden on landfills, although residue remains the main limiting factor.In SFD has a value that runs with the flow in or out. Waste management that applies alternative organic waste management strategies. After the simulation is formed, a re-check is carried out on the model to ensure that the system is running properly or there are no errors in the model formula, after ensuring there are no errors, the model can be run. The results of the simulation run in scenario 3 can be seen in Figure 16.

| Time | Population (Individu) | Total Waste (Ton) | 3RWPS (Ton) | IWPS (Ton) | Landfill (Ton) | l Open Dumping |
|---|---|---|---|---|---|---|
| 01 Jan 2024 | 1.318.086,00 | 219.654,00 | 20.791,00 | 13.359,00 | 9.198,00 | 9.198,00 |
| 01 Jan 2025 | 1.346.293,00 | 226.133,55 | 21.608,05 | 18.138,98 | 9.402,97 | 9.077,73 |
| 01 Jan 2026 | 1.375.104,00 | 231.025,28 | 22.354,08 | 19.255,19 | 9.612,64 | 8.957,07 |
| 01 Jan 2027 | 1.404.531,00 | 235.970,83 | 22.986,17 | 19.767,62 | 9.826,98 | 8.835,34 |
| 01 Jan 2028 | 1.434.588,00 | 241.020,61 | 23.560,09 | 20.204,07 | 10.046,07 | 8.712,47 |
| 01 Jan 2029 | 1.465.288,00 | 246.178,46 | 24.108,00 | 20.638,22 | 10.270,02 | 8.588,39 |
| 01 Jan 2030 | 1.496.645,00 | 251.446,65 | 24.647,22 | 21.080,11 | 10.498,93 | 8.463,05 |
| 01 Jan 2031 | 1.528.674,00 | 256.827,58 | 25.187,10 | 21.531,25 | 10.732,92 | 8.336,37 |
| 01 Jan 2032 | 1.561.388,00 | 262.323,82 | 25.732,72 | 21.992,02 | 10.972,08 | 8.208,30 |
| 01 Jan 2033 | 1.594.801,00 | 267.937,62 | 26.286,94 | 22.462,66 | 11.216,55 | 8.078,78 |
| 01 Jan 2034 | 1.628.929,00 | 273.671,37 | 26.851,37 | 22.943,37 | 11.466,44 | 7.947,74 |

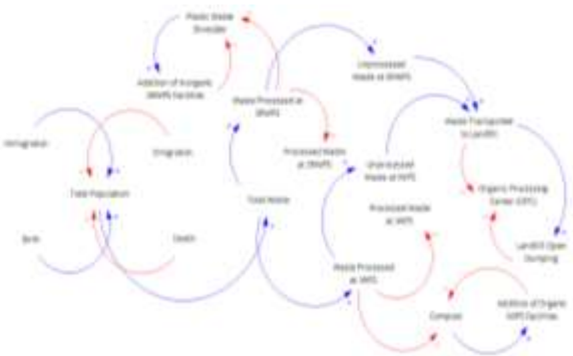
**Figure 16 Simulation results for Scenario 3**

Simulation results show that in scenario 3, through organic waste management and strengthening of IWPS (landfill site) and OPC (waste disposal facility) facilities, the rate of waste actually entering landfills and landfills open dumping can be reduced. Data shows that waste processed at IWPS increased from 13,359 tons in 2024 to 22,943 tons in 2034. Consequently, waste entering landfills decreased from 9,198 tons in 2024 to 7,947 tons in 2034.

d. *Scenario 4: Addition Management of Organic Processing Center, Management of Plastic Shredding at 3RWPS, and Management of Organic Compost Waste at IWPS*

Scenario 4 is a scenario developed by combining scenario 1 of OPC (Organic Processing Center) management, scenario 2 of OPC management and 3RWPS plastic shredding, and scenario 3 of OPC management and IWPS organic waste composting. The purpose of developing 3RWPS and IWPS is to reduce the amount of waste transported to the landfill, because waste at the landfill is not processed and is directly transported to the landfill open dumping. The goal is to find out the maximum with a combination of scenario 1, scenario 2 and scenario 3.

Causal Loop Diagram (CLD) Scenario 4 for OPC management, 3RWPS Plastic Shredding Management, and IWPS Organic Compost Management as well as Stock Flow Diagram (SFD) Model Scenario 4. The causal interaction between the variables that make up the scenario 4 system can be seen in the causal loop diagram depicted in Figure 17.



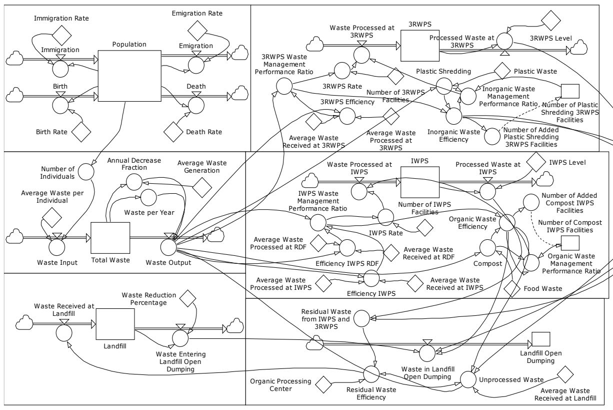


**Figure 17 Casual Loop Diagram (CLD) & Stock Flow Diagram (SFD) Model Scenario 4 Waste Management in Sleman Regency**

CLD Scenario 4 shows the balance between reinforcing forces (population growth and waste flow to landfill) and counterbalancing forces (processing through 3RWPS, IWPS, and OPC). This combination provides a comprehensive picture of how the waste management system can function dynamically in the long term. The SFD model is developed from the specific relationships between components in the CLD. The SFD model is built based on assumptions, constraints, and current data and conditions of waste management in Sleman Regency. After the simulation is created, a re-examination of the model is carried out to ensure that the system is running properly or that there are no errors in the model formula. Once there are no errors, the model can be run. The results of the simulation run in scenario 4 can be seen in Figure 4.



| Time | Population (Individu) | Total Waste (Ton) | 3RWPS (Ton) | IWPS (Ton) | Landfill (Ton) | l Open Dumping |
|---|---|---|---|---|---|---|
| 01 Jan 2024 | 1.318.086,00 | 219.654,00 | 20.791,00 | 13.359,00 | 9.198,00 | 9.198,00 |
| 01 Jan 2025 | 1.346.293,00 | 226.133,55 | 24.314,32 | 18.138,98 | 9.310,34 | 8.704,65 |
| 01 Jan 2026 | 1.375.104,00 | 231.025,28 | 26.582,89 | 19.255,19 | 9.424,08 | 8.207,44 |
| 01 Jan 2027 | 1.404.531,00 | 235.970,83 | 28.086,91 | 19.767,62 | 9.539,21 | 7.705,68 |
| 01 Jan 2028 | 1.434.588,00 | 241.020,61 | 29.186,60 | 20.204,07 | 9.655,74 | 7.199,25 |
| 01 Jan 2029 | 1.465.288,00 | 246.178,46 | 30.077,01 | 20.638,22 | 9.773,69 | 6.688,05 |
| 01 Jan 2030 | 1.496.645,00 | 251.446,65 | 30.862,36 | 21.080,11 | 9.893,08 | 6.171,96 |
| 01 Jan 2031 | 1.528.674,00 | 256.827,58 | 31.598,36 | 21.531,25 | 10.013,92 | 5.650,88 |
| 01 Jan 2032 | 1.561.388,00 | 262.323,82 | 32.314,84 | 21.992,02 | 10.136,23 | 5.124,72 |
| 01 Jan 2033 | 1.594.801,00 | 267.937,62 | 33.027,85 | 22.462,66 | 10.260,04 | 4.593,37 |
| 01 Jan 2034 | 1.628.929,00 | 273.671,37 | 33.746,10 | 22.943,37 | 10.385,35 | 4.056,73 |

**Figure 18 Simulation results for Scenario 4**

The model formula In scenario 4, there is insight into the landfill which is significantly reduced, with landfill reduced by an average of 17.56% while in landfill reduced by an average of 56.94% . This occurs because scenario 4 processes inorganic waste by 3RWPS and two times processing of organic waste by IWPS & OPC which are in the downstream and middle processes are key in reducing large waste piles in landfills.

*E. Comparison Between Scenarios*

The following is a comparison table between scenarios for each unit.

**Table 2 Landfill Open Dumping Compare**

| *Year* | *Existing OD Landfill* | *Landfill OD Scenario 1* | *Landfill OD Scenario 2* | *Landfill OD Scenario 3* | *Landfill OD Scenario 4* |
|---|---|---|---|---|---|
| 2024 | 9,198.0 | 9,198.0 | 9,198.0 | 9,198.0 | 9,198.0 |
| 2025 | 9,657.9 | 9,442.67 | 9,170.64 | 9,077.73 | 8,704.65 |
| 2026 | 10,312.54 | 9,705.8 | 9,143.08 | 8,957.07 | 8,207.44 |
| 2027 | 11,055.81 | 9,987.63 | 9,115.19 | 8,835.34 | 7,705.68 |
| 2028 | 11,836.74 | 10,287.98 | 9,086.97 | 8,712.47 | 7,199.25 |
| 2029 | 12,639.06 | 10,606.47 | 9,058.38 | 8,588.39 | 6,688.05 |
| 2030 | 13,456.11 | 10,942.66 | 9,029.44 | 8,463.05 | 6,171.96 |
| 2031 | 14,284.89 | 11,296.1 | 9,000.11 | 8,336.37 | 5,650.88 |
| 2032 | 15,124.13 | 11,666.35 | 8,970.39 | 8,208.3 | 5,124.72 |
| 2033 | 15,973.45 | 12,052.95 | 8,940.27 | 8,078.78 | 4,593.37 |
| 2034 | 16,832.97 | 12,455.49 | 8,909.73 | 7,947.74 | 4,056.73 |

Waste management scenarios can reduce the burden on landfills and landfills OD. Scenario 4 is the most effective scenario because it produces the largest reduction in waste volume, up to more than 40% compared to current conditions.

**Table 3 Landfill (Final Processing Site) Compare**

| *Year* | *Existing Landfill* | *Landfill Scenario 1* | *Landfill Scenario 2* | *Landfill Scenario 3* | *Landfill Scenario 4* |
|---|---|---|---|---|---|
| 2024 | 9,198.0 | 9,198.0 | 9,198.0 | 9,198.0 | 9,198.0 |
| 2025 | 13,092.76 | 9,892.4 | 9,402.2 | 9,402.97 | 9,310.34 |
| 2026 | 14,865.46 | 10,595.02 | 9,610.92 | 9,612.64 | 9,424.08 |
| 2027 | 15,618.54 | 11,291.43 | 9,824.29 | 9,826.98 | 9,539.21 |
| 2028 | 16,046.39 | 11,973.3 | 10,042.39 | 10,046.07 | 9,655.74 |
| 2029 | 16,341.04 | 12,638.71 | 10,265.33 | 10,270.02 | 9,773.69 |
| 2030 | 16,575.57 | 13,287.24 | 10,493.22 | 10,498.93 | 9,893.08 |
| 2031 | 16,784.75 | 13,918.94 | 10,726.17 | 10,732.92 | 10,013.93 |
| 2032 | 16,986.51 | 14,534.06 | 10,964.29 | 10,972.08 | 10,136.23 |
| 2033 | 17,190.3 | 15,132.93 | 11,207.69 | 11,216.55 | 10,260.04 |
| 2034 | 17,400.99 | 15,715.92 | 11,456.51 | 11,466.44 | 10,385.35 |

The TPA Compare table shows an annual increase in waste going to the landfill under existing conditions, while implementing management scenarios reduced it. Scenario 4 was the most effective, resulting in the largest reduction in waste volume compared to existing conditions.

**Table 4 IWPS Compare**

| *Year* | *Existing IWPS* | *IWPS Scenario 1* | *IWPS Scenario 2* | *IWPS Scenario 3* | *IWPS Scenario 4* |
|---|---|---|---|---|---|
| 2024 | 13,359.0 | 13,359.0 | 13,359.0 | 13,359.0 | 13,359.0 |
| 2025 | 14,361.54 | 14,361.54 | 14,361.54 | 18,138.98 | 18,138.98 |
| 2026 | 14,865.81 | 14,865.81 | 14,865.81 | 19,255.19 | 19,255.19 |
| 2027 | 15,213.04 | 15,213.04 | 15,213.04 | 19,767.62 | 19,767.62 |
| 2028 | 15,542.54 | 15,542.54 | 15,542.54 | 20,204.07 | 20,204.07 |
| 2029 | 15,875.68 | 15,875.68 | 15,875.68 | 20,638.22 | 20,638.22 |
| 2030 | 16,215.49 | 16,215.49 | 16,215.49 | 21,080.11 | 21,080.11 |
| 2031 | 16,562.51 | 16,562.51 | 16,562.51 | 21,531.25 | 21,531.25 |
| 2032 | 16,916.94 | 16,916.94 | 16,916.94 | 21,992.02 | 21,992.02 |
| 2033 | 17,278.97 | 17,278.97 | 17,278.97 | 22,462.66 | 22,462.66 |
| 2034 | 17,648.75 | 17,648.75 | 17,648.75 | 22,943.37 | 22,943.37 |

The table above shows the amount of waste managed at IWPS from 2024 to 2034. Under existing conditions and scenarios 1–2, the amount of waste is relatively the same each year, while in scenarios 3 and 4 there is a significant increase. This indicates that scenarios 3 and 4 are more effective in increasing the capacity and role of IWPS in waste processing, thereby reducing the burden of waste entering the Final processing site and landfills downstream.

**Table 5 3RWPS Compare**

| *Year* | *Existing 3RWPS* | *3RWPS Scenario 1* | *3RWPS Scenario 2* | *3RWPS Scenario 3* | *3RWPS Scenario 4* |
|---|---|---|---|---|---|
| 2024 | 20,791.0 | 20,791.0 | 20,791.0 | 20,791.0 | 20,791.0 |
| 2025 | 21,608.05 | 21,608.05 | 24,314.32 | 21,608.05 | 24,314.32 |

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| | | | | | |
|---|---|---|---|---|---|
| 2026 | 22,354.08 | 22,354.08 | 26,582.89 | 22,354.08 | 26,582.89 |
| 2027 | 22,986.17 | 22,986.17 | 28,086.91 | 22,986.17 | 28,086.91 |
| 2028 | 23,560.09 | 23,560.09 | 29,186.6 | 23,560.09 | 29,186.6 |
| 2029 | 24,108.0 | 24,108.0 | 30,077.01 | 24,108.0 | 30,077.01 |
| 2030 | 24,647.22 | 24,647.22 | 30,862.36 | 24,647.22 | 30,862.36 |
| 2031 | 25,187.1 | 25,187.1 | 31,598.36 | 25,187.1 | 31,598.36 |
| 2032 | 25,732.72 | 25,732.72 | 32,314.84 | 25,732.72 | 32,314.84 |
| 2033 | 26,286.94 | 26,286.94 | 33,027.85 | 26,286.94 | 33,027.85 |
| 2034 | 26,851.37 | 26,851.37 | 33,746.1 | 26,851.37 | 33,746.1 |

The table above shows the development of waste management capacity at the 3RWPF from 2024 to 2034. Under existing conditions and scenarios 1 and 3, the volume remains relatively constant each year, while significant increases occur in scenarios 2 and 4. This indicates that scenarios 3 and 4 can improve the effectiveness of waste management at the 3RWPF mid-process level, thus significantly reducing the burden on downstream IWPSs and Final processing site.

## CONCLUSION

Based on the results of the analysis and discussion that have been carried out based on the design of the implementation of a circular supply chain strategy using a dynamic system, the following conclusions were obtained :

a. On Existing Model, Based on the results of dynamic system analysis, the existing waste management model in Sleman Regency still shows the characteristics of a semi- linear supply chain system, namely a "collect and dispose" system. Transport waste" on the downstream side with a high dependence on the Piyungan Landfill. This model has not fully implemented the 5R principle (Reduce, Reuse, Recycle, Recover, Redesign) and has not integrated reverse logistics and an integrated recycling system. However, the basic structure of the waste management supply chain has been formed, including Decentralization in the upstream by neighborhood unit/ community unit, waste banks, 3RWPS and IWPS. This is the initial foundation that can be developed into a sustainable circular supply chain management . Then, the addition of the Organic Processing Center (OPC) downstream, the 3RWPS Plastic Shredder and IWPS Compost in the waste processing process in the middle to improve the waste processing system and waste reduction in Sleman Regency.

b. The Most Effective and Efficient Waste Management Scenario, of the four simulation scenarios developed, Scenario 4 proved to be the most optimal. This scenario integrates various subsystems, namely plastic shredding at 3RWPS, optimization for inorganic sorting and processing, and strengthening IWPS and Organic Processing Center (OPC) for processing organic waste into compost and alternative energy. The simulation results show an increase in recycling capacity of more than 35% and a reduction in the volume of waste sent to the landfill and 40% compared to existing conditions. In addition, Scenario 4 creates a multi-loop system that supports material circulation and new economic value from waste, thus becoming the basis for an efficient and adaptive CSCM system. Meanwhile, in second place is scenario 2 (Plastic Shredder 3RWPS & OPC) which can help reduce inorganic and organic waste significantly, then scenario 3 (Compost IWPS & OPC) advances in processing organic waste by IWPS and OPC and reduces landfill piles significantly, finally scenario 1 (OPC) creates a closed loop downstream.

c. Strategic Steps for the Sleman Regency Government: To strengthen CSCM implementation, the Sleman Regency Government needs to prepare policies based on multi-actor integration and an integrated information system. This includes:
    I. Improving the institutional capacity of Environment Agency and village officials in managing data and technology-based monitoring systems.
    II. Strengthening education and community participation in waste sorting from source (continuing and strengthening the upstream decentralization policy).
    III. Collaboration between the public, private and community sectors in building a circular supply chain

IV. Implementing the application of the scenario model design that has been created so that it can improve and assist waste processing in the middle and downstream processes, which can reduce the accumulation of waste or garbage in landfills.

V. Providing incentives for recycling initiatives and waste-based product innovation. With these steps, the concept of Circular Supply Chain Management can be implemented effectively to achieve sustainable, independent, and economically valuable waste management.

**SUGGESTION**

Based on the research results, there are several suggestions that can be given for the sustainability of the implementation of a circular supply chain management strategy using a dynamic system as follows:

a. For Local Government
   I. Immediately develop regional policies that integrate the principles of Circular Economy and CSCM in the Regional Waste Management Master Plan (RWMMP).
   II. Improve coordination between agencies, especially the Environmental Agency (EA), the Department of Industry, and the Department of MSMEs to support the creation of a local recycling industry ecosystem.
   III. Implementing a system of incentives and disincentives, such as reducing fees for people who actively sort waste and penalties for waste management violations.

b. For Society and Community
   I. Raising awareness of the importance of waste sorting from source through environmental education and waste to value community activities.
   II. Increase recycling cooperatives or waste banks that can be part of the regional circular supply chain management.
   III. Optimizing the economic potential of organic and inorganic waste, such as the production of compost, biogas, and alternative fuels based on RDF (Refuse-Derived Fuel).

c. For Academics and Further Researchers
   I. Triangulation validation is recommended to improve model validity. This approach integrates multiple data sources, analytical methods, theories, and expert judgment to ensure the model reflects real-world conditions and aligns with CSCM principles. By implementing triangulation, simulation results become more valid and realistic, supporting the formulation of sustainable waste management policies.
   II. Development and strengthening of upstream models that support decentralization, for example, local governments collaborate with waste producing companies, then the waste is returned or processed by the waste producing companies, such as Nestlé (Implementing sustainable packaging practices by reducing packaging weight, empowering waste banks, and launching products such as paper straws to reduce plastic waste.), Astra (circular economy program), IKEA (Implementing a go green program), Panasonic (implementing environmentally friendly initiatives), Circular Logistics Co (taking back used goods from its business partners, recycling raw materials for new products), etc.
   III. It is recommended to expand the dynamic system model by including social and economic variables, such as community behavior and the costs of adding waste processing units and logistics support units.

Thus, this study confirms that the implementation of dynamic systems-based Circular Supply Chain Management is not only a technical solution but also a comprehensive policy strategy towards sustainable and equitable waste management in Sleman Regency. This model can be replicated in other regions by adapting to local social, economic, and infrastructure characteristics.

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