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System Dynamics-Based Policy Scenario Evaluation for Sustainable Municipal Solid Waste Management in Ambon City, Indonesia

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ABSTRACT: Unmanaged waste and heavy reliance on landfill disposal highlight the urgent need for sustainable municipal solid waste management planning in Ambon City. This study developed a system dynamics model to evaluate policy scenarios for increasing managed waste and reducing landfilled waste. Using Powersim Studio 10, the model projected waste generation and waste management performance from 2026 to 2035 to evaluate the achievement of the 100% managed waste target by 2029 and the post-target effects of policy interventions on system performance. The model was tested through structure verification and behavior reproduction testing. The simulation results indicate that the business-as-usual scenario fails to meet the 2029 target due to limited upstream reduce, reuse, and recycle capacity and continued reliance on the conventional collect–transport–dispose approach. In contrast, the integrated policy scenario provides the most effective policy direction. Achieving a 30% source- and community-based reduce, reuse, and recycle (3R) target requires management capacity to increase by 38.43% annually. This upstream intervention reduces downstream handling burdens by lowering the required annual increase in collection and transportation capacity from 8.94% to 5.50%. Furthermore, developing an integrated waste processing facility (abbreviated in Indonesian as TPST) before landfill disposal, with a capacity of 74 tons/day, substantially reduces landfilled waste. The integrated scenario achieves the 100% managed waste target earlier, in 2028, maintains this level through 2034, and produces the lowest landfilled waste among all scenarios through 2035. The proposed dynamic model provides a decision-support framework for local government in formulating more effective and sustainable municipal solid waste management strategies.

KEYWORDS: Municipal solid waste management, system dynamics, policy scenario evaluation, waste management hierarchy, managed waste, landfilled waste.

INTRODUCTION

Municipal solid waste (MSW) management has become an important issue in sustainable urban development due to population growth, economic development, and changing consumption patterns (Popli et al., 2021). Globally, waste generation is projected to increase from 2.7 billion tons in 2019 to 4.54 billion tons by 2050. Nearly one-third of MSW remains uncollected, while 42% is disposed of in uncontrolled sites, openly burned, or leaked into the environment, posing risks to public health, environmental quality, and greenhouse gas emissions (Abubakar et al., 2022; Maalouf & Mavropoulos, 2023). In Indonesia, waste management is a priority in the National Medium-Term Development Plan 2025–2029, which targets 100% managed waste by 2029 (Government of the Republic of Indonesia, 2025). However, the national managed waste percentage has only reached 25%, indicating that waste management at the regional level still faces significant challenges (Ministry of Environment, 2025) .

These management challenges are also experienced by Ambon City. In 2025, waste generation in Ambon City reached 93,589.91 tons/year, with a managed waste percentage of 79.19%. Of this amount, waste management through reduce, reuse, and recycle (3R) activities accounted for only 10.59%, while 68.60% was still managed through the collect–transport–dispose approach (Ministry of Environment, 2025). Meanwhile, the remaining 20.81% of unmanaged waste has the potential to accumulate in the environment and pollute terrestrial and aquatic areas (Herdiansyah et al., 2021; Manullang et al., 2021). This condition is increasingly critical because continued dependence on final disposal may increase future land requirements, while land availability is limited due to the city's island characteristics. Therefore, a transition toward more sustainable waste management practices is needed to increase the managed waste percentage while reducing waste disposal to landfills.

To formulate more sustainable waste management strategies, an approach capable of representing the dynamic relationships among components of the waste management system is required. System dynamics (SD) is a suitable approach because it can represent the structure, interactions, and behavior of complex systems over time, while also allowing various policy scenarios to be tested to support decision-making (Berenjkar et al., 2021). Previous studies have applied SD in municipal waste management to evaluate current management performance and project waste generation, treatment, and disposal scenarios in England (Ng & Yang, 2023), as well as to optimize solid waste management systems and reduce waste flows to landfills in Tehran (Moradikia et al., 2024). In Indonesia, SD has also been used to assess technologies for reducing the volume of waste entering landfills (Heri Apriyanto et al., 2024), analyze the effects of waste reduction levels on management costs and landfill land requirements (Ermayendri et al., 2025), and estimate the required waste treatment facilities and transportation capacity to achieve local waste management targets (Chaerunnisa et al., 2025).

However, SD-based studies evaluating policy scenarios to simultaneously increase managed waste and reduce landfill disposal remain limited, particularly in Ambon City's municipal waste management system. Addressing this gap is important to evaluate whether policy interventions can support the achievement of 100% managed waste by 2029 while reducing dependence on landfills. Therefore, this study develops a system dynamics model to evaluate the performance of Ambon City's municipal waste management system and analyze the impacts of alternative policy scenarios. The findings are expected to provide insights for local governments in formulating more effective and sustainable waste management strategies.

MATERIALS AND METHODS

Overview of the Study Area and the Waste Management System

This study was conducted on the municipal solid waste (MSW) management system in Ambon City, the capital of Maluku Province, Indonesia, located in the southern part of X Island. The city covers a land area of 359.45 km² and a marine area of 17.55 km². In 2025, the population of Ambon City reached 360,919 people, with a population density of 1,004 people/km².

Municipal solid waste refers to solid waste generated from urban activities, including household waste and non-hazardous waste from commercial, industrial, institutional, and other sectors with characteristics similar to household waste. In Ambon City, waste management begins at the source and community levels through reduce, reuse, and recycle (3R) activities. At the source level, 3R practices are supported by policies such as restrictions on plastic bag use by communities and business actors. At the community level, 3R activities are carried out through 3R-based waste processing facilities (abbreviated in Indonesian as TPS 3R), waste banks, and informal collectors, which process waste into recyclable materials or compost.

Waste that is not managed through source- and community-based 3R activities enters the waste handling system through temporary collection sites (abbreviated in Indonesian as TPS), where it is collected before being transported to the final processing site (abbreviated in Indonesian as TPA), by the Environmental and Waste Management Agency of Ambon City. At the TPA, part of the incoming waste is sorted to recover valuable materials, such as plastic, cardboard, aluminum, and selected organic fractions. The remaining waste that is not recovered is disposed of as residue using a controlled landfill method.

Data Collection

The data used in this study consisted of quantitative and qualitative data obtained from both primary and secondary sources. Primary data were collected through field observations and stakeholder interviews with the Environmental and Waste Management Agency of Ambon City. Secondary data were obtained from the Environmental and Waste Management Agency of Ambon City, the National Waste Management Information System, the Statistics Agency of Ambon City, and relevant previous studies. Historical data covered the 2023–2025 period, depending on data availability. The quantitative variables included population, per capita waste generation, source- and community-based 3R activities, waste collection and transportation capacity to the final processing site, material recovery at the final processing site, and landfill disposal.

System Dynamics Approach

This study applied a system dynamics (SD) approach to evaluate the performance of Ambon City's municipal solid waste management system and analyze the impacts of policy intervention scenarios on system performance over time. The simulation model was developed using Powersim Studio 10. Following Sterman (2000), the modeling process consisted of five iterative stages that integrated qualitative and quantitative approaches, as shown in Figure 1. The process is iterative because each stage may provide feedback for refining earlier stages during model development.

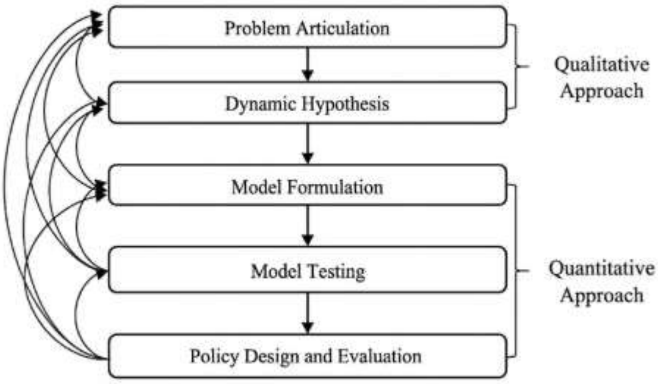

Figure 1. System dynamics modeling process adapted from Sterman (2000)

1. In the problem articulation stage, the main problem, simulation time horizon, key variables, and reference mode were defined.
2. In the dynamic hypothesis stage, a causal loop diagram (CLD) was developed to explain the endogenous structure assumed to generate the system behavior shown in the reference mode. The CLD represents causal relationships and feedback structures among variables affecting municipal solid waste management performance. In the CLD, variables are connected by causal links with positive (+) or negative (−) polarity. A positive polarity indicates that two variables change in the same direction, whereas a negative polarity indicates that two variables change in opposite directions (Bala et al., 2017).
3. In the model formulation stage, the CLD was translated into a quantitative stock-and-flow diagram (SFD) equipped with equations, parameters, and initial values. As shown in Figure 2, an SFD consists of stocks, flows, auxiliary variables, and constants. Stocks represent accumulations in the system, inflows increase stocks, and outflows decrease them. Auxiliary variables support model calculations, while constants represent fixed parameter values used in the model formulation.

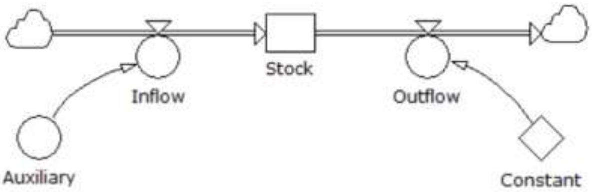

Figure 2. Basic elements of a stock-and-flow diagram

4. In the model testing stage, structure verification and behavior reproduction testing were conducted before the model was used for policy scenario simulations. Structure verification was performed by comparing the model structure with empirical conditions and theoretical relationships in the real system to assess its consistency with existing knowledge of the system structure (Bala et al., 2017). Behavior reproduction testing was conducted by comparing simulated behavior with observed historical data to assess the model's ability to reproduce real system behavior (Bala et al., 2017). Model fit was evaluated using mean comparison error (E_1) and error variance (E_2), which were calculated using Equation 1 and Equation 2. The model was considered capable of adequately reproducing historical behavior when $E_1 \leq 5\%$ and $E_2 \leq 30\%$ (Apriadi et al., 2024).

$$E_1 = \left|\frac{\bar{S}-\bar{A}}{\bar{A}}\right| \times 100\% \qquad (1)$$

Where $\bar{S}$ is the average simulated value and $\bar{A}$ is the average actual value.

$$E_2 = \left|\frac{S_S-S_A}{S_A}\right| \times 100\% \qquad (2)$$

Where S_S is the standard deviation of the simulation results and S_A is the standard deviation of the actual data.

5. In the policy design and evaluation stage, alternative policy scenarios were developed by considering the hierarchy of sustainable waste management, which prioritizes waste reduction, reuse, recycling, and resource recovery before final disposal. Scenario evaluation was conducted by comparing the main performance indicators, namely managed waste percentage and landfilled waste percentage. The best-performing scenario was determined based on its ability to achieve 100% managed waste by 2029 while reducing landfilled waste.

Sustainable Waste Management Concept

One of the main guiding principles in sustainable waste management is the waste hierarchy, which refers to the order of waste management priorities from the most preferred to the least desirable option. Its main objectives are to reduce waste generation, retain material value for as long as possible, and minimize final disposal. As shown in Figure 3, the waste hierarchy begins with prevention/reduction, which aims to prevent and reduce waste from the stages of design, material selection, production, and consumption. If waste is still generated, the next stages are reuse and repurposing, which aim to extend the service life of products or use materials for other functions. Waste is then managed through recycling and composting so that it can be returned as a resource with functional or economic value. If these options are not feasible, energy recovery, such as energy from waste, pyrolysis, or gasification, can be applied to generate energy. The final stage is disposal, such as landfill or incineration without energy recovery, because it has the greatest environmental impact and should only be used when no better alternatives are available (Ferehoun, 2026; Wikurendra et al., 2023; World Bank, 2022).

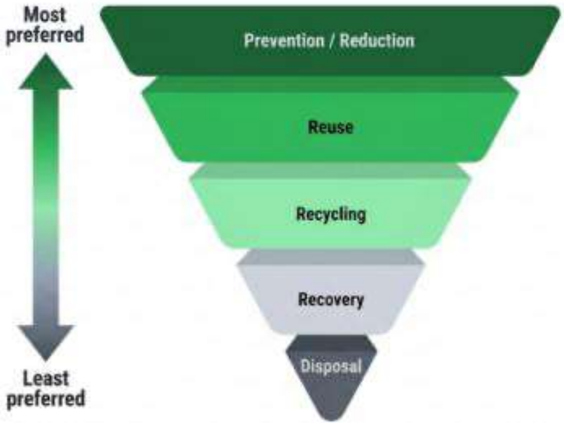

Figure 3. Waste management hierarchy

RESULTS

The central problem addressed in this study is the imbalance between increasing waste generation and the capacity of the existing waste management system to manage waste sustainably. This imbalance creates challenges for achieving the National Medium-Term Development Plan (abbreviated in Indonesian as RPJMN) target of 100% managed waste by 2029 while reducing dependence on landfill disposal. As shown in Figure 4, the reference mode from 2023 to 2025 indicates that waste generation increased, while managed waste did not improve proportionally. Unmanaged waste remained present, and landfill disposal continued to be a dominant pathway in the system. These patterns suggest that the existing system may face difficulty in achieving the 2029 target without additional policy interventions.

The simulation period was set from 2026 to 2035 to evaluate the system's ability to achieve the RPJMN target of 100% managed waste by 2029 and the post-target effects of policy interventions on system performance. Based on this problem formulation, the main policy question addressed by the model is how alternative waste management interventions can increase managed waste and reduce waste flow to landfill.

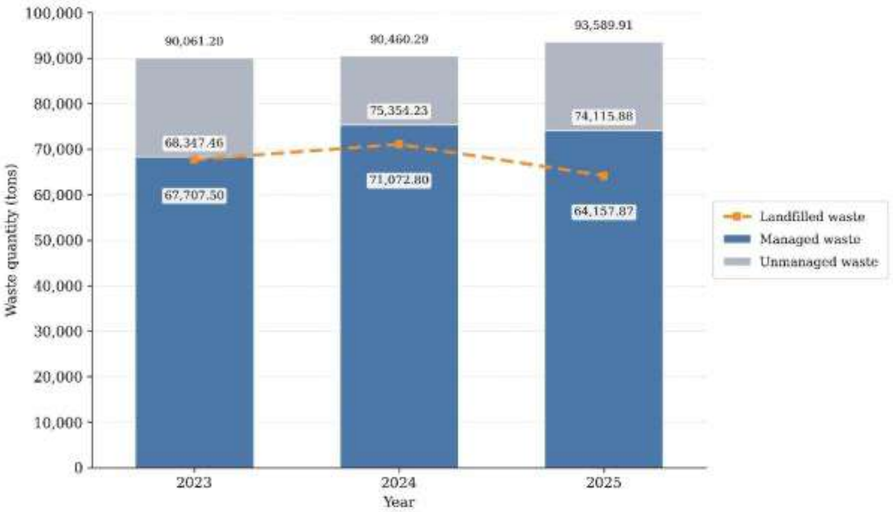

Figure 4. Reference mode of waste management performance in Ambon City (2023–2025)

Dynamic Hypothesis and Model Formulation of the Existing Model

The existing model structure was developed using a causal loop diagram (CLD) to explain the endogenous structure underlying the waste management behavior shown in the reference mode. As shown in Figure 5, the dynamic hypothesis suggests that population and per capita waste generation increase MSW generation, which subsequently increases the amount of waste requiring further handling. Source- and community-based 3R management acts as an upstream diversion mechanism by reducing waste requiring further handling and contributing to managed waste. However, because the existing contribution of 3R remains limited, most residual waste still depends on collection and transportation to the final processing site. Under this structure, collection and transportation can increase managed waste, but they also maintain dependence on landfill disposal because no waste processing facility is available before the final processing site. Material recovery at the final processing site reduces part of the landfilled waste, but its effect remains limited because recovery relies on sorting activities at the end of the management chain.

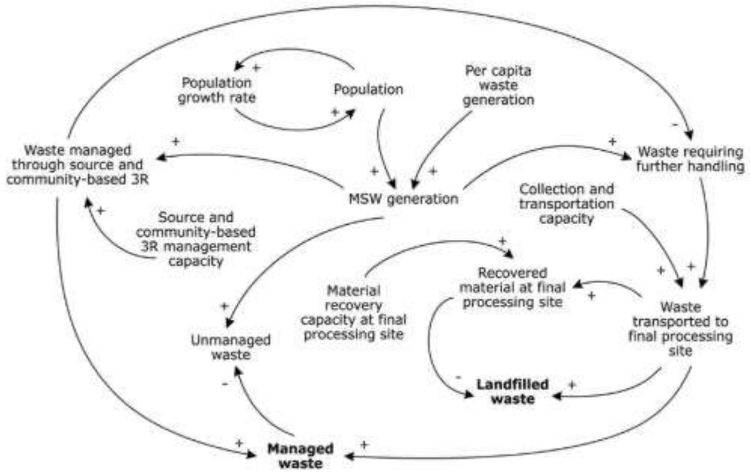

Figure 5. Existing causal loop diagram of Ambon City's municipal solid waste management system

The causal structure was then translated into a quantitative simulation model using a stock-and-flow diagram, as shown in Figure 6. Population was represented as a stock, while MSW generation was formulated as a function of population and per capita waste generation. Generated waste was allocated into waste managed through source- and community-based 3R and waste requiring further handling. Waste within the collection and transportation capacity was transported to the final processing site, while waste exceeding this capacity was categorized as unmanaged waste. At the final processing site, incoming waste was divided into recovered material and landfilled waste based on material recovery capacity. The formulated model produced the main performance indicators used in this study, namely managed waste percentage and landfilled waste percentage.

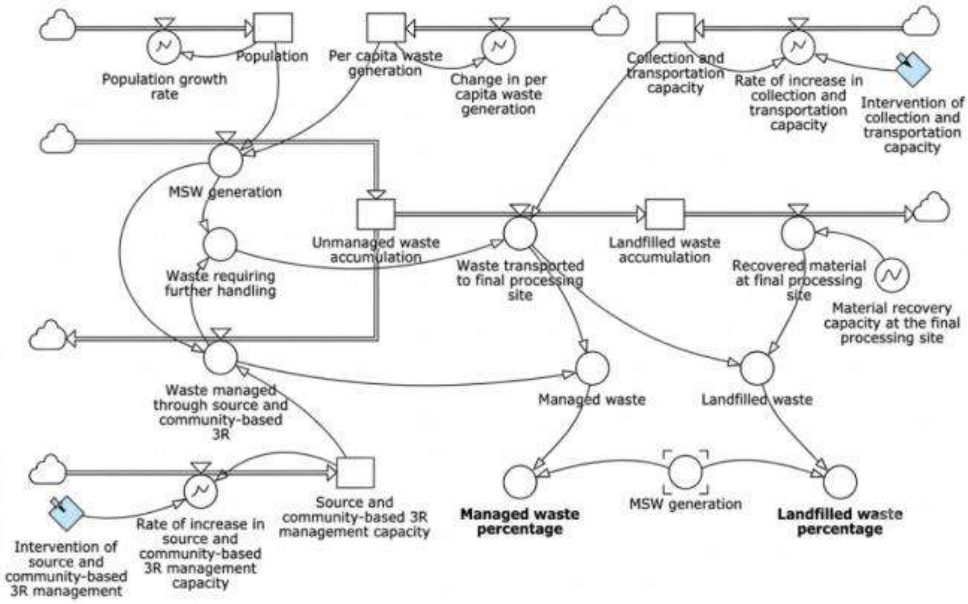

Figure 6. Existing stock-and-flow diagram of Ambon City's municipal solid waste management system

Model Testing of the Existing Model

Structure verification was conducted through theoretical and empirical verification. Theoretical verification confirmed that the model structure was consistent with system dynamics principles and the conceptual logic of municipal solid waste management, while empirical verification showed that the model represented the existing waste management system in Ambon City. The equations and units were also checked using the automated unit-checking feature in Powersim Studio 10, which showed no dimensional, formulation, or variable-relationship errors. This indicates that the model equations were dimensionally consistent.

Behavior reproduction testing was conducted by comparing simulated results with historical data from 2023 to 2025, based on data availability. The test was performed for the main model variables, including potential waste generation and managed waste. Model performance was evaluated using mean comparison error (E_1) and error variance (E_2). As shown in Table 1, all tested variables met the acceptance criteria of $E_1 \leq 5\%$ and $E_2 \leq 30\%$, indicating that the model was able to reproduce historical system behavior.

Table 1. Results of behavior reproduction testing

Variable	E_1	E_2	Decision
Potential waste generation	0.00120%	0.00502%	Accepted
Managed waste	0.00012%	0.00574%	Accepted

Policy Design and Evaluation

Business-as-usual scenario performance

The business-as-usual (BAU) scenario was simulated to represent the continuation of the existing waste management system without additional intervention. Figure 7 shows the projected MSW generation and waste management performance from 2026 to 2035. MSW generation increased throughout the simulation period, whereas managed waste and landfilled waste remained relatively constant under the existing management capacity. As a consequence, unmanaged waste increased. In the target year 2029, unmanaged waste reached 26,901.69 tons/year, equivalent to 73.70 tons/day.

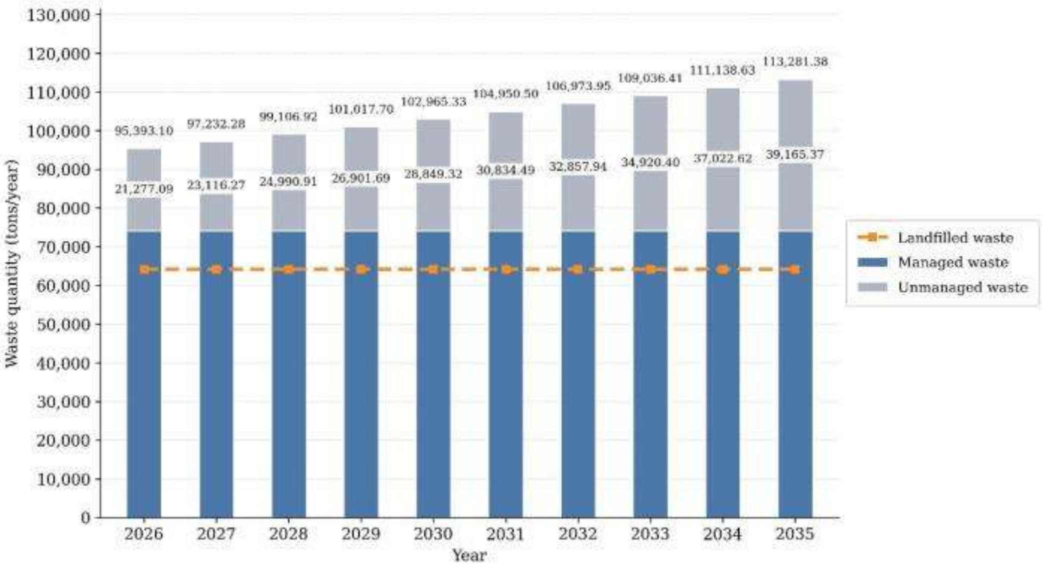

Figure 7. Projected MSW generation and waste management performance under the BAU scenario (2026–2035)

Proposed policy design

Based on the BAU projection, policy scenarios were developed to evaluate alternative capacity improvement pathways for achieving 100% managed waste by 2029 and reducing landfilled waste. The scenarios were structured from single interventions to integrated interventions. The interventions included improvement in source- and community-based 3R management capacity, improvement in collection and transportation capacity, and the introduction of an integrated waste processing facility (abbreviated in Indonesian as TPST), as a treatment facility before landfill disposal. The inclusion of TPST in the scenarios is aligned with the waste management policy direction of Ambon City, where TPST is assumed to begin operation in 2027. The proposed policy structure was developed by modifying the existing causal loop diagram and stock-and-flow diagram to include TPST as a treatment facility before landfill disposal, as shown in Figure 8 and Figure 9.

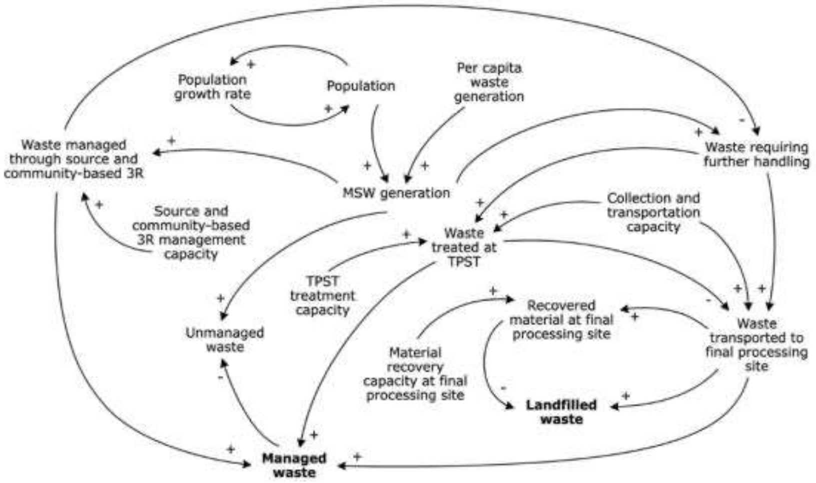

Figure 8. Proposed causal loop diagram of Ambon City’s municipal solid waste management system

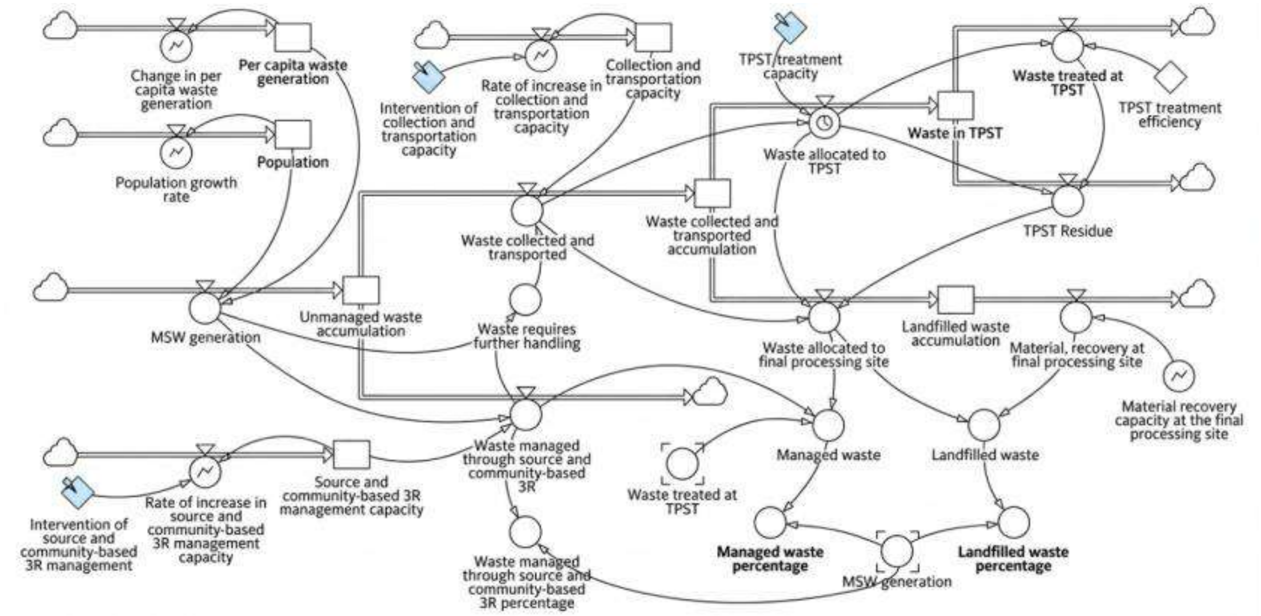

Figure 9. Proposed stock-and-flow diagram of Ambon City's municipal solid waste management system

In this structure, source- and community-based 3R management reduces the amount of waste requiring further handling, while collected waste can be allocated to TPST for treatment before residual waste is transported to the final processing site. The TPST capacity levels were defined based on the projected unmanaged-waste gap in 2029. Two capacity levels were evaluated: 37 tons/day and 74 tons/day, representing approximately 50% and 100% of the projected unmanaged-waste gap, respectively. These capacity levels were used to assess how different treatment capacities could contribute to reducing landfilled waste.

Source- and community-based 3R management capacity and collection and transportation capacity were increased annually during the 2026–2029 intervention period. After 2029, no additional capacity increase was assumed; however, the capacities achieved by 2029 were maintained until 2035 to assess post-target system performance. The annual capacity increase rates were estimated by calculating the required increase from the baseline condition to the target level in 2029 over the intervention period. The scenario parameters used in the simulation are presented in Table 2.

Table 2. Policy scenario parameters used in the simulation model.

Scenario	**Description**	**Rate of increase in source- and community-based 3R management capacity (%/year)**	**Rate of increase in collection and transportation capacity (%/year)**	**TPST treatment capacity (tons/day)**
BAU	Business-as-usual condition without additional intervention	0.00	0.00	0
S1	Intervention to achieve 30% source- and community-based 3R management by 2029	38.43	0.00	0
S2	Intervention to achieve 100% managed waste through collection and transportation capacity improvement under existing 3R conditions	0.00	8.94	0

S3a	S2 with partial-gap TPST treatment capacity equivalent to 50% of the unmanaged-waste gap in 2029	0.00	8.94	37
S3b	S2 with full-gap TPST treatment capacity equivalent to 100% of the unmanaged-waste gap in 2029	0.00	8.94	74
S4a	Integrated intervention with 30% 3R management, adjusted collection and transportation capacity, and partial-gap TPST treatment capacity	38.43	5.50	37
S4b	Integrated intervention with 30% 3R management, adjusted collection and transportation capacity, and full-gap TPST treatment capacity	38.43	5.50	74

Policy scenario performance

The policy scenarios produced different outcomes in terms of managed waste and landfilled waste, as shown in Figures 9 and 10. Under the BAU scenario, Ambon City did not achieve the target of 100% managed waste by 2029. This indicates that the continuation of the existing waste management system is insufficient to close the managed-waste gap because existing waste management capacity remains unchanged while MSW generation continues to increase. S1, which focused on achieving 30% source- and community-based 3R management by 2029, improved managed waste performance and reached 95.20% in 2029. However, this scenario remained below the target, indicating that upstream 3R improvement alone was insufficient to close the managed-waste gap.

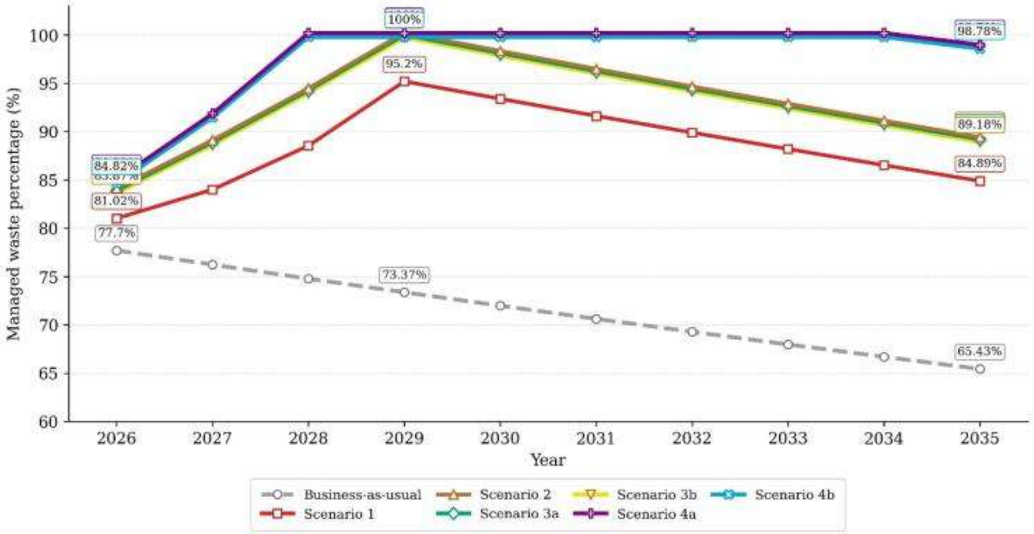

Figure 10. Managed waste percentage under policy scenarios (2026–2035)

S2, S3a, and S3b achieved 100% managed waste in 2029 through collection and transportation capacity improvement. Although these scenarios produced the same managed waste percentage, they resulted in different landfilled waste outcomes. S2 produced the highest landfilled waste percentage, reaching 90.14% in 2029. This indicates that collection and transportation expansion alone mainly shifts previously unmanaged waste into the landfill pathway. By contrast, the addition of TPST processing capacity in S3a and S3b reduced landfilled waste to 78.11% and 66.08%, respectively. Under the scenario assumptions, TPST did not directly increase the managed waste percentage when collection and transportation capacity remained the same, but it played an important role in reducing landfilled waste.

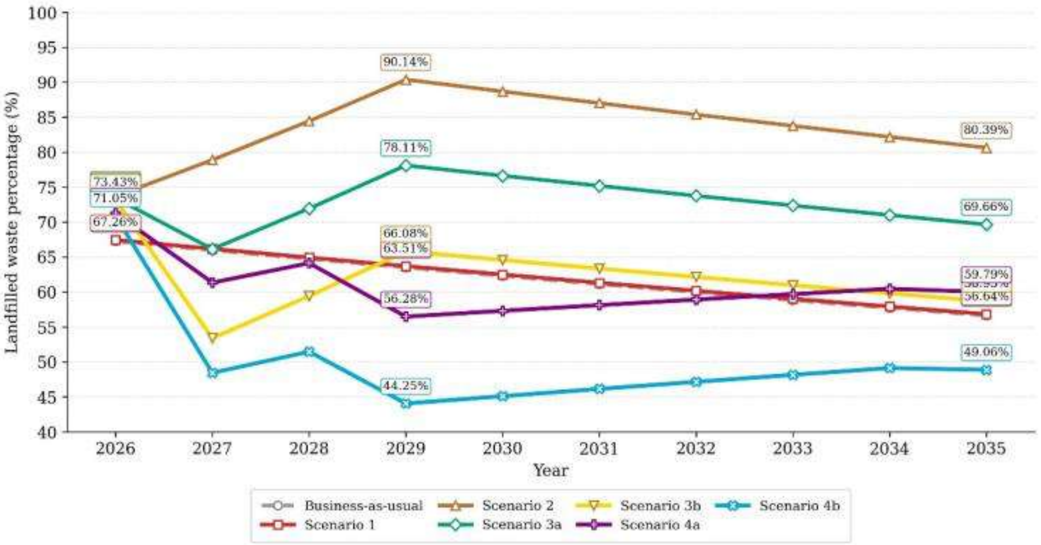

Figure 11. Landfilled waste percentage under policy scenarios (2026–2035)

The integrated scenarios, S4a and S4b, produced the best overall performance. Both scenarios reached 100% managed waste earlier, in 2028, and maintained this level until 2034. These scenarios also resulted in lower landfilled waste than the other interventions. In 2029, landfilled waste reached 56.28% in S4a and 44.25% in S4b. These results indicate that TPST with higer capacity, when combined with 30% source- and community-based 3R management and adjusted collection and transportation capacity, provides the most effective pathway for achieving managed waste targets while reducing landfill dependence.

However, the decline in performance observed in several periods after 2029 across the scenarios indicates that maintaining intervention capacities at the 2029 level may be insufficient as MSW generation continues to increase. Therefore, intervention capacities need to be evaluated and adjusted periodically to maintain waste management performance over the long term.

DISCUSSION

The simulation results indicate that achieving 100% managed waste does not necessarily represent a transition toward sustainable municipal solid waste management if most managed waste is still handled through a collect–transport–dispose approach. Although this approach can reduce unmanaged waste in the environment, it mainly shifts the waste burden to landfill rather. Consequently, landfill dependence remains high and may shorten the remaining landfill lifespan (Hajam et al., 2023). This explains why scenarios relying mainly on collection and transportation improvement could achieve the managed waste target but still resulted in high landfilled waste. Therefore, managed waste coverage should be evaluated together with landfilled waste reduction, as it only reflects the extent to which waste enters the management system and does not indicate whether waste is reduced, reused, recycled, recovered, or disposed of.

The integrated scenario provides the strongest policy implication for Ambon City. Sustainable municipal solid waste management requires connected improvements across the waste management chain rather than reliance on a single intervention. This is consistent with the principle that waste management should be integrated from upstream to downstream and should prioritize reduction, reuse, recycling, and recovery before disposal (Wikurendra et al., 2023). In Ambon City, source- and community-based 3R activities reduce the amount of waste requiring further handling, collection and transportation systems maintain service coverage and direct material flows to TPST and the final processing site, while TPST functions as a treatment facility before the final processing site to reduce landfilled waste.

Policy implications

The results suggest that Ambon City should prioritize an integrated strategy consisting of source-based reduction, community-based 3R strengthening, adjusted collection and transportation capacity, and TPST development before landfill disposal.

1. Strengthening source- and community-based 3R management

   The first capacity requirement identified by the model is the strengthening of source- and community-based 3R management. To achieve the 30% 3R target by 2029, this capacity must increase by 38.43% per year. This indicates that upstream 3R is essential for reducing the amount of waste requiring further handling, although it should not be treated as a stand-alone solution. The required improvement can be pursued through source-based reduction, TPS3R, waste banks, and integration of the informal sector.

   Source-based reduction can be supported through local policies restricting the use of single-use plastic bags by communities and business actors. Such policies can help prevent waste generation, but their effectiveness depends on consistent enforcement, public compliance, accessible reusable alternatives, and monitoring mechanisms. Without these supporting conditions, plastic bag restrictions may produce limited effects (Muposhi et al., 2022)

   At the community level, TPS3R should be strengthened as a facility for source-level collection, sorting, reuse, and recycling of organic and inorganic waste, so that only residual waste is transported to the TPA. Its sustainability depends not only on the number of facilities, but also on service fees, service coverage, and technical-operational capacity (Wulansari et al., 2023). Therefore, key improvements should include community participation in source separation, segregated collection facilities, organic and inorganic waste processing capacity, waste mass balance recording, accountable financial management, and competent human resources (Saleh & Sururi, 2024).

   Waste banks should also be strengthened to increase the recovery of economically valuable recyclable materials. Since waste banks generally operate through recyclable material transactions, their sustainability depends on active customers, material volume and quality, sales margins, and access to recycling markets (Wulansari et al., 2023)). Their contribution can be improved by establishing units in underserved areas, expanding customer participation, raising public awareness, using mobile-based information systems for collection scheduling and promotion, and offering competitive purchase prices for recyclable materials (Budiyarto et al., 2025).

   In addition, the informal sector, including waste pickers and scrap dealers, should be integrated into the municipal waste management chain. Local governments can strengthen their role through clear institutional arrangements, access to segregated recyclable materials, safer working conditions, data reporting mechanisms, and links to recycling markets. This integration can improve material recovery, reduce pressure on municipal waste services, and support local livelihoods (Bhandari et al., 2025; Dharmanu Yudartha et al., 2026; Kementerian PPN/Bappenas, 2022).

2. Adjusting collection and transportation capacity

   The second capacity requirement concerns collection and transportation. Under the existing 3R condition, collection and transportation capacity must increase by 8.94% per year to achieve 100% managed waste by 2029. However, when the 30% source- and community-based 3R target is achieved, the required increase decreases to 5.50% per year to handle the remaining waste and allocate it to TPST and the final processing site. This indicates that upstream 3R can reduce the burden on downstream handling capacity.

   Therefore, collection and transportation improvement should not only focus on adding trucks, workers, or collection frequency. It should be directed toward a segregated collection system that maintains waste separation from source to treatment facilities. Separate containers and transport units are needed for organic waste, recyclable materials, and residual waste to prevent sorted waste from being remixed. Without this system, source separation may lose its effectiveness, recyclable materials may become contaminated, and treatment facilities may receive mixed waste that is more difficult to process (Zhang et al., 2022).

3. Developing TPST as an integrated waste processing facility

   The third policy requirement is the development of TPST as an integrated waste processing facility to recover resources and reduce landfilled waste (Budihardjo et al., 2023). The simulation shows that TPST capacity equivalent to the full unmanaged-waste gap in 2029, namely 74 tons/day, provides greater landfill reduction than TPST capacity equivalent to half of the gap, namely 37 tons/day. However, TPST development should not only focus on closing the capacity gap, but also on aligning treatment technology with the waste composition of Ambon City.

The waste composition of Ambon City is dominated by food waste at 39%, followed by plastic at 16%, paper/cardboard at 12%, wood/branches at 9%, metal at 7%, glass at 5%, other waste at 5%, textiles at 4%, and rubber/leather at 3%. This composition indicates that TPST should be designed as a multi-fraction treatment facility. The treatment process should begin with sorting to separate organic waste, recyclable inorganic waste, non-recyclable waste, and final residues. Organic waste can be processed through composting or black soldier fly cultivation, while recyclable inorganic materials can be sorted and prepared as secondary raw materials. Non-recyclable waste with sufficient calorific value may be considered for refuse-derived fuel production if reliable off-takers are available, such as the State Electricity Company, referred to in Indonesia as PLN (Budhijanto et al., 2024).

Residual treatment, such as incineration, should be positioned as a last-resort option for final residues that cannot be recovered or treated through TPST. Although incineration can reduce waste volume by up to 90% (Hariyani et al., 2025), its implementation should only be considered if it complies with applicable emission standards and environmental requirements. Therefore, only residual waste that cannot be treated through TPST should be disposed of in landfill.

CONCLUSION

This study developed a system dynamics model to project waste generation and evaluate municipal solid waste management policy scenarios in Ambon City. The model was used to assess alternative interventions for achieving 100% managed waste by 2029, reducing landfilled waste, and examining post-target system performance until 2035. The scenario analysis shows that the business-as-usual scenario is insufficient to achieve the 100% managed waste target by 2029. Strengthening source- and community-based 3R management improves managed waste performance, but it does not fully close the target gap when implemented as a single intervention. Increasing collection and transportation capacity can achieve the target; however, without upstream reduction and treatment before landfill disposal, this approach maintains high dependence on landfill disposal. The introduction of TPST reduces landfilled waste, especially when higher treatment capacity is applied.

The integrated scenario provides the most effective policy direction for Ambon City. Achieving the 30% source- and community-based 3R target by 2029 requires 3R management capacity to increase by 38.43% per year. When this target is achieved, the required increase in collection and transportation capacity decreases from 8.94% to 5.50% per year, indicating that upstream 3R can reduce downstream handling burdens. In addition, TPST capacity of 74 tons/day provides greater landfill reduction than the lower capacity option of 37 tons/day. These findings suggest that Ambon City should prioritize source-based reduction, community-based 3R strengthening, segregated collection and transportation, and TPST development as a multi-fraction treatment facility. However, the post-target projection indicates that maintaining intervention capacities at the 2029 level may be insufficient in the long term as MSW generation continues to increase. Therefore, intervention capacities need to be evaluated and adjusted periodically to sustain waste management performance beyond the target year.

This study contributes a system dynamics-based policy evaluation framework that simultaneously assesses managed waste and landfilled waste. The proposed dynamic model also serves as a decision-support framework for local governments by providing insights for formulating effective and sustainable waste management strategies. Despite these findings, this study has several limitations. First, the proposed policy scenarios were developed based on the current waste management policy direction of Ambon City; therefore, other feasible policy alternatives were not fully explored. Second, the model was constrained by the availability of quantitative data, requiring several variables and waste flow processes to be represented in an aggregated form. Third, the analysis did not include detailed financial feasibility. Future research should evaluate additional locally feasible policy options, incorporate more detailed variables through primary data collection, and assess the financial feasibility of the proposed interventions.

REFERENCES

1. Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., AlShihri, F. S., AlShammari, M. S., Ahmed, S. M. S., Al-Gehlani, W. A. G., & Alrawaf, T. I. (2022). Environmental sustainability impacts of solid waste management practices in the Global South. *International Journal of Environmental Research and Public Health*, *19*(19), 12717. https://doi.org/10.3390/ijerph191912717

2. Apriadi, B. F., Setiawan, R. P., & Firmansyah, I. (2024). Policy scenario of plastic waste mitigation in Indonesia using system dynamics. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *42*(11), 1008–1018. https://doi.org/10.1177/0734242X241231396
3. Bala, B. K., Arshad, F. M., & Noh, K. M. (2017). *System dynamics*. Springer Singapore. https://doi.org/10.1007/978-981-10-2045-2
4. Barlas, Y. (1989). Multiple tests for validation of system dynamics type of simulation models. *European Journal of Operational Research*, *42*(1), 59–87. https://doi.org/10.1016/0377-2217(89)90059-3
5. Berenjkar, P., Li, Y. Y., & Yuan, Q. (2021). The application of system dynamics in different practices of a waste management system. *Environment, Development and Sustainability*, *23*(11), 15695–15724. https://doi.org/10.1007/s10668-021-01362-8
6. Bhandari, M., Tiwari, G., & Dhakal, M. (2025). Assessing waste management practices and sustainable recycling opportunities in Nepal. *Waste Management Bulletin*, *3*(3), 100228. https://doi.org/10.1016/j.wmb.2025.100228
7. Budhijanto, W., Marleni, N. N. N., Wulaningtyas, A. H., Istiqomah, I., Ahmad, J. S. M., & Marbelia, L. (2024). Techno-economic analysis on community-based municipal solid waste processing facilities: A case study in Sleman Regency Indonesia. *Environmental Development*, *52*, 101083. https://doi.org/10.1016/j.envdev.2024.101083
8. Budihardjo, M. A., Humaira, N. G., Ramadan, B. S., Wahyuningrum, I. F. S., & Huboyo, H. S. (2023). Strategies to reduce greenhouse gas emissions from municipal solid waste management in Indonesia: The case of Semarang City. *Alexandria Engineering Journal*, *69*, 771–783. https://doi.org/10.1016/j.aej.2023.02.029
9. Budiyarto, A., Clarke, B., & Ross, K. (2025). Overview of waste bank application in Indonesian regencies. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *43*(3), 306–321. https://doi.org/10.1177/0734242X241242697
10. Chaerunnisa, N. F., Samawi, M. F., & Tumpu, M. (2025). A dynamic system model for sustainable waste management in Bantaeng regency. *Ecological Engineering & Environmental Technology*, *26*(9), 232–239. https://doi.org/10.12912/27197050/209598
11. Dharmanu Yudartha, I. P., Yuwono, T., & Suwitri, S. (2026). Waste management in developing countries: a systematic literature review of policy implementation. *Frontiers in Environmental Science*, *14*. https://doi.org/10.3389/fenvs.2026.1812062
12. Ermayendri, D., Simarmata, M., Arianto, W., Reflis, R., Riwandi, R., & Sukiyono, K. (2025). Dynamic integrated model for sustainable solid waste management in Bengkulu City. *Environment and Natural Resources Journal*, *23*(6), 1–22. https://doi.org/10.32526/ennrj/23/20250048
13. Government of the Republic of Indonesia. (2025). *Presidential regulation of the Republic of Indonesia number 12 of 2025 concerning the national medium-term development plan for 2025–2029 (in Indonesian)*. https://peraturan.bpk.go.id/Details/314638/perpres-no-12-tahun-2025
14. Hajam, Y. A., Kumar, R., & Kumar, A. (2023). Environmental waste management strategies and vermi transformation for sustainable development. *Environmental Challenges*, *13*, 100747. https://doi.org/10.1016/j.envc.2023.100747
15. Hariyani, D., Hariyani, P., Mishra, S., & Sharma, M. K. (2025). A literature review on waste management treatment and control techniques. *Sustainable Futures*, *9*, 100728. https://doi.org/10.1016/j.sftr.2025.100728
16. Herdiansyah, H., Saiya, H. G., Afkarina, K. I. I., & Indra, T. L. (2021). Coastal community perspective, waste density, and spatial area toward Sustainable Waste management (case study: Ambon Bay, Indonesia). *Sustainability*, *13*(19), 10947. https://doi.org/10.3390/su131910947
17. Heri Apriyanto, Yanuar I. Dwiananto, Agung Wiratmoko, Sri H. Mukti, Hermawan Prasetya, Agus Sucipto, Suripto, Ugay Sugarmansyah, Warseno, & Agung Riyadi. (2024). The dynamics model of the waste reduction to the final processing site and greenhouse gas emissions in Bogor City, Indonesia. *Evergreen*, *11*(4), 2983–2995. https://doi.org/10.5109/7326939
18. Kementerian PPN/Bappenas. (2022). *Integrasi sektor informal ke dalam sistem pengelolaan sampah*. https://lcdi-indonesia.id/dokumen-publikasi-dkti-kajian-sektor-informal
19. Maalouf, A., & Mavropoulos, A. (2023). Re-assessing global municipal solid waste generation. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *41*(4), 936–947. https://doi.org/10.1177/0734242X221074116

20. Manullang, C. Y., Barends, W., Polnaya, D., Soamole, A., & Rehalat, I. (2021). Marine Litter and Grading of the Coastal Areas of Ambon Bay, Indonesia. *Omni-Akuatika*, *17*(2), 70. https://doi.org/10.20884/1.oa.2021.17.1.903
21. Ministry of Environment. (2025). *National waste management performance information system (in Indonesian)*. https://sampahnasional.kemenlh.go.id/
22. Moradikia, S., Omidvar, B., Abdoli, M. A., & Salehi, E. (2024). Developing a dynamic model for sustainable management of municipal solid wastes to reduce landfill. *Pollution*, *10*(4), 1176–1189. https://doi.org/10.22059/poll.2024.375146.2340
23. Muposhi, A., Mpinganjira, M., & Wait, M. (2022). Considerations, benefits and unintended consequences of banning plastic shopping bags for environmental sustainability: A systematic literature review. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *40*(3), 248–261. https://doi.org/10.1177/0734242X211003965
24. Ng, K. S., & Yang, A. (2023). Development of a system model to predict flows and performance of regional waste management planning: A case study of England. *Journal of Environmental Management*, *325*, 116585. https://doi.org/10.1016/j.jenvman.2022.116585
25. Popli, K., Park, C., Han, S.-M., & Kim, S. (2021). Prediction of solid waste generation rates in urban region of Laos using socio-demographic and economic parameters with a multi linear regression approach. *Sustainability*, *13*(6), 3038. https://doi.org/10.3390/su13063038
26. Saleh, S. A., & Sururi, M. R. (2024). Determination of critical indicators for community-based TPS 3R performance. *Jurnal Presipitasi: Media Komunikasi Dan Pengembangan Teknik Lingkungan*, *21*(2), 622–637. https://doi.org/10.14710/presipitasi.v21i2.622-637
27. Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Irwin/McGraw-Hill.
28. Wikurendra, E. A., Abdeljawad, N. S., & Nagy, I. (2023). A Review of Municipal Waste Management with Zero Waste Concept: Strategies, Potential and Challenge in Indonesia. *International Journal of Environmental Science and Development*, *14*(2), 147–154. https://doi.org/10.18178/ijesd.2023.14.2.1427
29. Wulansari, A., Adyatama, A. M., Widianarko, B., Kristiawan, D., Elpandri, Prihantoro, F., Sidabalok, H., Putra, K. I., Anggrainin, M. V., Anggraeni, M., Handayani, M. D., Nurhadi, Moh., Budiarti, R., Setiadi, R., Walinono, T., & Rahmawati, Y. (2023). *Towards sustainable and equitable waste management: Lessons from mentoring waste banks and TPS 3R in Semarang City (in Indonesian)*. Yayasan Bina Karta Lestari (BINTARI). https://bintari.or.id/menuju-pengelolaan-sampah-yang-berkelanjutan-dan-berkeadilan/
30. Zhang, X., Liu, C., Chen, Y., Zheng, G., & Chen, Y. (2022). Source separation, transportation, pretreatment, and valorization of municipal solid waste: a critical review. *Environment, Development and Sustainability*, *24*(10), 11471–11513. https://doi.org/10.1007/s10668-021-01932-w

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