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Redesigning Community-Based Waste Management Systems Using Behavioral Insights for Sustainable Rural Waste Management

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Abstract: Waste management remains a major challenge in rural areas of developing countries, including Indonesia, due to limited system capacity and low household participation in source separation. This study aims to redesign the waste management system in Cepogo Village by integrating behavioral insights, ecosystem analysis, and a Business Process Reengineering (BPR) approach. A mixed-methods approach was applied, combining field observations, semi-structured interviews, document analysis, scenario-based simulation, and financial feasibility assessment. The results show that the existing system is dominated by direct disposal to landfill due to low household sorting practices, dependence on downstream sorting at the TPS 3R, and increasing operational burdens that lead to a monthly financial deficit. Ecosystem analysis identifies key bottlenecks, including inconsistent sorting behavior, limited institutional regulation, and operational constraints in collection and processing. Simulation results indicate that increasing household waste separation can reduce landfill dependence, improve material recovery, and enhance financial performance. Financial analysis demonstrates a transition from deficit conditions to potential surplus across intervention scenarios, with payback periods ranging from 1.7 to 0.7 years. These findings highlight the importance of integrating behavioral, institutional, and technical interventions to improve sustainable rural waste management systems.

Keywords: *Business Ecosystem, Business Process Reengineering, Community Participation, Rural Waste Management, Sustainability*

INTRODUCTION

Waste management is a major environmental issue in many countries, including Indonesia, which is experiencing an increase in waste generation due to urbanization, lifestyle changes, and increased purchasing power of the population (Parinduri et al., 2024). The growth in waste volume is not matched by the development of adequate waste management infrastructure, especially in rural areas that often face limited facilities, technological and financial constraints, and low public awareness regarding waste management (Hajam et al., 2023; Leknoi, Painmanakul, et al., 2024; Lingga et al., 2024; Obani & Izu-Obani, 2025). These conditions result in improper waste disposal practices, such as open burning of waste and illegal waste disposal, which have an impact on environmental pollution and public health problems (Gebrekidan et al., 2024; Lima et al., 2021; Syafrudin et al., 2023).

Waste management in Cepogo Village, Boyolali Regency, Central Java, Indonesia, reflects this condition, where insufficient infrastructure and low community engagement in household waste sorting hinder system effectiveness. Regular waste bank activities have also not yet significantly encouraged changes in community behavior. Waste generation in Cepogo Village continues to rise along with population growth and expanding economic activity. As a center of metalcraft production, the increase in industrial activity has also led to higher consumption and household waste. This situation puts pressure on the operations of the Reduce, Reuse, and Recycle Waste Processing Facility (TPS 3R). The high proportion of mixed waste received has led to increased management costs and an increase in the volume of residue that must be transported to the landfill. According to Labib et al. (2021), sorting waste at the source is one of the most effective ways to address these challenges, which helps reduce waste volume and improve management efficiency (Kihila et al., 2021). However, community behavior toward waste sorting is influenced by a range of factors that determine the extent of public participation in waste management practices.

Previous research by Apriani & Liquiddanu (2025) found that in Cepogo Village, environmental awareness has the strongest influence on household attitudes toward waste separation. Environmental knowledge reinforces these attitudes by increasing awareness in decision-making related to waste management. Attitude strongly influences the intention that drives absolute waste sorting behavior. Role of government variables, which include both the regulatory role of the village government and the operational role of BUMDes as the TPS 3R manager, also have a positive influence on community intention. Conversely, situational factors weaken these intentions by creating practical barriers such as limited cooperation among household members, time constraints, and inadequate space for sorting. These findings align with Karim Ghani et al. (2013) and Luo et al. (2024) convenience and the availability of proper facilities play a critical role in shaping residents' willingness to separate waste. These challenges suggest that the issue extends beyond individual behavior and reflects weaknesses in the waste management system, which is not yet able to consistently support household-level waste sorting.

While previous research in Cepogo Village has provided important insights into the behavioral factors influencing waste sorting, its scope remains limited to identifying determinants without translating them into system-level improvements. However, waste management is a complex socio-technical process that depends not only on technical capacity but also on coordination and interaction among actors to achieve system sustainability (Helmefalk et al., 2023; Lingga et al., 2024). This gap highlights the need for a more integrated plan that links the understanding of community behavior with improvements in waste management practices. A systemic approach is necessary as consistent household waste sorting depends on sufficient infrastructure, effective governance, and strong operational support.

The purpose of this study is to address the challenges in Cepogo Village's current waste management system by integrating insights from previous behavioral research into system-level improvements. This study aims to design improvements to the waste management system in Cepogo Village in order to enhance the effectiveness and sustainability of village-level waste management. By integrating previous findings on community behavioral factors with an analysis of the existing waste management system, this study identifies key barriers that influence household waste sorting practices and formulates proposed improvements to the management system. The potential impacts of the proposed improvements are then evaluated through simulation analysis to estimate their implications for system performance. Through this approach, the study is expected to contribute to the development of a more effective, coordinated, and sustainable community-based waste management system in rural areas.

METHODS

The research method describes the research type, research object, population, sample, research time and location, instruments, analytical tools, and other matters related to the research procedure. This section may be divided into several paragraphs or subsections, but it should not use numbering. This study applied a mixed-methods approach that combined qualitative and quantitative techniques to ensure accurate and reliable results (Creswell, 2022; Donkoh & Mensah, 2023). The qualitative approach uses case studies to explore real and complex phenomena in a local context in depth, by collecting information from different sources, such as interviews, documents, and direct observations in the field (Yin, 2014). The quantitative approach uses technical and financial analyses through scenario simulations to evaluate system efficiency and the economic sustainability of the proposed improvements. The study was conducted in Cepogo Village, Boyolali Regency, Central Java, Indonesia, from January to June 2025, focusing on the village-level waste management system, using three main methods (observation, interviews, and document review) to ensure data triangulation and increase the validity of the findings.

Observations at the TPS 3R allowed direct examination of the waste management process and interactions among stakeholders. Semi-structured interviews were used because they facilitate in-depth data collection while maintaining the focus of the research (Mashuri et al., 2022). Informants were determined through purposive sampling techniques that targeted individuals directly involved in waste management activities, so that the data obtained was relevant, detailed, and efficient in terms of time and resources (Memon et al., 2025). The interview respondents are listed in Table 1. Document review was conducted on BUMDes operational reports and Community Service Program (KKN) reports related to the composition of waste in Cepogo Village.

The data analysis in this study is based on the findings Apriani & Liquiddanu (2025), who identified factors influencing household waste sorting behavior in Cepogo Village based on the Theory of Planned Behavior. These findings were used to understand the relationship between community behavior and the existing waste management system. A process analysis is then conducted to identify operational flows, bottlenecks, and system inefficiencies. In addition, a business ecosystem analysis is performed to map the actors involved, as well as the interrelationships and dependencies within the waste management system. Operational performance and the current economic condition of the system are also analyzed to assess sorting workload, waste inflow to the TPS 3R, and its implications for operational costs. Based on these results, process improvements were designed using a Business Process Reengineering approach and evaluated through waste reduction scenario simulations and financial feasibility analysis using the payback period.

Table 1. Interview Respondents

Actors	Frequency
Village government	1
BUMDes	2
Family Welfare Movement (PKK)	2
Household	8
Waste Collection Officer	2
Waste Sorting Officer	2

RESULTS AND DISCUSSION

Current Waste Management Process in Cepogo Village

Previous research has shown that environmental awareness and knowledge shape attitudes toward waste sorting, which in turn influence the intention to sort waste at the household level. The government's role helps reinforce these intentions, while situational factors such as time constraints, limited space, and coordination within the household can weaken their implementation in practice. In contrast, social norms and rule enforcement were found to have no significant influence, indicating that waste separation is not yet perceived as an obligation by the community. Although intentions have been formed, sorting behavior is not always consistently realized. This situation indicates the existence of an intention–behavior gap; therefore, these behavioral findings are used as a basis to examine how current waste management processes can support or, conversely, hinder waste sorting practices at the household level.

The waste management process in Cepogo Village is divided into two main parts: non-technical and technical. The non-technical process involves administrative activities and community engagement carried out before the waste is collected. The Village Government initiates the program and assigns BUMDes to operate the TPS 3R. Socialization activities are conducted by BUMDes together with the PKK at the neighborhood level to explain program registration procedures, household obligations, and the benefits of waste separation. Currently, socialization is limited and only targets homemakers, which restricts overall coverage and may create an unequal distribution of household roles. As one household stated, *"There is socialization, but it is not held regularly, only when necessary."*

Households that join the program through the PKK pay a monthly fee of IDR 16,000 and receive a membership sticker. Payments are recorded manually in notebooks and simple Excel files, occasionally causing discrepancies between registered members and actual users. Nonetheless, regular reminders via WhatsApp and personal contacts help maintain compliance. BUMDes also plans to update the member database long-term to improve accuracy.

The technical processes of waste management encompass collection, transportation, treatment, and disposal from the source to the final destination. The initial stage is sorting, where households, especially homemakers, sort inorganic waste that has a selling value and then deposit it in the waste bank unit managed by the PKK, as shown in Figure 1. However, organic and residual waste are often mixed during collection, as many households assume that further sorting will be conducted by waste management staff. This behavior reflects a dependence on waste management staff and a limited understanding of the importance of household-level sorting for achieving efficient waste management (Dipayani et al., 2025; Labib et al., 2021). Limited cooperation among family members and PKK socialization efforts that target only women diminish motivation and may reinforce gender role inequalities, thereby hindering sustainable collective behavioral change (Apriani & Liquiddanu, 2025; Muchangos & Vaughter, 2019).

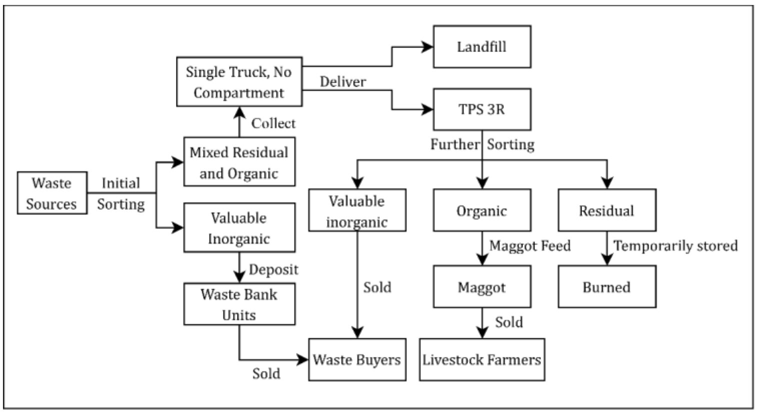

Figure 1. Current Waste Management Flow (As-Is)

The waste collection process is carried out by collection officers using a truck according to the neighborhood (RW) schedule. The use of single-compartment trucks often causes previously separated waste to become mixed during transportation, which makes residents lose trust in the system and less motivated to keep sorting their waste (Leknoi, Yiengthaisong, et al., 2024; Veliverronena & Davidsone, 2025). In fact, trust in waste management policies and programs is an important element that influences household participation in sorting (Rousta et al., 2016). In practice, the collection process may also experience delays due to weather or technical constraints, leading to waste accumulation at households or collection points. As noted by a collection officer, *"Sometimes the amount of waste at one collection point exceeds the target. Residents still mix their waste."*

After collection, waste is transported to the TPS 3R if capacity permits or directly to the landfill, with BUMDes paying a monthly fee to the Environmental Agency (DLH) based on the waste volume. At TPS 3R, waste is categorized into three types: organic waste is used as maggot feed and then sold to farmers; inorganic waste that has value is sold to waste collectors; and residues that cannot be recycled are burned. This sorting process enables the recovery and reuse of waste with economic value. Nevertheless, because of the limited capacity of the TPS 3R and the large amount of waste received, the sorting process is not always optimal, and some valuable materials end up mixed or unprocessed (Royhan et al., 2023). As stated by a waste sorting officer, *"The amount of incoming waste is large, but there are only a few sorting officers. Moreover, the sorting machine does not work optimally because soft waste often gets stuck."*

In the current waste management model, the primary burden of sorting remains concentrated at the TPS 3R, meaning the system's effectiveness is heavily dependent on the downstream stage. However, limitations in system support prevent the optimal implementation of behavioral changes regarding waste sorting at the household level. From an operational perspective, key inefficiencies occur in the waste collection and processing stages. The collection system does not fully support source separation because the transport fleet lacks compartmentalized trucks, causing previously sorted waste to be mixed again during collection. In addition, limited capacity and workload at the TPS 3R prevent the sorting process from operating optimally, resulting in the loss of potential economic value from recyclable materials. This situation highlights a mismatch between household-level sorting efforts and the system's final output, indicating weak connectivity between upstream and downstream stages in the waste management chain. Therefore, process redesign is required to ensure more consistent material flows and improve overall system effectiveness.

Waste Management Ecosystem Analysis in Cepogo Village

The waste management ecosystem in Cepogo Village comprises various interconnected actors with distinct roles and responsibilities, who collectively contribute to waste management value creation. The classification of actors in this ecosystem follows Peltola, Aarikka-Stenroos, Viana, & Mäkinen (2016), including focal actors, waste suppliers, intermediaries, complementors, and ecosystem enablers. To clarify the actor structure, roles, and interdependencies among parties, a summary of the waste management ecosystem is presented in Table 2.

Table 2. Waste Management Ecosystem Actors and Interdependencies

Actor Type	Actor	Role in the Ecosystem	Key Interdependencies
Ecosystem enabler	Village government	Provides policy direction, funding, and program legitimacy	Depends on BUMDes for the implementation of waste management operations
Ecosystem enabler	Environmental Agency (DLH)	Monitoring of residual waste disposal to the landfill and sets disposal fees	Depends on BUMDes for reducing waste sent to the landfill through TPS 3R processing

Actor Type	Actor	Role in the Ecosystem	Key Interdependencies
Focal actor	BUMDes	Coordinates waste collection, sorting, processing, and TPS 3R operations	Depends on households, PKK, operational officers, village government, and DLH for system operation
Waste supplier	Households	Source of waste and responsible for initial waste sorting	Depend on BUMDes for waste management services and the PKK for information and outreach
Intermediary	PKK	Community outreach, education, fee collection, and management of waste bank units	Depends on BUMDes for program coordination and on households for participation
Intermediary	Waste Collection Officer	Transport waste to TPS 3R or the landfill	Depends on coordination from BUMDes and waste supply from households
Intermediary	Waste Sorting Officer	Responsible for waste sorting and processing at the TPS 3R	Depends on the quality of waste from households and the transportation process
Complementor	Waste buyers/ livestock farmers	Waste buyers purchase inorganic waste; livestock farmers utilize processed organic waste	Depend on BUMDes for the availability and consistency of the supply

Based on Table 2, the waste management ecosystem in Cepogo Village consists of interdependent actors in a value chain from upstream to downstream. The Village Government acts as an enabler through policies and initial funding, while the DLH serves as an ecosystem enabler in establishing the regulatory framework for waste management. The BUMDes serves as the focal actor coordinating all operational activities, including waste collection, sorting, and processing at the TPS 3R. Households act as the primary source of waste and initial sorters, the PKK as the liaison for public outreach and fee administration, and operational staff as technical implementers. Meanwhile, waste collectors and livestock farmers act as complementors who absorb economically valuable materials from the waste processing output. This structure demonstrates the interdependence among actors in maintaining the continuity of material and value flows within the system. Although this interdependent structure has been established, several bottlenecks indicate an imbalance in the relationships among actors within the waste management ecosystem in Cepogo Village.

First, at the household level, there is inconsistency in the role of households as the primary actors in initial waste sorting. This indicates a weak relationship between households and downstream actors in maintaining the quality of material inputs into the system. As a result, the flow of value from upstream to downstream becomes unstable because the waste entering the TPS 3R is mostly mixed, as stated by a household respondent, *"... in a household, sometimes not everyone sorts the waste, so once it gets mixed up, it's impossible to separate it again because it's already dirty and smelly."* Second, there has been a shift in sorting responsibility from households to the TPS 3R, which reinforces dependence on downstream actors. The perception that sorting is done at the TPS 3R also arises due to a fee mechanism that leads some residents to believe that management responsibility has been transferred to the operators. One household stated, *"I do not separate organic waste because I joined the waste collection program, and the organic waste will be sorted later at the TPS 3R."*

Third, the discrepancy between the perceptions and practices of households and waste collectors, which results in inconsistent source separation throughout the ecosystem. Consequently, the flow of economically valuable materials cannot be consistently maintained from upstream to downstream, leading to lower input quality at the TPS 3R and additional workload for sorting officers. As a collection officer explained, *"The collection officers often mix the waste that has already been sorted at home when loading it into the truck, so it feels pointless for us to sort it in the first place."* Fourth, BUMDes shows a high dependence on PKK as an intermediary actor in outreach, fee collection, and management of waste bank units, resulting in uneven dissemination of information and community participation. This is reflected in PKK, where *"Socialization about waste sorting is conducted during PKK meetings because some members still do not understand which types of waste can be sold."* Fifth, the absence of mandatory waste sorting regulations from the Village Government represents a key bottleneck in the waste management ecosystem in Cepogo Village, as household participation remains voluntary and lacks binding enforcement mechanisms, as noted by the village government: *"There is no regulation regarding the obligation to sort waste from the Village Government itself."*

Overall, these bottlenecks indicate imbalances in interdependencies among actors, including role shifts, high dependence on specific actors, and weak institutional support, which collectively disrupt the stability of value flows within the ecosystem.

Analysis of Waste Management Performance and Economic Impacts in Cepogo Village

The direct impact of ecosystem barriers in the waste management system was examined through an analysis of the volume and distribution of waste brought to the TPS 3R and the landfill. This data reflects the extent to which household waste undergoes sorting before disposal, as shown in Table 3. Waste generation measurements are essential for planning and improving waste management (Syafrudin et al., 2023). Based on March 2024 retribution records and interviews with field officers, waste transportation is still dominated by direct disposal to the landfill, with 29 truck trips recorded and a total disposal fee of IDR 3,339,900.

Table 3. Volume and Distribution

Destination	Number of Trips	Volume per Trips (kg)	Total Volume (kg)	Proportion (%)
TPS 3R	8	2,560	20,480	21,62%
Landfill	29	2,560	74,240	78,38%
Total	37	-	94,720	100%

This data reinforces previous findings in ecosystem analysis, which show that sorting behavior among the community is not yet fully established, especially for organic waste and residues. In addition, Operational limitations, such as a truck without compartments, result in most waste being mixed before reaching the TPS 3R, with a large portion directly disposed of at the landfill without prior sorting, which corresponds with Zulkifli et al. (2025), who state that barriers to sustainable environmental-based waste management are not only low public awareness but also infrastructure limitations and insufficient stakeholder involvement. These conditions increase the operational burden at TPS 3R, where approximately 20,480 kg of waste is processed monthly by only two active sorting workers. Although staffing levels meet the standard of 3–6 workers per 1,000,000 kg per year (APEC Ocean and Group Fisheries Working, 2023), sorting efficiency remains low in practice due to the mixed condition of incoming waste, which aligns with Royhan et al. (2023), who emphasize that the low technical capacity of TPS 3R managers is one of the main causes of the limited volume of waste that can be processed.

The low level of waste sorting also leads to economic losses, as recyclable and reusable materials are discarded without added value. According to the KKN report, household waste in Cepogo Village consists of 62.07% inorganic and 37.93% organic materials, indicating a high potential for material recovery if proper sorting is implemented. However, most waste is still collected in mixed conditions and transported directly to the landfill. From the total waste disposed of, it is estimated that around 10% of the inorganic fraction still has potential economic value. The estimated economic loss is calculated based on the purchase prices of local waste buyers, as presented in Table 4.

Table 4. Estimated Economic Loss from Unsorted Waste

Waste Type	Composition	Volume (kg)	Price/kg (IDR)	Potential Loss (IDR)
Plastic	29.07%	1,339.57	700	937,698
Paper	17.28%	796.28	1,000	796,276
Glass	2.67%	123.04	200	24,607
Textile	5.69%	262.20	500	131,100
Total Loss	-	-	-	1,889,680

The estimated loss of IDR 1,889,680 per month reflects the economic opportunities lost due to the suboptimal sorting system at the household and management facility levels. This economic loss estimate not only reflects the loss of potential income from valuable waste but also increases the overall burden on the system, particularly in terms of transportation and disposal costs.

Subsequently, a financial analysis was conducted to evaluate the capacity of Cepogo Village's waste management system to operate independently. Based on field data, the monthly operational cost of the BUMDes is estimated at IDR 13,713,900, covering personnel salaries, truck operations, landfill fees, electricity, and other miscellaneous expenses. Meanwhile, the monthly revenue of BUMDes is estimated at IDR 12,835,000, derived from member dues, sales of inorganic waste, and maggot sales. Compared with operational costs, the system still runs a deficit of IDR 878,900, indicating that the waste management system is not yet financially sustainable. This situation is in line with Lohri et al. (2014), who highlight that a key challenge in financing waste management systems in developing countries is the difficulty of achieving cost recovery.

Overall, this analysis indicates that waste management in Cepogo Village is still dominated by direct disposal to the landfill, reflecting the low level of waste sorting practices at the household level. This situation increases the operational burden on the TPS 3R and reduces sorting efficiency because the waste received is still mixed. Furthermore, much of the economic value of recyclable materials is lost, while the system continues to face a monthly financial deficit. These findings indicate that operational, economic, and financial constraints remain the primary challenges in establishing a sustainable waste management system in Cepogo Village.

Proposed Improvements to the Waste Management System

Based on the integration of behavioral analysis results, evaluation of operational processes, and the ecosystem perspective, this study proposes three main strategies to improve the waste management system in Cepogo Village: behavioral, institutional, and technical interventions. This multidimensional approach is consistent with the concept of integrated waste management, which emphasizes the interconnection between community behavior, institutional governance, and operational systems in achieving a sustainable waste management system. Using a Business Process Reengineering (BPR) framework, the interventions are designed to remove existing system barriers to enhance overall efficiency and sustainability. The BPR approach not only aims to improve efficiency but also encourages cultural change and strengthens process control at the local level (Wang et al., 2024).

Behavioral interventions focus on strengthening the role of households as the starting point of waste separation. Although the community already possesses relatively good environmental knowledge and awareness, waste sorting practices remain inconsistent due to various situational barriers. Therefore, this strategy emphasizes continuous education and socialization through community-based assistance, as well as the village government and

BUMDes can implement nudging strategies with light incentives or reminders to encourage voluntary sorting habits. Incentives such as reduced fees or the provision of special trash bins can help overcome situational barriers (Mont et al., 2014; Velde et al., 2021).

Institutional interventions aim to strengthen the governance of the waste management system through formal regulations requiring household-level waste separation, supported by a monitoring system and coordination among village actors such as the village government, BUMDes, PKK, and the inclusion of Karang Taruna. The involvement of Karang Taruna together with PKK and BUMDes expands the outreach of community assistance to youth and male groups who have previously been less involved in waste separation education and practices (Leknoi, Painmanakul, et al., 2024). To improve community compliance, a retribution-based mechanism is implemented, providing benefits for households that consistently separate their waste, in line with individuals' tendency to consider cost–benefit trade-offs in decision-making (Chawla et al., 2024).

Meanwhile, technical interventions aim to improve operational efficiency in the collection and processing stages. This includes the use of a dual-compartment collection truck to maintain waste separation during transportation, capacity building for waste workers through training and SOPs, and optimization of the TPS 3R. The dual-compartment truck model refers to practices implemented in Indore, which show that the use of trucks with two compartments to separate wet and dry waste improves operational efficiency and community compliance (Rasmeet, 2021).

At the To-Be condition based on BPR, the waste management system is redesigned by shifting the main sorting point from the TPS 3R to the household level. Unlike the As-Is condition, where sorting is still mostly done downstream and only by a small number of households, in this new system all households are required to sort their waste at the source into three categories: organic, valuable inorganic, and residual waste, as shown in Figure 2. Households carry out initial sorting, where recyclable waste is directed to the waste bank, while organic waste is treated at the household level through composting or eco-enzym production. Recyclable materials are sent to the waste bank, while organic waste is treated at the household level through simple methods such as composting or eco-enzymes. Organic waste and residual waste that cannot be processed at the source are then sent to the TPS 3R for further treatment. To maintain separation during collection, waste is transported using dual-compartment trucks. After that, the TPS 3R no longer acts as the main sorting point, but as a processing center where organic waste is turned into maggot feed or compost, and remaining recyclable materials are recovered before the final residue is sent to the landfill.

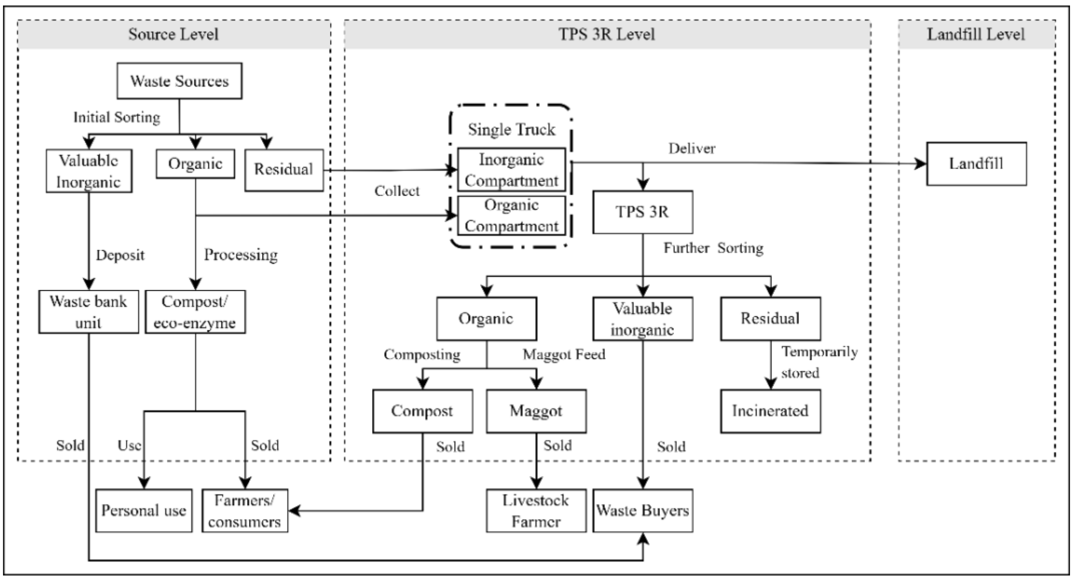

Figure 2. Proposed Waste Management Flow (To-Be)

Simulation of Improvement Scenarios

Simulations were conducted to examine how the proposed improvement strategies affect waste flow in Cepogo Village under three scenarios. On the As-Is condition, total waste generation is estimated at 98.97 tons per month, with 0.72 tons (2%) managed at household level, resulting in 94.72 tons entering the collection system as the baseline. All scenarios were based on the same integrated interventions (behavioral, institutional, and technical), with differences in the intensity of incentive reinforcement and behavioral nudging. The pessimistic scenario represents an initial implementation without economic incentives, where behavioral change remains limited, with 15% of organic waste processed at the source and 30% of inorganic waste directed to the waste bank. The moderate scenario reflects strengthened behavioral interventions through nudging and non-financial incentives, such as feedback mechanisms and supporting facilities, increasing participation to 20% and 40%. Meanwhile, the optimistic scenario represents full implementation with economic incentives based on waste service fees, where the system shifts from a household cluster scheme to an individual household scheme, enabling consistent waste-sorting households to receive fee reductions or exemptions. This leads to higher participation, reaching 30% for organic waste and 55% for inorganic waste.

Overall, increased household participation results in source-level waste reduction of 24% (pessimistic), 32% (moderate), and 46% (optimistic), which directly reduces the waste burden transported to the TPS 3R and the landfill. These parameters were defined as assumption-based scenario inputs based on the 30% national waste reduction target by 2025 stipulated in Presidential Regulation No. 97 of 2017 (Farahdiba et al., 2023), and by benchmarking with Balikpapan, where technical assistance, intensive socialization, and routine monitoring reduced waste generation by up to 30% in 2024, with a target of 50% by 2026 (Dani, 2025). The resulting changes in waste flow under each scenario are presented in Table 5.

Table 5. Waste Flow under Different Scenarios

Destination	As-Is	Pessimistic	Moderate	Optimistic
Waste reduced at source (ton/month)	4.25	24.06	32.08	45.05
Waste collected (ton/month)	94.72	74.91	66.89	53.92
Sent to TPS 3R (ton/month)	20.48	20.99	21.68	24.26
Sent to landfill (ton/month)	74.24	48.97	40.26	29.66

Based on the simulation results, increased household participation in waste sorting influences the distribution of waste flows within the system. The volume of waste processed at the TPS 3R facility increases from 426.63 kg/day under the As-Is condition to 468.17 kg/day in the pessimistic scenario, 487.72 kg/day in the moderate scenario, and 505.49 kg/day in the optimistic scenario, while the volume of waste sent to the landfill decreases. Although the amount of waste entering the TPS 3R increases, a larger share of the waste has already been separated at the source, which reduces the need for manual sorting. In addition, the availability of sorting and shredding machines supports more efficient processing operations at the facility.

Analysis of these changes in waste flow also has implications for the economic performance of the waste management system. Increased waste reduction at the source, together with higher material recovery through waste banks and processing at the TPS 3R, can enhance economic value while reducing landfill disposal costs. A financial analysis was therefore conducted based on the simulation results under different implementation scenarios, taking into account revenues from material recovery and operational costs of the system. The results, including estimated investment feasibility and payback period, are presented in Table 6.

Table 6. Financial Simulation Results under Different Scenarios

Indicator	As-Is	Pessimistic	Moderate	Optimistic
Recyclable Potential Loss (IDR)	1,889,680	1,246,493	1,024,772	754,843
Household recyclable revenue (IDR)	3,527,562	19,554,614	26,072,819	36,037,816
Monthly Revenue (IDR)	12,835,000	14,274,343	14,512,926	14,932,025
Monthly Costs (IDR)	13,713,900	12,535,828	11,737,269	10,641,824
Surplus / Deficit (IDR)	−878,900	1,738,515	2,775,657	4,290,201
Initial Investment (IDR)	–	35,400,000	35,400,000	35,400,000
Payback Period (years)	–	1.7	1.1	0.7

Table 6 presents the financial performance of the waste management system under various implementation scenarios. Under the As-Is conditions, the system still faces a deficit of Rp878,900 per month due to low recovery rates of valuable materials, high transportation costs, and the predominance of waste sent to the landfill. With the implementation of integrated interventions, financial performance improves in line with increasing household participation in source separation. This not only enhances household income through the sale of recyclable materials and compost but also generates economic incentives at the community level.

On the other hand, the BUMDes experienced increased revenue and reduced operational costs due to the decreased volume of waste sent to the landfill and improved processing efficiency at the TPS 3R. Consequently, the system shifted from a deficit to a surplus across all scenarios, with the highest achievement of Rp4,290,201 per month in the optimistic scenario. An initial investment of IDR 35,400,000 yields a relatively fast payback period of 1.7 years (pessimistic), 1.1 years (moderate), and 0.7 years (optimistic), indicating the economic feasibility of the proposed intervention.

Overall, the results show that source separation can improve the operational and economic performance of the waste management system. This improvement depends not only on households' ability to separate waste, but also on how this behavior is supported by collection and processing procedures, institutional regulations, and coordination among actors within the ecosystem. This indicates that household behavioral change needs to be incorporated into the system design rather than treated as a separate effort.

The novelty of this study lies in the integration of community-based behavioral interventions into Business Process Reengineering (BPR) to redesign the rural waste management ecosystem. Through this approach, behavioral change at the household level is directly linked to process, institutional, and technical changes, so that waste separation no longer depends primarily on sorting at the TPS 3R but starts at the source and is supported by actors throughout the system. Thus, this study extends the application of BPR in waste management by incorporating behavioral aspects into the redesign of processes and the waste management ecosystem to support more sustainable rural waste management.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

This study concludes that the waste management system in Cepogo Village is currently constrained by low household participation in source separation, resulting in inefficient material flow, high dependence on landfill disposal, and financial deficits. By integrating ecosystem analysis, behavioral insights, and Business Process Reengineering (BPR), the proposed improvement scenarios demonstrate that increasing household waste sorting participation can substantially enhance system performance. Improved source separation contributes to reducing landfill dependency, optimizing recyclable material recovery, and improving financial sustainability. The simulation results further indicate that the redesigned waste management system has the potential to generate financial surpluses under all proposed improvement scenarios, with relatively short payback periods. These findings highlight that waste management can be transformed from an environmental challenge into a source of economic value through an integrated and participatory approach.

Limitations

This study has several limitations. First, the proposed improvement scenarios were evaluated using simulation models; therefore, the results represent potential future outcomes rather than guaranteed real-world performance. The actual effectiveness of the proposed system may be influenced by external factors, such as community behavior, institutional commitment, operational capacity, and resource availability. Second, the behavioral analysis was conducted within the context of Cepogo Village, meaning that the findings may require adaptation before being applied to other rural areas with different social, economic, and institutional characteristics. Third, the financial evaluation depends on assumptions regarding waste generation, participation rates, operational costs, and revenue from recyclable materials, which may change during practical implementation.

Recommendations

Based on the findings, several recommendations are proposed to support the implementation of a more sustainable village waste management system. First, local authorities and waste management institutions should strengthen incentive-based waste sorting programs to increase household participation and encourage behavioral change at the source. Second, coordination among village government, waste management organizations, households, and recycling stakeholders should be improved to ensure effective system integration. Third, operational infrastructure, particularly waste collection systems and TPS 3R facilities, should be upgraded to support efficient material recovery and processing activities. Future studies are recommended to conduct empirical validation through pilot implementation, monitor long-term system performance, and refine the simulation model based on actual operational data and community responses.

Author Contributions

All authors contributed to this study. The first author was responsible for data collection, data analysis, and manuscript preparation. The second author contributed to the research conceptualization, project initiation, supervision, and manuscript revision. The third author contributed to supervision and critical review of the manuscript. All authors have read and approved the final version of the manuscript.

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