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Sustainable development model of community-based Reduce, Reuse, and Recycle (3R) waste management facilities for urban waste management

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ABSTRACT

Background: Urban waste management has become a strategic challenge in Indonesia due to increasing waste generation and limited final processing capacity. In Bogor City, 32 Community-Based Reduce, Reuse, and Recycle Waste Processing Facilities (TPS 3R) are only capable of processing approximately 22.5 tons of waste per day, equivalent to about 3% of the city's total waste generation, highlighting a gap between policy targets and local implementation. This study aims to identify variations in TPS 3R performance, analyze factors influencing the sustainability of community-based waste management, and formulate a more integrated and sustainable development model for TPS 3R in the City of Bogor. **Methods:** The study employs a mixed-methods approach with a comparative case study design across 15 TPS 3R units selected through purposive sampling. Data were collected through field observations, in-depth interviews, and analysis of operational documents and policies. Analysis was conducted using a weighted scoring system and thematic analysis, then integrated through a convergent mixed-methods approach. **Findings:** The results indicate variations in performance among 15 TPS 3R units. Units in the high-performance category demonstrated better operational capacity, community participation, and financial sustainability compared to those in the low-performance category. In general, the contribution of TPS 3R to urban waste reduction remains limited, and most units are still in the early stages of resource recovery. Key factors influencing sustainability include institutional capacity, community participation, governance, and circular economy mechanisms. **Conclusion:** The sustainability of TPS 3R is determined not only by technical waste processing capacity but also by the interaction between social, institutional, and economic factors. The development of TPS 3R needs to be directed toward strengthening community governance, community participation, and circular economy models based on material recovery. **Novelty/Originality of this article:** This study offers an integrative approach to the analysis of TPS 3R by combining technical, social, institutional, and circular economic dimensions within a single comparative analytical framework based on empirical learning from 15 TPS 3R units in the City of Bogor.

KEYWORDS: circular economy; community-based waste management; TPS 3R; urban waste management; waste reduction.

1. Introduction

Urban waste management has become one of the major challenges of sustainable urban development due to increasing waste generation, rapid urbanization, changing consumption patterns, and the growing pressure on waste treatment and final disposal systems. Global waste generation is expected to continue increasing as urban populations and consumption levels expand, particularly in rapidly developing urban areas where waste management infrastructure often fails to keep pace with the increasing volume and

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complexity of municipal solid waste (Hoornweg & Bhada-Tata, 2012; Kaza et al., 2018). The environmental consequences of inadequate waste management include land and water pollution, greenhouse gas emissions, public health risks, and the continued dependence on uncontrolled disposal practices (Vergara & Tchobanoglous, 2012; Wilson et al., 2015)

These challenges are particularly significant in developing countries, where municipal solid waste management systems frequently face institutional, technical, operational, and financial constraints. Limited collection coverage, inadequate treatment capacity, insufficient financing, weak institutional coordination, and the lack of reliable waste data continue to affect the effectiveness and sustainability of waste management services (Ferronato & Torretta, 2019; Guerrero et al., 2013). Therefore, waste management cannot be addressed solely through the provision of technical infrastructure. Sustainable waste management requires an integrated systems-based approach that considers the interactions among technical capacity, institutional arrangements, stakeholder participation, governance mechanisms, and financial sustainability (Marshall & Farahbakhsh, 2013; Tchobanoglous et al., 1993).

In response to these challenges, the waste management paradigm has gradually shifted from conventional collection-and-disposal systems toward approaches emphasizing waste prevention, reduction, reuse, recycling, and resource recovery. The application of the 3R principles—reduce, reuse, and recycle—has become an important foundation for integrated and sustainable waste management, particularly in urban areas seeking to reduce dependence on final disposal facilities and improve resource efficiency (Memon, 2010; Wilson et al., 2015). This transition is also closely associated with zero-waste and resource-efficient urban development, which emphasizes reducing waste generation at the source and maximizing material recovery throughout the waste management system (Zaman & Lehmann, 2011). Accordingly, decentralized and community-based waste management facilities have increasingly been recognized as an important component of urban waste management systems because they can support waste reduction at the local level while promoting community participation and material recovery.

In Indonesia, these broader urban waste management challenges are reflected in the continued reliance on collection-and-disposal systems and the limited capacity of waste treatment and resource recovery facilities in many cities. Rapid urban development, population growth, and changing consumption patterns have contributed to increasing municipal solid waste generation, while the capacity of existing waste management infrastructure and final disposal facilities remains uneven across regions. Indonesia has established a national policy framework that promotes waste reduction and environmentally sound waste handling through the principles of reduce, reuse, and recycle, while encouraging greater responsibility among governments, communities, and other stakeholders. However, the implementation of these policies at the local level continues to face challenges related to institutional capacity, financial sustainability, community participation, source separation, and coordination among actors within the waste management system. As a result, strengthening decentralized and community-based waste management has become increasingly important to support waste reduction at the source, reduce the volume of waste transported to final disposal facilities, and improve local resource recovery.

Within Indonesia's waste management framework, TPS 3R has been developed as a decentralized and community-based approach to support waste reduction, sorting, processing, and resource recovery closer to the source of waste generation. Rather than relying exclusively on centralized collection and final disposal systems, TPS 3R facilities are intended to promote the application of the reduce, reuse, and recycle principles at the community level by integrating waste segregation, recyclable material recovery, organic waste processing, and the management of residual waste. This decentralized approach has the potential to reduce the volume of waste transported to final disposal facilities while encouraging greater community participation and local responsibility for waste management. Community-based waste management systems are particularly relevant in urban areas because their effectiveness depends not only on the availability of processing infrastructure, but also on the capacity of local institutions, the continuity of community participation, and effective coordination among stakeholders (Guerrero et al., 2013; Marshall & Farahbakhsh, 2013). In addition, TPS 3R facilities can serve as local resource recovery hubs by connecting household waste reduction with recyclable material recovery and community-based circular economy activities, including linkages with formal and informal recycling networks (Velis et al., 2006). Therefore, the sustainability of TPS 3R should be understood not merely in terms of its technical waste processing capacity, but as the outcome of interactions among operational, institutional, social, and economic dimensions.

Despite their potential, community-based waste management systems do not automatically achieve long-term sustainability simply through the provision of waste processing facilities. Previous studies have shown that the performance and continuity of community-based waste management depend on the capacity of local institutions, community ownership, organizational effectiveness, stakeholder coordination, and the availability of sustainable financial mechanisms (Marshall & Farahbakhsh, 2013; Zurbrügg et al., 2012). The management of shared community-based facilities also requires effective local governance and collective action to establish clear responsibilities, maintain operational continuity, and encourage sustained participation among community members (Ostrom, 1990). In developing countries, these challenges are often compounded by limited institutional capacity, inadequate operational systems, financial constraints, and unstable markets for recyclable materials and recovered resources (Ferronato & Torretta, 2019). Therefore, the sustainability of community-based waste management should be understood as a multidimensional process shaped by the interaction between technical capacity and broader social, institutional, and economic conditions. This perspective suggests that evaluating TPS 3R performance requires an analytical approach that goes beyond waste processing capacity to consider institutional governance, community participation, financial sustainability, and resource recovery mechanisms.

From a circular economy perspective, sustainable waste management requires a transition from conventional linear waste systems toward systems that prioritize waste prevention, reuse, recycling, and resource recovery (Geissdoerfer et al., 2017; Ghisellini et al., 2016; Kirchherr et al., 2017). Within this framework, waste management facilities are expected not only to reduce the volume of waste but also to retain material value and support the reintegration of recovered resources into economic systems. However, circular economy implementation remains constrained by technological, institutional, and market limitations, particularly in developing-country contexts (Korhonen et al., 2018). In this regard, TPS 3R can potentially function as decentralized resource recovery hubs connecting household waste segregation, material recovery, organic waste processing, and local value creation. Their sustainability therefore depends not only on waste reduction performance but also on their ability to support resource recovery, market linkages, and economically viable circular mechanisms (Schroeder et al., 2019).

These broader challenges are also evident in Bogor City, where decentralized waste management through TPS 3R has been developed to support waste reduction and community-based resource recovery at the local level. However, the contribution of these facilities to the overall municipal waste management system remains limited. Based on the available operational data, the 32 TPS 3R units in Bogor City collectively process approximately 22.5 tons of waste per day, representing only around 3% of the city's total waste generation. This condition indicates a substantial gap between the strategic objectives of TPS 3R development and its actual implementation and contribution to urban waste reduction. Furthermore, differences in operational conditions among TPS 3R units suggest that the performance of these facilities is not uniform. While some facilities demonstrate relatively strong operational capacity, institutional management, and financial sustainability, others continue to experience challenges related to inactive management structures, limited human resources, inadequate waste sorting and processing, unstable financing, and low levels of community participation. These variations highlight the need to examine TPS 3R performance from a more comprehensive perspective in order to identify the factors that influence their long-term sustainability and effectiveness within the urban waste management system (Nofita et al., 2024; World Wide Fund for Nature Indonesia (WWF-Indonesia), 2023a, 2023b, 2024, 2025).

Previous studies have examined community-based waste management from various perspectives, including technical performance, institutional capacity, community participation, governance, and waste reduction. Research on waste management systems in developing countries has demonstrated that operational effectiveness is influenced not only by the availability of infrastructure and technical capacity, but also by institutional arrangements, stakeholder coordination, policy support, and community involvement (Dhokhikah et al., 2015; Guerrero et al., 2013; Marshall & Farahbakhsh, 2013). Studies on community-based waste management have further emphasized the importance of local ownership, organizational capacity, and sustained community participation in maintaining the continuity of decentralized waste management programs (Zurbrügg et al., 2012). From a broader resource management perspective, effective collective action and local institutional arrangements are also essential for managing shared community-based facilities and maintaining long-term operational sustainability (Ostrom, 1990).

However, previous research has often examined these dimensions separately or focused primarily on specific aspects, such as operational performance, waste reduction efficiency, technical infrastructure, or community participation. As a result, there remains a need for a more integrative understanding of how technical, institutional, social, and economic factors interact and jointly influence the sustainability of decentralized community-based waste management facilities. This gap is particularly relevant to TPS 3R in Indonesia, where differences in local operational conditions and institutional capacity may result in substantial variations in performance among facilities. Moreover, the integration of resource recovery and circular economy mechanisms into the assessment of community-based TPS 3R sustainability remains insufficiently explored (Zakianis et al., 2019). Therefore, a comparative and multidimensional assessment is needed to better understand the factors associated with performance variation and to identify pathways for developing more sustainable TPS 3R systems.

This study addresses the identified research gap by adopting an integrative and comparative approach to the assessment of community-based TPS 3R systems in Bogor City. Unlike previous studies that have primarily examined individual aspects of waste management performance, such as technical operations, waste reduction, institutional capacity, or community participation, this study evaluates the interactions among multiple dimensions within a single analytical framework. The assessment integrates technical and operational performance, institutional governance, financial sustainability, and community participation, while further interpreting the results through the perspective of resource recovery and circular economy. Empirically, the study compares 15 purposively selected TPS 3R units representing different performance conditions and operational characteristics. This comparative approach makes it possible to identify performance variations, examine the factors associated with higher and lower levels of sustainability, and generate empirical lessons from different community-based waste management practices. The originality of this study therefore lies in its multidimensional and comparative analytical framework, which positions TPS 3R not merely as decentralized waste processing facilities, but as community-based socio-technical systems shaped by the interaction of technical, institutional, social, and economic factors. Based on these findings, the study further proposes an integrated development model to support the long-term sustainability and effectiveness of community-based TPS 3R systems in urban areas.

Accordingly, this study aims to identify performance variations among selected community-based TPS 3R facilities in Bogor City, analyze the technical, institutional, financial, and social factors influencing their long-term sustainability, and formulate an integrated development model for more effective and sustainable community-based urban waste management. Using a comparative case study approach, the study examines 15 purposively selected TPS 3R units representing different operational and performance conditions. The findings are expected to contribute empirical evidence on the multidimensional factors influencing TPS 3R sustainability and provide practical insights for strengthening decentralized waste management, resource recovery, and circular economy development in urban areas. The remainder of this paper is organized as follows. Following this Introduction, the Methods section describes the research design, case selection, data collection, assessment criteria, and analytical procedures. The Results and Discussion section presents the comparative performance assessment of the selected TPS 3R facilities, examines the factors associated with their performance variations, and discusses the findings in relation to previous studies and the proposed integrated development model. Finally, the Conclusion summarizes the principal findings, contributions, limitations, and directions for future research, followed by the References.

2. Methods

This study employs a mixed-methods approach with a comparative case study design to analyze variations in the performance and management models of TPS 3R in the city of Bogor. This approach was chosen because urban waste management is a complex phenomenon influenced by the interaction between technical, social, institutional, and economic aspects, thus requiring the integration of quantitative and qualitative analysis to gain a more comprehensive understanding (Creswell & Creswell, 2017; Guerrero et al., 2013). A quantitative approach was used to evaluate the operational performance of TPS 3R based on several key indicators, namely processing capacity, waste reduction rates, community participation, institutional conditions, and financial sustainability. The analysis was conducted using descriptive and comparative statistics to identify variations in performance among TPS 3R units. The evaluation results were then used to classify the sustainability levels of TPS 3R into high, medium, and low categories based on a weighted scoring system that integrates technical, institutional, financial, regulatory, and community participation aspects.

Meanwhile, a qualitative approach was used to understand the factors influencing performance differences among TPS 3R units. The analysis examined institutional capacity, patterns of community participation, coordination mechanisms among stakeholders, policy support, and circular economy practices in TPS 3R. This approach allows the research not only to describe performance variations descriptively but also to identify the factors causing the success or operational stagnation of TPS 3R (Marshall & Farahbakhsh, 2013). Using a comparative case study design, this research focuses on 15 TPS 3R units selected through purposive sampling from a total of 32 such facilities in the city of Bogor. Case selection was based on variations in operational capacity, sustainability levels, institutional models, and financing conditions, thereby ensuring representation of the heterogeneity in TPS 3R across urban areas (Yin, 2018).

This study employs a convergent parallel mixed-methods design, in which quantitative and qualitative data are collected in parallel during the same research period (Creswell & Plano Clark, 2018). The quantitative approach was prioritized to map variations in performance and sustainability levels of TPS 3R units, while the qualitative approach was used to explain the factors influencing these performance differences. Data integration is conducted during the interpretation stage through convergent integration and triangulation of results, so that quantitative findings regarding performance patterns can be enriched with contextual explanations related to institutional dynamics, community participation, and circular economy mechanisms.

To enhance the validity and reliability of the study, source and method triangulation was employed through field observations, in-depth interviews, and analysis of operational documents from the TPS 3R and data from the Bogor City Environmental Agency (Creswell & Plano Clark, 2018). Data collection in this study utilized a combination of primary and secondary data to obtain a comprehensive picture of the variations in performance and sustainability of TPS 3R in the City of Bogor. This approach was used to capture quantitative aspects related to waste management operations while also understanding the social, institutional, and economic dynamics that influence the sustainability of urban waste management systems (Creswell & Plano Clark, 2018).

Primary data were collected through field observations and in-depth interviews at 15 TPS 3R units selected through purposive sampling from a total of 32 such facilities in the city of Bogor. The facilities were selected based on variations in processing capacity, levels of community participation, institutional models, and operational and financial sustainability. A purposive sampling approach was used to represent the heterogeneity of TPS 3R conditions and support comparative analysis across cases (Yin, 2018). Field observations were conducted to identify the operational conditions of the TPS 3R, including the sorting process, the treatment of organic and inorganic waste, the condition of facilities and infrastructure, as well as material recovery and circular economy activities. In-depth interviews were conducted with 20 key informants, consisting of 15 TPS 3R managers, 3 representatives from the Bogor City Environmental Agency, and 2 field assistants. The informants were selected to capture a variety of institutional, operational, and community participation perspectives in TPS 3R. This approach was used to gain an understanding of institutional capacity, patterns of community participation, policy support, and operational challenges of TPS 3R (Marshall & Farahbakhsh, 2013).

Secondary data was obtained from the TPS 3R's operational reports, documents from the Bogor City Environmental Agency, the TPS 3R's assessment reports, and policy documents related to urban waste management. This data was used to verify the results of observations and interviews, particularly regarding indicators of processing capacity, waste reduction rates, and the sustainability of funding. To enhance the validity and reliability of the study, source and method triangulation was employed through a combination of observation, interviews, and document analysis. Triangulation was conducted by comparing information across informants and data sources, ensuring that the research findings did not rely on a single source of information (Patton, 1999). This study has limitations because some of the operational data for the TPS 3R still relies on internal records kept by managers, which vary in quality across units. This situation has the potential to introduce reporting bias, particularly regarding data on processing volume, waste reduction rates, and operational revenue; therefore, the results were interpreted with caution through a process of triangulation and field verification.

Data analysis in this study was conducted by integrating quantitative and qualitative approaches to understand performance variations and the factors influencing the sustainability of TPS 3R in Bogor City. This approach was chosen because TPS 3R is a multidimensional phenomenon influenced by the interaction of technical, social, institutional, and economic aspects (Creswell & Plano Clark, 2018; Guerrero et al., 2013). A quantitative analysis was conducted on 15 selected TPS 3R units using descriptive and comparative statistics based on a weighted scoring system. The assessment aimed to identify performance variations among units based on five key aspects: operational technical, institutional, financial, regulatory, and community participation. Each indicator was scored on a scale of 1–3, then multiplied by a weight to produce a total TPS 3R sustainability score. The assessment results were then categorized into high, medium, and low sustainability levels.

This assessment system was developed based on an adaptation of the TPS 3R evaluation criteria and tailored to the context of urban waste management in the City of Bogor (Zakianis et al., 2019). A weighted approach was used to provide a comparative overview of the levels of operational and institutional sustainability among TPS 3R. Meanwhile, qualitative analysis was conducted using thematic analysis of data from interviews, observations, and documents. The analysis stages included data reduction, coding, theme categorization, and interpretation to identify factors influencing variations in TPS 3R performance, such as community participation patterns, institutional capacity, coordination mechanisms, and financial support (Braun & Clarke, 2006).

Each assessment aspect consisted of several indicators adapted from the TPS 3R evaluation framework and contextualized to the operational conditions of Bogor City. Each indicator was assigned a performance score based on field observations, interviews, operational records, and assessment documents. The indicator scores were subsequently aggregated within each assessment aspect and multiplied by the corresponding aspect weight to generate a composite performance score for each TPS 3R unit.

Table 1. Summary of TPS 3R assessment indicators

Assessment aspects	Key indicators	Weight
Technical Operations	Processing capacity, waste reduction, compost production	30%
Institutional	Legality, organizational structure, management capacity	30%
Finance	Community contributions, financial condition, operational assistance	20%
Community Participation	Waste sorting, customer development	15%
Regulations	Policy support and development plans	5 %

The composite scores were then used to compare the relative performance of the selected TPS 3R units and to classify them into high-, medium-, and low-performance categories. The quantitative assessment was not intended to provide a universal sustainability index but rather to provide a structured comparative basis for identifying performance variations across the selected cases. The resulting performance categories were subsequently interpreted together with qualitative findings from field observations, interviews, and document analysis.

The validity of the analysis was strengthened through triangulation of sources and methods by comparing the results of observations, interviews, and operational documents from the TPS 3R. Quantitative and qualitative data were integrated during the interpretation phase using a convergent mixed-methods approach, so that the research results not only revealed performance patterns across units but also explained the factors causing these differences (Creswell & Creswell, 2017). This method was deemed appropriate for the research objectives as it allows for a more comprehensive and contextual analysis in formulating a more adaptive and sustainable community-based TPS 3R development model.

3. Results and Discussion

3.1 Overview of TPS 3R performance in Bogor City

Preliminary research results indicate that the management of TPS 3R in Bogor City exhibits significant performance variations across units, particularly regarding processing capacity, waste reduction rates, community participation, institutional framework, and financial sustainability. Based on data from the Bogor City Environmental Agency and the Bogor City TPS 3R Study (WWF-Indonesia, 2025), there are 32 operational TPS 3R; however, this study focuses its analysis on 15 selected units that represent variations in community-based waste management conditions. Quantitatively, waste generation in Bogor City reaches approximately 775 tons/day, while the total processing capacity of all TPS 3R is only about 22.5 tons/day—or roughly 3% of the city's total waste generation (WWF-Indonesia, 2023a, 2023b, 2024, 2025). The average processing capacity of 32 TPS 3R units is around 0.7 tons/day per unit, indicating that most facilities are not yet operating optimally compared to their designed service capacity. This situation suggests that the contribution of TPS 3R units to the city's waste reduction system remains limited and has not yet been able to serve as the primary instrument for the decentralization of urban waste management.

Based on the weighted assessment results, units in the high-performance category—such as Ceremai, Cipaku, Mutiara Bogor Raya, Katulampa, and Mekar Mandiri—have sustainability scores above 80, with capacity utilization rates exceeding 60%, relatively consistent sorting systems, and more stable institutional and financial support. These units generally have more than one source of income, such as community fees, compost sales, and proceeds from the sale of recycled materials. In addition, there is higher community participation in household waste sorting and payment of service fees. In contrast, TPS 3R with low performance ratings—such as Kayumanis III, Citra Mandiri Kertamaya, and Sentral Kompos Cipaku—exhibit capacity utilization rates below 30%, limited operational staff, and low community participation in waste sorting. Some facilities also remain dependent on external assistance and lack a stable operational funding system. These conditions result in high volumes of residual waste still being transported to landfills and low effectiveness of waste reduction at the local level.

Table 2. Summary of performance categories for selected TPS 3R

Category	Representative TPS 3R units	Key characteristics
High	Ceremai, MBR Katulampa, Mekar Mandiri	Strong operational capacity, relatively high community participation, active institutional management, and diversified income sources
Medium	Griya Melati Bubulak, GWK Bubulak	Operationally active but with inconsistent institutional capacity, financial stability, or community participation
Low	Kayumanis III, Kertamaya	Limited operational capacity, weak institutional continuity, unstable financing, and low community participation

(WWF-Indonesia, 2025)

To further explain the differences among TPS 3R performance categories, Table 3 summarizes the key characteristics observed across institutional, technical, financial, and community participation aspects. The comparison highlights the multidimensional factors influencing TPS 3R sustainability in Bogor City. The comparative assessment indicates that performance differences among TPS 3R units cannot be explained by technical capacity alone. Instead, sustainability emerges from the interaction among institutional capacity, financial viability, community participation, and operational effectiveness.

Table 3. Comparative assessment of factors influencing TPS 3R performance and sustainability

Assessment aspect	High-performing TPS 3R (Ceremai, MBR Katulampa, Mekar Mandiri)	Medium-performing TPS 3R (Griya Melati, GWK Bubulak)	Low-performing TPS 3R (Kayumanis III, Kertamaya)
Institutional Capacity	Active *Kelompok Swadaya Masyarakat* (KSM) leadership, regular coordination, strong organizational structure	Management functions remain operational but institutional capacity is inconsistent	Weak leadership, limited organizational support, low institutional continuity
Technical Operations	Consistent waste sorting, active composting and recycling, higher processing capacity	Operational activities continue but processing efficiency remains moderate	Limited sorting activities, low processing capacity, equipment and maintenance constraints
Financial Sustainability	Multiple revenue sources from service fees, recyclables, and compost sales	Operational costs generally covered but limited reserves for maintenance	High dependence on external support and unstable operational funding
Community Participation	Relatively high participation in waste services and fee payments	Moderate participation with fluctuating engagement levels	Low participation in waste sorting and limited community involvement
Overall Sustainability	High operational continuity and stronger resource recovery performance	Operationally functional but not yet fully sustainable	Operational stagnation and weak long-term sustainability

(WWF-Indonesia, 2025)

Preliminary findings also indicate that the success of TPS 3R is influenced not only by the availability of infrastructure, but also by the integration of technical, institutional, social, and economic aspects. TPS 3R with active institutional structures, good coordination with local governments, and relatively consistent circular economy mechanisms tend to perform better than units that focus solely on reducing waste volume. This indicates that most TPS 3R in Bogor City still focus on waste reduction and simple sorting, and thus have not yet fully established a closed-loop material recovery-based waste management system. This situation indicates that TPS 3R are still in the early stages of the circular economy and tend to function solely as collection and waste reduction facilities (Ferronato & Torretta, 2019; Schroeder et al., 2019). Thus, the preliminary findings of the study indicate that the development of TPS 3R requires a socio-technical approach that integrates operational capacity, community participation, local institutions, and economic sustainability as a unified whole within an urban waste management model.

3.2 Analysis of results based on criteria or variables

The analysis results show clear performance differences among TPS 3R in Bogor City based on technical operational, institutional, financial, community participation, and regulatory support aspects. These differences not only reflect variations in waste processing capacity but also demonstrate how interactions among variables influence the sustainability of community-based waste management systems. Based on the results of the operational technical assessment, high-category TPS 3R such as Ceremai, Cipaku, and Mekar Mandiri TPS 3R units are capable of processing more than 60% of their planned service capacity with lower residual levels compared to other units.

a

b

c

Fig. 1. Material sorting and resource recovery activities at high-performing TPS 3R units in Bogor City (a) TPS 3R Ceremai; (b) TPS 3R Mutiara Bogor Raya Katulampa; (c) TPS 3R Mekar Mandiri

These conditions are supported by a relatively consistent sorting system, the availability of operational facilities, and more active composting and recycling activities. Conversely, TPS 3R units such as Kayumanis III and Citra Mandiri Kertamaya exhibit low capacity utilization due to limited operational staff, low supply of sorted waste, and insufficient equipment maintenance (WWF-Indonesia, 2024, 2025). Field observations revealed that high-performing TPS 3R units generally maintain active waste sorting and material recovery operations supported by dedicated personnel, relatively organized working areas, and continuous recyclable material processing activities. Figure 1 illustrates the operational conditions observed at TPS 3R Ceremai, TPS 3R Mutiara Bogor Raya Katulampa, and TPS 3R Mekar Mandiri, which represent high-performing TPS 3R units in Bogor City.

The observations indicate that these facilities have established relatively consistent waste segregation and recyclable material recovery practices. Although the scale of operation remains limited, the facilities demonstrate stronger operational management and higher levels of resource recovery compared with lower-performing TPS 3R units. These observations support the quantitative assessment showing that institutional capacity, operational continuity, and community participation are closely associated with TPS 3R sustainability. In contrast, field observations at lower-performing TPS 3R units revealed significant limitations in waste handling and resource recovery practices. At TPS 3R Citra Mandiri Kertamaya, residual waste accumulation was observed around the facility, indicating challenges in waste transportation and residual waste management. Meanwhile, TPS 3R Kayumanis III demonstrated limited sorting efficiency and inadequate operational organization, resulting in lower material recovery performance.

a

b

Fig. 2. Operational challenges observed at low-performing TPS 3R units in Bogor City (a) TPS 3R Citra Mandiri Kertamaya; (b) TPS 3R Kayumanis III

The contrast between Figures 1 and 2 demonstrates that TPS 3R performance cannot be explained solely by the availability of infrastructure or technical capacity. Instead, operational sustainability is shaped by the interaction among institutional governance, operational management, financial sustainability, and community participation. High-performing TPS 3R units were characterized by stronger organizational capacity, more stable financing mechanisms, and more consistent operational management, whereas low-performing units experienced multiple constraints across these dimensions. These findings indicate that technical capacity is closely linked to the social and institutional systems that support service continuity and stakeholder coordination in community-based waste management (Guerrero et al., 2013; Marshall & Farahbakhsh, 2013).

From an institutional perspective, units with better performance generally have active organizational structures, clear division of tasks, and relatively well-organized operational administration. At the TPS 3R in Mutiara Bogor Raya, Katulampa, and Kembang Setaman / BCC, managers routinely conduct internal coordination and receive support and guidance from both local governments and the surrounding communities. Conversely, at some low-performing TPS 3R units, there is a lack of management succession, limited managerial capacity, and minimal institutional support. These conditions indicate that the sustainability of TPS 3R units is heavily influenced by local institutional capacity, as explained in the theory of community governance and collective action (Ostrom, 1990).

Financial aspects also show a fairly consistent pattern regarding operational sustainability. High-category TPS 3R generally have more than one source of revenue, such as community fees, compost sales, and sales of recycled materials. This practice demonstrates the initial implementation of circular economy mechanisms through resource recovery processes and the creation of economic value from waste (Schroeder et al., 2019). Conversely, units with high dependence on external assistance tend to experience stagnation when operational support is reduced. This indicates that financial sustainability is a critical factor in maintaining the continuity of TPS 3R services. A similar relationship is also evident in community participation rates. TPS 3R with higher rates of household waste sorting tend to have better-quality recyclable materials and lower volumes of residual waste. At medium-category TPS 3R such as Griya Melati Bubulak and TPS 3R Asri Bubulak, operations are still active but not yet fully stable because community participation and consistency in fee payments remain fluctuating. These findings align with studies indicating that the success of waste management in developing countries is influenced by the level of community engagement and collective norms regarding environmental management (Guerrero et al., 2013).

Regulatory support and local policies also influence the sustainability of TPS 3R, although their implementation has not been uniform. Some waste collection points receive operational support and guidance from local governments, but not all units have institutional strengthening and sustainable incentive systems in place. This situation indicates that the implementation of 3R-based waste management policies still faces a gap between national regulatory design and implementation capacity at the local level. Overall, the analysis indicates that no single variable determines the success of TPS 3R. Operational sustainability is more strongly influenced by the integration of technical capacity, institutional strength, community participation, and economic sustainability within an interconnected socio-technical system. These findings reinforce the need to develop a TPS 3R model that is not only infrastructure-oriented but also focuses on strengthening community governance and circular economy mechanisms.

3.3 Comparison with previous studies

The results of this study indicate that the sustainability of TPS 3R units in Bogor City is influenced by the integration of technical capacity, institutional capacity, community participation, and economic sustainability. These findings are consistent with various studies on community-based waste management in developing countries, which emphasize that the success of waste management systems is determined not only by infrastructure (hardware) but also by institutional capacity, policy support, and community involvement in day-to-day waste management (software) that support the system's operations (Dhokhikah et al., 2015; Guerrero et al., 2013; Marshall & Farahbakhsh, 2013). Research indicates that waste management in developing countries is significantly influenced by institutional capacity, community engagement, and local policy support (Guerrero et al., 2013). Findings from a study in the city of Bogor reinforce this argument, particularly at high-category TPS 3R such as Ceremai, Cipaku, Mutiara Bogor Raya, and Katulampa, which demonstrate a combination of active institutional frameworks, relatively stable community participation, and more diverse financing systems. Conversely, units with relatively adequate technical capacity but weak institutions tend to experience operational stagnation.

These findings are also consistent with a study in Indonesia that found that the sustainability of community-based waste management is strongly influenced by community ownership, local organizational capacity, and the continuity of institutional support (Zurbrügg et al., 2012). However, this research expands on previous studies by demonstrating that the relationships between variables are more dynamic and mutually influential. In several cases in the city of Bogor, increased technical capacity does not automatically lead to improved performance if it is not accompanied by strengthened community participation and sustainable financing.

From a circular economy perspective, the results of this study show that some TPS 3R in Bogor City are still operating at the initial stage of resource recovery—limited to sorting and waste reduction—and are still dominated by downcycling practices with relatively low economic value. This situation is consistent with a 2019 study stating that waste management in developing countries still faces limitations in the recycling market, operational capacity, and financial support (Ferronato & Torretta, 2019). This study also supports the argument that the implementation of a circular economy in urban waste management requires integration between economic, social, and institutional aspects, not merely the optimization of waste processing technologies (Schroeder et al., 2019).

Compared to previous studies that placed greater emphasis on the technical evaluation of TPS 3R based on operational indicators, this study shows that institutional aspects and community participation have an equally important influence on operational sustainability (Zakianis et al., 2019). This is evident in medium-category TPS 3R such as the Asri Bubulak and Griya Melati Bubulak facilities, which remain operational despite facing technical limitations due to ongoing community support and community fee mechanisms. In a global context, the findings of this study also align with research on inclusive waste governance, which emphasizes the importance of integrating local actors, governments, and economic mechanisms in building sustainable waste management systems (Wilson et al., 2015). However, this study indicates that the implementation of 3R-based waste management policies at the local level still faces a gap between national regulatory design and operational capacity on the ground.

Academically, this study contributes by strengthening an integrative approach to the analysis of community-based TPS 3R. Unlike previous studies, which tended to evaluate technical, social, or institutional aspects separately, this study develops a model for community-based TPS 3R development by integrating technical, social, institutional, and circular economy dimensions into a single comparative analytical framework. This approach aligns with the perspective of sustainable transition governance, which emphasizes the importance of integrating institutional capacity, social learning, and multi-stakeholder coordination in urban resource management (Pahl-Wostl & Gorris, 2026). The empirical contribution of the research is further strengthened through an analysis across 15 TPS 3R representing variations in urban waste management conditions in the City of Bogor. Thus, the TPS 3R development model is not only oriented toward infrastructure improvement but also toward strengthening community governance, public participation, and the sustainability of the local economic system.

3.4 Implications of the findings and in-depth discussion

The research results indicate that the sustainability of the TPS 3R waste management system in Bogor City is influenced not only by technical waste processing capacity but also by the integration of local institutions, community participation, policy support, and economic sustainability. These findings reinforce the community-based waste management approach, which positions the community and local institutions as key elements in the success of urban waste management systems (Guerrero et al., 2013). High-performing TPS 3R such as Ceremai, Cipaku, Mutiara Bogor Raya, and Katulampa demonstrate that strong technical capacity tends to be accompanied by more stable community participation, functioning financing mechanisms, and stronger governance capacity. Conversely, some low-performing TPS 3R units have stagnated despite having basic waste processing facilities. This situation indicates that physical infrastructure without institutional strengthening and social support tends to result in low operational sustainability. These findings align with studies confirming that community-based waste management systems require integration of technical, social, and institutional aspects to be sustainable in the long term (Marshall & Farahbakhsh, 2013).

From a circular economy perspective, sustainable waste management requires a transition from conventional linear waste systems toward systems that prioritize waste prevention, reuse, recycling, and resource recovery (Geissdoerfer et al., 2017; Ghisellini et al., 2016; Kirchherr et al., 2017). However, the findings of this study indicate that most TPS 3R units in Bogor City are still operating at an early stage of resource recovery, primarily through the sorting of recyclable materials and limited organic waste processing. Recovered materials have not yet been consistently reintegrated into broader production and consumption systems, indicating that waste management practices may remain at a limited stage of circularity. In some cases, these practices also tend toward downcycling, where recovered materials generate lower economic value than the original products (Korhonen et al., 2018).

This condition is influenced by limitations in recycling markets, the quality and consistency of sorted materials, uneven operational capacity among TPS 3R units, and limited mechanisms for transforming recovered materials into economically viable products. Within a circular economy system, TPS 3R have the potential to function as local resource recovery hubs connecting household waste reduction, waste sorting, organic waste processing, recyclable material recovery, and local economic activities. Their role can therefore extend beyond waste volume reduction to supporting resource recovery, value creation, and more sustainable economic mechanisms (Schroeder et al., 2019).

Strengthening this transition requires greater integration among household waste segregation, waste banks, organic waste processing, recycling partnerships, and formal and informal material recovery networks. The development of economically viable products, including compost and other organic waste-derived products, together with stronger market linkages for recyclable materials, could improve the ability of TPS 3R to retain material value within the local economy. Therefore, the long-term sustainability of TPS 3R should be assessed not only by the amount of waste diverted from final disposal, but also by their capacity to recover resources, generate economic value, and establish sustainable linkages between community-based waste management and broader circular economy systems.

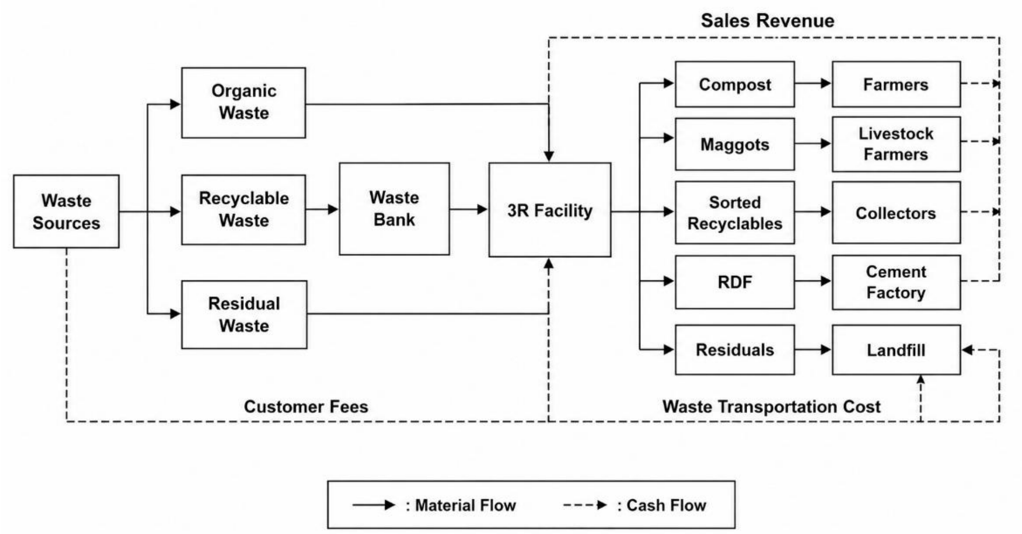

Fig. 3. Ideal circular economy-based material and cash flow model for TPS 3R in Bogor City (WWF-Indonesia, 2025)

Figure 3 illustrates an idealized circular economy model for TPS 3R in Bogor City, showing how material flows and cash flows can interact to support operational sustainability. In this model, waste from households is separated into organic, recyclable, and residual fractions. Recyclable materials may pass through waste banks before being processed by TPS 3R, while organic waste is converted into value-added products such as compost and maggots. Additional outputs include sorted recyclables and refuse-derived fuel (RDF), which can be sold to collectors, farmers, livestock operators, or cement industries. Residual waste is transported to the landfill.

From an economic perspective, TPS 3R sustainability depends on the ability to generate multiple revenue streams from customer service fees and the sale of recovered products.

Ideally, these revenues should be sufficient to cover operational costs, equipment maintenance, repairs, and waste transportation expenses. However, field observations indicate that many TPS 3R units still face difficulties in securing stable buyers for compost, recyclables, and other recovered materials. As a result, the circular economy chain remains incomplete and the financial viability of TPS 3R is constrained.

The figure therefore represents not only a technical flow of materials, but also a governance and market integration challenge. Achieving a functional circular economy requires stronger partnerships with recycling industries, agricultural users, and other downstream markets, as well as institutional support to improve product quality, market access, and contractual arrangements. In this context, TPS 3R can be positioned as a community-based resource recovery hub that connects household waste reduction with broader circular economy networks in urban areas. The facilities also have the potential to generate value-added products such as commercial compost, maggots, recyclable materials, and refuse-derived fuel (RDF), supported by extended producer responsibility (EPR) schemes and recycling marketplaces that can strengthen long-term financial sustainability. The effectiveness of this model, however, depends heavily on the quality of waste segregation at the household level to ensure that recovered materials can re-enter production chains in a more sustainable manner (Velis et al., 2006).

These findings demonstrate that TPS 3R play a strategic role as a connecting hub between household waste reduction, resource recovery, and the strengthening of community-based local economies. This supports the argument that the implementation of a circular economy in urban waste management requires integration between technical systems, institutional governance, and community behavior (Schroeder et al., 2019). Thus, the success of TPS 3R cannot be measured solely by the volume of waste processed, but also by their ability to build a socio-economic system that supports sustainable waste management. This study also has important policy implications for local governments. The results of the analysis indicate that an approach to TPS 3R that is overly focused on infrastructure provision is insufficient to improve the effectiveness of urban waste reduction. Strengthening the capacity of managers, institutional support, economic incentives, and increased community participation are factors that are just as important as the provision of physical facilities. Therefore, urban waste management policies need to shift from an infrastructure project approach toward an approach that strengthens community-based socio-technical systems.

In addition, the research findings indicate that the implementation of national policies related to waste reduction and the circular economy still faces challenges at the local level, particularly regarding the consistency of capacity building, the sustainability of funding, and coordination among stakeholders. This situation highlights the importance of a collaborative governance model that involves local governments, communities, the informal sector, and recycling stakeholders within a more inclusive waste management system (Wilson et al., 2015). Academically, this study reinforces the argument that the sustainability of TPS 3R is best understood as a socio-technical system shaped by the dynamic interplay between operational capacity, institutional governance, community participation, and circular economy mechanisms. In the long term, strengthening the integration among these aspects has the potential to increase the contribution of TPS 3R to reducing urban waste generation and transitioning toward a more sustainable waste management system. Further research is needed to develop a more quantitative model for evaluating the sustainability of TPS 3R, including measuring the effectiveness of the circular economy chain and examining the relationships among institutional, social, and economic variables in greater depth.

3.5 Summary of the discussion and research limitations

A synthesis of the findings of this study indicates that the performance and sustainability of TPS 3R in Bogor City cannot be explained by a single dimension, but rather result from a dynamic interaction among interrelated technical, social, institutional, and economic factors. Empirical findings from the 15 TPS 3R analyzed reveal a consistent pattern, wherein high-performing units are generally supported by a combination of strong community participation, adequate institutional capacity, and relatively well-functioning economic mechanisms. Conversely, low-performing units tend to exhibit weaknesses in all three aspects simultaneously. This indicates that the success of TPS 3R is systemic in nature and cannot be explained solely through a technical approach.

Conceptually, the findings of this study confirm that community-based waste management, governance, and the circular economy are interrelated in shaping the sustainability of TPS 3R. The community-based waste management approach positions the community as a key element in waste management operations, particularly through waste sorting practices and the payment of fees. However, the study's findings indicate that community participation does not occur automatically but is influenced by service quality, trust in the operators, and the community's perception of the economic benefits received. This demonstrates that the social dimension is closely linked to the effectiveness of governance and the capacity of local institutions (Guerrero et al., 2013).

From an institutional perspective, governance theory asserts that organizational capacity, coordination among actors, and the quality of governance are key factors in managing the complexity of a system. The analysis shows that TPS 3R with active organizational structures, strong leadership, and consistent government support tend to be more adaptive in addressing operational challenges. Conversely, passive institutions lead to low community participation and weak economic sustainability. These findings indicate that sustainability is determined not only by the existence of formal institutions but also by their capacity to coordinate actors, adapt to operational challenges, and maintain collective action over time (Emerson et al., 2012; Ostrom, 1990).

Meanwhile, from a circular economy perspective, this study found that most TPS 3R are still in the early stages of transitioning from a linear system to a circular system. Activities such as composting and recycling are indeed being carried out, but they have not yet been fully integrated into a sustainable business model. Furthermore, the research results indicate that the implementation of national policies regarding waste reduction and the circular economy still faces challenges at the local level, particularly regarding the consistency of capacity building, the sustainability of funding, and coordination among stakeholders. These conditions highlight the importance of a collaborative governance model that involves local governments, communities, the informal sector, and recycling actors within a more inclusive waste management system (Wilson et al., 2015).

Based on the integration of these findings, this study developed a TPS 3R model that treats the interaction between technical capacity, social participation, institutional governance, and economic support as a unified system. This model addresses the research gap in previous studies, which tended to view 3R waste management in a fragmented manner, focusing primarily on technical aspects or waste volume reduction. Thus, this study offers a more integrative approach to understanding the sustainability of 3R waste management in urban areas.

This study has several limitations. First, the analysis focused on 15 purposively selected TPS 3R units and therefore does not aim to provide statistical generalization to all TPS 3R in Bogor City or other Indonesian cities. Second, the study relied partly on operational records maintained by individual facility managers, whose completeness and consistency varied across units. Potential reporting bias was addressed through triangulation of field observations, interviews, and supporting documents. Third, the mixed-methods interpretation involved researcher judgment when integrating quantitative and qualitative findings. Future research should therefore develop longitudinal and multi-city comparative studies supported by standardized operational and financial datasets to further evaluate the scalability and long-term sustainability of community-based TPS 3R systems. Additionally, limitations in validating historical data mean that some quantitative data requires contextual interpretation and verification through the triangulation of field observations, interviews, and other supporting documents (Patton, 1999). The resulting synthesis confirms that an integrative approach combining social, institutional, and circular economic dimensions is key to improving the effectiveness of sustainable urban waste management.

4. Conclusions

This study demonstrates that the sustainability of community-based TPS 3R systems in Bogor City cannot be explained solely by technical waste processing capacity. The comparative assessment of 15 selected TPS 3R units revealed substantial variations in performance associated with the interaction among operational capacity, institutional governance, financial sustainability, and community participation. High-performing units generally demonstrated active institutional structures, more consistent operational management, stronger community support, and more diversified revenue sources, whereas lower-performing units experienced multiple and interrelated constraints across these dimensions.

The findings further indicate that most TPS 3R units in Bogor City remain at an early stage of resource recovery and have not yet fully developed into economically sustainable circular economy systems. TPS 3R should therefore be understood not merely as decentralized waste processing infrastructure, but as community-based socio-technical systems that connect household waste management, institutional governance, resource recovery, and local economic activities. This study contributes an integrative comparative framework for analyzing TPS 3R sustainability by combining technical, institutional, financial, social, and circular economy dimensions.

From a policy perspective, future TPS 3R development should move beyond infrastructure-oriented interventions toward integrated support for institutional strengthening, operational capacity building, community participation, sustainable financing, and market linkages for recovered materials. Strengthening partnerships among local governments, communities, formal and informal recycling actors, and downstream markets will be essential to improve long-term resource recovery and circular economy performance. The study is limited by the purposive selection of cases and variations in the quality of operational records; therefore, future research should apply longitudinal and multi-city comparative approaches to examine the scalability and long-term sustainability of community-based TPS 3R systems.

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Author Contribution
The author conceptualized the study, designed the methodology, collected and analyzed data, interpreted findings, drafted the manuscript, and approved the final version.

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During the preparation of this work, the author used Grammarly to assist in improving grammar, clarity, and academic writing style, and DeepL to assist in language translation. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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