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CASE STUDY

Multi-dimensional perspectives on sustainability in domestic waste management

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ABSTRACT

BACKGROUND AND OBJECTIVES: Sustainable waste management is a critical global challenge, demands a multifaceted approach to evaluate and boost its effectiveness. This study evaluates the sustainability of domestic waste management using a multi-dimensional scaling framework, focusing on five fundamental parameters,
such as environmental, economic, social interactions, technological, and regulatory sustainability. This study aims to pinpoint key leverage points for focused enhancements, promoting sustained resilience and efficiency within the system.
METHODS: A mixed-method approach was employed, combining literature reviews, research journal analysis, and initial data collection. Standardized surveys and focus group discussions were performed with stakeholders, including plant operators, managers, and experts. The rapid appraisal tool for waste management was used to assess thirty-three sustainability attributes, with responses measured using a Likert scale. The results were classified into four sustainability levels: unsustainable, less sustainable, fairly sustainable, and sustainable, which facilitated a structured analysis of the system's performance.
FINDINGS: The analysis indicates moderate sustainability across all dimensions, with economic sustainability scoring the highest at 55.27 percent signifying its role as the system's backbone. Nonetheless, there is a significant need for advancement in the areas of financial management and leadership. Technological sustainability followed at 54.44 percent, reflecting incremental advancements but underscoring the need for innovative waste treatment technologies. With a score of 52.12 percent, social sustainability reflects significant community engagement but also uncovers shortcomings in environmental education. The environmental dimension scored 47.1 percent, with leadership and inter-institutional cooperation emerging as under-utilized yet crucial factors. Ranking at a mere 45.1 percent, institutional sustainability was the lowest, indicating an urgent demand for effective governance structures and enhanced inter-agency collaboration.
CONCLUSION: Strengthening institutional frameworks through leadership development and formalizing inter-agency partnerships is essential for improving sustainability. Economic resilience can be fostered by incentivizing community-based waste management through grants and subsidies. Additionally, targeted public education and community engagement initiatives can bridge social sustainability gaps. The system exhibits a fair amount of progress; however, it is vital to undertake strategic actions to secure long-term sustainability and ensure it aligns with global environmental objectives.

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66	9	5

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INTRODUCTION

The global waste crisis has grown into one of the most severe environmental challenges, exacerbated by rapid population growth, urbanization, and increasing consumption patterns (Ferronato and Torretta, 2019). With the ongoing rise in waste generation, poor waste management practices are exacerbating serious environmental issues, including land and water pollution, biodiversity loss, and greenhouse gas (GHG) emissions (Dinis *et al*., 2022). Without effective waste management strategies, the accumulation of waste poses serious threats to public health and the sustainability of ecosystems (Godfrey *et al*., 2020). The issue of waste generation is a pressing environmental concern on a global scale, with annual solid waste production exceeding 2.24 billion tons, and over a third of this waste is not managed appropriately (Kaza *et al*., 2018). Developed nations such as Germany, Sweden, Japan, South Korea, and Singapore have achieved high recycling rates through integrated waste management systems and strict waste separation policies. Conversely, Indonesia faces ongoing challenges with inefficient waste management, predominantly utilizing landfills for disposal and lacking community-oriented practices for waste segregation (Lerpiniere *et al*., 2025). Limited infrastructure and insufficient funding remain key barriers to develop a sustainable waste management system. To overcome these obstacles, it is essential to implement policy changes, enhance waste separation techniques, and invest in recycling facilities to ensure sustainable practices in the long run. Sustainable waste management is essential for balancing human activities with environmental preservation. It not only mitigates pollution but also supports resource efficiency by promoting recycling, composting, and waste-to-energy (WTE) initiatives (Ahmad *et al*., 2015). A well-structured waste management system reduces landfill dependence, minimizes environmental hazards, and enhances economic opportunities through circular economy principles (Kurniawan *et al*., 2021). Sustainability indicators are crucial for assessing the effectiveness of these systems, as they measure waste management efficiency, evaluate environmental impacts, and inform policy development (Mulyatna *et al*., 2021). These indicators provide insights into key factors such as waste collection rates, recycling efficiency, and GHG emissions, helping policymakers make evidence-based decisions for long-term sustainability (Dinis *et al*., 2022). With the ongoing rise of urbanization, current waste management systems are under increasing strain to adjust to the growing volumes of waste and changing patterns of consumption. Identifying and implementing sustainable waste management strategies is critical to address the mitigating of global waste crisis while fostering environmental resilience and socio economic stability (Ferronato and Torretta, 2019). A comprehensive approach that integrates technological innovation, public participation, and strong policy frameworks is crucial for addressing waste-related challenges and ensuring a sustainable future. Indonesia, the largest archipelagic nation in Southeast Asia with a population of 275 million, generates over 65 million tons of municipal solid waste (MSW) annually, ranking among the world's largest waste producers (Hadinata *et al*., 2018; Kurniawan *et al*., 2021; World Bank, 2024). Only 7 percent (%) of Indonesia's total municipal solid waste (MSW) is recycled, with the remainder primarily ending up in open dumps sites or landfills (Jambeck *et al*., 2015; Khair *et al*., 2019). Inadequate sanitation at certain sites creates serious threats to environmental integrity and public health, causing pollution in water, soil, and air, and enabling the increase of disease vectors (Matee and Senzia, 2023). The environmental consequences of Indonesia's waste management inefficiencies are significant. Methane emissions from decomposing waste exceed three million tons per year, representing 16% of global methane emissions (Lando *et al*., 2021). Methane is a prominent greenhouse gas that contributes to climate change, reinforcing the urgent requirement for better waste management solutions (Eric, 2024; Pandey *et al*., 2015). Inadequate waste management practices, such as open dumping, inefficient landfills, and poor waste segregation, have severe long-term environmental impacts on soil health and biodiversity. Unregulated landfills contribute to soil contamination through leachate infiltration, reduce fertility and disrupt microbial communities, while plastic pollution and hazardous waste accumulation threaten ecosystems (Chen *et al*., 2025). Each year, Indonesia generates over three million tons of methane emissions from decaying waste, which plays a major role in exacerbating climate change (Sumarlin *et al*., 2023; Lando *et al*., 2021). To mitigate these effects, policy interventions

such as stricter landfill regulations, mandatory waste segregation, and Extended Producer Responsibility (EPR) can enhance waste recovery and recycling efforts (Liu *et al*., 2025). Enhancing enforcement strategies, advocating for WTE innovations, and expanding community-driven waste management programs, it can be effectively lessening environmental degradation and enhance sustainability. Regardless these challenges, significant potential exists for improvement Indonesia's waste management system. Waste bank programs that encourage community-based recycling have demonstrated potential in decreasing household waste (Khair *et al*., 2019). These programs, notably in metropolitan regions where waste sorting is more achievable, highlight the nation's ability to advance its recycling initiatives. Rimantho *et al*. (2022) highlights the recycling potential of domestic and commercial waste streams, specifically focusing on plastics and organic waste, which are identified as the most valuable materials for recycling. Ferdinan *et al*. (2022) created an index to analyze the efficiency of waste management operations by examining important characteristics such as waste elimination, recycling rates, and community engagement. This index serves as a quantitative tool for analyzing and refining waste management strategies. To confront the challenges of waste management, the Indonesian government has introduced various legislative and regulatory initiatives. Law Number 18 of 2008 on trash Management and the National Policy and Strategy for Waste Management (JAKSTRANAS) aim to achieve a 30% decrease in trash and a 70% increase in recycling by 2025 (Owusu-Acheampong *et al*., 2024). These efforts encounter substantial obstacles, such as insufficient infrastructure, limited public awareness, and irregular policy enforcement (Fariz *et al*., 2024). Financing issues and a lack of inter-agency collaboration pose major obstacles to the successful implementation of waste management programs. The absence of strong institutional support and active public involvement makes it challenging to reach these policy objectives (Khair *et al*., 2019 ; Kurniawan *et al*., 2021). Agamuthu and Babel (2023) contend that a circular economy approach, which optimizes resource recovery and reduces waste generation, may provide a more sustainable solution to Indonesia's waste management issues. Community-based disposal management solutions have arisen as a feasible solution to the Indonesian waste challenge, alongside government initiatives (Muktiningsih *et al*., 2023; Pratama *et al*., 2023). Rachman *et al*. (2016) present a model that combines composting and plastic recycling, specifically targeting rural and semi-urban regions with elevated local engagement. These models have demonstrated success in decreasing waste and improving sustainability within local communities, particularly in areas where governmental support is often insufficient. Integrating community-based models with national policies may enable Indonesia to construct a more sustainable and effective disposal management system that caters to the needs of both urban and rural areas (Ismiraj *et al*., 2023). This research was applied in the districts of Banyumas to analyze the business processes of domestic waste management in both areas. From 2018 to 2022, these regions made notable advancements in waste management, emerging as a leading example for other areas and nearby countries due to their efficient and sustainable approaches (Salam *et al*., 2021). During this period, the system efficiently processed domestic waste into three valuable co-products: recyclable materials that were sent to recycling industries, organic waste pulp used for feeding black soldier fly (maggot) larvae, and non-recyclable plastics converted into refuse derived fuel (RDF). However, in the past two years, the performance of waste management in both areas has declined, leading to waste accumulation at a reuse-reduce-recycle waste processing site (TPS3R) facilities and other storage sites (Chairani *et al*., 2023). The purpose of this study is to pinpoint the essential aspects of the waste management process that have contributed to this downturn, with the intention of revitalizing the system's sustainability to its prior achievements. While various tools and methods have been employed to assess sustainability, the integration of multi-dimensional scaling (MDS) in Indonesia's waste management system represents a novel approach. MDS allows for the evaluation of multiple dimensions environmental, social, economy, and technological providing a complete and quantitative representation of complex relationships within waste management systems. By adopting a transdisciplinary framework that encompasses environmental, economic, social, and technological aspects, this research delivers an all-encompassing analysis of the sustainability of Indonesia's waste

management system. The use of MDS to develop a sustainability index highlights key factors and critical drivers influencing waste management performance, providing policymakers with valuable insights for future strategies. This novel framework addresses the complexities of human-environment dynamics and offers a robust basis for decision-making aimed at achieving long-term sustainability. To determine the sustainability of Indonesia's waste management system, it is essential to adopt a thorough approach that integrates environmental, social, economic, and technological aspects. MDS is a useful way to assess the sustainability of various systems (Rachman *et al*., 2016). MDS offers a numerical representation of complex relationships, facilitating the assessment of similarities between groups, particularly in the context of waste management practices (Nieves and Delgado Ramos, 2023). The choice of MDS stemmed from its ability to flexibly analyze complex sustainability factors while considering the viewpoints of both experts and participants. Unlike life cycle assessment (LCA), which focuses mainly on environmental impact, or Analytical Hierarchy Process (AHP) and Fuzzy Logic models, which rely on rigid criteria, MDS provides a more adaptive and holistic assessment of waste management sustainability. MDS, initially utilized in fisheries policies, has been subsequently submitted in various agricultural comodities, such as algae biomass production (Santoso *et al*., 2023), duck farming (Bakrie *et al*., 2023), chocolate (Fairuzia *et al*., 2020), compost (Santoso *et al*., 2023a), beef (Rohaeni *et al*., 2024), buffalo (Rohaeni *et al*., 2023) dairy (Lovarelli *et al*., 2020), shrimp (Sivaraman *et al*., 2019), rice (Rachman *et al*., 2022), coconut sugar (Handayani *et al*., 2025), coffee (Yusuf *et al*., 2022), black soldier fly (Santoso *et al*., 2023b), integrated farming (Widjaja *et al*., 2023), and sago (Allaily *et al*., 2024). An index may provide a foundation for evaluating the effectiveness of Indonesia's waste disposal strategies, influencing future policy decisions to foster more sustainable outcomes. This study seeks to analyze the sustainability of Indonesia's domestic waste management system utilizing MDS as a framework. This research seeks to: 1) identify critical factors influencing waste management sustainability, 2) develop a sustainability index for Indonesia's waste sector, and 3) provide policy recommendations for improving waste management efficiency. The present research project was carried out at the Directorate of Environment, Maritime, Natural Resources, and Nuclear Policy, National Research and Innovation Agency, Indonesia in 2024.

MATERIALS AND METHODS

Research materials and procedure

This research concentrated on analysing the sustainability of the waste procedure in Banyumas regency and Purwokerto district, Central Java through a MDS approach. Literature and indexed research journals provided secondary data regarding the elements that support the sustainability of disposal management. The primer data was added to with information from a focus group discussions (FGDs) and the finalization of a structured question sheet covering 33 attributes related to the environmental, economic, social, technological, and institutional features of disposal systems. The selection of respondents was deliberate, focusing on individuals with a minimum of five years of experience who are actively engaged, skilled, and well-informed about waste management system. The respondents including plant operator, plant manager, waste management specialist, and entrepreneurs, were interviewed. The sustainability dimensions of MSW management are deeply interconnected, influencing system effectiveness and long-term viability. Economic considerations are pivotal in fostering investment in waste management systems and technological innovations. Studies reveal that financial strategies support the implementation of circular economy models and boost resource recovery rates, highlighting the link between economic value scores and successful waste management outcomes (Ferdinan *et al*., 2022). Institutional frameworks provide regulatory support, governance, and financial mechanisms to sustain these investments, particularly through policies that integrate stakeholder participation and optimize processes (Khosravani *et al*., 2023). Technological advancements enhance operational efficiency and environmental protection but require economic feasibility and institutional backing for large-scale adoption, as seen in cases where facility availability directly correlates with waste management outcomes (Ferdinan *et al*., 2022; Khosravani *et al*., 2023). Effective waste segregation and recycling heavily rely on social engagement, which includes public participation and shifts in

behavior. Research demonstrates that the knowledge and perspectives of the community have a direct effect on environmental sustainability (Widyaningsih *et al*., 2022). Strong institutional policies foster social inclusion, particularly in integrating informal waste sectors into formal systems, improving both economic and environmental outcomes (e.g., waste banks mobilizing community participation). A circular economy approach aligns economic growth with environmental benefits by promoting resource recovery and reducing reliance on landfilling (Ferdinan *et al*., 2022). Waste really affects sustainable agricultural processes, and of course this has a big impact on sustainable agricultural businesses. Furthermore, the contributions and correlation of five MSW dimensions toward sustainable MSW management in as shown in Fig 1.

Characteristics of the waste management in the location study

The study was performed in Banyumas district of Central Java Province, Indonesia. Banyumas Regency covers approximately 1,391.15 square kilometers (km^2) with a population estimated at 1,828,573 people at 2023 (Central Bureau of Stastitic, 2023). The glocation of the study area in Banyumas District of Central Java Province is shown in Fig. 2.

Assuming each resident generates an average of 0.32 kilograms (kg) of waste daily, the Regency is projected to produce around 585.14 tons of household waste per day. In Banyumas Regency, the approach to waste management is structured around three primary stages: upstream, midstream, and downstream. The ideal model, as illustrated in the provided image (Fig. 3), was designed to ensure that waste is sorted, processed, and disposed of efficiently, thereby minimizing the burden on final disposal sites (TPA). Nevertheless, the practical execution of this system has run into various operational inefficiencies, mainly caused by limitations in infrastructure and alterations in policy that followed changes in regional governance.

These challenges have disrupted the intended waste management flow, resulting in an increased volume of unprocessed waste reaching landfills. At the upstream level, waste is expected to be sorted at the household level, where organic waste is managed via Sampah online banyumas android-based waste management aplication (SALIMAS), and non-organic waste is handled through JEKNYONG. Waste banks

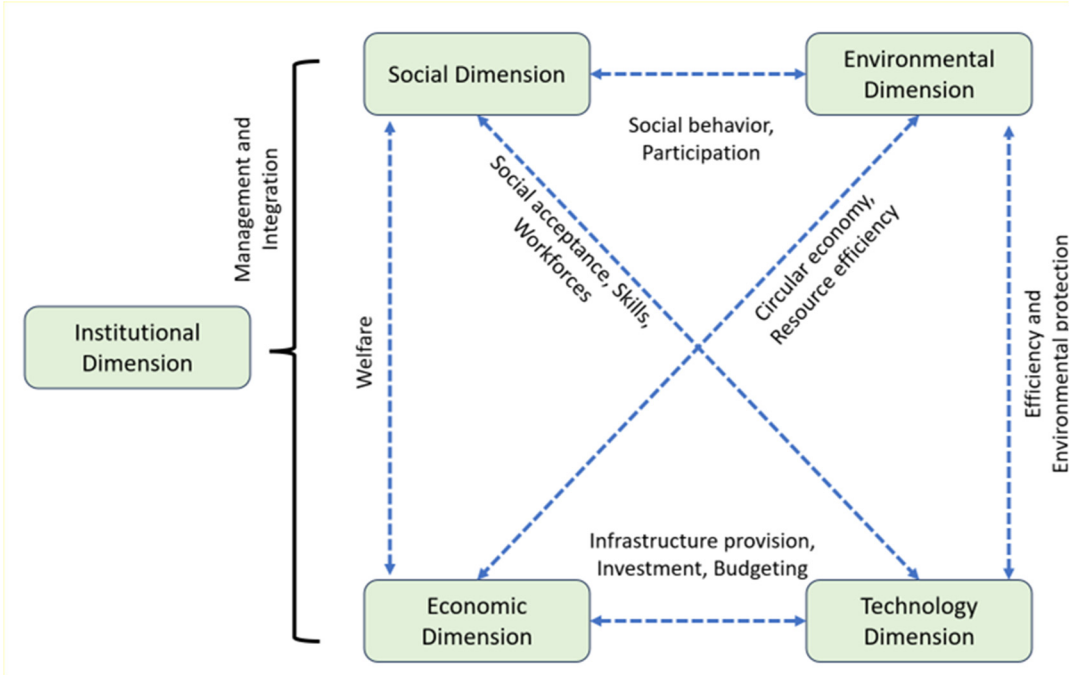

Fig. 1: The cotribution and correlation of five MSW dimensions, modified from (Khosravani *et al*., 2023)

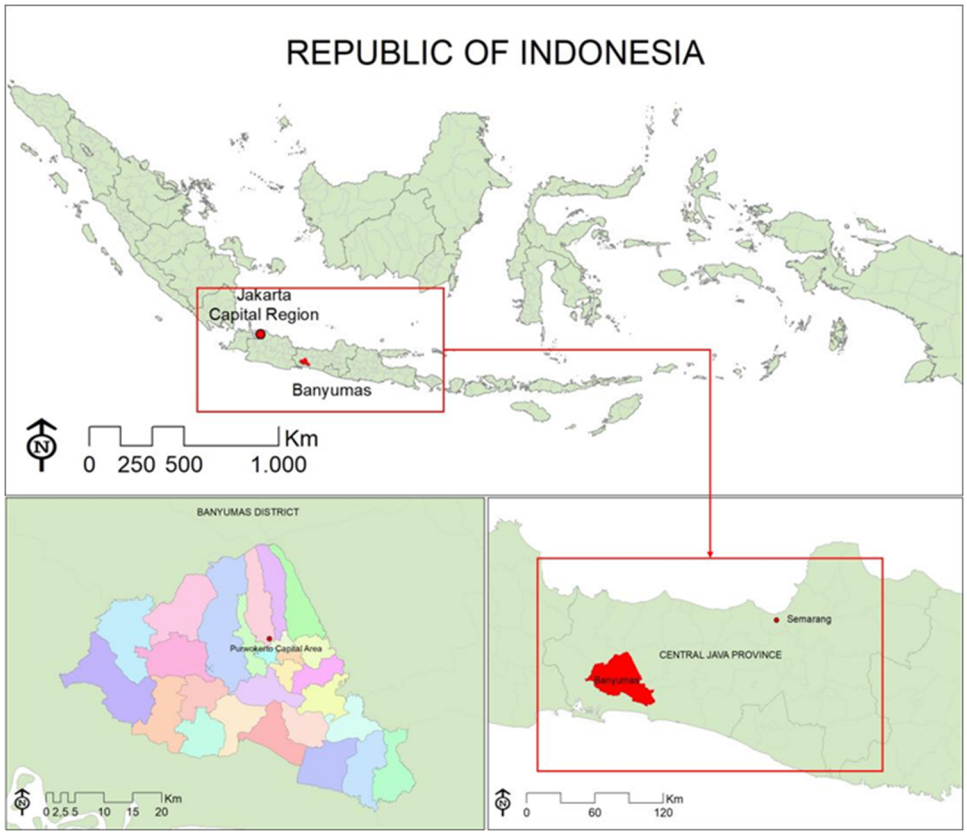

Fig. 2: Geographical location of the study area in Banyumas District of Central Java Province, Indonesia

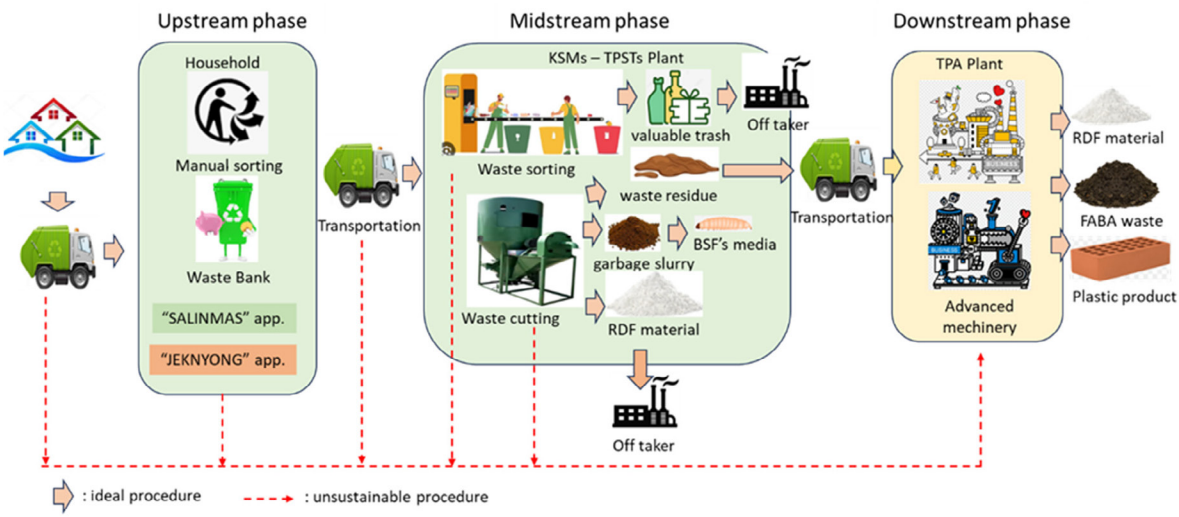

Fig. 3: Diagram of waste management at Banyumas district

Table 1: Waste management stations (TPSTs) at Banyumas District

No	TPSTs name	Capacity (t/day)	Personnel (person)	Waste generated (t/day)	Household
1	Soka Negara	5	20	5-6	974
2	Kedung Gede	9	25	9	730
3	Sumpiuh	10	31	10	1,008
4	Patik Raja	15	38	15	2,972
5	Karangklesem	8	19	4-5	1,342
6	Mugi Resik	9	15	3	1,681
7	Cilongok*	3	23	2	N/A
8	Bawa Berkah	10	29	8	1,404
9	Rawalo	8	19	2	1,087
10	Tipar Kidul	9	32	12	980
11	Arca Satria	10	4	4	1,010
12	Kamandaka	7	10	2	8,000
13	Migunami	8	15	6	956
14	Sejahtera	6	14	6	1,258
15	Sapu Resik	5	10	5	1,200
16	Cemara	1	4	1	530
17	Brayan	7	18	7	1,000
18	Gempar Jaya	8	12	4	1,160
19	Mandari	5	20	5	1,300

*Newly established

are vital in managing and redistributing recyclable materials that have financial significance. However, many households fail to sort or process their waste properly, and due to inefficiencies in the community self-help groups (KSMs) that are responsible for handling unprocessed waste, large quantities bypass the midstream stage and are sent directly to landfills. This interferes with the structured waste disposal process, compelling landfills to accept waste that ought to have been processed earlier. To support these KSMs, the Banyumas government constructed more than 19 multiple waste management stations (TPSTs) to accommodate unprocessed residual waste (Table 1).

In the midstream phase, TPSTs are responsible for processing waste using a combination of manual, mechanical, thermal, and biological methods. Ideally, employing mechanical processing methods such as shredding, composting, and incineration would substantially decrease the volume before it reaches TPA. However, in practice, technical failures in waste-processing machinery, such as sorting machines, waste incinerators, and shredders, frequently disrupt operations. When incinerators malfunction, residual waste that should have been reduced at this stage is instead transported to landfills, contributing to an increasing volume of unprocessed waste. Similarly, when shredders fail, non-organic waste that should have been repurposed into RDF remains unprocessed, further adding to landfill burden. The downstream phase is designed to manage final disposal through pyrolysis at TPST facilities before waste is sent to TPA. Nevertheless, due to the suboptimal functioning of the upstream and midstream processes, TPAs are encountering an overload of waste materials. Furthermore, the restricted processing capabilities of the TPSTs, coupled with inefficiencies in waste conversion facilities such as extruder and paving block production systems, has resulted in further waste accumulation. Consequently, a significant amount of RDF waste is left unmanaged instead of being converted into construction materials, further aggravating landfill overflow. The failures within the system reveal an urgent need for intervention to streamline waste processing throughout all levels. Ensuring that TPSTs function effectively, maintaining waste-processing infrastructure, and reinforcing household participation in waste sorting are essential for reducing the volume of waste reaching landfills. Furthermore, stronger policy enforcement and government support are needed to sustain a functioning, integrated waste management system in Banyumas. Without these improvements, the region risks continued environmental and operational inefficiencies, undermining the sustainability goals of its waste management framework.

Data analysis

Acquiring secondary data involves the collection of information from waste management guidelines, scholarly articles, and other relevant literature concerning income and the sustainability of waste management system. Primary and secondary data were acquired via FGDs and the submission of a question sheet covering 33 attributes related to environmental, social, economy, technological, and institutional concerns. This study specifically selected respondents who are actively engaged, skilled, and well-informed about waste management systems. FGDs were conducted to review the survey data, and six experts with at least five years of involvement in comprehensive waste management, including plant operators, plant managers, waste management experts, and entrepreneurs, were interviewed. An analysis of waste management sustainability was performed through the MDS approach, leveraging the Rapid Appraisal for waste management analysis tool (Rap-waste). These aspects and traits were defined using a Likert scale-based questionnaire. The Rapfish method, which applies MDS with the ASCAL algorithm, is highly adaptable for sustainability assessments, including waste management. Initially created for the fisheries sector, Rapfish integrates various factors and expert insights across environmental, social, economic, and institutional aspects. This flexibility ensures a comprehensive evaluation of waste-related challenges, making it a suitable tool for assessing waste management sustainability. The MDS implementation in this study followed a structured process: key sustainability attributes were identified, and a questionnaire was developed to capture expert assessments. The collected responses were analyzed using Rapfish software to generate sustainability scores. The findings were subsequently analyzed to evaluate sustainability levels and pinpoint key factors affecting waste management effectiveness. Expert responders answered the question sheet by grading 0 for bad, 1 for average, and 2 for good. The ordination technique used the alternating least squares procedure, which is releted on the Euclidean distance (squared distance) root and is referred to as the ASCAL algorithm. This method determines the ordination or the squared distance (d_{ij}) to squared data (origin = o_{ijk}) in three dimensions (i, j, k), which is then called S-stress. Determination techniques of ordination were depended on Euclidian distance in n-space, using Eq. 1 (Pitcher and Preischot, 2001; Lloyd *et al*., 2022):

$$d = \sqrt{\left(\left|x_1 - x_2\right|^2 + \left|y_1 - y_2\right|^2 + \left|z_1 - x_2\right|^2 + \ldots\right)} \quad (1)$$

Configurations of points in MDS determined by regressing Euclidian distance (d_{ij}) from point i to point j with point of origin (o_{ij}), using Eq. 2 (Lloyd *et al*., 2022):

$$d_{ij} = \alpha + \beta\delta\beta_{ij} + \varepsilon \quad (2)$$

The ALSCAL method determine squared distance (squared distance = d_{ijk}) against squared data (point of origin = o_{ijk}), which in three dimensions (i, j, k) is written in a formula called S-stress using Eq. 3 (Pitcher and Preischot, 2001; Lloyd *et al*., 2022):

$$s = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left[\frac{\sum_i\sum_j\left(d_{ijk}^2 - o_{ijk}^2\right)^2}{\sum_i\sum_j o_{ijk}^4}\right]} \quad (3)$$

Where, the squared distance is Euclidian distance assigned a value, using Eq. 4 (Lloyd *et al*., 2022):

$$d_{ijk} = \sum_{a=1}^{r} w_{ka}\left(x_{ia} - x_{ja}\right)^2 \quad (4)$$

The levels of sustainability performance are divided into 4 levels, resulting in intervals of 0, 25%, 50%, 75%, and 100%. The assessment categories are as follows: 75.01 – 100.00, good category or sustainable, 50.01 – 75.00, adequate category or fairly sustainable, 25.01 – 50.00, less category or less sustainable, and 0.00 – 25.00, poor category or unsustainable, as presented in Table 2.

The values of the leverage factors fall within the range of 2%-8%, indicating a moderate to good impact. If <2%, the factor is considered not influential, while if >8%, the factor is considered dominant (sustainable). Table 3 presents the factors that have an impact and are dominant.

The goal of Monte Carlo analysis is to investigate the chances of errors in establishing indicator score values and to analyze how variations in these scores may result from the differing ways respondents complete the questionnaire. The Monte Carlo simulation was conducted with 25 iterations to

Table 2: Parameter values of the levels of the sustainability performance

No.	Index value	Category	Status
1	0 – 25.0	poor	unsustainable
2	25.1– 50.0	less	less sustainable
3	50.1–75.0	quite	fairly sustainable
4	75.1–100.0	good	sustainable

Table 3: Parameter values of the leverage factor

No.	Factor value	Category	Description
1	<2.0%	Neutral	Not Influential
2	2-8%	Influential	Moderate to Good Impact
3	>8.0%	Significant	Dominant

ensure calculation stability and minimize variability. By considering variations in expert judgments, dimension weightings, and changes in input data, the sensitivity analysis assessed their impact on sustainability scores, thereby guaranteeing the consistency and reliability of the outcomes. If the difference between the MDS value and the Monte Carlo value is small (<5%), it indicates that the MDS analysis for determining sustainability is sufficiently accurate with a 95% confidence level.

RESULTS AND DISCUSSION

Identification of the attributes in each dimension of sustainability by scientific judgment will determine the accuracy of the estimation of the level of the sustainability index. An attribute's definition should be clear and encompass its temporal aspects. The 33 attributes of all dimensions consist of environmental, economic, social, technological, and institutional, presented in Table 4.

Index sustainability of waste management

A questionnaire was designed to evaluate the sustainability level at various stages of waste management, detailing the attributes of each dimension, and was subsequently reviewed by qualified scientific experts. Furthermore, the expert's assessment results were analyzed using the MDS method with the Raffish software. The final result of the estimation of the sustainability index are presented in Table 5 and Fig. 4.

Environmental dimension

The ordination result index for the sustainability status of integrated waste management at TPST / TP3R Banyumas Regency in the Environmental dimension is 47.17%. Based on the value parameter, it is categorized as less sustainable. The sustainability position of the environmental category is presented in Fig. 5. Attributes that play a crucial role in determining the sustainability status of the studied environmental category and can advance sustainability in that dimension are those with a root mean square (RMS) greater than 2. These attributes are organic waste treatment (RMS=4.61) and recycling rate (RMS=2.51). Organic waste management is an essential component of sustainable environmental management. The impact on the environment, especially the agricultural environment, waste can have an impact on reducing the quality of the soil and of course greatly affects the results of agriculture, and affects farmers' income. Improper management of organic waste, including food waste, garden refuse, and other biodegradable materials, can result in problems such as littering, air contamination, and increased greenhouse gas emissions. Organic waste management requires an integrated approach and involves various parties, including the community, government, and industry. With the right technology and high awareness of the importance of biodegradable waste management, the negative impact of organic waste on the environment will reduce and at the same time utilize its potential to become a useful resource. The integrated system's success is instrumental in guiding decisions related to resource distribution and in planning for the sustainability of waste management practices. Garbage banks are a possible community-based waste handling solution (Asteria and Heruman, 2016).

While the efficiency of traditional waste treatment methods can differ, they are capable of effectively eliminating various toxins from both soil and water.

Table 4: List of dimensions and their attributes

Environmental	Economy	Social	Technology	Institutional
1. Waste Reduction 2. Recycling Rate 3. Organic Waste Treatment 4. Hazardous Waste Management 5. Air Quality Around Waste Treatment Plants 6. Land Use Efficiency at Waste Treatment Plants 7. Rainwater Management at Waste Treatment Plants 8. Leachate Water Quality	9. Operational Funding 10. Waste Contribution Fee 11. TPS3R/TPST Income 12. Government and Other Subsidies 13. Equipment Maintenance Budget	14. Community Concern for Waste Management 15. Environmental Education 16. Management Services 17. Community Health Around Landfill 18. Gender Contribution 19. Community Conflict	20. Service coverage (Banyumas area) 21. Service coverage (Purwokerto area) 22. Integrated waste management at TPS3R/TPST and TPA 23. Organic waste processing into RDF 24. Organic waste processing into BSF maggots 25. Combustible waste processing into RDF 26. Plastic waste processing into building materials 27. Residual waste processing through burning 28. Final processing site 29. Waste data inventory	30. Leadership and Institutional Structure 31. Role and authority of the Environmental Service officer 32. Community Groups 33. Inter-Institutional Cooperation

Table 5: The results of the index of sustainability for every element and Associated accuracy requirements

Dimension	Index (%)	SQR	R^2 Stress
Environmental	47.17	0.9339	0.230
Social	52.12	0.9346	0.245
Economy	55.27	0.9344	0.246
Technology	54.44	0.9354	0.223
Institutional	45.10	0.9247	0.263
Average	50.82		

One of the primary causes of cultural eutrophication is the discharge of family trash into freshwater bodies. Agriculture can use organic debris floating in wastewater as a source of nutrients (Koul *et al.*, 2022). Conventional methods for the extraction and recycling of organic materials and wastewater may encourage the sustainable management of water resources moving forward (Rohmanna and Maharani, 2022). These days, scientists are looking for an organic waste management technique that is both economical, environmentally friendly, and advantageous to society as a whole. In the context of organic waste management, vermiculture is emerging as a promising and sustainable technique for waste treatment, indicating a positive outlook ahead (Rachman *et al.*, 2016). Since all of the waste produced was recycled, lowering emissions from landfills could be less expensive. Recycling construction

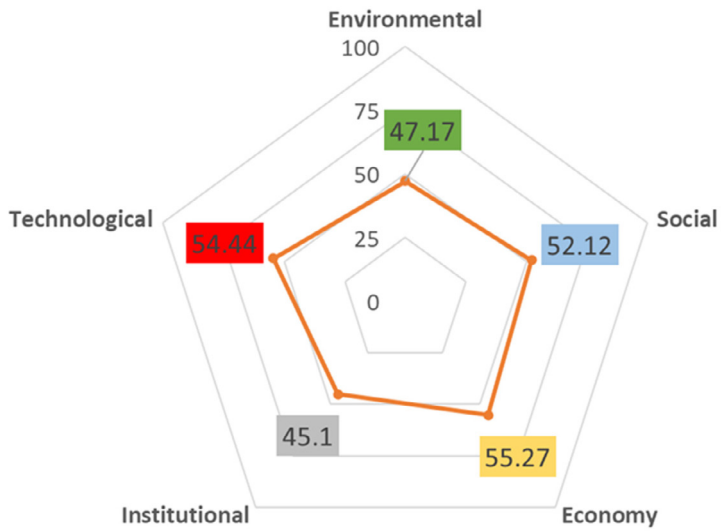

Fig. 4: Sustainability status of waste management program

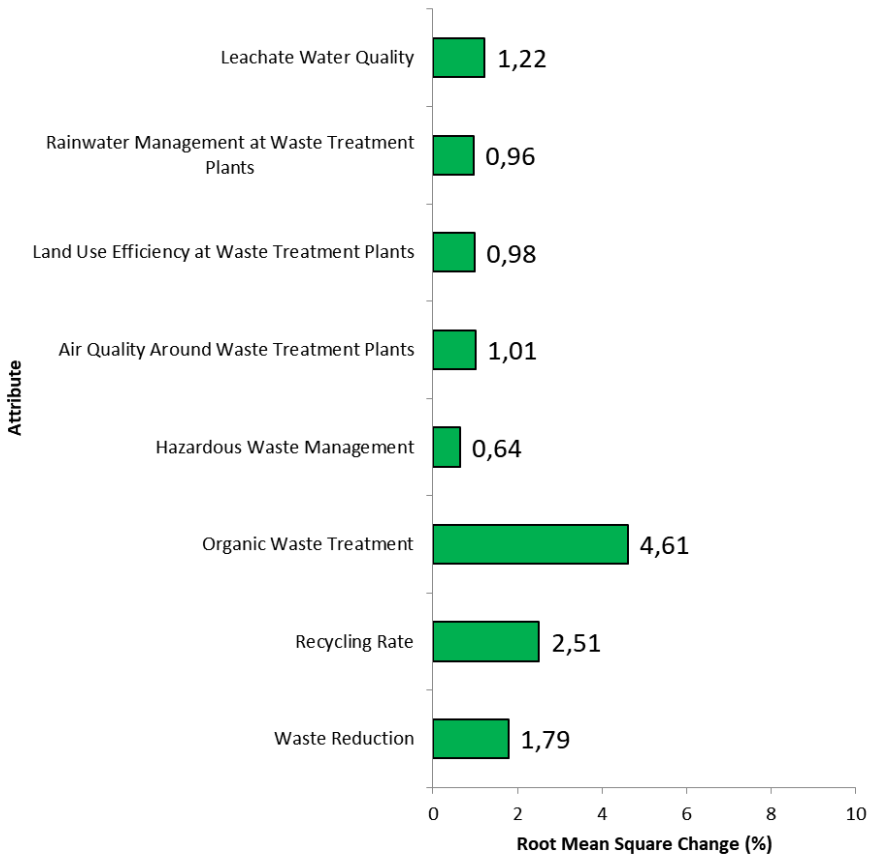

Fig. 5. Leverage of environment attributes

and demolition trash was strongly advised for long-term economic and environmental stability due to the anticipated benefits to the environment and economy (Berenjkar *et al.*, 2021). Improving recycling rates in waste management is a challenging endeavor; however, it is vital for mitigating harmful environmental effects and promoting the reuse of essential resources. Industries, governments, and communities have to collaborate closely to address the problem of increasing recycling rates in trash management. To boost environmental sustainability and minimize landfill waste, it is essential to increase public awareness, improve recycling facilities, establish supportive regulations, and leverage advanced technologies.

Social dimension

The social sustainability index for Banyumas district's waste management system, at 52.12%, reflects a moderate level of advancement, as indicated by a MDS analysis. Several social attributes contribute to this score, with the community's focus on waste management exerting the strongest influence at 2.23%, thereby making it the most influential factor (Fig. 6). Attributes like community conflict (1.33%), gender contribution (1.06%), and community health around landfills (0.82%) also contribute, though to a lesser extent, while factors such as environmental education (0.04%) have minimal impact, pointing to potential gaps in public awareness and education efforts (Godfrey *et al.*, 2020; Muktiningsih *et al.*, 2023). The strong impact of community awareness highlights the importance of public participation in advancing social sustainability within waste management practices. When communities are invested in waste issues, they are more likely to participate in activities like recycling and responsible disposal, which strengthen the system's sustainability. Strengthening community awareness, possibly through specialized educational campaigns or collaborative initiatives, could enhance the effectiveness of this attribute, motivating the local population to adopt sustainable waste management practices (Sewak *et al.*, 2021). Moreover, research by Permana *et al.* (2015) found that community practices like waste reduction and separation were

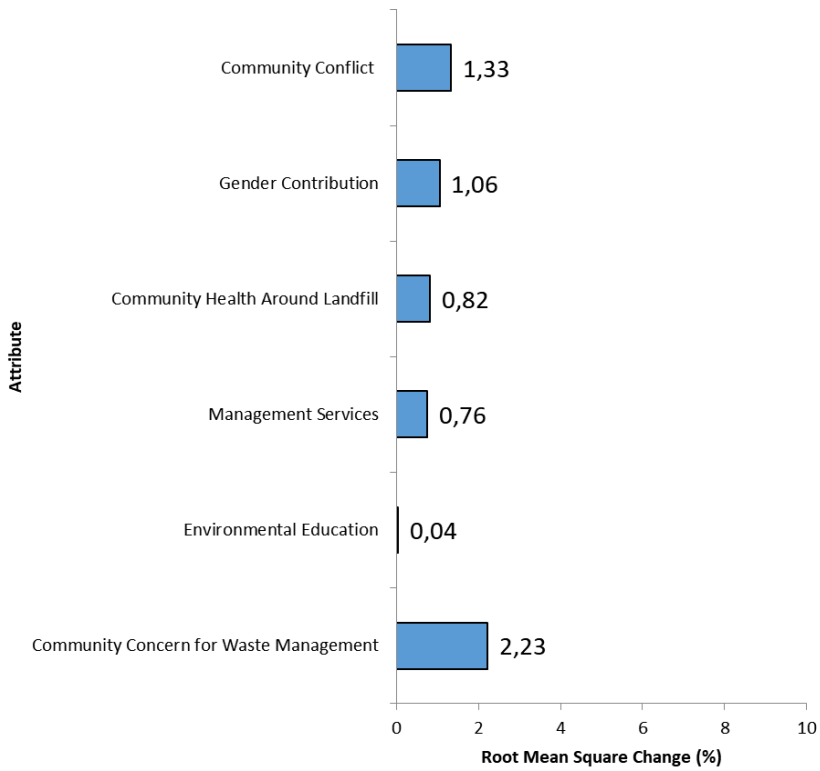

Fig. 6: Leverage of social attributes

closely linked to a collective sense of community cleanliness. Lower leverage for environmental education and service management implies that existing educational efforts are insufficient to make a meaningful social impact, potentially due to limited reach or engagement strategies (Nieves and Delgado Ramos, 2023; Idawati et al., 2024). Expanding community education initiatives will enable us to tackle this problem and foster lasting changes in waste disposal practices (Godfrey *et al*., 2020). To enhance social sustainability, the district might consider launching focused educational initiatives aimed at raising awareness of proper disposal methods. This could involve utilizing local campaigns, organizing workshops, and collaborating with schools to encourage community engagement. Establishing waste management committees could provide platforms for resolving conflicts and engaging diverse demographic groups, particularly in areas close to landfills. Providing incentives, including tax incentives or grants for community engagement, has the potential to increase participation, especially with an inclusive framework that highlights the importance of gender representation in waste management efforts (Rachman *et al*., 2016). Through these interventions, Banyumas could strengthen community support for sustainable waste practices, creating a cohesive, community-driven approach to waste management. Sustainable waste management in low-resource settings faces challenges such as inadequate infrastructure, weak policy enforcement, and limited public awareness (Kaza *et al*., 2018). Inadequate funding for waste collection and treatment commonly results in ineffective landfill operations and open dumping, thereby escalating risks to both the environment and public health. Context-specific policy interventions, including EPR and public-private partnerships (PPPs), can mobilize funding and improve waste processing infrastructure, as demonstrated in South Korea and Sweden (Hwang and Kim, 2022). In Indonesia, community-operated waste banks have shown to be effective in boosting recycling rates and promoting active participation among residents (Muktiningsih *et al*., 2023). Additionally, innovative approaches such as WTE technologies and micro-financing for small-scale recycling enterprises can enhance efficiency and economic opportunities in waste management (Sulaiman *et al*., 2021). Well-designed environmental education efforts can raise public consciousness and promote lasting involvement in sustainable waste practices. Hands-on learning activities, such as waste segregation workshops and recycling programs, encourage community participation and behavior change (Godfrey *et al*., 2020). Incorporating waste education into educational programs helps develop early awareness, a key factor for long-term sustainable waste management. Digital campaigns, including social media outreach and mobile apps, can expand educational reach, making waste management information more accessible (Sulaiman *et al*., 2021). Additionally, government policies that mandate waste education and training for businesses and households can institutionalize behavioral change, leading to broader adoption of sustainable practices (Rachman *et al*., 2016).

Economic dimension

The economic sustainability index for Banyumas district's waste management system, at 55.21% based on MDS, reflects a moderate level of economic viability with potential for growth. Key economic contributors, such as TPS3R/TPST income (8.83%), and waste contribution fee (7.33%) demonstrate influential leverage but remain within the "influential" range (2-8%) (Fig. 7). Notably, TPS3R/TPST income at 8.83%, show the highest leverage, underscoring the need for robust governance to drive economic efficiency in resource allocation and policy execution in the waste management sector (Kurniawan *et al*., 2021). Improving economic sustainability in Banyumas' waste management system could be beneficial to implement specific leadership development initiatives and forge strategic partnerships. Leadership and environmental service officers could benefit from training in resource management, financial accountability, and strategic planning, enhancing their ability to make informed economic decisions that optimize financial resources in waste management (Owusu-Acheampong *et al*., 2024). By formalizing cooperation between institutions via MOUs and structured partnerships, agencies can synchronize their objectives, optimize resource allocation, eliminate redundancy, and amplify the economic outcomes of their collaborative projects (Fariz *et al*., 2024). This approach is critical for streamlining resources across public and private sectors while encouraging consistent goal alignment

(Godfrey *et al.*, 2020). To further support local economic contributions, financial incentives for community TPS3R groups, such as micro-financing and subsidies, could enhance waste processing and recycling efforts, generating economic value and job opportunities at the community level (Muktiningsih *et al.*, 2023). By applying economic performance metrics in these community-operated facilities, it is possible to gather crucial data that can help optimize expenses and track income, ultimately strengthening economic resilience. Circular economy principles enhance waste management sustainability by minimizing waste generation, extending product life cycles, and promoting material reuse and recycling. The process of waste valorization, involving the production of bioenergy, composting, and upcycling, boosts long-term resource efficiency, lessens environmental harm, and fosters economic opportunities. Integrating these approaches strengthens financial resilience while fostering a more sustainable and resource-efficient waste management system. Financial planning plays a crucial role in sustaining waste management by ensuring balanced economic, environmental, and social priorities. Strategies such as EPR, PPP, and waste tariffs help stabilize funding, while investments in recycling infrastructure and WTE technologies enhance financial resilience and long-term sustainability (Kurniawan *et al.*, 2021; Godfrey *et al.*, 2020). The adoption of these specific strategies will enable Banyumas' waste management system to bolster its economic sustainability, aligning with Indonesia's overarching aims for sustainable waste management and economic development.

Technological dimension

The technological sustainability of Banyumas district's waste management system stands at a moderate 54.44%, with MDS analysis identifying service coverage as a critical factor. Service coverage in the Purwokerto district (2.25%) is the most influential attribute, reflecting its essential role in addressing waste management needs as urban areas expand (Fig. 8). In comparison, various technological elements, including pre-treatment equipment, incinerator, plastic waste processing, organic waste composting using black soldier flies, refuse-derived fuel, are essential for achieving sustainable management goals (Febijanto *et al.*, 2024; Pratama *et al.*, 2025; Wahyono *et al.*, 2023). Enhancing service coverage has the potential to significantly improve sustainability, as it reduces the volume of uncollected waste, thereby minimizing environmental pollution.

Technological sustainability enhances social engagement by improving waste management

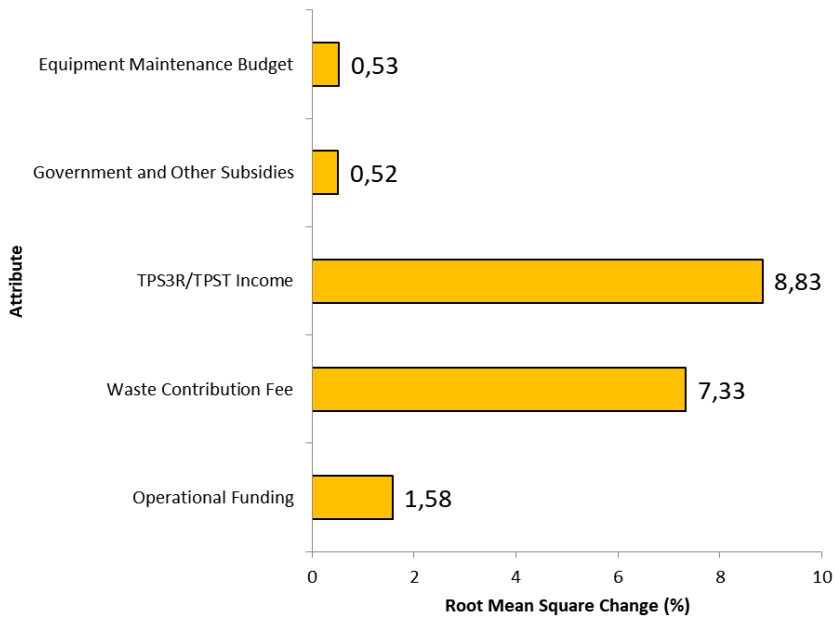

Fig. 7: Leverage of economic attributes

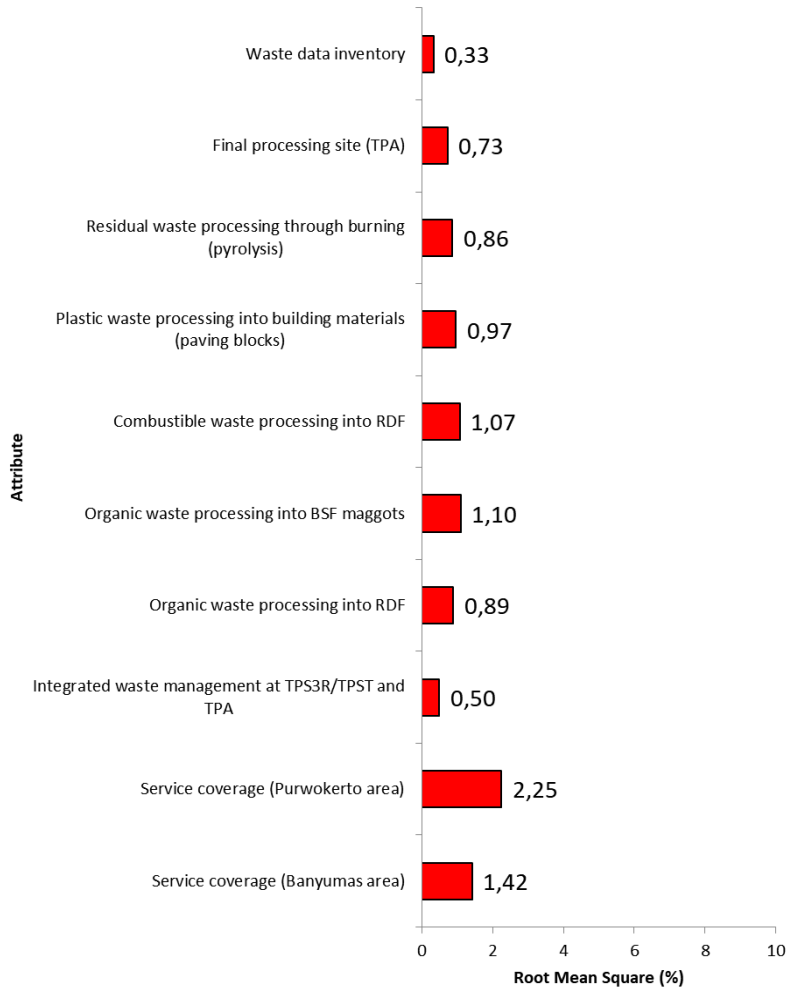

Fig. 8: Leverage of technology attributes

efficiency and accessibility. Innovations like smart waste collection systems, recycling technologies, and digital platforms enhance the efficiency of waste management, promoting higher levels of public engagement. When waste services become more reliable and user-friendly, communities are more likely to engage in sustainable practices, strengthening social responsibility in waste management. Implementing mobile collection units in underserved regions and using Internet of thing (IoT)-based tracking for efficient collection can help achieve these goals, mitigating health risks and enhancing the reach of disposal management services (Ahmad *et al*., 2015; Sulaiman *et al*., 2021). As urban areas continue to expand, implementing these measures becomes vital for sustaining efficient waste management practices. Technological advancements such as WTE systems (Kristiawan *et al*., 2021), IoT-based waste tracking, and bioconversion using black soldier fly larvae can enhance waste processing efficiency and recycling rates (Muktiningsih *et al*., 2023). By employing automated sorting technologies and AI-powered material recovery facilities, waste segregation is improved, resulting in lower contamination levels and a higher value of recyclable materials (Nieves and Delgado Ramos, 2023). Integrating these innovations into existing systems requires government incentives, PPP, and capacity building, ensuring cost-effective and scalable adoption in Banyumas' waste management infrastructure. Providing financial support through

subsidies or low-interest loans for facilities that engage in plastic repurposing and organic composting can encourage their broader implementation. Community engagement and awareness campaigns could also encourage public support for these technologies, reinforcing the sustainability of the system's technological infrastructure. Adopting these interventions, Banyumas can enhance its waste management resilience and continue progressing towards sustainable, technologically supported waste management (Nieves and Delgado Ramos, 2023; Muktiningsih *et al*., 2023).

Institutional dimension

With an MDS-derived index of 45.1%, the institutional sustainability of the waste management system in Banyumas district reveals a lower level of sustainability, suggesting opportunities for enhancement. Key attributes, including leadership and institutional structure (4.71%) and inter-institutional cooperation (3.68%), are moderately influential (Fig. 9).

To align policies and operations effectively and to cut down on inefficiencies, it is imperative to have robust governance and collaborative structures that engage agencies, non-governmental organizations (NGOs), and the private sector (Kurniawan *et al*., 2021). Community groups managing TPS3R facilities (3.17%) also play a vital role, emphasizing local involvement in waste segregation, which is particularly significant in semi-urban and rural areas (Rachman *et al*., 2016). To enhance the institutional sustainability of Banyumas, it is essential to strengthen leadership by implementing training programs that develop skills in resource management, policy execution, and sustainable governance practices. Formalizing inter-institutional partnerships with memorandums of understanding (MOUs) can strengthen collaborative efforts, clearly delineating roles and ensuring a unified approach to waste management goals (Fariz *et al*., 2024). To improve inter-agency partnerships, it is essential to establish formal agreements, ensure transparent coordination, and promote shared accountability. Memorandums of understanding (MOUs) establish clear roles among government bodies, NGOs, and community groups, ensuring efficient resource allocation and policy alignment (Fariz *et al*., 2024). PPPs in countries like South Korea and Sweden have demonstrated the effectiveness of structured collaboration, improving recycling rates and WTE initiatives. Enhancing operational efficiency and ensuring long-term sustainability in Banyumas can be achieved by bolstering institutional collaboration through regulatory reforms, innovative funding mechanisms, and the implementation of digital tracking platforms (Liu *et al*., 2025). The

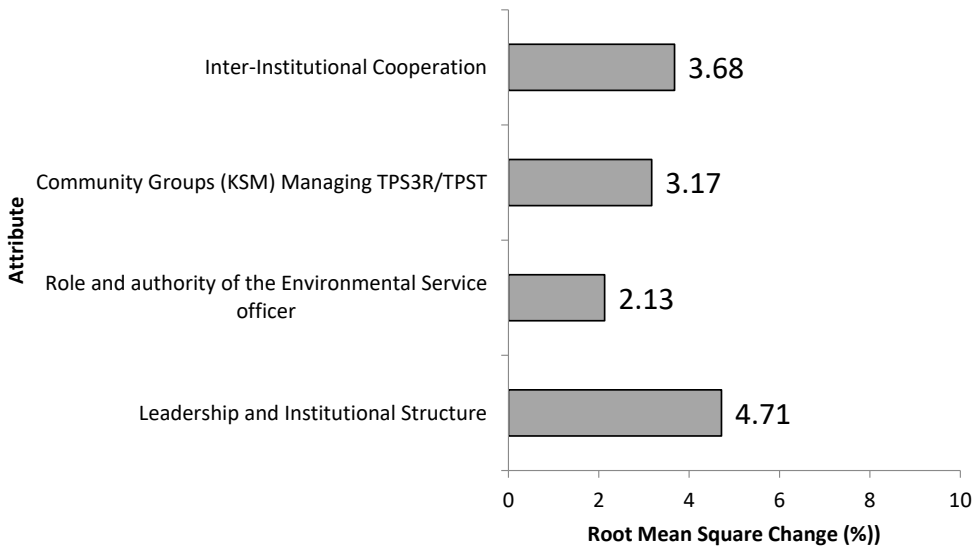

Fig. 9: Leverage of institutional attributes

government plays a pivotal role in ensuring the success of these policies by fostering a supportive regulatory environment and actively facilitating private sector participation. Overcoming existing challenges requires the establishment of effective governance mechanisms, which include clear regulatory frameworks, transparent permitting processes, and comprehensive monitoring systems. Improving coordination among relevant ministries and local governments can help eliminate regulatory inconsistencies and streamline waste management policies. Moreover, the government can enhance private sector involvement by establishing targeted funding programs and providing capacity-building initiatives for small and medium-sized enterprises in the recycling industry. Campaigns designed to enhance public awareness and involve the community are essential for encouraging sustainable waste management habits and guaranteeing the enduring effectiveness of policies. For TPS3R community groups, technical training in waste segregation and waste-to-resource conversion can boost operational efficiency, aiding local recycling and segregation efforts (Muktiningsih *et al*., 2023). Improvements in policy can further strengthen the position of environmental service officers by enabling them to enforce regulations effectively and foster community awareness regarding waste practices. Additionally, incentives like subsidies for community recycling initiatives or financial support for TPS3R facilities can drive local engagement and foster a more resilient waste management ecosystem (Ismiraj *et al*., 2023; Agamuthu and Babel, 2023). The purpose of these combined initiatives is to enhance the institutional framework of Banyumas, creating a sustainable model capable of tackling wider waste management issues. Policy gaps in waste management governance lead to inefficiencies, weak enforcement, and low stakeholder engagement, hindering sustainable waste practices. Strengthening governance mechanisms through regulatory reforms, EPR policies, and decentralized management can improve institutional effectiveness (Chen *et al*., 2025). Countries like South Korea and Sweden have seen improvements in waste processing efficiency through PPP. Furthermore, the implementation of digital waste tracking platforms enhances transparency and aids in better decision-making (Liu *et al*., 2025). Enhancing leadership and governance in waste management requires capacity building, decentralized governance, and regulatory reforms. Training environmental officers in financial management and strategic planning strengthens decision-making and institutional effectiveness (Kurniawan *et al*., 2021). By delegating waste management responsibilities to local governments and communities, efficiency is improved and public engagement is promoted, as illustrated by the waste bank initiatives in Indonesia (Muktiningsih *et al*., 2023). PPPs, such as those implemented in South Korea and Brazil, improve resource allocation and service delivery (da Silva and Elfany, 2021). PPP enhance waste management governance by leveraging private sector investment and expertise. Successful models in South Korea and Sweden have improved recycling rates and WTE initiatives, while India and Brazil have used PPPs to formalize waste collection and resource recovery (Sverige, 2021; da Silva *et al.,* 2021). These collaborations improve efficiency, reduce landfill dependency, and foster economic sustainability in waste management. Moreover, dependable funding mechanisms, like waste tariffs and subsidies, play a key role in ensuring the sustainability of waste programs in regions that lack adequate funding (Kaza *et al*., 2018). Enhancing institutional sustainability requires improvements in key supporting factors, with leadership and institutional structure being the most critical, followed closely by inter-institutional cooperation. Enhancing these factors, especially the collaboration among institutions, requires a robust strategy that includes effective communication, cooperative planning, and transparent assessment. Successful cooperation hinges on aligning common goals, clarifying roles, and ensuring that resources and policies are in place to facilitate collaboration (Adawiah *et al*., 2024). Strong partnerships and the success of collaborative efforts depend on effective coordination among the public, private, and community sectors. Improving leadership and institutional structure attributes can be achieved by enhancing institutional frameworks, reinforcing regulations, boosting community involvement, and ensuring adequate funding. Leaders' active engagement and government initiatives significantly contribute to a region's success. Furthermore, organizational path dependencies indicate that local waste policies in both democratic and authoritarian regimes are influenced by decisions made by higher levels of government in the past (Abdelsalam *et al*.,

2021). Waste management in Banyumas will find it difficult to attain the desired sustainability level unless this institutional aspect is properly addressed. An example of successful waste management in Depok, West Java, Indonesia can be seen through qualitative fieldwork. The findings suggest that the transformation of Depok's waste management occurred due to a series of policies implemented by the mayor in collaboration with the Depok City Government from 2006 to 2016. This situation highlights the importance of effective leadership in cultivating creative policies aimed at resolving societal issues. The vision of the leader was successfully turned into policy and carried out by bureaucratic institutions, leading to significant changes in the region. Additional key factors include the credibility of the leadership, protection from opposition, and access to necessary resources. Additionally, emphasize the crucial role of leadership in demonstrating effective waste management practices such as reduction, reuse, recycling, and community engagement to local populations. The ability of the leader to unite his ideas within the community and his commitment to sustainable change were crucial to the success of these policies (Azizah *et al*., 2021).

RECOMMENDATION

Enhancing environmental sustainability in Banyumas requires strengthening institutional frameworks, leadership, and inter-institutional coordination. Enhancing training programs for environmental officers and boosting financial assistance for community-based waste management organizations like TPS3R can foster greater community involvement in waste segregation and decrease reliance on landfills. Partnerships with NGOs and the private sector can optimize resource allocation and enhance environmental impact, supporting landfill diversion and pollution reduction (Fariz *et al*., 2024; Kurniawan *et al*., 2021). Strategic investments in leadership training, financial planning, and resource management are essential for fostering economic sustainability. Incentives, including grants, subsidies, and micro-financing, can strengthen TPS3R groups, promoting local recycling and creating employment opportunities. Structured inter-institutional collaborations improve financial accountability and streamline resource allocation between public and private stakeholders (Muktiningsih *et al*., 2023). Increasing awareness and education about waste management among the public is vital for fostering improving social sustainability. Targeted campaigns and school-based programs can bridge knowledge gaps and encourage long-term behavioural change. The creation of community waste committees aids in resolving conflicts and ensures that participation is diverse, including representation from different genders. Financial incentives, such as tax reductions for active participation, foster a community-driven waste management culture (Godfrey *et al*., 2020; Rachman *et al*., 2016). Advancing technological sustainability requires improved service coverage, particularly in underserved areas. Mobile waste collection units and IoT-based tracking systems optimize waste collection efficiency and minimize uncollected waste, reducing environmental health risks. By extending low-interest loans or subsidies to bolster financial support for plastic recycling and organic composting projects, we can expedite the implementation of sustainable waste technologies, thereby creating a more resilient waste management infrastructure (Ahmad *et al*., 2015; Sulaiman *et al*., 2021). Institutional sustainability can be strengthened through leadership development and structured governance reforms. Partnerships across various agencies, underpinned by memorandums of understanding, strengthen the collaboration between government organizations, NGOs, and private sector partners. Strengthening the authority of environmental service officers and providing specialized training for community-based waste groups improve operational efficiency and promote sustainable waste processing practices (Ismiraj *et al*., 2023; Agamuthu and Babel, 2023). Achieving long-term sustainability in the waste management system of Banyumas requires the development of thorough strategies that integrate governance, financial stability, community participation, technological innovation, and cooperation between institutions.

CONCLUSION

This study assessed the sustainability of Banyumas district's waste management system using the MDS approach, evaluating environmental, economic, social, technological, and institutional dimensions. The results show a moderate level of advancement in all areas; however, significant gaps persist, especially in the environmental, economic, and institutional

sectors. The environmental sustainability index at 45.1% reflects challenges in waste diversion and landfill reduction. Institutional attributes, including leadership (4.71%) and inter-institutional cooperation (3.68%), contributed positively but lacked sufficient influence to drive significant improvements. Enhancing governance frameworks and leadership capabilities is crucial for improving the efficiency of waste management processes. The economic dimension, with a sustainability index of 55.27%, highlighted resource allocation and financial resilience as critical concerns. While income from TPST facilities provided leverage, weak fiscal management within community-based waste programs limits long-term financial stability. Enhancing governance by means of training and strategic collaborations can lead to better resource management, boost economic participation, and establish reliable revenue sources for sustainable waste programs. The social dimension scored 52.12%, with community participation identified as a key driver of sustainability. Public engagement in waste management, particularly concern for waste practices (2.23%), demonstrated moderate leverage. However, gaps in environmental education suggest a need for targeted awareness programs to strengthen long-term public commitment. Technological sustainability, scoring 54.44%, reflected moderate advancements, with service coverage identified as a critical area for improvement. To mitigate environmental threats and boost service effectiveness, it is crucial to extend waste collection in areas experiencing rapid urbanization. Support for plastic waste processing and organic composting technologies would improve repurposing efforts and reinforce the technological infrastructure of the waste management system. With a score of 45.1%, institutional sustainability underscored the significance of effective leadership and systematic inter-agency coordination in boosting operational efficiency. Strengthening formal partnerships, clarifying roles between government and non-government stakeholders, and providing technical training for TPS3R community groups could enhance institutional effectiveness in waste segregation and recycling. The waste management system in Banyumas shows advancements in sustainability initiatives; however, it needs specific interventions to ensure lasting effectiveness. Strengthening governance capacity, fostering financial resilience, enhancing community participation, expanding technological applications, and improving institutional coordination are essential strategies. These measures will enable Banyumas to establish a more efficient, sustainable waste management system aligned with Indonesia's environmental and economic objectives.

AUTHOR CONTRIBUTIONS

Y. Ismail conducted a thorough analysis of the manuscript's substantial worth; R. Adji assisted with experimental; A.D. Santoso as a corresponding author and conducted the oversaw the work; S. Wahyono analysed and interpreted the data; M.A. Kholiq supervised written works; T. Handayani was responsible for the manuscript's validation; S.D.R. Pahri conducted a literature study and edited the manuscript; S. Putiamini assisted with experimentation and data collection; R.A. Pratama conducted a literature study and edited the manuscript; F. Nurfatriani supervised written works; F.L. Sahwan analyzed and interpreted the data; F. Suryanto assisted with experimental and administrative tasks; Prasetiyadi analyzed and interpreted the data; R.D. Tilottama assisted with experimental and administrative tasks.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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ABBREVIATIONS

%	Percent
AI	artificial intelligence
AHP	Analytical Hierarchy Process
ASCAL	Multidimensional scaling, other name biside MDS
BSF	Black soldier fly
d	Euclidian distance
dij	Euclidian distance from point i to point j
dijk	Squared distance
EPR	Extended producer responsibility
Eq	Equation
FGD	Focus group discussions
GHGs	Greenhouse gases
HVW	High value waste
IoT	Internet of thing (IoT)
I, J, K	Dimension
LVW	Low value Waste
JAKSTRANAS	National Policy and Strategy for Waste Management
KSMs	Community self-help groups
MDS	Multidimensional scaling
MOUs	Memorandums of Understanding
MSW	Municipal solid waste
MSME	Micro Small Medium Enterprise
NGOs	Non-Government Organizations
Oij	Point of origin
PPPs	public-private partnerships
Rapfish	Rapid appraisal for fisheries
R2 Stress	Coefficient of Determination and dissimilarities
RDF	Refuse Derived Fuel
RMS	Root mean square
S	Stress
SQR	Structured query reporter
SALIMAS	Sampah online banyumas android-based waste management aplication
t/day	Ton per day
TPA	Final disposal sites
TPS3R	Waste management stations and recycling center
TPST	Waste management stations
WTE	Waste-to-energy
y	Year

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