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Reconfiguring waste governance for a resilient circular economy

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ABSTRACT

BACKGROUND AND OBJECTIVES: Decentralized waste governance in resource-constrained regions presents complex challenges where infrastructural expansion alone does not guarantee systemic resilience. Banyumas Regency, Indonesia, provides a critical case: following the abrupt landfill closure in 2018, the local government launched the “Sumpah Beruang” program, which initially reduced landfill-bound waste by over 90 percent. However, persistent inefficiencies such as underutilized facilities, stockpiled refuse-derived fuel, and declining digital engagement exposed governance and market fragilities. This study aims to evaluate the effectiveness of Banyumas’s Zero Waste strategy by examining its institutional adaptability, financial resilience, and stakeholder dynamics, while situating its relevance within broader circular economy transitions in decentralized settings.

METHODS: A convergent mixed-methods approach was applied, combining policy content analysis, institutional scoring, and financial benchmarking. Primary data were obtained through 20 semi-structured interviews with government officials, waste operators, community-based waste groups, and industrial off-takers. Secondary data included facility operations, household surveys, and municipal records. Comparative benchmarking with international refuse-derived fuel systems and institutional frameworks was undertaken. Triangulation ensured validity across qualitative narratives, operational statistics, and economic indicators.

FINDINGS: Results show significant upstream-midstream trade-offs. While landfill diversion exceeded 90%, facility utilization averaged only 58.25%, and over 160,000 tons of refuse-derived fuel remained unsold due to unstable quality and limited market absorption. This paradox underscores the fragility of end-of-pipe solutions in circular economy contexts. Institutional assessment revealed the local public service agency governance model scored substantially higher (4.35/5) compared to the technical implementation unit system (2.7/5), suggesting improved fiscal autonomy and partnership flexibility. Stakeholder mapping highlighted asymmetrical power: cement factories and the state electricity company dominate refuse-derived fuel markets, while community-based waste management groups and households remain marginal actors. Financial analysis showed revenue dependency on household fees (more than 85%), leaving the system vulnerable to non-compliance. Scenario modeling indicated that refuse-derived fuel co-firing could reduce up to 140,000 tons of carbon dioxide equivalent annually, representing United States Dollar 0.7–1.4 million in potential climate finance revenue if integrated with global carbon markets.

CONCLUSION: The study reveals that transforming the current technical implementation unit model into a public service agency significantly enhances fiscal autonomy and stakeholder coordination. We propose an integrated framework combining institutional reform, digital citizen engagement, and climate finance instruments. As a single case study focused on Banyumas Regency, the findings may have limited generalizability to regions with different governance or market contexts.

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INTRODUCTION

Waste management remains a pressing global challenge, particularly in developing countries where rapid urbanization and population growth drive escalating waste volumes (Kumari and Raghubanshi, 2023; Alam et al., 2022; Nik Hasan and Panghao, 2025). The World Bank projects that global municipal solid waste will rise from 2.01 billion tons in 2016 to 3.40 billion tons by 2050, with over 90% of this increase occurring in low- and middle-income nations (Nartey and Nyarko, 2020; Kaza et al., 2018). In Southeast Asia, Indonesia ranks among the largest waste producers, struggling with limited processing infrastructure, weak regulatory enforcement, and low public participation in waste segregation (Pariatamby et al., 2020). These systemic issues highlight the need for governance innovation and circular economy integration, especially in decentralized regions (Dagnaw et al., 2025; Wang et al., 2021). Emerging evidence shows that sustainable waste systems require diversified utilization pathways Santoso et al., (2023) demonstrated that valorizing organic waste through black soldier fly cultivation not only reduces pollution but also generates high sustainability scores across economic and ecological dimensions. Such findings underline that circular waste management must go beyond end-of-pipe approaches like RDF to achieve resilience. A particularly illustrative case is Banyumas

Regency, Central Java, where the sudden closure of its only landfill in 2018 triggered a regional waste crisis (Diyanto and Warsono, 2020). The local government responded with the “Sumpah Beruang” as Sulap Sampah Berubah Jadi Uang (turning waste into money) initiative, emphasizing source-level sorting, organic waste valorization, and local recycling industries (Rosyidah, 2023). Initially, landfill-bound waste declined by over 90%, earning Banyumas recognition as a national model alongside Surabaya and Balikpapan (Muslihudin et al., 2023). However, subsequent performance deterioration marked by reduced digital engagement, stockpiled RDF, and policy discontinuity exposed governance and market fragilities (Indiahono, 2021; Fitrianingrum and Surjasatyo, 2023). These dynamics make Banyumas an ideal site for examining how institutional adaptability and financial mechanisms shape circular waste transitions in decentralized contexts. Existing studies on Indonesia’s waste governance often emphasize technical or behavioral aspects while overlooking institutional and financial interdependencies (Yusriadi et al., 2023; Anastasia et al., 2020). This study fills that gap by adopting an integrative sustainability framework linking policy, market, and institutional dimensions. Specifically, the research aims to: (i) *To evaluate the effectiveness of Banyumas’s Zero Waste policy in reducing landfill dependency and improving system performance;*(ii)



Fig. 1: Site location of the study in the Banyumas district

To assess institutional and financial resilience by comparing governance frameworks, technical implementation unit (UPT) vs. local public service agency (BLUD) and analyzing income diversification, operational funding, and market viability; (iii). To formulate strategic pathways for long-term sustainability through multi-stakeholder coordination and integration with global climate finance mechanisms. The scientific novelty of this research lies in its integration of institutional reform and fiscal resilience analysis within a circular economy framework at the subnational level, an analytical combination that has been rarely explored in previous waste governance literature. By linking governance adaptability, financial sustainability, and stakeholder participation, this study provides a new empirical basis for understanding systemic resilience in decentralized waste management systems. Similar integrative approaches combining digital innovation and circular resource flows have been demonstrated in the construction sector, where Building Information Modeling (BIM) frameworks are used to optimize material reuse and minimize demolition waste (Andriyani *et al.*, 2024). Position-

ing Banyumas within the broader circular economy transition allows this study to illustrate how governance flexibility, fiscal innovation, and citizen engagement interact to advance sustainable waste reforms in resource-constrained settings. The findings also offer practical insights for replicating resilient waste governance models across other decentralized municipalities in Indonesia and the wider Global South. To achieve these objectives, the research survey was conducted in the Banyumas District Center and the Directorate of Environment, Maritime, Natural Resources, and Nuclear Policy, National Research and Innovation Agency, Indonesia, Java, between July and October 2024.

MATERIALS AND METHODS

Research design and justification

This study employs a convergent mixed-methods design that synthesizes qualitative inquiry and quantitative metrics to comprehensively assess the sustainability of the zero-waste strategy in Banyumas Regency (Fig. 1). Given the multifaceted nature of the research objectives, ranging from institutional governance to technological

Table 1: Integrated solid waste management facility (TPSTs) at the 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

Source: (Ismail *et al.*, 2025)

feasibility, this approach facilitates the triangulation of policy insights, stakeholder narratives, and operational data (Rana and Chimoriya, 2025). The integration of both methods enhances analytical rigor by aligning contextual understanding with empirical validation, allowing for deeper exploration of institutional transitions (UPT to BLUD), financial resilience, and technology-market alignment. Field immersion and iterative data validation were employed to ensure both policy relevance and scientific reliability (Shah and Corley, 2006).

Data sources and collection

Primary data were collected through 20 semi-structured interviews with local government officials, waste management operators, community-based waste management groups (KSMs), and private partners, including Corporate Social Responsibility (CSR) affiliated industries. Respondent selection was carried out using a purposive sampling approach to ensure data validity and representativeness across stakeholder groups. This study specifically selected participants

who are actively engaged, skilled, and well-informed about the waste management system in Banyumas Regency. Focus Group Discussions (FGDs) were conducted to review and validate survey data, involving six experts with at least five years of experience in comprehensive waste management, including plant operators, plant managers, waste management specialists, and entrepreneurs. This rigorous selection process ensured that only qualified and knowledgeable participants contributed to the qualitative analysis, thereby enhancing the reliability and credibility of the findings. Secondary data were obtained from the Banyumas Environmental Agency (DLH), the National Waste Management Information System (SIPSN), and financial statements from selected 3R Waste Management Station (TPS3R) and Integrated Solid Waste Management Facility (TPST). A household survey involving 150 respondents was conducted to evaluate service coverage, community participation in waste segregation, and willingness to pay. Survey design followed best practices in environmental behavior research

Table 2: The results of the index of sustainability for every element and Associated accuracy requirements (Source: [Ismail et al., 2025](#))

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		

([Stern, 2000](#)). Waste banks 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 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. While the mixed-methods design and purposive sampling ensured data depth and contextual relevance, the survey sample may not fully represent the entire population of Banyumas Regency. Consequently, the findings should be interpreted as indicative rather than statistically generalizable, emphasizing analytical insight over population-level inference.

To support these KSMs, the Banyumas government constructed more than TPSTs to accommodate unprocessed residual waste ([Table 1](#)). It displays each station's installed processing capacity, workforce size, and waste input per day, along with the number of households served. These statistics reveal heterogeneity in coverage and performance, forming the empirical base for institutional benchmarking and resource allocation analysis.

Analytical strategy

The analytical framework is structured around four thematic pillars: policy effectiveness, institutional flexibility, financial sustainability, and technological viability.

1. Policy effectiveness was analyzed through qualitative content analysis of regulations, mayoral decrees, and Standard Operating Procedures (SOPs). Documents were coded thematically using NVivo to identify

gaps between policy design and field implementation.

2. Institutional performance was assessed using a structured scoring model across eight criteria: legal mandate, financial autonomy, operational flexibility, human resources, accountability, stakeholder coordination, responsiveness, and sustainability orientation. Each criterion was scored from 1 (very weak) to 5 (very strong), with a comparative analysis between UPT and BLUD formats.
3. Financial viability was examined using Cost-Benefit Analysis (CBA) and revenue source ratios. Operational expenditures (e.g., fuel, labor, maintenance) were compared against income from user fees, recyclable product sales, and CSR subsidies.
4. Technological benchmarking was conducted by comparing Banyumas's RDF systems with national and international models (e.g., Surabaya, Kamikatsu, Germany). Metrics included moisture control, storage efficiency, equipment durability, and off-take stability.

[Table 2](#) presents the sustainability index scores across five dimensions: environmental, social, economic, technological, and institutional. The indices were computed using the Multidimensional Scaling (MDS) approach with Rapfish software, incorporating expert validation. The inclusion of structured query report (SQR) and coefficient of determination (R²) stress values ensures the robustness of dimensional mapping ([Ismail et al., 2025](#)).

Validity and replicability

Data triangulation enhanced the validity of this study by cross-referencing interview data with

documentary evidence and direct observations. Thematic interpretations were validated through member-checking involving ten key informants, ensuring that the analysis accurately reflected stakeholder perspectives (Birt *et al.*, 2016). Reliability was strengthened through the use of multiple independent coders for institutional scoring and the deployment of pre-tested survey instruments. A comprehensive audit trail, including coding manuals and detailed documentation of analytical procedures, is maintained and available upon request to facilitate methodological transparency and replication. This rigorous approach reinforces the credibility and reproducibility of the findings, aligning with established standards in sustainability policy evaluation.

RESULTS AND DISCUSSION

Effectiveness of an integrated waste management system

The effectiveness of Banyumas Regency's Zero Waste strategy was assessed by analyzing its integrated waste management system across three principal levels: upstream, midstream, and downstream. At the upstream level, household waste segregation is promoted through community-based waste bank programs and digital platforms such as Jeknyong, which facilitates the collection of recyclables, and Salinmas, which manages organic waste streams. These initiatives, jointly administered by BUMD, were designed to promote household-level waste sorting and reduce landfill burden. However, in practice, programs such as Waste Bank, Jeknyong, and Salinmas have yet to reach massive implementation due to persistent behavioral and mindset barriers within the community. Consequently, the significant reduction in daily waste deliveries to the TPA landfill from 143 truckloads in 2018 to just 14 in 2022 is not primarily attributable to upstream household waste segregation. Instead, this reduction has been largely driven by midstream interventions, particularly the operational role of TPS3R and TPST facilities, which serve as the primary nodes for waste sorting and processing. These facilities have absorbed the bulk of municipal waste, effectively diverting it from final disposal and underscoring the pivotal role of infrastructure over behavioral change in the system's current effectiveness. (Suyanto and Lestari 2024). Midstream waste processing in Banyumas is carried

out at 29 TPS3R and 10 TPST units, where solid waste undergoes both manual and mechanical sorting. Manual sorting targets high-value recyclable materials such as Polyethylene terephthalate (PET) bottles, cans, Polipropilena (PP) cups, and cardboard, while separating residual waste that cannot be further recycled or processed into RDF. Mechanical sorting involves the use of shredders that divide waste into two main streams: combustible materials, primarily paper and plastic which are processed into RDF for use in cement kilns; and organic pulp, previously utilized for Black Soldier Fly (BSF) maggot cultivation but now entirely directed toward RDF production with organic content exceeding 95%, specifically for coal cofiring at power plants. These midstream operations significantly reduce the volume of waste requiring final disposal. Downstream, residuals that cannot be processed at the TPS3R or TPST level are incinerated at the BLE landfill. This facility also incorporates a buffer management system to handle surges in waste volume or interruptions in upstream and midstream processing (Muslihudin *et al.* 2023). The ideal model, as illustrated in the provided image (Fig. 2), was designed to ensure that waste is sorted, processed, and disposed of efficiently, thereby minimizing the burden on 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. Fig. 2 illustrates Banyumas's integrated Zero Waste system architecture. This three-tiered model consists of: (1) upstream sorting via households and digital platforms, (2) midstream processing at TPS3R/TPST units for recyclables and RDF, and (3) downstream incineration and final residue handling at the BLE landfill.

Each level plays a pivotal role in diverting waste from landfills, but recent findings show declining effectiveness at the source and technological stagnation midstream, underscoring the importance of synchronized system governance and adaptive institutional support. This study assessed the effectiveness of Banyumas Regency's Zero Waste strategy by examining its integrated waste management system, which operates across upstream, midstream, and downstream levels. System performance has shown signs of regression after 2023, attributed to political transitions and a decline in user engagement

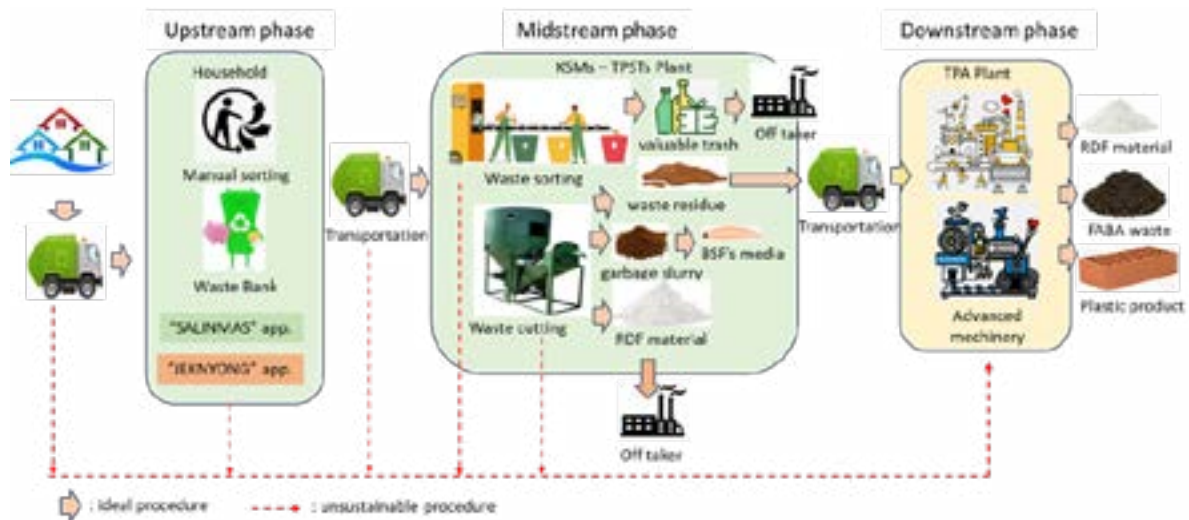


Fig. 2: Diagram of waste management at the Banyumas district

Source: (Ismail *et al.* 2025)

with digital tools (Suyanto and Lestari, 2024). Digital infrastructure lacks real-time tracking, incentive mechanisms, and user-centered interfaces, which limit household engagement. Similar lessons were observed in Surabaya and Seoul, where the absence of user rewards and infrastructure maintenance led to a breakdown in community participation (Wong, 2022). The sustainability of Banyumas's model depends on reinforcing digital incentives (e.g., gamification, rebates), upgrading household waste infrastructure (dual bins, QR-coding), and reactivating civil society campaigns. For a sustainable rebound, improvements are needed in upstream engagement. These include intensive community campaigns, gamified digital incentives (e.g., reward points or user fee reductions), and standardized household infrastructure such as dual-compartment bins and QR-coded containers for traceability. Prior research in emerging economies shows that source-level sorting supported by economic incentives significantly improves waste diversion and household compliance (Godfrey *et al.*, 2019). Without reinforcement at this level, Banyumas risks reversing its progress and overloading its downstream facilities. Similar patterns were observed in Surabaya, where citizen disengagement led to sharp declines in segregated waste supply. These findings confirm that policy design alone is insufficient without stable institutional incentives and behavioral reinforcement. Thus, while the integrated model showed early promise,

its sustainability hinges on system-wide coherence and long-term stakeholder commitment.

Operational gap in TPS3R and TPST utilization

Banyumas Regency's waste management system faces a significant operational imbalance in its TPS3R and TPST units. Although 39 facilities (29 TPS3R and 10 TPST) possess an installed capacity of 416 tons per day, only 242 tons are processed daily, equating to a utilization rate of just 58.25% (Budhijanto *et al.*, 2024). The finding of a low utilization rate (58.25%) should be understood not merely as a technical limitation, but as a reflection of the failure of institutional integration and community behavior in a decentralized system. This data confirms that infrastructure availability does not automatically guarantee effectiveness if it is not accompanied by adaptive governance and socio-economic incentives. Thus, the gap between installed capacity and actual usage reflects a misalignment between the logic of technocratic planning and the reality of citizen participation, a problem also frequently encountered in circular economy studies in developing countries. This structural inefficiency undermines the overall success of the waste reduction targets and risks overwhelming downstream facilities. The underutilization stems from two primary issues. First, a low percentage of households have subscribed to regular waste services, with many still relying on informal or illegal dumping. Second,

there is a chronic shortfall in operational funding for fuel, equipment maintenance, and worker compensation (Siagian *et al.*, 2019). Equipment such as *gibrig* machines, three-wheeled motor transporters, and conveyor systems often remain out of service for extended periods due to delayed or insufficient maintenance budgets. These constraints severely limit service coverage, particularly in high-density areas that remain underserved. Addressing existing gaps in waste management requires the concurrent application of both technical and social strategies. On the technical front, key interventions include increasing the frequency of waste collection, expanding transport fleets, and integrating customer monitoring systems via mobile applications. Provision of equipment renewal subsidies and operational training for KSM personnel can enhance the operational efficiency of existing facilities. Social strategies should focus on incentivizing community participation through mechanisms such as discounted service fees for new users and referral programs. These approaches, successfully demonstrated in cities like Surabaya and Balikpapan, have been shown to improve public engagement in waste management systems. From a financial sustainability perspective, 88.31% of TPS3R/TPST revenues come from household service fees, with only 11.69% derived from the sale of recyclables, 94% of which is from low-value scrap (Budhijanto *et al.*, 2024). Such heavy reliance on fees renders the system vulnerable to income fluctuations caused by fee resistance or non-compliance. International standards suggest that no more than 60–70% of revenue should be fee-based, with the remainder sourced from product sales, sectoral subsidies, and CSR programs (Kaza *et al.*, 2018). Strengthening Banyumas's financial model requires a reoriented business strategy that supports long-term viability. Establishing regional recycling hubs has the potential to improve economies of scale and enhance negotiating power with material off-takers. Diversification of revenue streams can be achieved by producing value-added outputs such as organic compost, solid fertilizers, and RDF briquettes. Although certain operational limitations persist, Banyumas possesses considerable latent capacity, including an extensive network of KSM organizations and robust local market demand. Institutional reforms that facilitate public-private partnerships, offer fiscal incentives for recycling initiatives, and

align CSR efforts can accelerate the transition toward a resilient and sustainable waste management ecosystem.

Technological and market constraints of RDF

In the midstream phase of Banyumas Regency's waste management system, the production of RDF yields two distinct products: approximately 60,000 tons of RDF derived from combustible materials such as plastic and paper, primarily intended for cement factories; and around 106,000 tons of RDF made from organic waste pulp, aimed at power plant operators. However, field data reveal serious bottlenecks in the downstream distribution and market absorption of these products. This finding is also connected to the dynamics of biomass co-firing in coal-fired power plants. Febijanto *et al.* (2024) emphasized that although sawdust co-firing at a ratio of 11.8% reduced global warming potential by nearly 20% and significantly lowered acidification and eutrophication impacts, it simultaneously caused substantial increases in land use and ozone depletion indicators. Thus, while RDF may be positioned as a coal substitute, its deployment requires a comprehensive life-cycle evaluation to ensure long-term sustainability. Two key factors underlie this stagnation. First, product quality remains unstable, most notably the moisture content of RDF, which frequently exceeds the 25% threshold acceptable to the cement industry in Central Java. Second, operational inconsistency among off-takers, including shutdowns due to overcapacity or routine maintenance, has limited regular procurement. The paradox between the achievement of reducing waste to landfill by more than 90% and the reality of RDF stockpiles illustrates a crucial policy trade-off. While emergency interventions successfully reduced the flow of waste to landfills, the intermediate solution of RDF actually created a new burden in the form of stocks that were not absorbed by the market. This contradiction demonstrates the limitations of end-of-pipe strategies in the context of a circular economy and strengthens the argument that sustainability transitions require synchronization between technical policies, market readiness, and multi-level governance coordination. Beyond main partners like the cement industry and electricity company, Banyumas has yet to establish active commercialization pipelines with alternative buyers, such as lightweight brick manu-

facturers, mineral processors, and biomass energy firms across Central Java. Our field data indicate that more than 160,000 tonnes of RDF remain stockpiled in Banyumas, with key quality constraints including high moisture (frequently above 25%), inconsistent particle size, and storage degradation that limit market absorption. Based on these conditions and the local market structure, several realistic alternatives merit consideration: (1) Immediate quality remediation through high-throughput shredding, forced-air drying, and covered storage to meet current industrial fuel standards; (2) Densification (briquetting or pelletizing) to stabilize calorific value and logistics, making RDF usable in industrial boilers, tile and brick manufacturing, and small energy plants; (3) Biological valorization of the organic-rich fraction by reintroducing BSF cultivation, composting, or anaerobic digestion to recover value as animal feed, fertilizer, or biogas; (4) Product diversification for construction use, converting mixed RDF streams into lightweight aggregates or composite bricks; and (5) Thermal conversion via gasification or pyrolysis for producing syngas and biochar. A staged approach is recommended, beginning with quality improvement and pilot-scale trials for densified fuels and construction materials (short-term), while simultaneously diverting the organic fraction for biological utilization and evaluating advanced thermal options (medium- to long-term). Each pathway should be tested with standardized quality control and environmental monitoring to assess absorption capacity, costs, and sustainability performance before wider adoption. This integrated strategy aligns with the broader objectives of Banyumas's circular waste governance framework, allowing unused RDF stocks to be reintegrated into productive value chains while mitigating environmental and storage risks.

Environmental risks in residue combustion

The final stage of Banyumas Regency's waste management chain, residue combustion at the Environmental Learning-based Landfill Facility (BLE landfill), faces serious environmental and education challenges. Field evaluations revealed significant mechanical damage in several incinerator units, including broken seals, frayed steel slings, and cracked refractory walls. These failures have led to the uncontrolled escape of smoke and flames, not through the designated chimney but from structural gaps and loose joints. The resulting emission leakage causes pungent odors,

visible air pollution, and acute health risks for both workers and surrounding residents. This condition violates the Best Available Techniques (BAT) principles outlined by the European Commission (Afgan, 2010), which demand high combustion efficiency and stringent emission control. Similar findings by Alao *et al.* (2022) show that uncontrolled incineration generates high levels of dioxins and fine particulate matter, both of which are known to exacerbate respiratory diseases and degrade ambient air quality. Preventing recurrent damage and enhancing combustion efficiency requires a dual approach that combines technical upgrades with managerial reform. Technically, preventive maintenance should be institutionalized within SOPs, incorporating scheduled inspections of thermal seals, slings, and heat-resistant linings using advanced thermal and pressure sensors. Recalibration of ventilation systems is necessary to ensure that emissions are directed exclusively through the designated chimney. Installation of early-warning systems equipped with high-temperature sensors can provide real-time detection of structural vulnerabilities or overheating, thereby mitigating operational risks and extending equipment lifespan (de Titto and Savino, 2019). On the managerial side, the adoption of a total productive maintenance (TPM) framework is highly recommended. This approach entails digital recordkeeping of equipment performance, maintenance intervals, and operational anomalies, with routine audits to ensure continuous improvement. Transitioning the current management structure from a UPT to a BLUD would provide greater flexibility in budgeting and procurement, enabling timely repair and replacement of critical components without bureaucratic delay (Ismail *et al.*, 2025). The implementation of safe and efficient thermal technologies is a vital element of Banyumas's broader green economy strategy. Not only does it minimize residual landfill waste, but it also significantly reduces long-term air pollution risks. In line with (Wilson *et al.*, 2015), investing in robust emission control infrastructure and institutional capacity will determine the environmental integrity and public health safety of Banyumas's waste-to-energy framework.

Institutional reform and multi-stakeholder partnership strategy

A critical structural bottleneck in Banyumas Regency's current waste management system is the

institutional framework, which remains embedded within a UPT under the Environmental Agency. While the UPT model provides legal legitimacy and bureaucratic integration, it is ill-suited for dynamic public service delivery. It lacks budgetary flexibility, inhibits efficient investment, and constrains partnership-building with private and civil society actors. This study's institutional assessment, based on eight core indicators of financial autonomy, operational efficiency, service quality, investment readiness, accountability, HR management, environmental sustainability, and regulatory compliance, revealed that the BLUD model scored 4.35 compared to UPT's 2.7 (Ismail et al., 2025). Technically, transforming into a BLUD would enable more autonomous financial management, allowing revenues to be sourced not only from service charges but also from product sales (e.g., recyclables, RDF, BBJP), consultancy services, and waste management training programs. Crucially, BLUD status would empower local waste management operators, especially at BLE and TPST units, to hire professional staff outside the rigid ASN framework under performance-based contracts. This is particularly important given the need for responsive and technically proficient personnel to manage technologies such as RDF systems, digital waste banking, and RDF production. Moreover, BLUD entities are allowed to directly sign contracts with industrial off-takers, CSR partners, and research institutions without having to navigate cumbersome public procurement rules. The efficacy of this approach has already been demonstrated in Surabaya's wastewater management BLUD and the Bali Urban Waste Project (World Bank, 2021), both of which benefited from streamlined decision-making, agile budget execution, and enhanced institutional accountability. Actor analysis reveals a power asymmetry in Banyumas waste management. The cement industry and PLN (State Electricity Company) act as dominant stakeholders with strong bargaining power in determining the price and quality of RDF, while KSMs (Citizens' Association) and the community are marginal stakeholders, financially and technically vulnerable. Shifting to a BLUD model has the potential to reduce this inequality by opening up space for direct contracts and flexible fund management, but also carries the risk of resistance from the local bureaucracy and political elite. Therefore, the power dynamics between actors need to be explicitly mapped to formu-

late a balanced collaborative strategy. Realizing the full potential of an improved institutional framework requires the establishment of a multi-stakeholder platform to coordinate the diverse actors engaged in Banyumas's circular waste economy. The proposed FSSB would bring together stakeholders, including local government representatives, KSMs, BUMD, major off-takers such as cement and electric company, and CSR contributors. Oversight of the platform would be assigned to the forthcoming BLUD, with facilitation by Bappeda. The forum is envisioned to serve three core functions: integrated strategic planning, collaborative negotiation for project financing, and systematic monitoring of zero waste program targets. The platform could also serve as a clearing house for RDF commercialization, establishing long-term off-take agreements and providing legal support for contract enforcement. In addition, it would facilitate stakeholder capacity-building and promote policy alignment between district-level authorities and provincial or national sustainability agendas. Beyond local coordination, the future of Banyumas's waste system depends on its ability to access international climate and green infrastructure funding. Global opportunities are increasingly available in the wake of climate transition imperatives. Banyumas should prepare comprehensive proposals for funding from the Global Environment Facility (GEF), Climate Investment Funds (CIF), or the Green Climate Fund (GCF). These proposals must demonstrate a clear emissions baseline, projected carbon reductions (in tons carbon dioxide equivalent (CO₂-eq)), and measurable co-benefits such as community inclusion and economic resilience. To strengthen the argument for climate finance, quantitative estimates are essential. Based on projections for RDF co-firing at a coal-fired power plant, every 100,000 tons of RDF absorbed can replace approximately 70,000 tons of coal, with a potential emission reduction of approximately 140,000 tons of CO₂-eq per year. Converted to the voluntary carbon market value (USD 5–10/ton), the potential funding reaches USD 0.7–1.4 million per year. The financial relevance of this pathway becomes clearer when linked to the urgency of mitigating individual and institutional carbon footprints. Haryanto et al. (2025) reported that employees at a national research institution in Indonesia had an average carbon footprint of 7.42 tons CO₂-eq per year, significantly higher than the national average. These findings



Fig. 3: Strategic pathways for strengthening zero waste governance

underscore the magnitude of emissions from institutional and consumption-related activities, further strengthening the argument that emission reductions projected through RDF co-firing hold strategic value not only for accessing climate finance but also for mobilizing institution-based mitigation actions. This figure demonstrates that the climate finance mechanism is not merely a normative option, but a concrete opportunity that can support the financial sustainability of the Zero Waste system in Banyumas. Eligible projects may include expanded RDF capacity to substitute coal, organic waste diversion programs, or digitized citizen engagement platforms. Collaborations with environmental non-government organizations (NGOs), local universities (e.g., Universitas Jenderal Soedirman), and national research institutions like BRIN would be essential for preparing technically robust and scientifically validated submissions. Insti-

tutionalizing long-term sustainability goals requires the Banyumas local government to develop a Green Investment Plan for the 2025–2030 period. This strategic roadmap should map investment priorities within the waste sector while aligning financial flows with national emissions reduction commitments and the Sustainable Development Goals (SDGs). Formal registration of the plan with international donor networks such as ICLEI-Local Governments for Sustainability, along with integration into funding pipelines managed by the United Nations Development Programme (UNDP), GCF, or the World Bank, would enhance its visibility and funding viability.

The Fig. 3 illustrates the hierarchical structure of Banyumas's institutional reform strategy toward a resilient circular economy. It consists of three interlinked layers: (i). Institutional Reform (foundation): transitioning from the UPT model

to the BLUD framework to improve financial autonomy and governance flexibility; (ii) Financial Innovation (intermediate layer): promoting income diversification, CSR engagement, and access to climate finance to enhance fiscal sustainability; and (iii). Community Engagement and Digital Integration (top layer): leveraging public participation and digital platforms (e.g., *Beruang Apps*) to strengthen accountability, citizen inclusion, and behavioral transformation. Together, these layers form an integrated strategic pathway linking structural reform, financial sustainability, and social participation within Banyumas's circular waste management system.

CONCLUSION

This study evaluated the effectiveness of Banyumas's Zero Waste policy through a multidimensional lens encompassing institutional, financial, technological, and social aspects. The findings demonstrate that Banyumas achieved significant landfill reduction and community-based circular practices but continues to face structural challenges related to RDF market absorption, governance continuity, and declining public engagement. The transition toward a BLUD model provides a promising framework for improving institutional and financial resilience; however, sustained progress depends on consistent policy alignment and stakeholder coordination across governance levels. To strengthen the clarity and practical relevance of this study, specific recommendations are now formulated for each level of governance:

- i. Local government level (district and municipal): prioritize the institutionalization of the BLUD model to ensure stable budgeting, transparent financial management, and professionalized waste service operations. Strengthen community engagement by reactivating digital platforms such as *Beruang Apps* with reward-based participation schemes and periodic outreach.
- ii. Provincial and regional level: facilitate market linkages for RDF and recyclable materials through regional cooperation, joint procurement schemes, and technology standardization among waste processing facilities. Provide technical assistance to municipalities transitioning toward integrated circular systems.
- iii. National level: align local zero waste initiatives with broader circular economy and climate

financing frameworks under national policy. Establish fiscal incentives and grant-based support mechanisms that reward verified reductions in landfill dependency and measurable improvements in recycling performance.

To ensure the effective implementation of these recommendations, a multi-tier monitoring system is proposed. At the local level, routine performance tracking should be integrated into the *Beruang Apps* dashboard to record waste diversion rates, financial transparency, and citizen participation. At the provincial level, coordination forums led by the Environmental Agency can conduct semi-annual evaluations, while at the national level, the Ministry of Environment and Forestry should integrate these local reports into the *SIPSN* database to enable benchmarking and inter-regional learning. This structure supports adaptive management by linking data-driven evaluation with policy feedback loops across governance levels. Implementing the proposed model may face several risks, including institutional resistance to administrative reform, financial dependency on local government budgets, and fluctuating market demand for RDF and recyclables. There is also the possibility of declining community participation if incentive mechanisms are not sustained. To mitigate these risks, the study recommends phased implementation supported by stakeholder consultation, diversification of funding sources through public-private partnerships, and continuous public engagement supported by transparent digital reporting systems. These multi-level recommendations ensure that Banyumas's experience contributes not only to local innovation but also to Indonesia's broader waste governance reform. The study highlights that sustainable transitions require synchronized action between institutional reform, financial innovation, and citizen participation, supported by adaptive governance mechanisms and continuous intergovernmental learning. This study is limited to a single case in Banyumas Regency, which may affect the generalizability of its findings to other regions. In addition, the reliance on stakeholder interviews and institutional records may introduce contextual bias. Future research should include longitudinal or cross-regional comparisons to enhance external validity.

AUTHOR CONTRIBUTIONS

A.D. Santoso prepared the manuscript, and critically analyzed the manuscript's crucial substantive

value; M.A. Kholiq critically analyzed the manuscript's crucial substantive value; S.D.R. Pahri performed recognition of data and handed material and operational support; I. Setiawati supervised manuscript preparation; E. Avianti prepared the manuscript and performed critical revisions; T.G. Franzisca performed recognition of data; Sarkiwan performed data curation; Diyono performed experimental operation; Suprpto analyzed the manuscript's crucial substantive value; A. Lusia performed recognition of data, and A. Wiratmoko performed recognition of data.

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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 (NOMENCLATURE)

%	Percent
BAT	Best available techniques
BIM	Building Information Modeling
BSF	Black soldier fly
BLUD	Badan layanan umum daerah (local public service agency)
CO ₂ -eq	carbon dioxide equivalent
CIF	Climate investment funds
CBS	Cost-benefit analysis
CSR	Corporate social responsibility
DLH	Dinas Lingkungan Hidup (local environmental agency)
GEF	Global Environment Facility
GCF	Green Climate Fund
KSMs	Community-based waste management groups
MDS	Multidimensional scaling
NGOs	Non-government organizations
PP	Polipropilena
PET	Polyethylene terephthalate
RDF	Refuse-derived fuel
R ²	Coefficient of determination
SDGs	Sustainable Development Goals
SOPs	Standard operational procedures
SQR	Structured query report

SIPSN	National Waste Management Information System
TMP	Total productive maintenance
TPSTs	Integrated solid waste management facility
TPS3R	3R Waste management station
TPA	Tempat pembuangan akhir (the final disposal site)
UNDP	United Nations Development Programme
UPT	Unit pelaksana teknis (the technical implementation unit)

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