ACCSCIENCE PUBLISHING

Asian Journal of Water, Environment and Pollution

ORIGINAL RESEARCH ARTICLE

Collaborative governance for circular economy-based household waste management in rural Indonesia: The CIRCLE-SIJAGO BU framework

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Abstract

Household waste is the dominant contributor to municipal solid waste generation in North Bengkulu Regency, yet much of it remains outside formal collection systems. This situation highlights the need for a better understanding of how community initiatives and collaborative governance arrangements can support circular waste management in rural settings. This study investigates community-driven household waste management in North Bengkulu Regency through a three-month qualitative study (September–November 2025) spanning five villages across two subdistricts. Methods included stakeholder interviews, field observations, focus groups, and document review covering six actor categories. Results show that households generate 186 tons/day of waste (50.78% of total municipal output), with formal collection covering just 22.72% and 77.28% disposed of haphazardly. Notable local adaptations, such as lamppost pickups and stacked bucket home composting, highlight community ingenuity when institutional support is in place. The proposed CIRCLE-SIJAGO BU model integrates household 3P practices, waste banks, multi-stakeholder coordination (community, government, micro, small, and medium enterprises, informal sector), material valorization, *gotong royong* traditions, and regulatory clarity to enable scalable rural circular systems anchored in indigenous social capital.

Keywords: Circular economy; Collaborative governance; Community-based waste management; Household waste; Rural development; Local wisdom

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Citation: Hardinata D, Fitri L, Damayanti R, *et al*. Collaborative governance for circular economy-based household waste management in rural Indonesia: The CIRCLE-SIJAGO BU framework. *Asian J Water Environ Pollut*. 2026;23(5):025510385. doi: 10.36922/AJWEP025510385

Received: December 15, 2025

Revised: March 30, 2026

Accepted: April 14, 2026

Published online: July 24, 2062

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1. Introduction

In rural and semi-urban Southeast Asia, household waste buildup presents a growing concern that intersects environmental degradation, public health risks, and missed community-level economic opportunities.[1,2] In North Bengkulu Regency, a district situated on Sumatra's west coast and representative of many rural Indonesian municipalities, daily waste generation reaches approximately 186 tons, a volume that

has grown steadily over the past five years in tandem with population expansion and shifting consumption behaviors.[3] The formal waste management system collects only 22.72% of generated waste, so more than three-quarters of household refuse is managed individually at the household level or accumulates in informal disposal sites with minimal environmental control.[3] This management gap is particularly consequential given that household waste comprises approximately 50.78% of total municipal waste streams in the regency, making residential consumption patterns the primary driver of waste generation dynamics.[4]

The lack of adequate waste infrastructure and community participation creates several environmental problems. The dominant waste disposal mechanism in North Bengkulu, operating under an open dumping system, poses well-documented risks, including soil and groundwater contamination, atmospheric methane emissions from the decomposition of organic matter, and the proliferation of vector-borne diseases.[5,6] Local health surveillance data corroborate these environmental risks: in 2024 alone, the regency recorded 913 cases of acute diarrhea and elevated respiratory infection rates in areas proximate to existing waste accumulation zones.[7] The composition of household waste—where organic matter represents 51.7% and plastic materials constitute 19.16% of total waste streams—further underscores the urgency of intervening at the source, as both components present distinct environmental and health challenges when mismanaged at scale.[3] In addition to environmental and health impacts, the current waste management system also represents a lost economic opportunity. The substantial volumes of organic waste suitable for compost production and recyclable materials (plastics, metals, paper) currently entering landfills could instead generate economic value through processing and reintroduction into productive cycles, a principle central to de facto circular economy frameworks gaining policy traction across Association of Southeast Asian Nations (ASEAN) member states.[8,9]

Policy responses to rural waste in Southeast Asia have typically focused on centralized, capital-intensive infrastructure such as larger sanitary landfills, expanded collection networks, and mechanical treatment facilities.[1,10] While such top-down approaches have demonstrated effectiveness in high-income, densely populated urban centers with established fiscal and technical capacity, their application in resource-constrained rural contexts has frequently proven ineffective or unsustainable.[2] In Indonesia specifically, the experience of large-scale landfill expansions in regencies comparable to North Bengkulu reveals common implementation failures: capital investments exceed local government capacity to maintain operational standards; community participation in waste segregation remains negligible in the absence of localized incentive structures; and dependency on centralized systems creates fragility when transport infrastructure or administrative capacity falters.[11,12] These findings point to the need for rethinking rural waste management through locally rooted, community-centered frameworks. They should leverage existing social institutions and connect waste reduction to tangible livelihood benefits at household and neighborhood levels.[13,14]

Recent ASEAN and Indonesian national policies have created enabling conditions for exploring innovative waste management approaches. Indonesia's 2025–2050 Circular Economy Roadmap, launched by the Ministry of National Development Planning (Bappenas) of the Republic of Indonesia, explicitly emphasizes material circularity and waste minimization through production redesign and changes in consumption patterns, with particular attention to community-led initiatives and the integration of the informal sector.[15] The ASEAN Community Vision 2025, which prioritizes environmental sustainability, provides policy legitimacy for testing models that integrate waste management with broader environmental governance and sustainable livelihood objectives.[16] In this policy context, an emerging body of practice literature documents the effectiveness of community-based waste management models, particularly those centered on waste banks, institutional mechanisms through which community members segregate valuable waste streams and exchange them for monetary compensation or essential goods.[17,18] Waste bank implementations have been documented in urban Indonesian settings (notably Jakarta, Surabaya, and Bandung),[19] yet empirical research on the feasibility and outcomes of comprehensive frameworks that integrate waste banks with broader collaborative governance mechanisms and circular economy principles in rural contexts remains limited.[20] This research gap emphasizes local institutional practices, such as *gotong royong* and existing social networks, as basic rather than supplementary features.[21,22]

Indonesia's *gotong royong*, mutual cooperation together with collective responsibility, provides solid ground for community environmental initiatives.[23] Studies show how local mutual aid traditions can boost participation in waste management efforts. A study in Sigerongan Village, West Lombok, demonstrates that waste management programs grounded in *gotong royong* values achieved high rates of community participation, with residents voluntarily contributing labor, equipment, and financial resources to support collective waste collection and environmental maintenance.[24] Research from Panggungharjo Village

in Yogyakarta similarly illustrates how social capital and *gotong royong* traditions can serve as powerful forces for reducing waste sent to landfills, with community cooperation mechanisms enabling decentralized waste processing that formal municipal systems struggle to achieve.[25] These practices showed that rural waste innovations do not need to fully adopt outside models. They can simply draw on local social institutions and values already rooted in the community.[26] The integration of *gotong royong* into formal waste management systems thus represents not merely an adaptation to local context, but rather a recognition that indigenous social institutions can serve as foundational enabling conditions for sustainable environmental governance.[27]

The third conceptual pillar is collaborative governance theory, which examines how public agencies, private actors, civil society organizations, and community members work together to address policy challenges that no single actor can solve alone. Ansel and Gash's[28] and Emerson *et al.*'s[29] framework identifies critical variables that shape collaborative governance success, including starting conditions (prior history of conflict or cooperation, power imbalances among stakeholders, incentives for participation), institutional design features (clear rules, inclusiveness, transparency), leadership quality (particularly facilitative rather than directive leadership), and collaborative process dynamics (face-to-face dialog, trust building, commitment development, shared understanding). Their analysis of 137 collaborative governance cases shows that successful collaboration often develops through iterative cycles in which early "small wins" build trust and commitment and enable more ambitious collective action.[28] Importantly, they emphasize that collaborative governance is not merely consultation or stakeholder engagement, but involves shared decision-making authority and joint responsibility for implementation outcomes.[30] This framework is especially useful for environmental governance problems where technical solutions depend on broad social acceptance and behavioral change.[31]

Recent empirical studies examining collaborative governance in Indonesian waste management contexts reveal both possibilities and persistent challenges.[11] Analysis of Malang City's waste policy implementation finds that despite formal commitments to participatory governance articulated in municipal regulations, actual collaboration remains limited in practice, with institutional gaps including absent coordination platforms for multi-stakeholder dialog, weak integration of community and private sector actors into formal waste management systems, and leadership approaches that emphasize bureaucratic control rather than facilitation of collective problem-solving.[11] Similarly, research in Kupang City documents that while waste banks exist and multiple stakeholders express willingness to collaborate, insufficient information sharing and unclear accountability mechanisms undermine sustained cooperation.[32] However, more positive examples also exist. Collaborative waste management at Reduce-Reuse-Recycle Processing Stations (TPS3R) across various Indonesian localities demonstrates that when properly designed with clear stakeholder roles, transparent decision-making processes, and adequate resources, community-based facilities can process substantial waste volumes while generating compost and other valuable products.[33,34] These mixed findings highlight the critical role of institutional design: collaborative governance does not emerge spontaneously from good intentions but demands deliberate structuring of coordination mechanisms, authority relations, information flows, and accountability.[31,35]

A key gap exists at the intersection of circular economy principles, community-based waste management, and collaborative governance, particularly in rural settings in developing countries.[36,37] While urban waste bank implementations have been documented extensively in Indonesian cities such as Jakarta, Surabaya, and Bandung, and collaborative governance research has examined municipal policy processes, relatively limited empirical attention has been directed toward comprehensive frameworks that integrate circular economy principles with collaborative governance mechanisms in rural settings where social capital and local institutional practices differ substantially from urban contexts.[17] Rural communities often have stronger bonding social capital through kinship and neighborhood ties but weaker links to external technical expertise, markets, and policy resources.[38] The informal waste sector, waste pickers and collectors operating outside formal systems, plays particularly important roles in rural areas, yet remains largely unrecognized in official waste management policies.[39] The importance of rural development and environmental sustainability across Southeast Asia can be improved by understanding how circular economy transitions can occur where formal infrastructure is scarce, informal systems are dominant, and local social institutions (as opposed to governmental ones) act as the primary coordinative structures.[40,41]

This study fills those gaps by examining a community-driven approach that blends circular economy principles with social capital, local traditions like *gotong royong*, and collaborative governance, intentionally bringing in stakeholders from multiple angles, by situating the analysis in North Bengkulu Regency, a rural district representative

of many Indonesian municipalities facing rapid waste growth with limited formal management capacity. The research provides empirical evidence on how resource-constrained rural areas can transition to sustainable waste management without wholesale dependence on centralized infrastructure or external technology transfer.[24] The study draws on collaborative governance theory to examine how trust is built among diverse stakeholders with different interests and capacities, how coordination mechanisms are structured to enable joint decision-making, and how policy instruments at the village level can operationalize national circular economy commitments.[31] It extends existing scholarship by demonstrating that local wisdom and social capital, when intentionally incorporated into institutional design rather than treated as supplementary cultural features, can serve as foundational enabling conditions for circular economy implementation in developing country contexts.[26]

2. Materials and methods

2.1. Research design

This study employed a qualitative case study approach to investigate community-based household waste management, collaborative governance, and the development of the circular economy in North Bengkulu Regency, Indonesia. The case study design was selected because it enables an in-depth examination of complex collaborative processes, institutional dynamics, and social interactions within their real-world contexts and dimensions, which is particularly important when studying waste management transitions involving multiple stakeholders with distinct interests and capacities. The research was guided by an interpretive paradigm that prioritizes understanding of meaning-making and social practices within communities, complemented by a participatory orientation that recognizes community members as active knowledge producers rather than passive research subjects.

The study was conducted across five selected villages in two subdistricts of North Bengkulu Regency during a three-month fieldwork period (September–November 2025). Study sites were selected based on documented evidence of active community engagement in waste management, operational waste banks, local government support, and accessibility for sustained fieldwork. The five villages selected were: Lubuk Saung, Marga Sakti, Padang Jaya, Purwodadi (kelurahan), and Rama Agung, located within Kecamatan Kota Arga Makmur (3 sites) and Kecamatan Padang Jaya (2 sites). These two subdistricts represented different settlement patterns: Kota Arga Makmur (population ≈ 43,473; density 710.83 residents/km^2) represents semi-urban character with denser settlement and greater market integration, while Padang Jaya (elevation 250–750 meters above sea level; population ≈ 32,997) represents rural character with dispersed settlement patterns and mixed agriculture-based livelihoods.

2.2. Participant selection and sampling strategy

Participant selection employed purposive sampling, a non-probabilistic approach appropriate for qualitative research to identify information-rich participants knowledgeable about the phenomenon under investigation. Participants were stratified across six stakeholder categories: household members (varying by age, gender, and occupational background); community waste bank managers and group leaders; informal sector workers (waste collectors/recyclers); village and subdistrict government officials; district-level technical officers from the Environmental Services Office and Planning and Research Agency; and small and medium enterprise (MSME) operators engaged in waste-based businesses.

Inclusion criteria specified that participants must be directly involved in or knowledgeable about household waste management practices, have at least one year of experience in relevant activities, and be willing to participate in interviews during the study period. This stratified approach enabled collection of diverse perspectives and triangulation of findings across different stakeholder positions.

2.3. Data collection

Data collection was conducted using four primary methods to capture multiple dimensions of the waste management system. Data collection was conducted through a systematic approach involving four primary methods: (i) in-depth interviews guided by a semi-structured interview protocol focusing on collaborative leadership and resource sharing; (ii) participatory observation using a structured checklist to record household waste segregation practices and waste bank operations; (iii) focus group discussions with community members, waste bank operators, and officials; and (iv) documentary studies of regional waste management regulations and performance reports. The research instruments are provided in Table 1 and the Appendix to ensure methodological transparency.

2.3.1. Participatory observation

Participatory observation involved direct engagement with waste bank operations, household waste segregation practices, community work arrangements (*gotong royong*), and village-level coordination meetings. Field notes documented observable activities, contextual

Table 1. Research instrument dimensions and data collection focus

Method	Core dimensions/Indicators	Source/Participants
In-depth interview	Policy synergy, collaborative leadership, funding mechanisms, and institutional barriers	Bapperida, environment agency, village heads
Participatory observation	Waste segregation at source (3P), waste bank transaction flow, and communal activities *gotong royong*	Households, waste bank operators
Documentary study	Regional Waste Management Strategic Plan (Jakstrada), and waste generation statistics, village regulations	Government reports, academic journals

details, informal interactions, and spatial arrangements illuminating social dynamics within waste management systems. Observations were recorded systematically using structured protocols that captured temporal sequences, participant interactions, and material flows.

2.3.2. In-depth interviews

Semi-structured in-depth interviews were conducted with selected informants across all stakeholder categories. Interview guides explored informants' experiences with waste management, perceptions of community capacity, perspectives on collaborative processes, economic impacts, and suggestions for program improvement.

2.3.3. Focus group discussions

Focus group discussions were conducted with community members, waste bank operators, and government officials in facilitated sessions to discuss implementation experiences, collaborative challenges, and solutions. Enabled observation of group dynamics, consensus-building processes, and stakeholder negotiation of priorities. Sessions were moderated using semi-structured guides while allowing organic discussion flow. Focus group discussions were conducted with 45 participants from the six stakeholder categories, including five village heads and two ward heads; two heads of district technical agencies; three village-owned enterprise directors; five MSME operators or community waste group leaders; five informal waste collectors or aggregators; and 23 community members.

2.3.4. Document review

Document review examined local waste management regulations, meeting minutes, activity records, financial reports from waste banks, and community organization records at village and subdistrict levels. These documentary sources provided secondary verification of data and evidence of formal institutional arrangements. Documents were cataloged systematically and cross-referenced with interview and observational data to establish chronology and institutional context.

3. Results

3.1. Study area context and waste generation profile

North Bengkulu Regency, located on the west coast of Sumatra Island, covers 4,324.6 km² and had a population of 313,520 residents in 2025, yielding a population density of 72.50 persons/km². The regency comprises 19 subdistricts with 185 villages and wards. Kecamatan Kota Arga Makmur, the district capital, exhibits the highest population density (710.83 persons/km²), reflecting semi-urban characteristics, with 43,473 residents, while Kecamatan Padang Jaya displays rural settlement patterns, with elevations ranging from 250–750 meters above sea level and 32,997 residents.

According to the 2024 waste balance report, the regency generated approximately 68,192.66 tons of waste annually, with only 22.72% (15,491.58 tons) managed and 77.28% (52,700.22 tons) remaining unmanaged.[42] Waste reduction activities accounted for less than 0.1%, indicating substantial gaps relative to the national targets of 28% reduction and 71% handling by 2024. Per capita waste generation stood at 0.2199 tons/person/year, or 18.32 kg/capita/month.

Subdistrict-level waste generation data revealed that Kecamatan Kota Arga Makmur produced the highest volume (26,083.80 tons/year), followed by Kecamatan Padang Jaya (19,798.20 tons/year), as presented in Table 2. This pattern correlates strongly with population density, urbanization level, and economic activity intensity, consistent with research indicating that waste generation is closely tied to demographic and consumption variables.[1]

Waste source distribution analysis (Figure 1) showed that households contributed 50.78% of total waste generation, followed by commercial activities (14.77%), markets (12.19%), and offices (6.03%).[42] This household dominance aligns with national data and underscores the critical importance of source-level interventions targeting domestic consumption patterns, source segregation, and behavior change.[5]

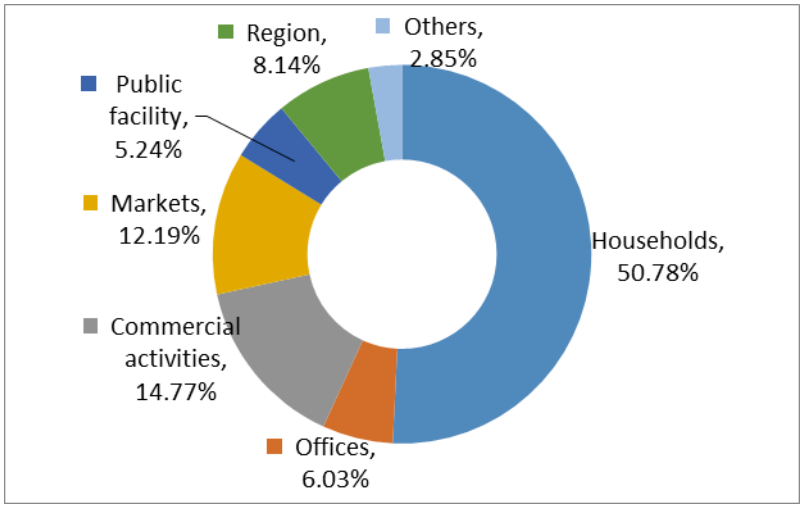

Figure 1. Waste source distribution in North Bengkulu Regency

Table 2. Waste generation by subdistrict in North Bengkulu Regency

No	Subdistrict	Waste generation (tons/year)
1.	Enggano	2,600.40
2.	Kerkap	7,813.80
3.	Kota Arga Makmur	26,083.80
4.	Giri Mulya	9,348,60
5.	Padang Jaya	19,798.20
6.	Lais	8,503.80
7.	Batik Nau	8,239.80
8.	Ketahun	12,618.60
9.	Napal Putih	5,176.20
10.	Putri Hijau	14,204.40
11.	Air Besi	6,204.60
12.	Air Napal	6,185.40
13.	Hulu Palik	7,087.20
14.	Air Padang	4,176.00
15.	Arma Jaya	8,026.80
16.	Tanjung Agung Palik	5,080.80
17.	Ulok Kupai	8,719.20
18.	Pinang Raya	10,698.00
19	Marga Sakti Seblat	10,698.00
Total North Bengkulu Regency		185,863.80

Source: North Bengkulu Regency Environmental Services Office.[42]

The waste composition shown in Figure 2 indicates that food waste is the largest fraction, followed by organic material, wood, and branches. This is consistent with waste composition in developing countries, where organic compounds are the largest fraction. Organic waste dominance indicates high fresh food consumption and household cooking activities, with high and low food waste management. Therefore, organic waste management through composting, biodigesters, and household food waste sorting is essential.

Inorganic waste with high value, such as plastic, paper/cardboard, metal, and glass, accounts for a significant fraction. This indicates an opportunity to strengthen the recycling chain through waste banks, improvements to TPS3R, and the integration of the informal sector. The high proportion of plastic also encourages the implementation of extended producer responsibility.

3.2. Existing waste management infrastructure

The regency's waste management infrastructure comprises formal government facilities, community-based units, and informal sector operations, as summarized in Table 3. The Waste Management Technical Implementation Unit (UPTD) in Rama Agung village has the largest capacity (40.59 tons/day) and serves as the backbone of the formal system.[42] Eight TPS3R units distributed across strategic subdistricts provide decentralized processing capacity totaling 13.95 tons/day.[42] This decentralized approach aligns with circular economy principles emphasizing waste management near the source to reduce transport burdens and maximize local material recovery.[43]

The waste bank network consists of one central waste bank in Gunung Selan village and 14 unit waste banks across government offices, villages, and schools, collectively managing 1.07 tons/day.[42] Analysis of individual waste bank capacities (Table 4) revealed substantial variation,

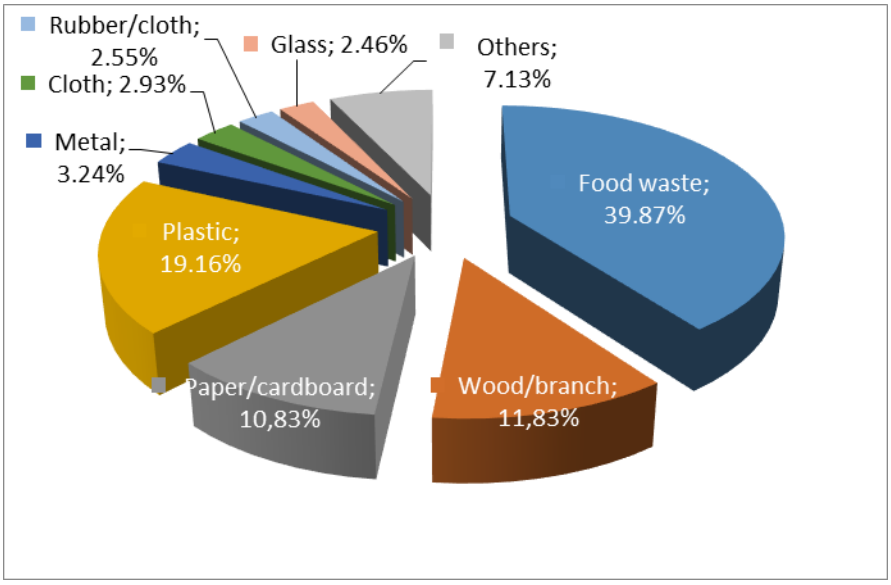

Figure 2. Waste composition in North Bengkulu Regency

Table 3. Existing waste management facilities in North Bengkulu Regency

No	Facility	Quantity	Location	Capacity (ton/day)
1.	Waste Management Technical Implementation Unit	1	Rama Agung Village	40.59
2.	TPST (Temporary final disposal site)	-	-	-
3.	TPS3R (Integrated waste reduction and handling facilities)	8	Kota Arga Makmur, Padang Jaya, Giri Mulya, Ketahun, Putri Hijau, Marga Sakti Seblat, Ulok Kupai	13.95
4.	Recycling center	1	Air Merah Village	0.003
5.	Central waste bank	1	Gunung Selan Village	0.04
6.	Waste bank	14	Government offices, villages, schools	1.07
7.	Composters	Data not available	Government offices, schools	1.83
8.	Non-formal waste aggregators	31	Throughout North Bengkulu Regency	111.346

with Usaha Bersama Waste Bank managing 0.5305 tons/day while others ranged from 0.0005 to 0.085 tons/day.[42] Waste banks have demonstrated effectiveness in enhancing community participation in waste segregation and promoting circular economy principles at the household level.[44,45]

Notably, the informal sector comprising 31 non-formal collectors/aggregators handles approximately 111.346 tons/day,[42] significantly exceeding the combined capacity of formal and community-based facilities. This confirms that informal waste workers constitute the backbone of material recovery in the regency, a pattern observed in many developing countries, where informal sectors achieve recycling rates of 30–40%, particularly for high-value materials such as plastics and metals.[46] Research emphasizes that effective and sustainable waste management strategies require the meaningful integration of informal collectors through formalization, training, and market linkages, rather than marginalizing this critical sector.[47]

3.3. Local innovations in household waste management

Fieldwork identified several notable community-driven innovations adapted to local contexts. In Lubuk Saung village, the village head initiated a lamppost modification system in which households hang segregated waste bags

Table 4. Waste banks in North Bengkulu Regency

No	Waste bank name	Village/Ward	Subdistrict	Waste managed (tons/day)
1	Usaha Bersama	Gunung Selan	Arga Makmur City	0.5305
2	Peduli Lingkungan Perumnas Abu Hanifah	Karang Anyar I Perumnas Lama	Arga Makmur City	0.08
3	BPBD	Gunung Selan	Arga Makmur City	0.02
4	Darling	Karang Anyar II	Arga Makmur City	0.04
5	Jegeg Asri	Rama Agung	Arga Makmur City	0.035
6	Mandiri	Karang Suci	Arga Makmur City	0.075
7	Mawar	Tebing Kaning	Arma Jaya	0.055
8	Saung Jaya	Lubuk Sahung	Arga Makmur City	0.085
9	Elementary School No.4	Karang Anyar II	Arga Makmur City	0.065
10	Sido Jaya	Sido Urip	Arga Makmur City	0.01
11	Teratai Indah	Tanjung Raman	Arga Makmur City	0.0005
12	Tunas Harapan	Marga Sakti	Padang Jaya	0.03
13	Arga Tirta Kemumu	Kemumu	Arma Jaya	0.01
14	Litara	Kelurahan Gungung Alam	Arga Makmur City	0.025

on designated hooks attached to lampposts, following a collection schedule (Monday, Wednesday, Friday), for a monthly fee of Rp 20,000. This innovation prevents indiscriminate disposal, facilitates systematic collection, and cultivates new waste handling norms rooted in local social structures. An approach consistent with research demonstrating that infrastructure adjustments aligned with existing social practices effectively alter waste behaviors.[48]

In Marga Sakti village, the "stacked bucket" (ember tumpuk) program processes organic household waste into compost and maggot larvae for livestock feed. Originally developed under the Climate Village Program (Proklim) with facilitation from WARSI (an environmental non-governmental organization), this approach integrates with TPS3R construction in Hamlet 5. The household-level organic processing aligns with circular economy principles, emphasizing the utilization of the organic fraction to support local agriculture and livestock systems.[49]

The waste savings program at Lubuk Saung Waste Bank provides economic incentives for households practicing source segregation. Recyclable materials are purchased by the waste bank and credited to individual household accounts, which can offset monthly service fees. This scheme effectively combines environmental and economic incentives, proven in the literature to enhance waste bank participation and program sustainability.[50,51]

In Rama Agung village, creative upcycling transforms glass bottles into decorative flower vases with woven nylon thread, adding economic value while reducing the burden of glass waste. An example of simple upcycling that creates both environmental and economic benefits for households.[52] Traditional community practices such as *gotong royong* (mutual cooperation) for village cleaning, though not regularly scheduled, demonstrate persistent social capital supporting collective environmental management.[53]

3.4. Stakeholder collaboration analysis

Analysis of interview themes from multiple stakeholders in five villages (Purwodadi ward, Rama Agung, Lubuk Saung, Marga Sakti, and Padang Jaya) highlights varying roles, capabilities, and limitations that characterize the local collaborative ecosystem. The results show limited household engagement in waste segregation, despite clear environmental awareness. Such knowledge-practice gaps are typical in community-driven waste management across developing nations.[54]

At the household level, knowledge of waste segregation remains limited despite general awareness of the importance of cleanliness. Segregation practices remain scarce, with burning and land disposal as the dominant

methods. Economic motivation for waste management remains low, as monetary incentives are insufficient. Nevertheless, households indicated readiness to engage provided that village authorities offer explicit guidance and tangible organizational support. This pattern aligns with existing studies that highlight the influence of factors such as information dissemination, environmental awareness, infrastructure access, and leadership involvement on community participation in waste management.[54,55]

Community waste management groups (waste banks, women's groups) serve as change agents and education facilitators but face sustainability challenges, including weak administrative systems, insufficient technical training, and a lack of market linkages for recyclables. Women's groups demonstrate greater involvement in organic waste processing but require advanced composting training. This finding reflects that community-based initiatives require sustained technical support and capacity building for long-term viability.[33]

Informal sector actors demonstrate a substantial capacity for sorting valuable materials, although they typically operate individually. Focus remains on high-value items, with low-value waste neglected, and volatile prices create ongoing sustainability risks. Integration of informal collectors through cooperative formation and formal recognition represents a critical policy need.[47]

Village governments recognize their role as facilitators, but most lack formal waste management policies and budget allocations. Some villages wish to establish waste banks but lack standard operating procedures and technical support. Notably, villages that have actively involved village head leadership showed better waste management practices. In accordance with collaborative governance research emphasizing leadership commitment as an important factor for multi-stakeholder coordination.[32]

Small and medium enterprise operators processing waste into eco-enzyme, compost, soap, and handicrafts face constraints including limited market access, capital shortages, and unstable raw material supply. Effective circular economy implementation requires structured supply chains connecting households, communities, and MSMEs.

District-level agencies possess institutional foundations and programs, but implementation remains suboptimal due to limited technical staff and uneven village coverage. Existing waste regulations have expired, and comprehensive circular economy policies are absent; programs remain linear (collect-transport-dispose) rather than circular.[42,11] This reflects broader governance challenges documented in Indonesian waste management literature regarding fragmented institutional arrangements and unclear coordination mechanisms.[56]

3.5. CIRCLE-SIJAGO BU model: Collaborative circular economy framework

Drawing on field observations, stakeholder interviews, and relationship mapping, this study proposes the CIRCLE-SIJAGO BU model (Circular and Collaborative Local Ecosystem-*Sirkulasi Jaga Gotong-Royong Bengkulu Utara*). The model integrates local wisdom, communal innovation, appropriate technology, and micro circular-economy value chains through measurable, participatory actions that emphasize behavioral change alongside technical waste management solutions.

Collaboration between stakeholders in three main phases—upstream (reduction and segregation, midstream (reuse and recycling), and downstream (marketing and regeneration)—to create sustainable waste management (Table 5). This collaboration is essential to solidify circular economy principles that require multi-stakeholder contribution.

The model consists of six interconnected components that function circularly (Figure 3): (i) households applying 3P principles (Segregate-Reuse-Process) through source segregation and basic processing such as composting and eco-enzyme production; (ii) community groups (waste banks, women's groups, informal collectors) collecting, processing, and adding value via TPS3R village facilities; (iii) village government establishing policy frameworks, budgets, and regulations by integrating into village development plans; (iv) MSMEs and businesses purchasing, processing, and marketing circular products; (v) external networks (regional aggregators, national recycling industries) ensuring sustainable material flows and price stability; and (vi) POINT-CYCLE monitoring-reward system tracking household contributions with points redeemable for economic benefits (shopping vouchers, seedlings, electricity tokens, basic goods), while generating real-time data to inform evidence-based village decision-making.

The model philosophy "Circle of Positive Impact Starting from Home Protecting Environment" utilizes collaborative circles linking households, communities, government, MSMEs/business sector, and external networks, returning to households and creating a living, sustainable circular ecosystem rather than a dead technical system. This approach puts collaborative governance principles into practice, requiring coordinated involvement from multiple actors: government, the private sector, and the community, in both decision-making and implementation.[28]

Table 5. Multi-stakeholder collaborative actions in circular economy phases

Stage	Primary Actors	Collaborative Activities	Output
Upstream: Reduction & segregation	Households, women's groups (PKK), neighborhood-level community units	- Segregation of organic waste (compost/livestock feed) and inorganic waste (plastic, glass, metal) - Weekly community service initiatives (*gotong royong*)	Segregated waste, reduced waste generation
Midstream: Reuse & recycling	Community groups (waste banks, women's groups), informal sector actors (waste pickers, aggregators), MSMEs	Waste collection; organic waste processing (eco-enzyme/briquettes); inorganic waste processing (handicrafts); village-level TPS3R operations	Economic value-added products
Downstream: Marketing & regeneration	Village/ward government, district environmental service (DLH), private sector	Local market development, producer extended producer responsibility (EPR) schemes, digital monitoring system, village fund facilitation	Inclusive income generation, reduced landfill overload

Abbreviations: MSME: Small and medium enterprise; TPS3R: Reduce-Reuse-Recycle Processing Stations.

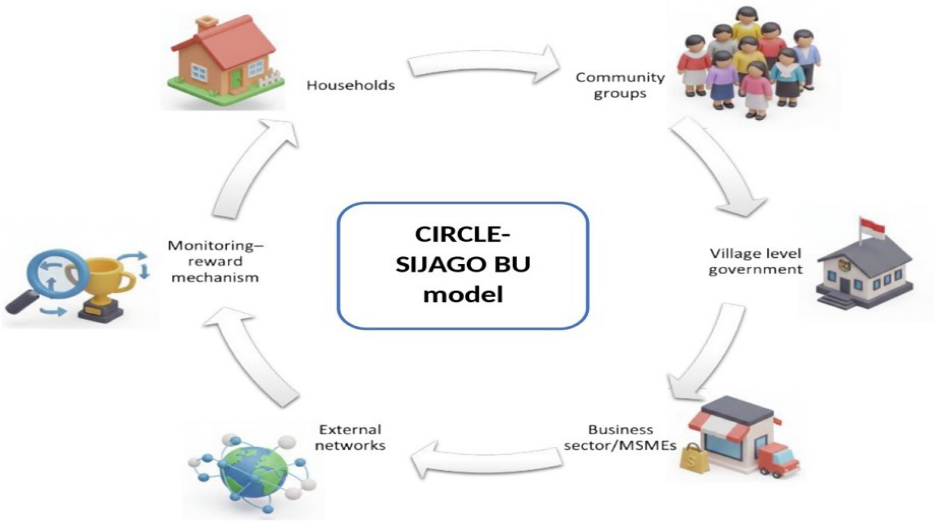

Figure 3. CIRCLE-SIJAGO BU collaborative model

3.6. Preliminary pilot effects

The CIRCLE-SIJAGO BU framework was formulated as a collaborative action innovation that integrates local wisdom, community innovations, and simple technologies to establish a micro-circular economy in North Bengkulu Regency.

Initial waste conditions show per capita generation of 0.6 kg/person/day or 186 tons/day, with only 22.72% transported to landfills and the remaining 77.28% managed independently or disposed of indiscriminately. Existing infrastructure includes one UPTD, eight TPS3R facilities, one central recycling unit, one main waste bank, 14 waste banks, and 31 informal collectors. The pilot targets efficiency gains for the unmanaged 77.28% waste fraction.

The framework is highly feasible given the operational community base. Preliminary testing via participatory observation and stakeholder surveys in North Bengkulu Regency showed that 4 out of 5 respondent households (80%) expressed readiness and were already applying the "sort-use-process" (3P) pattern. Supported by 14 waste banks as collaboration hubs, the framework simplifies inorganic waste supply chains.

Initial data indicate that applying *gotong royong* principles with supporting infrastructure could achieve 5–15% source reduction in pilot communities, compared with prior reliance on landfills.

As shown in Table 6, pilot quantitative data demonstrate high social acceptance (80%), confirming community

Table 6. Preliminary feasibility score of CIRCLE-SIJAGO BU

Evaluation dimension	Main indicator (Pilot)	Score	Feasibility category
Acceptability	Community willingness for organic/inorganic sorting (3P)	80%	High
Feasibility	Utilization of waste banks and TPS3R as circular hubs	14 waste banks; 8 TPS3R units	Feasible
Collaboration	Involvement of community cadres and local policy support	Active	Good
Circular impact	Household waste reduction potential to landfill	5–15%	Significant

readiness for the 3P pattern. Existing infrastructure (14 waste banks and 8 TPS3R units) provides the operational foundation for this circular ecosystem. Preliminary results suggest a 5–15% source-reduction potential, effectively addressing a substantial portion of the 186 tons/day of waste, with 77.28% remaining unmanaged.

3.7. Economic and environmental impacts

The CIRCLE-SIJAGO BU framework demonstrates measurable economic value, as shown in Table 7. Fourteen active waste banks collectively process 1.061 tons/day of recyclable inorganic waste, averaging 0.076 tons/day/unit. Based on current market prices for plastics, paper, metals, etc. (Rp 2,500/kg), this generates:

- Daily: 1,061 kg × Rp 2,500 = Rp 2,652,500
- Monthly (26 working days): Rp 2,652,500 × 26 = Rp 68,965,000
- Annual: Rp 68,965,000 × 12 = Rp 827,580,000 (~USD 53,000)

Table 7. Quantitative impacts of the CIRCLE-SIJAGO BU framework

Indicators	Achievement	Remarks
Active waste banks	14 units	Integrated circular hubs
Daily waste processing	1.061 tons/day	Collected & segregated
Efficiency per unit	0.076 tons/unit/day	High participation
Annual economic value	Rp 827,580,000	Household benefits

From an environmental perspective, this diverts 387.2 tons/year (1.061 tons/day × 365 days) from landfills, directly reducing the burden on North Bengkulu's waste infrastructure and addressing the 77.28% unmanaged waste fraction.[42]

3.8. Policy interventions for strengthening circular economy ecosystem

Multi-level interventions are required to operationalize the collaborative framework. Household interventions focus on: (i) targeted education via women's groups, health centers, and youth programs leveraging effective behavior change methods;[48,55] (ii) composting demonstrations featuring bamboo units and biopore systems; (iii) waste bank point systems rewarding dry waste contributions; and (iv) starter kits with clear waste segregation guides. These household-level interventions align with research emphasizing that routine dissemination of valid, persuasive messages significantly enhances public participation.[54]

Village-level interventions comprise: (i) small-scale transport services featuring regular collection schedules and affordable fees to ensure equitable access; (ii) TPS3R facilities with standardized layouts, organic processing zones (village composters), and dedicated sorting areas; (iii) village waste management units established as village-owned enterprises or cooperatives to oversee TPS3R operations and waste banks;[57] (iv) village regulations mandating segregation and service fees, backed by moderate sanctions and household reward mechanisms; and (v) waste bank business management training

At the regency level, strategic policy interventions encompass: (i) 5-Year Circular Economy Roadmap setting quantifiable waste reduction and waste bank development targets; (ii) regency regulation on waste and local extended producer responsibility mandating take-back schemes, producer contributions, and waste bank operational standards;[58] (iii) recognition and integration of informal collectors through operating permits, cooperative formation, and guaranteed market linkages improving worker livelihoods and formality;[47] (iv) mixed financing schemes combining regency budgets, village fund allocations, village-owned enterprises, and corporate social responsibility contributions; and (v) circular local procurement policies prioritizing recycled products (compost, recycled plastic handicrafts, woven goods)

ensuring guaranteed markets for local circular MSMEs and stimulating demand for recovered materials.[59]

4. Discussion

4.1. Role of local innovation and indigenous knowledge

Findings demonstrate that local innovations and indigenous practices play critical roles in realizing circular economies adapted to local socioeconomic and ecological conditions. The lamp post modification system in Lubuk Saung exemplifies how simple infrastructure adjustments, aligned with social norms, can systematically alter waste-handling behaviors without requiring sophisticated technology. The stacked bucket organic processing at Marga Sakti leverages traditional livestock-agriculture integration, transforming household organic waste into productive inputs. The waste-savings mechanism creates economic incentives that drive sustained participation. Cultural practices such as *gotong royong* provide social infrastructure enabling collective action, reducing transaction costs associated with organizing community waste management efforts.[53] These findings validate research documenting that community-based initiatives combining education, social norms, and simple innovations adapted to local contexts achieve tangible waste reduction.[48,50]

4.2. Collaborative governance and multi-stakeholder integration

The CIRCLE-SIJAGO BU model operationalizes collaborative governance principles by delineating clear yet interconnected roles across six stakeholder categories.[28] Unlike linear top-down waste management systems that treat households as passive waste generators, this model positions households as active circular economy actors incentivized through POINT-CYCLE mechanisms. Community groups bridge household-level actions and village governance and market systems, while village governments provide enabling policy environments that integrate waste management into formal development planning. Critical to model functionality is the integration of informal sector workers, who currently handle the majority of material flows (111.346 tons/day) yet remain marginalized within formal systems. Research consistently documents that formalizing informal collectors through cooperatives, permits, and market linkages enhances recycling rates, improves worker livelihoods, and stabilizes material supply chains.[46,47] The model's explicit recognition of this sector addresses a persistent gap in Indonesian waste management policy.[56,60]

The external networks component acknowledges that local circular economies cannot function in isolation; regional aggregators and national recycling industries provide essential market outlets, ensuring the economic viability of local collection and processing efforts. However, over-dependence on external markets creates vulnerability to price fluctuations and demand shocks, necessitating parallel development of local circular production systems (compost for agriculture, eco-enzyme for household use, handicrafts for local tourism) as buffers against market volatility.[61]

4.3. Challenges and opportunities

Implementation challenges span structural, social, technical, and market dimensions. Structurally, the expiration of regulations, the absence of circular economy roadmaps, and minimal environmental budg*et al*locations constrain systematic action.[42,11,56] Socially, limited knowledge of segregation, persistent disposal habits (burning, land dumping), and low perceived economic value of waste management hinder household-level transformation.[54] Technically, infrastructure deficits (TPS3R capacity, vehicle shortages, absent household composters) prevent effective material recovery even where motivation exists. Market challenges include unstable prices for recyclables, limited MSME access to markets, and the absence of structured supply chains connecting households to processors.

Despite challenges, significant opportunities exist. The regency's 50.78% contribution to household waste and a combined 51.70% organic fraction present substantial composting potential directly applicable to local agriculture and soil conservation.[42,62] Growing environmental awareness and emerging waste management initiatives in several villages provide social foundations for scaling.[63] Increasing demand for eco-friendly products creates market opportunities for circular MSMEs. Government commitment, evidenced by existing infrastructure (UPTD, TPS3R, waste banks) and programs, indicates political will for enhancement rather than initiation from scratch.[42]

The POINT-CYCLE innovation offers technological opportunity through digitalization, enabling transparent monitoring, data-driven policymaking, and sustained household engagement through gamification and visible rewards. This addresses common failure modes of community waste programs, loss of enthusiasm and accountability drift, by institutionalizing feedback loops and tangible benefits.[64] Digital systems that integrate waste value chains from collection to recycling can increase trust, transparency, and coordination among stakeholders while incentivizing private sector expansion of waste management businesses.[65]

5. Conclusion

This study demonstrates that sustainable household waste management in rural developing contexts can be achieved through deliberate institutional designs that integrate local social capital, indigenous collaborative practices, and recognition of the informal sector, rather than relying on capital-intensive centralized infrastructure. In North Bengkulu Regency, the CIRCLE-SIJAGO BU framework, which combines household-level waste segregation, community-based waste banks, collaborative governance among six stakeholder categories, and the formalization of informal waste workers, provides a replicable model that generates measurable waste reduction and economic benefits. Field evidence reveals that community-driven innovations, including lamppost collection systems, household organic processing, and waste savings programs, achieve tangible outcomes when coupled with village government support and clear institutional roles, demonstrating that social institutions and local wisdom can effectively substitute for capital and formal infrastructure as enabling conditions for circular economy implementation in rural waste management systems. However, this study has several limitations. As a three-month qualitative case study conducted in five villages within two subdistricts of North Bengkulu Regency, the findings are context-specific, not statistically generalizable, and the short timeframe limits analysis of seasonal variation in waste generation and community participation.

Acknowledgments

The author is grateful to the North Bengkulu Regency Regional Development Planning Research and Innovation Agency for providing institutional support during the preparation of this manuscript.

Funding

This work was supported by the North Bengkulu Regency Regional Development Planning Research and Innovation Agency.

Conflict of interest

The authors declare they have no competing interests

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Availability of data

The data are available from the corresponding author upon reasonable request.

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Appendix A. Participatory observation checklist

Level: Household

[ ] Waste segregation: Separation of organic (food waste) and inorganic (plastic, paper, metal) at the source

[ ] 3P protocol adoption: Evidence of sort-use-process (3P) activities

[ ] Waste collection: Regularity of waste pickup by local collectors or waste bank units

[ ] Knowledge: Household awareness of waste impacts and circular economy benefits.

Level: Village and community

[ ] Infrastructure: Availability of TPS3R or waste bank (*bank sampah*) units

[ ] Community action: Active involvement in weekly *gotong royong* (communal cleaning)

[ ] Local innovation: Creative products made from recycled waste (example: handicraft, organic fertilizer).

[ ] Local leadership: Active support from village heads and community leaders (PKK/Karang Taruna)

Remarks:

Monitoring of bin capacity and household compost decomposition duration.