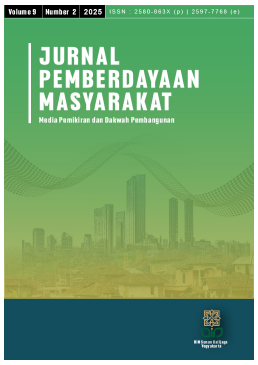

Jurnal Pemberdayaan Masyarakat
Media Pemikiran dan Dakwah Pembangunan

ISSN: (Print) (Online) Journal homepage:
https://ejournal.uin-suka.ac.id/dakwah/JPMI/index

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To cite this article: Arie Sujito & Nefa Wahyuning Anggraini (2025): Integration of Circular Economy Approaches and Community Participation in Waste Management Based on Campus-Village Partnerships, Jurnal Pemberdayaan Masyarakat: Media Pemikiran dan Dakwah Pembangunan, DOI:10.14421/jpm.2025.092-01

Type of paper: Research article

To link to this article: https://doi.org/10.14421/jpm.2025.092-01

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https://doi.org/10.14421/jpm.2025.092-01

Integration of Circular Economy Approaches and Community Participation in Waste Management Based on Campus-Village Partnerships

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The Special Region of Yogyakarta is facing an increasingly severe waste management crisis due to rapid urbanization and limited landfill capacity, with daily waste production has reached approximately 1,500 tons and a recycling rate of only around 15%. This study examines the campus-village partnership model as a transformative approach based on the circular economy (CE) to address this crisis, with a focus on the collaboration between Gadjah Mada University and the Sinduadi Village community. The method employed is a descriptive, qualitative approach, utilizing in-depth interviews, participatory observation, and documentation. The research results demonstrate that applying the application of ReSOLVE principles, including Regenerate through composting and maggot farming, Loop through waste banks, and Optimize through waste processing technology, has sparked social innovation and community-based entrepreneurship. However, these initiatives face structural constraints, including limited incentives, inadequate infrastructure, and underdeveloped distribution ecosystems. This study emphasizes the importance of adaptive institutional design, regulatory support, and strengthening local capacities as essential prerequisites for the sustainability of partnership-based CE, and recommends the reorientation of waste management policies toward a more participatory and context-based model.

ARTICLE HISTORY
Received 10 April 2024
Accepted 30 December 2025

KEYWORDS
Campus-Village Partnership, Circular Economy, Community-Based Waste Management; Quadruple Helix; ReSOLVE Framework

Introduction

The Special Region of Yogyakarta is facing a critical waste management emergency, as urbanization and population growth strain existing systems to their limits. This situation reflects a global trend in which urban expansion and increased human activity lead to the excessive exploitation of natural resources and a surge in domestic and industrial waste (Hoang et al., 2022; Worldometer, 2025). The city of Yogyakarta generates approximately 1,500 tons of waste daily; however, only 15% is currently recycled. The remainder either accumulates in temporary shelters or awaits transport. The closure of the Piyungan Final Disposal Site (TPA) due to overcapacity has exacerbated the crisis,

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resulting in large volumes of unmanaged waste throughout the city and disrupting daily waste collection and disposal.

Poor waste management in Yogyakarta has led to various environmental threats, particularly air, water, and soil pollution. Methane gas (CH_4) emitted from unmanaged waste contributes to global warming and poses direct health risks to nearby communities (Wang & Li, 2021). Simultaneously, leachate from decomposing waste infiltrates groundwater sources, spreading pathogens and heavy metals that are harmful to human health (Zhang et al., 2022). These issues mirror global trends in rapidly urbanizing regions, where inadequate waste systems lead to significant environmental degradation and declining urban livability (Voukkali & Zorpas, 2022). Therefore, without a circular economy-based management system and a waste reduction approach at the source, Yogyakarta will face a more severe escalation of environmental crises.

To address this issue, the local government has implemented a regulatory framework combining Regional Regulation No. 10/2012 (amended by No. 1/2022) and Mayor Regulation No. 40/2024. These laws promote waste reduction through sorting, recycling, and discouraging the use of single-use plastics. Programs such as the ZeroWaste Movement (2023) mandate waste segregation at the household level. However, enforcement remains weak due to infrastructural gaps and low public compliance. Decentralized initiatives, such as the construction of TPS 3R facilities in Nitikan, Karangmiri, and Kranon, indicate progress; yet questions remain regarding their scalability, capacity, and integration with broader city systems.

Amid this fragmented governance landscape, Universitas Gadjah Mada (UGM) plays a strategic role. Through academic research, community engagement, and partnerships with local authorities, UGM has the potential to champion circular economy models grounded in inclusivity and long-term sustainability. However, these efforts often lack coordination and measurable outcomes. Therefore, this study aims to investigate how university-government-community partnerships can co-produce more effective and equitable waste management strategies in Yogyakarta, focusing on UGM's role in catalyzing participatory, place-based solutions that support systemic transitions toward sustainable urban waste governance in the Global South.

Literature Review

Circular Economy in Waste Management

The concept of a circular economy (CE) has become central to sustainability discourse, offering a strategic alternative to the linear "take-make-dispose" model (Ellen MacArthur Foundation, 2015b). By emphasizing waste reduction, resource regeneration, and product life extension, CE frameworks promise both ecological and economic benefits (European Parliament, 2023; Geissdoerfer et al., 2018). A circular economy is an economic system designed to be restorative, aiming to reduce environmental impact and optimize resource utilization (Ellen MacArthur Foundation, 2015a). This system is based on three main principles: eliminating waste and pollution from the design stage, maintaining the use of

products and materials within the economic cycle, and regenerating natural ecosystems (Murray et al., 2017).

The application of these principles can be implemented across various sectors and contexts. For example, waste and pollution reduction can be achieved through the design of durable, modular products that are easy to repair or upgrade. Additionally, maintaining products within the economic cycle can be facilitated through sharing-based business models, leasing, or remanufacturing (CA Bakker et al., 2014). Furthermore, the regeneration of natural systems can be promoted by improving soil health, biodiversity, and carbon sequestration (Geng et al., 2019). Numerous studies demonstrate that implementing a circular economy yields significant environmental, social, and economic benefits, such as reducing greenhouse gas emissions (Ghisellini et al., 2016), job creation (Gravagnuolo et al., 2019), and cost efficiency.

One of the main benefits of the circular economy is the reduction of waste and pollution. By keeping materials and products in the usage cycle for as long as possible, the circular economy can reduce resource consumption and environmental impact, including the reduction of greenhouse gas emissions, land use, and water consumption (Kirchherr et al., 2017). In addition to environmental benefits, the circular economy also provides significant economic value. The more efficient use of resources allows businesses to reduce production costs and increase profitability. This economic model also encourages the emergence of new business opportunities, such as recycling and repair services, product as a service business models, and industrial symbiosis that utilizes waste as raw materials for other industries (Geissdoerfer et al., 2018). Furthermore, the implementation of the circular economy has the potential to create jobs in waste management sector, renewable energy, and environmentally friendly manufacturing (Murray et al., 2017).

However, there are several challenges in the implementation of the circular economy, one of which is changing consumer behaviour. In order for the circular economy to develop, consumer awareness and willingness to purchase recycled products and implement repair and reuse practices are necessary. These changes require efforts to raise awareness, provide incentives, and reduce barriers such as perceptions related to the convenience and quality of products (Murray et al., 2017). Another challenge in implementing the circular economy is the need for investment in new technologies and infrastructure. The transition to this system requires innovation in material design, product lifespan extension, and more effective waste management systems (Geissdoerfer et al., 2018). These challenges become even more complex for small and medium enterprises, which often face limitations in financial resources and technical expertise required to adopt the circular economy model. Despite various obstacles, the circular economy remains a key driver for sustainable development of resource utilization.

The ReSOLVE framework provides an operational lens for CE implementation, comprising six key actions: Regenerate, Share, Optimize, Loop, Virtualize, and Exchange (Ellen MacArthur Foundation, 2015a), While this framework is widely cited, empirical studies on its application in decentralized, community-based waste systems, especially in

Global South contexts remain scarce. Most literature focuses on industrial symbiosis and urban governance in high-income countries, with limited attention to how CE principles translate in semi-urban or peri-urban communities where infrastructure, incentives, and behavioural shifts pose serious constraints (Kirchherr et al., 2017). Furthermore, cultural and social dimensions of waste practices are often underexplored in CE discussions that privilege techno-economic perspectives.

The ReSOLVE framework includes various elements that can be applied to create a more efficient and sustainable waste management system.

The framework consists of six strategic components, each of which is described below.

Regenerate	Emphasizes the utilization of organic waste for compost and renewable energy, as well as the restoration of local ecosystems;
Share	Encourages the optimization of resources through community-based waste banks and shared processing facilities;
Optimise	Focuses on the efficiency of waste sorting, the use of monitoring technology, and strengthening the recycling supply chain;
Loop	ensures that the recycling cycle runs effectively through the reuse of materials such as plastic and paper in a community-based circular economy;
Virtualise	Supports the reduction of physical material used through the digitalization of waste bank systems and online education;
Virtualise	Focuses on waste management innovation through the adoption of new technologies, the replacement of non-biodegradable materials, and collaboration between academics, industry, and village communities. The implementation of ReSOLVE in partnership-based waste management can enhance community awareness and engagement, as well as create a more sustainable waste management ecosystem.

In this study, CE is examined not merely as a technical model but as a socio-institutional transformation, wherein universities can act as boundary organizations that broker between normative sustainability goals and local waste realities. This perspective complements critiques that call for place-based and relational approaches to CE (Gregson et al., 2015), aligning with our interest in how UGM's engagement in Yogyakarta's waste system can catalyze systemic shifts through knowledge co-production and partnership-based governance.

Collaborative Innovation following the Quadruple Helix Model

The Quadruple Helix concept is an extension of the Triple Helix, which adds society as the fourth actor in the innovation system—mainly through the roles of media, culture, and civil society (Carayannis et al., 2018). This model emerged to address the limitations of the Triple Helix in capturing the increasing complexity of innovation ecosystems,

which now demand deeper engagement with public opinion, cultural values, and civic participation in shaping innovation agendas and sustainability transitions.

This shift is particularly relevant to this study, which examines how university-government-community partnerships specifically involving Universitas Gadjah Mada (UGM) can co-create circular economy-based waste management solutions in Yogyakarta. In this context, the QH model offers a useful analytical lens to understand how civil society is not merely a passive recipient of innovation, but rather an active co-producer of knowledge and environmental action. The complexity of waste governance in Yogyakarta, marked by infrastructural limitations, behavioral barriers, and fragmented coordination, underscores the importance of multi-actor engagement beyond institutional mandates alone.

Building on Leydesdorff and Etzkowitz's early exploration (Carayannis et al., 2018), and later conceptualizations that highlight the role of media, culture, creative industries, and lifestyle values (Hasche et al., 2020), this study situates waste management as both a technical and cultural process. The inclusion of civil society—whether through *waste bank volunteers, local environmental activists, community leaders,* or digital campaigns reflects the fourth helix's emphasis on knowledge democracy and grassroots innovation.

Arnkil et al. (2010) outline four Quadruple Helix (QH) innovation models, ranging from user-driven innovation to citizen-led initiatives, emphasizing the increasing role of civil society in shaping innovation processes. These models are particularly relevant to the context of Yogyakarta, where initiatives such as the ZeroWaste Movement and TPS 3R highlight the necessity of active community participation. However, their success depends not only on engagement but also on the capacity of intermediary institutions particularly Universitas Gadjah Mada (UGM) to mediate, coordinate, and embed such participation within a sustained governance framework. By employing the QH perspective, this study critically examines the enabling conditions and institutional frictions that influence collaborative innovation in decentralized waste management, especially in cases where top-down policies alone prove inadequate.

Methods

This research uses a descriptive qualitative approach to systematically describe community-based waste management in Sinduadi Village, Sleman Regency, Special Region of Yogyakarta. This approach enables researchers to gain a profound understanding of the dynamics of waste management at the village level, including the roles of various stakeholders and the challenges to implementing environmental policies. The selection of informants was carried out using purposive sampling techniques, involving relevant parties with direct knowledge of waste management issues, such as village officials, managers of the waste management community (TPS Terpadu Sinduadi Gumregah Gayeng Regeng), academics from Gadjah Mada University, the Sleman Regent, and the Head of the DIY Environmental Agency.

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Data collection was conducted using three primary techniques: observation, in-depth interviews, and documentation. Direct observation was employed to record the community's activities and patterns in sorting and managing waste, as well as the waste management systems implemented. Interviews were held with key informants, including sanitation officers, residents actively involved in recycling programs, and waste bank managers, to explore their perceptions, experiences, and participation in environmental management. Documentation involved reviewing village regulations, waste management program reports, and environmental policies applicable at local and regional levels. The use of these varied techniques not only enriches the data but also supports the principle of triangulation, which aims to cross-verify information across different sources and methods.

Although this descriptive qualitative approach provides ample room for exploring local dynamics, this research remains aware of its limitations in geographical scope. Focusing on a single village area means that the results of this research cannot be directly generalized to other regions with different social or institutional structures. Therefore, this research is contextual and can serve as a foundation for further studies in other areas, enriching the understanding of community-based waste management in Indonesia.

Result and Discussion

Transformation of Waste Management as a Form of Community Response to the Ecological Crisis

The transformation of waste management in Yogyakarta following the closure of the Piyungan Final Disposal Site (TPA) highlights a structural failure in the environmental governance system, particularly in integrating state policy interventions with changes in community behavior. The accumulation of waste at various locations, including along the Southern Ring Road, pollutes the environment and increases the risk of waterborne diseases such as leptospirosis. A cross-stakeholder discussion forum revealed that the primary issues are inadequate infrastructure, a lack of credible public education, and insufficient government incentives, all of which exacerbate this crisis. The state's capacity to coordinate a systemic response to the increasingly fragile urban ecological shifts remains weak.

Empirical research in Sinduadi, Sleman, Yogyakarta, indicates that the community has become a central actor in creating locally based solutions amidst the

stagnation of state institutions. Active community participation, supported by critical education about ecology, is relevant to the knowledge, attitudes, and practices of sustainable waste management, such as sorting, reducing, and composting household waste (Firdaus, 2025; Subri et al., 2025).

In the context of weak state intervention, local communities play an active role in responding to the ecological crisis.

> *"If in the past, waste banks were driven at the community level, they managed themselves, sorted, processed, and practiced reduce, reuse, recycle..."*

> *"We need to trace how the community faces waste sovereignty. They produce tools, process them themselves, and raise awareness".*

These findings are reinforced by participatory observations that show a significant increase in the ecological literacy of the Sinduadi community, including awareness of the 3R Principles (reduce, reuse, recycle), which are now practiced sustainably. Social transformation in waste management also involves capacity building, group empowerment, and the formation of a new culture that is adaptive to environmental challenges (Brotosusilo et al., 2020). The Sinduadi community collectively initiated a manual sorting waste bank, household-scale composting, and environmental awareness campaigns. Amid technical and financial limitations, the local community initiated social entrepreneurship based on recycled waste, marking the emergence of grassroots socio-economic innovation.

However, despite community participation demonstrating social vitality in responding to the ecological crisis, the community's capacity has structural limitations that cannot be overcome without systemic support. In this context, it is essential to reassess the Circular Economy (CE) framework, which is widely regarded as a key solution to excessive consumption and uncontrolled waste (Lieder & Rashid, 2016). CE practices are often adopted normatively without considering the local socio-ecological context, which tends to make them technocratic and elitist. As criticized by Chenavaz & Dimitrov (2024), the implementation of CE is often hindered by weak regulations, low local technological innovation, and an underdeveloped market for recycled products.

The case of waste management transformation in Sinduadi provides a concrete illustration of this ecological issue. The effort to develop the Integrated Waste Management Site (TPST) by the Village-Owned Enterprise (BUMDes) is one manifestation of that collective response. Gadjah Mada University, through its community service program, supports this innovation by collaborating with the village government to build a waste processing unit that integrates various technologies such as machines (Refuse Derived Fuel), sorting tools, maggot cultivation, and biofish ponds. However, the transformation of waste management is accompanied by a series of structural challenges that reflect the complexity of circular economy practices in the

village context. For example, high operational costs, particularly in managing inorganic waste, pose a barrier to the sustainability of the waste management site (TPST). Additionally, the weak competitiveness and market access for recycled products, such as paving blocks made from plastic waste, indicate a disconnection between local innovation and the economic ecosystem.

The initiative of the Sinduadi community is not solely driven by technological logic, but rather by the strength of local institutions and the social networks that have formed. The village government plays a role by allocating funds from the Village Revenue and Expenditure Budget (APBDes) since 2023 to support the operations of the TPST. Meanwhile, community groups form management units, such as waste banks, environmental care cadres, and recycling-based BUMDes in line with the co-production model, which involves symbiotic partnerships to address resource limitations and strengthen local capacity (Amornsiriphong et al., 2025; Zunariyah et al., 2025). The production of policies and services for addressing ecological problems is not solely the domain of the state, but also arises from the reciprocal interaction between society and formal institutions. Key success factors include community leadership, incentives, and innovation in strategies based on economic and ecological values (Leknoi et al., 2024; Zunariyah et al., 2025).

The CE framework, in reality, is not just a single formula applied universally; this approach needs to be transformed into a place-based strategy, as Gomide et al. (2024) emphasize the importance of understanding social characteristics, institutional capacity, and local networks in formulating CE strategies. Addressing the waste problem in Sinduadi requires structural collaboration, supported by a robust legal and institutional framework, as well as sustainable local initiatives. Place-based CE approaches and sustainable development principles become the main strategies in responding to the waste crisis and encouraging a shift in mindset from linear consumption to sustainable resource utilization. This approach can encourage several aspects, such as waste sorting by type, optimization of landfill practices, and the implementation of CE that{Citation} aligns with local realities (Franceschi et al., 2022; Harbiankova & Kalinowski, 2023; Salazar et al., 2021).

Thematic Analysis of Waste Management Based on Circular Economy

Social Dimension: Participation, Education, and Environmental Culture

Community participation, education, and environmental culture are the main pillars of sustainable waste management. Higher education institutions play a crucial role as institutional actors in EC-based waste management, with centers for innovation, education, and policy catalysis. Gadjah Mada University must serve the community, one of which is implemented through relevant and sustainable environmental education in Sinduadi, Sleman. Sustainable environmental education can shape awareness and behavioral norms that support a positive ecological culture, even from an early age (AkiNtunde & AkiNtunde, 2023; Salazar et al., 2021; Sunarti et al., 2021). Borrero &

Yousafzai (2024) state that higher education institutions can serve as a means to develop more efficient waste processing technologies, create circular business models, and build collaborations with the government, private sector, and society.

Higher education institutions act as institutional entrepreneurs, leading in the production and dissemination of knowledge to drive the transition to a Circular Economy (CE) (Alonso-Almeida et al., 2021). Gadjah Mada University, as a multifaceted entity, not only conducts research on circular economy models but also initiates business incubators and develops best practices that serve as references for the implementation of CE (Millette et al., 2020; Sukiennik et al., 2021). Strengthening knowledge capacity in this research becomes a fundamental element in accelerating the adoption and sustainability of the CE system. Active community involvement, supported by educational programs, significantly enhances knowledge, attitudes, and waste management practices, such as sorting, composting, and recycling, at both household and community levels (Joleha et al., 2024; Nurhayati & Nurhayati, 2023; Subri et al., 2025).

Figure 3: Field training for the maintenance of wastewater treatment installations. *Source:* UGM Report

Figure 2: FGD Business Scheme with BUMKAL Sindu Mandiri. *Source:* UGM Report

Figure 3: Education from house to house with KKN activities. *Source:* UGM Report

Gadjah Mada University actively fosters strategic partnerships between universities and rural communities through various educational, consulting, and business mentoring initiatives. To strengthen the Village-Owned Enterprises (BUMDes) Sindu Mandiri, UGM provides interventions such as technical training, business scheme development, and community empowerment via the Community Service Program (KKN). This approach exemplifies the role of higher education institutions as agents of social change, focusing not only on knowledge development but also on its practical application at the community level. UGM's involvement in the waste management transformation process in Sinduadi highlights the contribution of academic actors within the quadruple helix framework, particularly in enhancing local social and institutional capacities.

One of UGM's tangible contributions to this program is on-site training for the maintenance of wastewater treatment facilities. This step aims to enhance the community's technical capacity to independently manage local resources while also

ensuring the sustainability of the environmental management system that has been implemented. In addition, business mentoring through focus group discussions (FGDs) with BUMKal Sindu Mandiri enables the creation of a sustainable and adaptive business model that aligns with the local economic potential. The success of the waste management program is greatly influenced by infrastructure support, regional leadership, and an approach tailored to the demographic characteristics (Pandey, 2025).

The strategic innovations implemented by UGM also target the household level. UGM organizes training sessions on household waste sorting and management. These sessions not only focus on technical aspects—such as methods for sorting organic and inorganic waste, small-scale composting, and the reuse of domestic waste—but also emphasize the importance of ecoliteracy and shifts in values related to daily consumption and production practices. The training provided by UGM at the household level serves as an educational tool and functions as a mechanism for knowledge production, challenging the dominance of top-down, technocratic state approaches.

The training on sorting and managing household waste successfully triggered a collective behavioral change. The Sinduadi community has begun incorporating the principles of the circular economy (CE) into their domestic practices, including sorting waste at the source, reducing single-use plastic consumption, and developing an independent organic composting system. This practice has expanded to the village level, where the community has organized communal activities such as compost gardens and micro waste bank units based on neighborhood associations (RT). The participatory, locally based approach used by UGM has a stronger transformative impact compared to an educational approach relying solely on administrative appeals.

During the training, residents acquired practical skills, including techniques for sorting organic and inorganic waste at the source, simple home composting methods, and the implementation of a 3R (reduce, reuse, recycle) system tailored to local needs. The training materials were contextually designed, considering the social characteristics and regional capacities of the residents. Consequently, the approach was participatory and dialogical rather than top-down and instructive. As a result, the training not only enhanced ecological literacy but also strengthened social solidarity among residents by fostering collective habits of sustainable waste management.

Furthermore, student involvement in the Community Service Program (KKN) serves as a strategic mechanism for enhancing the transfer of knowledge to the community. The house-to-house educational approach demonstrates that collaboration between the campus and the village is based not only on structural and institutional aspects but also on individual engagement. Intrinsic factors such as motivation, moral norms, and a sense of social responsibility—nurtured through education and participation—have been shown to drive behavioral change and increase citizen involvement (Brotosusilo et al., 2020; Sunarti et al., 2021). With this model, the Sinduadi community can gain a deeper understanding of the concept of social entrepreneurship and develop the skills necessary to effectively manage community-based enterprises.

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Overall, UGM's intervention in the form of training, FGD, and education through KKN not only represents the transfer of knowledge but also becomes part of a knowledge democratization project that encourages the decentralization of authority in environmental governance. In the context of Sinduadi, UGM's role demonstrates that the success of waste management transformation is not only determined by technical infrastructure but is rooted in community agency, institutional capacity, and contextual knowledge networks. This approach serves as a concrete example of how UGM plays a political and epistemic role in intervening in structural issues through an adaptive and participatory collaboration model.

Economic Dimension: The Role of BUMDes and Community-Based Schemes

The government has a strategic role in creating regulations, providing incentives, and building infrastructure that supports the implementation of a circular economy at the regional level. In the context of Sinduadi Village, the roles of the village government and the Sleman district government are crucial in strengthening the institutional capacity of the Village-Owned Enterprises (BUMDes) Sindu Mandiri, which serves as the leading actor in circular economy-based waste management. BUMDes acts as the main driver by managing waste banks, creating jobs, providing economic incentives, encouraging community participation, and increasing the village's original income (Faizin, 2024; Selfi Budi Helpiastuti et al., 2024).

Strengthening the circular economy system at the local level, the strategic role of the village government and BUMDes Sinduadi lies not only in institutional aspects but also in the operationalization of a community-based waste management system that is value-added oriented. One concrete example of the "Regenerate" and "Loop" principles within the RESOLVE framework is the utilization of organic waste for maggot cultivation and compost production by BUMDes Sindu Mandiri. The diversification of these processed products creates a new value ecosystem that strengthens local economic resilience while reducing the volume of residual waste ending up in landfills (TPA).

Maggot farming not only serves as a technology for processing organic waste but also becomes a circular business model that can simultaneously integrate social, economic, and ecological aspects. The harvest of maggots can be used as livestock feed or as raw materials for the feed industry. At the same time, local farmers can utilize the compost and liquid fertilizer produced from the decomposition of organic waste. The integration

between the waste management sector and the fisheries sector forms a circular ecosystem that not only strengthens local food security but also multiplies the economic potential of previously financially worthless organic waste streams (Budhijanto et al., 2024). This strategy reflects the "Loop" and "Exchange" dimensions within the RESOLVE framework by returning materials to the productive cycle and creating value through the substitution of primary resources with secondary ones.

BUMDes Sindu Mandiri holds control over the entire operational management of TPST Sinduadi, serving as both a technical operator and a business entity. The developed managerial structure involves two managers with clearly defined roles. First, focusing on the technical management of the facility, while the other handles business and financial aspects, including marketing the processed waste products to partners or potential consumers (Budhijanto et al., 2024). This management model reflects a professional approach to local environmental governance that not only relies on community participation but also applies measurable and data-driven principles of social entrepreneurship. In this context, BUMDes no longer functions passively as the implementer of village programs, but rather as a key actor in the local circular economy system with managerial, technical, and commercial capacities. This strengthens the position of BUMDes as an institutional hub within the quadruple helix framework, while also serving as an example of good practices in village institutional transformation during the era of ecological and economic transition.

This waste management scheme becomes an action in realizing the principles of exchange and regeneration of local resources, which are at the core of the circular logic. Community-based innovation contributes to reducing waste volume and alters the public perception that waste has economic value (Joleha et al., 2024; Nurhayati & Nurhayati, 2023). Nevertheless, waste management in Sinduadi faces significant challenges, primarily due to residue (a type of mixed waste that is unprocessed and has no direct economic value). The absence of advanced facilities for processing residues, combined with the limited capacity for initial sorting at the household level, makes residues the primary obstacle to creating a closed-loop cycle in the management system. The integration of the roles of village governments, communities, BUMDes, and Gadjah Mada University in managing the circular material flow reflects the quadruple helix approach, where the synergy between state actors, communities, the private sector, and higher education institutions forms a mutually reinforcing collaborative system.

However, despite the potential for a community-based circular economy starting to take shape, challenges such as limited human resources, the lack of permanent incentive schemes, and the absence of binding regulatory frameworks still pose structural obstacles. For example, the initiatives of maggot farming and compost production are not yet supported by a well-established distribution ecosystem, and there are no fiscal or non-fiscal incentives that encourage the participation of industries or households in this value chain. In the RESOLVE framework, this approach has not yet fully activated the "Optimize" and "Virtualize" dimensions, which can be realized through the integration of digital reporting systems, material traceability, and community-based online learning.

Therefore, in the future, BUMDes Sindu Mandiri needs to expand its role not only as an operator of TPST but also as an institutional platform that bridges community needs with green economic opportunities. This can be realized through incentive-based training programs, development of biomaterial-based products, and multi-stakeholder cooperation focused on knowledge transfer and social capital. Such strategies enable the circular economy system in Sinduadi to be not only materially efficient but also socially just and institutionally resilient.

Technology Dimension: Innovation and Operational Effectiveness

Waste management at TPST Sindu Mandiri reflects the application of the circular economy concept through the use of appropriate technology, aimed at optimizing the utilization of waste residues. The processing of organic waste involves the presence of a wastewater treatment system (Wastewater Treatment/WWT). This system is designed to handle wastewater from the cleaning of equipment and leachate droplets resulting from the decomposition of the organic fraction of waste (Budhijanto et al., 2024). Leachate is one of the primary sources of pollution in organic waste management, which, if not properly managed, can cause a pungent odor and contaminate surrounding soil and water bodies. WWT has become a critical infrastructure that supports the principles of regeneration and protection of the local ecosystem (Budhijanto et al., 2024; Catrawedarma et al., 2025).

The wastewater treatment (WWT) technology implemented at TPST Sinduadi combines anaerobic and aerobic processes, with intensified aeration achieved through an energy-efficient micro-bubble generator an innovation developed and patented by Gadjah Mada University. This technology enables the effective and efficient decomposition of organic compounds in leachate while maintaining low energy consumption. The system eliminates odors and organic pollutants and produces liquid fertilizer as a byproduct, which can be utilized in local agriculture after undergoing a nutrient enrichment process. The WWT unit not only mitigates environmental impacts but also generates added value, aligning with the "Regenerate" and "Optimize" principles within the RESOLVE framework.

In addition to wastewater management, TPST Sinduadi implements a strategy to optimize the inorganic residue fraction through an appropriate technological approach that supports the circular economy principle. According to the operational report, TPST processes approximately 500 kg of residual waste daily, which is treated using washing and drying systems to enhance material quality. Of this total, about 400 kg per day is allocated for the production of Refuse-Derived Fuel (RDF), an alternative fuel that industries can use as a substitute for coal. This strategy not only reduces dependence on fossil fuels but also decreases the volume of waste typically sent to landfills, while simultaneously lowering carbon emissions from conventional waste management systems.

Conclusion

The transformation of waste management in Sinduadi Village exemplifies the potential of a community-based circular economy (CE), supported by universities such as UGM, to address the ecological crisis. The implementation of 3R practices (reduce, reuse, recycle), social entrepreneurship, and local technological interventions has successfully driven change. However, structural challenges remain, including inadequate waste infrastructure, weak incentives, and inefficient distribution of recycled products. Although the Quadruple Helix model has emerged as a promising framework for collaboration, capacity gaps among actors in this semi-urban context must be addressed through adaptive institutional design. This research recommends regulatory reforms, community incentive schemes, and the digitalization of reporting systems to achieve an inclusive, sustainable, and locally based circular economy.

Acknowledgement

The author expresses gratitude to the Directorate of Community Service of Gadjah Mada University and the Sinduadi Village, Sleman Regency, for the successful collaboration on sustainable waste management.

Author's declaration

The authors declare that there are conflict of interest.

Funding

The authors received no financial support for the research, authorship, or publication of this article.

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

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