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Developing a Community-Based Organic Waste Management Model through Biofertilizer and Black Soldier Fly *(Hermetia illucens)* Production

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Abstract. Household organic waste in urban settlements remains a persistent environmental challenge due to limited community-based processing systems and low levels of waste valorization. Many waste management initiatives are still activity-oriented and lack an integrated participatory circular framework that connects environmental, economic, and social dimensions. This community engagement program aimed to develop a Participatory Circular Community Model through the conversion of household organic waste into biofertilizer and Black Soldier Fly (Hermetia illucens) feed production in Plamongansari, Semarang, Indonesia. The program applied a collaborative approach involving youth organizations and women's community groups through structured training, hands-on practice, production mentoring, and evaluation using pre- and post-assessment instruments. Organic household waste was processed into liquid and solid biofertilizer, while carbohydrate-rich residues were utilized as substrate for Black Soldier Fly larvae cultivation. The results demonstrate significant improvements in community knowledge, technical skills, and environmental awareness, accompanied by the production of economically valuable organic fertilizer and maggot feed. The developed model illustrates how participatory circular practices can reduce household waste volume while generating micro-economic opportunities. This model offers a structured framework for sustainable urban waste management and presents strong replication potential for other urban communities seeking environmentally and economically viable waste solutions.

Keywords: household organic waste management; circular economy; biofertilizer production; Black Soldier Fly (Hermetia illucens); community empowerment

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INTRODUCTION

Rapid urbanization increases the volume of municipal solid waste, particularly household organic waste, across developing countries. Urban waste management systems in many regions remain disposal-oriented, prioritizing collection and transportation to centralized landfill facilities rather than promoting localized resource recovery. Linear waste practices contribute to greenhouse gas emissions, environmental degradation, and escalating public expenditure. Organic waste, representing a substantial proportion of household waste streams, frequently remains underutilized despite significant recovery potential. Research conducted in Indonesia demonstrated that household waste management was dominated by collection-and-transport mechanisms with minimal community-level processing (Syafitri et al., 2024; Syafmaini et al., 2025; Yunian et al., 2025). Such structural dependence on landfill systems underscores the necessity for decentralized and community-driven waste management strategies that integrate environmental protection with economic value generation.

The circular economy paradigm provides a conceptual foundation for transforming organic waste into productive resources through biological conversion and nutrient cycling. Organic residues can be processed into compost or liquid biofertilizer, thereby enhancing soil fertility and reducing landfill reliance. Black Soldier Fly (*Hermetia illucens*) larvae have been recognized as efficient bioconversion agents capable of accelerating organic waste decomposition while generating high-protein biomass suitable for animal feed (Sumardjo et al., 2022; Susilawati et al., 2024; Yani Syafei et al., 2025). Empirical studies reported that *Hermetia illucens* larvae utilized diverse substrates, including banana peels, agricultural residues, and food waste (Sari et al., 2023; Soliati, 2019; Sukmareni et al., 2023). Experimental investigations further revealed that feed composition, such as potato waste sludge and fermented coconut residue, significantly influenced larval growth performance and conversion efficiency (Sari et al., 2023; Soliati, 2019; Sukmareni et al., 2023). Such findings indicate strong technical feasibility for integrating organic waste conversion with larval cultivation systems.

Economic implications further strengthen the relevance of maggot-based waste management. Replacement of fish meal with maggot meal in poultry rations improved broiler performance in controlled feeding trials (Santoso et al., 2024). Community-level maggot cultivation initiatives were associated with increased economic value derived from organic waste processing (Mufidah et al., 2024). Integration of organic waste conversion with maggot production therefore aligns with circular economy principles by simultaneously reducing waste volume and generating value-added outputs. However, existing scholarship predominantly emphasizes laboratory experimentation and technical optimization, while structured participatory community frameworks receive limited analytical attention.

Sustainable waste management requires more than technical feasibility. Social engagement, behavioral change, and capacity development determine long-term continuity of environmental programs. Empirical research on household waste behavior demonstrated that knowledge and awareness significantly influenced participation in waste management practices (Putra & Pratiwi, 2025; Ramadhani et al., 2025). Nevertheless, many community interventions were implemented as short-term training programs without systematic integration of empowerment mechanisms, mentoring structures, and economic utilization pathways. Absence of structured participatory circular models represents a conceptual gap between technical innovation and sustainable community adoption.

Plamongansari, an urban village in Semarang, Indonesia, exemplifies landfill-dependent waste management practices. Household waste is routinely transported to Jatibarang landfill, while localized organic waste valorization remains limited (Putra & Pratiwi, 2025; Ramadhani et al., 2025). Community organizations actively conduct social programs, yet structured circular waste initiatives have not been institutionalized. Development of a Participatory Circular Community Model was therefore undertaken to integrate technical waste conversion, capacity building, and economic valorization within a cohesive framework. The proposed model advances sustainable urban waste management by linking environmental conservation with community empowerment and offers replication potential for comparable urban settlements.

METHODS

A participatory action-based design was employed to develop a Participatory Circular Community Model for household organic waste management. Community-based waste management requires integration of technical capacity, environmental awareness, and local economic engagement to ensure sustainability. Circular economy principles emphasize resource recovery and localized valorization of organic residues, thereby reducing landfill dependency. A structured participatory framework was therefore applied to combine technical training, production mentoring, and collaborative engagement between the academic team and community members.

The program was conducted in Plamongansari Urban Village, Pedurungan District, Semarang, Indonesia, an urban settlement characterized by disposal-oriented waste practices. Household waste in the area is routinely transported to Jatibarang landfill without prior neighborhood-level processing. Participants consisted of 25 residents affiliated with the “Sari Maggot” community group, including members of youth associations and women’s community organizations. Participation was voluntary and based on expressed interest in environmental management initiatives. Selection criteria prioritized active involvement in community activities to support program continuity.

Implementation occurred in three sequential phases: preparation, execution, and evaluation. During the preparation phase, coordination meetings were conducted between the university team and community representatives to identify local waste challenges and determine training priorities. Educational modules were developed to address organic waste sorting, biofertilizer production, and Black Soldier Fly (*Hermetia illucens*) cultivation techniques. The execution phase involved structured training sessions

Figure 1. Containers to accommodate household organic waste

combining lectures, guided discussions, and supervised practical activities. Participants practiced organic waste separation, fermentation-based liquid and solid biofertilizer production, and substrate preparation for larval cultivation. Carbohydrate-rich organic residues were processed as feed substrate for larvae. Mentoring activities supported technical accuracy, hygiene standards, and production consistency.

Evaluation assessed knowledge acquisition, technical competence, and program outcomes. Pre-test and post-test instruments measured changes in conceptual understanding of organic waste processing and maggot cultivation. Observational assessment documented participant capacity to independently produce biofertilizer and manage larval growth cycles. Quantitative assessment results were analyzed descriptively to identify knowledge improvement, while qualitative observations were interpreted to evaluate enhancement of environmental awareness and sustainability potential. Integrated analysis indicated that participatory engagement combined with circular production practices strengthened community capacity for decentralized organic waste management.

RESULTS AND DISCUSSION

Operationalization of the Participatory Circular Community Model

Implementation of the Participatory Circular Community Model began with systematic collection of household organic waste from participating residents in Plamongansari. Organic residues consisted primarily of vegetable scraps, fruit peels, leftover cooked food, and carbohydrate-based kitchen waste. Waste sorting

Figure 2. Organic liquid fertilizer results from household organic waste

Figure 3. Containers for breeding moggot

practices were introduced prior to processing to separate biodegradable materials from inorganic fractions. Such separation represents a foundational principle in decentralized waste valorization systems and determines efficiency of biological conversion processes shown in Figure 1.

Organic residues were transferred to perforated plastic containers designed to facilitate leachate drainage and aerobic–anaerobic stabilization. A stacked container configuration allowed liquid accumulation in a lower chamber while maintaining semi-closed fermentation conditions in the upper compartment shown in Figure 2. Fermentation resulted in the production of dark-colored liquid biofertilizer, indicating advanced decomposition and nutrient concentration. Solid residue underwent gradual stabilization and functioned as compost-like organic fertilizer. Production processes were conducted using low-cost locally available materials, reinforcing accessibility and scalability potential shown in Figure 3.

Carbohydrate-rich fractions were allocated to Black Soldier Fly (*Hermetia illucens*) larvae cultivation. Larvae consumed organic substrates efficiently and demonstrated accelerated biomass growth within several days of feeding cycles. Observational monitoring confirmed reduction in visible waste volume during larval feeding periods. Previous empirical research reported similar outcomes, indicating strong substrate adaptability of *Hermetia illucens* larvae across diverse organic materials (Asropi et al., 2023; S. Diana et al., 2025; Masniawati et al., 2023; Wicaksono et al., 2025). Experimental findings regarding alternative feed compositions, including tofu residue and fermented coconut waste, informed substrate diversification strategies applied in Plamongansari (Aprillianto et al., 2025; Ardhana et al., 2025; Aristya et al., 2025).

Operationalization of the model extended beyond technical processing. Participatory meetings, collaborative decision-making, and community dissemination sessions strengthened collective ownership. Local leaders, neighborhood representatives, and municipal stakeholders attended dissemination forums to observe outcomes and discuss replication possibilities. Community engagement embedded technical activities within social structures, ensuring continuity beyond a single training cycle.

Knowledge Transformation and Skill Acquisition

Assessment of participant knowledge was conducted using structured pre-test and post-test instruments. Baseline evaluation indicated limited familiarity with fermentation processes, nutrient cycling principles, and larval bioconversion mechanisms. Post-intervention evaluation demonstrated measurable improvement in conceptual understanding and procedural awareness. Participants articulated fermentation stages, moisture control requirements, and larval growth indicators with greater accuracy after completion of training sessions.

Figure 4. Disseminating the results of activities to the residents of Plamongansari

Skill acquisition progressed through guided hands-on practice and iterative mentoring. Early sessions revealed uncertainty in substrate moisture adjustment and larval density management. Subsequent sessions showed increasing technical confidence and precision. Participants independently executed waste sorting, container arrangement, and feeding cycle monitoring during final stages of the intervention Shown in Figure 4. Observational documentation confirmed competence development in organic fertilizer dilution procedures prior to application (Alfikri & Silfia, 2025; Barsei et al., 2023; Chaerul et al., 2025; W. Diana et al., 2025).

Educational literature emphasizes that behavioral transformation emerges from experiential learning combined with contextual relevance. Knowledge internalization strengthened when technical content was directly connected to everyday household waste practices. Such integration supports sustained engagement rather than temporary compliance. Enhancement of technical capacity therefore represents both cognitive and behavioral advancement within community-based waste management frameworks.

Environmental Performance and Waste Diversion

Environmental impact analysis focused on qualitative observation of waste reduction patterns and stabilization outcomes. Larval consumption visibly reduced organic waste mass within short feeding intervals. Fermentation processes transformed biodegradable material into stable organic fertilizer products, minimizing odor generation and vector attraction. Such biological conversion contributes to reduction of landfill-bound organic fractions.

Decentralized processing reduces transportation dependency and associated environmental burdens. Previous research documented reliance on centralized disposal systems in Semarang, where household waste was transported to Jatibarang landfill(Barsei et al., 2023; Chaerul et al., 2025; W. Diana et al., 2025; Diener et al., 2009). Community-level valorization interrupts linear disposal chains and retains nutrient cycles within local ecosystems. Although quantitative tonnage measurement was not conducted, consistent diversion of organic residues from routine collection streams was observed throughout implementation.

Environmental awareness also increased among participants. Waste separation practices expanded beyond program sessions, indicating early-stage behavioral spillover effects. Circular waste initiatives require alignment between technical efficiency and social adoption. Participatory engagement therefore functions as a reinforcing mechanism for environmental responsibility.

Economic Prospects and Value Creation

Production outputs consisted of liquid biofertilizer, solid compost, and larval biomass. Liquid biofertilizer required dilution prior to agricultural application, while solid residue functioned as soil amendment. Larval biomass presented opportunities for poultry and aquaculture feed supplementation. Replacement of fish meal with maggot meal demonstrated positive broiler performance in controlled feeding experiments (Khairin et al., 2025; Maharani et al., 2025; Ma'rifah & Nuphanudin, 2025; Meindrawan et al., 2024), supporting market viability of larval products.

Economic incentives enhance sustainability of environmental initiatives. Community members expressed interest in small-scale commercialization through packaging and neighborhood sales. Maggot cultivation has been associated with increased economic value derived from organic waste streams at community scale (Mufidah et al., 2024; Pinandita et al., 2025; Ramadhani et al., 2025). Integration of waste reduction and income generation strengthens resilience of circular systems by aligning ecological and economic motivations.

Participatory economic pathways reduce dependency on external funding cycles. Local production and consumption of fertilizer products contribute to agricultural self-sufficiency at household level. Revenue diversification through larval biomass sales expands livelihood opportunities. Circular value chains therefore reinforce long-term program sustainability (Ma'rifah & Nuphanudin, 2025; Ramadhani et al., 2025).

Conceptual Integration of the Participatory Circular Community Model

Development of the Participatory Circular Community Model demonstrates integration between circular economy principles and community empowerment theory. Circular economy frameworks emphasize resource regeneration, waste minimization, and localized value creation. Community empowerment theory highlights participatory decision-making, capacity development, and collective ownership. Convergence of both perspectives produces a structured model that transcends technical waste processing and embeds social transformation within environmental management (Ariandi et al., 2023; Asropi et al., 2023).

The model consists of four interconnected components: participatory governance, technical capacity building, circular production cycles, and economic valorization. Participatory governance involves collaborative planning, shared responsibility, and transparent communication between academic facilitators and community members. Technical capacity building includes structured training, hands-on practice, and iterative mentoring. Circular production cycles encompass organic waste separation, fermentation-based fertilizer production, and Black Soldier Fly larval bioconversion. Economic valorization connects production outputs with potential market pathways and household-level utilization (Meindrawan et al., 2024).

Interdependence between components strengthens systemic resilience. Technical competence without participatory ownership risks program discontinuation. Participatory enthusiasm without economic incentives limits long-term commitment. Circular production without governance structure lacks coordination. Integration of all components generates a reinforcing feedback system that enhances sustainability potential. Such systemic articulation distinguishes the Participatory Circular Community Model from fragmented or short-term environmental interventions (Meindrawan et al., 2024; Sukmareni et al., 2023).

Comparison with Existing Waste Management Models

Conventional waste management programs in developing urban contexts frequently emphasize centralized collection and landfill expansion. Technical innovation often remains detached from community structures. Laboratory-based research on Black Soldier Fly bioconversion predominantly investigates substrate optimization and growth performance under controlled conditions. Although such studies contribute valuable technical knowledge, translation into community-scale practice remains limited (Chaerul et al., 2025; Ramadhani et al., 2025).

Community composting initiatives represent another model, yet many operate without integration of larval bioconversion or economic valorization strategies. Compost-only approaches reduce waste volume but do not maximize protein recovery potential from organic residues. Inclusion of Black Soldier Fly cultivation enhances nutrient recovery efficiency and expands economic prospects through animal feed production (Ma'rifah & Nuphanudin, 2025; Putra & Pratiwi, 2025).

Participatory waste programs implemented in various Indonesian municipalities often prioritize awareness campaigns and environmental education. Behavioral messaging alone rarely results in sustained structural change without accompanying technical infrastructure and income-generating pathways. The Participatory Circular Community Model addresses such gaps by combining awareness, skill development, production systems, and market linkage within a unified framework (Heriyanti et al., 2025; Khairin et al., 2025; Maharani et al., 2025).

Sustainability and Institutionalization Potential

Sustainability analysis considers technical continuity, social acceptance, economic viability, and institutional support. Technical continuity depends on availability of organic substrate, maintenance of container systems, and regular monitoring of larval cycles. Plamongansari households generate consistent organic waste streams, providing stable substrate supply. Container systems utilize affordable materials accessible within local markets, supporting replicability (Ardhana et al., 2025; Barsei et al., 2023; Diener et al., 2009).

Social acceptance was demonstrated through active attendance in dissemination forums and positive feedback from neighborhood leaders. Public endorsement by local governance representatives increases legitimacy and encourages cross-neighborhood diffusion. Collective ownership reduces reliance on external facilitators and fosters local accountability(Ariandi et al., 2023; Heriyanti et al., 2025; Khairin et al., 2025).

Economic viability emerges through dual pathways: household-level fertilizer utilization and larval biomass commercialization. Revenue diversification strengthens resilience during fluctuating market conditions. Institutionalization requires integration into neighborhood organizational structures. Community groups such as Sari Maggot function as operational hubs capable of coordinating waste collection and production schedules. Embedding circular waste management within existing social institutions enhances durability beyond project cycles (Ariandi et al., 2023; Handayani et al., 2021; Heriyanti et al., 2025).

Decentralized organic waste valorization aligns with Sustainable Development Goal 11 concerning sustainable cities and communities and Sustainable Development Goal 12 related to responsible consumption and production. Reduction of landfill dependency supports urban environmental resilience, while nutrient recycling advances sustainable agricultural practices. Black Soldier Fly bioconversion contributes to resource efficiency and alternative feed production, reducing pressure on marine fish stocks commonly used for fish meal (Maharani et al., 2025; Ma'rifah & Nuphanudin, 2025; Meindrawan et al., 2024).

Local governments benefit from decreased transportation burdens and landfill saturation rates. Integration of community-based circular models into municipal waste strategies enhances multi-level governance coordination. Policy frameworks that incentivize decentralized organic processing, provide technical assistance, and facilitate microenterprise licensing can accelerate adoption across urban settlements (Mufidah et al., 2024; Putra & Pratiwi, 2025; Ramadhani et al., 2025).

Academic institutions play strategic roles as knowledge brokers and capacity-building agents. Collaboration between universities and communities strengthens applied research relevance and supports translational environmental innovation. Institutional partnership models expand societal impact beyond conventional academic dissemination channels (Putra & Pratiwi, 2025; Retno et al., 2023; Santoso et al., 2024).

Several limitations warrant consideration. Quantitative measurement of waste volume reduction and greenhouse gas mitigation was not conducted during implementation. Future research should incorporate systematic mass-balance analysis and life-cycle assessment methodologies to quantify environmental performance more precisely. Economic profitability analysis, including cost–benefit evaluation and market demand assessment, would strengthen financial sustainability projections (Sari et al., 2023; Soliati, 2019; Sukmareni et al., 2023).

Longitudinal studies are necessary to evaluate persistence of behavioral change and institutional stability over extended periods. Comparative analysis across multiple urban villages could determine contextual variables influencing replication success. Integration of digital monitoring tools may enhance efficiency and data transparency within community-based circular systems (Sumardjo et al., 2022; Susilawati et al., 2024; Yani Syafei et al., 2025).

Despite limitations, implementation in Plamongansari provides empirical evidence supporting feasibility of integrating participatory governance, technical bioconversion, and economic valorization. Model articulation offers conceptual and practical contribution to sustainable urban waste management scholarship (Syafitri et al., 2024; Syafmaini et al., 2025; Yunian et al., 2025).

Findings demonstrate that household organic waste can be transformed from environmental liability into ecological and economic resource through structured participatory engagement. Technical processes of fermentation and larval bioconversion reduced visible waste volume and generated marketable outputs. Knowledge assessments indicated cognitive and procedural advancement among participants. Economic prospects reinforced motivation for sustained engagement.

Critical integration of circular economy principles with community empowerment mechanisms strengthens structural sustainability. Participatory governance fosters accountability and ownership. Technical competence ensures operational feasibility. Economic valorization supports continuity. Environmental awareness enhances behavioral adaptation. Synergistic interaction among components produces a cohesive model capable of replication in comparable urban contexts.

Development of the Participatory Circular Community Model contributes to discourse on decentralized environmental governance and circular resource management. Evidence from Plamongansari indicates that community-scale bioconversion systems can complement municipal waste infrastructure while generating localized socio-economic benefits. Sustainable urban transformation therefore requires convergence between technical innovation and participatory social architecture.

CONCLUSION

Development of the Participatory Circular Community Model demonstrates that household organic waste can be transformed into environmentally and economically valuable resources through structured community engagement. Implementation in Plamongansari integrated participatory governance, technical capacity building, circular production cycles, and economic valorization within a cohesive framework. Organic residues were processed into liquid and solid biofertilizer, while carbohydrate-rich fractions supported Black Soldier Fly (*Hermetia illucens*) larval cultivation. Knowledge assessment results indicated measurable improvement in conceptual understanding and technical competence among participants, accompanied by enhanced environmental awareness and operational confidence. Findings confirm that sustainable community-based waste management requires convergence between technical feasibility, social participation, and economic incentives. Participatory governance strengthened collective ownership, while production-based learning reinforced behavioral adaptation in waste separation and resource recovery practices. Economic prospects derived from fertilizer utilization and larval biomass commercialization increased motivation for long-term continuity. Integration of circular economy principles with empowerment mechanisms addresses structural limitations found in awareness-centered environmental programs and provides a replicable framework for decentralized urban waste governance. Future development requires quantitative environmental impact measurement, economic feasibility analysis, and policy integration to strengthen institutional sustainability. Participatory circular frameworks therefore represent a viable pathway toward sustainable urban waste management that aligns environmental conservation with community empowerment and localized economic resilience.

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