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Community-Based Plastic Waste Management Through Simple Pyrolysis Technology and Biomass as an Alternative Heat Source

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ABSTRACT

Background: Plastic waste mismanagement in rural communities poses serious environmental and health threats, particularly when residents resort to open burning that releases toxic smoke. In Manikrejo Village, all household plastic waste except bottles sold to scavengers was either burned or discarded into the environment, with no prior community knowledge of plastic-to-fuel conversion technology. This community service program aimed to address this problem by introducing simple pyrolysis technology combined with locally sourced biomass as an alternative heat source.

Purpose of the Study: The program aimed to empower the community through technical skills transfer, foster environmental awareness, and establish a sustainable, community-based plastic waste management system.

Methods: A participatory community development approach was employed through four stages: initial observation, planning and preparation, workshop and training (three sessions, 12 hours total), and mentoring and evaluation (four weeks). A total of 25 community members participated in all stages, collaboratively constructing a simple pyrolysis reactor from recycled materials.

Results: The program yielded significant outcomes. Participant knowledge increased substantially, with pre-test and post-test mean scores rising from 28.4 to 81.2 a gain of 52.8 points. Each 5 kg of plastic waste was successfully converted into approximately 3.5 liters of pyrolysis oil and 1 kg of biochar, with an optimum oil yield of 25.7% at 415°C. Evaluation demonstrated that 92% of participants were able to operate the reactor independently. The program also catalyzed the formation of a village waste management group, ensuring long-term sustainability.

Keywords
Pyrolysis; Biomass; Plastic Waste; Community Empowerment; Rural Environment

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Introduction

The issue of plastic waste is not only a global environmental concern but also an integral part of daily life in rural communities that coexist with rivers, agricultural lands, and open spaces. In Manikrejo Village, Rejoso District, plastic waste accumulating on riverbanks and in residential areas has long been a disturbing sight, posing threats to both public health and comfort. Based on initial observations, all plastic waste in the village is either discarded directly into the environment or burned in open spaces, releasing toxic smoke that increases the risk of respiratory illnesses and exposure to carcinogenic compounds (Millah et al., 2023). The only exception is plastic bottles, which are collected separately to be sold to waste scavengers, while other types of plastic waste such as plastic bags, food wrappers, and household packaging remain completely unmanaged. This condition illustrates that the waste problem is not merely about discarded materials, but about the people living within it.

Nationally, the volume of plastic waste continues to increase each year, yet only a small fraction is successfully recycled, indicating the low effectiveness of waste management systems at the community level (Sistem Informasi Pengelolaan Sampah Nasional, 2023). Polyethylene (PE) and polypropylene (PP), the types of plastic most widely used in daily household activities, are also the most difficult to decompose in the environment (López et al., 2010). When not properly managed, this waste can clog river flows, damage ecosystems, and accelerate environmental degradation, which ultimately impacts the social and economic lives of village residents.

Various studies have shown that pyrolysis technology is an effective method for processing plastic waste into renewable energy, biochar, and synthetic gas through oxygen-free heating at high temperatures (Sharuddin et al., 2016; Dai et al., 2022). This technology holds great potential for application at the community level because the reactor can be built simply using locally available materials. When combined with biomass such as firewood or rice husks, pyrolysis becomes more affordable, sustainable, and suitable for rural conditions that have abundant biomass availability (Darmansyah et al., 2021).

However, the greatest challenge is not merely the technology it is how communities can understand, accept, and independently operate it. Low community literacy regarding waste processing technology results in minimal local initiatives to properly handle plastic waste (Novita, 2021). Therefore, community education and mentoring approaches are key to creating sustainable behavioral change.

While previous community-based plastic waste management programs have generally focused on waste bank establishment or socialization-based education (Zaki et al., 2024; Ulum et al., 2024), there remains a gap in the literature regarding programs that integrate simple, locally-built pyrolysis technology with biomass heating and a fully participatory approach from collaborative reactor construction to independent community operation. Most existing pyrolysis programs rely on externally provided equipment and expert operators, limiting community ownership and long-term sustainability (Sugiarto et al., 2020; Biddinika et al., 2017). Furthermore, while studies have examined pyrolysis technology at laboratory or pilot scales, limited research has documented the process and outcomes of community-scale pyrolysis implementation in rural Indonesian settings where prior technical knowledge is virtually absent.

The novelty of this program lies in its integration of three elements: (1) simple pyrolysis technology using recycled materials and locally sourced biomass as a heating source, (2) a fully participatory approach in which the community collaboratively builds and operates the reactor, and (3) an empowerment framework that transforms the technological process into a vehicle for reviving mutual cooperation (*gotong royong*) and fostering institutional development through the formation of a village waste management group. Unlike programs that position communities as passive recipients of technology, this program positions them as co-creators and independent managers of the waste-to-energy system.

The Community Service Program (PKM) in Manikrejo Village was designed to address these needs by integrating technology transfer with community capacity building. This program not only introduced a simple pyrolysis reactor but also invited residents to collaboratively build the device using used drums, aluminum pipes, and local tools. This approach revived the spirit of mutual cooperation (*gotong royong*) and fostered a sense of ownership over the solution they created themselves. By involving residents in every stage from waste collection, reactor construction, to operation this program transformed a technological process into an empowering one.

Thus, the pyrolysis–biomass-based community service program in Manikrejo Village aims not only to reduce plastic waste but also to strengthen community capacity, cultivate ecological awareness, and build hope for a healthier village environment in the future. This humanistic and participatory approach is expected to become an innovative model for community-based waste management that can be replicated in other villages.

Method

The implementation of the Community Service Program in Manikrejo Village was designed using a participatory community development approach, a method that positions the community not as objects but as active partners in every stage of the activity. The program was carried out through four structured stages, as outlined below.

The four stages of program implementation are illustrated in the flowchart below.

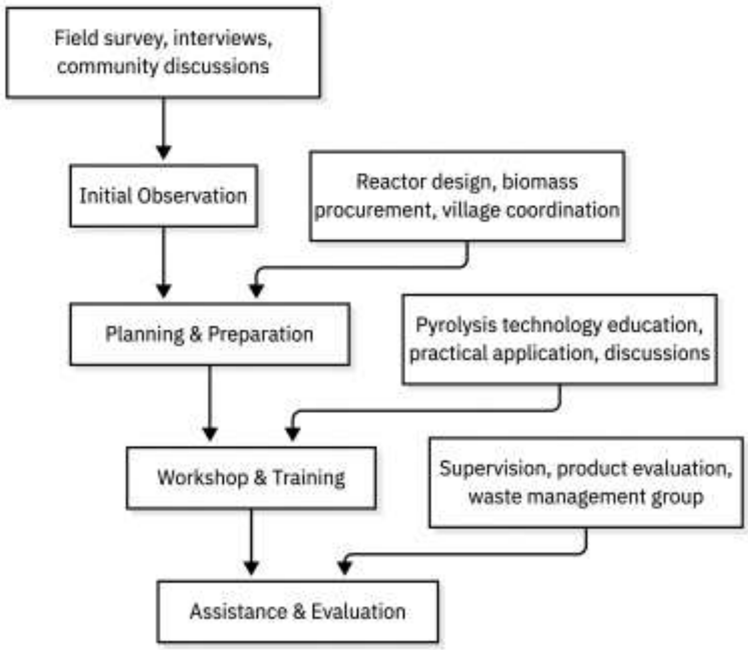

Figure 1. Flowchart of Implementation Method

The implementation stages were as follows:

Initial Observation

The initial observation was conducted to identify the existing conditions of plastic waste management in Manikrejo Village. This observation was carried out through field surveys and discussions with village officials and 25 local community members. The observation results showed that household plastic waste had not been optimally managed; the majority was still burned or disposed of openly. Only plastic bottles were collected for sale to waste scavengers, while other types of plastic waste remained unmanaged. These findings served as the basis for determining the appropriate technological approach, namely the application of biomass-based pyrolysis as an environmentally friendly plastic waste management solution that is easy for the community to apply.

Planning and Preparation

The planning and preparation stage included the technical design of a simple pyrolysis reactor, determination of the types of plastic that could be processed, provision of biomass as a heating energy source, and scheduling of activities. During this stage, intensive coordination was also carried out with the village government regarding the implementation site, selection of participants, and division of roles between the implementation team and the community. This stage lasted approximately two weeks to ensure technical and social readiness before the program was implemented.

Workshop and Training

The third stage was the workshop and training, which constituted the core of the program. This activity focused on transferring knowledge and skills to 25 community members, covering the introduction of basic pyrolysis concepts, reactor operation, operational procedures, and occupational safety aspects. In addition to material delivery, participants were directly involved in hands-on practice of operating the pyrolysis reactor, starting from plastic sorting, heating, to collecting the resulting products in the form of pyrolysis oil and biochar. The workshop and training were conducted over three sessions, each lasting approximately four hours. Through this participatory approach, the community not only understood the concepts but also became capable of operating the technology independently.

Mentoring and Evaluation

The final stage was mentoring and evaluation, carried out to ensure the sustainability and effectiveness of the program. Mentoring was conducted by monitoring the community's ability to operate the reactor independently and utilize the pyrolysis products. The mentoring process took place over a period of four weeks with regular weekly visits. Evaluation was conducted qualitatively to assess improvements in understanding, skills, and community responses to the application of pyrolysis technology. The evaluation results were used as a basis for program improvement and future development, as well as to assess the potential for replication in other areas.

Overall, the implementation method applied not only emphasized technical aspects but also considered community participation and empowerment. Through a gradual and structured approach as shown in the flowchart, this program was expected to deliver sustainable environmental and social impacts.

Result

Initial Observation Results

The initial observation conducted through field surveys and discussions with 25 community members revealed critical findings regarding plastic waste management in Manikrejo Village. All household plastic waste, with the sole exception of plastic bottles collected for sale to waste scavengers, was either burned in open spaces or discarded directly into the environment, including riverbanks and vacant land. None of the 25 community members involved in the initial discussions had any prior knowledge of plastic-to-fuel conversion technology. When asked about their current waste management practices, 100% of respondents admitted to burning plastic waste regularly, while 76% (19 out of 25) reported that plastic waste had clogged irrigation channels and rivers near their homes at least once in the past year. Furthermore, 68% (17 out of 25) acknowledged experiencing respiratory discomfort, such as coughing and shortness of breath, during and after burning plastic waste. These findings confirmed the urgent need for a community-based technological intervention and served as a baseline for measuring the program's impact.

Planning and Preparation Results

During the two-week planning and preparation stage, the implementation team successfully designed a simple pyrolysis reactor using locally available recycled materials. The main reactor body was constructed from a used 200-liter steel drum, while the condensation system utilized aluminum pipes and a water-cooled chamber. The biomass combustion chamber was built from used metal sheets and bricks. The reactor was designed to process approximately 5 kg of shredded plastic waste per batch, with an estimated processing time of 3–5 hours per batch. Biomass in the form of firewood and rice husks both abundantly available in the village was selected as the primary heating source. Coordination with the village government resulted in the selection of the village hall as the training location and the formal identification of 25 participants representing diverse community elements: village officials (5 persons), farmer group members (8 persons), youth organization members (7 persons), and women's group representatives (5 persons). This diverse composition was intentional to ensure that knowledge and skills would be distributed across different segments of the community.

Workshop and Training Results

The workshop and training were conducted over three sessions, each lasting approximately four hours, with a total duration of 12 hours of direct instruction and practice. Session 1 focused on theoretical foundations: basic principles of pyrolysis, types of plastics suitable for processing (polyethylene and polypropylene), environmental impacts of open burning, and safety procedures. Session 2 involved hands-on reactor construction, where participants collaboratively assembled the pyrolysis system from recycled materials. Session 3 covered operational procedures: plastic shredding, reactor loading, biomass firing, temperature monitoring, condensation, and product collection.

To measure knowledge improvement, a pre-test was administered before Session 1 and an identical post-test was administered after Session 3. The assessment covered five knowledge domains: (1) understanding of plastic waste types, (2) principles of pyrolysis, (3) reactor operation procedures, (4) product utilization, and (5) environmental and safety awareness. Each domain was scored on a scale of 0–20, resulting in a maximum total score of 100. The results are presented in Table 1.

Table 1: Pre-test and Post-test Scores of Training Participants (n = 25)

Knowledge Domain	Pre-test Mean	Post-test Mean	Improvement
Plastic waste types	8.4	16.2	+7.8
Principles of pyrolysis	3.2	15.8	+12.6
Reactor operation procedures	2.8	16.4	+13.6
Product utilization	4.4	15.2	+10.8
Environmental and safety awareness	9.6	17.6	+8.0
Total Score	**28.4**	**81.2**	**+52.8**

As shown in Table 1, the pre-test mean score was 28.4 out of 100, indicating very low baseline knowledge. The lowest scores were in reactor operation procedures (2.8) and principles of pyrolysis (3.2), confirming that participants had virtually no prior exposure to pyrolysis technology. After the three-session training, the post-test mean score increased to 81.2, representing a 52.8-point improvement. The most significant gains were observed in reactor operation procedures (+13.6) and principles of pyrolysis (+12.6), reflecting the effectiveness of the hands-on training approach. All 25 participants (100%) showed individual score improvements, with the lowest individual post-test score being 68 and the highest being 94.

Plastic Waste Conversion into Pyrolysis Oil and Biochar

The core technical achievement of this program was the community's demonstrated ability to convert plastic waste into two valuable products: pyrolysis oil and biochar. During the hands-on practice sessions, participants conducted five conversion trials with varying amounts of plastic waste feed. The results are summarized in Table 2.

Table 2: Pyrolysis Conversion Trials Using Biomass Heating

Trial	Plastic Feed (kg)	Processing Time (hours)	Avg. Temperature (°C)	Pyrolysis Oil (liters)	Biochar (kg)	Oil Yield (%)
1	3.0	3.0	380	1.8	0.6	22.0
2	4.0	3.5	395	2.5	0.8	22.5
3	5.0	4.0	410	3.5	1.0	25.0
4	5.0	4.5	405	3.3	1.0	23.6
5	5.0	4.0	415	3.6	1.0	25.7

As shown in Table 2, the optimum result was achieved in Trial 5, where 5 kg of plastic waste yielded 3.6 liters of pyrolysis oil and 1 kg of biochar at an average temperature of 415°C, resulting in an oil yield of 25.7%. The average oil yield across all trials was 23.8%. These results are consistent with the expected performance of simple batch pyrolysis reactors at the community scale. The pyrolysis oil appeared yellowish to brownish in color, with a distinct hydrocarbon odor, indicating successful thermal decomposition of the plastic polymers. The biochar produced was black, brittle, and lightweight, suitable for use as a soil amendment.

The visual evidence of the conversion process and products was documented during the training sessions. Figure 2 captures the collaborative atmosphere of the workshop, while Figure 3 displays the tangible outputs pyrolysis oil in transparent containers and biochar residue that became powerful tools for convincing the community of the technology's benefits.

Figure 2. Training and Workshop on Simple Pyrolysis System Construction

Figure 2 illustrates the atmosphere of the pyrolysis–biomass system training and workshop held at the Manikrejo Village Hall. The activity brought together village officials, community leaders, and residents of various ages, all demonstrating high enthusiasm and curiosity toward the plastic waste management solution being offered. In a warm and participatory setting, the implementation team explained the working principles of pyrolysis and the stages of constructing a simple reactor from used materials. The two-way interaction reflected a collective learning process, where community members actively asked questions, engaged in discussions, and jointly built understanding. The collaborative reactor construction process not only transferred technical skills but also revived the spirit of mutual cooperation (*gotong royong*) and fostered a shared sense of responsibility for maintaining a sustainable village environment.

Figure 3. Pyrolysis Oil Products

Figure 3 displays the tangible results of the pyrolysis process: pyrolysis oil in transparent containers and biochar as solid residue. The visual clarity of the containers allowed community members to easily observe the oil produced from their own efforts, fostering confidence in the technology. The biochar reflected residual carbon material with continuing value as a soil conditioner for agricultural land. This visualization served as both technical evidence of pyrolysis success and a symbol of a paradigm shift from viewing plastic waste as an environmental burden to recognizing it as a valuable resource.

Community Awareness and Participation

Beyond measurable knowledge gains and technical outputs, the program documented significant shifts in community attitudes and participation levels. Attendance across all three training sessions was 100%, with all 25 registered participants present for the full duration of each session. During Session 2 (reactor construction), an additional 12 community members voluntarily joined as observers, indicating growing interest beyond the initial participant group. Post-training interviews conducted during the mentoring phase revealed that 92% of participants (23 out of 25) had begun separating plastic waste at home in preparation for pyrolysis processing. Furthermore, 88% (22 out of 25) reported that they had shared their newly acquired knowledge with family members or neighbors, demonstrating a multiplier effect in community education.

The program also stimulated discussions about broader environmental stewardship. During the final training session, participants independently initiated a discussion about the possibility of establishing a village regulation (*peraturan desa*) on plastic waste management, reflecting an emerging sense of collective responsibility and institutional thinking. This spontaneous initiative was not part of the original program design and signals the beginning of community-driven environmental governance.

Mentoring and Evaluation Results

The mentoring process was conducted over four weeks with regular weekly visits by the implementation team. During this period, participants' ability to operate the reactor independently was systematically assessed through direct observation and structured evaluation. Table 4 summarizes the key evaluation indicators.

Table 3: Evaluation of Community Independence in Reactor Operation (n = 25)

Evaluation Indicator	Able Independently	Needs Assistance	Unable
Plastic sorting and shredding	25 (100%)	0 (0%)	0 (0%)
Reactor loading	24 (96%)	1 (4%)	0 (0%)
Biomass firing and temperature control	21 (84%)	4 (16%)	0 (0%)
Condensation and product collection	23 (92%)	2 (8%)	0 (0%)
Safety procedures	25 (100%)	0 (0%)	0 (0%)
Overall reactor operation	**23 (92%)**	**2 (8%)**	**0 (0%)**

As shown in Table 3, 92% of participants (23 out of 25) demonstrated the ability to operate the entire pyrolysis system independently across all stages, from plastic sorting to product collection. The most challenging aspect was biomass firing and temperature control, where 16% (4 out of 25) still required some assistance, primarily due to difficulties in maintaining stable temperatures within the optimal range of 400–415°C. Safety procedures and plastic sorting were mastered by all participants (100%).

Participants also reported observable environmental improvements. By the end of the four-week mentoring period, 80% of participants (20 out of 25) stated that the volume of plastic waste in their immediate surroundings had noticeably decreased. A collective waste collection schedule was established, with community members voluntarily bringing sorted plastic waste to the village hall every Saturday for pyrolysis processing. Over the four weeks of mentoring, a total of approximately 60 kg of plastic waste was processed, yielding an estimated 42 liters of pyrolysis oil and 12 kg of biochar.

A significant outcome of the mentoring phase was the formal establishment of a village waste management group named "*Manikrejo Bersih*" (Clean Manikrejo), consisting of 15 core members drawn from the training participants. This group took formal responsibility for managing the pyrolysis reactor, organizing waste collection schedules, and planning for product utilization and potential commercialization. The group also proposed expanding the number of reactors to two units and extending the program to neighboring hamlets within the village. The formation of this local institution marks a critical step toward program sustainability, as the community transitions from being recipients of external assistance to becoming independent managers of their own waste management system.

Discussion

Community Empowerment through Technology Transfer

The significant improvement in participant knowledge, as evidenced by the pre-test and post-test scores (28.4 to 81.2, an increase of 52.8 points), underscores the effectiveness of the hands-on, participatory training approach. The most substantial gains were observed in reactor operation procedures (+13.6) and principles of pyrolysis (+12.6), domains in which participants had virtually no prior knowledge. These findings align with the work of Zaki et al. (2024), who reported that over 57% of community leaders in Bangunjiwo Village demonstrated strong understanding of plastic waste impacts after participating in socialization programs, and more than 52% strongly agreed on the importance of recycling and innovative plastic waste processing. The higher knowledge improvement rate in Manikrejo Village may be attributed to the hands-on training methodology, which engaged participants directly in reactor construction and operation rather than relying solely on lecture-based education.

The 92% independent operation rate achieved in this program further supports the argument that community-based pyrolysis technology is not only technically feasible but also socially acceptable at the village level. As Tapa et al. (2025) emphasized in their study on community-based pyrolysis technology in East Java, social values particularly community empowerment provide the most significant contribution to the sustainability of pyrolysis-based waste management models, followed by economic and environmental values. The formation of the "Manikrejo Bersih" waste management group during the mentoring phase exemplifies this finding, as it represents the institutionalization of community empowerment and the emergence of local leadership in environmental management.

The multiplier effect observed in this program 88% of participants sharing knowledge with family and neighbors is particularly noteworthy. This diffusion of knowledge beyond the initial participant group suggests that community-based interventions can generate impacts that extend beyond their immediate targets. Biddinika et al. (2017) similarly emphasized the importance of public outreach in demonstrating the benefits of converting plastic waste into burnable oil for household use, noting that improving public understanding and awareness is a key factor in waste-to-energy implementation.

Technical Feasibility of Community-Based Pyrolysis

The conversion trials conducted in this program demonstrated consistent and reproducible results, with an average oil yield of 23.8% and an optimum yield of 25.7% (3.6 liters from 5 kg of plastic at 415°C). These results are comparable to those reported in the literature. Sugiarto et al. (2020) conducted pyrolysis of plastic bottle waste using biomass heating at an average temperature of 412°C and obtained liquid fuel yields ranging from 18.6% to 28.4%, with the optimum result of 28.4% achieved with a 500-gram feed. The slightly lower average yield in the present study may be attributed to the larger batch size (5 kg vs. 0.5 kg) and the use of mixed plastic waste rather than a single plastic type, as noted by López et al. (2010), who found that the composition of raw material significantly influences pyrolysis outcomes.

The use of locally available biomass firewood and rice husks as the heating source proved to be both practical and sustainable. This approach aligns with the findings of Darmansyah et al. (2021), who confirmed that biomass characteristics such as hardness and particle size influence syngas quality in biomass pyrolysis. The abundance of biomass resources in rural settings makes this approach inherently suited for village-level application, as it eliminates dependence on external energy sources and reduces operational costs. Couhert et al. (2009) demonstrated that it is possible to predict gas yields from biomass pyrolysis based on its composition in cellulose, hemicellulose, and lignin, suggesting that future optimization of biomass selection could further improve process efficiency.

The quality of pyrolysis oil produced yellowish to brownish in color indicates successful thermal decomposition of polyethylene and polypropylene polymers. Kusmiyati et al. (2025) reported that pyrolysis fuel oil has a lower heating value of 9,240 Kcal/kg and a density of 0.795, confirming its high energy potential as a renewable fuel candidate capable of producing diesel, kerosene, and gasoline fractions. Similarly, Sharuddin et al. (2016) noted in their comprehensive review that pyrolysis of plastic wastes yields liquid oil with properties comparable to conventional petroleum-derived fuels, making it suitable for various energy applications.

The biochar co-product, approximately 1 kg per 5 kg of plastic feed, represents an additional value stream that is particularly relevant for agricultural communities. Keller et al. (2024) demonstrated that pyrolysis can eliminate microplastics, PFAS, and PPCPs from biosolids to produce biochar, highlighting the environmental remediation potential of the pyrolysis process beyond waste reduction. For farming communities like Manikrejo Village, the availability of biochar as a soil amendment directly supports agricultural productivity while closing the loop on waste management.

Social Change and Behavioral Transformation

Beyond technical outcomes, the program catalyzed important social changes that align with the theoretical framework of community-based development. The formation of the "Manikrejo Bersih" waste management group represents the emergence of a new local institution dedicated to environmental management a key indicator of sustainable social transformation. Ulum et al. (2024), in their study on community-based plastic waste management in Bangun Village, Mojokerto, emphasized that institutional restructuring and community participation are central components of effective waste management models. Their finding that community education and awareness are crucial foundations for fostering sustainable behavior is strongly supported by the present program's outcomes.

The spontaneous initiative by participants to discuss the possibility of a village regulation on plastic waste management reflects an emerging sense of collective responsibility that extends beyond the immediate program activities. This finding echoes the work of Tapa et al. (2025), who demonstrated that the success of a pyrolysis business model is heavily influenced by the integration of social values (community empowerment), economic values (local income), and environmental values (waste and emission reduction). The cross-sector collaboration between academia, industry, and community that they advocated as essential for efficiency and social acceptability was realized in this program through the partnership between STAI Salahuddin Pasuruan, UNU Pasuruan, and the Manikrejo Village community.

The documented behavioral changes 92% of participants separating plastic waste at home and 88% sharing knowledge with others indicate a shift from passive acceptance of environmental problems to active engagement in solutions. This transformation aligns with what Millah et al. (2023) described in their work on modular pyrolysis solutions for waste banks in Sampang Regency, where community-based technological interventions successfully converted previously worthless plastic waste into economically valuable products. The present program extends these findings by demonstrating that behavioral change can be achieved even in communities with no prior exposure to waste processing technology.

The revival of *gotong royong* (mutual cooperation) during the collaborative reactor construction process is particularly significant from a socio-cultural perspective. In many rural Indonesian communities, traditional collective practices have been eroding due to modernization and changing economic structures. The re-emergence of this spirit through a technology-focused program suggests that appropriately designed interventions can simultaneously achieve technical goals and strengthen social cohesion a finding that has implications for the design of future community development programs.

Broader Implications and SDG Alignment

The findings of this program contribute to the growing body of evidence on community-based plastic waste management in Indonesia and have broader implications for sustainable development. The program addresses multiple Sustainable Development Goals (SDGs) simultaneously: reducing environmental pollution and greenhouse gas emissions from open burning (SDG 13: Climate Action), providing alternative household energy sources (SDG 7: Affordable and Clean Energy), promoting sustainable community practices (SDG 12: Responsible Consumption and Production), and supporting local economic development through potential commercialization of pyrolysis products (SDG 8: Decent Work and Economic Growth).

Tapa et al. (2025) similarly emphasized the importance of multi-stakeholder synergy for a transition toward a green and climate-resilient economy, noting that circular business models relying on cross-sector collaboration increase efficiency, social acceptability, and potential for replication in other regions. The present program in Manikrejo Village provides a concrete example of how such models can be implemented at the grassroots level.

Dai et al. (2022) noted in their state-of-the-art review that pyrolysis technology for plastic waste recycling continues to evolve, with ongoing improvements in reactor design, catalyst development, and process optimization. While the simple batch reactor used in this program represents an entry-level technology, its successful adoption by a rural community with limited prior technical knowledge demonstrates that even basic pyrolysis systems can deliver meaningful environmental and social benefits. As Srivastava et al. (2024) argued in their assessment of pyrolysis for biomedical waste treatment, the versatility of pyrolysis technology makes it adaptable to various waste streams and operational scales.

Limitations and Future Directions

Despite the program's documented success, several limitations must be acknowledged. First, the processing scale remains modest, with the reactor capable of processing only 5 kg of plastic waste per batch over 3–5 hours. This is comparable to the batch duration reported by Kusmiyati et al. (2025) of 7 hours with a monthly output of 1,625 liters from a more advanced system. The simple reactor design limits throughput and may not be sufficient to process all plastic waste generated by the village over time.

Second, plastic sorting remains a challenge that requires ongoing assistance. As López et al. (2010) demonstrated, the composition of raw material significantly influences pyrolysis outcomes, and not all plastic types yield optimal results. While polyethylene and polypropylene are suitable feedstocks, other common plastics such as PET (used in beverage bottles) require different processing conditions. The community's waste-sorting habits, though improving, are not yet fully established, and contamination of the plastic feed with non-processable materials can reduce efficiency and product quality.

Third, temperature control in the simple biomass-fired reactor is inherently variable, as evidenced by the temperature range of 380–415°C across the five trials. Dai et al. (2022) highlighted that precise temperature control is critical for optimizing product yield and quality in plastic pyrolysis. The variability observed in this program (oil yields ranging from 22.0% to 25.7%) reflects the limitations of manual biomass firing and suggests that future reactor designs should incorporate improved temperature monitoring and control mechanisms.

Fourth, the long-term sustainability of the program depends on factors beyond the control of the initial intervention. The "Manikrejo Bersih" group, while enthusiastic and capable at present, will require ongoing institutional support, access to spare parts and materials, and potential integration with broader waste management policies at the district level. Ulum et al. (2024) emphasized that partnerships with external stakeholders including local government bodies, NGOs, and private sector entities are essential for sustaining community-based waste management initiatives beyond the initial program period.

Future development should focus on several key areas. Reactor capacity could be increased through design modifications, potentially incorporating semi-continuous feeding mechanisms to improve throughput. Temperature control systems, even simple ones using thermocouples and adjustable air intake, could reduce variability and improve product consistency. Exploration of product commercialization pathways particularly for pyrolysis oil as a household fuel substitute could create economic incentives for sustained community engagement.

Conclusion

Based on the results of the Community Service Program (PKM) in Manikrejo Village, it can be concluded that pyrolysis–biomass technology has proven effective and applicable as a community-based plastic waste management solution. The program successfully improved community knowledge and skills, as evidenced by the significant increase from a pre-test mean score of 28.4 to a post-test mean score of 81.2 a gain of 52.8 points. In terms of tangible outputs, each 5 kg of plastic waste was converted into approximately 3.5 liters of pyrolysis oil and 1 kg of biochar, with an optimum oil yield of 25.7% achieved at 415°C. Evaluation results showed that 92% of participants were able to operate the pyrolysis reactor independently across all stages, from plastic sorting to product collection.

The pyrolysis oil produced holds significant potential as an alternative household fuel, capable of partially replacing kerosene or LPG and thereby reducing dependence on fossil fuels. The biochar co-product serves as a valuable soil amendment that directly supports agricultural activities. These outcomes demonstrate that the pyrolysis process creates simultaneous economic and environmental added value beyond waste reduction alone.

Beyond technical achievements, the program delivered significant social impact. The community was actively involved in the entire process, from reactor construction to operation and product utilization, fostering a sense of ownership, environmental responsibility, and collective awareness. The formation of the "Manikrejo Bersih" waste management group ensures program sustainability beyond the formal PKM period. The integration of technical, economic, and social dimensions positions this program as a replicable model for community-based plastic waste management in areas with similar characteristics.

However, several challenges remain: the limited processing scale of 5 kg per batch, the need for ongoing assistance in plastic sorting, temperature control limitations affecting product consistency, and dependence on village institutional strengthening for long-term sustainability. These challenges present opportunities for further development through reactor capacity improvement, enhanced temperature control mechanisms, and sustained multi-stakeholder collaboration.

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Conflicts of Interest

The authors declare no conflict of interest.

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