INOVASI LOKAL
Pemberdayaan Masyarakat dalam Pembangunan Berkelanjutan
Vol. 4, No. 2, 2026 | E-ISSN: 3024-9716
TARQABIN NUSANTARA GROUP

Research Article OPEN ACCESS

Utilizing Coconut Shell Waste as an Alternative Fuel Through Charcoal Making to Improve the Economic Value of the Liprak Kidul Village Community

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DOI: 10.62255/noval.v4i2.347

Received: 10 September 2026
Revised: 25 October 2026
Accepted: 30 October 2026

Keywords: Coconut Shell Waste; Charcoal Production; Circular Economy; Community Empowerment; Quasi-Experimental Design.

How to cite*:** *Jannah, M., Ramadani, M. R., Bahtiar, A. I., Tamam, B., Andreal, R., & Adawiyah, R. (2026). Utilizing Coconut Shell Waste as an Alternative Fuel Through Charcoal Making to Improve the Economic Value of the Liprak Kidul Village Community. Inovasi Lokal: Pemberdayaan Masyarakat dalam Pembangunan Berkelanjutan, 4(2), 125-134.* ***https://doi.org/10.62255/noval.v4i2.347

ABSTRACT

Background: Coconut shell waste is abundantly generated in rural agrarian communities but is predominantly subjected to open dumping or uncontrolled burning, leading to environmental degradation and missed resource valorization opportunities. Despite the known calorific potential of this biomass, there is a critical gap in scalable, community-driven methodologies to transition rural households from linear waste disposal to circular energy production.
Objective: To evaluate the effectiveness of a participatory quasi-experimental intervention in enhancing the technical skills and economic perceptions of rural residents regarding coconut shell carbonization for alternative fuel production.
Methods: A one-group pretest–posttest quasi-experimental design, aligned with TREND reporting guidelines, was conducted in Liprak Kidul Village, Probolinggo Regency. Thirty purposively selected residents underwent a structured intervention comprising baseline assessment, hands-on carbonization training using low-cost, oxygen-limited kilns, and post-intervention evaluation. Pre- and post-intervention data on technical knowledge, practical skill proficiency, and economic perception were collected via validated questionnaires and skill rubrics, then analyzed using paired t-tests and thematic analysis.
Results: Participants completed the entire production sequence and produced charcoal suitable for household fuel use. Post-activity assessments indicated better understanding of moisture control and the carbonization sequence, increased confidence in performing the process independently, and a shift toward viewing shells as a resource rather than refuse.
Conclusion: Participatory, low-cost carbonization training effectively bridges the gap between environmental waste management and grassroots economic empowerment. These findings imply that integrating structured, hands-on technical training into rural community programs can successfully catalyze the adoption of circular economy practices and decentralized renewable energy production.

Key Points (Highlights):

- *Coconut shells are abundant but often discarded or burned, causing pollution.*
- *Participatory carbonization empowers rural communities to produce clean fuel.*
- *Low-cost charcoal production bridges waste management and local economic growth.*

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E-ISSN: 3024-9716 DOI: https://doi.org/110.62255/noval.v4i2.347

INTRODUCTION

The accumulation of agricultural and household biomass waste in rural agrarian societies presents a persistent challenge for local environmental management and sustainable development (Yusup & Inayat, 2021). In many tropical regions, including Desa Liprak Kidul in Probolinggo Regency, coconut shells a ubiquitous byproduct of local agriculture and household consumption are frequently marginalized as valueless refuse (Madhusanka et al., 2025). Consequently, this carbon-rich biomass is predominantly subjected to linear disposal methods, such as open dumping or uncontrolled burning (Jannah et al., 2025). These practices not only exacerbate local environmental degradation through the emission of particulate matter and greenhouse gases but also represent a significant loss of potential renewable energy resources (Adhitasari et al., 2025). Transitioning from this linear waste paradigm to a more sustainable model requires addressing both the physical management of the waste and the underlying socio-economic behaviors that perpetuate its underutilization (Yirijor & Bere, 2024).

The theoretical frameworks of the Circular Economy (CE) and Waste-to-Energy (WtE) provide a robust lens for addressing this challenge by positing that organic waste should be valorized rather than discarded (Hutasuhut et al., 2026). In the context of rural biomass, carbonization offers a pragmatic pathway to actualize these concepts by converting agricultural residues into energy-dense charcoal, thereby mitigating environmental externalities while generating decentralized fuel sources (Malabago et al., 2026). Although the physicochemical viability of coconut shells as a precursor for high-quality charcoal and briquettes is well-documented in technical literature, the translation of these macro-level concepts into micro-level community practices frequently encounters barriers (GatiSriUtami et al., n.d.). These barriers often stem not from the complexity of the technology itself, but from socio-economic inertia, a lack of localized technical know-how, and the absence of pedagogical models that effectively embed new practices into the community's daily routines (Afnan et al., 2025).

Desa Liprak Kidul exemplifies this disconnect between theoretical potential and practical application. The village generates a substantial volume of coconut shell waste daily, yet the local population largely lacks the structured knowledge and practical skills required to harness its calorific potential for alternative fuel (Lubis, 2026). While previous community service initiatives and technical studies have successfully demonstrated charcoal and briquette production in controlled or industrial settings, there remains a distinct scarcity of literature detailing the socio-technical processes of introducing these technologies to non-industrial, rural communities (Amrie et al., 2026). The critical research gap, therefore, lies in understanding how to effectively design and implement participatory methodologies that bridge the divide between scientific potential and grassroots adoption, ensuring that the technology is not only transferred but also sustainably adopted by the community (Prakoso et al., 2026).

To address this gap, this paper details a participatory community service initiative designed to empower the residents of Liprak Kidul through the practical, hands-on conversion of coconut shell waste into alternative fuel. Moving beyond purely technical evaluations, this study adopts a socio-technical approach that integrates practical carbonization training with community empowerment principles, focusing on knowledge transfer, skill acquisition, and behavioral shift (Dewi et al., 2026; Syafeí et al., 2025). The primary objective is to evaluate the effectiveness of this participatory intervention in enhancing the community's technical proficiency, shifting their environmental perceptions regarding waste, and identifying localized economic opportunities (Hidayat et al., 2025). By documenting this process, the study aims to contribute actionable insights to the broader discourse on community-driven circular economy implementations, offering a scalable model for rural waste valorization in developing contexts (Razali et al., 2025).

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MATERIALS AND METHODS

Reporting Guidelines and Study Design

This study was designed and reported in strict accordance with the TREND (Transparent Reporting of Evaluations with Nonrandomized Designs) statement, which is the EQUATOR network's recommended guideline for quasi-experimental research. The study utilized a one-group pretest-posttest quasi-experimental design embedded within a Participatory Action Research (PAR) framework. This design was selected to rigorously measure the changes in community knowledge, technical skills, and waste management behaviors before and after the intervention, while maintaining the collaborative, emancipatory core of PAR. The intervention was conducted in Desa Liprak Kidul, Kecamatan Besuk, Kabupaten Probolinggo, selected purposively due to its high abundance of unmanaged coconut shell waste.

Participants and Setting

The subjects of this intervention comprised local residents of Desa Liprak Kidul, village officials, and university students facilitating the program. Participants were selected using purposive sampling, targeting households involved in coconut processing and local micro-entrepreneurs. A core group of 30 participants was actively involved in the hands-on technical training (the experimental cohort), while the broader community (n=150) participated in the socialization and post-intervention evaluation phases. The setting included community gathering halls for theoretical sessions and designated open, well-ventilated areas for the practical carbonization process.

Intervention Sequence (TIDieR Framework)

To ensure reproducibility and detailed reporting, the intervention sequence was structured according to the TIDieR (Template for Intervention Description and Replication) checklist, divided into four systematic phases:

1. **Phase 1: Baseline Assessment & Socialization (Pre-test).** Initial observations, focus group discussions (FGD), and pre-intervention surveys were conducted to map current waste management practices and baseline knowledge. This was followed by theoretical socialization on the circular economy, the calorific value of coconut shells, and the economic potential of charcoal.
2. **Phase 2: Preparation and Pre-treatment.** Participants were trained in the systematic collection, sorting, and cleaning of coconut shells to remove residual coir and dirt. Crucially, they were taught the solar drying process to reduce moisture content (targeting
3. **Phase 3: Hands-on Carbonization (Pyrolysis).** The core practical training involved the carbonization process using modified, low-cost 200-liter steel drum kilns. Participants learned to manage the thermal decomposition by restricting oxygen flow. They were trained to monitor the process by observing smoke emission (transitioning from thick white steam to bluish/clear smoke) to determine the exact endpoint of carbonization.
4. **Phase 4: Post-Intervention Evaluation (Post-test).** The final phase involved assessing the physical quality of the produced charcoal, administering post-intervention knowledge and skill assessments, and conducting a reflective FGD on the economic viability and future scalability of the enterprise.

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Data Collection and Analysis

Data were collected through direct observation, practical skill rubrics, pre- and post-intervention questionnaires, and semi-structured interviews. Quantitative data from the questionnaires (measuring knowledge and perception shifts) were analyzed using descriptive statistics and paired comparisons to determine the magnitude of the intervention's effect. Qualitative data from interviews and FGDs were analyzed using thematic analysis to identify shifts in community perception, behavioral changes, and socio-economic readiness.

Ethical Statement

This community service project adhered to strict ethical standards for human subject research. Informed consent was obtained from all participants prior to the baseline assessment, ensuring they understood the voluntary nature of their involvement and their right to withdraw. Environmental and occupational safety protocols were strictly enforced during the carbonization process, including the provision of basic PPE (gloves, masks) to prevent exposure to heat and particulate matter. The project received formal ethical clearance and administrative approval from the Village Head of Liprak Kidul and the institutional review board of Institut Ahmad Dahlan Probolinggo.

RESULTS

The quasi-experimental intervention yielded comprehensive data detailing the transformation of both the physical waste product and the community's socio-technical capacities. The results are categorized into baseline conditions, process execution, and post-intervention outcomes.

Baseline Conditions (Pre-Intervention)

Prior to the intervention, observational data and pre-test surveys revealed a linear and unsustainable waste management paradigm. Approximately 80% of the coconut shells generated from household and local market activities were either dumped in open spaces or burned indiscriminately in open fires. The pre-intervention knowledge assessment indicated that 90% of the participants viewed coconut shells solely as organic waste with no economic or energetic value, and none possessed prior knowledge of controlled carbonization or pyrolysis techniques.

Process Execution and Technical Outcomes

During the intervention, the community successfully executed the entire value chain of charcoal production. The pre-treatment phase (sorting and sun-drying) effectively reduced the initial moisture content of the shells, which was critical for the subsequent pyrolysis. The carbonization process utilizing the modified drum kilns proved highly effective. By controlling the air intake, participants successfully achieved the anaerobic conditions required for carbonization. The visual indicator of smoke color transition (from white to bluish) was successfully adopted by the community as a reliable metric for process completion.





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Figure 1. The carbonization process: Community members actively managing the pyrolysis of coconut shells in a modified low-oxygen drum kiln, monitoring smoke emission to determine process completion.

The physical transformation resulted in a high-quality, carbon-rich charcoal. Based on the mass balance observed during the practical sessions, the carbonization process yielded approximately 25-30% of the initial dry weight of the coconut shells in the form of solid charcoal, a standard and efficient yield for traditional low-tech kilns. The resulting charcoal exhibited high structural integrity, low moisture content, and sustained combustibility, proving its viability as a household alternative fuel.



Figure 2. Post-carbonization: The finished coconut shell charcoal undergoing cooling and initial quality assessment by the community participants before storage.

Post-Intervention Outcomes and Impact

The post-intervention evaluation demonstrated a profound shift across technical, environmental, and socio-economic metrics. The structured training significantly enhanced the community's technical capability and environmental awareness. Furthermore, the tangible production of charcoal catalyzed discussions regarding local economic development.

Table 1. Comparison of Evaluation Metrics: Baseline (Pre-Intervention) vs. Post-Intervention Outcomes in the Coconut Shell Waste Utilization Program

Evaluation Metric	Pre-Intervention (Baseline)	Post-Intervention (Outcome)	Change / Impact
Waste Management Practice	Open dumping and uncontrolled open burning (~80% of households).	Systematic collection, sorting, and controlled carbonization.	Shift from linear disposal to circular valorization; significant reduction in open burning emissions.
Technical Knowledge & Skill	Zero knowledge of carbonization; reliance on conventional firewood/fossil fuels.	Proficient in moisture reduction, kiln operation, smoke monitoring, and safe pyrolysis.	High skill acquisition; 100% of core participants passed the practical skill rubric.
End Product Quality	Ash and particulate matter (from open	High-carbon, low-smoke charcoal (25-30% yield	Creation of a viable, energy-dense alternative

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E-ISSN: 3024-9716 DOI: https://doi.org/110.62255/noval.v4i2.347

	burning).	rate).	fuel for household use.
Socio-Economic Perception	Viewed as a disposal burden with zero economic value.	Recognized as a revenue-generating asset; potential for local MSME.	Paradigm shift; initiation of discussions for cooperative formation and briquette upscaling.

Qualitative feedback from the post-intervention FGDs revealed that the simplicity and low-cost nature of the technology were the primary drivers of the community's confidence. Participants expressed a strong willingness to replicate the process independently. The successful intervention not only achieved its immediate technical objectives but also laid the foundational mindset required for the community to explore further value addition, such as briquetting, thereby securing the long-term sustainability of the waste-to-energy initiative.

DISCUSSION

The successful conversion of coconut shell waste into charcoal in Desa Liprak Kidul provides a compelling empirical validation of the Circular Economy (CE) theory at the micro-community level. By shifting the paradigm from linear disposal to circular valorization, the intervention demonstrated that environmental remediation and economic generation are not mutually exclusive (Safita et al., 2026). The community's transition from viewing coconut shells as a disposal burden to recognizing them as a feedstock for alternative energy aligns with the core tenets of CE, which advocate for the decoupling of economic activity from the consumption of finite resources (Sukmayadevi et al., 2025). This localized application of CE proves that circularity is not solely the domain of industrial ecosystems but can be effectively operationalized in rural, agrarian settings through appropriate, low-tech interventions (Kurfer & Brandl-Bredenbeck, 2023; Sidiq et al., 2025).

Furthermore, the efficacy of this initiative is deeply rooted in the principles of Social Learning Theory and community empowerment. Unlike top-down technological transfers that often fail due to a lack of local ownership, this participatory action research ensured that the community was actively involved in the "learning by doing" process (Fajri et al., 2025). The hands-on carbonization training fostered self-efficacy and collective problem-solving. By positioning the residents not merely as beneficiaries but as co-creators of the solution, the intervention built local capacity and resilience (Zuber-Skerritt et al., 2020). This socio-technical approach highlights that the sustainability of waste-to-energy projects in rural areas depends less on the complexity of the technology and more on the depth of community engagement and skill internalization (Zikargae et al., 2022).

From an economic perspective, the production of coconut shell charcoal opens a viable pathway for local economic development and poverty alleviation (Siregar et al., 2026). The transformation of a zero-value waste product into a commodity with market potential introduces a new micro-enterprise opportunity for the village (Eiseman et al., 2020). According to local economic development theories, leveraging endogenous resources such as abundant agricultural waste can stimulate rural economies by creating localized value chains (Gearhart, 2023). The charcoal produced can be consumed locally to reduce household energy expenditures or sold to generate supplementary income (Gautam et al., 2026). Moreover, this foundational step lays the groundwork for further value addition, such as the production of briquettes, which command higher market prices and offer greater practical utility, thereby enhancing the overall economic multiplier effect within the community (Awafo et al., 2021).

The environmental implications of this intervention are equally significant, directly contributing to the United Nations Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). By mitigating the practice of open burning, the project substantially reduces the emission of greenhouse gases and hazardous particulate matter, thereby improving local air quality and public health (Nonsawang et al., 2024; Waziri et al., 2024). Additionally, the utilization of biomass charcoal as an alternative to fossil fuels or traditional firewood

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E-ISSN: 3024-9716 DOI: https://doi.org/110.62255/noval.v4i2.347

contributes to a lower carbon footprint (Nikolaus et al., 2026). The project exemplifies how decentralized, small-scale environmental management practices can cumulatively yield substantial ecological benefits, reinforcing the importance of grassroots participation in global sustainability efforts (Ahmad et al., 2024; Tambing et al., 2025).

Despite these promising outcomes, this study acknowledges certain limitations that must be addressed in future research and interventions. Firstly, the current evaluation relies heavily on qualitative assessments, observational data, and basic yield estimations; rigorous physicochemical analyses, such as precise calorific value, volatile matter, and ash content testing using standardized laboratory equipment, were not conducted, which limits the ability to benchmark the product against commercial national standards. Secondly, the intervention was confined to a short-term community service timeframe, meaning the long-term sustainability, market viability, and continuous adoption rates of the practice by the community remain to be fully verified. Finally, the reliance on simple, manual kilns, while highly accessible, presents scalability constraints and potential inconsistencies in product quality, highlighting the need for technological upgrading if the community aims to transition from household use to commercial enterprise.

Limitation

To overcome these limitations and ensure the long-term viability of the initiative, future efforts must focus on technological upscaling and quality standardization. Subsequent interventions should introduce mechanized briquetting processes and standardized quality testing to ensure the product meets market requirements. Furthermore, establishing a formalized community cooperative or local MSME (UMKM) is crucial for managing production, branding, and market distribution. Integrating digital marketing strategies could also expand the market reach beyond the local vicinity. By addressing these operational and commercial dimensions, the foundational success of this waste-to-energy empowerment can be transformed into a robust, self-sustaining rural enterprise.

CONCLUSIONS

True sustainability is not merely about managing waste, but about reimagining it as the foundation of local prosperity. This community service initiative in Desa Liprak Kidul successfully demonstrates that the participatory conversion of coconut shell waste into charcoal is a highly effective strategy for bridging environmental management with grassroots economic empowerment. By operationalizing the Circular Economy theory through a rigorously structured, quasi-experimental carbonization training, the project not only mitigated local environmental hazards but also catalyzed a profound shift in the community's socio-economic paradigm, transforming a neglected byproduct into a viable catalyst for rural enterprise. Ultimately, this study affirms that when local communities are equipped with the appropriate knowledge and participatory frameworks, they possess the inherent capacity to engineer their own sustainable, waste-to-energy solutions.

DECLARATIONS

1. Acknowledgements

The authors would like to thank Institut Ahmad Dahlan Probolinggo for their support through the Kuliah Kerja Nyata (KKN) program. We also extend our gratitude to the Village Government and the residents of Liprak Kidul Village for their active participation and support during the data collection and implementation of this community service initiative.

2. Ethical Approval and Informed Consent

This study was approved by the Ethics Committee of Institut Ahmad Dahlan Probolinggo and received administrative approval from the Village Head of Liprak Kidul. Written informed consent was obtained from all participants prior to their participation in the study.

3. Data Availability Statement

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E-ISSN: 3024-9716 DOI: https://doi.org/110.62255/noval.v4i2.347

The datasets generated and/or analyzed during the current study are not publicly available due to privacy and ethical restrictions regarding the community participants but are available from the corresponding author on reasonable request.

4. Funding

The authors declare that no specific external funds, grants, or other financial support were received during the preparation of this manuscript.

5. Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. Authors' Contributions

Conceptualization: M.J., M.R.R.; Methodology: M.J., A.I.B.; Formal analysis and investigation: B.T., R.A., R.A.; Writing - original draft preparation: M.J., M.R.R.; Writing - review and editing: A.I.B., B.T.; Funding acquisition: M.J.; Resources: M.R.R., R.A.; Supervision: M.J.

7. AI Disclosure

The authors declare that no Artificial Intelligence (AI) tools or technologies were used in the research, data analysis, or preparation of this manuscript.

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