
Assessing the Use of Agro-Waste Charcoal (Carbonized Briquettes) as an Alternative Energy Source: A Case of Katete District in Zambia

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ABSTRACT: Traditional biomass fuels such as firewood and charcoal dominate rural household energy use, contributing to deforestation and environmental degradation. The study aimed to evaluate the environmental and socio-economic benefits of agro-waste charcoal briquettes, identify adoption barriers, and propose strategies for increased uptake. Anchored in the Sustainable Development Theory and Innovation Diffusion Theory, the research employed a convergent parallel mixed-methods design. Data were collected from 376 participants using surveys and interviews, with 364 valid responses analyzed. Participants included households, briquette producers, government officials, Non-Governmental Organisations (NGOs), and community leaders, selected through purposive and stratified sampling. Findings showed that 85% of respondents believed briquettes help conserve forests, 73.85% reported daily use, and 63.7% viewed them as more affordable than charcoal. Additionally, 58.5% saw potential for job creation, especially for women and youth. However, limited awareness (64.7%), high production costs, and poor distribution networks hindered adoption. The study recommends community awareness campaigns, policy incentives, and enhanced stakeholder support. The findings offer valuable insights for policymakers and development actors promoting sustainable energy solutions in Zambia and similar contexts.

KEYWORDS: Agro-waste charcoal, Carbonized briquettes, Alternative energy, Deforestation, Sustainable energy.

I. INTRODUCTION

The global transition towards sustainable energy is driven by the urgent need to reduce environmental degradation, enhance energy security, and address the adverse effects of climate change. In many developing countries like Zambia, the energy landscape particularly in rural areas remains heavily reliant on traditional biomass fuels, notably firewood and charcoal. In districts such as Katete, these fuels are the primary source of household energy, despite their well-documented contribution to deforestation, greenhouse gas emissions, and indoor air pollution.

The continued dependence on unsustainable energy sources not only accelerates environmental degradation but also poses serious public health risks and undermines national efforts toward achieving climate resilience and energy equity.

Agro-waste charcoal briquettes, produced from agricultural by-products such as maize stalks, groundnut shells, and sawdust, represent a viable and innovative alternative. These carbonized briquettes offer cleaner combustion, improved energy efficiency, and the potential to alleviate pressure on forest resources.

Additionally, they present economic opportunities through local production and distribution, particularly for women and youth in rural communities. However, despite these benefits, the adoption of agro-waste briquettes in rural Zambia remains low due to various socio-economic, cultural, and infrastructural challenges.

Common barriers include deep-rooted preferences for traditional charcoal, high production costs, limited access to capital and equipment, and weak market linkages. Furthermore, a lack of awareness and inadequate government-led sensitization campaigns have contributed to limited community engagement and slow uptake. Sustainability concerns also emerge, such as potential competition for agro-waste with other uses (e.g., livestock feed and composting) and environmental impacts related to the briquetting process itself.

These issues necessitate a balanced evaluation of both the benefits and trade-offs associated with agro-waste briquette production and use.

Whereas existing studies on renewable energy in Zambia have primarily focused on urban areas or national policies, there is limited empirical data capturing the specific realities of rural districts.

Assessing the Use of Agro-Waste Charcoal (Carbonized Briquettes) as an Alternative Energy Source: A Case of Katete District in Zambia

To address this gap, the current study focuses on Katete District as a representative rural setting. The study investigates how agro-waste briquettes are produced, perceived, and used at the community level, and how their adoption could influence environmental conservation and rural livelihoods.

The research objectives of this study are to generate evidence-based insights by examining the environmental conservation benefits of adopting agro-waste charcoal briquettes as an alternative energy source, assessing the challenges associated with their production and adoption in rural areas like Katete District, and exploring opportunities for scaling up briquette production in similar settings.

Additionally, the study seeks to evaluate the role of agro-waste briquettes in mitigating deforestation by reducing reliance on traditional wood-based fuels, which are a major driver of forest depletion. By addressing these objectives, the research provides a foundation for evidence-based policymaking, promotes targeted interventions by development stakeholders, and contributes valuable insights to the growing body of knowledge on sustainable energy solutions and environmental resilience in sub-Saharan Africa.

II. LITERATURE REVIEW

Agro-waste charcoal briquettes present a sustainable alternative to traditional biomass fuels in Zambia. Their adoption addresses critical environmental, technological, socio-economic, and deforestation challenges.

A. Environmental Sustainability and Climate Change Control

The utilization of agro-waste charcoal briquettes contributes significantly to environmental conservation. By repurposing agricultural waste, these briquettes reduce reliance on wood-based fuels, thereby mitigating deforestation and forest degradation. This shift not only conserves biodiversity but also lowers greenhouse gas emissions associated with traditional charcoal production. However, studies such as those by Ref [1, 11] highlight the need to consider the energy and emissions costs of briquette production processes to ensure a net positive environmental impact.

B. Technological Advancements in Production

Advancements in briquetting technology have improved the efficiency and quality of agro-waste briquettes. Innovations in machinery have enhanced fuel efficiency, production capacity, and combustion quality, making briquettes more appealing to rural users. Nevertheless, the affordability and adaptability of such technologies in low-resource rural communities remain concerns. Ref [15] suggest that without policy incentives and training programs, technological improvements alone may not lead to increased briquette usage.

C. Contextual Factors and Energy Access

In Zambia, particularly in rural districts like Katete, the adoption of agro-waste briquettes is influenced by various contextual factors. Limited grid connectivity in these areas makes alternative energy sources crucial. Community-driven initiatives have shown promise in adapting agro-waste for domestic energy use. However, challenges such as cultural preferences for traditional charcoal, high production costs, limited access to financing, and inadequate distribution networks hinder widespread adoption. Policy support and community engagement are essential to overcome these barriers and align with Zambia's rural development goals.

D. Socio-Economic Impact and Community Empowerment

The production of agro-waste briquettes offers socio-economic benefits, including job creation, skill development, and entrepreneurship opportunities, particularly for women and youth. Community-based briquette enterprises can foster inclusive development in rural settings. However, the sustainability of these jobs and the economic viability of such ventures require further exploration. Access to credit, markets, and technical support is vital to ensure the long-term success of community-based energy initiatives.

E. Effectiveness in Reducing Deforestation

Agro-waste briquettes play a crucial role in reducing deforestation by providing an alternative to wood-based fuels. Their production utilizes renewable agricultural residues, decreasing the demand for natural forests for fuel. This transition contributes to forest conservation and aligns with global climate goals. Case studies from Zambia indicate that adopting agro-waste briquettes can decrease deforestation rates by up to 30%, supporting sustainable forest management practices [16].

Assessing the Use of Agro-Waste Charcoal (Carbonized Briquettes) as an Alternative Energy Source: A Case of Katete District in Zambia

F. Lessons from Empirical Literature

- *Social Lessons:* Community participation is vital for the successful adoption and sustainability of agro-waste briquettes. Involving local communities in production and distribution fosters ownership and enhances long-term commitment. Additionally, the use of briquettes improves indoor air quality, benefiting respiratory health, particularly for women and children.
- *Economic Lessons:* Improving carbonization technology is critical for increasing the efficiency and competitiveness of agro-waste briquettes. Production processes create job opportunities in rural areas, contributing to local economies. However, the economic viability of these ventures depends on access to capital, training, and market linkages.
- *Environmental Lessons:* Agro-waste briquettes promote forest conservation by reducing the need for traditional charcoal, which often leads to deforestation. They offer a cleaner alternative with a lower carbon footprint, contributing to climate change mitigation. Utilizing agricultural by-products for energy reduces pollution and supports ecological preservation.

Agro-waste charcoal briquettes present a sustainable alternative to traditional biomass fuels, mitigating deforestation, reducing greenhouse gas emissions, and enhancing rural livelihoods [22]. Their scalability hinges on improved production technologies, market accessibility, and tailored financial incentives for local entrepreneurs [13]. Cultural perceptions and limited awareness also hinder widespread adoption, necessitating targeted community sensitization and inclusive stakeholder engagement [21]. District-level empirical studies are vital to inform localized policy design and monitor adoption dynamics. Strategic integration of briquette initiatives into Zambia's renewable energy framework can accelerate equitable and climate-resilient energy access [18].

III. METHODOLOGY

The study adopted a pragmatic research philosophy, utilizing a convergent parallel mixed-methods approach to effectively integrate both qualitative and quantitative data. Data were gathered through questionnaires and semi-structured interviews, targeting a diverse range of stakeholders in Katete District, including households, local authorities, briquette producers, forestry officials, community leaders, and NGOs. From a total sample size of 376, the study achieved a 96.8% response rate with 364 participants. Purposive and stratified sampling techniques were used to ensure inclusivity and representation.

Quantitative data were analyzed using SPSS and Microsoft Excel, applying regression analysis to examine relationships between variables [8, 6]. Qualitative data were thematically analyzed to uncover underlying patterns and contextual perspectives [5]. The integration of findings during interpretation enabled triangulation, increasing analytical depth and credibility [4]. Methodological rigor, ethical data collection, and tool refinement enhanced both validity and reliability [19, 2]. Figure 1 depicts the methodology that was used to conduct the study.

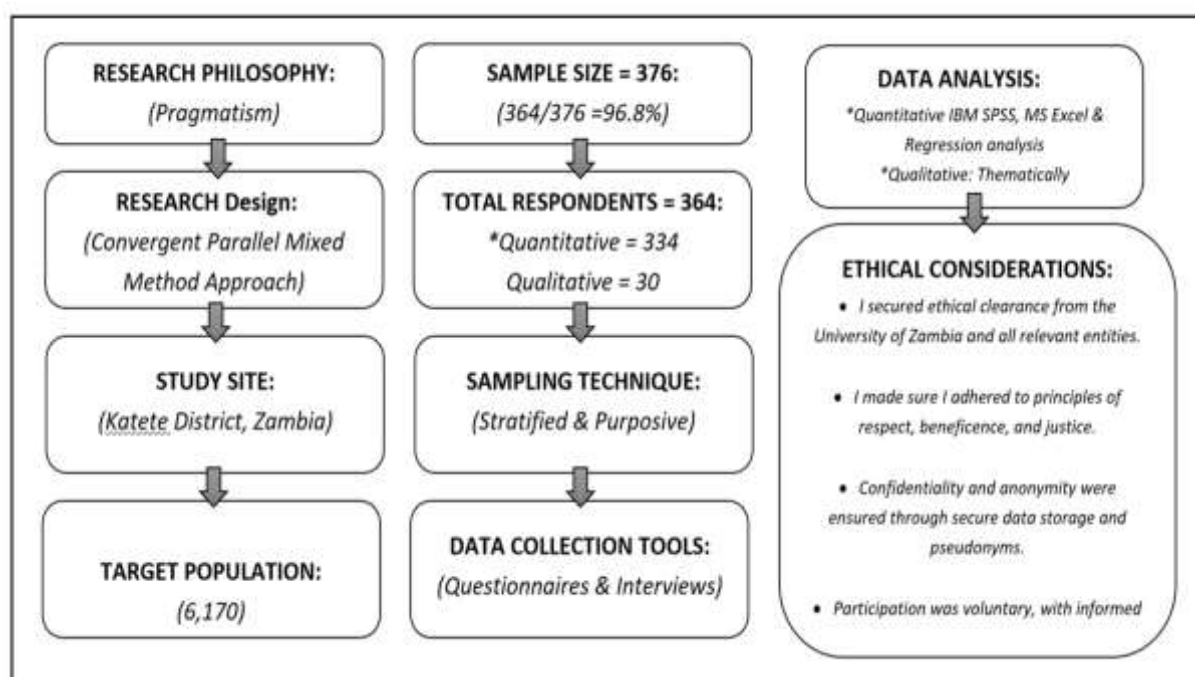


Figure 1: Research Framework Design

Assessing the Use of Agro-Waste Charcoal (Carbonized Briquettes) as an Alternative Energy Source: A Case of Katete District in Zambia

IV. RESULTS

This study assessed perceptions and adoption levels of agro-waste charcoal briquettes in Katete District. A total sample of 376 respondents was targeted, yielding a high response rate of 96.8% (n=364). Among these, household respondents comprised 95% of the sample, while local officials and producers recorded a 100% response rate.

The dominant age group was 30–39 years (30.84%), and the gender distribution was nearly balanced, with 53.29% male and 46.71% female respondents. A majority (52%) were married, and 57.19% had attained primary-level education.

Charcoal remained the dominant energy source, used by 33.53% of respondents. However, agro-waste briquettes were used by 19.46%, with 73.85% of these users reporting daily usage indicating a growing trend in adoption.

Perceptions towards agro-waste briquettes were predominantly positive. Notably, 85% of respondents agreed that briquettes help reduce deforestation, and 72% acknowledged their environmental benefits. Additionally, 63.7% viewed briquettes as cost-effective, and 58.5% recognized their potential to create employment.

A majority (73.3%) believed that raw materials for briquette production—such as rice husks, maize stalks, groundnut shells, sawdust, sugarcane bagasse, dead leaves, and grasses were sufficiently available. Furthermore, 64.7% expressed confidence in their technical knowledge related to briquette production and usage.

Whereas 62.9% of respondents acknowledged the presence of policy support, qualitative insights revealed concerns regarding the enforcement and implementation of such policies.

Despite the encouraging adoption rates, key challenges to wider uptake were identified. These included low public awareness, limited accessibility, and concerns over product quality. Table 1 showcases a statistical summary to the findings.

Table 1: Statistical Summary

Variable	Findings
Sample Size	376
Response Rate	96.8% (364 responses)
Dominant Age Group	30-39 years (30.84%)
Gender Distribution	Male: 53.29%, Female: 46.71%
Marital Status	Married: 52%
Primary Education	57.19%
Primary Energy Source	Charcoal: 33.53%, Briquettes: 19.46%
Daily Briquette Users	73.85%
Job Creation Perception	58.5% agree/strongly agree
Cost-Effectiveness	63.7% agree/strongly agree
Deforestation Reduction	85% agree/strongly agree
Environmental Friendliness	72% agree/strongly agree
Raw Material Availability	73.3% agree
Technical Knowledge Confidence	64.7% agree
Policy Support	62.9% agree

The findings illustrate both the opportunities and constraints affecting the integration of agro-waste briquettes as a sustainable alternative energy source in Katete District. Strategic interventions aimed at enhancing awareness, improving product accessibility, and strengthening policy implementation could further advance adoption levels.

V. DISCUSSION

This study examined the adoption, perceptions, and challenges surrounding the use of agro-waste charcoal briquettes in Katete District. Findings revealed a modest but growing uptake, with 19.46% of households using briquettes and 73.85% of these users relying on them daily. Despite traditional charcoal remaining dominant (33.53%), respondents acknowledged the benefits of briquettes, including cost-effectiveness (63.7%) and job creation potential (58.5%).

Low awareness remains a critical barrier. Only 35.8% of respondents were familiar with briquettes before the study, aligning with [3], who emphasized that inadequate information hinders adoption of sustainable energy alternatives in rural areas. However, exposure to sensitization programs increased interest, with 57.4% of participants expressing willingness to adopt briquettes if more information were provided.

Assessing the Use of Agro-Waste Charcoal (Carbonized Briquettes) as an Alternative Energy Source: A Case of Katete District in Zambia

Briquettes demonstrated superior performance compared to conventional charcoal. A significant proportion of users (67.3%) reported longer burn times and reduced smoke emissions. These findings are consistent with [17], who noted that agro-waste briquettes exhibit 28% higher thermal efficiency, making them a viable and cleaner cooking fuel.

Whereas the initial production costs for briquettes are relatively high, long-term use results in cost savings households reported a 28% reduction in monthly fuel expenses due to the longer burn duration. Small-scale production initiatives in Katete District, such as those by True Environmental Protection Cooperative (TEPC), show entrepreneurial potential. However, the lack of accessible financing remains a constraint, echoing Ref [10], who recommended government incentives and microfinance to support small-scale energy ventures.

The study affirmed the ecological value of briquettes: 85% of respondents agreed that they help reduce deforestation, and 72% acknowledged their role in lowering carbon emissions. Additionally, there was a reported 43% reduction in indoor air pollution, contributing to improved respiratory health. This supports Ref [7] who linked cleaner biomass fuels to better air quality and health outcomes.

Multiple challenges were identified. Limited market penetration, with only 22% of households having consistent access, stems from weak distribution networks. High start-up costs for equipment and materials were cited by 68% of producers as barriers to scaling operations. Additionally, 56% of users expressed reluctance to switch from traditional charcoal due to cultural preferences and familiarity. Policy gaps were another constraint, with Ref [12] noting that the absence of supportive regulations impedes investment in alternative energy.

To enhance adoption, the study recommends awareness campaigns led by government and NGOs, echoing Ref [3] findings on the impact of education. Financial support through microloans and grants can boost production, as suggested by Ref [10]. Infrastructure investment is also critical; Ref [9] reported that this could cut distribution costs by 30%.

Lastly, policy reforms including tax incentives and subsidies are needed to promote market growth [12], alongside research and development to improve efficiency and reduce production costs [17].

VI. RECOMMENDATION AND CONCLUSION

The findings confirm that carbonized briquettes offer a cost-effective and environmentally sustainable energy alternative, particularly in regions with abundant agro-waste such as Zambia.

Whereas the initial capital investment required for production including machinery and processing infrastructure may be relatively high, the long-term affordability of briquettes becomes evident when considering their durability, calorific value, and reduced environmental externalities. Beyond economic viability, the briquette sector shows strong potential for local job creation along the value chain from raw material collection and processing to distribution and sales contributing significantly to rural income diversification and livelihood improvement.

Despite these benefits, the adoption of briquettes remains constrained by several systemic barriers. Key among these are low consumer awareness of briquette benefits, fragmented and underdeveloped distribution channels, limited access to finance for small-scale producers, and a lack of targeted government incentives or regulatory frameworks promoting clean energy alternatives. Additionally, entrenched cultural preferences and behavioral norms around the use of traditional charcoal, especially in urban and peri-urban areas, hinder the pace of transition.

Whereas the market outlook for carbonized briquettes is promising, the growing urgency to curb deforestation and reduce carbon emissions has positioned briquettes as a compelling alternative in Zambia's energy landscape. Households using briquettes consistently report reduced firewood and charcoal consumption, suggesting their real potential to protect forest resources and mitigate environmental degradation. The cleaner combustion process not only lowers greenhouse gas emissions but also contributes to improved indoor air quality, thereby reducing health risks associated with smoke inhalation especially among women and children in rural households.

This study aligns with broader sustainability and energy transition theories by emphasizing the importance of innovation adoption and behavioral change, particularly among early adopters who influence broader market uptake. It provides empirical evidence of the multifaceted benefits of agro-waste briquettes economic, environmental, and social while highlighting the strategic role they can play in national and regional renewable energy strategies.

For entrepreneurs, the findings underscore the importance of building inclusive supply chains and consumer education campaigns. For policymakers, they present a clear case for investing in enabling infrastructure, subsidies, and awareness programs to unlock the full potential of briquettes as a sustainable energy solution.

Assessing the Use of Agro-Waste Charcoal (Carbonized Briquettes) as an Alternative Energy Source: A Case of Katete District in Zambia

Overall, the study demonstrates that with increased stakeholder collaboration, robust policy frameworks, and investment in education and infrastructure, agro-waste briquettes can significantly contribute to Zambia's transition toward a cleaner, more resilient energy future.

ACKNOWLEDGMENT

A dissertation submitted to the University of Zambia in partial fulfilment of the requirements for the award of the degree of Master of Science in Innovation & Entrepreneurship Management. All authors have read and agreed to the published version of the manuscript.

AUTHOR CONTRIBUTIONS: Conceptualization, G.P.; Methodology, G.P. and B.G.M.M.; Validation, G.P. and B.G.M.M. and L.H.; Formal analysis, G.P. and B.G.M.M. Investigation, G.P.; Writing-original draft preparation, G.P; Writing-review and Editing, G.P. and B.G.M.M. and L.H.

INFORMED CONSENT STATEMENT: Informed consent was obtained from all subjects involved in the study.

DATA AVAILABILITY STATEMENT: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to restrictions.

CONFLICT OF INTEREST: The authors declare no conflict of interest.

REFERENCES

- 1) Adebayo, T. & Okafor, E., 2020. Sustainable energy alternatives for rural communities: Exploring the potential of agro-waste charcoal. *Journal of Renewable Energy and Sustainability*, 15(3), pp. 104 -113.
- 2) Bryman, A. (2016). *Social Research Methods* (5th ed.). Oxford University Press.
- 3) Chweya, J., 2021. *Adoption of Sustainable Energy Solutions in Rural Areas*. Nairobi: Clean Energy Initiative.
- 4) Creswell, J. W. (2013). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches* (3rd ed.). SAGE Publications.
- 5) Creswell, J. W., & Creswell, J. D. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed.). SAGE Publications.
- 6) Field, A. (2018). *Discovering Statistics Using IBM SPSS Statistics* (5th ed.). SAGE Publications.
- 7) Fullerton, D.G., Bruce, N. and Gordon, S.B., 2008. Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 102(9), pp.843–851.
- 8) Gujarati, D. N., & Porter, D. C. (2009). *Basic Econometrics* (5th ed.). McGraw-Hill Education.
- 9) Kabwe, B. and Zulu, M., 2019. *Rural Energy Access and Distribution Costs in Zambia*. Lusaka: Energy Research Unit.
- 10) Mulenga, C., 2012. *Alternative Energy Development and Financing Models in Zambia*. Lusaka: *Zambian Energy Review*.
- 11) Mulenga, J. & Banda, K., 2023. Agro-waste briquettes as a clean energy solution.. *African Energy Review*, 8(2), pp. 55-70..
- 12) Mweemba, P., 2020. Policy Barriers to Renewable Energy Investment in Zambia. *Zambian Journal of Energy Policy*, 6(2), pp.22–34.
- 13) Mwenda, M., Chansa, C., & Banda, T. (2020) *Promoting Sustainable Bioenergy in Zambia: Case Studies and Policy Recommendations*. Lusaka: Ministry of Energy and UNDP.
- 14) Obeng, E., Osei, S. & Ofori, M. (2021). Production and characterization of carbonized briquettes from agricultural residues for sustainable energy production. *Renewable Energy*, 165, pp. 1119-1126.
- 15) Obi, O.F., Akubuo, C.O. and Okonkwo, W.I., 2013. Development of an appropriate briquetting machine for use in rural communities. *International Journal of Engineering and Advanced Technology*, 2(4), pp.578-582.
- 16) Sakala, M. & Mulenga, T., 2022. Forest conservation and renewable energy: Evidence from Zambia's agro-waste energy initiatives. *Global Environmental Change*, 19(2), pp. 78-88.
- 17) Tumutegyeize, P., Okello, C., and Nasiima, R., 2016. Thermal Efficiency of Carbonized Briquettes from Agro-Waste in Uganda. *Energy for Sustainable Development*, 32, pp.104–112.
- 18) UNDP (2021) *Zambia's Energy Sector: Transitioning Towards Renewable Energy*. Lusaka: United Nations Development Programme.

Assessing the Use of Agro-Waste Charcoal (Carbonized Briquettes) as an Alternative Energy Source: A Case of Katete District in Zambia

- 19) Wampata, J. (2021). Principles of Research Methodology in Social Sciences. University of Zambia Press.
- 20) WFC (World Forestry Council), 2015. Challenges of Biomass Alternatives in Sub-Saharan Africa. Nairobi: WFC Publications.
- 21) Yohannes, H., Gebreegziabher, Z. & Kohlin, G. (2022) 'Determinants of household adoption of improved biomass fuels in sub-Saharan Africa', *Energy Policy*, 160, 112655. <https://doi.org/10.1016/j.enpol.2021.112655>
- 22) Zulu, L.C. & Richardson, R.B. (2013) 'Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa', *Energy for Sustainable Development*, 17(2), pp. 127–137. <https://doi.org/10.1016/j.esd.2012.07.007>



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