

Design and Development of a Double Cylinder Biomass Stove for Efficient Thermal Energy Production

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ABSTRACT: This study addressed the urgent requirement for efficient and sustainable cooking solutions in rural regions with restricted access to modern energy, where conventional biomass cooking practices result in environmental and health challenges. It investigates designing and developing a multifunctional double-cylinder biomass burner that utilizes wood, pellets, and coconut shells. The stove's modular architecture, improved airflow regulation, and optimized combustion chamber are designed to promote fuel efficiency and diminish harmful emissions. Laboratory analysis of wood pellets indicates an average calorific value of 3136.45 calories, with stove efficiency recorded at 47%, surpassing many traditional biomass stoves. Air quality assessments verified acceptable pollutant concentrations, signifying efficient combustion. The research underscores the stove's capacity to decrease fuel usage, diminish interior air pollution, and alleviate environmental deterioration, positioning it as a viable alternative for rural energy requirements. Nonetheless, there is potential for enhanced efficiency relative to sophisticated liquid fuel stoves. Future research should optimize stove design and investigate novel materials to improve performance and support global sustainable energy efforts.

KEYWORDS: Air quality, Biomass stove, Combustion efficiency, Rural energy, Sustainable cooking solutions, Wood pellets.

I. INTRODUCTION

The rapid growth in global energy demand, particularly in rural areas with limited access to modern energy infrastructure, has increased the urgency of developing affordable and sustainable energy alternatives. According to Jiang et al. (2024), traditional biomass remains the dominant energy source for cooking in many developing countries despite its environmental consequences. Narnaware and Panwar (2022) further emphasized that biomass-based energy systems have significant potential to support climate change mitigation while improving rural energy access. Likewise, Yunusa et al. (2023) explained that biomass cookstoves have become an important technological solution for enhancing clean cooking practices through improved combustion efficiency. Although LPG is widely available in urban areas, Hollands and Daly (2023) reported that access to clean cooking fuels remains limited in many remote regions, making biomass-based cooking technologies an essential alternative. Similarly, Khavari et al. (2023) demonstrated that geographical disparities continue to hinder access to clean cooking technologies, particularly in Sub-Saharan Africa. Biomass is considered one of the most promising renewable energy resources because of its widespread availability and compatibility with agricultural and forestry residues. Venkatraman et al. (2024) highlighted that agricultural residues and woody biomass can provide sustainable energy while reducing dependence on fossil fuels. Furthermore, Zhang (2022) argued that accelerating the transition toward clean cooking requires technological innovation supported by appropriate policies and community engagement.

Traditional cooking systems commonly used in rural households still rely on open fires or inefficient stoves with poor combustion performance. Jiang et al. (2024) reported that incomplete biomass combustion produces substantial quantities of particulate matter and gaseous pollutants that degrade environmental quality. Similarly, Mir et al. (2024) found that black carbon emissions from biomass combustion significantly contribute to climate change and deteriorating air quality. Venkatraman et al. (2024) also explained that biomass combustion releases hazardous compounds, including polycyclic aromatic hydrocarbons (PAHs), which pose serious risks to human health. In addition, Onah et al. (2021) observed that households using traditional biomass stoves experience greater exposure to indoor air pollution than those adopting improved cookstoves. Supporting this finding, Abokyi et al. (2024) showed that the transition toward cleaner cooking fuels substantially improves household health

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outcomes. Moreover, Islam et al. (2021) demonstrated through long-term field measurements that traditional biomass stoves generate considerably higher pollutant emissions than cleaner cooking technologies.

Improved biomass cookstoves have been developed to overcome the limitations of traditional cooking systems by increasing combustion efficiency and reducing harmful emissions. Yunusa et al. (2023) explained that recent biomass cookstove designs incorporate advanced combustion chambers and improved air supply systems to maximize thermal efficiency. Field evaluations conducted by Wathore et al. (2023) confirmed that optimized biomass cookstoves significantly reduce fuel consumption while improving cooking performance under real household conditions. Likewise, Himanshu et al. (2022) demonstrated experimentally that gasifier biomass stoves fueled by biomass pellets achieve higher thermal efficiency than conventional biomass stoves. Regarding fuel characteristics, Ismail et al. (2025) reported that biomass pellets possess superior thermal properties because of their high density and low moisture content. Similarly, Kumar et al. (2022) found that biomass pellets manufactured from agricultural residues provide stable combustion and higher calorific values. Mencarelli et al. (2022) further concluded that biomass briquettes and pellets are suitable fuels for domestic heating and cooking applications because of their consistent energy performance.

Beyond environmental improvements, biomass cookstoves also provide significant socioeconomic benefits. Manaye et al. (2022) found that improved biomass cookstoves substantially reduce fuelwood consumption and carbon emissions while decreasing the burden of fuel collection for rural households. Furthermore, Mperejekumana et al. (2024) emphasized that sustainable household cooking systems contribute not only to energy security but also to poverty reduction and rural development. From a climate perspective, Kavindi et al. (2025) demonstrated that biomass-based energy technologies can effectively reduce greenhouse gas emissions through sustainable biomass utilization. Likewise, Wang et al. (2022) concluded that biomass conversion technologies support environmental sustainability when evaluated using life-cycle assessment approaches. In addition, Hollands and Daly (2023) highlighted that expanding access to clean cooking technologies is essential for simultaneously achieving energy access and climate mitigation goals, while Khavari et al. (2023) and Zhang (2022) emphasized the importance of integrating technological innovation, public policy, and community participation to accelerate the transition toward clean cooking systems.

This study therefore focuses on designing and evaluating a multi-fuel biomass cookstove capable of utilizing firewood, biomass pellets, and coconut shells efficiently. Irro et al. (2024) demonstrated that appropriate stove design, particularly thermal mass optimization, can significantly reduce biomass fuel consumption. Furthermore, Yu et al. (2022) recommended improving biomass conversion efficiency to maximize energy utilization while minimizing environmental impacts. The field evaluation conducted by Wathore et al. (2023) also confirmed that optimizing airflow and combustion conditions substantially enhances stove performance under actual operating conditions. In addition, Narnaware and Panwar (2022) argued that the development of efficient biomass technologies is essential for supporting sustainable rural energy systems and reducing dependence on conventional fossil fuels.

II. METHOD

This study was conducted at the Food Technology and Process Research Center, National Research and Innovation Agency, located at JL. Jogja-Wonosari, km 31, 5. Kec. Playen, 174 WNO, Gading II, Gading, Playen, Gunungkidul Regency, Special Region of Yogyakarta 55861.

A. Design Procces

As shown in Figure 1, the stove design prioritizes modularity and adaptability for many fuel types, including wood, pellets, and coconut shells. This modular design enables users to swap components or modify the stove based on the available fuel type, ensuring optimal efficiency across diverse conditions. A prominent characteristic of this stove is its meticulously engineered airflow management. The airflow control system allows users to modify combustion intensity as required, providing efficient and stable fuel combustion. The fuel delivery mechanism is engineered for ease of operation, facilitating the seamless fuel addition without interrupting the combustion process. The geometry of the combustion chamber is a crucial aspect of this design. A specially engineered combustion chamber facilitates even heat distribution, enhancing thermal efficiency and minimizing pollutants. This configuration facilitates excellent air movement, promoting the complete combustion of various fuel types employed.

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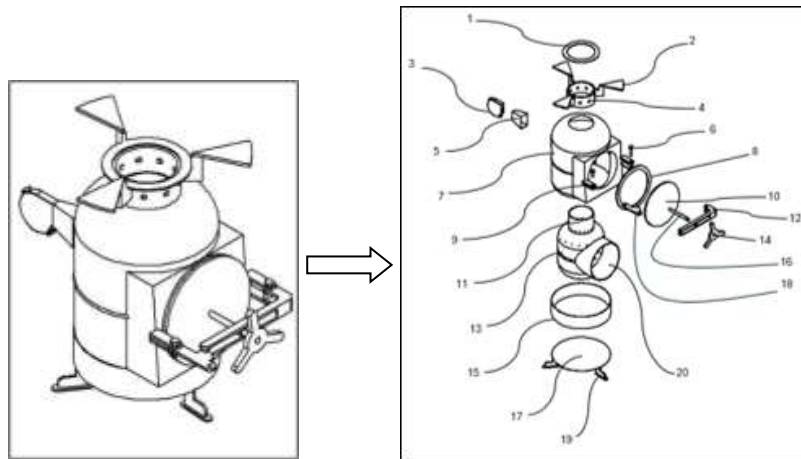


Figure 1. Exploded View and 3D Representation of a Modular Stove Design

(1. Ring stove, 2. Stove mount, 3. Blower DC, 4. Air vents for fire direction, 5. Blower funnel to stove, 6. Hinge locking bolts, 7. Large tubes, 8. Ring in tube, 9. Hinge mount, 10. Stove door cover circle, 11. Small tube pipe for container to large inner tube, 12. Door hinges, 13. Small Tube, 14. Stove opener, 15. Lower tube bottom loop ring, 16. Stove lock nature, 17. Large tube holder base, 18. Stove hinge lock, 19. Stove stand legs, 20. Funnel for inserting fuel).

B. Instrument utilized

The equipment used in the design is a solid work application. The equipment used in the manufacturing process consists of Mitutoyo IP/67 Caliper, Lakoni Falcon 120E Interfer 900 Watt Brand Electric Welding Machine, Gweike 3015 LN Laser Machine, Makita 4 inch Hand Grinding Machine, and KRISBOW/DRILL PRESS 13 x 350 mm DD1335CA 10063883. The instrument performance measurement apparatus comprises a Casio HS-3 (V) stopwatch and a Fluke 59 max infrared thermometer. Emission evaluation was measured using the Bosen TZ01 CO₂ CO PM_{2.5} HCHO TVOC Monitor T-Z01 Air Quality Detector.

C. Materials Selection

The primary components of this stove consist of two utilized freon tubes, R410A and R32, with diameters of 245 mm and 193 mm, respectively. After its formation, the little tube sits within the giant tube. To ensure adequate airflow in the combustion chamber, the wall of the tiny tube features 42 uniformly distributed apertures, each with a diameter of 3 mm. This appliance features a Fan Stove Deck WGFJ-G006 220V AC to control the combustion chamber fire size, with specifications of Voltage: 220V $\pm$ 10%, 50Hz, Rated Power 25W, Current 0.14A, Rotation Speed 2850 r/min, and Insulation Grade B. The additional components include a 2 mm iron plate measuring 1000x1000 cm for the bottom stove ring, a 3-inch iron pipe, a 4-inch iron pipe, two M13 bolts and nuts, 15 cm long M12 bolts, and a 4 mm iron plate measuring 1000 x 1000 cm for door handles, hinges, stove holders, stove legs, and stove front washers. The materials used for the performance evaluation of the stove consist of wood pellets, water, and benzoic acid (for calibration and titration solution).

III. PERFORMANCE EVALUATION

A. Measuring the calorific value of wood pellets

The calorific value of wood pellets is determined using a bomb calorimeter. The combustion occurs in an enclosed space filled with pure oxygen. As the pellets combust, the adjacent water will absorb the generated heat. The released heat signifies the energy per unit mass contained in the pellet, computed using the subsequent empirical formula: $Q = m \times c \times \Delta T$, where Q represents the energy released, m denotes the mass of water, c signifies the specific heat capacity of water, and ΔT indicates the temperature change. The test was carried out three times.

B. Measuring the performance of the designed stove

The furnace performance testing emphasises several critical parameters: stove efficiency, steam production, heat requirements for steam generation, fuel consumption rate, and emissions produced. Comparing the energy that the fuel provides to the energy that the working fluid absorbs as steam yields an efficiency rating. The steam production rate is calculated by dividing the quantity of steam generated by the duration under defined operating circumstances. The energy necessary to raise the water's temperature to its boiling point and the energy required for its evaporation determine the heat required to produce steam. The fuel consumption rate is established by quantifying the fuel utilised per unit of time throughout the combustion process. The examination was conducted three times.

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C. Emission evaluation

Emissions generated are analyzed using Air Quality Detector, to detect Temperature ($^{\circ}\text{C}$), relative humidity (%RH), formaldehyde concentration, (HCHO , mg/m^3), the concentration of fine particulate matter with a diameter of 2.5 micrometers or smaller ($\text{PM}_{2.5}$ ($\mu\text{g}/\text{m}^3$), Total Volatile Organic Compounds (TVOC, mg/m^3), Carbon monoxide concentration (CO (ppm), Carbon dioxide concentration (CO_2 (ppm) and Air Quality Index (AQI) which gives an overall assessment of air quality.

IV. RESULTS AND DISCUSSION

This section presents the research results that include the design stages up to the fabrication of the dual-cylinder biomass stove prototype, as well as its performance evaluation through tests of fuel calorific value, stove thermal efficiency, fuel consumption, steam production rate, and emission quality.

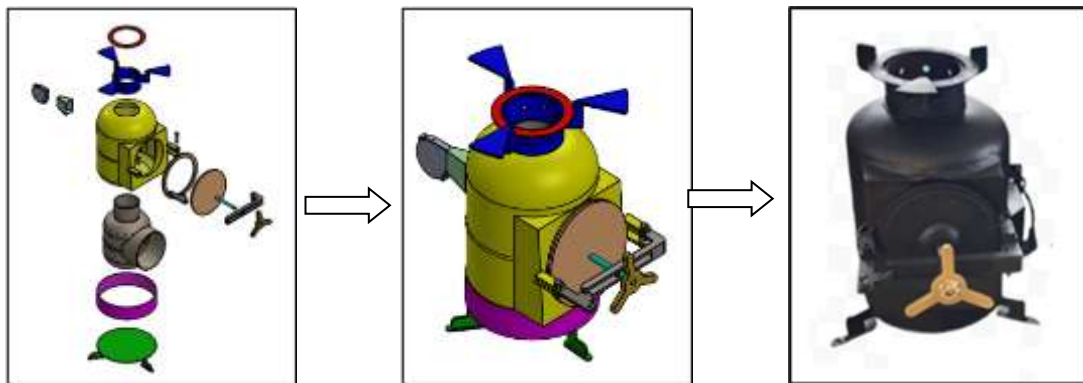


Figure 2. Double Cylinder Biomass Stove Manufacturing Stages: From Technical Design to Prototype.

Figure 2. illustrates the stages involved in manufacturing a double cylinder biomass stove, starting from the technical design and progressing to the creation of a physical prototype. The designed double cylinder biomass stove has overall dimensions, height 460.99 mm, width 648.47 mm, and weight 16 kg. The process begins with presenting an exploded view of the technical drawing, detailing individual components such as the combustion chamber, ventilation systems, doors, and other mechanical parts. This stage involves designing and specifying the parts that will later be assembled. In the next stage, the 3D assembly of the double cylinder biomass stove brings the components together into a complete 3D model. This step ensures that all parts fit correctly and allows for the identification of any potential issues in the assembly process before proceeding to production. Finally, the physical prototype represents the entirely manufactured stove based on the earlier designs. This prototype is used for practical testing to assess the stove's functionality and to make any necessary adjustments before moving into full-scale production. The image highlights the seamless transition from conceptual design to a tangible product, emphasizing the importance of each phase in ensuring the double cylinder biomass stove's effectiveness and durability.

Table 1. Calorific Value of Wood Pellets

Parameters	Trial			Unit
	1	2	3	
Sample Weight	1.0244	1.0343	1.0265	g
Titration Settings	1.0000	1.0000	1.0000	Cal/ml
Wire settings	2.3000	2.3000	2.3000	Cal/cm
Titration Volume	4.5000	4.5000	5.1000	ml
Length of Burnt Wire	6.4000	7.1000	10.0000	cm
(W) Benzoic Acid	2443.9900	2443.9900	2443.9900	Cal
r1	0.0200	0.0640	0.0280	$^{\circ}\text{C}/\text{min}$
T	1.3160	1.3232	1.3492	$^{\circ}\text{C}$
tx60%	0.7896	0.7939	0.8095	$^{\circ}\text{C}$
Horizontal Line	26.7696	26.3539	26.0495	$^{\circ}\text{C}$
e1	4.5000	4.5000	5.1000	Cal
e2	0.0000	0.0000	0.0000	Cal
e3	14.7200	16.3300	23.0000	Cal
Calorie Value Sample	3119.9204	3105.5045	3183.9306	Cal

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Table 1. presents the results of a laboratory experiment to determine the calorific value of wood pellets using a bomb calorimeter. The experiment involved multiple trials, each with different sample weights and titration settings. The data collected in each trial includes the sample weight, titration settings, wire settings, titration volume, length of burnt wire, calorific value of benzoic acid, cooling rate (r), temperature rise (t), temperature at 60% of rise (tx60%), horizontal line, and heat absorbed by the calorimeter (e1), heat lost to the surroundings (e2), and heat released by the sample (e3).

By analyzing these data, the calorific value of the wood pellet samples can be calculated. The results show that the calorific value of the wood pellets varies slightly between trials, ranging from 3105.5045 to 3183.9306 calories. The average calorific value of the wood pellets is 3136.4532 calories. The variation in the calorific values of the wood pellet samples is primarily due to differences in moisture content. Even small variations in moisture content can significantly impact the measured calorific value, as higher moisture levels reduce the energy output. This happens because some of the energy is consumed to evaporate the moisture during combustion (Islam et al., 2021; Irro et al., 2024). Consequently, when the moisture content varies slightly between samples, the measured calorific values also differ. Additionally, the inhomogeneity of the wood pellets can play a role in this variation. Wood pellets may not always have a uniform composition, with differences in the type and proportion of wood species, binder materials, or pellet density influencing the energy output; samples with denser wood particles may produce higher energy output (Manave et al., 2022). Furthermore, variations in the efficiency of the combustion process across trials can contribute to differences in results. Factors such as oxygen flow and temperature control during testing can impact how completely the pellets burn, thereby affecting the measured energy release (Kavindi et al., 2025; Wang et al., 2022). Together, these factors contribute to the observed variation in calorific values between trials.

Table 2. Double cylinder biomass stove test measurement and analysis data

Stove Test Measurement Data									
Stove Test Analysis Data									
Stove Test Results									
Stove Test Summary									
Stove Test Conclusion									
Stove Test Recommendation									
Stove Test Acknowledgment									
Stove Test Disclaimer									
Stove Test Contact Information									
Stove Test Footer									

Table 2. presents the measurement data from the stove test performance, together with the calculated results for stove efficiency, steam output, the heat required for steam generation, and the determination of fuel consumption rate. The stove test results indicate an efficiency of 47%, meaning that less than half of the energy from the fuel is effectively utilized to produce steam, with the remainder lost due to inefficiencies. The steam production rate is 3.05 kg/h, a key factor in determining the stove's capability to convert fuel energy into usable steam for industrial or residential purposes. The heat output associated with steam production is 7,352 kcal/h, reflecting the amount of energy transferred into generating steam. The fuel consumption, at 6.21 kg/h, is relatively high given the efficiency, suggesting that a large amount of fuel is being used without converting most of it into usable energy.

The stove test result of 47% efficiency compares favorably with several previous studies on stove efficiencies. Conventional stoves using Eucalyptus wood as fuel showed a thermal efficiency of 15.17%, which is significantly lower than the 47% reported. In contrast, improved biomass stoves, such as an integrated rice parboiling stove (IRPS), initially had an efficiency of 29%, which increased to 46% after the addition of a heat exchanger extension. This is very close to the 47% efficiency mentioned, suggesting similar performance levels. Biomass cookstoves designed for community cooking exhibited a thermal efficiency of approximately 36.38%, which is lower than the stove's efficiency reported, indicating that the tested stove outperforms these community designs (Suresh et al., 2016).

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Charcoal stoves tested had thermal efficiencies ranging from 38.7% to 47.5%, with the 47% efficiency falling within this range, showing that the stove in question performs comparably to the best-performing charcoal stoves. In comparison, natural-draft semi-gasifier stoves had a maximum measured efficiency of 42%, slightly lower than the 47%, indicating the tested stove has better performance. However, kerosene pressure stoves with porous radiant inserts exhibited higher efficiencies, ranging from 55% to 62%, which outperforms the 47% efficiency. This suggests that while the stove in question performs well compared to many biomass and charcoal stove designs, it is still outmatched by certain liquid fuel stoves with specialized efficiency-boosting features. Referring to the rate of fuel utilization, stoves using wood pellet fuel at 6.21 kg/hour will be most effective in several applications, including hybrid heating systems (Martinez-Gomez et al., 2016).



Figure 3. Air Quality Measurement Using BOSEAN Detection Equipment

Figure 3. shows results of an air quality measurement. The formaldehyde (HCHO) level is at 0.042 mg/m³, which is well within the safe limit for indoor spaces, generally considered safe under 0.1 mg/m³. The PM2.5 concentration is 26 µg/m³, indicating a good air quality level, as it falls below the typical threshold of 50 µg/m³, which marks the transition to moderate air quality. For TVOC (Total Volatile Organic Compounds), the reading is 0.286 mg/m³, suggesting that the level of organic chemical vapors is low and within safe limits, as values under 0.3 mg/m³ are generally considered good.

The carbon monoxide (CO) concentration is 4 ppm, a safe level well below the indoor safety threshold of around 9 ppm for prolonged exposure. Additionally, the CO₂ reading is at 487 ppm, indicating proper ventilation as it falls within the ideal indoor range of 400-1,000 ppm. The overall Air Quality Index (AQI) stands at 18, categorized as “Good”, which means the air is clean and suitable for breathing for most individuals.

The device also records a temperature of 26°C, providing a comfortable indoor climate, along with a relative humidity of 67%, which, though slightly high, still lies within a range that many people find comfortable (ideally between 40% and 60%). Overall, the measurements suggest that the indoor environment is healthy and conducive for regular activities.

V. CONCLUSIONS

The comprehensive examination of the double cylinder biomass stove manufacturing process, from design to prototype, reveals a meticulous approach ensuring functionality and durability in the final product. The stages illustrated in the technical drawings and 3D models are critical in addressing potential issues early in the design phase, thereby streamlining the transition to production. Laboratory experiments on the calorific value of wood pellets further underscore the importance of material characteristics such as moisture content and pellet density on energy output. These findings are crucial for optimizing stove design to enhance energy efficiency.

The stove test results highlight a moderate efficiency of 47%, which, although superior to several conventional and community stove models, still lags behind more advanced liquid fuel stoves. This suggests potential areas for improvement in design and material utilization to enhance efficiency. Additionally, the air quality measurements from the stove’s use confirm its environmental safety, with all pollutants within safe limits, indicating effective combustion and ventilation systems.

This study not only advances our understanding of double cylinder biomass stove manufacturing and performance but also demonstrates the critical role of precise material and design choices in achieving high efficiency and environmental compliance. Future efforts should focus on refining stove designs and exploring innovative materials that could further elevate efficiency and reduce emissions, aligning with sustainable energy goals.

ACKNOWLEDGMENT

Gratitude is extended to the Home Program of Appropriate Technology and Processes, the Agricultural and Food Research Organization, National Research and Innovation Agency, and Majalengka University for facilitating this study. We also express our appreciation to the collaborative team for their efforts in conducting these activities.

REFERENCES

- 1) A. F. Hollands and H. Daly, "Modelling the integrated achievement of clean cooking access and climate mitigation goals: An energy systems optimization approach," *Renewable and Sustainable Energy Reviews*, vol. 173, p. 113054, 2023, doi: <https://doi.org/10.1016/j.rser.2022.113054>.
- 2) A. Manaye, S. Amaha, Y. Gufi, B. Tesfamariam, A. Worku, and H. Abrha, "Fuelwood use and carbon emission reduction of improved biomass cookstoves: evidence from kitchen performance tests in Tigray, Ethiopia," *Energy Sustain Soc*, vol. 12, no. 1, pp. 1–9, 2022, doi: 10.1186/s13705-022-00355-3.
- 3) A. Mencarelli, R. Cavalli, and R. Greco, "Energy characterization of wood briquettes and possible use in automated domestic heating systems," in *2022 IEEE Workshop on Metrology for Agriculture and Forestry (MetroAgriFor)*, 2022, pp. 22–27. doi: 10.1109/MetroAgriFor55389.2022.9964889.
- 4) B. Khavari, C. Ramirez, M. Jeuland, and F. Fusco Nerini, "A geospatial approach to understanding clean cooking challenges in sub-Saharan Africa," *Nat Sustain*, vol. 6, no. 4, pp. 447–457, 2023, doi: 10.1038/s41893-022-01039-8.
- 5) E. Abokyi, P. Appiah-Konadu, E. F. Oteng-Abayie, and K. F. Tangato, "Consumption of clean and dirty cooking fuels in Ghanaian households: The role of financial inclusion," *Cleaner and Responsible Consumption*, vol. 13, p. 100187, 2024, doi: <https://doi.org/10.1016/j.clrc.2024.100187>.
- 6) G. A. G. Kavindi, L. Tang, and Y. Sasaki, "Assessing GHG Emission Reduction in Biomass-Derived Biochar Production via Slow Pyrolysis: A Cradle-to-gate LCA Approach," *Resour Conserv Recycl*, vol. 212, p. 107900, 2025, doi: <https://doi.org/10.1016/j.resconrec.2024.107900>.
- 7) G. Venkatraman *et al.*, "Environmental impact and human health effects of polycyclic aromatic hydrocarbons and remedial strategies: A detailed review," *Chemosphere*, vol. 351, p. 141227, 2024, doi: <https://doi.org/10.1016/j.chemosphere.2024.141227>.
- 8) Himanshu, O. P. Kurmi, S. Jain, and S. K. Tyagi, "Performance assessment of an improved gasifier stove using biomass pellets: An experimental and numerical investigation," *Sustainable Energy Technologies and Assessments*, vol. 53, p. 102432, 2022, doi: <https://doi.org/10.1016/j.seta.2022.102432>.
- 9) I. Onah, A. Nyong, and K. H. Ayuba, "A case study of improved cookstoves and clean fuel use by selected Nigerian Households," *World Dev*, vol. 142, p. 105416, 2021, doi: <https://doi.org/10.1016/j.worlddev.2021.105416>.
- 10) J. Martínez-Gómez, D. Ibarra, S. Villacis, P. Cuji, and P. R. Cruz, "Analysis of LPG, electric and induction cookers during cooking typical Ecuadorian dishes into the national efficient cooking program," *Food Policy*, vol. 59, pp. 88–102, 2016, doi: <https://doi.org/10.1016/j.foodpol.2015.12.010>.
- 11) K. A. Mir, P. Purohit, M. Ijaz, Z. Bin Babar, and S. Mehmood, "Black carbon emissions inventory and scenario analysis for Pakistan," *Environmental Pollution*, vol. 340, p. 122745, 2024, doi: <https://doi.org/10.1016/j.envpol.2023.122745>.
- 12) K. Jiang *et al.*, "Pollutant emissions from biomass burning: A review on emission characteristics, environmental impacts, and research perspectives," *Particuology*, vol. 85, pp. 296–309, 2024, doi: <https://doi.org/10.1016/j.partic.2023.07.012>.
- 13) M. Irro, C. Adihou, H. Ibrahim, A. Maza, C. Houngan, and M. Anjorin, "Effect of Thermal Mass on Fuel Consumption of Solid Biomass Cooking Stoves," *Science Journal of Energy Engineering*, vol. 12, no. 3, pp. 48–58, 2024, doi: 10.11648/j.sjee.20241203.13.
- 14) M. M. Islam, R. Wathore, H. Zerriffi, J. D. Marshall, R. Bailis, and A. P. Grieshop, "In-use emissions from biomass and LPG stoves measured during a large, multi-year cookstove intervention study in rural India," *Science of The Total Environment*, vol. 758, p. 143698, 2021, doi: <https://doi.org/10.1016/j.scitotenv.2020.143698>.
- 15) P. Kumar, P. M. V. Subbarao, L. Kala, and V. K. Vijay, "Influence of physical, mechanical, and thermal properties of biomass pellets from agriculture residue: Pearl millet cob and mix," *Bioresour Technol Rep*, vol. 20, p. 101278, 2022, doi: <https://doi.org/10.1016/j.biteb.2022.101278>.
- 16) P. Mperejekumana, L. Shen, M. S. Gaballah, and S. Zhong, "Exploring the potential and challenges of energy transition and household cooking sustainability in sub-sahara Africa," *Renewable and Sustainable Energy Reviews*, vol. 199, p. 114534, 2024, doi: <https://doi.org/10.1016/j.rser.2024.114534>.

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- 17) R. I. Ismail, C. Y. Khor, and A. R. Mohamed, "Thermal Characteristics of Malaysian Khaya Senegalensis Wood Fuel Pellets: Densification-Induced Changes at Different Feedstock Moisture Levels," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 49, no. 2, pp. 90–101, Jul. 2025, doi: 10.37934/araset.49.2.90101.
- 18) R. Suresh, V. K. Singh, J. K. Malik, A. Datta, and R. C. Pal, "Evaluation of the performance of improved biomass cooking stoves with different solid biomass fuel types," *Biomass Bioenergy*, vol. 95, pp. 27–34, 2016, doi: <https://doi.org/10.1016/j.biombioe.2016.08.002>.
- 19) R. Wathore, R. Hedao, A. Ahmad, A. Gupta, A. S. Dhoble, and N. Labhasetwar, "Field based performance evaluation of optimized improved biomass mud cookstoves in rural India," *Renew Energy*, vol. 219, p. 119567, 2023, doi: <https://doi.org/10.1016/j.renene.2023.119567>.
- 20) S. L. Narnaware and N. L. Panwar, "Biomass gasification for climate change mitigation and policy framework in India: A review," *Bioresour Technol Rep*, vol. 17, p. 100892, 2022, doi: <https://doi.org/10.1016/j.biteb.2021.100892>.
- 21) S. U. Yunusa et al., "Biomass cookstoves: A review of technical aspects and recent advances," *Energy Nexus*, vol. 11, p. 100225, 2023, doi: <https://doi.org/10.1016/j.nexus.2023.100225>.
- 22) Y. Zhang, "Accelerating Access to Clean Cooking Will Require a Heart-Head-and-Hands Approach," *Development*, vol. 65, no. 1, pp. 59–62, 2022, doi: 10.1057/s41301-021-00297-x.
- 23) Z.-H. Wang, L.-Q. Li, L. Zhao, C. Chen, S.-S. Yang, and N.-Q. Ren, "Comparative life cycle assessment of biochar-based lignocellulosic biohydrogen production: Sustainability analysis and strategy optimization," *Bioresour Technol*, vol. 344, p. 126261, 2022, doi: <https://doi.org/10.1016/j.biortech.2021.126261>.
- 24) Z. Yu, H. Ma, X. Liu, M. Wang, and J. Wang, "Review in life cycle assessment of biomass conversion through pyrolysis-issues and recommendations," *Green Chemical Engineering*, vol. 3, no. 4, pp. 304–312, 2022, doi: <https://doi.org/10.1016/j.gce.2022.08.002>.



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