



COMPARATIVE LIFE CYCLE AND SOCIAL COST ANALYSIS OF HOUSEHOLD COOKING FUELS IN GHANA: IMPLICATIONS FOR CLEAN ENERGY TRANSITIONS

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ABSTRACT: *This study compares the costs of household cooking fuels in Ghana, focusing on biomass briquettes as an alternative. Using Life Cycle Cost Analysis (LCCA) and Social LCCA (S-LCCA), six cooking systems were evaluated under discount rates of 5%, 10%, and 15%, incorporating capital, operational, maintenance, and replacement costs alongside social externalities such as carbon emissions and health impacts. Results indicate that LPG and improved cookstoves (Gyapa) with charcoal offer the lowest and most stable life-cycle costs. While firewood appears cheapest financially, its overall affordability declines when environmental and health costs are considered. Biomass briquettes, though nearly carbon-neutral, are less competitive due to high fuel costs. Sensitivity analysis shows LPG and Gyapa stoves are most resilient to cost variations. The study highlights the need for policy support, briquette cost implications, and awareness to advance clean cooking transitions.*

KEYWORDS: Life Cycle Cost, Social Cost, Clean Cooking, Biomass Briquettes, Carbon.



INTRODUCTION

Cooking is more than a means of food preparation; it embodies culture, identity, and social cohesion. Across the world, cooking practices reflect shared traditions passed down through generations and remain central to daily life. However, the choice of cooking fuel profoundly affects sustainability, health, and socio-economic development outcomes. Globally, about 2.1 billion people still rely on traditional cooking fuels such as firewood, charcoal, and coal, lacking access to cleaner alternatives (SEforAll, 2024). In Ghana, approximately 70% of households continue to depend on traditional fuels, particularly in rural and peri-urban communities (Sasu, 2024), which are affordable but associated with high health risks, deforestation, and carbon emissions. Modern and transitional fuels, such as LPG, electricity, and biomass briquettes, offer cleaner alternatives, yet there is limited evidence on the long-term economic viability and affordability of biomass briquettes in Ghana. This study evaluates the cost and social impacts of biomass briquettes relative to conventional fuels using life cycle and social life cycle cost analyses, providing evidence to guide households, policymakers, and investors in Ghana's clean cooking transition.

LITERATURE REVIEW

Traditional Cooking Fuels and Impact

While traditional fuels remain affordable and accessible, they impose significant health, environmental, and social costs. Women and children disproportionately bear these burdens, spending long hours collecting firewood and facing exposure to harmful smoke that increases the risk of respiratory and cardiovascular diseases (Batchelor et al., 2017; Hosier et al., 2017; Pratiti et al., 2020; Rousseau & Scott, 2022). Moreover, emissions from traditional cooking contribute approximately 3% of global carbon dioxide output, driving deforestation and environmental degradation (United Nations, 2023).

Modern and Transitional Cooking Fuels

Modern and transitional fuels such as liquefied petroleum gas (LPG), electricity, and biomass briquettes present viable alternatives. Among these, biomass briquettes have gained attention for their environmental and economic promise. Produced from agricultural and forestry residues, such as sawdust, rice husks, and sugarcane bagasse, briquettes address both waste management and clean energy access challenges (Quartey, 2011; Takase et al., 2022, 2023). Their lower carbon emissions, potential affordability, and compatibility with existing stoves make them attractive options for households transitioning away from traditional fuels (Mawusi et al., 2023; Onochie et al., 2023).



Economic and Environmental Assessment of Cooking Fuels: Evidence and Research Gaps

While biomass briquettes are widely promoted, evidence on their long-term economic viability in Ghana remains limited (Lartey et al., 2025). Most prior studies focus on technical feasibility, fuel properties, or production potential, rarely evaluating full life cycle costs or household affordability (Bot et al., 2023). Life Cycle Cost Analysis (LCCA) allows assessment of total costs, including capital, fuel, maintenance, and replacement expenses, while Social Life Cycle Cost Analysis (S-LCCA) incorporates environmental and social externalities, such as carbon emissions and health impacts (Bot et al., 2023; Qi et al., 2017). This integrated approach is critical for understanding trade-offs between affordability, efficiency, and sustainability.

Most economic assessments of biomass briquettes have been conducted outside Ghana, limiting their relevance due to differences in fuel markets, pricing, and household energy behaviors. Additionally, environmental and social costs are often excluded, preventing comprehensive comparisons with firewood, charcoal, and LPG. This study addresses these gaps by applying LCCA and S-LCCA to evaluate both financial and environmental viability of biomass briquettes relative to conventional fuels within the Ghanaian context. By combining economic, environmental, and social dimensions, the study provides evidence to guide household decisions, inform policy interventions, and support private investment in clean cooking solutions, contributing to a sustainable energy transition in Ghana.

METHODOLOGY

Study Area

This study is situated in Ghana, a West African country of approximately 30 million people, where household cooking remains heavily dependent on traditional biomass fuels. National data show that 67% of households rely on polluting fuels, with firewood (33.3%) and charcoal (34.1%) being the most common, while LPG accounts for 34.8% and electricity less than 1% of primary cooking energy (Bawakyillenuo et al., 2021). Fuel use varies geographically: firewood dominates in rural areas, whereas urban households use charcoal and LPG, often through fuel stacking. The biomass fuel market is largely informal and supplied by small-scale producers. Although improved cookstoves such as Gyapa have been promoted, adoption remains limited due to affordability constraints and cultural preferences. Recent initiatives such as the Cylinder Recirculation Model and the introduction of biomass briquettes reflect growing national efforts toward clean cooking. Ghana therefore provides a relevant context for assessing the economic feasibility of briquettes and their potential role in accelerating household energy transitions (Bawakyillenuo et al., 2021; Bofah et al., 2022).



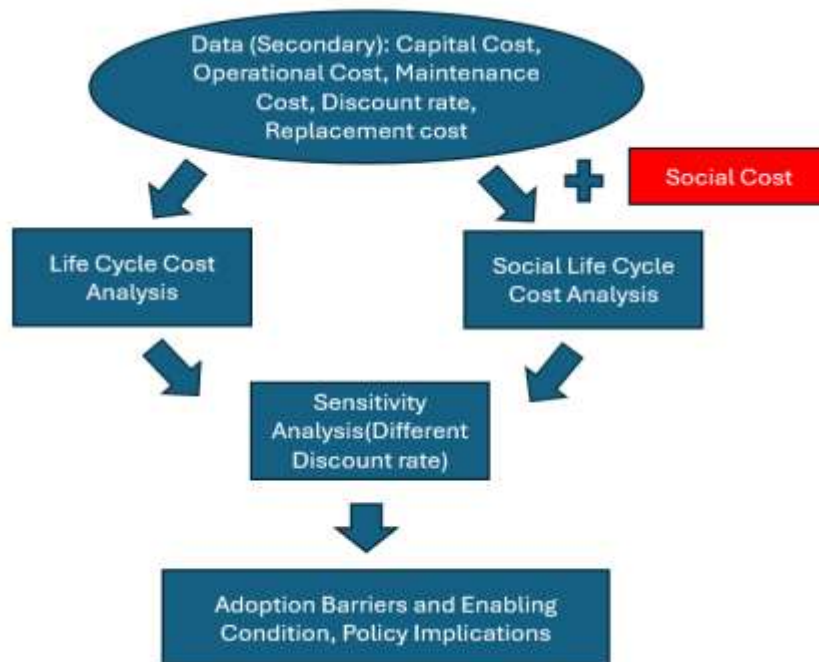
Research Design

This study employs a quantitative research design to evaluate the Life Cycle Cost (LCC) and Social Life Cycle Cost (S-LCC) of selected household cooking fuels in Ghana. This approach enables the systematic quantification of economic, environmental, and social costs across the full life cycle of each fuel, allowing for an objective comparison between traditional and cleaner cooking options. Emphasis is laid on biomass briquettes due to their growing relevance as a potential substitute for charcoal and firewood within Ghana's clean cooking transition.

A systems-based framework is applied by pairing each fuel with its typical cooking technology to reflect actual household use. Firewood is assessed with the traditional three-stone stove; charcoal with both traditional metal and improved Gyapa stoves; biomass briquettes with similar stove technologies due to comparable combustion characteristics; and liquefied petroleum gas (LPG) with a standard two-burner domestic stove.

The study relies primarily on secondary data owing to limited access to primary stakeholders and field constraints. Data are sourced from reputable national and international institutions, including the Ghana Statistical Service, Energy Commission, Ministry of Energy, International Energy Agency, World Bank, and Stichting Nederlandse Vrijwilligers (SNV). The analytical framework integrates LCCA and S-LCCA to capture both financial costs and social externalities, providing a comprehensive assessment of household cooking energy systems in Ghana. The research design is illustrated in Figure 1.

Figure 1: Research Design for the Study (Source: Author's Construct)





Data Collection

Data for this study were obtained entirely from secondary and publicly available sources, selected for their credibility and relevance to Ghana's household energy market. Given the absence of a single comprehensive dataset on cooking fuels, data triangulation was employed, combining information from government reports, academic literature, international databases, and verified online market surveys to ensure reliability and contextual accuracy.

For the analysis, data were grouped under five cost categories, capital, operational, maintenance, social, and replacement costs. Each was estimated using market-verified or literature-based values to reflect realistic household energy conditions in Ghana.

Cost Category One: Capital Cost

Capital costs represent the initial investment required to acquire infrastructure and components for each cooking system. Data were collected from reputable e-commerce platforms such as Jiji Ghana, Melcom Online, and Clean Cooking Market, where multiple price points were averaged to obtain representative market values. All capital cost data reflect market prices as of September 2025 and are reported in constant Ghana cedis (GHC) as shown in Table 1.

Table 1: Selected cooking fuels and their Capital Cost

Cooking Fuel	Capital Technology	Capital Cost (GHC)
Firewood	3-stone firewood	0
Charcoal – Traditional Metal	Traditional metal charcoal cookstove	50
	Handheld fan	15
Charcoal – Gyapa cookstove	Gyapa cookstove	85
	Handheld fan	15
Biomass Briquettes – Traditional Metal	Traditional metal charcoal cookstove	50
	Handheld fan	15
Biomass Briquettes – Gyapa cookstove	Gyapa cookstove	85
	Handheld fan	15
LPG	Gas stove	200
	Cylinder	450
	Regulator	80
	Gas tube	30

For firewood, the traditional three-stone firewood stove was assumed to have no capital cost, as it is typically constructed from locally available materials. Charcoal and biomass briquette systems used similar stove technologies, with capital costs ranging from GHC 65 (traditional metal stove + fan) to GHC 100 (Gyapa stove + fan). The LPG system required a higher investment due to its multiple components, with a total setup cost of GHC 760.



Cost Category Two: Operational Costs

Operational costs account for the recurring expenses of fuel consumption during regular household cooking. Average household consumption levels were estimated for a four-person household, consistent with the Ghana Statistical Service (2019) presented in Table 2.

Table 2: Selected fuel-technologies and their fuel consumption per annum

Fuel Technology	Fuel Consumption (kg/year)	Source
Firewood – 3-stone	5,960	(World Bank, 2022)
Charcoal – Traditional	3,600	(World Bank, 2022)
Charcoal – Gyapa	2,390	(World Bank, 2022)
LPG	174	(SNV, 2020)
Briquettes – Traditional	6,321.42	Author's construct
Briquettes – Gyapa	3,441.31	Author's construct

The estimation of biomass briquette consumption introduced a novel approach by applying an energy density ratio between charcoal and biomass briquettes, acknowledging their similar combustion technologies but differing energy intensities. The energy density of charcoal (29.5 MJ/kg) was compared to that of biomass briquettes (16.8 MJ/kg) (Climate Innovation Centre Ghana, 2019), allowing the annual fuel requirement for briquettes to be derived proportionally from established charcoal data. This method provides a realistic and transferable approach to estimating fuel demand for emerging solid biofuels, especially where direct consumption data are scarce. Fuel prices were sourced from verified publications and recent market data as shown in Table 3.

Table 3: Selected cooking fuels and their price of fuel per kg

Fuel	Price (GHC/kg)	Source
Firewood	0.0765	(Atinga & Bannor, 2022)
Charcoal	2.47	(Energy Commission, 2024)
LPG	14.26	(Citi News Room, 2025)
Biomass Briquettes	3.50	(Climate Innovation Centre Ghana, 2019)

For firewood, costs were modeled as transportation expenses rather than direct purchase, reflecting the effort and opportunity cost of fuelwood collection in rural areas. Charcoal operational costs, largely driven by fuel purchase prices, are drawn from 2024 market data. LPG operational costs are likewise based on 2024 price data, while biomass briquette operational costs rely on 2019 market estimates, as reported in the respective reference sources. All operational costs are expressed in Ghana cedis (GHC).



Cost Category Three: Maintenance Costs

Maintenance costs include minor repairs, cleaning, and servicing. These were estimated at 5% of the total capital cost per year, following conventional household energy appliance maintenance assumptions (Phillip et al., 2023).

Cost Category Four: Social Costs

Social costs represent the environmental externalities associated with household fuel combustion, focusing on CO₂ emissions. Total CO₂ emissions were computed by multiplying each fuel's emission factor (kg CO₂/kg fuel) by annual household consumption and then applying a carbon price of €18.36 per tonne CO₂ (Organisation for Economic Co-operation and Development (OECD), 2024) This monetized approach reflects the broader societal cost of fuel use beyond household expenditure.

Cost Category Five: Replacement Costs

Replacement costs account for equipment renewal over the 10-year analysis period, depending on each component's lifespan. Table 4 illustrates each technology alongside its corresponding lifespan in years.

Table 4: Selected fuel-technology and their life span

Cooking Fuel	Capital Technology	Life Span (years)
Firewood	3-stone firewood	1
Charcoal – Traditional Metal	Traditional metal stove	3
	Handheld fan	1
Charcoal – Gyapa	Gyapa cookstove	5
	Handheld fan	1
Biomass Briquettes – Traditional	Traditional metal stove	3
	Handheld fan	1
Biomass Briquettes – Gyapa	Gyapa cookstove	5
	Handheld fan	1
LPG	Gas stove	5
	Cylinder	10
	Regulator	10
	Gas tube	3

Uncertainty and Assumptions

Due to data limitations, this study relies primarily on secondary data from peer-reviewed literature, government and institutional reports, and verified online sources. Consequently, datasets originate from different reference years, although all were selected to ensure present relevance and consistency within the Ghanaian context. Emission factors were adopted from Intergovernmental



Panel for Climate Change (IPCC) default values, with biomass briquettes assumed to have a zero-emission factor in accordance with IPCC guidance for sustainably sourced biomass. Household biomass briquette consumption was estimated using an energy density ratio approach, adjusting charcoal consumption based on relative energy densities. Energy density values and technology lifespans were obtained from IPCC reports, published studies, and verified online marketplaces.

Analytical Framework

Life Cycle Cost Analysis (LCCA)

Life Cycle Cost Analysis (LCCA) quantifies the total cost of ownership and operation of each cooking fuel technology over a 10-year analysis period, which corresponds to a typical household appliance lifetime. The LCC is computed using Equation 1 (Afrane & Ntiamoah, 2012),

$$LCC = C_{initial} + \sum_{t=1}^n \frac{(C_{operating} + C_{maintenance} + C_{replacement})}{(1+r)^t} \quad \text{Equation 1}$$

Where:

LCC=life cycle cost (GH¢)

$C_{initial}$ =Capital Cost (GH¢)

$C_{operating}$ =Operational cost (GH¢)

$C_{maintenance}$ =maintenance cost(GH¢)

$C_{replacement}$ =disposal cost (GH¢)

r=discount rate (%)

t=specified year period (year)

Social Life Cycle Cost Analysis (S-LCCA)

The Social Life Cycle Cost Analysis (S-LCCA) extends the conventional LCCA by incorporating the monetized social cost of carbon (SCC) and other externalities such as health impacts from indoor air pollution and time savings from reduced fuel collection. The inclusion of these factors provides a more realistic depiction of the societal cost of energy choices. The formula used is presented in Equation 2(Bôt et al., 2023):

$$S - LCC = C_{initial} + \sum_{t=1}^n \frac{(C_{operating} + C_{maintenance} + C_{replacement} + C_{social})}{(1+r)^t} \quad \text{Equation 2}$$

S-LCC=Life cycle cost including social cost (GH¢)

$C_{initial}$ =Capital Cost (GH¢)

$C_{operating}$ =Operational cost (GH¢)



$C_{\text{maintenance}}$ =maintenance cost (GHC)

$C_{\text{replacement}}$ =replacement cost (GHC)

r =discount rate (%)

t =specified year period (year)

Sensitivity Analysis

A sensitivity analysis based on varying discount rates is employed in this study to examine the effect of discount rate fluctuations on the overall life cycle cost outcomes. The selected discount rates are 5%, 10%, and 15%, representing lower, medium, and higher economic scenarios, respectively. By assessing both the Life Cycle Cost (LCC) and the Social Life Cycle Cost (S-LCC) of each cooking fuel across these varying discount rates, the analysis aims to understand how affordability and cost-effectiveness change under different financial conditions. The sensitivity analysis is evaluated using Equation 3 (Bôt et al., 2023);

$$S = \frac{LCC_{\text{new}} - LCC_{\text{base}}}{LCC_{\text{base}}} * 100\% \quad \text{Equation 3}$$

Where:

S =Sensitivity

LCC_{new} =Life cycle cost after changing discount rate (GHC)

LCC_{base} =Life Cycle Cost at base discount rate (GHC)

Ethical Considerations

This study follows strict ethical standards, using publicly available or properly cited data and maintaining confidentiality. Ethical clearance was obtained per institutional guidelines. Findings are interpreted objectively, supporting sustainable and equitable clean energy initiatives in Ghana while acknowledging data and model uncertainties.

RESULTS

Comparative Life Cycle Costs of Household Cooking Fuels

LCCA was conducted on selected cooking fuels at a discount rate of 12% for the 10-year cooking period. As shown in Figure 2, there is a significant variation in the LCC values among the different fuel types, driven by their capital, operational, replacement, and maintenance costs. The LCC of each fuel type declines over time due to the discounting effect, which reduces the present value of future costs.



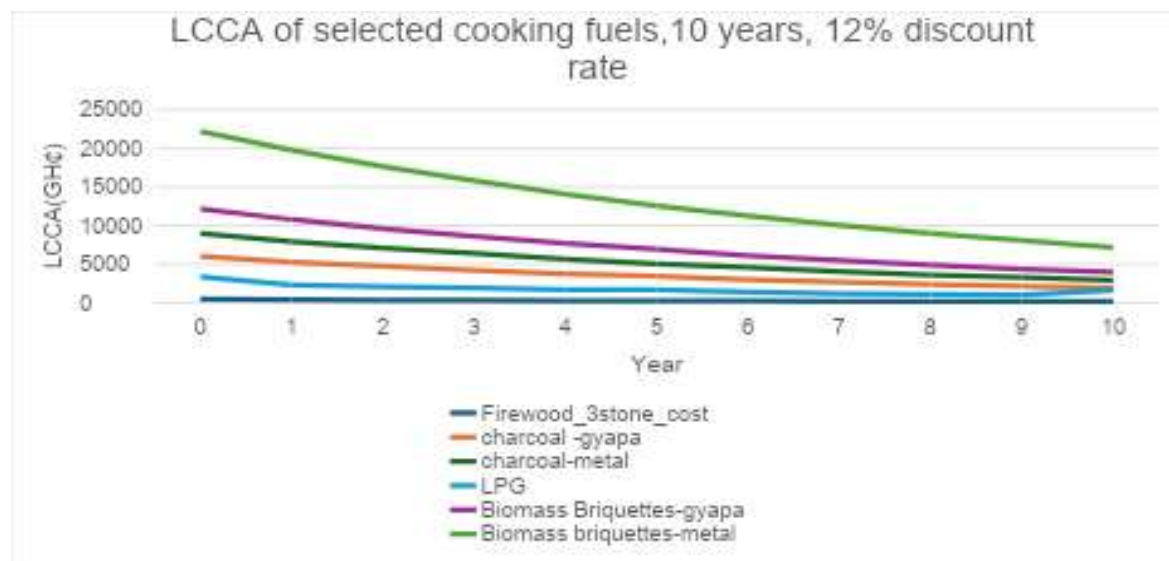
Among the fuels analyzed, biomass briquettes used with the traditional metal cookstove had the highest total cost throughout the 10-year period, initially exceeding GHC 22,000 and declining to approximately GHC 10,000 by year 10. This relatively high cost is primarily due to the high annual fuel consumption required to compensate for the lower energy density of briquettes compared to charcoal, coupled with their higher unit price.

In contrast, LPG demonstrates one of the lowest life cycle costs among modern fuels, remaining below GHC 4,000 at the end of the analysis period. Although its initial capital investment, comprising the cylinder, regulator, and stove, is relatively high, LPG's high combustion efficiency and low operational costs make it affordable over the long term.

Charcoal, particularly when used with the improved Gyapa stove, exhibits moderate life cycle costs. Gyapa's higher thermal efficiency reduces annual fuel consumption, resulting in clear cost advantages over the traditional metal stove. This highlights how technological improvements in stove design directly enhance household economic savings.

The firewood-three-stone system consistently recorded the lowest LCC, primarily because firewood is often collected freely by households, with minimal or no purchase costs, and also has a low transport cost per kg.

Figure 2: LCCA of selected cooking fuel-technology at a discount rate of 12% over a 10 year period (Source: Author's Computation)



Overall, the LCCA indicates that, from a purely economic standpoint, firewood and LPG remain the least costly cooking fuels for households, followed by charcoal (Gyapa), charcoal (metal), biomass briquettes (Gyapa), and biomass briquettes (metal). These findings are consistent with previous studies (Bot et al., 2023; Dey et al., 2024; Nerini et al., 2017; Okoko et al., 2018) which similarly identified LPG and firewood as the most economically favorable cooking options. In contrast, charcoal is comparatively more expensive, while biomass briquettes exhibit the highest



costs, largely due to their lower energy density which necessitates higher fuel consumption and their relatively higher unit price per kilogram.

Integrating Social Costs: Environmental Externalities in Focus

The second objective extends the LCCA framework by incorporating the social cost of carbon emissions associated with each cooking fuel (Figure 3). Incorporating the social carbon cost enabled a more comprehensive assessment by internalizing the environmental externalities arising from carbon emissions throughout the fuel life cycle. The social carbon cost adopted for this study was £18.36 per tonne of CO₂, reflecting Ghana's 2023 average carbon price (OECD, 2024).

The total carbon emissions for each fuel type were estimated from their respective annual household fuel consumption and corresponding emission factors (EFs). The resulting CO₂ emissions were then multiplied by the social carbon cost to determine the annualized social cost associated with each cooking fuel. Conversion to local currency was performed using the 2023 average exchange rate of GHC15.43 per euro (Bank of Ghana, 2024). A summary of the relevant emission factors and calculated social costs is provided in Table 5. The emission factor for biomass briquettes was assumed to be zero, consistent with IPCC default values, which classify sustainably sourced biomass as carbon-neutral (Chum et al., 2011).

Table 5: Selected Fuel Technology and Social Cost

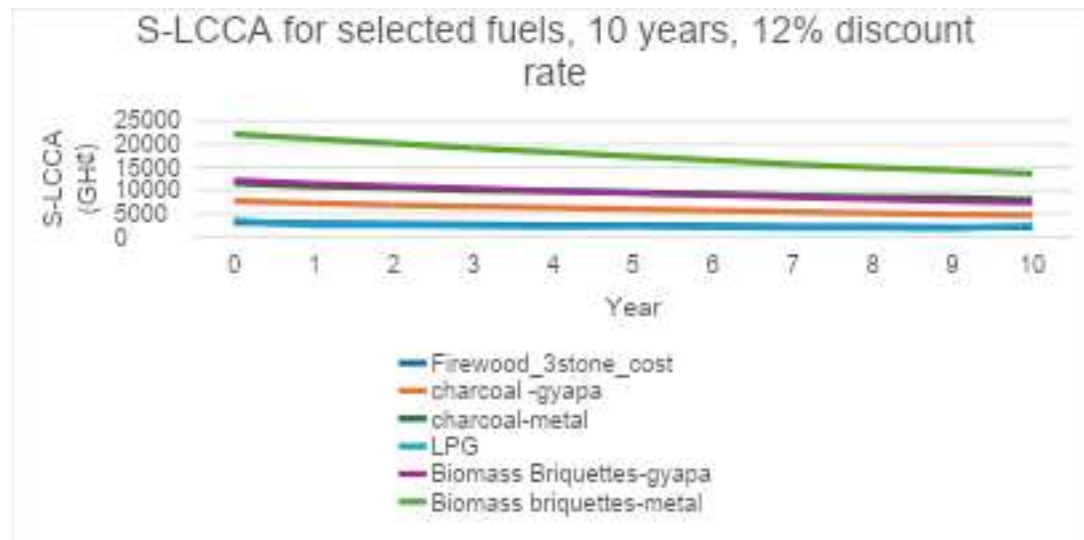
Fuel technology	EF of fuel(kg/kg)	CO₂ of fuel(kg/year)	Cost (GHC/tCO₂/year)
Firewood_3stone	1.56 (Bhattacharya & Salam, 2002)	9297.6	2,633.961732
Charcoal_traditional	2.567 (Bhattacharya & Salam, 2002)	9241.2	2,617.98
Charcoal_Gyapa	2.567 (Bhattacharya & Salam, 2002)	6135.13	1,738.05
LPG	2.82 (Bhattacharya & Salam, 2002)	490.68	139.0070925
Briquette_traditional	0 (Chum et al., 2011)	0	0
Briquette_Gyapa	0 (Chum et al., 2011)	0	0

As illustrated in Figure 3, the inclusion of social costs leads to a marginal increase in the total life cycle cost (LCC) for all fuels; however, the relative cost hierarchy among the fuels remains largely



unchanged. The biomass briquette–metal stove continues to show the highest social life cycle cost (S-LCC), primarily due to elevated fuel consumption associated with its lower thermal efficiency and higher unit fuel price.

Figure 3: S-LCCA of selected fuel technology at 12% discount rate over a 10 -year period (Source: Author’s Computation).



At a 12% discount rate, all cooking fuels show a gradual decline in Social Life Cycle Cost (S-LCC) over the 10-year period due to the discounting of future expenditures. However, important differences emerge across fuel–technology systems. The charcoal-traditional metal stove exhibits a persistently higher S-LCC compared to other options. After briefly converging with the biomass briquettes–Gyapa system around Year 4, its cost trajectory remains consistently elevated. This pattern reflects the stove’s low thermal efficiency, frequent replacement needs, and high fuel consumption. When carbon externalities are internalized, the relatively high emissions from charcoal combustion further increase its total social cost, highlighting both economic and environmental inefficiencies.

In contrast, the biomass briquettes–Gyapa system maintains a flatter and comparatively lower S-LCC trajectory. Its improved combustion efficiency, reduced fuel requirements, and minimal emissions contribute to stronger long-term sustainability performance. LPG also demonstrates competitive S-LCC outcomes despite being a fossil fuel. Its high efficiency and substantially lower CO₂ emissions per unit of useful energy reduce overall social costs, suggesting that shifting from traditional biomass to LPG can deliver both economic and environmental gains.

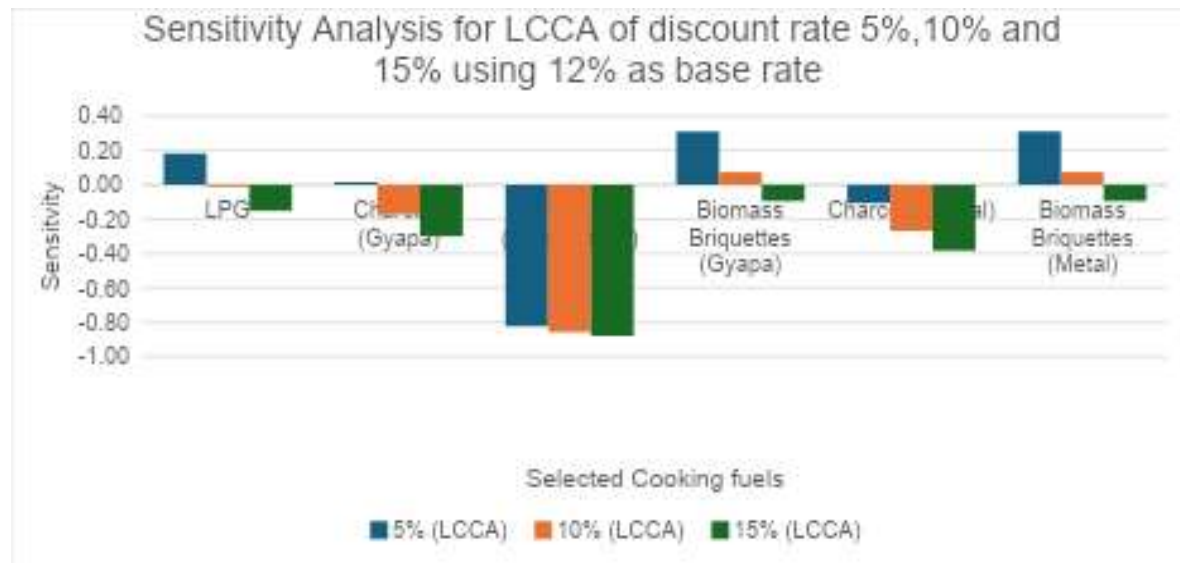
The improved Gyapa charcoal stove performs better than the traditional metal stove, with lower fuel consumption and reduced emissions. This underscores the importance of scaling improved cookstove programs. While firewood appears inexpensive under conventional LCCA, incorporating social costs reveals significant environmental burdens. Overall, internalizing externalities repositions LPG and improved stove technologies as more sustainable alternatives within Ghana’s clean cooking transition.



Sensitivity of Life Cycle Costs to Discount Rate Variations

To evaluate the influence of varying discount rates on the economic performance of household cooking systems, a sensitivity analysis was conducted by adjusting the discount rate from the 12% base case to 5%, 10%, and 15% and shown in Figure 4.

Figure 4: Sensitivity Analysis for LCCA of discount rate 5%,10% and 15% using 12% as base rate (Source: Author's Computation)



Sensitivity at 5% Discount Rate

Future costs carry greater present-value weight, highlighting technologies with high recurring fuel expenses. LPG and biomass briquettes record positive sensitivity coefficients of 0.182 and ~0.31, respectively, indicating that lower discounting increases their total LCC due to frequent fuel purchases and periodic replacements. In contrast, firewood (−0.823) and charcoal-metal stoves (−0.107) show strong negative sensitivities, reflecting cost structures dominated by upfront expenditures. The Gyapa charcoal stove exhibits near-zero sensitivity (~0.015), indicating balanced costs over its lifespan and minimal fluctuation under varying financial scenarios.

Sensitivity at 10% Discount Rate

Under the 10% scenario, life cycle costs slightly rise compared to the 12% base case. The relative ranking of sensitivities remains consistent. Firewood retains high negative sensitivity (−0.85), confirming front-loaded costs. Charcoal stoves demonstrate moderate negative values, with Gyapa at −0.17 and metal stoves at −0.27, reflecting a mix of initial stove purchase and recurring fuel costs. LPG shows negligible sensitivity (−0.012), indicating a stable cost profile. Biomass briquettes in both Gyapa and metal stove configurations have the highest positive sensitivities (~0.074), driven by frequent fuel consumption.



Sensitivity at 15% Discount Rate

At the 15% discount rate, life cycle costs decrease for all fuels compared to the 12% base case. This is expected because higher discount rates reduce the present value of future expenses, particularly for fuel-intensive systems. All technologies therefore exhibit negative sensitivity values, including firewood (-0.88), charcoal-Gyapa (-0.30), charcoal-metal (-0.38), LPG (-0.15), biomass briquettes Gyapa (-0.094), and briquettes-metal (-0.095). Firewood's large negative value reflects its minimal long-term operating cost; as discounting increases, the weight of its limited future expenditure diminishes sharply. Charcoal systems also show negative sensitivity, although to a lesser degree due to their recurring fuel costs. LPG and briquettes demonstrate smaller negative values because their costs are more evenly distributed across the 10-year period; thus, the reduction in the present value of future costs is less pronounced.

Sensitivity of Social Life Cycle Costs to Discount Rate Variations

A sensitivity analysis was conducted to evaluate the effect of variations in the discount rate on the Social Life Cycle Cost Assessment (S-LCCA) of household cooking systems. A discount rate of 12% was used as the base case, while additional scenarios of 5%, 10%, and 15% were assessed. Table 6 presents the summary of the LCC (GH¢) and S-LCC (GH¢) of the selected cooking fuels under the various discount rates (5%, 10%, and 15%). Table 7 provides the summary and interpretation of the sensitivity analysis results for the LCCA and S-LCCA of the selected fuel technologies.

Sensitivity at 5% Discount Rate

Reducing the discount rate to 5% increases the present value of future expenditures, leading to higher total Social Life Cycle Costs (S-LCCA) across all cooking fuels. Fuel-intensive systems, particularly biomass briquettes and traditional charcoal stoves, experience the largest cost increases due to their frequent fuel purchases and replacement needs. In contrast, more efficient technologies such as LPG and the improved Gyapa charcoal stove are less affected because of lower long-term fuel consumption and fewer replacement requirements.

All sensitivity coefficients at 5% are positive, confirming that total social costs rise when future expenses are weighted more heavily. Biomass briquettes and charcoal stoves show the highest sensitivities (around 0.31), while LPG demonstrates moderate sensitivity (0.26). Firewood (0.24) and charcoal-metal stoves (0.21) are comparatively less responsive due to lower long-term cost exposure. Overall, technologies with high recurring costs are more sensitive to lower discount rates, whereas systems with balanced or front-loaded costs remain relatively stable.

Sensitivity at 10% Discount Rate

At a 10% discount rate, S-LCCA remains higher than the 12% base scenario, but the cost hierarchy and behavior of the technologies are unchanged. All sensitivity coefficients are positive, indicating that total social life-cycle costs rise moderately when future expenses receive additional weight.



Computed sensitivities include firewood (0.06), charcoal-Gyapa (0.0742), charcoal-metal (0.052), LPG (0.061), briquettes-Gyapa (0.0738), and briquettes-metal (0.0741). Briquettes and charcoal-Gyapa stoves are the most sensitive, reflecting the influence of recurring fuel expenditure and stove replacement on long-term costs. LPG shows moderate sensitivity due to continuous fuel use, while firewood and charcoal-metal stoves remain less affected, consistent with front-loaded expenditure patterns. As with the 5% case, briquette sensitivity is driven purely by cost, since emissions were assumed to be zero.

Sensitivity at 15% Discount Rate

At a 15% discount rate, total S-LCCA decreases for all technologies compared to the 12% base case, since higher discounting reduces the present value of future social and operational costs. Sensitivity values are uniformly negative: firewood (−0.073), charcoal-metal (−0.0949), charcoal-Gyapa (−0.0667), LPG (−0.078), briquettes-Gyapa (−0.094), and briquettes-metal (−0.0947).

Negative sensitivity reflects cost structures dominated by early-stage or capital expenses, which are less impacted by discounting. Charcoal-metal and briquette systems show the largest negative values (≈ -0.094), consistent with high upfront investment and recurring expenditures. LPG and firewood are less sensitive (−0.078 and −0.073), indicating more balanced cost distribution. The moderate sensitivity of charcoal-Gyapa (−0.0667) reflects improved thermal efficiency that reduces long-term fuel dependence.

Table 6: Summary of LCC (GHC) and S-LCC (GHC) of Selected Cooking Fuels and Various Discount Rates (5%,10% and 15%) (Source: Author's Computation)

Fuel-Technology	LCC (5%)	LCC (10%)	LCC (15%)	S-LCC (5%)	S-LCC (10%)	S-LCC (15%)
Firewood (Three-stone)	3,976.59	3,257.49	2,744.20	27,988.06	23,833.86	20,868.55
Charcoal (Gyapa)	51,865.23	42,489.96	35,799.24	67,024.05	54,907.58	46,260.17
Charcoal (Metal)	77,944.25	63,911.61	53,893.89	106,260.94	91,820.38	81,453.62
LPG	24,627.86	20,571.83	17,676.59	26,156.94	22,100.90	19,205.67
Biomass Briquettes (Gyapa)	105,524.68	86,528.35	72,968.57	105,524.68	86,528.35	72,968.57
Biomass Briquettes (Metal)	193,368.87	158,474.08	133,565.83	193,368.87	158,474.08	133,565.83



Table 7: Summary of Sensitivity Analysis of LCCA and S-LCCA of Selected Fuel-Technology (Source: Author's Computation)

Fuel-Technology	Overall Viability Rank	Interpretation
LPG	1	Demonstrates consistent economic stability under both social and financial discounting; low emissions and efficient combustion make it the most viable long-term option.
Charcoal (Gyapa)	2	Improved design lowers fuel use; remains moderately sensitive to higher discount rates but maintains cost-effectiveness and performance balance.
Firewood (Three-stone)	3	Low direct cost but high environmental and social externalities; front-loaded cost structure limits long-term viability despite affordability.
Biomass Briquettes (Gyapa)	4	Socially beneficial due to zero-emission assumption, but high unit fuel price and moderate energy density reduce financial competitiveness.
Charcoal (Metal)	5	Inefficient heat transfer and frequent replacement cycles raise life-cycle costs, making it less favorable in both private and social valuations.
Biomass Briquettes (Metal)	6	Highest total life-cycle cost due to low stove efficiency and high briquette cost; not competitive even when social costs are considered.

DISCUSSION

The findings of this study underscore the importance of adopting a holistic approach to evaluating household cooking systems by integrating both financial and social cost dimensions. While conventional Life Cycle Cost Analysis (LCCA) suggests that firewood and LPG are the most economically attractive options, the inclusion of environmental externalities through Social Life Cycle Cost Analysis (S-LCCA) significantly reshapes the interpretation of affordability and sustainability.

Firewood, which consistently records the lowest financial cost, illustrates the limitations of relying solely on direct economic metrics. Its apparent affordability is largely driven by the assumption of zero or minimal acquisition cost, as many households collect it freely. However, once environmental costs, particularly carbon emissions, are internalized, firewood emerges as a less sustainable option. Beyond emissions, firewood use is widely associated with deforestation, land degradation, and adverse health outcomes from indoor air pollution. This suggests that its continued dominance in rural energy systems is less a reflection of true affordability and more an



indication of structural and access constraints, including limited availability of cleaner alternatives and upfront capital barriers.

LPG stands out as a strong performer across both LCCA and S-LCCA frameworks. Despite its relatively high initial investment requirements, its high combustion efficiency, lower fuel consumption, and significantly reduced emissions per unit of useful energy contribute to its overall cost-effectiveness and environmental performance. The sensitivity analysis further reinforces LPG's robustness, as it remains relatively stable under varying discount rate scenarios. This stability reflects a balanced cost structure, where neither upfront nor recurring costs disproportionately dominate. In practical terms, this positions LPG as a viable transitional fuel within Ghana's clean cooking agenda, capable of delivering immediate economic and environmental benefits. However, its classification as a fossil fuel raises longer-term sustainability concerns, particularly in the context of global decarbonization goals, suggesting that its role may be transitional rather than permanent. Also, LPG expansion in Ghana remains uneven, with refill infrastructure concentrated in urban areas, limiting rural access. even where the technology is financially viable (Bawakyillenuo et al., 2021; Lewis & Pattanayak, 2012). This then leads to discontinuation of use, reducing the practical benefits identified in life-cycle assessments.

Charcoal systems present a more nuanced case. Traditional charcoal stoves exhibit high life cycle and social costs due to inefficient combustion, high fuel consumption, and significant emissions. The improved Gyapa stove, however, demonstrates how technological innovation can substantially alter this outcome. By increasing thermal efficiency and reducing fuel consumption, the Gyapa stove lowers both financial and environmental costs, making it a more competitive option. This highlights the critical role of improved cookstove technologies in bridging the gap between affordability and sustainability, particularly in contexts where a complete transition to modern fuels such as LPG may not yet be feasible. Nonetheless, even with improved efficiency, charcoal remains associated with upstream environmental challenges, including unsustainable wood harvesting and inefficient production processes, which continue to limit its long-term sustainability.

Biomass briquettes represent an interesting paradox within the analysis. On one hand, they offer clear environmental advantages, particularly under the assumption of carbon neutrality, which results in negligible social costs in the S-LCCA framework. On the other hand, they consistently rank as the least cost-competitive option across both LCCA and sensitivity analyses. This is primarily due to their lower energy density, which necessitates higher consumption rates, and their relatively high market prices, which are often driven by inefficient and small-scale production systems. The findings suggest that, in their current state, biomass briquettes are unlikely to achieve widespread adoption without significant improvements in production efficiency, economies of scale, and distribution networks.

This also points to a broader insight: environmental sustainability alone is insufficient to drive energy transitions at the household level unless it is accompanied by clear economic advantages.

The sensitivity analysis provides further depth to these findings by illustrating how different cost structures respond to changes in discount rates. Systems with high recurring costs, such as LPG



and biomass briquettes, are more sensitive to lower discount rates because future expenditures carry greater weight. Conversely, systems with more front-loaded costs, such as firewood and traditional charcoal stoves, exhibit negative sensitivity, indicating reduced total costs under higher discounting. LPG and the Gyapa stove demonstrate relatively low sensitivity across scenarios, reinforcing their economic resilience. This stability is particularly important in real-world contexts where financial conditions, interest rates, and policy environments are subject to change.

Taken together, these results highlight the complex trade-offs that characterize household cooking energy decisions. Affordability, efficiency, environmental impact, and accessibility are deeply interconnected, and no single fuel currently satisfies all criteria perfectly. The evidence suggests that a transition pathway that combines short-term promotion of LPG and improved cookstoves with long-term investment in sustainable alternatives such as biomass briquettes may be the most pragmatic approach.

IMPLICATION FOR RESEARCH AND PRACTICE

The study highlights the value of integrating economic and social analyses to assess household cooking fuels, suggesting that future research should incorporate environmental, health, and behavioral dimensions for a more comprehensive understanding (Bofah et al., 2022). Technological improvements, such as energy-efficient stoves, and innovations compatible with carbon-neutral fuels are critical for enhancing cost-effectiveness and adoption. At the practical level, promoting LPG through targeted subsidies, rural distribution, and awareness programs can accelerate short-term adoption (Bawakyillenuo et al., 2021; Lewis & Pattanayak, 2012), while biomass briquettes require financial instruments, economies of scale, and quality assurance to become viable alternatives. Strengthening supply chains and maintenance services and aligning clean cooking strategies with climate and health goals will enhance sustainability. Regional experiences studies in Cameroon (Bôt et al., 2023), Kenya (Okoko et al., 2018), Tanzania (Okoko et al., 2018), and Rwanda (Hakizimana & Kim, 2016) indicate that supportive policies and incentives are key to scaling sustainable fuels across West Africa.

CONCLUSION

This study finds that LPG and improved Gyapa charcoal stoves are currently the most economically and socially sustainable cooking options in Ghana. Although firewood seems cheaper, its environmental damage and health risks reduce its overall sustainability. Biomass briquettes offer strong environmental and social benefits, including lower emissions and carbon neutrality, but high operating costs limit their competitiveness. Combining briquettes with improved stoves enhances their performance and viability. Using both Life Cycle Cost Analysis and Social Life Cycle Cost Assessment shows that clean cooking policies must address social, environmental, and health impacts, supported by aligned policies, incentives, and infrastructure.



FUTURE RESEARCH

This study is limited by its reliance on secondary data, which may not fully capture household-level variations in cooking fuel use. Due to limited data on biomass briquette usage, assumptions based on energy density ratios were applied, which may introduce some uncertainty in the results. Future work could focus on collecting primary household-level data to validate these assumptions and explore additional economic metrics, thereby providing more robust insights into the affordability, viability, and adoption pathways of alternative cooking fuels.

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