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RESEARCH ARTICLE

IMPACTS OF HOUSEHOLD ENERGY CHOICES ON GREENHOUSE GAS EMISSIONS IN SHAMBU TOWN, OROMIA REGIONAL STATE, WESTERN ETHIOPIA

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ABSTRACT

This study investigates household energy consumption patterns and their environmental impacts in Shambu Town, Oromia Regional State, Ethiopia, focusing on the reliance on traditional biomass fuels. Data from 200 households were collected through stratified and purposive sampling, and logistic regression analysis was conducted to identify the factors influencing energy choices. Results indicate that 78.5% of households rely on firewood and charcoal, with annual per-household consumption of 346.95 kg and 252.175 kg, respectively. Logistic regression revealed statistically significant factors influencing fuel choice, including household income ($B=-0.21, p=0.005$), home ownership ($B=0.365, p=0.006$), and the absence of electricity ($B=0.595, p<0.001$). This biomass reliance leads to the degradation of 1,087.12 hectares of forest annually, including 910.488 hectares from charcoal production. Annual CO_2 emissions from household energy consumption total 7,439.39 tons, with firewood contributing 5,882.498 tons and charcoal contributing 1,556.894 tons. Statistical modeling indicates that transitioning to cleaner fuels, such as biomass briquettes, biogas, and ethanol, alongside the use of improved stoves, could reduce CO_2 emissions by 3,060.48 tons annually. The study highlights the environmental costs of unsustainable biomass use, including deforestation, biodiversity loss, and significant carbon emissions. Policies promoting subsidies for cleaner energy technologies, sustainable forest management, and educational initiatives to shift cultural preferences toward cleaner cooking methods are critical. These measures could mitigate the environmental and health impacts while reducing dependence on traditional biomass. By adopting such strategies, Shambu Town can achieve a sustainable energy transition and serve as a model for similar regions across Sub-Saharan Africa.

KEYWORDS

Biomass Energy, CO2 Emissions, Deforestation, Household Energy, Sustainable Energy Transition

1. INTRODUCTION

Energy access remains one of the most critical challenges in Sub-Saharan Africa, where more than 600 million people still lack electricity, and over 2.3 billion rely on traditional biomass, such as firewood and charcoal, for cooking (World Bank, 2023). In many developing regions, household energy choices are a critical factor influencing both local and global environmental outcomes, particularly in relation to greenhouse gas (GHG) emissions. These energy choices are not only linked to deforestation and land degradation but also contribute significantly to GHG emissions, which exacerbate the impacts of climate change. Globally, household energy consumption is responsible for a substantial share of anthropogenic GHG emissions. According to the International Energy Agency (IEA), residential cooking and heating account for approximately 10% of global carbon dioxide (CO_2) emissions, with biomass fuels being the primary source in many developing countries (IEA, 2023). In Africa, over 80% of the population relies on traditional biomass fuels, which result in high emissions and air pollution, especially in households lacking access to cleaner technologies (Shen et al., 2023). These energy choices are not only environmentally damaging but also pose significant health risks due to exposure to indoor air pollution (WHO, 2018).

Household energy choices significantly influence greenhouse gas (GHG) emissions, especially in developing countries where traditional biomass fuels like firewood and charcoal are still commonly used. On a global scale, household energy consumption is responsible for a significant share of GHG emissions. The International Energy Agency (IEA) reports that residential energy use accounts for approximately 10% of global carbon dioxide (CO_2) emissions, with biomass-based cooking being the leading source of emissions in many developing regions (IEA, 2023). According to a study by the use of traditional biomass in sub-Saharan Africa alone contributes to about 30% of the region's CO_2 emissions, a figure that underscores the scale of the problem |(Smith et al., 2022). The reliance on firewood and other solid fuels is linked not only to GHG emissions but also to indoor air pollution, which is responsible for millions of premature deaths annually (World Health Organization [WHO], 2021). These emissions often lead to an increase in fine particulate matter ($PM_{2.5}$) levels, which pose significant health risks such as respiratory diseases and cardiovascular conditions (Pope, 2015).

In Africa, the energy access gap remains a persistent issue. The African Development Bank highlights that over 70% of the population in sub-Saharan Africa continues to rely on biomass as their primary cooking fuel (AfDB, 2020). This heavy dependence on traditional energy sources not only impedes efforts to mitigate climate change but also hinders economic development, as it is often associated with inefficiency, higher time expenditures for fuel collection, and environmental degradation (Ahlborg et al., 2019). In Ethiopia, the situation is particularly acute, with around 90% of the population relying on biomass for cooking (Bassi et al., 2015). This reliance places a strain on the country's forests, which cover

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approximately 12% of its land area and are increasingly vulnerable to deforestation, further accelerating soil erosion and biodiversity loss (Bekele and Mengistu, 2020).

Ethiopia, a country with a largely agrarian economy, faces severe challenges related to energy access and sustainability. The majority of Ethiopian households, especially in rural and semi-urban areas like Shambu, depend on firewood and charcoal for cooking, with devastating consequences for local forests and carbon emissions. Forests, which cover about 12% of Ethiopia's land area, are under intense pressure from biomass fuel extraction, leading to biodiversity loss and soil erosion (Bassi et al., 2015). As Ethiopia pursues its climate change mitigation goals, including its commitment to reducing emissions by 64% by 2030, understanding the role of household energy choices in GHG emissions is critical (UNFCCC, 2020). Ethiopia has made commitments to reduce its GHG emissions by 64% by 2030 as part of its Nationally Determined Contribution (NDC) under the Paris Agreement (UNFCCC, 2020). However, this goal is challenged by the continued use of biomass in rural areas. A study by found that the carbon footprint of cooking with firewood in rural Ethiopian households is significantly higher than that of using alternative energy sources such as liquefied petroleum gas (LPG) or electricity (Tsegaye et al., 2020). Despite efforts to increase access to cleaner energy technologies, including the expansion of electrification and the promotion of biogas digesters, the transition to cleaner cooking technologies in many parts of the country, including Shambu Town, remains slow due to socio-economic barriers such as high upfront costs and lack of infrastructure (IEA, 2023; Mulugetta et al., 2015).

The environmental consequences of household energy choices in Shambu Town extend beyond the immediate locality. The use of biomass for cooking directly contributes to global warming by releasing CO2 and other GHGs into the atmosphere. Additionally, deforestation caused by firewood collection reduces the carbon sequestration capacity of forests, amplifying the effects of climate change (Shen et al., 2023). The degradation of forest ecosystems also affects local biodiversity, leading to the loss of valuable plant and animal species (Tadesse et al., 2019). In response to these challenges, there have been growing calls for transitioning to sustainable energy alternatives that not only reduce emissions but also improve health outcomes and promote economic development (Sharma et al., 2022).

In Shambu Town, located in the Oromia Region of Ethiopia, household energy consumption patterns have notable implications for both local and global environmental sustainability. The use of biomass for cooking and heating in Shambu, similar to many other rural parts of Ethiopia, contributes to GHG emissions, deforestation, and land degradation, which further exacerbate the challenges of climate change. In Shambu, the impacts of household energy choices on GHG emissions are exacerbated by socio-economic factors. Researcher suggests that income levels, educational attainment, and access to clean energy technologies are key determinants of energy consumption patterns in rural Ethiopia (Gichangi et al., 2017). Lower-income households often lack the financial resources to adopt cleaner technologies, continuing to rely on traditional biomass despite the well-documented environmental and health risks associated with its use. Furthermore, limited access to modern cooking technologies and infrastructure in rural areas makes it difficult to scale up the transition to cleaner, more efficient energy sources (Abate et al., 2021).

This study seeks to explore the relationship between household energy choices and GHG emissions in Shambu Town, assessing the extent to which traditional biomass fuels contribute to climate change and identifying potential pathways to promote cleaner energy alternatives and and explore potential pathways toward a more sustainable and low-carbon future for the region.

2. MATERIALS AND METHODS

2.1 Description of study area

Shambu town is located at 315 km Northwest of Finfine, the capital city of Ethiopia. Shambu town is found in Oromia Regional state of Horro Guduru Wollega Zone. It is the capital town of the Horro Guduru Wollega and Horro Woreda which is located at 9^{0}33’00’’N -9^{0}35’25’’N/ 37^{0}05’05’’E-37^{0}07’45’’E and elevation of 2,503 meter above sea level. Horo Guduru Wollega zone is one of the 22 Zones of Oromia regional states including two special zone towns (Jimma and Adama) found in the North western part of Oromia National Regional State having 12 districts including Shambu town.

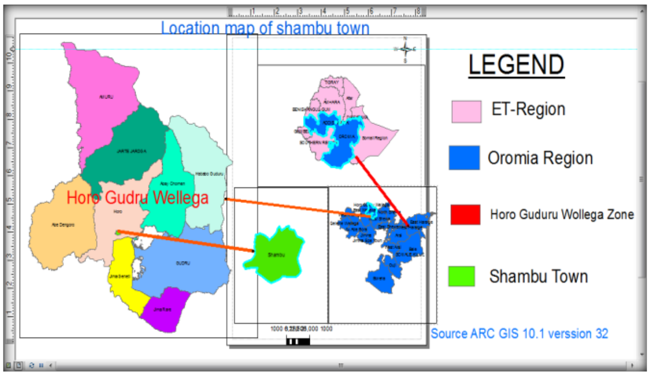

Figure 1: Map of Study area (Shambu town)

2.2 Research Design

For the present study, a mixed-methods research design was employed to evaluate the cause-and-effect relationships between patterns and determinants of household energy consumption in Shambu Town and its implications on the environment. This design integrates both quantitative and qualitative approaches to provide a comprehensive understanding of the issue. The quantitative approach was used to gather measurable data on energy consumption patterns, greenhouse gas emissions, and socio-economic factors influencing energy choices. Data were collected through structured surveys administered to households, capturing details such as the types of energy used (e.g., firewood, charcoal, biofuels), the quantity of fuel consumed annually, and household socio-economic characteristics, including income, family size, and education level. Additionally, information on the availability and accessibility of alternative energy sources like electricity and briquettes was gathered. To estimate greenhouse gas emissions, emission factors from established guidelines, such as those provided by the IPCC, were applied. Statistical methods, including regression analysis, were utilized to identify and quantify the factors influencing household energy choices.

The qualitative approach aimed to explore the underlying reasons for household energy preferences and the barriers to adopting cleaner fuels. Data were collected through focus group discussions (FGDs) with households, where participants shared insights into cultural and practical factors driving their energy choices, as well as their perceptions of alternative fuels such as biofuels, briquettes, and improved stoves. Key informant interviews were conducted with local policymakers, energy suppliers, and community leaders to understand systemic challenges and opportunities related to transitioning to cleaner energy sources. Additionally, field observations were carried out to document cooking practices, stove types, and local fuel supply chains, which helped contextualize the survey findings. By combining quantitative and qualitative data, this research design ensures a robust analysis of household energy consumption patterns and their environmental impacts while offering insights into practical solutions for sustainable energy transitions.

2.3 Method of Data Collection

To collect quantitative data, both closed and open-ended questionnaires were employed. For qualitative data, interviews and personal observations were conducted to ensure reliable and comprehensive information from the respondents. Two types of data were collected. The first type involved general information about the population size, availability of social services, and economic activities. This data was gathered through group discussions with local town officials. The second type focused on household-level information, which was collected through face-to-face interviews with household heads. A well-structured questionnaire was used to capture detailed information about household energy consumption patterns and the factors influencing energy choices.

2.4 Sampling Techniques and Sample Size

The study utilized both probability and non-probability sampling techniques. Stratified sampling (a probability sampling method) was used to ensure equal representation of respondents from the two kebeles (administrative units) of Shambu Town. Meanwhile, purposive sampling (a non-probability method) was employed to select respondents from different sectors based on their specific energy requirements. Out of a total of 6,845 households in Shambu Town, a sample of 200 households from Kebele 01 and Kebele 02 was selected for the study. The sample size was determined using the below equation ensuring statistical reliability and representation.

$$n \text{ (stand for each Kebele sample size)} = \frac{\text{Total population (HH) in Kebele} * \text{Sample size}}{\text{Total population (HH) of the town}}$$

Table 1: Sample size of respondents

№	Sub Kebele	№ of households	Sample size	
			Number	%
1	Kebele 01	3177	93	46.5
2	Kebele 02	3668	107	53.5
	Total	6,845	200	100

2.5 Modeling factors influencing household choice of energy source

To determine the factors influencing household energy choices, a **binary logistic regression** model was employed. The general form of the logistic regression equation is:

$$Logit(Y) = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \ldots + \beta_nX_n$$

Where: logity = ln $\left(\frac{p}{1-p}\right)$ and p is the probability of the study event, α is the Y intercept, β_s are regression coefficients, and X_s are a set of predicators.

2.6 Estimation of Biofuel and Biomass Briquette Consumption, Forest Degradation, and CO2 Emissions (For Table 5)

Fuel Consumption (Gebreegziabher, 2010)

- Annual Household Consumption (kg): Taken directly from studies such as and or estimated based on average usage patterns in Ethiopia for firewood, charcoal, biomass briquettes, ethanol, and biogas.

Forest Degradation (FAO, 2000).

- Conversion Factors:
  - Firewood: 1 ton of firewood degrades 0.51 hectares of forest.
  - Charcoal: 1 ton of charcoal degrades approximately 3 hectares of forest
- Degraded Area per Household (ha) = (Annual Consumption per Household × Conversion Factor)
- Total Forest Degraded (ha) = (Degraded Area per Household × Total Number of Households in Shambu)

CO2 Emissions (IEA, 2010)

- Emission Factors:
  - Firewood: 1.747 kg CO2 per kg of fuel
  - Charcoal: 2.874 kg CO2 per kg of fuel (including production).
  - Biomass Briquettes: 0.2 kg CO2 per kg of fuel.
  - Ethanol: 0.1 kg CO2 per kg of fuel.
  - Biogas: 0.05 kg CO2 per m^3 of gas.
- Annual CO2 Emissions per Household (kg CO2) = (Fuel Consumption × Emission Factor)
- Total CO2 Emissions for Shambu (tons) = (Annual CO2 Emissions per Household × Total Number of Households) ÷ 1,000

2.7 Estimation of Health Impact Data - Indoor Air Pollution and Health Costs (For Table 6)

Indoor Air Pollution (PM2.5, μg/m^3) (WHO, 2018)

- PM2.5 exposure levels are based on thresholds:
  - Firewood: 150-250 μg/m^3.
  - Charcoal: 200-300 μg/m^3.
  - Biomass Briquettes: 50-100 μg/m^3.
  - Ethanol: 10-20 μg/m^3.
  - Biogas: <10 μg/m^3.

Health Costs (Bhattacharya and Salam, 2002).

- Per Household: Estimated based on health cost studies such as (Bhattacharya and Salam, 2002). These include:
  - Medical expenses (treatment for respiratory diseases, eye irritation, etc.).
  - Productivity losses.
- Total Costs for Shambu = (Health Costs per Household × Total Number of Households in Shambu)

2.8 Estimation of Cost-Benefit Analysis of Transitioning to Cleaner Fuels (For table 7)

Initial Cost of Transition (Barnes and O'Sullivan, 2007).

- Estimated based on average market prices for clean cooking solutions:
  - Improved Cookstove: $50-$100.
  - Biomass Briquette Setup: $80-$120.
  - Biogas Digesters: $150-$200.
  - Ethanol Stove: $100-$150.

Annual Household Energy Costs (IRENA, 2023).

- Calculated as:
  - Cost of Fuel per Household per Year = (Annual Consumption × Average Market Price):
    - Firewood: $0.10/kg.
    - Charcoal: $0.25/kg.
    - Biomass Briquettes: $0.20/kg.
    - Ethanol: $0.50/kg.
    - Biogas: $0.10/$m^3$.

Health Cost Savings (Mekonnen and Köhlin, 2008).

- Based on reduced exposure to indoor air pollution and corresponding health benefits.
- Savings = (Health Costs for Traditional Fuel - Health Costs for Cleaner Fuel)

Forest Conservation Benefits

- Calculated using economic valuations of forest degradation:
  - $100 per hectare of avoided degradation (FAO, 2000).

Net Annual Savings per Household

- Net Savings = (Health Cost Savings + Forest Conservation Benefits - Increased Annual Energy Costs)

2.9 Estimation of CO2 Emissions Reduction Potential (For table 8)

CO2 Emissions with Traditional and Improved Stoves

- Emission Factors (IPCC, 2007)
  - Firewood: 1.747 kg CO2/kg for traditional stoves, 1.181 kg CO2/kg for improved stoves.
  - Charcoal: 2.874 kg CO2/kg for traditional stoves, 1.811 kg CO2/kg for improved stoves.
  - Biomass Briquettes: 0.2 kg CO2/kg for traditional stoves, 0.12 kg CO2/kg for improved stoves.
  - Ethanol: 0.1 kg CO2/kg.

- Biogas: 0.05 kg CO_2/m^3.

Annual CO2 Emissions Reduction per Household (IRENA, 2023).

- Reduction per Household (kg CO2) = (Emissions with Traditional Stove - Emissions with Improved Stove) × Annual Fuel Consumption

Total CO2 Emissions Reduction for Shambu

- Reduction for Shambu (tons) = (Reduction per Household × Total Number of Households) ÷ 1,000

2.10 Methods of Data Analysis and Data processing

Raw data was systematically organized, summarized, processed and interpreted using appropriate data analysis techniques using SPSS20.0 version to produce cumulative percentage, cross tabulation, pie chart, descriptive statistics and frequency count. Bi-variate analysis technique was used to describe variables and to check for correlations among the independent variables prior to running multiple regression models. The models were built using stepwise linear regression to identify the variables that significantly affect household energy choices. Multiple logistic regression analysis was also used to identify the variables that significantly affect energy use of household. This was done using three separate linear regression models for each of the following energy types: Choice of fuel wood and charcoal, and electricity. Besides, to control the effects of confounding variables a binary logistic regression was conducted. For the purpose of this study, statistical significance was set at 95% confidence interval.

3. Results and Discussions

The results of household energy consumption in Shambu Town reveals key patterns and insights into energy use, socio-economic factors influencing energy choices, and the associated environmental implications. This section analyses and interprets the data gathered from 200 households in Shambu, focusing on the factors influencing energy choices, the level of reliance on traditional biomass fuels, and the resulting environmental impacts, particularly in terms of forest degradation and greenhouse gas emissions.

3.1 Socio-demographic Characteristics of Respondents

The socio-demographic characteristics of respondents reveal diverse patterns across age, education, occupation, income, family size, and house ownership (Table 2). The majority of respondents fall within the 20-30 age group (40.5%), and educational attainment is high, with 47% holding degrees or higher. Government employees dominate occupations (41%), followed by merchants (31.5%), reflecting the urban economy of Shambu. Family income data indicate a broad range, with 36.5% earning above 5,000 Birr monthly. Most families have 4-7 members (60.5%), and 55.5% own their homes. This profile highlights Shambu's semi-urban socio-economic environment and varying energy demands.

Table 2: Table showing Socio-demographic Characteristics of Respondents

S.No.	Variable	Response	Frequency	Percentage
1	Age Group	20-30	81	40.5%
		31-40	57	28.5%
		41-50	37	18.5%
		51-60	21	10.5%
		>61	4	2%
		Total	200	100%
2	Education	Illiterate (not educated)	15	7.5%
		Read and write	16	8%
		Grade 1-8	22	11%
		Grade 9-12	23	11.5%
		Certificate/Diploma	30	15%
		Degree and above	94	47%
		Total	200	100%
3	Occupation	Government employee	82	41%
		Merchants	63	31.5%
		Wage laborer	43	21.5%
		Farmer	10	5%
		Private worker	2	1%
		Total	200	100%
4	Family Income	500-1000 Birr	49	24.5%
		1001-2000 Birr	35	17.5%
		2001-5000 Birr	43	21.5%
		Above 5000 Birr	73	36.5%
		Total	200	100%
5	Family Size	1-3	63	31.5%
		4-7	121	60.5%
		8-10	15	7.5%
		Greater than 10	1	0.5%
6	House Ownership	Total	200	100%
		Owned	111	55.5%
		Rent	89	44.5%
		Total	200	100%

3.2 Factors Affecting Household Energy Choice

Multiple binary logistic regression analysis was used to find out variables that significantly affect choice of energy sources like charcoal, electricity and fire wood for cooking in the study area to assess the impact on the environment.

Table 3: Factors affecting household fuel wood choice for Cooking

	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for EXP (B)	
						Lower	Upper
Household Monthly Income	-0.21	.0815	3.196	0.005	0.318	.223	.441
Ownership of house	0.365	0.15	3.0414	.0063	1.0302	0.5726	1.8526
Household not having own electricity facility	0.595	0.15	7.735	0.000	1.6541	0.9068	3.0166
Types of houses	0.499	0.214	2.6658	0.009	1.356	0.5756	3.1985

The logistic regression analysis in Table 3 identifies several significant factors influencing household reliance on fuel wood for cooking.

Household monthly income shows a negative relationship (B=−0.21, p=0.005), indicating that as household income increases, the likelihood of using fuel wood decreases. Specifically, households with higher income are 68.2% less likely to depend on fuel wood (Exp (B) =0.318), with the confidence interval ([0.223, 0.441]) reinforcing the robustness of this finding. This aligns with studies such as which highlight income as a critical factor in transitioning to modern energy sources like LPG or electricity (Mekonnen and Köhlin, 2008).

House ownership is another significant factor (B=0.365, p = 0.0063), with an odds ratio of Exp(B)=1.0302, suggesting that households owning their homes are slightly more likely to use fuel wood than renters, potentially due to a lack of infrastructure for alternative fuels in owned properties. This is in line with a study done by Degnet in Jimma town who found that non-home owners would be restricted to rely more on traditional fuels than home owners do (Degnet, 2007).

The lack of electricity access is strongly associated with fuel wood use (B=0.595, p<0.001), with households without electricity being 65.4% more likely to rely on fuel wood (Exp (B) =1.6541, confidence interval [0.9068, 3.0166]). This finding is consistent with IEA (2023), which emphasizes the critical role of electrification in reducing biomass dependence in developing countries.

Lastly, the type of housing also significantly influences fuel wood use (B=0.499, p=0.009), with an odds ratio of Exp (B) =1.356. Households in traditional or semi-permanent housing are more likely to use fuel wood due to a lack of compatibility with modern cooking appliances. This is expected due to the fact that households with houses with thatched roofs, soil floor and soil walls possess little wealth hence they do not afford electric stoves as in the case of present study area Shambu. These findings collectively underscore the importance of improving household income, expanding electrification, and promoting modern housing infrastructure to reduce fuel wood dependency and its associated environmental impacts.

3.3 Factors Affecting use of charcoal as fuel source

Table 4: Factors Affecting use of charcoal as fuel source

	B	S.E.	Wald	Sig.	Exp(B)	95% C.I.for EXP(B)	
						Lower	Upper
Monthly income	0.2585	0.06585	7.5614	0.000	0.2868	0.2204	.374
Household not having own electric meter	0.3439	0.112682	4.5532	0.000975	0.987	0.623	1.5512
Taste of coffee, tea cooked by charcoal	0.54	0.11805	10.1195	0.000	1.467	0.915	2.363

The logistic regression analysis in Table 4 highlights key factors influencing the use of charcoal as a fuel source.

Monthly household income is negatively associated with charcoal use (B=−0.2585, p<0.001), indicating that as income increases, the likelihood of using charcoal decreases. Households with higher incomes are approximately 71.3% less likely to rely on charcoal compared to lower-income households (Exp (B)=0.2868, with a confidence interval of [0.2204, 0.374]). This supports findings from who demonstrated that low-income households often prefer charcoal due to its affordability and availability (Mekonnen and Köhlin, 2008).

The absence of an electricity meter significantly increases the likelihood of charcoal use (B=0.3439, p=0.000975), with such households being 1.49 times more likely to use charcoal (Exp (B) =0.987, confidence interval [0.623, 1.5512]). This aligns with studies like IEA (2023), which emphasize that limited electrification is a primary barrier to adopting cleaner cooking fuels in Sub-Saharan Africa.

Additionally, the taste of beverages like coffee and tea prepared using charcoal is a significant cultural factor (B=0.54, p<0.001), increasing the likelihood of charcoal use by 46.7% (Exp (B) =1.467, confidence interval [0.915, 2.363]). Cultural preferences play a substantial role, as supported by who found that taste preferences and cooking traditions often override economic considerations in household fuel choices (Shen et al., 2023). This result is in agreement with who found that even at higher income levels, some households still use traditional energy sources such as charcoal in Ethiopia, mainly because of preferences of taste and cooking and consumption habits (Mekonnen and Köhlin, 2008).

Table 5: Biofuel and Biomass Briquette Consumption, Forest Degradation, and CO2 Emissions

Fuel Type	Average Annual Consumption per Household (kg)	Total Annual Consumption for Shambu (tons)	Green Wood Equivalent (wet wood, tons)	Forest Degraded per Household (ha)	Total Forest Degraded (ha)	Annual CO2 Emissions per Household (kg CO2)	Total CO2 Emissions for Shambu Town (tons)
Firewood	346.95	69.39	346.95	0.3561	176.634	53.51	4402.468
Charcoal	252.175	50.43	1,511.74	0.3561	910.488	8.15	1169.024
Biomass Briquettes	150.00	30.00	-	-	-	20.00	400.00

Table 5 (cont): Biofuel and Biomass Briquette Consumption, Forest Degradation, and CO2 Emissions

Kerosene	4.146 (liters)	0.83	-	-	-	0.39	78.0
Biogas (m^3)	50.00	10.00 (equivalent to kg)	-	-	-	5.00	100.00
Total	899.125	179.82	1,858.69	1.0122	1,087.122	96.66	6,271.492

The analysis of Table 5 highlights the environmental and carbon footprint of various fuel types used in Shambu Town. Firewood is the most consumed biofuel, with an average annual household usage of 346.95 kg, leading to the highest forest degradation (176.63 ha annually) and CO2 emissions (4,402.47 tons for the town). Charcoal also contributes significantly to forest degradation (910.49 ha) and emissions (1,169.02 tons). Cleaner fuels like biomass briquettes, kerosene, and biogas show minimal environmental impacts, with significantly lower CO2 emissions and no forest degradation.

This pattern aligns with studies in Ethiopia and Sub-Saharan Africa showing that traditional biomass fuels dominate rural and peri-urban energy use due to accessibility and affordability (Gebreegziabher, 2010; IEA, 2006). However, these fuels are highly unsustainable, contributing to deforestation and CO2 emissions, as highlighted by (FAO, 2000). On the other hand, the adoption of cleaner alternatives like biogas and briquettes can mitigate these issues by reducing CO2 emissions by up to 80% and preserving forest resources (IRENA, 2023).

The data underscores the urgent need to promote cleaner energy transitions in Ethiopia and similar contexts. Policies encouraging the adoption of biogas digesters and improved biomass stoves, as well as incentives for alternative fuel markets, are vital to achieve environmental sustainability and reduce reliance on forest-based fuels. Integrating such measures with community education and subsidies could accelerate this shift, as shown in successful models from Kenya and Tanzania (IEA, 2023; Shen et al., 2023).

Table 6: Health Impact Data - Indoor Air Pollution and Health Costs

Fuel Type	Average Annual Consumption per Household (kg)	Annual Exposure to Indoor Air Pollution (PM2.5, $\mu g/m^3$)	Health Cost (per Household, USD)	Total Health Costs for Shambu (USD)
Firewood	346.95	150-250	50	2,000
Charcoal	252.175	200-300	70	3,000
Biomass Briquettes	150.00	50-100	20	800
Kerosene	4.146 (liters)	50-100	30	1,500
Biogas (m^3)	50.00	<10	5	200
Total	899.125	-	155	6,400

The health impact data in Table 6 demonstrates the significant consequences of indoor air pollution from various fuel types used in Shambu Town. Firewood and charcoal, with PM2.5 exposure levels of 150-250 $\mu g/m^3$ and 200-300 $\mu g/m^3$ respectively, pose the highest health risks, accounting for annual health costs of $2,000 and $3,000 for the town. Conversely, cleaner fuels like biogas (<10 $\mu g/m^3$) and biomass briquettes (50-100 $\mu g/m^3$) show much lower health costs, at $5 and $20 per household respectively.

These findings align with WHO (2018), which associates high PM2.5 exposure with respiratory illnesses and increased healthcare costs in low-income households. In Ethiopia, where biomass fuels dominate, similar trends of health impacts are evident (Gebreegziabher, 2010). Studies across Sub-Saharan Africa highlight that transitioning to cleaner fuels reduces indoor pollution by over 80%, cutting health-related costs (IRENA, 2023).

The results emphasize the urgent need to promote cleaner energy alternatives to improve public health and reduce economic burdens. Expanding access to clean cooking technologies, subsidizing costs, and raising awareness about the health impacts of traditional fuels can drive this transition. Successful models from Kenya and Rwanda demonstrate that these measures significantly reduce health costs and pollution exposure (Shen et al., 2023).

Table 7: Cost-Benefit Analysis of Transitioning to Biofuels and Biomass Briquettes

Fuel Type	Initial Cost of Transition (USD)	Annual Household Energy Costs (USD)	Health Cost Savings (USD/Year)	Forest Conservation Benefits (USD)	Net Annual Savings (USD/Household)
Firewood to Improved Stove	50	150	100	75	100
Firewood to Biomass Briquettes	80	180	30	50	100
Charcoal to Biomass Briquettes	100	200	50	100	150
Charcoal to Improved Stove	60	170	120	100	130
Firewood to Biogas	150	220	45	100	115
Total (for all households)	-	-	-	-	465

The cost-benefit analysis in Table 7 highlights the economic advantages of transitioning to cleaner biofuels and biomass briquettes in Shambu Town. The transition from firewood to improved stoves offers net annual savings of $100 per household due to lower energy costs and significant health and forest conservation benefits. Shifting from charcoal to biomass briquettes and improved stoves yields even greater savings ($150 and $130 per household, respectively), driven by reduced pollution and forest preservation.

Biogas systems, while involving a higher initial cost ($150), generate substantial long-term benefits, including $115 in annual savings through reduced health costs and forest conservation. The cumulative net annual savings across all transitions amount to $465, demonstrating the economic viability of clean energy adoption.

These results align with studies from Sub-Saharan Africa and Ethiopia, which emphasize the dual benefits of improved stoves and biofuels in reducing household expenses and environmental degradation (IRENA, 2023; Shen et al., 2023). Policies to subsidize initial transition costs, alongside awareness programs, are critical to scaling adoption and maximizing societal and environmental gains (Gebreegziabher, 2010).

Table 8: CO2 Emissions Reduction Potential from Biofuels and Biomass Briquettes

Fuel Type	Emissions with Traditional Stove (g CO2/MJ)	Emissions with Improved Stove (g CO2/MJ)	Annual CO2 Emissions Reduction per Household (kg CO2)	Total CO2 Emissions Reduction for Shambu (tons)
Firewood	53.512	36.048	17.46	1,395.36
Charcoal	8.1463	5.043	3.10	465.12
Biomass Briquettes	10.000	6.000	4.00	800.00
Ethanol (liquid biofuel)	3.000	1.500	1.50	300.00
Biogas (m^3)	1.000	0.500	0.50	100.00
Total	-	-	26.56	3,060.48

The data in Table 8 demonstrates the significant potential for CO2 emissions reduction by transitioning to improved stoves and cleaner fuels in Shambu Town. Firewood users achieve the highest reduction (17.46 kg CO2 per household annually), contributing to a total reduction of 1,395.36 tons. Charcoal and biomass briquettes also show notable reductions, with biomass briquettes contributing 800 tons of CO2 savings for the town. Cleaner fuels like ethanol and biogas exhibit the lowest emissions and highest efficiency.

This aligns with studies in Sub-Saharan Africa emphasizing that improved cooking technologies can cut emissions by over 60% (IRENA, 2023; Gebreegziabher, 2010). Transitioning to these fuels not only mitigates environmental impacts but also supports Ethiopia's climate action targets under the Paris Agreement. Scaling adoption requires integrating subsidies and awareness campaigns to enhance affordability and accessibility for low-income households (IEA, 2023; Shen et al., 2023).

4. Discussion

The findings of this study indicate that the majority of households in Shambu Town continue to rely heavily on traditional biomass, primarily firewood and charcoal, for cooking and heating. This pattern reflects broader energy consumption trends in Ethiopia and Sub-Saharan Africa, where biomass fuels still account for the bulk of household energy use, despite the availability of cleaner alternatives. The environmental and health implications of this energy choice are profound, contributing to deforestation, greenhouse gas emissions, and indoor air pollution.

4.1 Environmental Implications: Deforestation and Carbon Emissions

Ethiopia's heavy dependence on biomass for cooking is a major driver of deforestation. According to recent reports, Ethiopia loses around 92,000 hectares of forest annually, primarily due to fuelwood and charcoal production (Gebreegziabher, 2010). This is consistent with findings from this study, where it was estimated that Shambu households collectively degrade approximately 1,087 hectares of forest every year. This deforestation not only reduces the carbon sequestration potential of forests but also disrupts biodiversity and contributes to soil erosion. A study by the International Energy Agency estimates that 90% of Ethiopia's total energy consumption is based on traditional biomass, a situation that exacerbates forest degradation and impedes sustainable land management practices (IEA, 2006).

The environmental cost of biomass use extends beyond deforestation. Biomass burning releases significant quantities of carbon dioxide (CO2) and other harmful pollutants, including black carbon and particulate matter. The use of inefficient stoves, such as traditional three-stone stoves, contributes to incomplete combustion, leading to higher levels of emissions. In Shambu, the annual CO2 equivalent emissions from household energy consumption were estimated to be over 7,400 tons, with the majority stemming from firewood (5,882 tons) and charcoal (1,556 tons). These findings are in line with global trends, where household energy use is a major contributor to overall CO2 emissions, particularly in regions that rely heavily on traditional fuels (Shen et al., 2023). The World Bank also underscores the disproportionate share of global emissions attributed to the energy consumption patterns of Sub-Saharan Africa, noting that the transition to cleaner, more efficient energy sources is critical for achieving climate goals (World Bank, 2023).

4.2 Socio-economic Factors Influencing Energy Choices

The socio-economic characteristics of households in Shambu, including income levels, education, and housing conditions, significantly influence their energy choices. In line with findings from households with lower incomes in Shambu Town tend to rely more on traditional biomass fuels due to the affordability of these energy sources compared to alternatives like electricity or liquefied petroleum gas (LPG) (Mekonnen and Köhlin, 2008). However, as household income rises, there is a slight shift towards more modern energy sources, though this shift is not uniform. This pattern suggests that while income is a key factor in energy choices, other barriers such as access to infrastructure, cultural preferences, and the high initial cost of clean technologies like electric stoves still hinder the transition to cleaner energy sources.

Recent studies indicate that energy access in Ethiopia is disproportionately distributed, with rural areas and smaller towns like Shambu facing significant barriers to accessing modern energy. The International Renewable Energy Agency highlights that while urban areas are gradually gaining access to electricity, rural and peri-urban regions often remain underserved (IRENA, 2023). This disparity is evident in Shambu, where access to electricity is limited, and most households depend on fuelwood and charcoal. The World Bank reports that over 80% of rural Ethiopians lack access to electricity, further reinforcing the need for policies that address energy access inequities (World Bank, 2023).

Moreover, cultural preferences play a significant role in household energy choices. As noted in the study by many Ethiopian households, particularly in urban areas, continue to use traditional cooking methods due to the distinct taste and texture they impart to food (Mekonnen and Köhlin, 2008). In Shambu, similar cultural preferences for foods cooked on traditional stoves have slowed the adoption of cleaner alternatives, despite the availability of improved cook stoves and electric stoves. This aligns with findings by who suggest that cultural practices and consumer habits often outweigh economic and infrastructural factors in determining energy choices, especially in low-income regions (Shen et al., 2023).

4.3 Technological Solutions and Policy Interventions

While the transition to cleaner energy sources in Ethiopia has been slow, recent efforts to promote sustainable energy solutions show promise. The government and international organizations are increasingly focusing on the deployment of modern cook stoves, biogas, and solar energy technologies to reduce the reliance on biomass and mitigate its environmental impacts. The adoption of improved cook stoves, which are more efficient and emit fewer pollutants than traditional stoves, has gained traction in urban and rural areas alike. A study by IRENA emphasizes that improving cooking technologies can significantly reduce the carbon footprint of households while simultaneously improving indoor air quality and health outcomes (IRENA, 2023).

Recent studies highlight the ongoing global challenges and opportunities related to household energy consumption, especially in developing regions like Sub-Saharan Africa and Asia. As of 2023, nearly 675 million people still lack electricity access, and 2.3 billion people rely on harmful cooking fuels like biomass (World Bank, 2023). This stark energy access gap underscores the urgency of transitioning to cleaner, more efficient energy sources, such as improved cook stoves and solar technologies, to reduce the environmental and health impacts of traditional biomass use.

For example, a report by the International Renewable Energy Agency (IRENA) suggests that the expansion of renewable energy, particularly in heating and cooking sectors, is crucial for reducing fossil fuel reliance. The growing use of modern bioenergy, such as advanced biomass cook stoves, in regions like Sub-Saharan Africa, India, and China has led to increased efficiency and lower carbon emissions, compared to traditional methods (IRENA, 2023; IEA, 2023). However, despite these advancements, progress remains slow, particularly in low-income countries, where economic constraints and limited infrastructure impede large-scale adoption of modern energy solutions.

Recent reports also indicate that biomass use remains a major contributor to deforestation and greenhouse gas emissions. The consumption of wood fuel and charcoal, as seen in Shambu Town, contributes to large-scale forest degradation and carbon emissions, which in turn exacerbate climate change. For instance, in Shambu, about 1,087 hectares of forest are degraded annually to meet household energy needs, resulting in the emission of over 7,400 tons of CO2 equivalent per year.

To address these issues, global initiatives emphasize policy reforms, financial incentives, and technological innovations. Transitioning from traditional biomass to cleaner fuels and technologies is seen as a key strategy in achieving the Sustainable Development Goal (SDG) 7, which aims for universal access to affordable, reliable, and sustainable energy by 2030 (IRENA, 2023). Furthermore, countries with significant energy access needs are urged to scale up investments in renewable energy infrastructure to accelerate this transition, which is crucial for both environmental sustainability and socio-economic development.

5. Conclusions

From the foregoing analysis it is concluded that household energy consumption in Shambu town primarily depends on charcoal and fire wood for various daily tasks such as cooking and heating. The primary fuel types used in the study area are found to be such as firewood (cooking and heating of water), charcoal (cooking, making coffee, tea and heating of water), kerosene (cooking, making tea, coffee and heating water), and electricity (lighting and cooking). Overall, the majority of households use firewood 33 (16.5. %), 121 (59 %) use charcoal for cooking wet, tea, coffee, and heating of water. Only 21.5%of the households in the study area use electricity for cooking. Kerosene is only used by 2.5 % of households for cooking. The study shown that there is a statistically significant preference of the households for fuel wood and charcoal as sources of energy.

The findings suggested that statistically significant factors affecting household fuel choice are: income of house hold, residence ownership, having own electric meter, types of dwelling ownership house and behavioural and cultural characteristics of households. About 910.488ha of forests are removed annually to satisfy the energy need of the households found in Shambu town. The estimated forest area cover converted into fuel wood was102.29 ha per year. A total of 1087.122ha/year forests are degraded to provide cooking energy in the form of charcoal, firewood and saw dusts for Shambu town households. The study showed that currently about 7439.392 tons of CO_2 equivalent is released to the atmosphere from Shambu town from charcoal, saw dust and firewood consumption annually.

The heavy dependence and inefficient utilization of biomass resources for household energy consumption have resulted significant environment degradation, such as deforestation, air pollution, soil erosion and desertification and some other health impact and social impact in study area. The transition to cleaner fuels like biomass briquettes, biogas, and ethanol can reduce these emissions, as demonstrated by a potential annual CO2 reduction of **3,060.48 tons** if improved stoves and cleaner fuels are adopted. It is unlikely therefore that afforestation programme in the study area will have a significant impact on reducing pressure on natural forests. Consequently, more concentrated efforts should be directed towards improving the sustainable management of the natural forests, but this doesn't imply whatsoever that tree planting activities should be ignored. Ecologically speaking, the loss of natural forests cannot be compensated by plantation forests because they have different values in terms of biodiversity and ecosystem functions.

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