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Original Research

Performance Evaluation of the "Bilise" Improved Biomass Cookstove in Reducing Fuel Wood Use and CO_2 Emissions in Aira District, Western Wallaga Zone, Oromia, Ethiopia

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Abstract

The unsustainable utilization of solid biomass fuels through inefficient Traditional Cook stoves (TCS) remains a major challenge to achieving energy and environmental security in Ethiopia. This study analyzed the efficiency of the Improved Multipurpose Mud Cook Stove (IMPMCS) in reducing household fuel wood consumption and carbon emissions in the Aira District. A cross-sectional research design supported by a mixed-methods approach was employed, involving 170 households. Data were collected through questionnaires, key informant interviews, focus group discussions, and field observations. Additionally, a simple experimental comparison was conducted for seven consecutive days involving 10 IMPMCS users and 10 TCS users under normal household cooking conditions. Dried Eucalyptus *globulus wood was used as the biofuel source. Descriptive and inferential statistics were applied using Microsoft Excel and IBM SPSS Version 26. Statistical tests indicated significant differences in fuel wood consumption between IMPMCS and TCS users ($p < 0.05$). Carbon emission reductions were estimated using the IPCC default net calorific values, emission factors, and carbon storage parameters. The results showed that IMPMCS reduced fuel wood consumption by an average of 1.78 tons per household per year and lowered annual CO_2 emissions by 2.82 tons CO_2e compared to TCS. The study concludes that IMPMCS improves household energy efficiency, promotes sustainable biomass utilization, reduces indoor and outdoor pollution, and contributes substantially to climate change mitigation. It is recommended that awareness creation and technology scaling efforts be strengthened so that rural households still using TCS can transition to IMPMCS.*

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INTRODUCTION

Improved Cook Stoves (ICS) are designed to increase fuel efficiency and reduce harmful emissions produced during cooking. These stoves typically use less fuel, such as wood, charcoal, or biomass, and have features that enhance combustion, reduce smoke, and redirect heat to the cooking pot (Global Alliance for Clean Cook stoves, 2014). ICS are a sustainable solution to reduce biomass consumption, improve indoor air quality, and mitigate climate change (World Bank, 2014). On the other hand, UNEP (2018) emphasizes the importance of ICS interventions in achieving biomass sustainability, reducing deforestation, and improving the health and well-being of communities. Accordingly, Alzate *et al*. (2019) provide evidence on the efficiency of improved cook stoves as an intervention to address biomass sustainability and improve household living conditions. Bailis *et al*. (2010) studied that improved cook stoves often have better insulation materials and designs, which help retain heat within the combustion chamber. This prevents heat loss and ensures a higher proportion of the generated heat is transferred to the cooking vessel.

In contrast to improved cook stoves, traditional cooking stoves (TCS) are inefficient. Recent studies have shown that TCS are inefficient in burning solid biomass, resulting in high levels of household air pollution and low thermal efficiency (Beltramo *et al*., 2019). These stoves contribute to global climate change and pose health risks, with millions of deaths annually. Studies have shown that fuel-efficient cook stoves can reduce fuelwood use and household air particulates, but the reductions achieved are often lower than laboratory predictions and fall short of pollution targets set by organizations like the World Health

Organization (Beltramo *et al*., 2019). Grieshop *et al*. (2011) confirmed that traditional stoves typically use an open fire or an outdated combustion system, which leads to incomplete combustion of the fuel, resulting in the production of harmful pollutants such as smoke, carbon monoxide, and particulate matter. Smith *et al*. (2011) stated that indoor air pollution resulting from the use of traditional stoves can lead to various health issues, such as respiratory diseases, eye irritation, and cardiovascular problems.

Despite the benefits of ICS, approximately 3 billion people worldwide still rely on traditional cook stoves or open fires for cooking and heating their homes (WHO, 2018). The prevalence of improved cook stoves varies significantly between developed and developing countries. ICS are more prevalent in developed countries like the United States due to improved energy efficiency and technology adoption (Bonjour *et al*., 2013). Developing countries have a low prevalence of improved cook stoves due to limited access, high costs, lack of awareness, and cultural preferences for traditional methods (Global Alliance for Clean Cook stoves, 2014). Global Alliance for Clean Cookstoves, a United Nations Foundation-led public-private partnership, is promoting the adoption of clean cook stoves and fuels in developing countries (Petach *et al*., 2019). Even though traditional open-fire cook stoves are dominant, Resources for the Future (2014) reported that Ethiopia's use of improved cook stoves has surged in recent years, offering cleaner, more efficient cooking technologies, reduced fuel consumption, and improved insulation, thereby reducing indoor air pollution.

The Ethiopian government, non-governmental organizations (NGOs), and international development partners have been actively promoting the adoption of improved cook stoves to combat health issues caused by indoor air pollution and deforestation. These efforts have facilitated the expansion of improved cook stoves in Oromia and other regions of the country. The Ethiopian Evangelical Church Mekena Yesus Development and Social Service Commission is implementing integrated rural development activities in Ethiopia, primarily focusing on the construction of improved multipurpose mud stoves, called Bilise, which are part of multipurpose mud technology designed to provide rural households with durable and efficient cooking solutions. These activities are funded by the German charity Protestant Agency for Diakonia Development (PADD) and other organizations.

However, despite the increasing adoption of ICS, limited studies have assessed the efficiency of multipurpose mud stoves like Bilise in reducing fuel wood consumption and mitigating climate change at the local level. Therefore, this study aims to examine the efficiency of improved multipurpose cook stoves and their contribution to climate change mitigation compared to traditional three-stone open fire stoves in the Aira District.

METHODOLOGY

Description of the study area

The study was carried out in the Aira District, which is 80 km from the West Wallaga Zone and 520 km west of Finfinne. Gulliso to the north, Yubdo to the southeast, and the Kelem Wallaga zone to the south and west define its borders (Figure 1). The administrative hub is Aira town. District coordination situated between 9 1 5'59 n latitude and 35 , 23'59 e longitude. For a total of 18 kebeles, the district consists of 3 town kebeles and 15 rural peasant associations

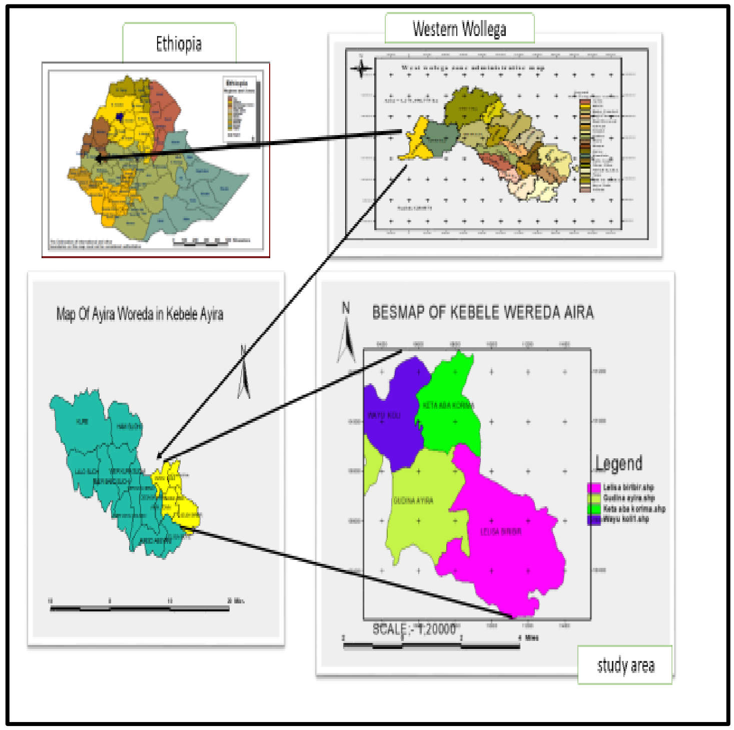

Figure 1. Map of the study area

Research design

This study employed a mixed-methods approach combining qualitative and quantitative data using a cross-sectional research design. The rationale for this approach was to capture detailed household perspectives while allowing statistical generalizations, addressing questions that could not be resolved using only qualitative or quantitative methods.

Source and type of data

Both primary and secondary sources provided data for the study. Primary data was gathered through focus groups, key informants, simple experiment testing, observation, and homes in the target study locations. Secondary data were gathered from non-governmental Social Service and Development Commission Bibir Dilla Synod Branch Office, compiled documents, and the Aira District Administration office, water and energy office, agricultural and natural resource office, and environmental, forest protection, and climate change office at the district level, at the administrative office of the kebele. Both primary and secondary sources provided data for the study. Primary data were gathered from households, focus groups, key informants, simple experimental testing, and field observations. Secondary data were collected from the non-governmental Social Service and Development Commission Bibir Dilla Synod Branch Office, compiled documents, and the Aira District Administration office, including the water and energy office, agricultural and natural resource office, and environmental, forest protection, and climate change office at the district and kebele levels.

Data Collection tools

Household survey

A structured household survey was conducted to collect both qualitative and quantitative data on the type of stove used (IMPMCS vs. three-stone stoves), fuel wood consumption, time and labor for firewood collection, adoption level of IMPMCS, and sources of fuel wood. The questionnaire also captured household characteristics, land holding, farming systems, assets, and wealth. Trained Development Agents conducted face-to-face interviews after a two-day orientation session. The questionnaire was translated into Afan Oromo for better comprehension.

Key informant interviews

Key informants were individuals with specialized knowledge of IMPMCS development, promotion, and usage. A total of 16 key informants (8 male and 8 female) were selected based on their expertise. Four female household heads, four agricultural extension workers, and four other extension workers (one from each kebele) were chosen, alongside representatives from NGOs, agricultural offices, and district water and energy offices.

Focus group discussion

Four FGDs were conducted, one per watershed zone. Each FGD included 12 participants (6 male, 6 female) selected from both TCS and IMPMCS users to ensure representation of stove types and gender.

Field observation

All selected kebeles were observed to document biomass fuel usage, stove types, livelihoods, population density, land use, forest type, forest coverage, soil type, and housing system. Observations were recorded and photographed.

Simple experimental test

A direct experimental assessment was conducted in 20 households to measure fuelwood usage. Ten households using IMPMCS and ten using TCS were purposefully selected from the four kebeles. Each household was oriented before testing. The experiment lasted seven consecutive days, recording daily fuelwood use in kilograms. Eucalyptus globulus, the most common local biomass fuel, was used. Average daily and total consumption were recorded for each stove type and later extrapolated for comparison.

Sampling techniques and Sample size determination

A multistage sampling approach was used. Western Wallaga Zone was chosen for its population density and high reliance on biomass fuel. The Aira District was selected for a high incidence of natural resource degradation. Four kebeles were chosen due to existing IMPMCS implementation by EECMY DASSC. Household heads from these kebeles were listed, and systematic random sampling was applied. The total sample size of 170 was determined using Yamane's (1967) formula at a 93% confidence level and 7% precision. K-values (sampling intervals) for each kebele were calculated based on population proportion, ensuring equal probability for IMPMCS and TCS users.

$$n = \frac{N}{[1 + N(e)^2]} \quad \ldots\ldots\ldots\ldots(1)$$

Where

n = is the sample size,

N = is the population size, and

e = level of precision at 0.07 % (sampling error at 7%)

N= 998

n= 998/ [1+998(0.07) ^{2}] = 170 households

Table 1. Sample of respondents' households from each kebele

No	Name of kebeles	Total number of Household head	Total sample unit
1	Keta Abba Korma	131	22
2	Wayu Koli	230	40
3	Gudina Aira	320	54
4	Lalisa Birbir	317	54
	Total	998	170

Source: Aira District rural land office (2022)

Using systematic random sampling techniques, the sample unit (respondent household selected from the entire population) was identified. Kothari (year). Users of conventional stoves and users of the upgraded multipurpose mud stove have an equal chance of being sampled.

$$K=\frac{nxpi}{N} \quad \text{------------------------------}(2)$$

Where

K=sample household respondent in each kebele

n=the sampled size selected from all selected kebeles

Pi= population included from stratum

N=Total Households in four kebeles

$K = \frac{nxp}{N} =$ 22x170/998 = 4 interval for kata aba korma kebele

$K = \frac{nxp}{N} =$ 40 x170/998 = 7 interval for wayu koli kebele

$K = \frac{nxp}{N} =$ 54x170/998 = 9 intervals Gudina Aayira kebele

$K = \frac{nxp}{N} =$ 54x170/998 =9 intervals for Lalisa bibir kebele

Method of Data Analysis.

Descriptive statistics

Descriptive statistics were used to summarize fuelwood consumption and other variables. Quantitative data were coded and analyzed in SPSS 26 and Excel, while qualitative data from interviews, FGDs, and observations were analyzed thematically. Graphs and tables were used for visualization.

Inferential Statistics

Correlation and regression

Pearson correlation was applied to examine the relationship between fuel wood consumption (kg) and carbon emissions (tCO_2). Multiple linear regression was used to test the causal effects of independent variables, including fuel wood consumption, collection time, and stove type, on carbon emissions. Control variables, such as household size and location, were included to isolate effects.

$$r = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\sqrt{[\Sigma(x-\bar{x})^2(y-\bar{y})^2]}} \quad \ldots\ldots\ldots\ldots (3)$$

Where r=Correlation coefficient, xi= values of the variable in a sample, x= mean of the values of the x-variable, yi= values of the y-variable in a sample, y= mean of the values of the y-variable

Regression analysis was used to test the causal effect between Carbon dioxide emitted and amount of fuelwood combustion in kilogram and the time of fuelwood collection.

The formula for a multiple linear regression model was:

Y= β0+ β1X1 + β 2X2+ β 3X3 …………..+ β n X n+ e……………..………………....... (4)

Where,

Y = the dependent variable, ß0 = the intercept/constant, the predicted value of y when the X1, X2………X n is 0, ß1, ß2, β 3… ß n= the regression coefficient – how much we expect y to change as X1, X2, X3. Increases, X1, X2, X3 ...X n = the independent variable (the variable we expect influencing y), e = the error of the estimate, or how much variation there is in our estimate of the regression coefficient (Kothari, 2004). Finally, substituting the variables into the model results

Carbon Emission Estimation formula

Carbon emissions were estimated following the IPCC procedure using fuelwood saved, fraction of non-renewable biomass (88%), net calorific value (15 MJ/kg), and default emission factor (119.5 tCO_2/TJ). This allowed comparison of emissions between IMPMCS and TCS according to the formula:

E = FWS× fNRB, × NCV× EF---(5)

Where: E- Emission

FWS -Fuel wood saved in tons (kg)

FNRB- a fraction of non-renewable biomass: (88%) in the Ethiopian case.

NCV- The net calorific value of the non-renewable woody biomass that is substituted

(IPCC default for wood fuel, 0.015 TJ/tone or 15 MJ/kg)

EF-default emission factor for the substitution of non-renewable woody biomass, and use a value of 119.5 tCO2/TJ.

RESULT AND DISCUSSION

Demographic Characteristics and Socioeconomic Status of the Respondent

Sex of respondent

For the validity of the data gathered from the household survey, the mixing of both sexes, male and female, helped to obtain information from different gender perspectives and experiences of the household heads.

Table 2. Sex of respondents household

		Frequency	Percent
Valid	Male	109	64.1
	Female	61	35.9
	Total	170	100.0

Table 2 above indicates that among the 170 sampled households, 64.1% were male-headed and 35.9% were female-headed, ensuring gender representation in the dataset.

Education of household respondents

Table 3. Educational Status of Households

Level of education	Frequency	Percent
Non formal education	50	29.4
1-4	75	44.1
5-8	27	15.9
9-10	10	5.9
11-12	8	4.7
Total	170	100.0

According to Table 3, the percentage of respondents who were illiterate was 29.4%, for grades 1–4 it was 44.1%, for grades 5–8 it was 15.9%, for grades 9–10 it was 5.9%, and for grades 11–12 it was 4.7%. Education enhances households' understanding of new technologies like IMPMCS, improves decision-making, and facilitates acceptance of interventions to optimize livelihood and environmental outcomes.

Family size respondent household

Table 4. Total family members of respondent households

Family member	frequency	Percentage
3	9	5.3
4	8	4.7
5	31	18.2
6	28	16.5
7	28	16.5
8	28	16.5
9	18	10.6
10	15	8.8
11	5	2.94
Total	170	100

Table 4 shows that respondents' minimum, maximum, and average family sizes were 3, 11, and 7, respectively, which is higher than the national average of 5 persons per household (CSA, 2021). A larger family size may influence fuel wood consumption patterns and stove adoption.

Comparison of IMPMCS and TCS Fuel Wood Consumption

Fuel wood consumed by users of the IMPMCS cook stove

The purpose of the survey was to gather data from IMPMCS customers regarding the quantity of fuel wood that each home uses on a weekly basis for improved multipurpose stoves.

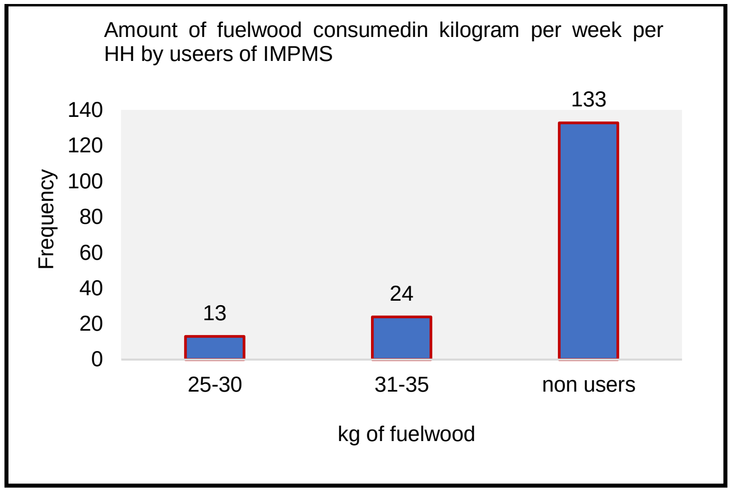

Figure 2. Amount of fuelwood consumed by IMPMCS

Figure 2 illustrates that weekly fuelwood consumption by households using IMPMCS ranged from 25 to 35 kg. Approximately 13 respondents consumed 25–30 kg, while 24 respondents used 31–35 kg per week. This reduction demonstrates improved fuel efficiency and potential for economic and environmental benefits.

Fuel wood consumed by users of the traditional cook stove

In order to gather data for the study's objectives regarding the amount of wood that traditional open-fire cook stoves in each household utilize each week, the survey question also asked respondents who were TCS users.

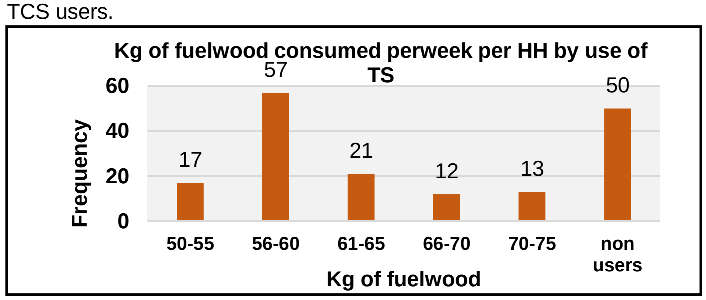

Figure 3. Amount of fuelwood consumed by the traditional cook stove

As illustrated in Figure 3, the average weekly fuel wood consumption per family among 120 users of traditional cook stoves ranged from 50 to 75 kg. While 57 respondents verified that 56–60 kg of fuel wood was consumed weekly per family, 17 respondents confirmed that 50–55 kg of fuel wood was consumed weekly per household. In contrast, 61–65 kg of fuel wood per week per family was proposed by 21 respondents, while 12 respondents confirmed 66–70 kg of fuel wood consumption. Nonetheless, 13 respondents stated that each home uses 70–75 kg of firewood every week. When compared to a regular three-stone stove, the upgraded stove's fuel wood consumption dropped dramatically. Given that the trial used less fuel wood than a typical stove, it was consistent with AEPC (2012).

The results of the household survey, which are shown in Figures 2 and 3, as well as those from field research, focus groups, and key informant interviews, show that households using enhanced multipurpose mud stoves and conventional three-stone stoves utilize different amounts of fuel wood. A random measurement from an adult woman's back caring was done to determine the weight of fuel wood caring capability per person. One adult woman's back caring equaled 25 kg on average (the highest being 30 kg and the lowest being 20 kg).

Traditional stoves that use solid fuels for cooking and heating produce large amounts of pollutants that are harmful to human health, including carbon monoxide and particulates (Eshetu, 2014). According to the author's findings, conventional cook stoves use fuel wood inefficiently and release a lot of particulate matter into the air.

Simple excremental test

The results of the simple excremental test, which are displayed in Table 4.4, showed that the use of IMPMCS significantly reduced the amount of fuelwood consumption per household per week when compared to TCS. The average amount of fuelwood used per week by 10 households using IMPMCS was 30.7 kg, while the same households using TCS used 65.5 kg. Therefore, the difference between the uses of both stoves was 34.8 kg, or 34.8 kg of fuelwood saved as a result of using IMPMCS per household each week. It is also evident that the amount of carbon dioxide emissions decreased by that amount.

Table 4. Fuel-wood consumption efficiency of IMPMCS compared to TCS of sampled Households for the simple excremental test

S/N	Household code	fuelwood consumed by TCS per hh/week	carbon dioxide emitted by TCS in tj per hh per week	fuelwood consumed by IMPMCS per hh /week	carbon dioxide emitted by IMPMCS in tj per hh week	amount of fuelwood saved per hh per week by use of IMPMCS	co2 emission reduced per hh per week by use of IMPMCS in tj
1	01	54	85.1796	28	44.1672	26	41.0124
2	02	69	108.8406	33	52.0542	36	56.7864
3	03	58	91.4892	27	42.5898	31	48.8994
4	04	62	97.7988	32	50.4768	30	47.322
5	05	75	118.305	34	53.6316	41	64.6734
6	06	71	111.9954	31	48.8994	40	63.096
7	07	72	113.5728	35	55.209	37	58.3638
8	08	67	105.6858	31	48.8994	36	56.7864
9	09	65	102.531	29	45.7446	36	56.7864
10	10	62	97.7988	27	42.5898	35	55.209
	Total	655	1033.197	307	484.2618	348	548.9352
	AVER	65.5	103.3197	30.7	48.42618	34.8	54.89352

Fuel wood saved by the use of IMPMCS

The quantity of fuel wood saved as a result of the upgraded stove was the difference in fuel consumption between the use of an improved multipurpose mud cook stove and a traditional cook stove, which decreased the weekly fuelwood consumption per household.

Table 5. Average tone of fuel wood saved per household by use of IMPMCS

Fuel wood saved per HH per week	Fuel wood saved Per HH per month	Fuel wood saved per HH year
0.0348 ton	0.1491 ton	1.7892ton

The results of a straightforward experimental test, in addition to the household survey, support the findings shown in Table 5. When using an upgraded multipurpose mud cook stove, households used 30.7 kg of fuel wood per week as opposed to an average of 65.5 kg when using a traditional cook stove. The study's findings showed that there was an average annual difference of 34.8 kg in fuelwood saved per household when using an enhanced multipurpose mud cook stove compared to TCS.

Benchmarks for TCS and IMPMCS users were established by triangulating the survey data with the data gathered from direct measurements in a straightforward experimental test. This was done in order to calculate the average weight of fuel wood used by both stoves to determine the weekly, monthly, and annual fuel wood consumption per home. When opposed to the utilization of TCS, IMPMCS provides significant advantages for the entire society. These advantages range from lessening the need for biomass fuelwood and enhancing household economic and health outcomes to promoting forest conservation and lowering greenhouse gas (GHG) emissions (Bailis *et al*., 2007; Bensch and Peters, 2015). The authors' findings are consistent with the study's findings, which show that households using IMPMCS consume substantially less fuelwood than those using TCS.

Average Carbon Dioxide Emission

Fuelwood gathering and consumption are intimately tied to carbon dioxide emissions since both processes have an impact on the amount of carbon released into the atmosphere. Lower carbon emissions demonstrate the stove's contribution to climate change mitigation, improved indoor and outdoor air quality, and public health benefits.

Table 6. Average tCO_2e Emission Reduced per household by IMPMCS

Emission reduced/HH/week	Emission reduced/HH/month	Emission reduced/HH/year
0.05489 tCO_2e	0.2352CO_2e	2.8224 tCO_2e

Using the IPCC 2006 technique, the carbon dioxide emission was calculated from the carbon balance between the enhanced multipurpose mud stove and the traditional three-stone stove. The computation, which follows the formula, is based on emission factors, carbon storage in forests, and IPCC default net calorific values. E = FWS× fNRB, × NCV× EF IPCC (2006).

E= 34.8 kg or 0.0348 ton (0.0348t x0.88x0.015x119.5) = 0.05489 tCO_2 e

Based on the fuel wood consumption data from the basic experimental test that is displayed in Table 1, IMPMCS reduced CO2 emissions by 0.05489 tCO2e per household per week. Therefore, lower carbon dioxide emissions enhance both the interior and outdoor environments in the kitchen. There is less pollution to the environment, both macro and micro, because of the lower and less hazardous emissions. Table 6 illustrates how the usage of IMPMCS, as opposed to TCS, decreased 2.82tCO2e emissions per family annually by extrapolating week to month and year. Better cooking stoves could lessen the negative impact of indoor air pollution caused by outdated, ineffective biomass cook stoves (WHO, 2010). The study's findings are consistent with the evaluation that using IMPMCS instead of TCS reduces carbon dioxide emissions

Correlation and Regression Analysis

The strength and link between the dependent and independent variables: carbon dioxide emission, fuel wood consumption, and time spent collecting fuel wood were assessed using bivariate/persons' correlation analysis.

Table 7. Correlation analysis

Correlations		
	ACEPHHPW	AFCPHHPW
ACEPHHPW	1	
AFCPHHPW	1.000**	1
**. Correlation is significant at the 0.01 level (2-tailed).		

The correlation coefficient between the average fuel wood consumption per household per week (r-value; AFCPHHPW) = 1 and the average carbon dioxide emission per home per week (AFCPHHPW) has a positive perfect relation with a probability value of P = 0.000, as shown in Table 7. above.

Table 8. Regression analysis

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.857[a]	.735	.659	4.698
a. Predictors: (Constant), ATFCPHHPW, AFCPHHPW				

Table 8 shows multiple correlation coefficient measurements demonstrate the high and positive association between fuel wood use and carbon dioxide emissions. Regression analysis ($R = 0.857$, $R^2 = 0.735$) confirms that 73.5% of the variation in carbon emissions is explained by fuel wood consumption and time spent collecting fuel wood, highlighting the importance of efficient stoves for environmental and health improvements.

Types of Stoves Utilized by Households

Three different types of stoves were noted in the study region based on household surveys and information acquired using various techniques indicated in Figure 2. Households use three different types of stoves: the upgraded multipurpose mud stove, the *mirti* stove, and the traditional three-stone open fire.

Table 9. Types of biomass stoves utilized by households in the study area.

		Frequency	Percent
Valid	MPMCS	37	21.8
	Mirt stove	13	7.6
	TCS	120	70.6
	Total	170	100.0

According to Table 4.9's results, the majority of households still use the traditional three-stone stove (70.6%), followed by the upgraded multipurpose stove (21.8%) and the Mirti stove (7.6%). Data from the relevant Kebeles Agricultural Extension Workers Office indicates that the demand for using the improved multipurpose mud cook stove is directly influenced by the raising of awareness by relevant bodies. Despite this, the improved stove's level of dissemination is low in relation to its urgent importance, and the study area's rate of improved multipurpose mud cook stove construction and use has been slowly increasing over time.

Figure 4. Traditional three-stone backing, Cooking, and boiling stoves

Cooking is done traditionally on a three-stone, Stones of a height of 12 to 15 cm were employed, as seen in Figure 2. With just three appropriate stones that must all be the same height to support a cooking pot over a fire, it is the least expensive stove to make. The stoves were divided into three sections, each with a distinct function for boiling, cooking, and preparing food.

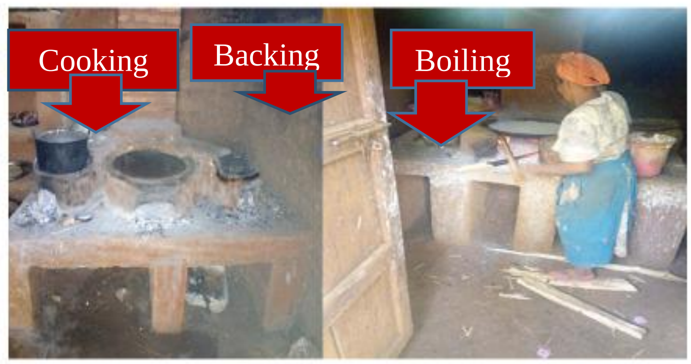

Figure 5. Improved multipurpose mud biomass cook stove.

The stove tested in homes, known as the Multipurpose Mud Stove (Figure 3), is used for baking, cooking, and boiling. Constructed above ground from mud bricks and straw with an integrated chimney, it has three burning chambers: one for baking Injera and two for cooking other dishes like wot. The stove sits on a 180 cm × 150 cm smoke-free mud bed, 70 cm above the ground. The three stoves on the bed are connected by channels that allow smoke to burn fully before exiting through the chimney. The Injera stove is cylindrical, 25 cm tall and 60 cm in diameter, matching the mitad. The main stove is 40 cm in diameter and 23 cm high, while the secondary stove is 25 cm in diameter and 21 cm high. The chimney, built from mud bricks, reaches 150 cm, and each brick has a 16 cm × 14 cm central hole, made using two different molds.

CONCLUSION

In this study, the performance of the "Bilise" improved biomass cook stove was evaluated with respect to its effectiveness in reducing household fuel wood consumption and associated carbon dioxide emissions in Aira District, Western Wallaga Zone, Oromia, Ethiopia. The results indicate that, relative to the traditional three-stone open fire commonly used in the study area, the improved multipurpose mud cook stove (IMPMCS) "Bilise," constructed using locally available materials, substantially decreases both fuel wood demand and CO_2 emissions. On average, the IMPMCS reduced annual household fuel wood consumption by 1.78 tons compared to the traditional cook stove (TCS). Correspondingly, the IMPMCS lowered annual household CO_2 emissions by an estimated 2.82 tons of CO_2e relative to the TCS. In general, the study concludes that promoting the adoption of the IMPMCS can enhance household energy efficiency, support the sustainable use of solid biomass resources, reduce indoor and outdoor air pollution, and contribute to broader climate-change mitigation efforts.

Data availability

All findings are presented within the article, and the raw data will be made available upon reasonable request to the corresponding author.

Competing interests

The authors declare that they have no conflict of interest.

REFERENCES

Alzate-Sanchez, D. M., & Ladino-Orjuela, G. (2019). Evaluating the effect of improved cook stoves on indoor air pollution and other social and economic outcomes in rural areas: A systematic review. *Renewable and Sustainable Energy Reviews, 115*, 109404. https://doi.org/10.1016/j.rser.2019.109404

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional wood fuels. *Nature Climate Change, 5*, 266–272. https://doi.org/10.1038/nclimate2491

Bailis, R., & Liao, F. (2010). The promise and challenge of improving cook stove performance. *Journal of Industrial Ecology, 14*(5), 620–623. https://doi.org/10.1111/j.1530-9290.2010.00278.x

Beltramo, T., Blalock, G., Harrell, S., Levine, D. I., & Simons, A. M. (2019). The effects of fuel-efficient cookstoves on fuel use, particulate matter, and cooking practices: Results from a randomized trial in rural Uganda. *CEGA Working Paper Series No. 85*. Center for Effective Global Action. https://escholarship.org/uc/cega_wps/WPS-85.pdf eScholarship+1

Bonjour, S., Adair-Rohani, H., Wolf, J., et al. (2013). Solid fuel use for household cooking: Country and regional estimates for 1980–2010. *Environmental Health Perspectives, 121*(7), 784–790. https://doi.org/10.1289/ehp.1205987

Carlton, C. A., Roberts-Gray, C., Shiner, B., & Larson, M. J. (2013). Key informant perspectives on policy and practice changes to improve co-occurring traumatic brain injury and mental health. *American Journal of Psychiatric Rehabilitation, 16*(1), 16–38. https://doi.org/10.1080/15487768.2013.770367

Global Alliance for Clean Cookstoves. (n.d.). What is an improved cook stove? Retrieved from https://www.cleancookstoves.org/focus-areas/technology/what-is-an-improved-cookstove.html

Grieshop, A. P., Marshall, J. D., & Kandlikar, M. (2011). Health and climate benefits of improved cook stove technologies. *Environmental Science & Technology, 45*(17), 7585–7592. https://doi.org/10.1021/es201518u

Johnson, B., & Christensen, L. (2014). *Educational research: Quantitative, qualitative, and mixed approaches* (5th ed.). SAGE Publications.

Kothari, C. R. (2004). *Research methodology: Methods and techniques* (2nd ed.). New Age International.

Oliver, H., & Unger, D. (2001). The role of “key informants” in community-based participatory research: A case study example. *Journal of Public Health Management and Practice, 7*(2), 57–62. https://doi.org/10.1097/00124784-200103000-00012

Petach, H., Dalenberg, D., Berrueta, V., et al. (2019). The adoption of clean fuels and cook stoves: Evidence from cooking schools in urban Burkina Faso. *Energy Policy, 129*, 1394–1404. https://doi.org/10.1016/j.enpol.2019.03.059

Resources for the Future. (2014). *The welfare impacts of rural electrification and climate mitigation in Ethiopia: A DREAM-W model literature review.* Retrieved from https://www.rff.org/publications/working-papers/the-welfare-impacts-of-rural-electrification-and-climate-mitigation-in-ethiopia-a-dream-w-model-literature-review/

Smith, K. R., & Sagar, A. (2014). Making the clean available: Escaping India’s chulha trap. *Energy Policy, 75*, 410–414. https://doi.org/10.1016/j.enpol.2014.10.016

The Global Alliance for Clean Cookstoves. (2014). *What is an improved cook stove?* Retrieved from https://www.cleancookstoves.org/focus-areas/technology/what-is-an-improved-cookstove.html

United Nations Environment Programme (UNEP). (2018). *Sustainable biomass fuel and improved cook stoves: Good practice guidelines.* Retrieved from https://wedocs.unep.org/xmlui/handle/20.500.11822/25324/Guide%20-%20Sustainable%20Biomass%20Fuel%20and%20Improved%20Cookstoves_English.pdf

World Bank. (2014). *Improved cook stoves: The benefits, costs and environmental impacts of clean cooking options.* Retrieved from https://openknowledge.worldbank.org/handle/10986/19082

World Health Organization. (2005). *WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide: Global update 2005.* World Health Organization.

World Health Organization. (2010). *A conceptual framework for action on the social determinants of health.* World Health Organization.

World Health Organization. (2018). *Household air pollution and health.* Retrieved from https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

Yamane, T. (1973). *Statistics: An introductory analysis* (3rd ed.). Harper and Row