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Comparison of kitchen performance test on firewood consumption and emission of improved mirt and traditional three stone open cook stoves in Amaya, and Bure districts of Ethiopia

Miftah Fekadu✉, **Zenebe Mekonnen**, **Muse Tesfaye**

Central Ethiopia Environment and Forest Research Center, P.O. Box: 33042, Addis Ababa, Ethiopia

✉**Author for communication:**
E-mail: mfkedir@gmail.com; Tel. +251911574736

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ABSTRACT

Firewood biomass has been the main source of energy for cooking in Ethiopia. Such biomass is used in inefficient traditional open three stone/ point stoves that created wastage of wood. Although improved stoves were distributed since 1980s to improve the efficiency of the traditional open three stone stoves, a number of households still use traditional open three stone stoves. National Improved Cook Stoves Program was designed to distribute 34.2 million improved stoves up to the year 2030. The production of improved cooking stoves has been growing over time by different organizations. Then cookstove testing was crucial because we

can't know what problem exists without testing. The objective of the present study was to test kitchen performance on fire wood consumption of distributed stoves called "mirt" improved "*injera*" baking stoves. *Injera* is a traditional staple food in many parts Ethiopia made from Teff plant (*Eragrotistef*). The study was conducted in two districts, Bure, and Ameya of Ethiopia, in 100 households each. Locally dried firewood used during baking was weighed directly after measuring the moisture content of the wood. Then the amount of wood consumption was compared between mirtand open three stone stoves and the opinion of local people was interviewed about the improved stoves. Quantitative data was analyzed by SPSS and excel software. In the districts studied, women using improved *mirt* stove protected their hands from fire burns. Mirtstove reduced wood consumption, enduse emission and deforestation by 37.4% in Bure and 42% in Ameya. The efficiency was lower than other mirt stoves elsewhere because of size unfitness of plates with stoves. Therefore, awareness creation should be made on management of improved mirtstoves and linking of mirt stove and plate manufacturers.

Key words: household, plate, session, wood consumption, wood moisture, sustainability, climate change

1. INTRODUCTION

Solid biomass has been the main source of energy for cooking in Ethiopia in 2020s. The efficiency of traditional three-point openfire stoves (three stone open fire) are very low and create wastage of energy. Then improved solid biomass stoves were developed in 1980s to improve the efficiency of the traditional open three-point stoves (Peters-Stanley and Yin, 2013). Enhancing cook stoves fuel efficiency reduces the amount of fuel required and can lessen the amount of time and the cost spent for gathering biomass fuel, and reduce the strain on the environment as a result of fuel consumption. Rural households in Ethiopia consumed over 86% of the biomass fuel of the country in 2004-2009. The household firewood consumption in Ethiopia has doubled from $41.3*10^6$ m^3 in 1990 to $82.1*10^6$ m^3 in 2017 (Geissler et al., 2013). Then Ethiopia shared 4.7% of the world firewood consumption and ranked fourth in the world and second in Africa. Since this is a critical issue of development concern, the green economy strategy toward sustainable forestry and reduce firewood demand has focused partly on the dissemination and usage of fuel-efficient stoves, called improved stoves like mirt stoves (CRGE, 2011).

A national improved cook stoves program (NICSP) of Ethiopian government was designed to support the implementation of 34.2 million improved cook stove distribution up to2030. In the growth and transformation plan I (GTP I) (2010-2015) about 9million and in GTP II (2015-2020) about 11.45million improved stoves were planned to be distributed (CRGE, 2011). In 50 administrative counties (woredas) of Ethiopia, Barr foundation assisted the distribution of improved stoves of Mirt 17,6305 since 2013 for baking Ethiopia tradition flat bread called "*injera*". *Injera* is fermented flat bread produced from crops like "*Teff*", (*Eragrotistef*(Zucc.) Trotter.), "maize" (*Zea mays* L.), wheat (*Triticumaestivum* L.) or barely (*Hordeumvulgare* L.). The desire for improved cooking stoves across the community has been growing over time. So different non-government organizations (NGOs), and entrepreneurs entered in to the market of cook stove manufacturing, promotion and distribution in order to attract a larger population to the product. Then cookstove kitchen performance testing (KPT) is crucial for the cooking sector in order to identify the existing problems in the stoves and their wood consumption efficiency. Testing cook stove makes a trustworthy, consumer loyalty to the products, great public image,and a fair market share,etc. KPT is designed to assess actual impacts on household fuel consumption, in real world of settings of cook stoves because the whole fuel consumption is measured directly. There are two methods of KPT, the first is longitudinal type that monitors kitchen performance of improved stove and its experimental control of tradition open stoves on the same family. The second is cross sectional type that monitors kitchen performance of the two types of stoves on different families (Ochieng et al., 2013). Both types of methods are comparable using the adult equivalent factor conversion of household members. The objective of the present study was to assess the kitchen performance test of wood consumption of improved "Mirt" cook stoves in comparison with traditional open three point stoves in two districts (woredas), Bure and Ameya of Ethiopia namely.

2. MATERIAL AND METHODS

2.1. Description of the study areas

The study was conducted in two districts, one from North eastern Ethiopia, Amahra region and the other from Central Ethiopia, Oromia region named Bure district and Amaya district with geographic and agroecological description given in Table 1.

2.2. Description of improved and traditional cook stoves

The improved stove called Mirtstove (Figure 1) had specific materials and dimensions as designed in Ministry of water and energy of Ethiopia and GIZ in 2011 (GIZ ECO, 2011). It is produced with mortar using a mixture of river sand with cement. It serves for more

than five years. It has six parts that are joined together, four parts fit to make a cylindrically shaped enclosure and two other parts joined one on top of the other and are fitted with the cylindrical enclosure from behind. The two parts serve as smoke outlet and rest for the cooking pot. The stoves were classic and slim Mirt stove type with wall thicknesses 4-6cm, weight 45- 65kg, diameter 64-70cm, height 22-24cm, fuel/air inlet 24cmx11cm, and smoke outlet 19cmx7cm. For rear parts width is32cm wide, depth 26cm deep and height 35cm (Figure 1), that could be made from stone or clay. The traditional stoves were three point open stoves (Figure 1). In both types of stoves, the plates used were similar and made locally from clay soil.

Table 1. Geographic and agroecological description of Bure and Ameya districts.

No.	Region	woreda	Ppt.(mm)	Temp. (°C)	Location		
					N	E	Altitude
1.	Amhara	Bure	1750	17-27	10°42'15''	37°03'33''	700–2750
2.	Oromia	Ameya	1310	12-32	8°35'25''	37°44'59''	1946-2026

Figure 1: *Mirt* stove (left) and three-point open stove (right).

2.3. Methods of data collection

In both Ameya and Bure woredas, one hundred households each who have improved *Mirt*stoves and open three point stoves were purposely selected for the assessments of KPT. Household refers to group of people that live together and share the food prepared in the house.

Data collectors, called enumerators, who were graduated from universities in forestry and related field were selected from the woreda. The enumerators were trained on how to make household interview, how to measure moisture content and weight of wood during each baking session. Then households were interviewed to give the general overview of the perception on the use of improved Mirtcook stoves, the management, advantages and disadvantages of the stoves in the households using pretested questionnaire. In the next step, kitchen was observed by the field assessment crew and firewood was supplied to the selected households that was sufficient to prepare three rounds of *injera* baking in improved *Mirt*and three rounds in traditional open three point stoves. The baking was done in two days' interval in day1, day4, and day7. Despite the variation in the frequency of baking *injera* for household consumption in the districts, an agreement was made with households to bake *injera* for three days, so that the amount of wood consumption was measured every three days after supplying sufficient amount of wood for nine days. Actually, households in rural towns use crop residues, leaves and other types of solid biomass for baking and cooking. However, the present study dealt only the consumption of wood of *Eucalyptus camaldulensis* at the moisture content registered during baking *injera*. Just before each baking day, moisture content and weight of locally well dried wood to be consumed was measured with moisture meter (dry weight %), and balance (0.1kg), respectively. The remaining wood after baking was also measured. For moisture content, three pieces of wood samples were taken randomly and measured using moisture meter at the top, middle and bottom parts. The adult equivalent for households was also calculated for each baking day. Then constant values for household members in gender and age

was converted to adult equivalent as child with age 0-14 years 0.5; female over 14 years 0.8; male with 15-59years 1; and male over 59years' age 0.8. The calorific value of the common woody species used was considered as 18MJ kg^{-1} (Shell Foundation, 1984).

2.4. Data analyses

An excel software developed by Shell foundation (1984) was used to calculate the sessional fuel and energy consumption by a household. Independent sample t-test was used to compare the consumption rate of wood and energy when households were using improved cook stove and traditional ones. Analysis of variance (ANOVA) was used to determine whether there is significant difference in the consumption of wood and energy by using the two different cook stoves. Qualitative social data on the perception of households about ICS were analyzed by SPSS software and descriptive results were produced for interpretation and description.

Improved mirt stoves in reducing deforestation

The deforestation caused by open three point stove was compared with the improved Mirtstoves in the studied districts using the woody biomass stock density of 85.5 tones ha^{-1} (Moges *et al.,* 2010)(Equation 1) modified from Chidumayo and Gumbo (2013).

$$\mathbf{Defo\ (ha)} = \frac{\mathbf{Annual\ solid\ biomass\ required\ (Tone/year)}}{\mathbf{Stock\ density\ (ton/ha)}} \quad \textbf{Equation 1}$$

Where: - Defo (ha) is deforestation in hectare/year; Stock density (tone/ha) is the stocking of the forest or woodland in ton/ha.

3. RESULTS

3.1. Household members using different cook stoves

The household survey showed that the selected households for the KPT study were closely similar in Bure and Ameya districts about 4.7(Table 2).

Table 2: Members of households in Bure and Ameya woredas.

Woreda (number of households)	Number of residents by age category (Mean ± Std.er.)					Mean adult equivalent
	Children 0-14	Women 14+	Men 15-59	Men 59+	Total	
Bure (n=100)	1.5±0.1	1.7±0.1	1.4±0.1	0.2±0.1	4.7±0.2	3.7
Ameya (n=100)	1.9±0.1	1.5±0.1	1.3±0.1	0.1±0.1	4.8±0.2	3.5

3.2. The perception of households towards using Mirtinjera baking stoves

In the studied woredas, women using improved *Mirt*stove responded that the stove shortened the time to prepare meals, improved the health condition of a household by reducing smoke particulate matter and protected their hands from fire burns and also saved firewood. About 16%, and 27% of the interviewed households, in Bure, and Ameya, respectively, responded as the improved stoves reduce fire burn (Table 3). However, they perceived some drawbacks in using the improved *Mirt*stoves such as the size unfitness of plates with improved stoves, longer time taken to set and start up fire (absence of air holes to allow air for fast combustion of the fuel), the stove did not heat room in cold seasons, blocked light for visibility in rooms and lack of smoke outlet or chimney.

Table 3: Improved cookstove perception as responded '**yes'** by thehouseholds.

Questions about improved Mirt stove	Responses	Households in selected woreda (%)	
		Bure (n=100)	Ameya (n=100)
Taking longer time to set fire inside the stove	Yes	100	100
Do meals take shorter time to prepare using the new stove?	Yes	100	100
What do you like most about the stoves?	efficiency in time saving	6	8
	fire protection	1	1
	smoke protection	1	3
	efficiency in wood saving, --fire and smoke protection	17	2
	wood saving	12	16

	smoke protection and wood saving	13	32
	efficiency in time & wood saving	43	38
	fire protection and wood saving	7	0
The stove causes burns	Yes	16	27
The pots are not stable	Yes	22	4
The pots and plates do not fit	Yes	23	1
Fire turns pots black	Yes	58	43
Stove takes long to get hot	Yes	41	9
Fire inside the stove is hard to start	Yes	32	7
Cannot fit preferred size of fuel	Yes	23	11
Stove does not heat the room in cold seasons	Yes	4	60
Stove does not provide light	Yes	3	48
Stove breaks easily	Yes	4	9
Stove needs a lot of maintenance	Yes	19	3
Satisfaction in the use of the improved cook stove	Neutral	1	1
in respect to efficiency and design	Satisfied	24	50
	Highly satisfied	75	49
Is there an improvement in your health condition by using improved stove?	Yes	69	71
The stove is warm to touch	Yes	57	34
There are ashes inside	Yes	54	43
There are soot around the fuel chamber	Yes	81	42
There cracks in the stove	Yes	28	16

3.3. Management of improved injera baking stoves

The overall management and maintenance of improved stoves that include cleaning, and repairing the stoves were dependent on the experience of households. Some of the problems observed and defects recognized in the improved stoves were created by the absence of the frequent maintenance and improper placement of the improved stoves (Table 4). The women interviewed were cleaning ashes from improved stove at different intervals, for example 23% of the respondents in Bure, and 68% in Ameya had done it in a weekly basis (Table 4). In Bure, and Ameya woreda about 23%, and 17% households, respectively clean the stoves ash daily. The damages to the stove were created by the placement of the stove and the length of fire wood used, most of which responded that two arms near to 1m was used during baking.

The improved *Mirt*stoves were used not only for baking *injera* for households' consumption but also for preparing feed for livestocks and for commercial purposes. As can be seen in Table 4, about 70%, and 17%households in Bure, and Ameya, respectively use the improved stoves for preparing food/drink for commercial sale. However, 4%, and 80%households in Bure, and Ameya woreda, respectively were using the improved stoves solely for household baking for about one year. The local people in both districts were observed in usingclay pot, clay plate, iron plate, and iron potfor baking and cooking.

The majority of the respondents91%, and 89% in Bure, and Ameya, respectively were using their improved stoves for several times per week (two tosix days) for baking *injera*. About 95% in Bure, and 52% in Ameya had installed the cook stove on elevated bed and the remaining on earth floor (Table 4) with 93%, and 97%of the households placed the stoves in separate kitchen, respectively.

Table 4: Management options of improved mirtstoves by percent of households

Questions	Response	Household frequency	
		Bure (n=100)	Ameya (n=100)
How often does the family use the stove (days)?	every day	5	10
	several times a week (2-6days)	91	89
	one time per week	4	0

	every fifteen days	0	1
Stove installation	elevated bed	95	52
	earth floor	5	48
Cleaning stove ashes	never	10	5
	daily	23	17
	weekly	54	68
	monthly	13	10
Repairing cracks	never	51	80
	daily	4	0
	weekly	5	1
	monthly	40	19
Other maintenance tasks	never	73	100
	daily	2	0
	weekly	11	0
	monthly	14	0
Stove used for any purpose other than cooking food for the family	preparing food for livestock	24	3
	preparing food/drink for commercial sale	70	17
	used for other purpose	2	0
	no other purpose	4	80
Where is the stove placed?	inside main house	1	2
	inside separate kitchen	93	97
	outside	6	1
The length of firewood used	less than one arm	9	10
	one arm	20	55
	two arms	59	34
	more than two arms	12	1
How long has the family been using this stove?	1-2years	99	18
	2-4 years	1	82

3.4. Wood consumption in cook stoves during baking

The wood consumption in baking *injera* varies with households' number of residents (Table 5). The wood consumption was strongly correlated (97.7%) with the household size at given moisture content of wood (Table 5).

Table 5. Correlation of wood consumption and size of adult equivalent

		Average sessional wood use (kg) in a household	Average wood per capita (kg/person)
Household adult equivalent	Correlation	0.102	0.977
	Significance (2-tailed)	0.042	0

A household was observed to use a maximum of 31.4kg per session in Bure woreda and a minimum of 2.2kg per session in Ameya in open three point stove and Mirt, respectively. The improved *injera* baking *Mirt* stoves had saved wood by 37.4% and 42% as compared with the three-point open stoves in Bure and Ameya, respectively (Table 6).

The one-way analysis of variance (ANOVA) showed highly significant difference ($p < 0.001$) between improved mirt and open three point stove both in sessional firewood and energy used by household for baking *injera* (Table 7).

3.5. Per capita wood consumption during baking injera

The per capita firewood consumption of different household naturally varies with the type of food item cooked or baked. On average, the highest wood consumption was observed in Bure woreda traditional open stoves and Mirt improved than Ameya woreda (Figure 1).

Table 6: Wood consumption of improved stoves compared to three point open stoves in baking *injera*

Woreda	Wood and energy consumption by household per session	Mean±Std.er.	Min.	Max.
Bure	Wood used (kg)-in *Mirt* stove (n=100)	8.2±0.3	3.6	21.2
	Wood used (kg) -open stove (n=100)	13.1±0.5	6.8	31.4
	Energy used (MJ)-*Mirt* stove (n=100)	150.3±4.9	66.0	390.0
	Energy used (MJ) -open stove (n=100)	243.9±9.3	126.0	582.0
Ameya	Wood used (kg)-in *Mirt* stove (n=100)	6.1±0.2	2.2	14.0
	Wood used (kg) -open stove (n=100)	10.5±0.4	4.7	30.7
	Energy used (MJ)-*Mirt* stove (n=100)	113.6±3.9	42.0	258.0
	Energy used (MJ) -open stove (n=100)	197.2±7.6	90.0	564.0

Table 7: ANOVA for improved cook stoves performance in wood consumption

Woreda	Average values used per household	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Bure	Sessional wood use(kg)	Between Groups	1,239.6	1	1239.6	77.0	0.000
		Within Groups	3,187.9	198	16.1		
		Total	4,427.5	199			
	Sessional energy use (MJ)	Between Groups	438,553.6	1	438553.6	80.4	0.000
		Within Groups	107,9531.7	198	5452.2		
		Total	1,518,085.3	199			
Ameya	Sessional wood use(kg)	Between Groups	995.0	1	995.0	93.5	0.000
		Within Groups	2,107.0	198	10.6		
		Total	3,102.0	199			
	Sessional energy use (MJ)	Between Groups	349,782.5	1	349782.5	95.8	0.000
		Within Groups	723,334.1	198	3653.2		
		Total	1,073,116.6	199			

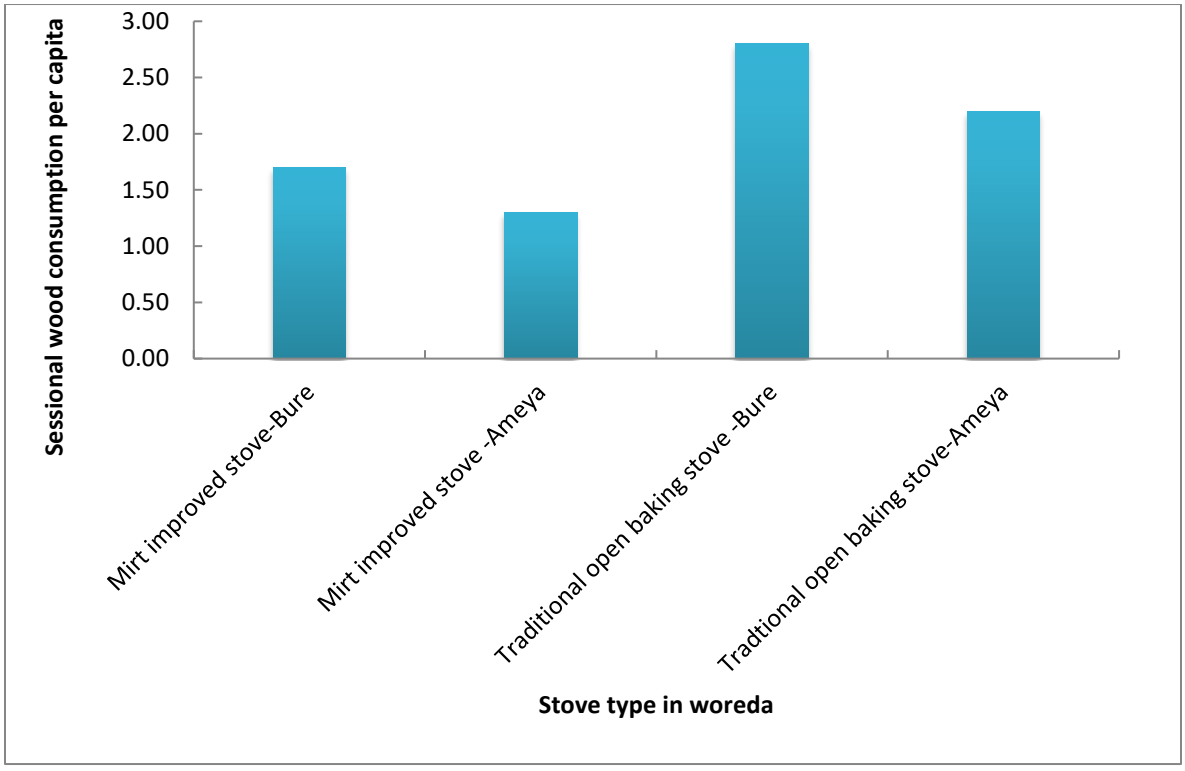

Figure 1: Wood consumption per capita in mirt stoves and traditional three point open stoves.

3.6. Carbon dioxide emission reduction potential of Mirt baking stoves

Improved mirtstoves reduce the amount of wood consumption by reducing the amount of energy loss. The use of improved Mirtstoves in using firewood for baking *injera* emitted 1.37- 1.84 tonCO_2 but the three point open stoves emitted 2.35-2.93 ton CO_2 per household which is statistically different at P<0.001. Such improved baking stoves reduced end uses emission from 37-42% of the carbon dioxide that is created by three point open stoves (Table 7).

Table 7: Carbon emission of improved mirtand traditional three point open baking stoves.

Woreda	Type of stoves	Total amount of CO_2 emission per household (kg)	Emission reduction of Mirt improved stoves (%)
Bure	*Mirt* improved stove	1,835.73	37.4
	Three point open stove	2,932.70	
Ameya	*Mirt* improved stove	1,365.61	41.9
	Three point open stove	2,350.64	

3.7. Forest saving potential of improved mirtstoves

The amount of annual wood consumption in Mirt stoves was 0.7-1.0 tone as compared to the 1.2-1.6tone in open three point stove, then about 11.7 ha forest or wood land is deforested in comparison to 18.7ha by using open three point stoves in each household (Table 8). Such improved baking stoves reduced deforestation from 37-42% of that created by three point open stoves (Table 8).

Table 8. Firewood consumption in improved Mirt stoves and open stoves

Woreda	**Type of stoves**	**Annual wood consumption in baking *injera* per household (kg)**	**Forest area deforested (ha)**	**Deforested area reduction in percent**
Bure	*Mirt* improved stove	1000.4	11.7	37
	Three point open stove	1598.2	18.7	
Ameya	*Mirt* improved stove	744.2	8.7	42
	Three point open stove	1281	15.0	

4. DISCUSSION

The perception of households towards using Mirt *injera* baking stoves was mostly positive and showed great interests to expand to different households. As observed in Table 3, about 75% of the respondents in Bure and 49% in Ameya woreda were highly satisfied in using improved Mirt stoves. The draw backs perceived in improved stove utilization is attributed to the lack of training on how to use the stoves. For example, the greater time responded to be taken in fire setting (Table 3) could be solved by setting fire outside the stove and then putting the fire inside the stove. Similarly, the blockage in lighting room during baking in closed improved stoves could be solved by additional light sources like solar light. However, the lack of smoke outlet called chimney was a general problem which was totally lacked in the observed improved mirtstoves. Therefore, the present study is in line with other studies stating the problems with improved stove such as lack of appropriate size of plate, lack of preparing appropriate size of firewood that can be inserted to improved stoves, lack of separate kitchen, cost of stoves, lack of awareness creation training and lack of proper follow up (Miftah et al., 2017; Kedir et al., 2019). Other studies made by Tamire et al. (2018) stated the need for Health education at community level on improved stove cooking behavior.

In the management aspect of ICS the removal of ash was very common. However, repairing crack was rare as never done in 51% of the respondents in Bure and in 80% of Ameya respondents. This showed lack of interest in repairing of ICS which is also true in ICS study in Peru as the need for repairing reduced the interest in ICS (Keese et al., 2017). Other maintenance tasks including painting to make the ICS attractive were almost negligible as shown in Table 4. The short time since the families started using ICS about 4 years' maximum could limit to develop repairing experience of ICS. In installing the ICS, elevated bed and earth floor were common but entire installation on the elevated bed was better to make easier fire setting but not done by some households. Then it is an indicator of a need for awareness creation on the management of ICS. In wood saving by ICS, it was found strong correlation between the amount of wood and household size at about 97% (P<0.001) (Table 5). The improved *injera* baking Mirt stoves saved wood by 37.4% - 42% of the wood used by three-point open stoves (Table 6) which is lower than similar other studies (Kedir et al., 2019) that saved up to 54%.

The analysis of variance of wood consumption of improved mirt stoves and open three point stoves showed highly significant difference in sessional firewood and energy used by household' for baking *injera* (Table 7).

The household and the per capita firewood consumption of the households in the two districts (Table 6; Figure 3) were higher than the other studies (Ochieng et al., 2013; Egeru, 2014) probability because of the inappropriate use of the stove usually the wider opening created for firewood insertion, and the free supply of firewood.

Improved mirtstoves reduce the amount of wood consumption by reducing the amount of energy loss. The use of improved Mirt stoves in using firewood for baking *injera* emitted 1.37- 1.84 ton CO_2 but the three point open stoves emitted 2.35-2.93 ton CO_2 per household (Table 7). Then improved stoves also reduce the possible deforestation created by open three point stoves. Therefore, such improved baking stoves reduced end uses emission and deforestation from 37-42% of the one created by three point open stoves which is in line with the previous studies like Ochieng et al. (2013).

5. CONCLUSION AND RECOMMENDATION

The study showed that households with similar cook stove and household members could have differences in fuel consumption. These differences might be attributed to cooking culture, the moisture content of wood used, the management options used by a household and the agro-ecology.

In both woredas, the improved mirt stove users complain about improper installation. In our observation, it was found lack of proper management (e.g. not removing the ashes timely, accumulation of unburned fuel around the exhaust) and improper installation of the stove (i.e. on earth floor). There is a need to make awareness training and advocacy works on how to keep the kitchen as clean as possible. There is size variation in the pots and plates based on cooking culture of communities which also require further awareness creation. Generally, it was also found that improved stoves reduce end use emission, biomass consumption and deforestation in about 37-42% when compared with the open fire three point stoves. This improvement in reduction of wood consumption of the mirt stove was not sufficient. Therefore, additional efforts should be done to increase the efficiency by proper installation of the mirt stove that reduce heat wastage like narrowing the gap of firewood insertion and using the rear opening for placing pots.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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Data and materials availability

All data associated with this study are present in the paper.

Peer-review

External peer-review was done through double-blind method.

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