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# Problems of *Mirt*, and potentials of improved *Gonzie* and *traditional open cook stoves* in biomass consumption and end use emission in rural wooden houses of Southern Ethiopia

Miftah Fekadu Kedir[a,b,*], Tsegaye Bekele[a], Sisay Feleke[c]

[a] Hawassa University, WGCFNR, P.O. Box: 128 Shashemene, Ethiopia
[b] Central Ethiopia Environment and Forest Research Center, P.O. Box: 30708, Addis Ababa, Ethiopia
[c] Wood Technology Research Center, P.O. Box: 2322, Addis Ababa, Ethiopia

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ABSTRACT

The efficiency of traditional open cook stoves in supplying firewood energy is usually low. Accordingly, firewood saving, improved stoves called "*Mirt*" made of cement and "*Gonzie*" made of local clay soils were made in 1980s in energy sector of Ethiopia. However, the dissemination of *Mirt* stove was unknowingly limited and the potential of *Gonzie* was less known. In this study the two improved cook stoves, *Mirt* and *Gonzie* were compared with open stoves in biomass consumption and end use emission at three agro-ecologies (lowland, midland and highland) and corresponding sample peasant associations (PA) or Kebeles (Ener Kola, Daemir and Awed) in Enemorina Ener district (county), Southern Ethiopia in 2017. At hierarchical administrative level, first district energy offices were interviewed about stoves used in PA. Then the next administrative level called PA was selected in turn to select rural households and focus groups, in order to interview about the problems of getting *Mirt* stoves and to test the potential of local clay soils in making *Gonzie* stoves. In each PA, 30% of the houses with common cooking condition, about 6 to 21 households; 3–5 pottery workers; and PA representatives were interviewed. Then, *Gonzie* stoves were manufactured, and biomass consumption was evaluated using controlled cooking test. The results showed that the problems in dissemination of *Mirt* stoves were the unaffordable cost of stoves, lack of training in using improved stoves and inappropriate size plates. The households in remote lowland and highland PAs had no knowledge about improved stoves. The overall quality of *Gonzie* stoves of highland and lowland PAs were comparably better than the midland PA. Curing a single *Gonzie* stoves consumed 1.8 to 2.0 times greater firewood than the daily requirement of a household, but lower than the firewood for other clay based utensils that consume 42 to 75 kg firewood weekly. *Gonzie* stoves saved 33.9 to 54.2% of the firewood used by open stoves for baking *"Injera"*. The reduction in end use emission from *Gonzie* stoves was comparable to *Mirt* stoves. Therefore, rural households, and local pottery makers should be trained to use and manufacture improved stoves, respectively. In cooking food and curing local clay made utensils improved stoves should be used to save wood and protect fire damage.

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* Corresponding author.
*E-mail address:* mfkedir@gmail.com (M. Fekadu Kedir).

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## Introduction

Rural households in Ethiopia commonly use traditional open fire three-point solid biomass cook stoves, also called three-point stoves or simply open stoves with low thermal efficiency of 5-15% [1]. However, minor technological modification can improve heat delivery efficiency and reduce indoor smoke like controlling air intake for combustion directed to heat cooking pots, and attaching exhaust smoke with chimney. Stoves efficiencies can be increased to 90% in brick closed stoves [2] and 10 to 50% in other improved stoves [3]. Improved stoves are used to reduce the amount of firewood consumption, end use emission and indoor pollution [4,5]. The inefficiently used firewood was the main cause of deforestation in Sub-Saharan Africa [6–8].

Wood is a source of daily energy for over two billion people in developing countries [9,10]. In Ethiopia, the household sector consumes 90% of total solid fuels [11] and cooking accounts 99.6% of the energy consumed in the sector [12]. The stable food items called *"Injera"* or *"Kotcho"* baking consumes over 50% of the entire household cooking fuel [13]. In the absence of alternative cooking energy other than firewood in rural areas, efficient stoves are highly important [14,15]. Based on the needs of baking *"Injera"*, fermented flat bread produced from crops like "*Teff*", (*Eragrotis tef* (Zucc.) Trotter.), "maize" (*Zea mays* L.), wheat (*Triticum aestivum* L.) or barely (*Hordeum vulgare* L.) in urban and in many rural parts of Ethiopia; and *"Kotcho"* (fermented bread, produced from "*Enset*", (*Enset ventricosum* (Welw.) Cheesman), in rural parts of southern Ethiopia, circular solid biomass cooking improved stoves called "*Mirt* stoves" and "*Gonzie* stoves" were developed in 1980s to improve the efficiency of open three-point stoves [16]. In response to climate resilient green economy of Ethiopia (CRGE), improved stoves were one of the means to achieve energy efficiency from off grid system of renewable energy [17]. *Mirt* stove is made from cement, while *Gonzie* is from clay soils. *Gonzie* referes to improved *Gonzie throughout this paper*. The performance of the stoves is usually compared by water boiling, controlled cooking and kitchen performance tests [18]. *"Mitad*" or plate placed on top of stoves used for baking had been made from clay for *"Injera"* and *"Kotcho"* or iron sheet for *"Kotcho"*.

Globally, biomass burning is the largest source of primary fine carbonaceous particles and the second largest source of trace gases [19,20]. Cement production that use fossil fuels emits 5% of the global Greenhouse gases (GHG) with 0.4985–0.91 ton of carbon dioxide per ton of cement [21]. In 2010, forest degradation due to wood-fuel consumption emitted about 34% of the total emission in Africa [22] and 25.3 Mt $CO_2^e$ in Ethiopia [17]. Improved stoves reduce 50% firewood consumption and up to 70% indoor pollution and minimize atmospheric emission [4,5,23]. The CRGE strategy of Ethiopia has planned to disseminate 9 million efficient *Mirt* stoves by 2015 and 34.2 million by 2030 [24] in addition to solar home lighting system [17]. Countries with hydroelectricity for electric stoves have no emissions at the end use, although it might have emissions from power generation [25].

In Ethiopia, there are still different rural areas that lack improved stoves. Actually, the dissemination of *Mirt* stoves was by far higher than *Gonzie* stoves, although they have similar wood saving potentials [26]. Local pottery workers had been making clay materials like household utensils, cooking pot, and three-point open clay stoves from clay soils, but they lack information to make improved *Gonzie* stoves that minimize the burden to produce long fetched *Mirt* stoves. The unquantified wood loss due to open curing by pottery workers was possible cause of fire damage and deforestation [27], which was aggravated by increased temperature due to climate change [28,29]. Accordingly, the objective of the present study was to identify the problems in dissemination of *Mirt* cook stoves, and the potential of local clay soils in manufacturing improved *Gonzie* cook stoves, and to quantify the stoves' biomass consumption and end use emission during curing and cooking.

## Material and methods

### *Description of the study area*

The study was conducted in 2017 in three adjoining agro-ecological zones of Enemorina Ener district, Southern Ethiopia (Fig. 1), which are represented by Ener Kola peasant association (PA) or Kebele in lowland, Daemir PA in midland and Awed PA in highland (Table 1).

The different agro-ecologies have different climate and different vegetation type (Table 1), and consume different amount of firewood [30,31]. The district was described by Negussie [32] and the rainfall and temperature is given in Fig. 2 [33]. In 2005–2013 the mean monthly rainfall in Enemorina Ener district, capital town, Gunchire ranged from 21.65 to 266.5 mm, with annual mean of 1290 mm [33]. The main rainy season was June to September. In 2005–2013, the neighboring district, maximum monthly temperature ranged from 21.7 to 26.8 °C and minimum temperature from 6.7 to 11.9 °C (Fig. 2).

### *Data collection*

An official discussion was held with Enemorina Ener district energy office to select PAs or Kebeles. Since different types of houses have different types of firewood preferences [34], about 30% of the households in each PA [35] with common wood structure of houses were selected. About 6 to 21 households that use different stoves were interviewed about the type of stoves used and the problems with the dissemination and use of *Mirt* stoves. About 3–5 local clay stoves makers (pottery workers) were interviewed about the place of fetching local clay soils for stove making and the distance was measured by vehicle speedometer. The weekly requirement of biomass for curing the clay stoves and other utensils was measured using balance (Adam Lab.equipment Leicester LE67FT-England, 0.1 g).

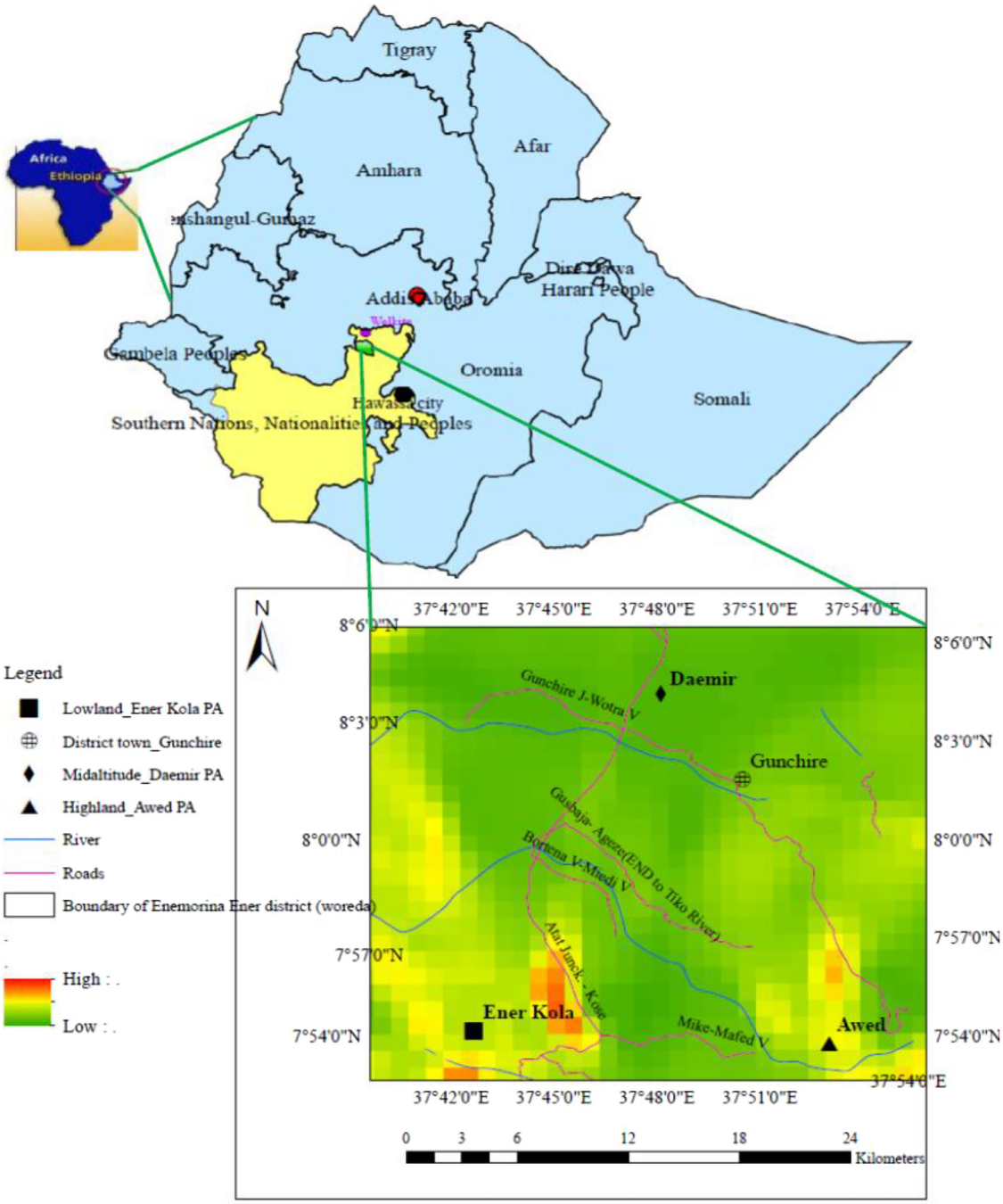


**Fig. 1.** Location map of the study area. (The legend and scale refers only to the three study peasant associations or Kebeles' and nearby features.)

Local clay soils samples were collected, and moistened by tap water. *Gonzie* stoves were manufactured from local clay soils (Fig. 3) with the same size and design as *Mirt* stove molds obtained from Enemorina Ener district energy office. Then the local clay soils and the corresponding *Gonzie* stoves were evaluated qualitatively and quantitatively. The qualitative assessment was based on the interview of locally agreed criteria that include ease of acquisition of clay soils for stove making (availability of clay soils excavation site, accessibility of excavation site to residential area and conflict of ownership of the excavation site); ease of molding (workability of the clay soils, easiness to mix with water and elasticity of the clay materials) [36]; ease of air drying the molded clay stoves under shade (easiness to air drying and sensitivity to crack); ease of curing the molded stoves using heat generated from grass and woody biomass (heat resistance, degradation or damage by heat, length of heat retention and cracking by heat) [37]; market demand of clay stoves (interest of local people to use

**Table 1**
The altitudinal ranges and dominant vegetation of the studied PA or Kebeles.

| Peasant Association /Kebeles | Agro- ecologies | Agro-climate | Altitude (m) above sea level | Rainfall (mm)/Temp. (°C) | Dominant natural vegetation |
|---|---|---|---|---|---|
| Ener Kola | Lowland | SA1-1: Hot to warm semiarid-lowland plains | 500–1600 | 900/27.5–21 | *Acacia albida* (syn. *Faidherbia albida*) (Delile) A. Chev., *Acacia seyal* Delile, *A. tortilis* (Forssk.) Hayne, *Balanitus* sp., *Combretum* sp., *Euclea schimperi* (A.DC.) Dandy, and *Acokanthera schimperi* (A.DC.) Schweinf., *Cordia africana* Lam. |
| Daemir | Midland | SM2-1: Tepid to cool submoist lowland plains | 1600–2400 | 1150/21–16 | *Acacia abyssinica* Hochst. ex Benth, *Eucalyptus camaldulensis* Dehnh., *Juniperus procera* Hochst. ex Endl., *Olea species, Phoenix reclinata* Jacq., *Podocarpus falcatus* (Thunb.) R.Br. ex Mirb., *Syzygium guineensis Willd. DC., Bersama abyssinica* Fresen., and *Croton macrostachyus* Hochst. ex Delile. |
| Awed | Highland | M3-7: Cold to very cold moist mountains | 2400–3200 | 1400/16–11 | *Eucalyptus globulus* Labill. *Juniperus procera* Hochst. ex Endl., *Ficus sur Forssk.*, and *Yushania alpina* (K. Schum.) W.C.Lin |

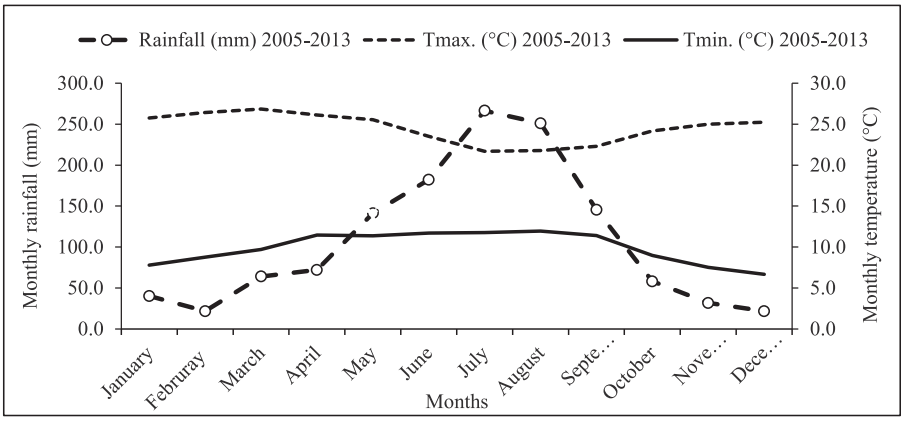


**Fig. 2.** Rainfall and temperature (2005–2013) of Enemorina Ener district capital, Gunchire town. (The temperature is from neighboring district in 2005–2013). (Source: [33]).

clay stoves, number of people engaged with clay pottery business, access to market place and demand of clay utensils in the market); and suitability in utilization and handling of clay stoves (weight, strength, attractiveness and durability of clay stoves) [38].

Quantitative evaluation of the *Gonzie* stoves was conducted at two stages using controlled cooking test [18]. First, the amount of dry wood and grass biomass (10–12% moisture content) used to cure the *Gonzie* stoves of each PA clay soils was measured using balance (Adam Lab.equipment Leicester LE67FT-England, 0.1 g). Second, the amount of *Eucalyptus camaldulensis* firewood consumption and time taken in controlled cooking (baking) a given amount of *"Injera"* or *"Kotcho"* was compared among *Gonzie* stoves of different PAs with *Mirt* stoves, common electric stoves and open three-point clay stoves. End product and end use emission of the four types of stoves were compared [39]. In *Gonzie* and open three-point clay stoves, the end product emission was created by transporting and curing stoves by firewood and grass biomass (Table 3). In *Mirt* stoves, the end product emission was created by cement production based on IPCC emission factor data base [40] that for example, the carbon dioxide ($CO_2$) emission as 0.4985 ton per ton of cement but no methane ($CH_4$) and nitrous oxide ($N_2O$) (Table 2).

*Mirt* stove production usually utilizes some 8 kg of cement per stove [42]. In electric cook stoves, the end product emission was created by transporting the iron and steel used in making the stoves about 10 kg steel (iron) per stove (personal observation). The end use emission in the three types of stoves was created by baking *"Injera"* or *"Kotcho"* using the energy

**Fig. 3.** Local clay soils in "*Gonzie* " production by pottery workers, 1–7 steps.

**Table 2**
Emission factors and global warming potential (GWP) of three common GHG.

| Greenhouse Gas | Emission factor for stationary combustion from residential source | | | | Transport car emission factor (kg of GHG /Liter of diesel) | GWP (100-yr time horizon) |
|---|---|---|---|---|---|---|
| | Firewood in conventional wood stoves (kg/TJ) | Other Primary Solid Biomass (like grasses straw) (kg/TJ) | Cement production (ton GHG/ ton cement) | *Iron and steel production (ton GHG/ ton iron and steel) | | |
| $CO_2$ | 112,000 | 100,000 | 0.4985 | 1.06 | 2.33 | 1 |
| $CH_4$ | 210 | 300 | – | 0.00007 | 0.0002 | 23 |
| $N_2O$ | 4 | 4 | – | 0.00004 | 0.0002 | 296 |

(*Source:* [39–41]).
* Global Average Factor (65% basic oxygen furnace (BOF), 30% electric arc furnace (EAF), 5% open-hearth furnaces (OHFs).

**Table 3**
Transportation distance, lifespan and biomass requirements for making different stoves.

| Stoves type | Transportation | | Amount of | | Life span (year) | Fixed cost (Birr) (2017) |
|---|---|---|---|---|---|---|
| | distance (km) | diesel* (liter) | woody biomass (kg) | grass biomass (kg) | | |
| Electric stove | 200 | 28.57 | 0 | 0 | 25 | 2000 |
| Awed *Gonzie* stoves | 6 | 0.86 | 7 | 6 | 7 | 120 |
| Daemir *Gonzie* stoves | 6 | 0.86 | 10 | 7 | 7 | 120 |
| Ener Kola *Gonzie* stoves | 6 | 0.86 | 13 | 9 | 7 | 120 |
| Awed open clay stoves | 6 | 0.86 | 7 | 6 | 5 | 18 |
| Daemir open clay stoves | 6 | 0.86 | 10 | 7 | 5 | 15 |
| Ener Kola open clay stoves | 6 | 0.86 | 13 | 9 | 5 | 15 |
| *Mirt* stoves | 25 | 3.57 | 0 | 0 | 10 | 220 |

* *Note:* diesel based on 7 km travel by using a liter.

sources but the end use emission in baking by the hydroelectric powered stoves was considered zero [25]. The distance of transport and amount of diesel fuel used by vehicles was measured by vehicle speedometer in kilometer and graduated cylinder in liter, respectively. The lifespan of stoves was assessed and cross checked from individual pottery workers, shops, focus groups and elders (Table 3).

The biomass emissions were determined by the net calorific value (NCV) of *E. camaldulensis* firewood, 14.45 MJ $kg^{-1}$ and grass straw, 16.02 MJ $kg^{-1}$ (Eq. (1)), and global warming potential (GWP) (Table 2). NCV is assumed to be 80% of gross calorific value (GCV) of firewood and 95% of liquid fuel [43,44]. The emission reduced by improved stoves was extrapolated from the factors of 50% wood reduction for 70% emission reduction of the open stoves ([4,23]; Venkataraman et al., 2012) (Eq. (2)). Rural households with family size of five members were usually baking *"Injera"* twice per week and 104 times per year. The emissions at different steps of stoves production were based on the materials listed in Table 3. The emission factors used in different raw materials of stoves and during *"Injera"* baking from the assumed biomass fuel and the emission from cement and iron/ steel production, and transportation was determined based on emission facto data base (EFDB) [39,40] (Eq. (1)) and (Table 2).

*Statistical data analyses*

The data were analyzed using SPSS version 16 and Excel spread sheet 2016. The emissions of $CO_2$, $CH_4$ and $N_2O$ in carbon dioxide equivalent from firewood, and grass straw net calorific value and cement and iron/steel was computed using IPCC [39] as Eq. (1).

$$\mathbf{EF} = \sum_{\mathbf{i}=1}^{\mathbf{n}} \mathbf{FC_{(ijk)}\ x\ EFF_{(ijk)}\ x\ GWP_{(ijk)}} \tag{1}$$

**Where:** - EF: Emission of GHG from fuel (kg $CO_2{}^{e-}$); FC is Fuel Consumption in net calorific value ($MJkg^{-1}$); EFF is Emission Factor of Fuel ($kgTJ^{-1}$); i is $CO_2$, j is $CH_4$ and k is $N_2O$.

The emission reduction from improved stoves was calculated as [23] and Venkataraman et al., [4] (Eq. (2)).

$$50\% \pm \mathbf{WRIS} = 70\% \pm \mathbf{ER}\ (\%) \tag{2}$$

**Where: -** 50% is the wood saved from open stoves by using improved stoves; **WRIS** is Wood Reduction of the Improved Stoves (%); **ER** is Emission to be Reduced (%); 70% is the reduction in indoor pollution from open stoves by using improved stoves.

## Results

The most common stoves used by the rural households in the study area were traditional open three-point stoves made of stones or clay soils (Fig. 4). The most common open stoves called three-point local clay stoves were accessible, and the households responded that these stoves are cheap in the market and can serve up to 5 years in cooking (Table 3). The open stone stoves were used for outdoor cooking specially in lowland areas during dry season in order to avoid excessive heat indoor pollution (Fig. 4).

*Problems with Mirt cook stoves utilization in rural wooden households*

The local people responded that, *Mirt* stoves were disseminated to different peasant associations or Kebeles of Enemorina Ener district in 2014 at a fixed cost of 220 Birr (Table 3). However, the dissemination was mainly to Kebeles closer to road transportations. From the interviewed households, only 2% were using "*Mirt* stoves" that recognized the presence of indoor pollution (Table 4).

**Fig. 4.** Traditional open three-point stoves in rural wooden houses (stone in left & clay in right side).

**Table 4**
Households' smoke impact indoor pollution in stoves types and lighting devices.

| Smoke impact | Type of stoves and source of light | | | |
|---|---|---|---|---|
| | Open traditional stoves and kuraz(%) | Open traditional stoves-charcoal-kerosene stoves-kuraz and solar PV(%) | Open traditional stoves, kuraz and hand dry cell torch(%) | *Mirt* stoves-kerosene stoves-solar PV(%) |
| Indoor pollution | 74 | 13 | 7 | 2 |
| No indoor pollution | 0 | 2 | 2 | 0 |
| Total | 74 | 15 | 9 | 2 |

(*Source:* [34]).

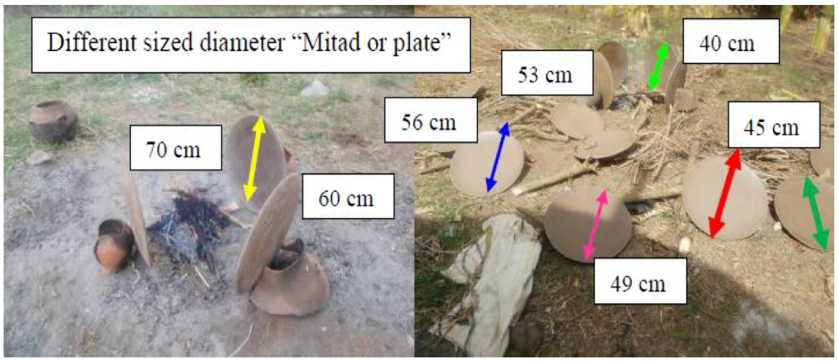


**Fig. 5.** Different sized plate in pottery workers of rural areas of Ener Kola PA.

It was observed that there was inappropriate installation and lack of chimney in *Mirt* stoves. On the other hand, households in lowland, Ener Kola; and highland, Awed PA had no exposure and no knowledge about *Mirt* stoves to save firewood. Generally, the households who acquired the *Mirt* stoves faced different problems as described below.

*Inappropriate size matching of the "Mirt stoves" and "plate"*

The "*Mirt*" stoves were made without the knowledge of the local pottery workers who were making the "*Mitad*" or plate. The plate was simply made at different sizes by pottery workers usually to put on the open three-point stoves with no consideration of the size of circular improved *Mirt* or *Gonzie* stoves. The different sized, 40–70 cm diameter, plate (Fig. 5) was not appropriately fitting the 50–60 cm diameter "*Mirt* stoves". Therefore, searching a size of plate that fits the improved stoves was an additional task in the market as explained by the stoves owners. This lack of appropriate size of plate created smoke exposure and difficulty to the cook (Fig. 6).

*Lack of training on how to install, use, maintain and replace Mirt cook stoves*

All the interviewed households responded that they were not trained about how to install the *Mirt* stoves, how to replace, how to maintain, and how to protect indoor pollution by using chimney that can serve as an outlet of smoke to the outside of the houses (personal communication). Moreover, there was lack of training to prepare appropriate size of firewood to be used in *Mirt* stoves.

**Fig. 6.** The smoking in kitchen from inappropriate sized "*Mirt* stoves" and plate.

**Table 5**
Interest and limitation of separate kitchen in three agro-ecologies of Enemorina Ener district.

| Agro-ecology, PA | Interest of separate kitchen | Reason for the absence of separate kitchen |
|---|---|---|
| Highland, Awed | No interest to construct separate kitchen. | Few family members were unable to guard the kitchen from robbery because the separate kitchen is usually located outside the main house. There was also no sufficient wood and the presence of cold weather increased the necessity of indoor heating. |
| Midland, Daemir | High interest to construct separate kitchen to avoid indoor pollution due to high rate of heating especially in dry season. | Lack of technical and economic support and lack of official obligation to build separate kitchen. |
| Lowland, Ener Kola | High interest to construct separate kitchen to avoid indoor pollution. But in rainy season they need indoor heating and cooking. | Lack of technical and economic support, and no knowledge about kitchen because the area is inaccessible for transportation. |

**Table 6**
Firewood consumption and length of wood used in peasant associations'/ Kebeles'.

| Agro-ecology, Peasant association/ Kebele | *Mean weight of firewood consumed daily (kg day$^{-1}$) | Mean length (m) of firewood |
|---|---|---|
| Highland, Awed | 3.443 | 1.0 |
| Midland, Daemir | 5.164 | 1.5 |
| Lowland, Ener Kola | 7.278 | 1.65 |

* *Source:* [34].

*Lack of separate kitchen*

Separate kitchen is necessary for the solid biomass energy using households to properly place improved stoves with chimney. The traditional small sized, single room houses were not sufficient to put *Mirt* stoves and there was fear of fire damage in the wooden houses. The interest of having separate kitchen was dependent on family size, economic and technical capacity of households (Table 5), as observed in the field, although there were households that installed improved stoves without separate kitchen and *vice versa*.

*Type of house cover, length and amount of wood used*

Most of the houses' roof (74%) were covered with grass [34] that increases fire risk of installing *Mirt* stoves with chimney. Similarly, the long firewood (1.0–1.65 m) (Table 6). twigs and leafy type biomass were difficult to be used with the 60 cm diameter *Mirt* stoves. The right size of wood was found to be <30–40 cm long and 5–10 cm thick (personal observation).

*Affordability of the "Mirt stoves"*

"*Mirt* stoves" were made from cement, but getting cement or *Mirt* stoves was not affordable to rural poor.

**Table 7**
Clay material and firewood collection sites of pottery workers in PAs.

| Agro-ecology, Peasant association | Distance to clay excavation site (m) | Distance to firewood collection site (m) | Number of pottery workers |
|---|---|---|---|
| Lowland, Ener Kola | 550±28.87[a] | 113.33±18.56[a] | 200 |
| Midland, Daemir | 700±57.74[a] | 208.33±22.05[a] | 125 |
| Highland, Awed | 1083.33±60.09[b] | 433.33±88.19[b] | 65 |

*Note:* [a], [b] and [c] are statistically significant at $p<0.05$.

**Fig. 7.** Local clay soils excavation sites in the lowland (left) and highland (right).

**Table 8**
Biomass requirement for local utensils and *Gonzie* curing by PAs pottery workers.

| Agro-ecology, Peasant association/ Kebele | Biomass consumption of local utensils in pottery weekly (kg) (Mean± St. Err.) | | Biomass consumption for single *Gonzie* stoves manufacturing once in seven years (kg) (Mean± St. Err.) | |
|---|---|---|---|---|
| | Firewood | Grass | Firewood | Grass |
| Lowland, Ener Kola | 75±2.89[c] | 53±2.08[c] | 13±0.64[c] | 9 ± 0.29[c] |
| Midland, Daemir | 57.33±3.71[b] | 42±1.53[b] | 10±0.42[b] | 7 ± 0.29[b] |
| Highland, Awed | 42.33±1.45[a] | 36.17±43.72[a] | 7 ± 0.58[a] | 6 ± 0.46[a] |

*Note:* [a], [b] and [c] are significant at $p<0.05$.

*Potential of local clay soils for making Gonzie stoves*

In each of the studied PAs, local pottery workers were making traditional stoves, household utensils and plates from clay soils. Although improved stoves called *Gonzie* can be made from local clay soils, there was no *Gonzie* improved stoves in the studied households. About 65 to 200 individuals were making pottery activities using clay soils in each PA (Table 7). Firewood and grass biomasses were used for curing the clay made materials or utensils. The curing was done in open air during dry days but inside shades/ houses during rainy days. The local pottery workers usually make the stoves for the local market wholesalers or retailers. Firewood and grass biomasses were collected in the nearby houses at about 113.33 to 433.33 m distance away from the residential places (Table 7). The clay stove makers in Awed PA were travelling longer distances to collect both clay soils and firewood but the Ener Kola PA were getting the necessary materials in shorter distances (Table 7). The excavation site in Awed PA was usually hilly and susceptible to erosion (Fig. 7). The respondents explained that, most of the clay stoves and utensils supplied to the nearby market were produced from Ener Kola PA. Therefore, the local clay soils and local pottery workers have the required potential to make *Gonzie* improved stoves. However, the lack of training to the households and the pottery workers limited the local manufacturing and dissemination of *Gonzie* improved stoves.

*Firewood and grass biomass consumption for local clay stoves and utensil manufacturing*

In the studied area, there were two bigger market days per week when pottery workers sell the clay stoves and utensils, then wood and grass biomass collection or purchase for curing was done mainly twice per week. The weekly biomass consumption was statistically different at $p<0.05$ level among the PAs (Table 8). The firewood and grass biomass consumed in lowland, Ener Kola PA for example was about 75±2.89 kg and 53±2.08 kg per week per stoves maker, respectively. In making a household *Gonzie* stoves the households responded that, once in every seven years consumed less than one fifth of the weekly biomass required by local pottery workers (Table 8). Curing a single *Gonzie* stoves consumed 1.8 to 2.0 times the daily firewood requirement of a household, which was lower than the firewood for other clay based utensils that consume 42 to 75 kg firewood weekly (Tables 6 and 8).

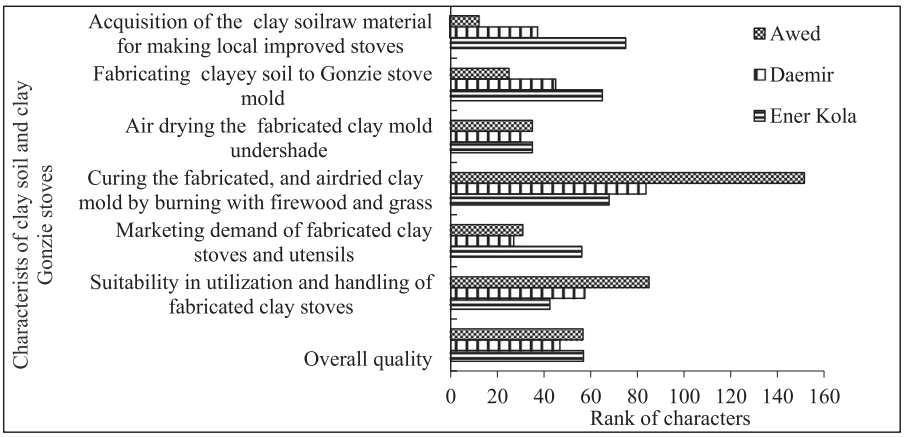


**Fig. 8.** Characteristics quality of local clay soils and *Gonzie* stoves.

**Table 9**
Comparison of four types of stoves per session of baking *"Injera"* or *"Kotcho"*.

| Stoves type | Power taken (kWh) | Values per session (Mean ±Std. error) | | | |
|---|---|---|---|---|---|
| | | Time taken (minutes) in cooking/baking | Heat retention (minutes) | Amount of air dried wood (kg) | Amount of firewood saved (%) |
| Electric *"Injera"* stoves | $6.5 \pm 0.3^{a}$ | $63.3 \pm 3.3^{a}$ | $20.3 \pm 0.3^{d}$ | 0.00 | 100 |
| Awed *Gonzie* stoves | $12.3 \pm 0.7^{ab}$ | $145 \pm 7.6^{b}$ | $16 \pm 0.6^{c}$ | $3.06 \pm 0.2^{a}$ | 49.3 |
| Daemir *Gonzie* stoves | $11.1 \pm 0.6^{ab}$ | $145 \pm 7.6^{b}$ | $15.7 \pm 0.9^{c}$ | $2.77 \pm 0.2^{a}$ | 54.1 |
| Ener Kola *Gonzie* stoves | $16.1 \pm 1.2^{ab}$ | $133.3 \pm 18.6^{b}$ | $12 \pm 0.6^{b}$ | $4.00 \pm 0.3^{a}$ | 33.8 |
| Three-point open stoves | $24.3 \pm 2.2^{c}$ | $71.7 \pm 13.6^{a}$ | $7.7 \pm 0.9^{a}$ | $6.05 \pm 0.6^{b}$ | – |
| *Mirt* concrete stoves | $12.7 \pm 0.9^{ab}$ | $140 \pm 5.8^{b}$ | $18.3 \pm 0.3^{cd}$ | $3.16 \pm 0.2^{a}$ | 47.8 |

*Note:* [a], [b] and [c] are significantly different at $p<0.01$.

*Qualitative assessment of locally made Gonzie stoves*

The clay soils for making *Gonzie* stoves showed different acquisition, molding, and drying characteristics among the three PAs agro-ecology. The marketing of clay made materials were also different among agro-ecology. In acquisition, the Ener Kola PA clay soils ranked the highest because clay soil was abundant and easily obtained from public land (Table 7 and Fig. 8). In curing clay molds using fire, the clay soils from Awed PA was resistant to curing defects like cracking and change of shape. The overall quality assessment of the clay soils in making *Gonzie* stoves depicted that the Awed and Ener Kola PA clay soils were better than the Daemir PA.

*Quantitative assessment of locally made Gonzie stoves*

*Energy consumption of different stoves during baking or cooking*

From the different cook stoves (Figs. 9 and 10), the highest firewood consumption was observed in three-point open stoves, 6.05 kg at 10–12% moisture content, and generated 24.3 kWh per session. This created a wastage of 2.80 kg firewood when compared with "*Mirt* stoves" (Table 9). About 26.75% of the wood energy (6.5 kWh) in open stoves was used and 17.79 kWh was wasted when compared with electric stoves. *Gonzie* stoves saved 33.8 to 54.1% of the biomass used for baking in open three-point stoves. The lowest amount of wood saved (33.8%) was due to the dominance of clay and lack of sand in the soils used for *Gonzie* making as responded by the pottery workers. From *Gonzie* stoves, the highest wood consumption was observed in lowland, about 4.0 kg and the lowest in midland, about 2.77 kg per session of baking *"Injera"*. The heat retention time of electric stoves was the highest and bake greater number of *"Injera"* or *"Kotcho"* within the heat retained. The minimum cooking time was taken by electric stoves followed by open three-point stoves (Table 9). Extra biomass fuel of any dimensions can be added easily to open stoves from open directions but *Mirt* or *Gonzie* stoves require adjusting the biomass dimension.

*End use emission of different types of stoves*

The end use emission at household level ranged from zero in hydroelectric stoves to 1.1 t $CO_2^e$ per year in open three-point stoves in baking *"Injera"* or *"Kotcho"* using *E. camaldulensis* firewood (Fig. 11). During cooking/ baking, *Gonzie* stoves were comparable to *Mirt* stoves in reducing end use emission from 53.85 to 74.14% per day per household of the open three-point clay stoves (Fig. 11).

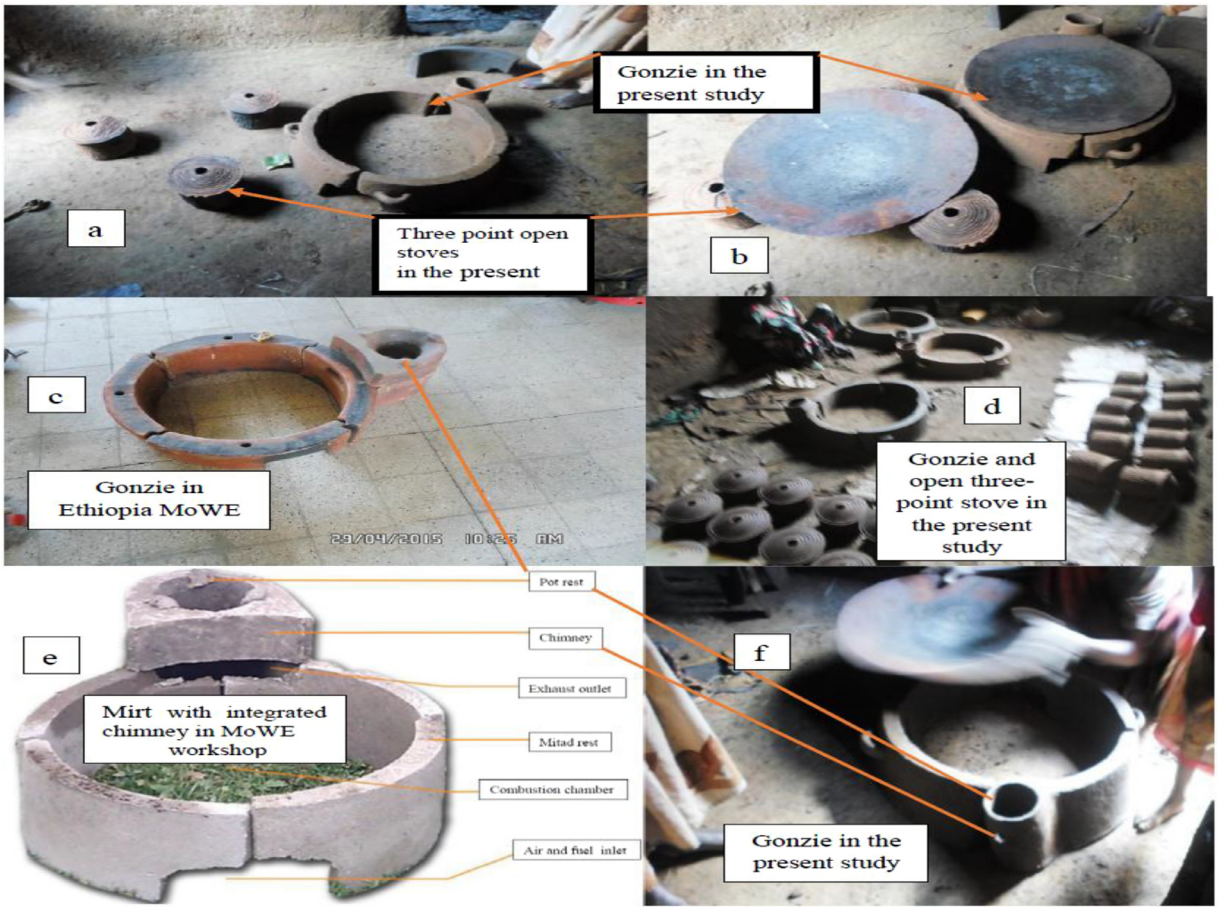


**Fig. 9.** Closed improved stoves and open three-point stoves.

**Fig. 10.** Energy consumption of stoves during baking *"Injera"*.

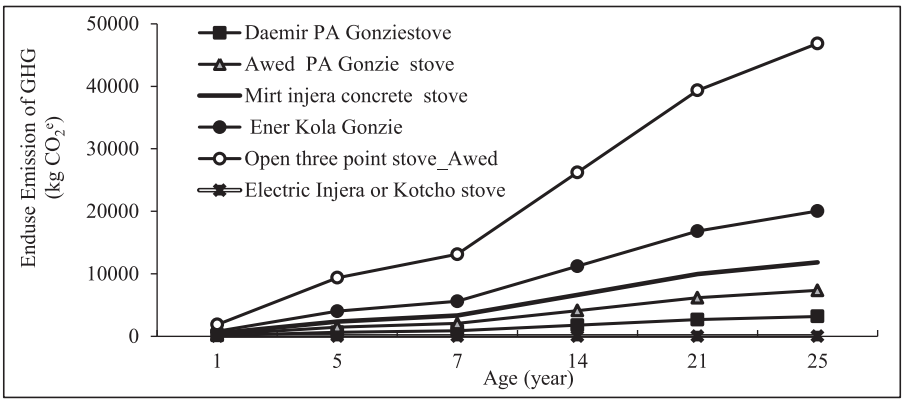


**Fig. 11.** Emission of GHG from four types of stoves during cooking in rural wooden houses.

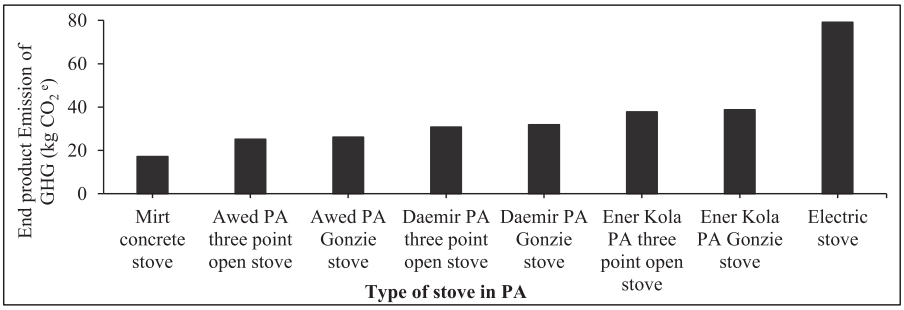


**Fig. 12.** Comparative end product emission during preparation of different stoves.

**Fig. 13.** Open traditional curing by pottery workers.

In making stoves and replacement at possible life span, example 25 years for electric stoves (Table 3), the highest end product emission was obtained from the manufacturing of iron and steel made electric stoves, about 79.1 kg $CO_2^e$, while the lowest from the manufacturing of *Mirt* stoves, about 17.2 kg $CO_2^e$ at the first year of manufacturing (Fig. 12). In producing open three-point clay stoves about 32.3 kg $CO_2^e$ (Fig. 12) was emitted as end product which is a bit higher than *Gonzie* stoves (Table 8).

*The challenges with open stoves to fire risks*

The curing of the clay stoves and utensils during manufacturing were made outdoor in open fire (Fig. 13) and it was the cause of windblown fire damage as responded by the interviewed households. Thus a kind of closed outdoor cooking clay

**Fig. 14.** *Awuramba* stoves for outdoor cooking.

made stoves locally called "*Awuramba* stoves" (Fig. 14) which were well known somewhere else in Ethiopia are required for curing. These stoves can be made locally as a possible solution to reduce out door fire risks during outdoor cooking and curing. However, this *Awuramba* type of stoves were not disseminated to the rural people in Southern Ethiopia because of the lack of information (personal communication).

## Discussion

Solid biomass fuel commonly burnt in traditional open three-point cook stoves were the causes of indoor pollution, and the fire set has higher chance of attacking the cook (Fig. 4). The appropriate use of improved cook stoves including *Mirt* and *Gonzie* reduce the loss of heat energy, and reduce fire and smoke risks [45]. However, field observation revealed that most of the local people who purchased *Mirt* stoves were not using chimney. So the indoor pollution reduction role of *Mirt* stoves was not properly attained because of the lack of appropriate size of plate that exactly fits the *Mirt* stoves, the lack of separate kitchen and the lack of training. Therefore, local way of linking the *Mirt* stoves makers and plate makers is very important which was missed by the *Mirt* stoves distributors in the present study area, especially in central part of Enemorina Ener district, Gunchire town and its surrounding in Southern Ethiopia. Moreover, the cooking habit of the local people did not adapt to the *Mirt* stoves. Different studies indicated that the longer ignition time taken and the smaller length of wood sticks required as opposed to Table 6, has reduced the interest of adoption of the improved *Mirt* cook stoves by the local people [13,45,46]. Thus, the wood required to be small based on the size of the *Mirt* and *Gozie* stoves. Although separate kitchen affects the installation of improved stoves with chimney, the interests of having separate kitchen were dependent on agro-ecology, size of family per household, economic and technical capacity of households (Table 4). About 56.6% of the interviewed households responded that lack of separate kitchen hindered installation of *Mirt* stoves [34].

The materials required for *Mirt* stoves making need to consider and compromise conflicting concepts of affordability, durability, functionality, safety, availability and ease of manufacture [47]. According to Smith [2] stoves for rural poor must also be uncomplicated to manufacture, inexpensive, based on local materials and compatible to the customs of those who use them without precluding further technological improvement. Hence, use of readily available clay soils *Gonzie* stoves or locally accessible *Awuramba* stove making with technical support of local pottery workers is preferable to the cement made *Mirt* stoves.

In the present study, it was identified that different firewood and grass species were used as cooking and curing fuel in different agro-ecologies. In lowland, Ener Kola PA, there were many firewood species with different degrees of preferences including *Combretum species* and *Acacia species* (Table 1). One of the respondents in the lowland who was purchasing Eucalyptus as firewood stated that one pile of *Acacia species* was better than ten piles of *E. camaldulensis* because of the fire maintained for longer time in the former than the latter. In midland, Daemir PA and highland, Awed PA, the diversity of firewood species was very few, mainly *Eucalyptus species*. In dry seasons other woody and non woody species including crop residues were used as energy sources. In open three-point stoves, the woody biomass consumption in addition to kerosene in the studied district was 3.443 to 7.278 kg day$^{-1}$ per household [34] (Table 6), which was comparable to other studies [15,48]. The scarcity of firewood affects the interest of using firewood saving technologies.

The suitability of clay soils for making local *Gonzie* stoves depends on the availability of clay soils, the willingness of the land owners to excavate clay soils, the erodibility of the soils by erosive agents (Fig. 7) and the availability of firewood. Clay soils collection to make improved *Gonzie* stoves in lowland, Ener Kola PA was easy because of the availability of clay soils excavation public land, with low risk of landslide. In midland, the land was either publicly or privately owned lands with

different degree of susceptibility to erosion. In the highland, the excavation sites were mostly privately owned, undulating and susceptible to landslide (Fig. 7) which prohibited excavation. Therefore, careful agreement should be done among local pottery workers, landowners and local administrators on the ways of protecting excavation of sloppy lands and making pottery business sustainable source of income to the households engaged. There was suitable clay soils excavation site and well established clay stoves market in Ener Kola PA; and therefore, it is a good venue for promotion of improved stoves.

In making and curing stoves, the highest firewood saving was observed in Daemir PA *Gonzie* stoves when compared with open stoves (Table 8), which could be attributed to the presence of sand in the clay soils that heats easily using less amount of heat. In comparison to the open three-point stoves, about 33.85% wood consumption reduction was obtained in lowland, Ener Kola PA *Gonzie* stoves and 54.14% in Daemir PA *Gonzie* stoves (Table 9) which is comparable to REN21 [3] and NMA [49]. Therefore, the Ethiopians initiative of distributing millions of improved *Mirt* stoves just to save woody biomass and reduce emission [50] could be supported by local production of *Gonzie* stoves from locally available clay soils with proportional addition of sand.

From *Gonzie* stoves, the lowest end product emission was obtained from the highland, Awed PA (Fig. 12) because of the consumption of relatively lower amount of biomass in curing. In the open three-point stoves, the highest end product emission was obtained from the lowland, Ener Kola PA probably because of the availability of more firewood and the clay dominated soils (Table 8). Although the stoves possess different extent of durability, it was generally believed that the older the improved stoves, the highest is the emission. Using modern electric *"Injera"* stoves reduced enduse emission but the end product emission from the manufacturing materials of iron/ steel stoves was higher. On the other hand, since improved stoves reduce enduse emission, the cost of production of stoves can be obtained from the saved wood. Accordingly, if improved stoves are disseminated without charge, the rural houses could save firewood that could otherwise be burnt for cooking or baking. Open fire stoves were not only the cause of indoor pollution [27] but also causes of fire risk and damage. The open fire stoves set for cooking was usually held outside the house in dry season because of increasing room temperature specially in lowland PA. In societies that use open fire biomass fuel, and in the absence of any barrier to occasional wind in dry season, the occurrence of fire damage was very common in grass covered rural wooden houses and nearby forests. Similarly, open curing of local clay made materials and utensils consumes 42 to 75 kg firewood weekly (Table 8), and therefore, requires a kind of closed stoves like *Awuramba*. Moreover, closed fire system like *Awuramba* stoves (Fig. 14) and other stoves like *Lorena* stoves, which were known somewhere in Africa [51] are crucial both for household outdoor cooking and for curing clay materials using solid biomass.

## Conclusion and recommendation

Locally made improved solid biomass stoves from local clay soils called *Gonzie* stoves showed comparable results of firewood saving and reducing end use emission as cement made *Mirt* stoves. However, the dissemination of improved *Gonzie* stoves in the studied rural areas was highly impaired by the lack of awareness and training to the households and pottery workers. In a rural household with five family members cooking with *Mirt* stoves reduced wood consumption by 48%, while *Gonzie* stoves reduce wood consumption by 33.85 to 54.14% depending on the presence of sand on the clay soils, when compared to open three-point stoves. *Gonzie* stoves were environmentally suitable because clay soils can be excavated from appropriate local areas where the land is not susceptible to erosion. However, cement to make *Mirt* stoves was unaffordable to most of the rural people. The lowest cost of stove acquisition, but the highest end use emission was obtained from open three-point stoves in contrast to the highest cost and the lowest end use emission of modern electric stoves. Therefore, most of the households own open three-point stove. The use of *Gonzie* stoves for cooking reduced emission by 53.85 to 74.14% per household as compared to open three-point stoves emission of 1.1 t $CO_2^e$ per year per household. In the cases of complete renewability of biomass, the emission from burning firewood and grass create only indoor pollution and may not have greenhouse gas effect in the atmosphere. Therefore, technological support and training should be provided to rural solid biomass and traditional stoves users in order to reduce wood consumption, and reduce indoor pollution and GHG emission. The highland and lowland PAs produced comparably quality *Gonzie* stoves. However, the clay excavation site in the highland was susceptible to soils erosion because of the rugged train and it requires careful planning and appropriate site selection. In introducing solid biomass fuel saving stoves, the local pottery workers should be trained on the processes of making improved stoves and the complimentary materials required for cooking like appropriately sized clay plate. Indoor pollution and fire damage should be protected in rural areas using combination of locally available technologies of closed stoves, chimney, separate kitchen and *Awuramba* stoves without precluding the introduction of modern energy sources and solid fuel saving technologies. The use and manufacture of improved stoves should continuously be trained to the local community with proper follow up.

## Conflict of interest

The authors have no competing interests.

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