Cost reduction and forest preservation potential of advanced stoves and challenges of their adoption in higher education: the case of werabe university, Ethiopia

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ABSTRACT

Enjera baking is the most energy-intensive activity in Ethiopia which causes an economic problem, forest degradation and CO2 emission. This research aims to quantify fuel cost reduction, forest preservation, carbon dioxide emission reduction potential of advanced stoves and influencing factor of their adoption in Werabe University, Ethiopia. To attain its objectives: firstly, Control cooking test on traditional cooking stoves and both single clay and double clay electric stoves was conducted to quantify their fuel use efficiency. Secondly, document analysis was used to investigate forest reservation, fuel cost reduction and carbon dioxide emission reduction. Thirdly, focus group discussion with bakers used to identify the health impact of the traditional cookstove. Fourthly, an interview was also conducted to identify factors determining the adoption of electric cookstoves. The results show, substituting traditional cookstoves by single clay electric stoves or double clay electric stoves can reduce fuel cost by 159% and 148% y^{-1}. Electric cookstoves can preserve 4.76 and 9.77 ha of dense and open forest cover. The finding also reveals that single clay electric stoves and double clay electric stoves reduce CO2 emission by 99.08% and 98.87% y^{-1}. The study also indicates switching traditional cookstove to cleaner stoves avoids IAP; consequently, it improves cooks health. Finally in Werabe University adoption of cleaner stoves is influenced by transmission failure of electricity and lack of attention about the benefit of the clean cookstove. To conclude the study may have economic, environmental and social implication.

1. Introduction

The UN is aimed to achieve 17 global goals by 2030 [1]. Goal no.7 of the agenda has recognized the role of modern energy to achieve sustainable development [2]. However, under the current policy and population growth trends 2.3 billion people will remain unable to access clean cooking technologies in 2030 [3]. Hence, strongly reliant on traditional and inefficient biomass stove negatively affects public health [4] and become a major cause for environmental degradation [5, 6].

In some African countries, few urban households use electricity as a primary source for cooking [7]. In Ethiopia, the national electrification rate is around 25%; of which 85% is in the urban areas and only 15 % is found in the rural areas [8]. The largest population of the country still use traditional biomass for cooking [9]. So, it is expected that biomass will use as the primary energy source for the majority of Ethiopia [10].

Today in Ethiopia, about half of biomass is used for cooking injera [11]. Injera, a circular pancake or flat-bread with a diameter of 52 cm and 2–4 mm thick, is the national dish in Ethiopia and Eritrea [8]. Injera is made with teff flour mixed with water and allowed to ferment for several days, as with sourdough starter [11]. It can also be made from wheat, barley, maize, sorghum, or from a mixture of them [12]. The prepared flat-bread is porous, soft, thin, and sour-tasting [13, 14]. To prepare injera, a ceramic plate called mitad, is required to be placed on top of the stove [15]. Injera cooking using the traditional stove is known for its energy-intensive and the main driver of forest degradation [6] results in a net loss of forest ecosystems [11].

Researches reveal that baking injera consumes the most fuelwood and accounts for about 60 per cent of total household fuel consumption [12], and it is estimated that 50 million m3 of wood per year [15] is used for cooking and lighting. This has contributed to the rapid loss of tree resources. This, in turn, has caused a loss of soil nutrients and decline in agricultural productivity [16].

In response to reducing deforestation and indoor air pollution, improved biomass cooking stoves were introduced in the early 1980s in
Ethiopia [13]. Although improved biomass stoves minimize the pressure on the environment, deforestation is continuing [17]. Thus, there is a need for a new efficient and clean stove that can drastically reduce; fuel consumption, pollutant emissions and indoor air pollution [18].

Since the introduction of advanced stoves programs in Ethiopia [19], cookstoves become concerned for many researchers [20]. However, it has remained rarely quantified the socio, economic and environmental benefits of electric cookstoves comparing to traditional cookstoves in Ethiopia higher education in general and Werabe university in particular.

Therefore, this study aimed to quantify fuel cost reduction, forest preservation and carbon dioxide emission reduction of advanced stoves and challenges of their adoption in Werabe University, Ethiopia.

The specific objectives of the research are:

i. To calculate the amount of money saved as a result of utilizing electric stove in the study area.
ii. To quantify CO₂ emissions reduction of electric cook stoves comparing to traditional cooking stoves.
iii. To estimates the forest preservation potential of electric cook stoves.

Consequently, the finding of the study will have both theoretical and practical significance to fill the prevailing knowledge gap of practitioners, policymakers, institutions and the local community about the importance of scaling up the traditional cooking device into their counterpart modern cooking once.

2. Material and method

2.1. Study area

The study was conducted in Werabe University which is located 173 km from Addis Ababa in South Nation and Nationality and people's regional state of Ethiopia. In werabe town the majority of the households use fuelwood and the remaining use a mix of fuel-wood and electricity to bake injera. In 2018/19 (2011 E.C) the University hosts around 3100 students. Making injera accounts for the bulk of the institution fuel consumption.

2.2. Selection of the study area

Werabe University was selected purposefully although Universities are the major sources of knowledge, this institution relays on fuelwood for cooking. Proximity to the researcher was also another reason for purposefully selecting the study site.

2.3. Selection of sample cookers

In Werabe University cookers are working in three shifts, consisting of 12 members in each. To obtain the health impact of the traditional cookstove, the researchers randomly selected one shift of cookers and made open group discussion with them. However, before proceeding into

Figure 1. Pictures of (a) Traditional cookstove (b) Single clay electric cookstove (c) Double clay electric stove.
the discussion, the researcher told the purpose of the research and assured the interest of the cookers to participate in the discussion.

2.4. Descriptions of the stoves

2.4.1. Traditional cookstove

The stove has been specifically designed to cook Injera on the so-called mitad, with a radius of about 60 cm and a thickness up to 4 cm. The mitad is locally produced from clay and is sold separately, which in practice often causes efficiency losses due to improper fitting. The stove is assembled and closed with metal. The mitad sits above a combustion chamber (Figure 1). The fuel and air inlet are made with a height of about 60 cm and width of around 34 cm.

2.4.2. Electric stove

For the evaluation of fuel efficiency in the injera baking process, three series of baking experiments were performed on single and double clay injera baking electric stoves or Mitads. The selection was done because of their technical simplicity, wide availability and commonly usability in Ethiopia [21]. Both stoves are locally made, developed by the Ethiopian Electrical Power Corporation; can be found all over Ethiopia, wherever electricity is available. Clay plate starts up time is 15–20 min.

The single clay electric stove consists one baking clay which is found at the top surface and the bottom side of the clay is embedded with an electrical resistor. In the double clay stove two clays are placed one on top and the other at the bottom. The top clay is used as the baking clay and the bottom clay is used to embed the electrical resistor. Single or double clay plate 8–12 Kgs. The thickness of double clay layer stove is in the range of 12–22 mm; of which the top or baking clay is 12–14 mm and the bottom or heating element holder clay is about 16–22 mm. The clay diameter of both electric stoves ranges from 550 to 580mm (Figure 1).

2.5. Data collection

Data were collected using a controlled cooking test (CCT), interview, group discussion and document analysis. The CCT was conducted to test sample stoves fuel use efficiency. The test was carried out in Addis Ababa Laboratory of Alternative Energy Development and Promotion Center. CCT is a better indicator [22], of specific fuelwood consumption to cook a given amount of food, in our case it was injera. The interview was used to identify the factors that hinder the university not to adopt modern cooking stoves. Group discussion with sampled cookers, was also used to examine the health impact of the traditional cookstove. Document analysis of the University and other written literature was used, to quantify the amount of forest deforestation and carbon dioxide emission of the stoves.

2.6. Calculations

2.6.1. Carbon dioxide emission

Carbon dioxide emission was calculated by the conversion of saved firewood as a result of using modern cooking stoves. It was calculated based on IPCC [23], revised report on Guideline for National Greenhouse Gas Inventory (the conversion rate of 1kg firewood emit 1.83 kg of CO\textsubscript{2}). The amount of carbon dioxide that can be emitted from fuelwood can be calculated as it is depicted hereunder:

About 50% of dry wood is carbon. If we take a log which is weighed about 1,000 kg, about 500 kg of the wood is carbon.

When an atom of carbon combined with a molecule of oxygen, CO\textsubscript{2} can be seen as follows:

\[ \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \]  

(1)

Since C has a molar mass of 12 g, 500 kg of C is 41,700 mol of C.

To find out the number of moles in 500kg of carbon we need to convert the kilogram into gram and divide by 12 (500,000g/12 = 41700 mol).

This produces 41,700 mol of CO\textsubscript{2}. CO\textsubscript{2} has a molar mass of 44 g per mole which is 1,834.8 kg (That is, 44g should be converted to Kgs and multiply by 41,700).

Therefore, 1000 kg of wood will produce about 1,833.8 kg of CO\textsubscript{2}. If 1,000kg of fuelwood holds 1,833kg of CO\textsubscript{2},1kg of fuelwood would contain:

\[ \frac{1,833,000}{1,000} = 1.833 \text{ kg of CO}_2 \]  

(2)

2.6.2. Cost of firewood consumption

In one hand, to estimate the University annual firewood consumption using traditional cookstove, first, the price of a bundle of firewood was weighed and then conversion of one bundle of firewood was done into kilograms. Finally, the amount of fuelwood used to bake 1 injera was calculated.

On the other hand, the electric cooking stove energy cost was calculated based on the current Ethiopian Electric Power Corporation (EEPCo) electricity tariff which is 0.56 birr per kWh [24] to cook 1 injera.

2.6.3. Fuel cost reductions (FCR)

Fuel cost Reductions (FCR) calculation for each electric stove was accomplished by comparing with the corresponding values of the traditional stoves using the formula below.

\[ \% \text{ reduction} = \frac{\% \text{ ts} - \% \text{ es1}(2)}{\% \text{ ts}} \times 100 \]  

(3)

Where, % reduction = Fuel cost Reductions

\% ts - Fuel cost of Traditional stove

\% es1 - Single clay electric stove

\% es 2 - Double clay electric stove

2.6.4. Statistical analysis

The statistical differences in SFC and emission of CO\textsubscript{2} among the stoves were computed by T-test using SPSS statistical software version 20 at 5% level of significance.

2.6.5. Ethical consideration

The researcher ensures the ethical aspects of the research methodologies used in collecting both the primary and secondary data, as well as conducting the data analysis. The names of the interviewees participated in this study were not disclosed in the data analysis; that the participants freely expressed their ideas and feelings. It also conducted a short discussion with the selected respondents, state the purpose of the study, assuring them all with confidentiality and the researchers careful in enhanced the co-operation of the respondents.

The researcher used more of open-ended questions, that enable the informant to speak freely, and some close-ended questions to get specific answers. He also urged the informant to elaborate on certain subjects where he found to be more important or sometimes unclear and incomplete.

Issue of ethical clearances was approved by Werabe university Research Ethical review committee based on the standard operational procedures of national and institutions ethical guidelines. Written informed consent was obtained from all participants. The informed consent process emphasizes that participation in the study is voluntary & consent to participation can be withdrawn at any time, without giving a
reason as well as without affecting their current or future benefits to which the participants are entitled.

3. Result and discussion

The overall environment and economic attractiveness of the alternatives stoves were compared to the baseline of a traditional stove, using the most important Marc J. and Jie-Sheng T [25]. criteria (Table 1).

3.1. Stove’s energy consumption performance based on CCT

The price of firewood was not similar thorough out the year so that, we take the annual average price of firewood purchased [26]. Based on this, the current Werabe University average firewood price to cook 1 injera using traditional stoves is 0.32 birr (Table 2). Whereas the cost required cooking 1 injera using single clay and double clay electric stove is 0.105 and 0.141 birr (Table 2).

The above table showed the energy cost to cook the same amount of food using both single clay and double clay electric stove is less than the traditional cookstove.

3.2. Electric stoves cooking cost reduction per year

To compare the cost benefits of different cooking device, it is necessary to consider their fuel consumption. Therefore data obtained from CCT and the actual cost of fuelwood was considered during cookstove economic analysis.

The annual energy cost of traditional cook stove is estimated 595,200 birr (equivalent to 21,257 USD). Similarly the energy cost using single clay and double clay electric stove is estimated to 195,300 and 260,400 birr (equivalent to 6,975 and 9,300 USD) y⁻¹ respectively (Table 3) (see Table 4).

As it is indicated above, single clay and double clay electric stoves can reduce fuel cost by 159 % and 148 % y⁻¹ respectively (Table 3). Fuel consumption of single clay and double clay electric stove is substantially less than that of the traditional cookstove. The result showed reliance on solid fuels and inefficient and polluting cookstoves costs the university dearly. This finding is in line with a technical report by Global alliance for clean cookstoves which showed the effects of solid fuel dependence costs the world $ 38–40 billion annually, of which a significant share is avoidable by using clean cook stove [19].

The research conducted in India [27] regarding the efficiency of modern cookstove proved that modern solid biomass cookstoves in rural kitchens have impressive performances in wood consumption as compared with the traditional ones. Survey data from Uganda [28] also suggests that fuel cost could be reduced up to 80 % depending on the type of cooking technology used. The result showed that single clay and double clay electric stoves were found to be more economical in fuelwood consumption.

3.3. Health benefits

To estimate the health effects of the traditional cooking stove, the researcher directly observed the situation in the cooking room of the University and at the end of the cooking process made open discussion with bakers. One of the cooks explained the health impact of traditional cooking stoves: “... the smoke produced during the cooking process makes our eye to irritate and then cry; it also makes us cough and creates a headache.”

As the group discussion with the bakers indicated that exposure to indoor air pollution (IAP) is linked to several adverse health effects including acute respiratory infection, chronic obstructive lung disease, pregnancy complications, daily discomfort in women from coughs, headaches, stinging eyes and backaches.

The finding of the paper indicated that switching traditional cookstove to cleaner stoves lowers IAP which is a risk factor for many illnesses, and consequently, it improves the health of the cooks. A study in Ethiopia [29] supports this finding that modern stoves can reduce IAP by 70 %, reducing the risk of a range of health impacts. Another study in urban Ethiopia [17] supports that exposure to IAP can be reduced by the use of cleaner stoves. Modern stove decisively reduces [30] the smoke in the kitchen, resulting in better health conditions.

A technical report by Global alliance for clean cookstoves also states 4.3 million premature deaths annually and 110 million disability-adjusted life years resulting from household air pollution, including lower respiratory infections, chronic obstructive pulmonary disease, lung cancers, heart disease, and cataracts [3].

3.4. Preservation of forest reserves

One of the most prominent drivers of substituting traditional cookstoves to the modern stove is its impact on forest degradation. In this study, estimates of fuelwood impacts on biomass stocks degradation are based on baseline information provided by the Ethiopian National Woody Biomass Inventory and Strategic Planning Project [31]. WBISPP estimated above-ground volume for dense (50–80% crown cover) broadleaf forest to be 82 t/ha biomass and 40 t/ha for open forest [31].

The estimated annually forest degradation for cooking is 4.76 ha and 9.77 ha of dense forest cover and open forest cover of biomass respectively. To calculate the benefits due to preserved forest resources as a result of substitution by electric cookstove were determined based on the following assumption: all of the firewood consumed for cooking purposes comes from the forest cover [32] and the cost of the forest reserve is equals the cost of afforestation vice versa.

Therefore, substituting traditional cookstove by modern cookstoves can preserve the annual cost of fuelwood, which is equivalent to the costs needed for afforestation of 4.76 and 9.77 ha of dense and open forest cover respectively. Thus, the present results have implications concerning forest degradation since fuelwood is the major cause of deforestation which damages the ecosystem [14]. Thus the use of modern cookstoves can reduce pressure on forests [33] for cooking activity.

This finding is also supported by WBISPP that in Ethiopia fuelwood for energy consumption, leads to massive degradations of the biomass, estimated to 14 t per year and its impact on degradation is expected to reach, 22 t per year by 2030, as the evolution of fuelwood consumption is strongly correlated to population growth [34]. The result is also consistent with other earlier studies, who document the importance of modern cookstoves to reduce forest degradation [35].

3.5. Carbon dioxide emission

As we see from Table 5 and Table 6 below the annual CO2 emission of Werabe University using traditional cookstove, single clay and double clay electric stove was 714.8 t, 6.53 t and 8.03 t respectively (see Table 7).

Carbon dioxide emission of single clay and double clay electric stove was 6.53 t and 8.03 t which is less than the traditional cookstoves 714.8 t CO2 emissions. Comparing CO2 emissions reduction for stoves using different energy sources is complicated [36]. Therefore, for better comparison emissions factors of different energy sources need to be normalized and expressed in commensurate terms.
Consequently, traditional cooking stove CO2 emission was calculated by the emission factor of 1kg firewood [23] multiplied by the total amount of firewood used Table 5. Similarly, emissions of CO2 using electricity energy source is calculated by the emission factor for Ethiopia grid electricity [37] 0.1189 kg CO2 per KWh.

The CO2 emission of traditional cookstoves can be reduced by 99.08% and 98.87% if single clay and double clay electric stove have been used. A study by Dino et al also indicates, electric stove reduces CO emission by 99% [8]. The t-test made to evaluate the CO2 emission variation of the two electric stoves showed that the difference is statistically insignificant.

Cooking food using a traditional device is a major cause of CO2 especially in developing countries [37]. However, substitute traditional stove by modern stove enables emission reduction of CO2 Table 6[1].

A study by FDRE [34] supports our finding that using fuelwood saving stoves enables to reduce greenhouse gas (GHG) emission offering a potential of almost 35 t CO2e reductions.

Anhalt and Holanda’s, research support the present study that modern cooking stoves can be a solution to current global GHG emissions resulted from traditional biomass stoves [38]. Another studies [39] also document that, on a per–meal-equivalent basis, burning of biomass fuel in inefficient stoves could contribute more to global warming than fossil fuel using stoves.

Hence the research implies modern cooking stoves are one option of mitigating climate change by reducing CO2 emissions. Thus from this study, we conclude that CO2 emissions reductions are another environmental benefit obtained from modern cookstoves.

### 3.6. Transition to modern energy

According to energy ladder theory, as income increases, households to purchase more of clean energy sources also increases and viss versa [40]. Here the theory indicates a transition from a traditional energy source to the modern energy source is influenced by households’ income level. As the discussion with the responsible persons for cooking activity indicates, the sampled university still relies on the traditional energy source. The study shows, as higher education’s runs huge budget the cost of electric cookstoves, which don’t exceed 3,000 birr (107 USD) to afford...
modern energy appliance is not an income problem. From this one can understand that, for higher institution income level don’t affect to substitute traditional energy device by the clean one.

The finding of this study is different from the energy ladder theory because energy ladder theory states the importance of income [41] to adopt modern cooking appliance at the household level. Therefore, the current study disagrees on the significance of income to adopt modern cooking appliance at the institution level.

So, to identify factor influencing electric stove adoption, interview with the University’s student service representative person was made. Accordingly, the respondent gave two reasons why the university has not been substituting traditional stove by advanced or electric stoves. The first reason for not cooking food using the advanced stove is frequent transmission failure of electricity in the area.

“… in Werabe town transmission failure of electricity is a serious problem. Therefore, due to transmission failure of electricity, cooking food using electric power in Werabe University is impossible”.

Lack of attention about the benefits of advanced stoves is the other determinant factor that hinders the adoption of the advanced cooking stove in the study area.

“…the university has not considered the cost reduction, forest preservation and other related issues of the electric stove”.

The finding of this study shows the failure of electricity and lack of attention in the university is the most determinant factors for advanced stove adoption in the institution. Thus this study concludes substitution traditional cooking stove by modern cooking stove is influenced by transmission failure of electricity and lack of attention. This finding is supported by a study conducted in urban Ethiopia [17] which recognizes the significance of awareness for cookstove adoption.

4. Conclusion

Majority of people living in developing countries use biomass for cooking and baking, and injera baking is one of the main cooking activities undertaken in the eastern part of Africa, especially in Ethiopia. This study shows that Electric injera baking stoves are much better than traditional cooking devices for several reasons.

The first benefit of cooking food using electric stoves is their fuel cost reduction. The energy cost for cooking injera using the traditional stove is 595,200 birr (equivalent to 21,257 USD) \( y \) \(^{-1} \). However, if the cooking process is done by using single clay electric stove and double clay electric stove the cost of fuel is reduced to 195,300 and 260,400 birr (equivalent to 6,975 and 9,300 USD) \( y \) \(^{-1} \) respectively (Table 3). Consequently, a single clay electric stove reduces energy cost by 159 % and double clay electric stove reduces by 148 % \( y \) \(^{-1} \). Therefore the finding of this study may have economic implication for the country in general and Werabe University in particular.

The second advantage of injera baking electric stove over the traditional stove is their forest preservation potential. On average Werabe University uses 390.6 t of fuel wood \( y \) \(^{-1} \) only for injera baking, which is equivalent to deforestation 4.76 ha and 9.77 ha of dense and open forest. Therefore, deforestation 4.76 ha and 9.77 ha of dense and open forest can be avoided by using an electric baking stove. The result of this study shows the role of the electric baking stove in reducing the pressure of traditional stove on forest cover, which has a contribution to minimize loss of soil nutrients and to maximize in agricultural productivity [14].

Researchers also reveal that in Ethiopia 50 million m\(^3\) of fuelwood is used for cooking and lighting which is a major cause of deforestation [13]. Hence, the present study indicates switching from traditional cookstove into electric cook stove plays a substantial role to reduce environmental degradation.

The third benefit of injera baking electric stove is their \( CO_2 \) emissions reduction. In Werabe University baking injera using traditional cookstove is a cause of 714.8 t \( CO_2 \) emissions \( y \) \(^{-1} \) which can be reduced to 6.53 t and 8.03 t of \( CO_2 \) by using single clay electric stove and double clay electric stove.

Therefore, \( CO_2 \) emission of traditional cookstoves can be reduced to 99.08% and 98.87% by using single clay electric stove and double clay electric stove. The study conducted in Ethiopia also indicates electric stove reduces \( CO \) emission by 99% [8], hence; it has an impact on climate change [18]. Technical report by Global alliance for clean cookstoves also shows that wood fuel consumption across Africa and Asia causes up to 3% of annual global \( CO_2 \) emissions equivalent to 0.5–1.2 billion t in \( CO_2 \) and 25% of global black carbon emissions; which contributes to \(~1.36\) billion t of forest degradation and deforestation [19]. Thus, our study concludes that electric stove has an impact on the reduction of \( CO_2 \) emission which is used as one option of climate change mitigation.

Health benefits are the fourth important role in switching traditional cookstove to electric cookstoves. This study indicates electric cookstoves lowers IAP which is a risk factor for many illnesses, and that the reduction consequently improves health. Assessment on the implementation of the 2030 Agenda for Sustainable Development indicates that globally each year, close to 4 million people die prematurely [4] due to illness to air pollution attribute from inefficient cooking practices [8] which can be reduced by utilizing cleaner stove.

Furthermore, the study identifies the most important barriers for electric stoves adoption in Werabe University. An electricity transmission failure and lack of attention about the benefits of clean cookstoves are the determinant factor of electric stove adoption in the institution.

Finally, the present study concludes, clean stoves are better option to reduce multiple health, environmental and economic effects of solid fuel dependence [42].

4.1. Recommendation

Despite being aware of the negative health and environmental impacts of traditional biomass, the institution has not adequately mainstreamed the advantage of clean cooking into its focuses agenda. There is, therefore, an urgent need for the administration of the university to target the deployment of clean cooking technologies. On the bases of the research finding the authors forward the following recommendations:

1. Even though both single and double clay electric stoves are better than traditional cookstove, single clay electric stove is more efficient than double clay electric stove. Hence single clay electric stove is economically, environmentally and socially the best injera cooking device.

2. When the research findings indicate, electricity transmission failure and lack of attention about the benefits of clean cookstoves are the determinant factor of electric stove adoption in the institution.

Finally, the present study concludes, clean stoves are better option to reduce multiple health, environmental and economic effects of solid fuel dependence [42].

Declarations

Author contribution statement

Fikadu Mamuye Bayu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.
Additional information

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