# Assessing the contribution of improved stove to the household income and environmental protection in Musanze district, Rwanda.

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**Abstract:** In Rwanda, fuel products such as charcoal, firewood, crop residues and dung are usually used for cooking. Firewood collection is perceived as an increasing difficult task, and many people walk long distances to look for it. To overcome the shortage of fuelwood and environmental degradation issues, several solutions are possible: reforestation, improving the performance of the charring, the use of improved stoves and other sources of energy such as sun, peat and biogas. The purpose of this study was to investigate how improved stove can both contribute to the forests protection and to increase the household income. The methodology used was a cooking test experiment by repeating three times each trial and a boiling water test. The experimentation was conducted throughout both cooking the required food for the family of about 5 members as well as boiling water test to determine the stove's efficiency. Some quantity of food such as 1 kg of rice, 3 kg of potatoes, 3 liters of maize porridge and 1 kg of dried beans have been cooked on metal improved firewood stove model as well as on a traditional one. Thus, the cooking time and the firewood consumption of all complete cooking spans have been determined. The boiling test has used 3 liters of water in order to determine the thermal efficiency of different studied stoves. The rate of forest protection, firewood and time saved and the cost benefit resulting from the adoption of the improved stove over the use of traditional stove have been determined by using the formulas. The final findings prove that metal improved firewood stove model contributes to protect forests significantly at the rate of 50.33%. This can save firewood consumption at a considerable proportion, reduce the cooking time for about 21% and contribute to increase household income at 50.33% referring to the budget reserved to the use of firewood by households.

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## 1. Introduction

Energy is critical for the daily life of people in Rwanda and for the development of the country. More than 98% of energy for cooking is drawn from fuel wood (firewood and charcoal) and vegetable materials. Firewood alone accounts for more than 80% (MININFRA, 2009). Almost all firewood used in Rwanda is locally produced and it is used for domestic purpose. Unfortunately, the consumption of firewood for cooking currently used by Rwandese was not sustainable and firewoods are not sufficient. Indeed, when firewood is scarce in rural areas, residents typically move down the ladder to crop residues and dung, occasionally they even turn to grass and roots for cooking energy.

Rwanda depends on biomass for 95% of its total energy use. However, inefficient transformation and use of biomass and a rapidly growing population have put Rwanda's natural resources base under intense pressure. Excessive cutting of trees for fuel, farming, and urbanization has led to deforestation, soil erosion, and excess run-off that have reduced the lifespan of dams and hydro-electric power. Lacks of energy in some regions has exacerbated food security and nutritional deficiencies undermining the country's effort to meet its development objectives.

In Rwanda, the demographic pressure has great major influence on cultivable space and natural resources (MINICOFIN, 2002). It is found that firewood is the dominant energy source for the most cooking activities done by the rural populations, including cooking food, keeping the houses warm, heating water and so on. Fuels such as crop residues, charcoal and firewood are used for cooking in considerable amount. Firewood collection is perceived as an increasingly difficult task and many people walk long distance looking for wood (Okorio et *al.*, 2003) and the problem is acute in all areas of Rwanda. Forestlands decreased by 70 % from 1958 to 1996 due to cutting trees by looking for pasture or cropland.(e.g Gishwati and Mukura forest reserves with respectively 86 % and 90 % of their area destroyed while Mutara hunting domain disappeared completely). About 96, 2 % of households in Rwanda use wood as a source of energy whereas more than 60 % of urban populations use charcoal as a source of energy. Rwandan flora contains 699 plant species recognized as medicinal plants but the population pressure on forests provokes their extinction. The surface area of natural forest reserve fell from 510,000 ha in 1958 to 447,900 ha in 1985. It fells dramatically further from 446,800 ha in 1960 to 193,510 ha in 1999 signifying a 62 % reduction in 40 years (MINICOFIN 2002).

For more than half the world's population living in rural areas or the cities of the third world, fuel wood and its derivatives, charcoal is essential to survival as food itself. The problem of fuel wood is more crucial than it was usually noticed. As more wood is cut, deserts will spread (De Lepeleire et al., 1981).

Many strategies of forest protection in Rwanda have been adopted such as biogas and hydroelectric plants. However, it is expensive to operate those sources of energy production. The imported fossil fuel is also too expensive. Indoor air pollution due to the biomass fuel has been shown to be in an important factor increasing the prevalence of acute respiratory infections in infants and children, and chronic obstructive lung diseases (cold), often leading to heart damage, in adult women. Studies undertaken by De Lepeleire et al., (1981) show that exposure to harmful indoor air pollutant, and thus the mobility and mortality it can cause, could be significantly reduced by installation, adoption and use of improved stoves. Women and children are the main suppliers of fire wood accounting to 60 % and 23 % respectively; men account 13 % and housemaids 4 %. Using improved stoves would reduce time utilized in fetching firewood and use it in other development activities.

Improved stove programs have almost been promoted in Rwanda in order to reduce the use of wood for fuel and thus to reduce deforestation rate. To overcome the shortage of fuel wood and environmental degradation, several solutions are possible such as reforestation, improved performance of the charring, use of improved firewood and charcoal stoves and use of alternative energy resources such as sun, peat and biogas. The specific objectives of this study were: (i) to determine the annual firewood saving by using improved firewood stoves over the traditional ones; (ii) to estimate money saved by using improved firewood stoves; (iii) to calculate the time saved by using the improved firewood stoves instead of local ones; (iv) to estimate the saved total surface of trees cut down when using improved firewood stoves over the use of traditional stoves. Upon the completion of this study, the following hypotheses should be tested and verified: (i) there is a high interest gained by using the improved firewood stoves than the traditional ones; (ii) the studied stoves use equal time and firewood while cooking the same food; (iii) the improved firewood stoves contribute to forest protection; (iv) the use of improved firewood stoves contribute more to save money than using local stove.

## 2. Material and methods

### 2.1 Study area description

The study was conducted in Busogo Sector, Musanze District of the Northern Province, in Rwanda. This region surrounds the Volcanoes National Park with a gently undulating slope of about 15 %. The area has a tropical climate, high altitude with an average temperature of $20^0$C. The annual rainfall varies between 1400 mm and 2000 mm. The altitude varies from 2,500 m to 2,700 m but the mean altitude of Busogo sector is 2,000 m a.s.l. The Climate regime has two rainy seasons and two dry seasons allocated during the year as follows: From June to mid –September : the long dry season, from January to mid-March : early season, from mid-March to late May : the big rainy season, from mid September to late December : the small rainy season (Annual Report, District of Musanze, 2006)

### 2.2 Materials

This study needs the data collection about the improved cooking stove and traditional stove for which the experiment is carried out. Hence the following materials are used:

**Table 1: Material used for cooking**

| $N^O$ | Material | Description | Quantity |
|---|---|---|---|
| 1 | Improved stove | Improved stove made with metal | 1 |
| 2 | Traditional stove | Traditional stove made with 3 opened stones | 1 |
| 3 | Firewood | Dried firewood from *Eucalyptus sp* | - |
| 4 | Beans | Dried beans | 6 kg |
| 5 | Potatoes | Harvested potatoes | 18 kg |
| 6 | Rice | Harvested Rice | 6 kg |
| 7 | Maize flour | After grinding maize | 1.45 kg |
| 8 | Water | To prepare different kind of food | - |
| 9 | Balance | To weight firewood | 1 |
| 10 | Knife | To prepare potatoes | 1 |
| 11 | Chronometer | To record time | 1 |

| | | | |
|---|---|---|---|
| 12 | Salt | To put in food | 0.5 kg |
| 13 | Pan pot | To cook | 3 |
| 14 | Termometer | To record temperature of water | 1 |

Two cooking stoves are used. They are specified by the name Metal Improve firewood stove and traditional firewood stove. The distinctive figures are given below:

**Photograph 1: Metal improved cooking stove Photograph 2: Traditional cooking stove**

The experimental set consists of different firewood stove such as metal improve firewood stove and traditional firewood stove, have been used for this study. The objective is to make comparison between these different stoves in order to determine which one uses little quantity of fire wood and time in order to further reduce overexploitation of forests and to increase household income. Before cooking test, the firewood was weighed in order to find the quantity of firewood consumed by cooking stove.

**2.3 Methods**

The methodology was described as the elaboration of a cooking test by preparing the daily quantity of food required for the 5 members in household by repeating three times for each experience and boiling water test in order to evaluate the thermal efficiency of the stoves.

**Potatoes cooking test**

The first test consists of cooking 3 kg of potatoes on each stove. After cooking potatoes, the following data were collected: Firewood used was recorded by weighing the quantity of firewood before and after cooking on each stove. The time taken for cooking test was recorded by using chronometer.

**Beans cooking test**

The second test consists of cooking 1 kg of beans on each stove. After complete cooking of each stove, firewood used and time taken for cooking have been determined: Firewood consumption: firewood used was recorded by weighing the quantity of firewood before and after cooking on each stove. The time taken for cooking test was recorded by using chronometer.

**Rice cooking test**

The third test was done by cooking 1 kg of rice on each stove. It means that firewood consumption by using a three open stone stove and metal improved stove was recorded. Then, the time taken by cooking rice was determined. Firewood consumption: firewood used was recorded by weighing the quantity of firewood before and after cooking on each stove. The time taken for cooking test was recorded by using chronometer

**Maize porridge cooking test**

The fourth test was to prepare three liters of Maize porridge on metal improved firewood stove as well as on local one. After complete cooking on each stove, the firewood consumption and time taken were determined. Firewood consumption: firewood used was recorded by weighing the quantity of firewood before and after cooking on each stove. The time taken for cooking test was recorded by using chronometer

**Water boiling test**

Boiling test was carried out to measure the performance of different cooking stoves in this study. For all stoves, the amount of fuel consumed and burning time were recorded, the evaporated water was recorded, as well as the temperature, the thermal efficiency was calculated from the calorific value of firewood.

**2.4 Data analysis**

In data analysis the following formulas have been used to determine parameters such as:

1. Annual firewood saved**:** It will be determined by calculating the annual firewood consumed by local firewood stove minus the annual firewood used by improved cooking stove. Thus, annual firewood consumed means the daily firewood consumption multiplied by 365 days. Daily firewood saved equals the daily firewood consumed by using a traditional stove minus daily firewood quantity consumed by using improved cooking stove.

$$\text{Fire wood saving rate} = \frac{\text{Annual firewood saved}}{\text{Annual firewood consumed by traditional stove}} \times 100$$

(Okorio et al., 2003)

2. Time saved**:** It has been found by calculating the difference between the time taken by local stove minus time used by improved firewood stove.
3. Benefit cost of improve cooking stove over traditional firewood stove**:** It was found out by analyzing the cost reduction rate in terms of money saved by adopting the improved firewood stove over the local one.
4. The forest protection rate: It was determined by the total areas required by using traditional firewood stove used in cooking meal of 5 family members minus total areas required by using an improved firewood stove used in cooking meal of 5 family members.

## 3. Results and discussion

### Potatoes cooking test

For each potato cooking test 3 kg of Irish potatoes added with quantity of water has been cooked in a pan pot on the metal improved firewood stove as well as on a local stove. The pan was covered in order to avoid the heat loss due to the evaporation while cooking. The firewood consumed while cooking was weighted and the time used by cooking in test experience has been recorded. The potatoes were cooked until they get the desirable state to be consumed. The following table is summarizing the results.

**Table 2: Firewood and time used while cooking potatoes**

| Nº of test | Firewood consumption / Kg | | Time used / min | |
|---|---|---|---|---|
| | Metal Improved stove | Local stove | Improved stove | Local stove |
| 1 | 1 | 1.78 | 30 | 49 |
| 2 | 0.96 | 1.73 | 30 | 47 |
| 3 | 0.8 | 1.68 | 32 | 45 |
| Mean | 0.92 | 1.73 | 31 | 47 |

The metal improved firewood stove used 0.92 kg of dried wood to cook 3 kg of potatoes during 31 minutes whereas the traditional firewood stove consumed the high quantity of firewood of 1.73 kg during the cooking time of 47 minutes.

### Beans cooking test

The same quantity of dried beans with variable quantity of water has been cooked on a metal improved fire wood stove respectively on local stove. The pot pan was covered to avoid the loss of heat while cooking. Beans with water were cooked until the level of being eaten. After repeating three times to find the mean of each stove while cooking, the amount of firewood consumption has been weighed and the time taken for complete cooking was recorded.

**Table 3: Firewood and time used while cooking beans**

| Nº of test | Firewood consumption / Kg | | Time used / min | |
|---|---|---|---|---|
| | Metal Improved stove | Traditional stove | Metal Improved stove | Traditional stove |
| 1 | 3 | 5.97 | 155 | 179 |
| 2 | 2.95 | 5.95 | 153 | 183 |
| 3 | 3 | 6.2 | 150 | 175 |
| Mean | 2.98 | 6.04 | 153 | 179 |

Regarding the information from the table 3, metal improved stove used 2.98 kg of dried wood to cook 1 kg of beans during 153 minutes whereas the traditional firewood stove consumed the high quantity of firewood of 6.04 kg during the cooking time of 179 minutes.

### Rice cooking test

One kg of rice with 3 liters was cooked on metal improved firewood stove model, as well as on a three open stones stove namely local stove. The difference between the studied stoves according to the firewood and time saved is shown in the following table 4.

**Table 4: Firewood and time used while cooking rice**

| N° of test | Firewood consumption / Kg | | Time used / min | |
|---|---|---|---|---|
| | Metal Improved stove | Local stove | Improved stove | Local stove |
| 1 | 0.8 | 1.75 | 36 | 45 |
| 2 | 0.8 | 1.65 | 35 | 47 |
| 3 | 0.8 | 1.62 | 38 | 50 |
| Mean | 0.8 | 1.67 | 36 | 47 |

From this table 4, it is observable that metal improved stove save firewood more than traditional one. While rice are cooked improved stove consumed low quantity of firewood 0.8 kg and the cooking time of 36 minutes but traditional firewood stove consumed high quantity of firewood like 1.67 kg and uses only 47 minutes.

**Maize porridge cooking test**

The maize porridge test was done three times both on metal improved stove and traditional stove. 3 liters of maize mush porridge have been prepared; this quantity is assumed to be sufficient for 5 members of a Rwandan household. The used firewood and the total time consumed for complete cooking have been calculated. The findings are summarized in the table 5.

**Table 5: Firewood and time used while cooking maize porridge**

| N° of test | Firewood consumption / Kg | | Time used / min | |
|---|---|---|---|---|
| | Metal Improved stove | Local stove | Improved stove | Local stove |
| | | | | |
| 1 | 0.49 | 0.95 | 15 | 20 |
| 2 | 0.50 | 1.1 | 12 | 23 |
| 3 | 0.48 | 0.99 | 14 | 24 |
| **Mean** | 0.49 | 1.01 | 14 | 22 |

The results showed that the mean quantity of firewood used while maize porridge preparation on metal improved firewood stove is 0.49 kg but the traditional one consumed high quantity of firewood about 1.01 kg and it take highest time more than improved firewood stove due to their low heating efficiency like 14 minutes for improved firewood stove than 22 minutes for traditional one.

**Table 6: Total daily quantity of firewood used in by Rwandan household**

| N° | Cooking food | Quantity of food cooked | Quantity of firewood and time used in cooking test | | | |
|---|---|---|---|---|---|---|
| | | | Metal improved firewood stove | | Traditional firewood stove | |
| | | | Quantity of firewood in kg | Time used/min | Quantity of firewood in kg | Time used/min |
| 1 | Potatoes | 3kg | 0.92 | 30.6 | 1.73 | 47 |
| 2 | Beans | 1kg | 2.98 | 152.6 | 6.04 | 179 |
| 3 | Rice | 1kg | 0.8 | 36 | 1.67 | 47 |
| 4 | Maize porridge | 3L | 0.49 | 13.6 | 1.01 | 22 |
| 5 | Total | | 5.19 | 233 | 10.45 | 295 |

The results from above table 6, showed the total daily quantity of firewood used and time used by using metal improved cooking stove and local one in cooking 1 kg of beans, 1 kg of rice, 3 kg of potatoes, and 3 liters of maize porridge on improved stove, we have used 5.19 kg and 233 min while for cooking 1kg of beans, 1 kg of rice, 3 kg of potatoes,, and 3 liters of maize porridge, by using traditional cooking stove, we have used10.45 kg of firewood and 295 min.

**Boiling water test**

Boiling water test was done in order to measure the different performances between an improved firewood stove and the traditional firewood stove involved in the study according to the thermal efficiency of cooking stove which is the ratio of energy content in the fuel. The thermal efficiency has been determined through the following procedures in each stove three times:

1. 3 liters of water have been measured and boiled;
2. The quantity of firewood consumed has been recorded;
3. The evaporated water has been recorded;
4. Thermal efficiency has been calculated from the calorific value of firewood.

Boiling test is used to determine thermal efficiency of cooking stoves. The achieved results will help us to choose the more efficiency stove which will be recommended and popularized to the users of fire wood as cooking fuel. To achieve this objective, boiling water test carried out by using pot pan, but the pan was not covered to avoid evaporation.

Before cooking test, the firewood was weighed in order to find the quantity of firewood consumed by cooking and temperature has been recorded until it will be constant. The purpose was to determine the firewood used for certain time and amount of water evaporated in that time. In this method, efficiency ($n_c$) is defined as the ration of useful heat energy used to the input heat energy.

$$n_c = \frac{\text{Useful heat energy}}{\text{In put heat energy}} \times 100$$

Useful heat energy is the sensible and latent heat absorbed by boiled water whereas input heat energy is the one, which was released from the burning of firewood in each stove. According to Okorio e*t al.,* (2003), the useful heat energy efficiency of fire wood is mathematically defined as:

$$n_c = \frac{Mw\,Cpw(Tb - Ti) + MweLv}{Mfwu\,Cvfw} \times 100$$

Where:

- $n_c$ = Thermal Efficiency of stove
- Mw = the initial mass of water in kg
- Cpw = specific heat capacity of water = 4.2 x1 $0^3$ $jkg^{-1}$
- Tb = Final temperature of water in degree centigrade
- Ti = Initial temperature of water in degree centigrade
- Mwe = mass of water lost due to evaporation
- Lv = latent heat of vaporization of water =2.258 x $10^6$ $jkg^{-1}$
- Mfw = mass of fire wood used
- Cvfw = calorific value of fire wood =1.68 x $10^7$ $jkg^{-1}$

During the experiment, two experiments have been done successively on metal improved stove and traditional stove by boiling 3 liters of water and the mean efficiency of three repetition obtained from each stove has been taken as the average of thermal efficiency. The temperature rise after 5 minutes for each stove has been also recorded.

**Table 7: Temperature rise in water boiling test**

| **Time in minutes** | **Temperature rise ($^o$c) in two different stoves** | |
|---|---|---|
| | **Improved stove** | **Local stove** |
| 0-0 | 19 | 19 |
| 0-5 | 42 | 45 |
| 5-10 | 50 | 52 |
| 10-15 | 69 | 62 |
| 15-20 | 77 | 75 |
| 20-30 | 89 | 84 |
| 30-35 | 91 | 89 |
| 35-40 | 92 | 90 |

The table 7 above illustrates how the temperature increases the first time in local stove than into the improved one because it is little difficult to burn firewood at the first moment then after 10 minutes the temperature increase more than in the traditional one.

**Table 8: Table of data used to calculate the thermal efficiency for two different cooking stoves**

| **Parameter** | **Metal improved stove** | **Traditional stove** |
|---|---|---|
| Mw =Initial mass of water in l | 3 | 3 |
| Mwe= Water evaporated in l | 1.1 | 0.78 |
| Ti= Initial water temperature $^o$c | 19 | 19 |
| Tf= Final water temperature $^o$c | 92 | 90 |
| Mfwu= firewood used in kg | 1.28kg | 2.1kg |
| Lv = latent heat of vaporization of water | 2.25 x $10^6$ $jkg^{-1}$ | |
| Cvfw = calorific value of fire wood | 1.68 x $10^7$ $jk^{-1}$ | |
| Cpw = specific heat capacity of water | 4.2 x1 $0^3$ $jkg^{-1}$ | |

The thermal efficiency of metal improved firewood stove ($n_{ca}$) has been calculated with the following calculation.

$$n_{ca} = \frac{3 \text{ x } 4.2 \text{ x } 103 \text{ jkg -1} (92 - 19) + 1.1 \text{ x } 2.258 \text{ x } 106 \text{ jkg -1}}{1.28 \text{ x } 1.68 \text{ x } 107 \text{ jk -1}} \times 100 = 15\%$$

The thermal efficiency of traditional firewood stove ($n_{cb)}$ has been calculated with the following calculation.

$$n_{cb} = \frac{3 \text{ x } 4.2 \text{ x } 103 \text{ jkg -1} (90 - 19) + 0.78 \text{ x } 2.258 \text{ x } 106 \text{ jkg -1}}{2.1 \text{ x } 1.68 \text{ x } 107 \text{ jkg -1}} \times 100 = 7.53\%$$


**Figure 1: The thermal efficiency of used stoves**

As evidenced by the figure 1 above that the thermal efficiency of metal improved firewood stove in this experience is 15 % whereas the thermal efficiency of traditional firewood stove is 7.53 %. The difference is very high because traditional firewood stove lost a lot of energy since the heat obtained by combustion is not concentrated on the cooking pot but the metal improved firewood stove used achieve more complete combustion and force as much heat into the pot as possible. Hence, referring to the thermal efficiency, it is better to adopt improved firewood stove instead of traditional one. This shows how improved firewood stove contributes a lot to save firewood and time over traditional stove. The total daily quantity of firewood consumed while cooking have been weighted and the time saved was determined.

The following figure 2 shows the difference between the 2 studied stoves on firewood.

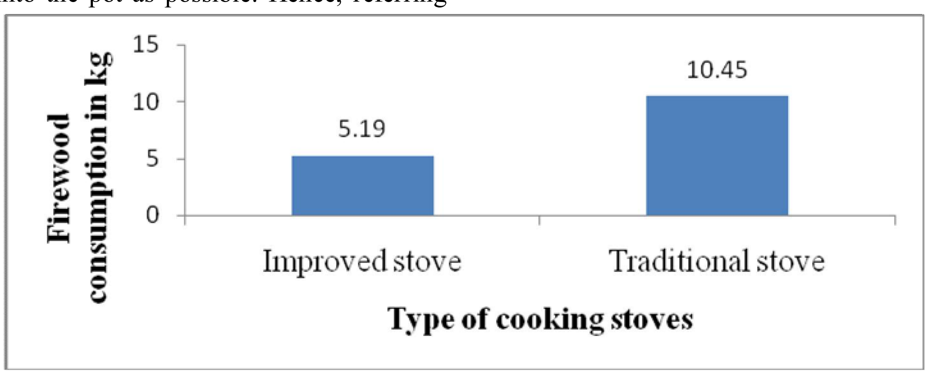


**Figure 2: Daily mean of firewood consumption**

As shown in the figure 2, the daily quantity of firewood consumed for cooking is 10.45 kg and 5.19 kg respectively on the traditional firewood stove and the improved firewood stove. Our results are lower than what found by (Harerimana, 2010) in the same area who obtained 5.823 kg and 11.97 kg respectively for improved stove and local stove. This variation was caused by types of firewood used, stoves used and variety of food cooked.

The following figure 3 shows the time in minute for a household by using the different cooking methods such as improved cooking stove and traditional one.

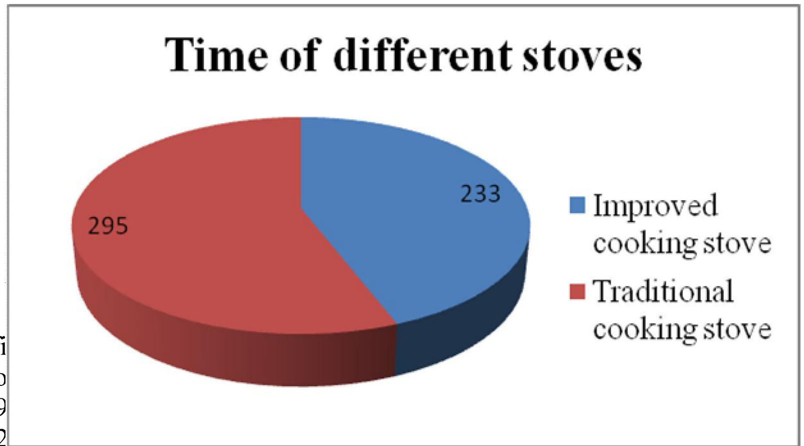


**Figure 3: The daily**

From the fi
cooking all daily foo
of 5 members is 29
firewood stove and 2
stove. The daily time saving and the annual firewood saved have been determined by adopting the formulas explained above.

**The time saved by using improved cooking stove over the traditional one**

The experience done was about to cook daily quantity of food required for required for a Rwandan household of 5 members like: 1 kg of rice, 3 kg of potatoes, 1 kg of beans and 3 little of maize porridge. The following formulas were used to determine the saving of time in percentage.

**The saving time in percentage** =

$$\frac{\text{time saved}}{\text{Time for traditional stove}}\times 100$$

**The saving time in percentage** =

$$\frac{295-233}{295}\times 100 = 21\%$$

The metal improved firewood stove used save the time at the rate of 21% per day, more than one hour can be saved. This saved time can be used by everyone engaged in cooking for other different activities. This result is lower than what found by Harerimana, (2010) 24% of time saved. The variation is caused by different factor such as firewood, stoves and varieties of food cooked.

**Annual quantity of firewood saved by using improved firewood stove for cooking**

The annual firewood saved by adopting the improved firewood stove over local one have been found by calculation of difference between annual firewood consumption of a traditional firewood stove and an improved one.

AFS = AFCL - AFCI

AFC = DFC X 365jrs

AFCL= 10.45 kg/jr X 365jrs = 3,814.25kg

AFCI = 5.19 kg/jr X 365jrs = 1,894.35kg

AFS =3,814.25kg-1,894.35kg=1,919.9kg of firewood saved in a year

$$\frac{AFS}{AFCL}\times 100 =$$

$$\frac{\ldots}{3{,}814.25\text{kg}}\times 100 = 50.33\%$$

Where:

**AFS:** Annual Firewood Saving

**AFCL:** Annual Firewood Consumption for Local stove

**AFCI:** Annual Firewood Consumption for Improved stove

**AFC:** Annual Firewood Consumption

**DFC:** Daily Firewood Consumption

According to the results coming from the substitution of metal improved stove used and traditional one, it is clear that the rate of firewood saved per year per household is 50.33%. The result obtained in our test is lower than the one got by Harerimana, (2010) who obtained 51.3% and the study done in Uganda (Helga Habermehl Eschborn, 2006) showed that the average fuel saving rate for improved stoves was 55% which is also higher than our results. Therefore, it is important to use improved firewood stove instead of traditional one.

**Roles of improved cooking stove in forest protection**

In Rwanda, the total actual population is estimated at 11,000,000 inhabitants with the mean family members of 5 persons.

Then, the total families in Rwanda are =

$$\frac{11{,}000{,}000}{5} = 2{,}200{,}000 \text{ families}$$

According to the data from 3rd census 2002, 84.4 % of families in Rwanda used firewood as source of cooking energy. The Rwandan families using firewood for cooking were $\frac{2{,}200{,}000\text{x } 84.4}{100}$ = 1,856,800 families per year

The annual quantity of firewood used when all those Rwandan families use traditional firewood stoves is 1,856,800×3,814.25=7,082,299.4 tons of dried firewood. But, by adopting an improved firewood stove, the annual quantity of firewood required is 1,856,800×1,894.35=3,517,429.08 tons. It was assumed that one hectare produces 20 dry tons of firewood: to satisfy the users of traditional cooking stoves in Rwanda, we need 7,082,299.4t/20t/ha=354,114.97ha; to satisfy the users of traditional cooking stoves in Rwanda, we need 3,517,429.08 t/20t/ha=175,871.45ha.

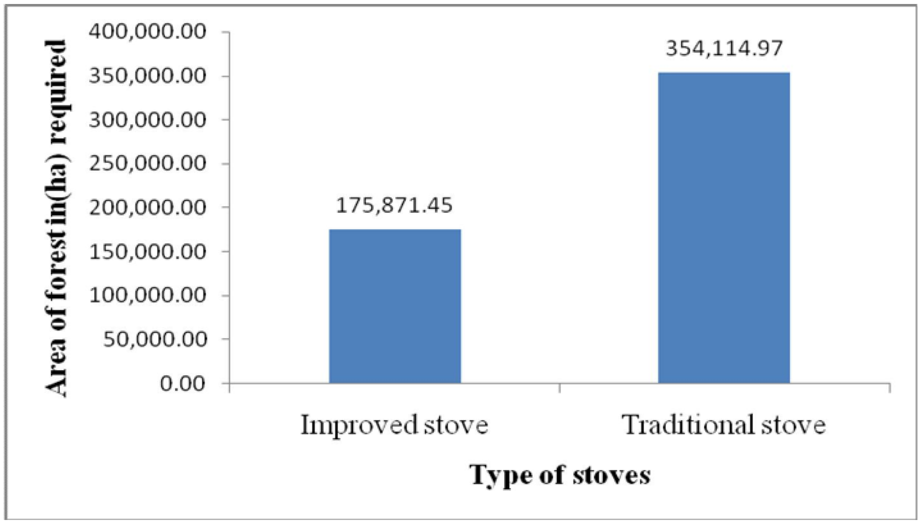


**Figure 4: Areas of forest required for used stoves**

The figure 4 shows how improved firewood stoves contribute to reduce deforestation rate. Then, if all Rwandan family users of firewood as cooking energy adopt improved firewood stoves over local stoves, the 178,243.52 ha of trees plantation will be saved. From the above results, improved firewood stove contributes to reduce deforestation at the rate of 50.33% over local stove. Our results differ from what Harerimana, (2010) found (186,407.53 ha) which was higher than ours. The variation is caused by the increase of population, stoves and firewood used.

**Cost benefit analysis of cooking on different stoves**

The cost- benefit analysis while using different stoves for cooking daily food for Rwandan household is done by working out the following aspects: Cooking cost for each stove and benefit cost reduction when using improved firewood over local stove.

**Cooking cost**

For comparing the cooking cost between improved firewood stove over local stove, the quantity of firewood used to satisfy the daily requirement in food of five members of household has been measured for each firewood stove used by multiplying the weight of firewood in kg and the price rate per kilogram of firewood. The present rate of one kg is 40 Rwf. The comparison of cooking cost is shown in the following table 9.

**Table 9: The comparison of cooking cost**

| Stove | Daily firewood/kg | Daily cost in Rwf | Annual cooking cost in Rwf |
|---|---|---|---|
| Local stove | 10.45 | 418 | 152,570 |
| Improved stove | 5.19 | 207.6 | 75,774 |
| Saving | 5.26 | 210.4 | 76,796 |

From the above table 9, the cooking cost is directly proportional to the daily firewood consumption of each stove. Considering the amount in Rwandan francs related in the table 9, the cooking cost is very lower on improved firewood stove than traditional ones. The benefit cost from the improved firewood stove over traditional one has been found by analyzing the cost reduction in the term of money saved by adopting an improved firewood stove over traditional one. The cost reduction by adopting improved firewood stove instead of local one has been found by using the below formula.

$$\text{Cost reduction} = \frac{\text{Cost saved}}{\text{Cost of traditional stove}} \times 100 = \frac{76{,}796\text{Rwf}}{152{,}570\text{Rwf}} \times 100 = 50.33\%$$

The Total amount of budget will be reduced at 50.33% per year for a household of 5 persons.

Therefore, adopting improved firewood stove results in high cost reduction rate 50.33% compared to the traditional one. Hence, considering the cost benefit analysis, it is better to adopt improved firewood stove for firewood burnt cooking application. This result is also lower than what obtained by (Harerimana, 2010) who obtained 51.35%. The variation was caused by improved cooking stove used and firewood.

**Area protected by adopting improved cooking stove =** Area required for traditional stove minus Area required for improved stove (354,114.97ha-175,871.454ha) =178,243.516ha

**Forest protection rate**

$$= \frac{\text{Areas protected}}{\text{Areas required for traditional stove}} \times 100$$

$$= \frac{178{,}243.51}{354{,}114.97} \times 100 = 50.33\%$$

The metal improved firewood stove used save the forest at the rate of 50.33% per year.

## 4. Conclusion

The general objective of this study was to assess how improved firewood stoves contribute to forest protection while increasing the household's income. The methodology used was to establish two cooking stove and cook different food by repeating three times each experience and using a boiling water test. Thus, the cooking time and firewood consumption of all complete cooking spans have been determined. The rate of forest protection, the firewood and time saved as well as the cost benefit got by adopting improved firewood stove over local ones have been determined. Regarding the findings from the cooking tests, the improved firewood stove plays a greater role on forests protection and contributes to the increase of household's income. The results of all cooking tests indicate that one family with 5 members per household would use 5.19 kg of firewood per day when using improved firewood stove and 10.45 kg of firewood per day by using traditional one. The time used for cooking by using traditional stove is 295 minutes and 233 minutes by using improve stove with the difference of 62 minutes. The improved stove can protect the forest at the rate of 50.33% at the national level once used further. Hence there is a high difference between metal improved cooking stove over traditional stove on the fire wood quantity and time used for cooking food. With the improved firewood stove, the annual firewood budget will be reduced at the rate of 50.33% per year instead of using traditional stove. Once, the improved firewood stove is adopted by all Rwandan families using firewood as cooking energy, it will save 178,243.516 ha of forests, and this will lead to the prevention of the desertification process, soil erosion, green house effect and the destruction of the environment. It could also contribute to the poverty reduction by generating income to the Rwandan people from rural and urban society. The thermal efficiency of metal improved firewood stove in this experience is 15 % whereas the thermal efficiency of traditional firewood stove is 7.53 %.

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