Journal of Environmental Protection, 2018, 9, 619-635
http://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Environmental Impacts (ER CO_2) of an Improved Multi-Fuel Gasifier Forced Air Cookstove in the City of Kinshasa

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How to cite this paper: Ilunga, O.M. and José, H.P.E. (2018) Environmental Impacts (ER CO_2) of an Improved Multi-Fuel Gasifier Forced Air Cookstove in the City of Kinshasa. *Journal of Environmental Protection*, **9**, 619-635.
https://doi.org/10.4236/jep.2018.96039

Received: March 29, 2018
Accepted: May 28, 2018
Published: May 31, 2018

Abstract

Sub-Saharan African countries depend 80% on the biomass-wood to meet their daily needs in terms of cooking foods. Traditional cookstoves are much more used to this effect. Many change programmes for replacing cookstove model have been planned. Yet many of these programmes have not been preceded by environmental impact studies. This work offers high-performance cookstove models and determines their impact on the reduction of CO_2 emissions, a very harmful greenhouse gas causing the planet warming and climate change. Replacing the traditional cookstove by an improved stove may lead to an economy in terms of fuel ranging from 33.2% to 75.4% according to the model of cookstoves. Yet the Gasifier using pellets as fuel remains the most beneficial stove in terms of fuel saving (75.4%) and in terms of ER CO_2, *i.e.* 2748 t CO_2/Year. An improved gasifier cookstove is multi-fuel. He can use charcoal, pellets and wood. This is an indispensable cooking tool with alternative fuels. In this work, the ER CO_2 was evaluated using two methods. The KPT, which is a field method and the CCT which is a laboratory method. By the KPT method a gasifier ICS/GAS/P records up to an ERCO_2 of 2748 t CO_2/Year, while with the same gasifier, an ERCO_2 of 2619 t CO_2/year is found by the CCT method. The comparison between the two methods shows the same trend but with very high values of ERCO_2 for the KPT method results. The variation between the two methods ranges between 1% approximately to 6.9 percent.

Keywords

Improved Cookstove, Biomass, Gasifier, CO_2 Emissions

1. Introduction

More than half of the world's population still depends on biomass combustion to meet their basic energetic needs [1]. Sub Saharan African countries do use 80% the wood biomass for their basic needs in cooking foods. Biomass cookstoves contribute significantly to the current problems of climate change [2]; contributing 22% of global emissions of black carbon, compared with only 7% of the burning of fossil fuels [3] [4] [5]. It is estimated that more than 2.5 billion people in the world use biomass for cooking. The burning of biomass is one of the major contributors to the emission of carbon dioxide (CO_2)—a main gas in global warming and climate change. One way to reduce CO_2 emissions is the adaptation of efficient and clean energy technologies. This number is expected to increase to 2.7 by 2030 due to the growth of the human population [6]. Biomass burning is one of the major contributors to emissions of carbon dioxide (CO_2)—a main gas in global warming and the climate change. One way to reduce CO_2 emissions is the adaptation of efficient and clean energy technologies [7] [8] [9]. The authors [9] in their study attempted to examine the energy efficiency of cookstoves in the Amboseli ecosystem by comparing the cooking time, the use of energy, and wood fuel consumption and the emissions of carbon as referential of comparison with famous and old traditional three-stone fireplace. The study showed that improved cookstoves enabled the saving of 12.7% - 33.3% of firewood compared to traditional three-stone stove [9]. The sources of renewable energy, including bioenergy, currently attract considerable attention as a possible substitute for fossil fuels. Among the different sources of bioenergy, biomass can no doubt play an important role in the reduction of greenhouse gases and the provision of a stable energy supply. The study answers these questions by referring to a case of a Japanese rural community using the firewood for residential heating [10]. The results showed that the use of woody biomass to solve the needs of residential heating allows to reduce dependence on fossil fuels and to mitigate climate change. These results provide new perspectives on sustainable development in rural communities [11] [12].

For the moment, the general assumption is that the use of biomass for energy production is "carbon neutral" on its life cycle because the biomass combustion releases the same amount of carbon dioxide captured by the plant during its growth [13] [14].

However, there are also greenhouse gas (GHG) emissions arising during the production stages because external fossil inputs are required to produce and collect the biomass. It is advisable to take into account all energy inputs and GHG emissions that occur during the stages of production from the point of view of the life cycle [13] [14] [15].

In many countries of sub-Saharan Africa, collecting firewood is one of the main drivers of deforestation and especially the degradation of forests [16]. In a detailed field study in the region of Kafa, in the South of Ethiopia, they have assessed the potential of improved cookstoves to mitigate the negative impacts of harvesting of firewood on forests [17]. Eleven thousand improved "Mirt" type cookstoves (ICS) have been disseminated. The results show a high rate of acceptance of the "Mirt" cookstove out of approximately one hundred forty interviews, including users and nonusers of the "Mirt" ICS. Studies have shown savings of nearly 40% in the cooking of the popular local meal "injera" using the Mirt cookstove as opposed to the traditional three-stone fireplace. This allows a total annual saving of 1.28 tonnes of firewood per household. Given the approximate share of firewood from non-sustainable sources, these savings translate into 11,800 tonnes of CO_2 saved for 11,156 improved Mirt cookstoves disseminated. This corresponds to the amount of carbon stored in more than 30 hectares of local forest. These studies confirm that effective cookstoves, if they are well adapted to the local culinary habits, can make a significant contribution to forest conservation and the prevention of carbon emissions due to clearing and to the degradation of the forests [16] [18] [19] [20] [21]. Poor performance traditional cookstove emit more CO_2, which contributes to global warming and climate change. The warming effect of CO_2 is known to be ±15%, while the estimated effect of black carbon (Black carbon BC) is subject to a triple uncertainty or higher [4]. In this study, the authors evaluated the carbon monoxide (n = 54) and fine particles (PM = 2.5) (n = 58) with non-smoker Honduran cooks, who cook with a traditional or improved woodstove in two communities: semi-urban and urban.

At the same time, indoor air pollution from traditional cooking is a major risk for health [22]. Maggie L. and her teammates have not assessed (n = 54) carbon monoxide and fine particles (PM = 2.5) (n = 58) with Honduran non-smoker cooks, who cook with a traditional or improved woodstove in two communities: a semi-urban and the other urban [23]. In [24] the authors are conducting a field study on a few households in three countries in West Africa (Guinea Bissau, Senegal and Gambia) to evaluate the effect of improved air quality in the kitchen. A study on measuring carbon monoxide (CO) and fine particles (PM2.5) was conducted for a period of 24 hours, before and after the installation of cookstoves. To avoid the problem of the great variability of the results, all measurements must be taken, before and after the installation of improved cookstoves, during the same season and under the same climate conditions [25] [26]. Smith and his teammates, 2007 in their studies [27], have shown major and statistically significant improvements in levels of pollution of indoor air in CO and PM2.5 for households using improved cookstoves. The CO levels are reduced by 30% to 70% and concentrations of PM2.5 from 25 to 65 percent.

This work shows the importance of the impact on the environment, more specifically in the reduction of CO_2 emissions and the adoption of "gasifier" cookstoves compared with the old traditional system and other existing direct burning models of cooking.

2. Material and Methods

2.1. Methods

2.1.1. The Controlled Cooking Test CCT2.0

The controlled cooking test (CCT) has been used for conducting the various tests. The CCT is a laboratory test consisting in cooking a real typical meal.

Cooks are selected who prepare a real meal. The amount of fuel at the start and at the end of cooking work is strictly measured. All the other ingredients involved in cooking are measured: water, oil, salt, tomato, etc. In order to minimise errors due to the operator, the T27 (a series of 27 CCT tests) was used, which consists of 27 tests with 3 selected cookers with 3 cookstoves. Every cook will make 3 tests on every cookstove. That makes a total of 27 tests made. All tests are performed under the same environmental conditions in order to avoid disturbances due to external variables: winds, temperature, pressure etc. Wang Y. and his teammates, 2013 suggest that the number of tests is higher than 20 tests for good accuracy in the results [18] [28] [29]. Before the CCT test, cooks should have had enough time to get used to the use of the new cookstoves to be tested. A 2 weeks' period of use of new cookstoves was granted to all 3 testers. During the entire testing time, the 3 cooks freely prepare their local meals without receiving external orders. Balis R. and his teammates, 2004 indicate that the controlled cooking test (CCT) is designed to evaluate the performance of the improved cookstoves compared with the traditional cookstoves that the improved model must replace. Cookstoves are compared using a standard kitchen task that is closer to the real cooking that people do every day. A dry meal consisting of 1200 g beans and 1200 g of rice was cooked during all the different tests. This is a popular meal preferred by the inhabitants of Kinshasa. This amount of food is equal to the daily consumption of a household of 10 people. The key CCT parameters can be calculated as follows [30]:

- **The total mass of cooked foods**: it is calculated simply by the relationship (1) just at the end of cooking.

$$Wf = Wfp - Wp \quad (1)$$

with: Wf: mass of meals prepared [Kg]. Wfp = mass of the pot + prepared meals [Kg]. Wp = mass of the empty pot without meals [Kg].

- **Specific fuel consumption** (SFC): is the main performance indicator when a CCT is performed. This is the amount of fuel required to cook a given quantity of food for a common and typical meal. It is calculated as a simple relationship of the mass of fuel on the mass of food. The SFC is calculated by the following relation (2).

$$SFC = \frac{Wfuel}{Wfp} \quad (2)$$

with: SFC: Specific fuel consumption [$g \cdot Kg^{-1}$]. $Wfuel$: is the mass of fuel used for cooking the mass meal Wfp [g]. Wfp is the mass of cooked meals [Kg].

- **Total cooking time** (Δt): the cooking time is an important indicator of performance in the CCT. This time is calculated by the relationship (3), as a simple difference of time.

$$\Delta t = tf - ti \quad (3)$$

with: Δt: the total cooking time [min]. tf: time of ending the cooking [min]. ti is the time of starting the cooking work [min].

2.1.2. The Kitchen Performance Test KPT

Balis *et al.*, 2007 remind us that the Kitchen Performance Test KPT is the main way or real methodology usable in the ground to demonstrate the effect of interventions of cookstoves on domestic fuel consumption [30]. The KPT has two main objectives: 1) to evaluate the qualitative aspects of the performance of the improved cookstoves through household surveys and 2) to compare the impact of improved cookstoves household fuel consumption. To achieve these objectives, the KPT includes quantitative studies on fuel consumption and qualitative studies on the performance and the acceptability of the improved cookstove. This type of test, the KPT, when carefully conducted, is the best way to understand the impact of cookstove on the use of the fuel and the characteristics and general behaviour of the household, because this test is performed on the very ground, at the house of the real user of the cookstove and under real use conditions. The number of tests for a KPT is equal to about 10% of number of households. For a city or village of more than 1000 households, the number of tests can be fixed at 100 tests [30].

During the CCT test, we tried to cook a much preferred and consumed staple in Kinshasa. It is a meal composed of 1400 g or rice and of 1400 g of beans. This food is the daily consumption of food for a family of 10 people. Therefore, to achieve a good comparability of the CCT and the KPT results, we chose 40 households in 3 poor municipalities of Kinshasa. A total of 120 households are selected in the municipalities of Masina, Ndjili and Kimbaseke. In these municipalities, it is estimated that 95% of the population depends entirely on biomass for their culinary needs. Households freely cook their daily meals. To carry out the test of KPT well, a small practical training on size measurement is provided to the various people who work in the KPT. In each daily cooking activity, the cook takes the following measures: the start fuel, the end fuel, the remaining quantity of charcoal in the cookstove, the start time and end time of the cooking.

2.1.3. Estimate of the Fuel Saving of an ICS

When substituting a traditional cookstove (TCS) for an improved cookstove (ICS), the economy in the use of the fuel can be calculated using the following Equation (4):

$$E_{f\%} = \frac{\text{Fuel TCS} - \text{Fuel ICS}}{\text{Fuel TCS}} * 100 \quad (4)$$

with: $E_{f\%}$ = fuel saving in an ICS. TCS Fuel = amount of fuel used by a TCS for a special cooking task [Kg]. Fuel ICS = amount of fuel used by an ICS for the same task of cooking [Kg].

2.1.4. Environmental Analysis of the Impact of an ICS

- Estimate of the carbon dioxide (CO_2) reduction [31] [32] [33] [34].

Calculations for the reduction of carbon dioxide (ER) emissions result from the use of non-renewable wood in cookstoves. The ER CO_2 are calculated using the AMS-II G methodology included in the clean development mechanism of the framework Convention of the United Nations on climate change as stipulated in the UNFCC literatures, 2016 and UNFCC, 2015 [31] [32] [33] [34]. The relationship (5) can be used to assess these reductions of carbon dioxide.

$$ER_{y,i,j} = N_{y,i,j} X \mu_y X f_{NRB,y} XNCV_{\text{biomass}} XEF_{\text{project fossil fuel}} \quad (5)$$

with: $B_{y\,\text{savings}}$ = Quantity of woody biomass that is saved in tonnes per cook stove device of type i and batch j during year y [tonnes];

$N_{y,i,j}$ = Number of project devices of type i and batch j operating during year y;

Adjustment to account for any continued use of pre-project;

μ_y = devices during the year. Use 1.0 in other cases;

$f_{NBR,y}$ = Fraction of woody biomass that can be established as non-renewable biomass using survey methods or government data or default country specific fraction of non-renewable woody biomass (f_{NRB} = Default values of DR Congo is 90%);

NCV_{biomass} = Net calorific value of the non-renewable woody biomass that is substituted (IPCC default for wood fuel, 0.015 TJ/tonne, based on the gross weight of the wood that is "air-dried") [TJ/tonne]. If fuel used in the project device is charcoal, 0.029 TJ/tonne may be used;

$EF_{\text{project fossil fuel}}$ = Emission factor for the fossil fuels projected to be used for substitution of non-renewable woody biomass by similar consumers. Use a value of 81.6 t CO_2/TJ.

When charcoal is used as fuel by the reference cookstove (former) or by new projects (ICS), the amount of woody biomass will be determined by using a conversion factor of 6 kg of wood (wet) for 1 kg of charcoal (dry basis). Alternative and credible local conversion factors can be applied on the basis of a study of ground or a documentary study (UNFCC, 2014) [33].

According to the UNFCC, 2016 [31], in the case of cookstoves, the methodology is applicable to the introduction of portable cookstoves for one pot or several pots with a rated energy efficiency of at least 20%. i, j due to the implementation of effective cookstoves (ICS improved cookstoves) is estimated according to the following options: with a KPT, a CCT or a WBT. In this article, we made a parallelism between two methods: the KPT and the CCT.

***With the KPT method**, we have the following relationship (6):

$$B_{\text{y,savings},i,j} = B_{\text{old},i,j} - B_{\text{new,KPT},i,j} \quad (6)$$

where: B_{old} = Annual quantity of woody biomass that would have been used in the absence of the project activity to generate useful thermal energy equivalent to that provided by the project device type i *and* batch j [t/año].

B_{new} = Annual quantity of woody biomass used in tonnes per project device of type i and batch j, measured as per the KPT protocol, for the initial efficiency determined in the year of its commissioning [tonnes].

***With the CCT method**, it can be calculated using the following relationship (7):

$$B_{y,\text{savings},i,j} = B_{\text{old},i,j} * \left(1 - SC_{\text{new},i,j} / SC_{\text{old}}\right) \quad (7)$$

In which: SC_{old} = Specific fuel consumption or fuel consumption rate of the pre-project devices [t fuel/unit].

SC_{new} = Specific fuel consumption or the fuel consumption rate of the devices of type i and batch j deployed as part of the project [t fuel/unit].

2.2. Material

2.2.1. Forced Air "Gasifier" Improved Cookstove

The biomass gasification cookstove works with two phases unlike a natural ventilation charcoal cookstove (biomass direct burning cookstove) that works in one phase, which is the phase of the biomass combustion. The two phases of the gasification cookstove are: pre-combustion phase: in this phase the solid fuel is broken down into gaseous elements (H_2, CO, NH_4). Phase of combustion: the broken down gaseous elements in the first phase are completely burnt. For this purpose, there must be two air intakes in the combustion chamber. Primary Air: introduced through small holes (10 holes of 2×10^{-2} m at the bottom part of the combustion chamber). It is a small amount of air, sufficient to establish the gasification of biomass. Secondary Air: its essential function is to cause a complete burning of syngas (30 holes of 2×10^{-2} m). Figure 1 represents the broken down model of the biomass gasification cookstoves. The combustion chamber is cylindrical with a diameter 12×10^{-2} m and 18×10^{-2} m in height, covered of ceramic material.

2.2.2. Cookstoves Tested in the City of Kinshasa

The cookstoves tested in this study are represented in Figure 2. The artisanal traditional cookstove (TCS) is represented in Figure 2(A), the improve charcoal cookstove with natural ventilation (ICS/MM1/C) is shown in Figure 2(B) with a 3 mm thick metallic combustion chamber, insulated by glass wool. The

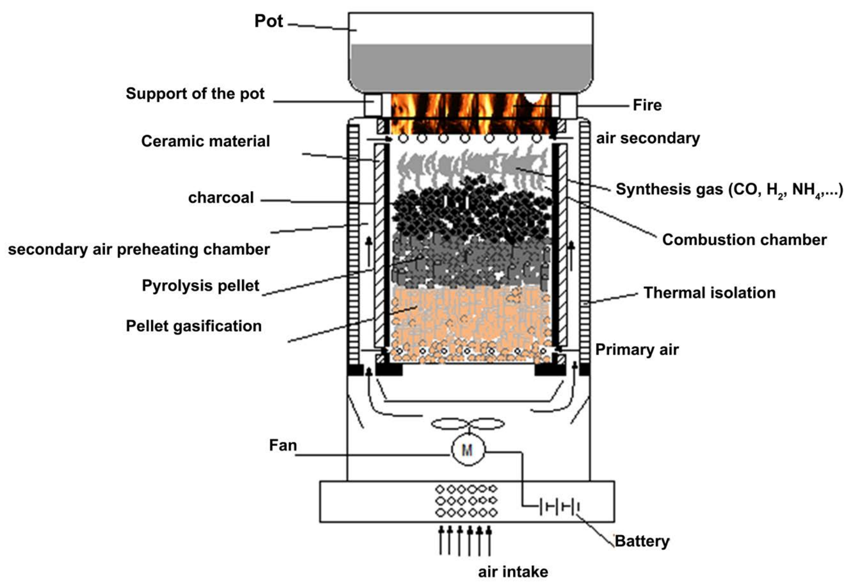

Figure 1. Improved cookstove with forced air biomass gasification.

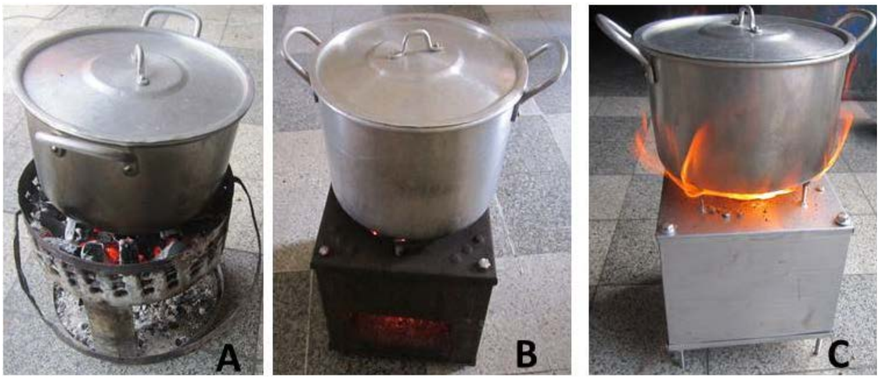

Figure 2. Cookstoves used in the city of Kinshasa.

ICS/MM2/C cookstove is identical externally to the ICS/MM1/C cookstove, but its combustion chamber is Metal-ceramic. Yet, Figure 2(C) shows the multi-fuel forced-ventilation gasification cookstove (ICS/GAS).

2.2.3. Fuels

For fuel, we had used the grain size 30 × 30 mm charcoal obtained from the wood of auriculiformis acacia as shown in Figure 3(A), with a moisture content of 7%, and the pellet of 20 × 60 mm with a humidity level of 7% (Figure 3(B)). The wood used is a species of auriculiformis acacia in 30 × 30 × 100 mm stem with a humidity level of 7% (Figure 3(C)). The following Figure 3 illustrates the different types of fuels used.

3. Results and Discussions

Table 1 gives the results of the CCT tests. This table spreads the SFC and B savings for different types cookstoves with the CCT method. This table shows the result of the CCT test conducted at the laboratory. In the CCT, a common and usual meal is prepared under strict laboratory conditions.

In the laboratory a TCS-23 traditional cookstove consumes 1724 g (SD: 262 HP: 15) of charcoal for 4.12 Kg (SD: 018 Cv: 4.37) of cooked meals). ICS/MM/C consumes 1085 g (SD: 121 Cv: 11) of charcoal for 4 Kg (SD: 019 Cv: 4.9) prepared meals. Then the same cookstove under a same size ceramic combustion chamber requires 1045 g (SD: 111 Cv: 10) of charcoal for 4.18 Kg (SD: 0.2 Cv: 3.6) of cooked meals. The laboratory test confirmed a better consumption of biomass with the "gasifier" with pellets as fuel for a consumption of 2145g (SD: 254 Cv: 12) of pellet for 4, 2 Kg (SD: 0.16 Cv: 3.9) of cooked meal.

Yet it should be indicated that that in the UNFCC literature, 2016 [31] and Schenkel *et al.*, 1997 [36] enables to make the conversion from wood charcoal using the relationship (8) below:

$$M_{\text{wood}} = M_{\text{charc}} * 5 \tag{8}$$

with: M_{wood} = mass of wood [kg]. M_{charc} = charcoal mass [kg]. This is assuming a yield of 20% carbonization [36]. This same transformation will be used as at first approximation for the equivalence of the pellet fuel in charcoal.

Table 1. SFC and B savings for different types cookstoves with the CCT method.

		TCS		ICS/MM1/C		ICS/MM2/C		ICS/GAS/C		ICS/GAS/P*		ICS/GAS/W**	
	n		27		27		27		27		27		27
Fuel [g]	SD	1724	262	1085	121	1045	111	784	79	2145	254	2789	349
	Cv		15		11		10		10		12		3.9
	n		27		27		27		27		27		27
Meal [Kg]	SD	4.12	0.18	4	0.19	4.21	0.2	4.18	0.2	4.2	0.17	4.09	0.16
	Cv		4.37		4.9		4.9		3.6		4		3.9
SFC [g/Kg]		418.45		273.75		248.22		187.56		102.14		136.38	
B olds [t/year]		0.629		-		-		-		-		-	
B savings [tcharc./Year]		0		0.218		0.256		0.347		0.476		0.424	
B savings [twood./Year]		0		1.088		1.280		1.736		2.378		2.121	

*Fuel Pellet; **Fuel Wood SD: standard deviation Cv: Coefficient of variation.

Figure 3. Fuels used during the test.

Table 2 gives the fuel consumption and the amount of biomass saved by the KPT method. The KPT is a true test conducted on the ground being carried out in the very household where the cookstove is to be used. It reflects the reality, because the test is carried out in real conditions with one real meal. TCS traditional cookstoves tested under real daily conditions of use gives a daily consumption of 1812 g (SD: 554 Cv: 31) of charcoal to meet daily needs in cooking foods, *i.e.* an annual consumption of 0.661 t of charcoal. The improved ICS/MM1/C cookstoves using coal shows a consumption of 1200 g (SD: 325, Cv: 27) charcoal. The enhanced cookstove with ceramic ICS/MM2/C using coal, records a 1080 g (SD: 2458, Cv: 23) consumption of charcoal. The “gasifier” is multi fuel. This ICS/GAS/C can consume 823 g (SD: 230 Cv: 28) of charcoal. This same ICS/GAS/P requires 2244 g (SD: 462 Cv: 20.7) of pellets to carry out culinary daily activities. This quantity of pellet is in first approximation equal to 444.8 g of charcoal (with a yield of carbonization of 20%). The B savings for ICS/GAS/P is estimated at 2495 t Wood/Year for the same type of W/GAS/ICS cookstove using wood as fuel, as you can see, the “pellet” fuel would be one of the most economical ways to use the biomass-wood. It gives incredible savings. However, the variation coefficients during the KPT test are very high and reach values of 31%. This shows very large results variability as shown by other studies [35].

The percentage of fuel saved using each type of improved cooking stove is

Table 2. Fuel consumption and B savings for different types cookstoves with KPT method.

		TCS		ICS/MM1/C		ICS/MM2/C		ICS/GAS/C		ICS/GAS/P*		ICS/GAS/W**	
	n		108		108		108		108		108		108
Fuel [g]	SD	1812	554	1200	325	1080	245	823	230	2224	462	2825	676
	Cv		31		27		23		28		20.7		23.9
B olds [t/year]		0.661		-		-		-		-		-	
B savings [tcharc./Year]		0		0.219		0.266		0.36		0.499		0.456	
B savings [t wood./Year]		0		1.098		1.334		1.804		2.495		2.28	

*Fuel Pellet **Fuel Wood SD: standard deviation Cv: Coefficient of variation.

shown in Figure 4. The benefits of using improved cooking stoves are therefore clearly visible. Improved cookstoves present very significant savings in fuel compared with the traditional model of cookstove as you can see in Figure 4. A Moto Makx cookstove without MM1ceramic can save up to 33.2% fuel compared to traditional cookstove used in the city of Kinshasa TCS-23. An ICS/MM2/C of the same model as the first, but with the ceramic in the combustion chamber saves 40% of fuel. An ICS/GAS/C Gasifier using charcoal as fuel saves 54.5% of fuel. An ICS/GAS/P using the pellets as fuel reached a better fuel economy, 74.5% (this percentage is calculated taking into account the conversion chain of wood into charcoal of 20%). Wood pellets made dense would be the best way to use the biomass-wood from the point of view of consumption compared to charcoal, given the low transformation performance of carbonization of wood into charcoal.

The results of testing by the CCT method, a strict method of laboratory shows the following reductions in CO_2 emissions for the different cookstoves as you can see in Figure 5: ICS/MM_1/C, ER CO_2 1.198 t CO_2/Year; ICS/MM_2/C ER CO_2 1.409 t CO_2/Year; ICS/GAS/C ERCO_2 of 1.942 t CO_2/Year; ICS/GAS/P ERCO_2 2.619 t CO_2/Year and ICS/GAS/W, ERCO_2 of 2.336 t CO_2/Year. The largest ER CO_2 is for the improved "Gasifier" cookstove using the pellets as fuel.

The method of KPT is carried out on the ground, under real conditions. Despite the variability of the results we can notice in Figure 6 below the following values in the evaluation of the ER CO_2: 1.21 t CO_2, 1469 t CO_2, 1988 t CO_2/Year, 2748 t CO_2/Year and 2511 t CO_2/Year respectively for following improved cookstoves: ICS/ MM_1/C, ICS/MM_2/C, ICS/GAS/C, ICS/ GAS/P and ICS/GAS/W.

The method of KPT is carried out on the ground, under real conditions. Despite the variability of the results we can notice in Figure 7 below the following values in the evaluation of the ER CO_2: 1.21 t CO_2, 1469 t CO_2, 1988 t CO_2/Year, 2748 t CO_2/Year and 2511 t CO_2/Year respectively for following improved cookstoves: ICS/MM_1/C, ICS/MM_2/C, ICS/GAS/C, ICS/GAS/P and ICS/GAS/W.

The comparison between the two methods shows the same trend but with very high values of ERCO2 for the KPT method results. The variation between the two methods ranges between 1% approximately to 6.9 percent. The reason

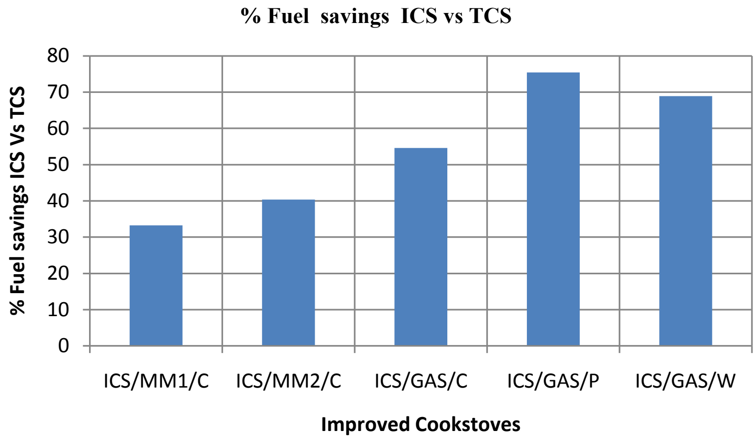

Figure 4. Fuel saving improved cook stoves Vs traditional cookstove.

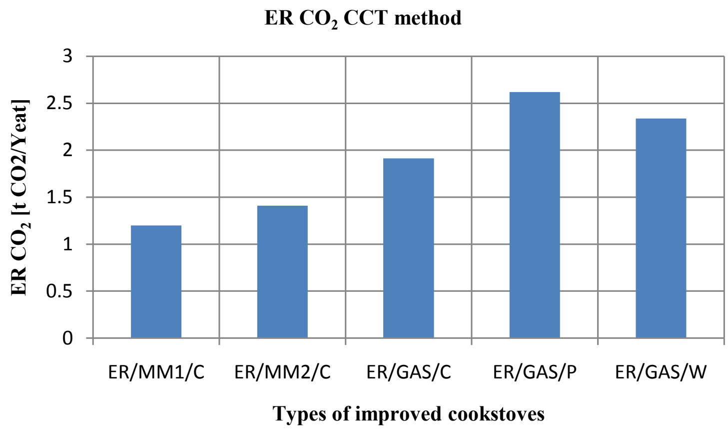

Figure 5. ER CO_2 by CCT method.

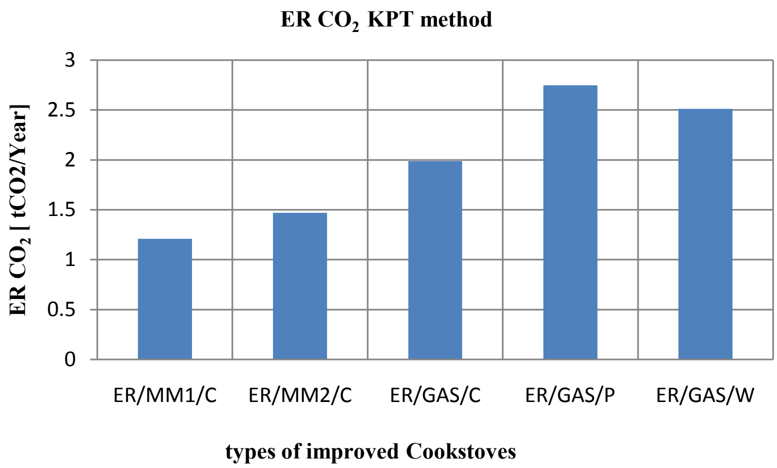

Figure 6. ER CO_2 by KPT method.

for somehow high values in the method of CCT laboratory is that for a KPT the tests are in a real universe in which we cannot control all the test settings as compared to a CCT in which everything is strictly controlled and monitored.

Figure 8 shows estimates of $ERCO_2$ over a lifetime period of 5 years for

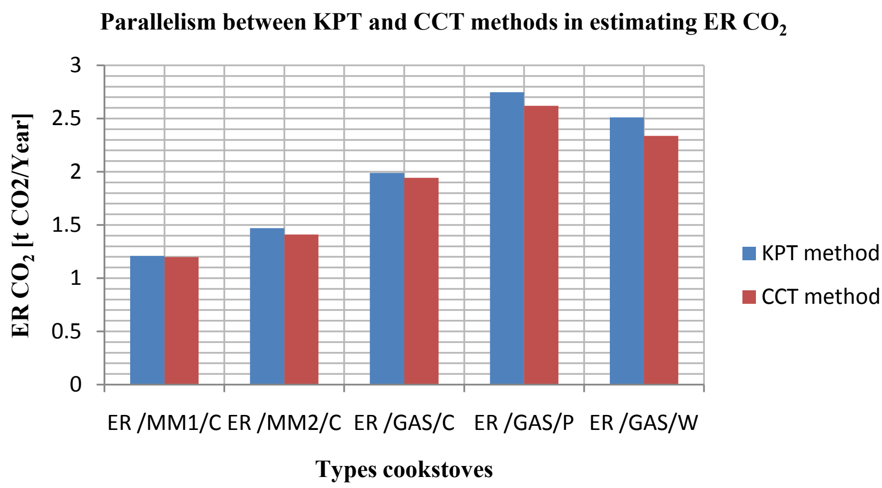

Figure 7. Parallelism between KPT and CCT methods in estimating ER CO_2.

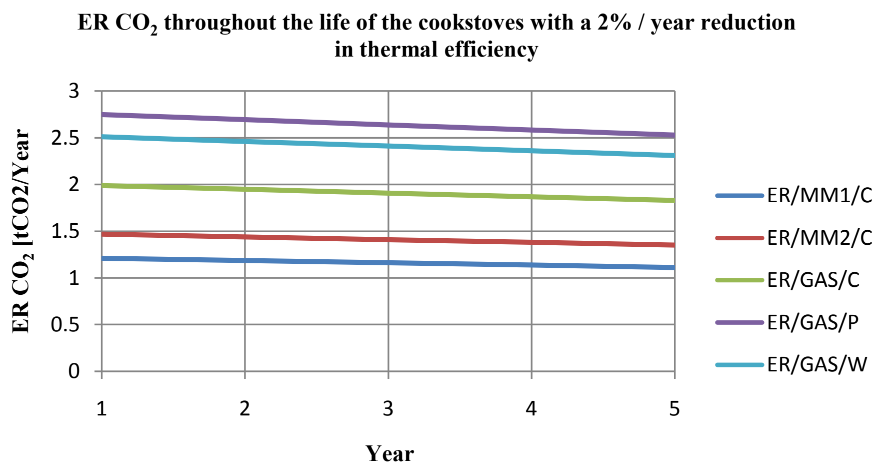

Figure 8. ER CO_2 Estimate over 5 years with a 2% thermal performance depreciation/Year.

a cookstove with a 2% performance reduction/Year compared to the initial value. When the cookstove is used under the effect of heat, there is a degradation of the chamber of combustion materials, thermal and other insulation materials. It is therefore necessary to provide in the estimation of the CO_2 ER a depreciation of the thermal efficiency, therefore also a depreciation of the $ERCO_2$. We see for example for an ICS/MM_1/C, the following values year after year over 5 years of estimated lifetime: 1210 t CO_2 year 1, 1.186 t CO_2 $year_2$, 1161 t CO_2 year 3, 1.137 t CO_2 year 4 and 1, 113 t CO_2 year 5.

Figure 9 shows estimates of the reduction of CO_2 emissions for the city of Kinshasa in the Democratic Republic of the Congo for a total change of 100% in the use of traditional TCS cookstove by improved ICS cookstoves. The current population in the city of Kinshasa is estimated at 16 million inhabitants, with an annual growth rate of the population of 3.15%. By applying the relationship (9) [37], it is easy to make the population projection and estimates of ER CO_2 2030 taking into account that only 80% of the population depends mainly on biomass

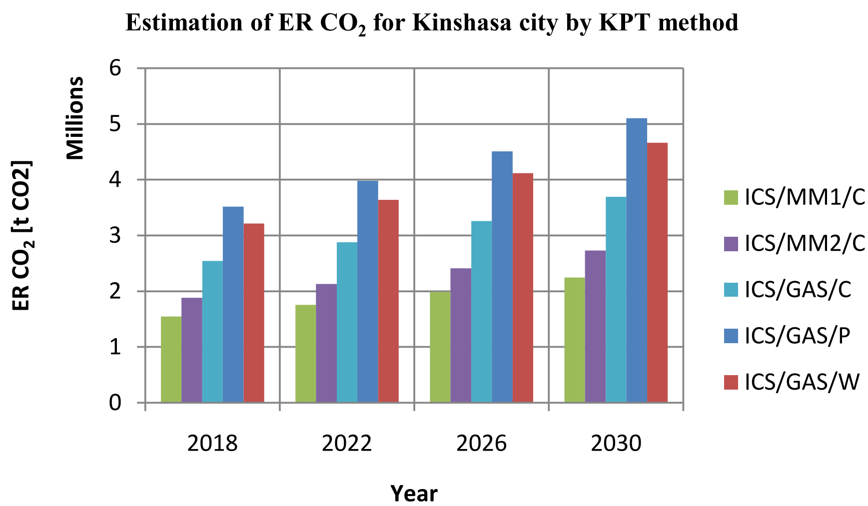

Figure 9. Estimation of ER CO_2 for Kinshasa city by KPT method.

to solve its daily cooking needs.

$$P_n = P_o\left(1+\sigma\right)^n \tag{9}$$

with: P_n = population at time n. P_o = population at initial time σ = population growth rate [%] n = projection time in years [37].

An ICS/MM1/C cookstove ensures an ER CO_2 of 1.21 t CO_2 for a household of 10 people. This brings us to 121 Kg CO_2 per person, 274 CO_2/person and 251.1 Kg CO_2/person for the cookstoves ICS/MM2/C, ICS/GAS/C, ICS/GAS/P and ICS/GAS/W by the KPT method. The estimates give ER CO_2 of 154,800 TCO_2 for ICS/MM1/C and of 1,880,320 TCO_2 for ISC/MM2/C. In all such scenarios, the most beneficial cookstove in ER CO_2 remains the biomass gasification cookstove ICS/GAS using pallets as fuel with an ER CO_2 estimated at 3,517,440 t CO_2 for 2018.

4. Conclusions

The CO_2 is one of the potent greenhouse gases contributing to global warming and climate change. Several measures to limit or reduce CO_2 emissions are taken worldwide. For poor countries in Africa that depend almost entirely on biomass energy to meet their energy needs in terms of cooking. The reduction of CO_2 emissions is based on a change of attitude in the cooking methods of food. Traditional cookstoves with low efficiency consume too much bio fuel. An improved cookstove can save 30% to 75% of biomass. This has the primary benefit of limiting or slowing down deforestation.

Improved cookstoves remain useful tools in the Sub-Saharan countries to reduce CO_2 emissions and to therefore stop the climate change and global warming of the planet. More than 90 percent of the population in Kinshasa use traditional cookstoves of poor energetic performance. Several cookstove models were proposed on the market, but their real impacts have not been assessed in terms of the ER CO_2. This work has just shown that improved cookstoves significantly reduce CO_2 emissions. An improved charcoal cookstove with natural ventilation, ICS/MM1 can reduce up to 1.21 t CO_2/Year. Yet the present study has just pointed out that the most advantageous use in terms of $ERCO_2$ remains the use of multi fuel gasification cookstove. This type of cookstove can reduce up to 2748 t CO_2/Year through KPT method and 2619 t CO_2/Year by using CCT method using the pellets as fuel.

The gasifier has multiple advantages: the power of fire can be set; it uses solar energy for ventilation control; the energy stored in the solar system and the small battery can be used effectively at night to solve the lighting problems in rural areas in African rural areas feeding small efficient LED lamps. In addition an improved "Gasifier" cookstove is multi fuel. It can use the charcoal, pellets and wood. This is an indispensable tool for cooking with alternative fuels.

References

[1] Rehfuess, E., Mehta, S. and Prüss-Üstün, A. (2006) Assessing Household Solid Fuel Use: Multiple Implications for the Millennium Development Goals. *Environmental Health Perspectives*, **114**, 373-387. https://doi.org/10.1289/ehp.8603

[2] Tigabu, A. (2017) Factors Associated with Sustained Use of Improved Solid Fuel Cookstoves: A Case Study from Kenya. *Energy for Sustainable Development*, **41**, 81-87. https://doi.org/10.1016/j.esd.2017.08.008

[3] Ramanathan, V. and Carmichael, G. (2008) Global and Regional Climate Changes due to Black Carbon. *Nature Geoscience*, **1**, 221-227. https://doi.org/10.1038/ngeo156

[4] Ramanathan, V. (2007) Role of Black Carbon in Global and Regional Climate Changes. http://www-ramanathan.ucsd.edu/files/bc-testimony.pdf

[5] Thacker, K.S., Barger, K.M. and Mattson, C.A. (2017) Balancing Technical and User Objectives in the Redesign of a Peruvian Cookstove. *Development Engineering*, **2**, 12-19.

[6] Adria, O. and Bethge, J. (2013) What Users Can Save with Energy-Efficient Cooking Stoves and Ovens. Wuppertal Institute for Climate, Environment and Energy. http://www.bigee.net/media/filer_public/2014/03/17/appliance__residential_cookingstoves__user_savings__20140220__8.pdf

[7] OECD/IEA (2006) Energy for Cooking in Developing Countries. https://www.iea.org/publications/freepublications/publication/cooking.pdf

[8] Bryden, M., Still, D., Scott, P., Hoffa, G., Ogle, D., Bailis, R. and Goyer, K. Design Principles for Wood Burning Cook Stoves. http://www.bioenergylists.org/stovesdoc/Pcia/Design%20Principles%20for%20Wood%20Burning%20Cookstoves.pdf

[9] Manoa, D.O., Oloo, T. and Kasaine, S. (2017) The Efficiency of the Energy Saving Stoves in Amboseli Ecosystem-Analysis of Time, Energy and Carbon Emissions Savings. *Open Journal of Energy Efficiency*, **6**, 87-96. https://doi.org/10.4236/ojee.2017.63007

[10] Sawauchi, D., Kunii, D. and Yamamoto, Y. (2015) Carbon Dioxide Emissions and Energy Self-Sufficiency of Woody Biomass Utilization for Residential Heating: A Case Study of Nishiwaga, Japan. *Journal of Environmental Protection*, **6**, 321-327. https://doi.org/10.4236/jep.2015.64032

[11] Halder, P. (2014) Forest Biomass for Energy Production: Perceptions of State For-

estry Professionals from China and India. *Challenges*, **5**, 338-350.
https://doi.org/10.3390/challe5020338

[12] Mac Cormic, K. and Kautto, N. (2013) The Bioeconomy in Europe: An Overview. *Sustainability*, **5**, 2589-2608. https://doi.org/10.3390/su5062589

[13] Cherubini, F., Bird, N.D., Cowie, A., Jungmeier, G., Schlamadinger, B. and Gallasch, S.W. (2009) Energy- and Greenhouse Gas-Based LCA of Biofuel and Bioenergy Systems: Key Issues, Ranges and Recommendations. *Resources, Conservation and Recycling*, **53**, 434-447.

[14] Cherubini, F. and Stromman, A.H. (2011) Life Cycle Assessment of Bioenergy Systems: State of the Art and Future Challenges. *Bioresource Technology*, **102**, 437-451. https://doi.org/10.1016/j.biortech.2010.08.010

[15] Havlík, P., Schneider, U.A., Schmid, E., Böttcher, H., Fritz, S., Skalský, R., Aoki, K., Cara, S.D., Kindermann, G., Kraxner, F., Leduc, S., McCallum, I., Mosnier, A., Sauer, T. and Obersteiner, M. (2011) Global Land-Use Implications of First and Second Generation Biofuel Targets. *Energy Policy*, **39**, 5690-5702.
https://doi.org/10.1016/j.enpol.2010.03.030

[16] Dresen, E., DeVries, B., Herold, M., Verchot, L. and Muller, R. (2014) Fuelwood Savings and Carbon Emission Reductions by the Use of Improved Cooking Stoves in an Afromontane Forest, Ethiopia. *Land*, **3**, 1137-1157.
https://doi.org/10.3390/land3031137

[17] Hosonuma, N., Herold, M., de Sy, V., de Fries, R.S., Brockhaus, M., Verchot, L., Angelsen, A. and Romijn, E. (2012) An Assessment of Deforestation and Forest Degradation Drivers in Developing Countries. *Environmental Research Letters*, **7**, Article ID: 4009. https://doi.org/10.1088/1748-9326/7/4/044009

[18] Pérez, E.J.H., Ilunga, O.M. and María Cristina Moros Gómez et Carlos Vargas Salgado (2017) Analyse des impacts économico-environnementaux du changement d'usage d'un foyer de cuisson traditionnel par un foyer de cuisson amélioré optimisé à charbon de bois dans les ménages de la ville de Kinshasa.
http://lodel.irevues.inist.fr/dechets-sciences-techniques/index.php?id=3714

[19] Egeru, A.S. (2014) Rural Households' Fuelwood Demand Determinants in Dryland Areas of Eastern Uganda. *Energy Sources, Part B: Economics, Planning, and Policy*, **9**, 39-45.

[20] Lewis, J.J. and Pattanayak, S.K. (2012) Who Adopts Improved Fuels and Cookstoves? A Systematic Review. *Environmental Health Perspectives*, **120**, 637-645.
https://doi.org/10.1289/ehp.1104194

[21] Jetter, J., Zhao, Y., Smith, K.R., Khan, B., Yelverton, T., Decarlo, P. and Hays, M.D. (2012) Pollutant Emissions and Energy Efficiency under Controlled Conditions for Household Biomass Cookstoves and Implications for Metrics Useful in Setting International Test Standards. *Environmental Science & Technology*, **46**, 10827-10834.
https://doi.org/10.1021/es301693f

[22] Johnson, M., Pilco, V., Torres, R., Joshi, S., Shrestha, R.M., Yagnaraman, M., Lam, N.L., Doroski, B., Mitchell, J., Canuz, E., *et al.* (2013) Impacts on Household Fuel Consumption from Biomassstove Programs in India, Nepal, and Peru. *Energy for Sustainable Development*, **17**, 403-411.

[23] Clark, M.L., Reynolds, S.J., Burch, J.B., Conway, S., Bachand, A.M. and Peel, J.L. (2010) Indoor Air Pollution, Cookstove Quality, and Housing Characteristics in Two Honduran Communities. *Environmental Research*, **110**, 12-18.
https://doi.org/10.1016/j.envres.2009.10.008

[24] Candela, S., Julio, L., Javier, M., Adolfo, N., Luz, F. and Rafael, B. (2014) Effective-

ness of Improved Cookstoves to Reduce Indoor Air Pollution in Developing Countries. The Case of the Cassamance Natural Subregion, Western Africa. *Journal of Geoscience and Environment Protection*, **2**, 1-5.

[25] Dutta, K., Shields, N.K., Edwards, R. and Smith, K.R. (2007) Impact of Improved Biomass Cookstoves on Indoor Air Quality near Pune, India. *Energy for Sustainable Development*, **11**, 19-32. https://doi.org/10.1016/S0973-0826(08)60397-X

[26] Edwards, R., Hubbard, A., Khalakdina, A., Pennise, D. and Smith, K.R. (2007) Design Considerations for Field Studies of Changes in Indoor Air Pollution due to Improved Stoves. *Energy for Sustainable Development*, **11**, 71-81. https://doi.org/10.1016/S0973-0826(08)60401-9

[27] Smith, K.R., Dutta, K., Chengappa, C., Gusain, P.P.S., Masera, O., Berrueta, V., *et al.* (2007) Monitoring and Evaluation of Improved Biomass Cookstove Programs for Indoor Air Quality and Stove Performance: Conclusions from the Household Energy and Health Project. *Energy for Sustainable Development*, **11**, 5-18. https://doi.org/10.1016/S0973-0826(08)60396-8

[28] Wang, Y., Sohn, M.D., Gadgil, A.J., Wang, Y., Lask, K.M. and Kirchstetter, T.W. (2013) How Many Replicate Tests Do I Need Variability of Cookstove Performance and Emissions Has Implications for Obtaining Useful Results. https://www.osti.gov/scitech/servlets/purl/1172123

[29] The Controlled Cooking Test (CCT) Version 2.0. (2004). https://cleancookstoves.org/binary-data/DOCUMENT/file/000/000/80-1.pdf

[30] Bailis, R., Kirk, R. Smith, K.R. and Edwards, R. (2007) Kitchen Performance Test (KPT) Versión 3.0, 2007. https://cleancookstoves.org/binary-data/DOCUMENT/file/000/000/83-1.pdf

[31] UNFCC (2016) AMS-II.G. Small-Scale Methodology: Energy Efficiency Measures in Thermal Applications of Non-Renewable Biomass Version 08.0 Sectoral Scope(s): 03. https://cdm.unfccc.int/filestorage/S/0/5/S05JFDNZBV9YMCQT2UE6XWO174PL3A/EB90_repan13_AMS-II.G_%28v08.0%29.pdf?t=YTZ8cDhndjRsfDD3bWwvx3pL3IruY8Uqr_Ga

[32] UNFCC (2015) AMS-II.G. Small-Scale Methodology: Energy Efficiency Measures in Thermal Applications of Non-Renewable Biomass Version 07.0 Sectoral Scope(s): 03. https://cdm.unfccc.int/filestorage/X/J/5/XJ5UFAGWDEM7L30CSYPO6B842N19QV/EB85_repan14_AMS-II.G_%28v07.0%29.pdf?t=MmV8cDhndmRtfDCwC-SzoKiy-aVKktffMeQx

[33] UNFCC (2014) AMS-II.G. Small-Scale Methodology: Energy Efficiency Measures in Thermal Applications of Non-Renewable Biomass Version 06.0 Sectoral Scope(s): 03. https://cdm.unfccc.int/filestorage/E/I/W/EIWYRJZHSD6KXUL8G9C5NB03V1TO2M/EB77_repan11_AMS-II.G_ver%2006.0.pdf?t=azV8cDhndm1lfDB06xx0AZsHDi-y5vNyqOh

[34] UNFCC (2012) AMS-II.G. Small-Scale Methodology: Energy Efficiency Measures in Thermal Applications of Non-Renewable Biomass Version 06.0 Sectoral Scope(s): 03. https://cdm.unfccc.int/filestorage/7/m/24G3EKN6PT0QJ1BHRICMYDX97OW8UF.pdf/EB70_repan30_AMS-II.G_ver05.0.pdf?t=Y0J8cDhndnJ4fDA1hxTPIeILYsB3twggG60c

[35] Medina, P., Berrueta, V., Martínez, M., Ruiz, V., Ruiz-Mercado, I. and Masera, O.R. (2017) Closing the Gap between Lab and Field Cookstove Tests: Benefits of

Multi-Pot and Sequencing Cooking Tasks through Controlled Burning Cycles. *Energy for Sustainable Development*, **41**, 106-111.

[36] Yves, S., Paul, B., Stéphane,V. and José, C. (1997) Une évaluation de la technique de la carbonisation en meule. *Biotechnologie*, *Agronomie*, *Société et Environnement*, **1**, 113-124. http://popups.ulg.ac.be/1780-4507/index.php?id=16126

[37] Kabore, I. (2011) Méthodologies de projections de population. Ouagadougou. http://slideplayer.fr/slide/486065/