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Sustained Usage of Energy Efficient Firewood Cook Stoves and Climate Change Mitigation in Siaya County, Kenya

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Abstract

The importance of using energy efficient firewood cook stoves to reduce fuel consumption and greenhouse gases (GHGs) emissions is widely acknowledged. Consequently, different types of energy efficient firewood stoves have been and continue to be disseminated in many rural households in Kenya. However, the anticipated benefits can be fully actualized only with the sustained longterm usage of these stoves. There has been an existing knowledge gap regarding the link between the sustained utilization of energy-efficient stoves and climate change mitigation in Siaya County, Kenya. This study evaluated the relationship between sustained usage of the energy efficient firewood cook stoves and climate change mitigation. The study employed an experimental design in which 100 households equipped with energy efficient twin brick rocket cook stove were randomly selected. This was followed by a Kitchen Performance Test (KPT), adopting a paired-sample study. Data was analyzed both descriptively and through correlation analysis to test the relationship between the energy efficient stove's sustained usage and climate change mitigation. The key study finding was that a single twin brick rocket energy efficient cook stove could save approximately 1.1315 tonnes of firewood translating to 1.4099 tonnes of CO_2e (41.3%) per year compared to the three stone open fire. The energy efficient stove remarkably reduced firewood consumption and GHGs emissions hence its sustained usage could have tangible impact on climate change mitigation. The study recommends enhanced sensitization on the climate change mitigation benefits of using the energy efficient stoves and scaling up adoption and usage of the energy efficient firewood cook stove through integration of approaches that allow deep understanding of context-specific needs and cooking practices.

Key words: Sustained usage, Cook stove, Climate change.

Introduction

Climate change is arguably the current major global challenge requiring urgent action. Solid biomass fuels including firewood burned on inefficient cook stoves emit greenhouse gases (GHGs) contributing to climate change (Floess *et al*., 2023). Globally, about 3 billion people comprising 40% of the world's population rely on solid biomass fuels to meet their primary cooking energy demand (Samad & Portale, 2019). Whereas considerable variations exist in different regions and sectors based on local practices and the types of fuels and technologies used, developing countries in Africa and Asia are generally recognized as dominant source regions of cooking related GHGs and products of incomplete combustion (PICs) emissions (Gustafsson *et al*., 2009).

In many parts of the Sub Sahara Africa (SSA), over 75% of the rural households including 900 million people, rely on firewood mainly burnt on three stone open fire to meet their demands for cooking energy (Bensch, Jeuland & Peters, 2021; Nzengya, Maina & Njeru, 2021). In Kenya solid biomass fuels like firewood provide the overall cooking energy requirements to around 75% of the approximately 8 million households (Schiefer, 2021). Significantly, over 90% of the populations in rural parts of Kenya use the polluting solid biomass fuels. In Siaya County for instance, 98% of households inefficiently use wood fuel for cooking contributing significantly to national GHG emissions (Okoyo, 2017).

Bensch *et al.* (2021) observes that despite the optimistic suppositions about electricity and liquefied petroleum gas (LPG) dissemination increasingly emphasized by the global policy discourse, emissions related with the solid biomass fuels might evolve until 2050 in SSA. Again, massive investments in infrastructure, that might also take considerable amount of time to materialize, will be required to establish a dependable electricity and LPG supply across the Global South. This coupled with increasing population growth and urbanization in the region, might result in substantial increase in demand for biomass energy, exerting more pressure on forests and resulting in even much higher emissions (Nzengya *et al*., 2021). Here, interventions that enhance access to improved and clean cooking solutions are greatly needed (CCAK, 2019).

According to Samad and Portale (2019) the use of energy efficient cook stoves remains a good transitional solution. Garg *et al.* (2010) also observed that for the economically backward villages with very limited access to modern fuels, improved cook stoves present a desirable option. Consequently, there have been efforts to substitute the traditional inefficient biomass stoves with more energy efficient improved solid biomass stoves to curb the negative impacts associated with the inefficient biomass stoves (Karanja & Gasparatos, 2019). The improved energy-efficient biomass cooking stoves (ICS) can reduce the climate-forcing emissions, with substantial climate change mitigation potential (Bensch *et al*., 2021). Clean cooking has been identified by the Sustainable Energy for All (SE4All), a global platform for facilitating access to modern energy for all by 2030, as one of its high impact opportunities (Rogelj, McCollum & Riahi, 2013). Adoption and sustained usage of clean energy fuels and technologies will partly be used to measure progress towards the achievement of SDG7 (Karanja & Gasparatos, 2019). A report by Clean Cooking Association of Kenya indicates that by shifting to clean and efficient cooking solutions as a means to climate change mitigation, the Kenya government is projecting an abatement potential of 7.3 Mt CO_2e by 2030 (CCAK, 2019). The wide acknowledgement of the importance of using energy efficient firewood cook stoves for reducing firewood consumption and anthropogenic GHGs emissions has led to various stove and fuel options being made available to Kenyan consumers including households in Siaya County by both the government through a strong policy push and numerous local and international initiatives. The interventions have helped to either commercially or under carbon market schemes produce, import and disseminate different types of clean cook stoves and fuels in the Country (Practical Action, 2010). For instance, Tembea Youth Centre for Sustainable Development (Tembea) had since 2010 installed about 127242 twin brick rocket stoves in the Siaya households. However, the anticipated environmental benefits could only be fully realized with the stoves' sustained long-term usage (Samad & Portale, 2019).

Using the Tembea's twin brick rocket energy efficient cook stove, the study determined the relationship between sustained usage of energy efficient firewood stoves by households and climate change mitigation. Effect of sustained usage of energy efficient firewood stoves on climate change mitigation remained unclear and lowly researched in Siaya County. The link between the adopted stoves' sustained usage and climate change mitigation had not been clearly established. Previous studies in the area mainly focused on the factors influencing initial adoption of improved cooking stoves and energy consumption more than the adopted stoves' sustained usage and the associated environmental benefits. While the studies provided insights into the determinants of initial uptake of the stoves, they did not establish the determinants of the stoves' sustained usage, the stoves' sustained usage rates in terms of the proportion of the households using their improved stoves long after their adoption and the relationship between the improved stoves' sustained usage and climate change mitigation measured through firewood consumption and CO_2e emission. This study determined the cook stoves' usage rate, analyzed the social, economic and technological circumstances under which the stoves are used or not and determined the relationship between the energy efficient stoves' sustained usage and climate change mitigation in Siaya County. The presented study findings would hopefully be a useful source of information to researchers, policy makers, the energy efficient cook stove promoters and the entire society to understand and appreciate the contribution of sustained usage of energy efficient firewood cook stoves to climate change mitigation.

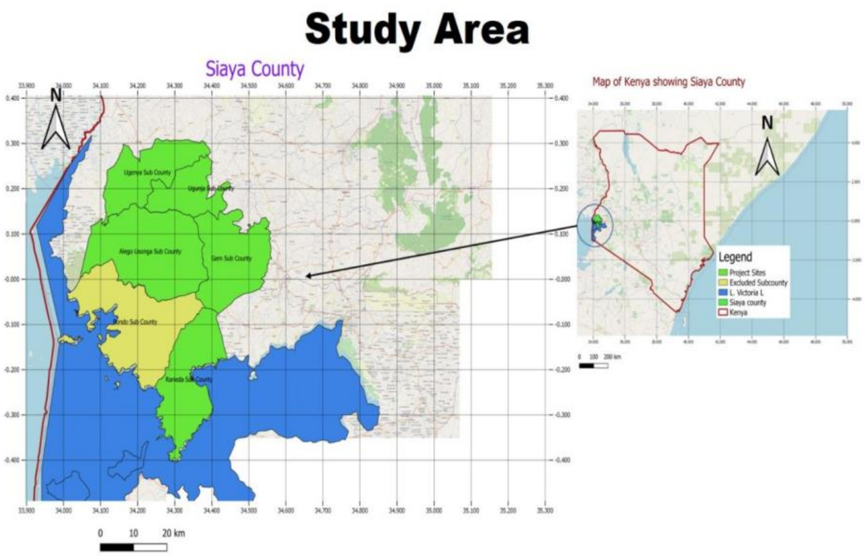
Source: Tembea (2023).

Figure 1: Twin brick rocket cook stove promoted by Tembea

Materials and Methods

The study area

The study was conducted in five out of the six Sub-Counties of Siaya County, Kenya, (where the energy efficient twin brick rocket cook stove had been disseminated by Tembea) including Ugenya, Ugunja, Alego-Usonga, Gem and Rarieda lying between latitude 0º 26´ South to 0º 18´ North and longitude 33º 58´ and 34º 33´ East. According to Siaya County Government (2018) firewood is the main source of cooking fuel for 84.2% of the households. 71.4% of the households use traditional three stone open fire with 14.5% using improved cook stoves.



Source: Researcher (2024).

Figure 2: Map of Siaya County showing the study area

The Research Design

Experimental design following Kitchen Performance Test (KPT) protocol was adopted in the study. The KPT adopted a **paired-sample** approach in which a comparison of the fuel consumption by the energy efficient twin brick rocket firewood cook stove and the old three stone open fire was done for the same households. The first round of the test involved the households being provided with firewood to use over a seven days period on their energy efficient firewood cook stoves. In the second round, the same households were provided with

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firewood to now use on the three stone open fire for another seven days. In both cases, the participants followed their normal cooking patterns and only used firewood from the provided pile for their cooking needs on a typical day throughout the KPT period.

The Study Population, Sampling Procedure and Sample Size Determination

The study population comprised households already adopting the energy efficient twin brick rocket firewood cook stove. A simple random sampling was used to select the KPT participants. Bailis *et al.* (2018) recommends a sample size of at least 20 households for a paired-sample study. Gold Standards, on the other hand, recommends minimum sample size of 30 test subjects for a paired-sample study and further guides that to take care of variations that may exist in the amounts of fuel used and saved, which is usually the case in KPTs, larger sample sizes may be considered (Standard G., 2021). To keep the KPT sample size manageable but also allow for derivation of a detailed data (Singh, & Masuku, 2014), 100 households were sampled to participate in the KPT. Low coefficient of variance (0.2) and standard error (0.02) were used to lower the degree of dispersion from the mean in the data to be generated from the sampled households. The sample size was determined using Nassiuma (2000) formula:

$n= NC^2 / (C^2+ (N-1) e^2)$

Where:

n = sample size

N= accessible population

C= Coefficient of Variance

e= standard error

$n=127242 \times 0.2^2 / (0.2^2+ (127242-1) 0.02^2 = 99.92$

Therefore, 100 households were sampled for the study.

Data Collection

Each participating household was visited on days 1, 3, 5 and 7, at almost the same time for each visit, but with a lot of care not to be intrusive. During the first visit, weights of the initial firewood supplied to the households were taken using calibrated weighing machine and recorded in a KPT questionnaire. In the subsequent visits, fuel consumption was recorded by weighing the firewood remaining in the provided pile. Firewood was added to the households' stock as was necessary to ensure that the households had adequate supplies for the entire KPT period. Apart from the fuel consumption, data was also captured on the household characteristics and other variables on the cooking habits over the KPT period including number of meals prepared, persons for whom the meals were prepared together with the qualitative aspects of stove performance. The procedure was repeated for the three stone open fire.

Data Analyses

Data was chiefly analyzed quantitatively (De Leon & Chough 2013). The descriptively analyzed quantitative data was presented in tables and as percentages. The quantified data came in handy not only for measuring change regarding the research topic but in comparing and contrasting similar research findings. The sustained usage of the energy efficient cook stove was measured by the number of meals per stove per day or the average daily meals across the tested stoves and climate change mitigation was measured by the change in CO_2e emission ($\Delta CO_2\text{-}e$) calculated based on changes in firewood consumption (ΔFC) and the GHGs emissions per unit of firewood the stoves helped save.

Measuring the Relationship between Sustained Stove Usage and Climate Change Mitigation

The impact estimate was derived from comparison of firewood consumption by the energy efficient cook stove and the traditional three-stone fire. The GHGs emissions was calculated according to formula adopted from the Gold Standard's guidelines on Emission Reduction Calculations for Technologies and Practices to Displace Decentralized Thermal Energy Consumption (Standard G., 2011):

$$\mathbf{ERy = \sum_{b,p}(N_{p,y} * U_{p,y} * P_{p,b,y} * NCV_{b,fuel} * (f''NRB,_{b,y} * EF_{fuel,CO2} + EF_{fuel,nonCO2})) - \sum LE_{p,y}} \quad \mathbf{(1)}$$

Where:

$\sum_{b,p}$ - Sum over all relevant (baseline b/project p) couples

$\mathbf{N_{p,y}}$ - Cumulative number of project technology-days included in the project database for project scenario p against baseline scenario b in year y

$\mathbf{U_{p,y}}$ - Cumulative usage rate for technologies in project scenario p in year y, based on cumulative adoption rate and drop off rate revealed by usage surveys (fraction)

$\mathbf{P_{p,b,y}}$ - Specific fuel savings for an individual technology of project p against an individual technology of baseline b in year y, in tons/day, as derived from the statistical analysis of the data collected from the field tests

$\mathbf{f''NRB,_{b,y}}$ -Fraction of biomass used in year y for baseline scenario b that can be established as nonrenewable biomass

$\mathbf{NCV_{b,fuel}}$ - Net calorific value of the fuel that is substituted or reduced (IPCC default for wood fuel, 0.015TJ/ton)

$\mathbf{EF_{b,fuel,CO2}}$ - CO_2 emission factor of the fuel that is substituted or reduced (112 tCO_2/TJ for wood)

$\mathbf{EF_{b,fuel,nonCO2}}$ - NonCO_2 emission factor of the fuel that is reduced

$LE_{p,y}$ - Leakage for project scenario p in year y (tCO_2e/yr)

Ethical Considerations

This study ensured confidentiality and anonymity by the respondents being only identified by codes and pseudo-names and no detail was stored in a form that would lead to their identification (Kombo & Tromp, 2006). The participants' consent was sought before any information was recorded from them. The respondents were informed of what to expect from their participation in the study and only those who volunteered participated (Fisher & Anushko, 2008). Approval was granted by Masinde Muliro University of Science and Technology's department of postgraduate studies (MMUST-DPS) and a research permit obtained from the National Commission for Science, Technology and Innovation (NACOSTI).

Results

The study determined the relationship between sustained usage of the energy efficient firewood stoves by the households and climate change mitigation by measuring firewood consumption and CO_{2e} emission. The findings were as presented and discussed in following sections.

Comparative Firewood Consumption

Data generated from the kitchen performance test (KPT) was used to calculate daily and annual firewood consumption by both the three stone open fire and the energy efficient twin brick rocket stove. The fuel savings was determined by calculating the difference between fuel consumption by the two stoves. Results were as in Table 3.1.

Table 3.1: Firewood consumption by twin brick rocket stove and three stone open fire

Firewood consumption	Firewood consumption by three stone open fire in tonnes	Firewood consumption by twin brick rocket stove in tonnes	Fuel Savings	Percentage Fuel Savings (%)
Average Daily Consumption (tfirewood/day/stove)	0.0075	0.0044	0.0031	41.3
Average Annual Consumption (tfirewood/year/stove)	2.7375	1.6060	1.1315	41.3

Source: Researcher (2024).

Comparative CO_2e Emissions

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The CO_2e emission by both the three stone open fire and the twin brick rocket energy efficient cook stove per year was estimated based on their respective firewood consumption. The model: $ERy = \sum_{b,p}(N_{p,y}*U_{p,y}*P_{p,b,y}*NCV_{b,fuel}*(f''NRB,_{b,y}*EF_{fuel,CO2}+EF_{fuel,nonCO2}))– \sum LE_{p,y}$ was used to separately estimate the CO_2e emissions for each of the stove type. The parameter values used in the model were either from the calculated KPT data or IPCC and CDM default values as presented in Table 3.2.

Table 1: Parameters used to quantify the CO_2e emissions

Item	Unit	Value	Source
Days stove in use (N)	days	365	Stove users' database
Cumulative Usage Rate (U)	fraction	0.710	Calculated
Daily Fuel Savings (P)	tfirewood/day/stove	0.0031	Calculated
Non-renewable biomass fraction (NRBf)	fraction	0.92	CDM default value for Kenya
Net Carolific Value for wood (NCV wood)	(TJ/ton fuel)	0.0156	IPCC default 2006
CO_2 emission factor for wood (EF wood, CO_2)	tCO_2e/t wood	1.7472	Calculated
Non-CO_2 emission factor for wood (EF wood, nonCO_2)	tCO_2e/t wood	0.1476	Calculated
Leakage LE	tCO_2e/t year	0	Project Design Document
Daily Firewood Consumption by Three stone open fire	tfirewood/day/stove	0.0075	Calculated
Daily Firewood Consumption by Twin brick rocket stove	tfirewood/day/stove	0.0044	Calculated

Source: Researcher (2024) and IPCC (2006).

The CO_2e emission was quantified by considering the number of days in a year the stove was in use (N), its cumulative usage rate (U) and daily firewood consumption in tonnes (tfirewood/day/stove). Other parameters used in the quantification were the fraction of non-renewable biomass (NRBf), the CO_2 emission factor for wood (EF wood, CO_2), non-CO_2 emission factor for wood (EF wood, nonCO_2). Emission leakage (LE) - whether the emissions reductions here was causing increase in emissions elsewhere - was also factored in. For the three stone open fire, the estimated tonnes of carbon dioxide equivalent emitted was 3.4111 tCO_2e, as worked out below:

E_{tsof} = (N*U*tfirewood/day/stove)*(NRBf*EF wood, CO_2+EF wood, nonCO_2)-LE
= (365*0.710*0.0075)*(0.92*1.7472+0.1476)-0
= 3.4111 tCO2e

The annual CO_2e emission by the twin brick rocket cook stove, also quantified using the same parameters as in the case of three stone open fire but with values specific to the efficient stove, was 2.0012 tCO_2e, as worked out below:
E_{tbrs} = (N*U*tfirewood/day/stove)*(NRBf*EF wood, CO_2+EF wood, nonCO_2)-LE
= (365*0.710*0.0044)*(0.92*1.7472+0.1476)-0
= 2.0012 tCO_2e

CO_2e Emission Reduction (ER)

The difference between the carbon dioxide equivalent (CO_2e) emissions by the three stone open fire and the twin brick rocket cook stove was calculated to determine the tonnes of carbon dioxide equivalent emission that could be reduced by using the efficient stove. Therefore:
Emission Reduction = Emission by three stone open fire - Emission by twin brick rocket cook stove
ER = 3.4111 tCO_2e - 2.0012 tCO_2e
ER = 1.4099 tCO_2e

Discussion and Conclusion

Table 3.1 indicates that the three stone open fire consumed 2.7375 tonnes of firewood per year. The energy efficient twin brick rocket stove, on the other hand, consumed 1.6060 tonnes, ultimately saving 1.1315 tonnes (41.3%) of firewood per year. A similar study in Tanzania found out that a household using three stone open fire consumes around 2.88 tonnes of firewood per year while improved firewood stove consumes 1.728 tonnes thereby reducing the firewood consumption by around 1.152 tonnes comprising 40% and equivalent to 20 trees per year (Njogu, 2011). Similarly, GIZ (2018) and Orlale and Odee (2013) reported that, if used properly with dry firewood, a fixed inbuilt household stove saves up to 40% of firewood compared to the three stone open fire. Although all these results are lower than that of Kamfor (2002) reporting that rocket stoves can help conserve wood by over 60%, it is evident that rocket stoves can help conserve significant amount of firewood.

The energy efficient stoves are a likely beneficial intervention for climate change mitigation. Regarding the CO2e emission reduction, the calculated results, based on collected data, indicate that using a twin brick rocket energy efficient firewood cook stove annually reduces 1.4099 tCO_2e (41.3%) emissions, compared to the three stone open fire. This means that the use of the twin brick rocket energy efficient firewood cook stove is associated with reduced CO_2e emissions. Besides the emissions reduction due to the reduced fuel consumption, the sustained usage of the twin brick rocket energy efficient firewood cook stove could potentially enhance carbon sink. Reduced fuel consumption translates to decreased demand for firewood, potentially lowering forest degradation. Hosonuma *et al.* (2012) reports that high demand for wood fuel can contribute to forest degradation. Forest degradation reduces the ability of the forests to sequester and store carbon (Jandl *et al*., 2007), negatively impacting climate change mitigation. From this study, approximately 1.1315 tonnes of firewood translating to a reduction of CO_2e by 1.4099 tonnes could be achieved through the use of a single twin brick rocket energy efficient cook stove in a year. Drawing from TaTEDO (2005) cited in Njogu (2011) an equivalent of 20 trees would be saved by consistently using a single twin brick rocket per year. If all the 127,242 twin brick rocket cook stoves so far installed were to be consistently used, then approximately 2,544,840 trees could be saved per year in Siaya County. Over, the stoves minimum lifespan of five years, approximately 12,724,200 trees would be conserved. Again, going by Flammini *et al. (*2023) estimation that burning 1 kilogram of wood releases approximately 1.87 kilogram of carbon dioxide then emission of as much as 2.1159 tonnes of CO_2 would be avoided annually by using a single energy efficient twin brick rocket stove.

In conclusion this study showed that sustained usage of the energy efficient firewood stoves by households positively affected climate change mitigation. Sustained usage of the energy efficient stove could have tangible impact on climate change mitigation by remarkably reducing firewood consumption and GHGs emissions. Therefore, the null hypothesis: *There is no significant relationship between sustained usage of the energy efficient firewood cook stoves by households and climate change mitigation in Siaya County* was rejected.

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