ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue IV, April 2025

Do ICS Contribute to Global Warming? Correlation Between ICS Usage and GHG Emissions

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DOI : https://doi.org/10.51583/IJLTEMAS.2025.140400048

Received: 11 April 2025; Accepted: 22 April 2025; Published: 09 May 2025

Abstract: Global warming is mainly the results of human activities on the environment. It is the leading cause of change in weather patterns. The activities are linked to different ways of generating and using energy. Researches have revealed that 80% of households in Sub-Sahara Africa use traditional wood fuel. This implies that chunks of trees are usually cut yearly to provide the fuel. It leads to greenhouse gas emissions and deforestation of up to 39 hectares per year. Unfortunately, the households have limited access to ICS. The high costs of stoves, lack of government support and unwillingness to substitute traditional cooking practices with clean cooking methods limit the uptake of the improved stoves. This means that there is more use of biomass fuel, which highly increases GHG emission. For instance, each household is estimated to use approximately 4 bags of charcoal annually. The yearly charcoal demand for the entire continent is approximately 4 billion bags. To meet this demand, about 715 million trees have to be cut annually.

ICS present a promising solution for conserving trees. As per the terminal evaluation on the usage of the stoves, only 25% of the trees that are currently burned to produce charcoal will be required to meet the annual charcoal demand. The 537 million trees that shall be preserved will sequent 0.013425 $GtCO_2$ in a single year. Working towards Paris Agreement strategies on GHG emissions, ICS usage in Africa will therefore enable CDR up to 5.034% within a 25-year period. To achieve this, strategies aimed at increasing adoption rate should be implemented. If households outside Africa that are still using traditional stoves adopt ICS for cooking, we should expect even better and more promising changes. The GHG emissions will have to drop leading to a decrease in global warming.

Keywords: Improved cooking stoves, greenhouse gas, clean cooking, global warming, biomass, wood fuel, emissions

Nomenclature

CO_2 - - -- Carbon Dioxide

Gt CO_2 ---- Gigatons

KES ---- Kenyan Shillings

Ppm - - - Units of measurements of CO_2 to imply parts per million (ppm)

SNV -------- Netherlands Development Organization

Abbreviations

CDR ------- Carbon Dioxide Removal

DAC -------- Direct Air Capture

ICS ------- Improved Cook Stoves

KCJ -------Kenya Ceramic Jiko

MJ -------- mega joules

LPG -------- Liquefied Petroleum Gas

TSOF -------Three Stone Open Fire

I. Introduction

Background

There have been changes in weather patterns in most parts of the world. This is due to increase in global temperature that is linked to human activities. Burning of fossil fuel is the main contributor to the increase in temperature. The burning leads to emissions of carbon dioxide, methane and black carbon – some of the most important contributors to global climate change. According to United Nations, 75% and 90% of GHG emissions and carbon dioxide respectively emanate from the fossil fuels: United Nations [1]. The

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GHG emissions trap some of the sun's heat being re-radiated from the earth to the atmosphere. The end results are global warming, a threat to life on the surface of the earth.

Electricity generated by burning of coal, oil or gas, use of biomass in cooking, deforestation, automobile activities and other human activities largely contribute to emission of carbon dioxide to the atmosphere. By July 2023 CO_2 level in the atmosphere stood at 419.17ppm according to Mauna Loa Observatory in Hawaii. Human activities have contributed to the increase in the contents by at least 50% during the last two centuries. The rising CO_2 has led to global warming, extreme weather patterns (prolonged droughts, floods and high temperature), increase in acidity of the seas and oceans and increase in the rate of melting glaciers and ice caps. All these lead to interference with the balance in ecosystems, agricultural activities & productivity and impact on human health: *CO_2 METER: Gas* [2].

Awuor et al asserted that households using traditional fuels were contributing to deforestation of 39 hectares of land per year. According to them, 80% of primary energy fuel in Sub-Sahara Africa is fuelwood. This was concluded after interviewing 436 and 40 households and wood fuel sellers respectively in Kisii County of Kenya. The highest percentage of the fuel was being transferred from other counties (89.7%). The 63% of the interviewed households were willing to adopt the biofuel and ICS. However, high cost of the stoves, lack of government support and unwillingness to substitute traditional cooking practices with clean cooking hinders the embracing of modern cooking practices that use less fuel with reduced GHG emissions. On the other hand, Awuor and his team further argued that one fully grown tree produces an average of 5.65 bags of charcoal. According to their research paper, a household uses approximately 201.6 tins of charcoal per year; which is equivalent to 4.0352 bags of charcoal: *Awuor et al* [5].

Removing and minimizing emissions from the atmosphere is one of the strategies towards attaining SDG. Compared with tree sequestration, DAC happens to be large scale remover but is costly and requires higher energy input. It is thus not cost-effective. However, it requires a smaller footprints compared to tree planting: *NEG8 Carbon* [15]

Objective

This study aims to ascertain whether it is viable and cost-effective to enhance the uptake of improved cook stoves. The goal is to minimize GHG emission and increase sequestration of the emissions.

Desk Review

By 2017, there was 41.2 $GtCO_2$. Assuming that afforestation and reforestation are embraced to deal with the CO_2 level, we will require 500 million hectares of land to plant trees so that they can sequester 3.7 $GtCO_2$ per year for about 12 years. On the other hand, $Noco_2$.org postulated that, if on average one person emits 5 tonnes of CO_2 per year, then 3.7 $GtCO_2$ per year can handle CO_2 emitted by 700 million people within the same year: *n0co2.org* [3].

EED Advisory conducted a study to ascertain the supply and demand of cooking solutions at household level in Kenya. The findings revealed that, the type of cooking used in households were majorly determined by costs and preferences. 13%, 20.9% and 26.5% of those interviewed preferred KCJ, TSOF and LPG 6kg complete gas respectively. From the study, it was evident that there was variation in preference of the cooking appliance between urban and rural areas. However, only 4% of the interviewees were not having the stoves they preferred due to cost, safety concern at 30% and availability of fuel (45%). The access to KCJ and LPG was limited by the cost of the stoves. Those households that had the stoves acquired them by upfront payment. According to the research findings, 71% and 69% of the households were willing and ready to pay for the 6kg complete LPG and burn stoves if their prices were KES 1,125 and KES 973 respectively: *CCAK & Ministry of Energy* [4].

African countries lag behind in uptake of ICS. The continent has a lower adoption rate of the stoves compared to developing countries in other continents. Overall, the adoption rate was at 25% in 2017. By then, only 7% of households in Sub-Sahara Africa had adopted the ICS: *Massawe & Bengesi* [14]

In 2024, it was estimated that approximately one billion households in Africa were still cooking using wood fuel; which have high emissions and health hazards: *Voa* [6]. In evaluating how forests change climate, Schulze and his team argued that, one-meter cube of wood contains about 300 kg of carbon, which is equivalent to one ton of CO_2. They further claimed that one hectare of forest sequent one to two tons of CO_2 every year: *Jacob* [7]. To narrow it down, a single mature tree absorbs an average of 25 Kilograms of carbon dioxide per year: *Ecotree* [8]

By 2016, 70% of households in Sub-Sahara Africa were using wood fuel for energy: *Mo Ibrahim Foundation* [10]. In addition, Rose and her team compiled data from different sources in Sub-Sahara Africa on usage of charcoal for cooking. The team revealed that by 2022, 195 million and about 200 million people were using charcoal as primary and secondary fuel respectively: *Julian et al.* [9]. It has to be noted that firewood releases 16 MJ/kg: *United Nations* [11].

Paris Agreement on GHG emissions requires that, global warming be capped to 1.5^0 C by 2100. To meet the strategy of this agreement, CDR strategies have to be deployed. The National Academy of Science estimated that if by CDR per annum will hit 10 and 20 Gigatons by 2050 and 2100 respectively, then the agreement's objective will be achieved*: C2ES* [12].

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Limitation of Literature Review

The material neither quantifies nor discusses the approaches to use to ensure that the approximated quantity of the Gt CO_2 that can be removed by using ICS. They have also not presented the anticipated duration needed to offset a certain level of CO_2 from the atmosphere while focusing on the strategy of The Paris Agreement on GHG emissions; which requires that global warming be capped to 1.5^0 C by 2100. The reviews have also not exploited fully the measures to use in order to ensure that all households that use traditional methods of cooking (that have high emissions) embrace the uptake of ICS.

II. Project Approach/ Methodology

Sampling (cluster, stratified, SRS, purposive)

The eight regions of Kenya were put into clusters (Central, Coastal, Eastern, Nairobi, Nyanza, Western, North and South Rift). Using the sales records from distributors of ICS, the data was stratified to rural and urban households.

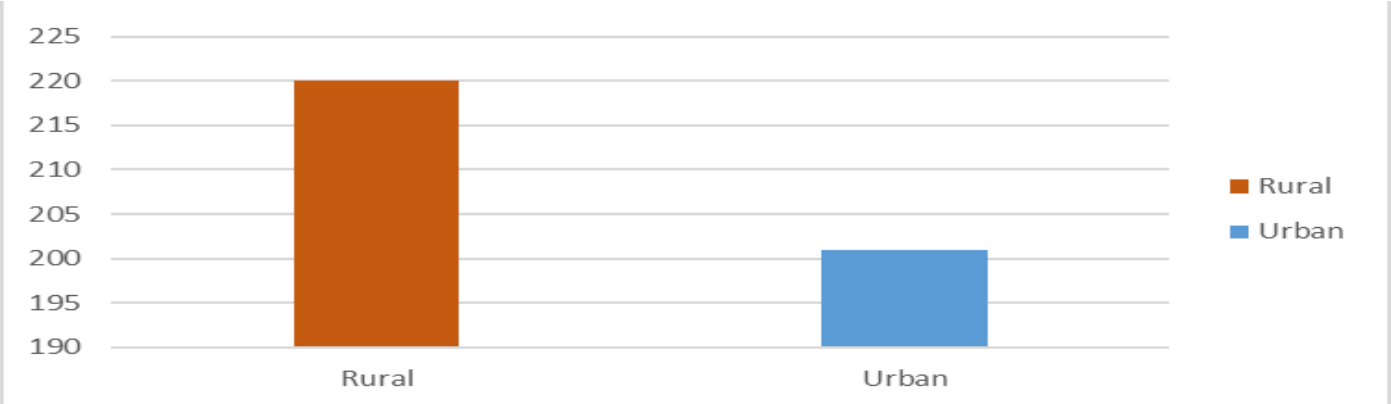


Figure 1: Rural-Urban Stratification

Different stove vintages (models of stoves and their years of sale) were allocated a sample size depending on their proportion of sale, availability of the vintages and the type of wood fuel (charcoal or firewood) used.

Table 1: Showing Different Stove Models & their Useful Lifespan

Stove model	**Fuel**	**Useful lifespan (years)**
Jiko Malkia	charcoal	5
Jiko Bora Mama Yao	Charcoal	5
Jiko Fresh	Charcoal	3 – 7
Jiko okoa	Charcoal	2 – 3
Home stove	Firewood	10 – 20

The gender to be interviewed was randomly selected depending on the household's member that usually use the stove for cooking.

CDR Formula

Carbon accounting formulae:

$GHG\ Emissions = activity * emission\ factor$, where emission factor is a coefficient

Trees CO_2 sequestration formulae:

$TC = 0.5 * TDW$; where TC is total carbon and TDW is tree's dry weight which is 72.5% of the dry matter. 27.5% is water component.

*TDW = 0.725*TB*; where TB is Total tree biomass

Thus, *TC = 0.5*0.725TB = 0.3625*TB*

*TB = AGB + BGB = 1.2*AGB*

since *BGB=0.2*AGB*; where ABG and BGB are above ground biomass and below ground biomass respectively and

*AGB = 0.25*D^2*H*; whereby D=diameter of the tree (in cm) and H= height of the tree in meters.

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Hence $TC = 0.3625*1.2*0.25* D^2*H = 0.10875\ D^2*H$

Carbon dioxide weight sequestered by a tree in its lifetime:

CO_2 *weight* $= 3.67*TC$; where 3.67 is the ratio of oxygen to carbon molecules since carbon's and oxygen's atomic weights are 12µ and 16µ respectively.

CO_2 *weight* $= 3.67*0.10875\ D^2*H$

Tree's yearly sequestration rate:

$$\textit{Annual } CO_2 \textit{ sequestered} = \frac{CO2\ weight}{age\ of\ the\ tree} = \frac{CO3.67*0.10875\ D2*H2\ weight}{age\ of\ the\ tree}$$

Sequestration variability:

Studies have shown that at each age, sequestration rate at each age of the tree. When the annual rates are plotted, a sigmoid curve is formed due to variation in absorption rates of CO_2 at different tree ages: *Fransen* [13]



Figure 2: Sigmoid Curve Showing Age of Tree in Relation to Carbon Quantity Sequestered Per Hectare

Data collection

The data collection exercise took place between January 2023 and August 2024. The exercise involved visiting households, verification of serial numbers of the stoves and comparing them with what was in the sampled data before interviewing the households. One of the interests was to compare the difference between traditional stoves and improved stoves in terms of time saved, fuel used and cost benefits associated with ICS. Using the smallest unit of measuring the charcoal in the market and the number of firewood used to cook certain types of foods, we could easily determine the differences between the two types of stoves.

In assessing the time saved because of cooking using the improved stoves, 442 households were interviewed in four phases; January and June 2023, January and June 2024. The time taken to cook a certain food using ICS was compared with the duration to cook similar foods while using the traditional stove. It was then multiplied by the number of times the cooking takes place in a day and week. To Assess the fuel saved whenever using the ICS, the survey was conducted in August 2024. The smallest unit of measurement of wood fuel was used. For instance, some respondents were saying that a 2kg tin of charcoal could be filled 4 times in the ICS before exhausting the charcoal, compared to traditional stove that used take the whole quantity just once. The ICS that use firewood were being compared with TSOF.

Verification of usage

During the fieldwork, there was assessment on the usage of the stoves. For instance, existence of the ash in the ash chamber, warmth and slight change in color of the stoves due to wear and tear indicated the usage of the stoves for cooking. There was also confirmation of serial numbers whether they were similar with whatever were captured in data during the sales. The data collection tools were also recording GPS coordinates.

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Data Synthesis

Data analysis

For two-year period, the survey assessed the efficiency of the stoves. From the data that was collected, it is evident that 100% of the households interviewed were using their improved cook stoves for cooking and 73.4% of them confirmed that there is saving of time whenever cooking using ICS.

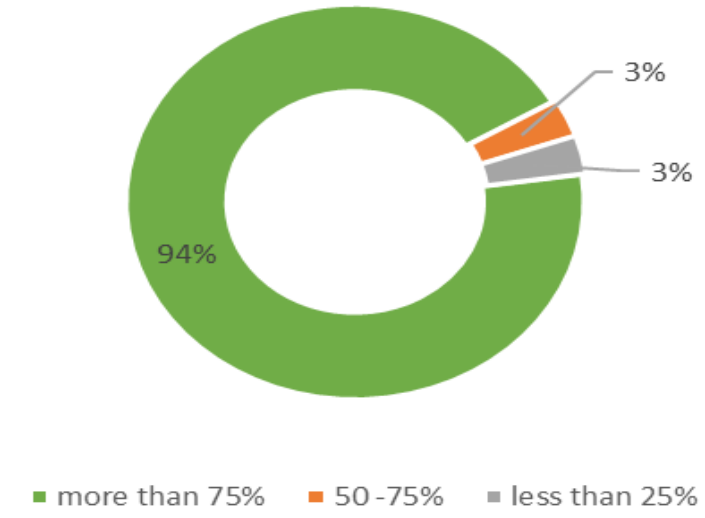


Figure 3: Quantity of Fuel Saved by using ICS

Out of the 411 households that save time, approximately 15% and 11% of them confirmed to be saving 70 and 210 minutes respectively. 140 and 420 minutes were saved by 37 and 38 households.

Out of the 442 households that were interviewed, 20% of them were having only one stove; the ICS, which was used for cooking. Only 11 households were purely using the ICS for cooking using firewood. The reasons stated for using other forms of cooking were: availability of fuel, cost & convenience of the fuel and the size of the family. It was noted that the ICS stoves are smaller in size thus not convenient to cook food for larger families. Some households have difficulty in accessing and affording the charcoal while others perceive that the stoves are convenient to use when the family intends to cook food that takes a longer period to be ready.

To assess the efficiency of the ICS stoves, it was prudent to confirm whether there was saving of fuel whenever these improved stoves were used in cooking. The data was collected using kobo in the month of August 2024. Out of the 32 households that were interviewed, 93.75% of respondents were female. This is because most of the time, cooking in African context is done by women. Also, it happens that the end users of the stoves are mostly women. This is a major issue of concern when designing sales and distribution strategies. Financial decision making is done by head of households; mostly the man in African context. Marketing of the ICS targets the final users (women) who are mostly financially dependent on men. They, on contrary perceive cooking and kitchen issues to be feminine responsibility. This may be the main cause of low adoption rate in the continent.

All the participants were using the stoves for cooking on daily basis and they confirmed that there was reduction in fuel used in cooking. This was attributed to using the ICS. 93.75% of the households said that they save more than 75% of the fuel they were using before transiting to ICS. The rest claimed to be saving 50% to 75% and less than 25% each.

During the interviews, the households also stated different sources where they get their fuel. 65.63%, 18.75% and 15.63% stated to be purchasing, collecting and both (collecting and purchasing) respectively. 66.67% of those who collect fuel were cooking using firewood. The participants that purchase the wood fuel were also asked whether there was monetary amount they were able to save per year by using the ICS. 26 of them confirmed to be saving money. 84.62% (of those who claim to save) asserted that they were saving more than KES 10,000 per year. 11.54% and 3.85% were saving KES 7,000-10,000 and KES 5,000-7,000 respectively. Lastly, all the interviewed households confirmed the significant reduction in emission of smoke and soot on utensils while cooking using ICS.

Inferential statistics

During data collection, 100% of the respondents confirmed that they save move and use less fuel while using ICS to cook. The attracted our interest to determine whether there existed any association saving fuel and spending less. We thought the finding could give a hint to revamp the uptake of the stoves. We assumed that the association between saving of fuel and amount of money spared

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per annum (when ICS is used for cooking) did not exist. We therefore used generalized log linear model to test the existence of any association between the two; the amount spent on fuel being response variable. This model utilizes Poisson regression. It uses takes count data as dependent variable. This variable is expected to be rare in occurring i.e saving money by cooking. This is the same character of Poisson distribution.

The regression only tests the existence of association between the variables of interest (that is rarely expected); in this case, saving money and using less fuel. The analytical finding revealed negation of the null hypothesis. On the contrary, it confirmed the existence of interaction between fuel and money saved while using the stoves. The table below presents the output of the regression model.

Table 2: Association between amount of money saved and quantity of fuel used for cooking

Parameter	Estimate	Std. Error	Z	p-value	95% Confidence Interval	
					Lower Bound	Upper Bound
Constant	3.384	0.184	18.382	0.000	3.024	3.745
[saving of fuel]	-2.468	0.658	-3.750	0.000	-3.758	-1.178

With P-value being less than 0.05, there exists association between saving of money to spent on fuel and quantity of fuel used for cooking. This is the motivating factor behind the 100% use of ICS for cooking.

It was also prudent to test the relationship between using of the ICS and saving of fuel in comparison to ordinary stove. To ascertain how many times an ICS is likely to save over 75% of the fuel, there was the use of odd ratio given by the formula below.

$$odd\ ratio = \frac{\text{odd of saving 75\% of fuel or more}}{\text{odd of saving less than 75\% of the fuel}} = \frac{\text{No. of HHs with 75\% or more saving}}{\text{No. of HHs with less than 75\% saving}}$$

The findings revealed that, ICS under study were 15.67 times more likely to save over 75% of the wood fuel compared to the traditional stoves. Moreover, when using the ICS, the end users are 24 times more likely to save time while cooking with the stoves. Over 50% of the households were saving at least 140 minutes per week.

Limitation of the study

The study did not quantify the percentage in reduction of emissions while using the ICS. It only focused on the fuel saved, which could lead to computing the number of trees that would be spared in case all the traditional methods of cooking are faced-out. Moreover, the computation of time saved while using ICS was pegged on the frequently cooked food by the households, thus the findings are just estimates since the end users cook different foods using the same stoves. In addition, the study did not consider the age and parts of the tree that were being used as fuel in cooking. Also, the analysis did not incorporate the moisture content in the firewood during cooking. We only relied on the responses from the participants, thus hard to give accurate emission rate. We could also not give the mass of trees that produce one bag of charcoal. Lastly, the scope of the study was limited to the stoves and the end users. We did not estimate the age of trees of the trees used to make fuels, thus not easy to tell quantity of CO_2 sequestered per annum by each. May be with enough funding in future, we will conduct further studies to estimate measurements and moisture content of trees used for cooking with the stoves.

III. Results & discussion

Recap

The findings presented in introduction and desk review revealed that; one-meter cube of wood contains about 300 kg of carbon, which is equivalent to one ton of CO_2. One hectare of forest sequent one to two tons of CO_2 every year. Moreover, one fully grown tree produces an average of 5.65 bags of charcoal. It, however, absorbs about 25 Kgs of CO_2 from the atmosphere per year. One household use approximately 202 tins of charcoal per year; which is equivalent to about 4 bags of charcoal. Lastly, we require at least 10 Gt of CO_2 being removed from atmosphere per annum.

IV. Discussion

From the analysis, the following insights are evident:

The end users of ICS stoves are motivated by the low fuel consumption of the stoves which enable them to save financially and in terms of time.

Difference in the quantity of fuel saved between charcoal and firewood per annum while using ICS is negligible.

The time saved was dependent on the type of food cooked and frequency of cooking in a day.

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Projections

Assuming that there is still use of traditional stoves, Africa will still need approximately 4 billion bags of charcoal per year to meet the households demand. This is on assumption that; all the one billion households will be using charcoal for cooking. This implies that about 715 million trees will have to be cut every year.

Applying the findings presented in data analysis and desk review, use of ICS will enable the continent to save at least 75% of these trees per year. This is approximately 537 million trees. We anticipate that the trees will be able to sequent almost 13.425 million tons of CO_2 from the atmosphere. This is about 0.013425 $GtCO_2$; the CDR contributed by use of ICS for cooking in Sub-Sahara Africa only per annum. In 25-years period, it is anticipated that ICS will indirectly contribute to removing 0.3336 $GtCO_2$, which is 5.034% of the 2100 CDR target. Extending the initiative to households in other continents where wood fuel is still the main source of energy for cooking and heating, the expected CDR will be higher than 5.034%. The assumptions are that the growth of number of households that rely on wood fuel and the rate of afforestation will remain constant. Also, all the households with ICS will use them for cooking on daily basis.

Summary and Conclusions

Changes in weather patterns have links to increase in global temperature caused by human activities. Most of the activities are related to generation and use of energy whose sources are not clean. The actions lead to GHG emissions. About 80% of households in Africa use traditional methods of cooking; mostly wood fuel that has low calorific level. The end result is the use of high quantity of biomass that contribute to increase in emission of carbon dioxide to atmosphere.

Desk review has revealed that 500 million hectares of land are required for afforestation and reforestation to sequent 3.7 $GtCO_2$ per year for about 12 years in order to end the 41.2 $GtCO_2$ in the atmosphere. In Sub-Sahara Africa, most of the households are not in position to cook using either ICS or clean energy due to high initial costs and difficulty in accessing the fuel. Africa still lags behind in embracing the uptake of clean cooking. About one billions households in the continent still use wood fuel for cooking. This rarely contributes to meeting the strategy of The Paris Agreement on GHG emissions which requires that; global warming be capped to 1.5^0 C by 2100.

The initiative of enhancing uptake of ICS to minimize GHG emissions was the issue of concern for this research paper. There is need to ascertain the role of ICS in reducing the emissions or increasing the absorption of GHG from the atmosphere. Usage of the stoves in the sampled households and vintages was verified and data analysis conducted. The findings revealed that ICS enable saving of wood fuels by at least 75% in addition to minimized emissions. If all the households in Sub-Sahara Africa that use wood fuel in cooking were to embrace ICS, 158 million trees could be spared per year. By year 2100, the ICS will indirectly enable CDR up to 5.034% of 2100 Paris Agreement strategies on GHG emissions. This implies that in case households outside Africa, that still use traditional stoves and wood fuel for cooking, will be included in the initiative of adopting ICS for cooking, we should expect even better and more promising changes in GHG emissions thus decrease in global warming.

Recommendation

Investing in clean cooking may be vital. Partners specializing in energy nexus and combating climate change should prioritize injecting resources towards clean cooking. This will minimize deforestation as well as GHG emissions. Manufacturers, distributors, sellers and buyers of ICS should be incentivized for every unit of the stoves that reach the end users. There has to be credit for these stakeholders for every stove that used; i.e carbon credit.

Taxes and tariffs on ICS should be lifted to minimize hindrances to the purchasing, distribution and using of the ICS. Import duties on the ICS should be removed especially when entering developing nations. This should be implementable initiatives by partner countries and manufacturers.

It high time for governments in developing nations to enact a bill that enforce all the households to have ICS. This will give relief to women in terms of getting financial support from male household members. The 93.75% of stove users being female should be a guiding principle when designing marketing material. Programs and the material should be in favor of women. As part of sensitization, all adult women in that have phones in developing countries should be receiving sms alerts on the essence and health benefits of using ICS in cooking. They should also be informed on how to get funding for purchasing the stoves.

Even so, men ought to be taught the health effect related to the use of ICS. Health awareness should be incorporated in the sensitization programs. They should also be informed about the financial gains in form of savings when cooking using the ICS.

Financial institutions have to introduce new loan products geared towards enabling their customers afford the stoves. Female customers should be the main target by either giving favorable terms for the loanees of this gender or including a feminine gift to the stoves.

There is also need for governments to foresee the charges on the ICS and set price ceilings. This will enhance the adoption rate. On the other hand, firms that assemble the ICS should be major beneficiaries of carbon credit for every unit sold regardless of their country of operation.

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Lastly, the funders, partners and stakeholders of the climate adaptation sector should take full responsibilities to enable GHG emission reduction. They should give credits for every tree planted and preserved in developing nations. They should also foresee the distribution and allocation of incentives and credits to industry players. They also need to organize community engagement and sensitization programs at regional, national then to grass root level to ensure that there is awareness of the essence of ICS usage compared to TSOF. It would be better if they compel governments to incorporate ICS technology to be part of education curriculum in every country.

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