SIMPLE TECHNOLOGY TO REDUCE CARBON EMISSION IN RURAL CHARCOAL PRODUCTION IN SIERRA LEONE

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ABSTRACT- Charcoal is the primary source of energy for cooking and heating-related activities like blacksmithing, fish drying and other small scale industrial uses in Sierra Leone. The use of charcoal is prominent in urban households and is preferred to firewood due to its high calorific value per unit of weight, ease of transportation, and comparatively less smoke.

The continued reliance on the consumption of charcoal has a very serious effect on the environment that captures the concern of the Sierra Leone Government. Some Governments and development partners have concluded that charcoal production is responsible for deforestation.

The burning of wood during the charcoal production process releases greenhouse gases (GHGs), such as carbon mono-oxide (CO), methane (CH_4), and nitrous oxide (N_2O), into the atmosphere. These gases trap heat in the Earth's atmosphere, contributing to the greenhouse effect and leading to global warming and climate change. Furthermore, if this smoke, containing these dangerous gases emitted, is inhaled by charcoal producers will lead to compounding health issues.

The aim of this study is to contribute to the reduction of the greenhouse effect leading to global warming and climate change as well as improving the health status of charcoal producers and their communities.

Field experiments were conducted using improved Tumulus kiln with a chimney designed with fractionating columns to aid the fractional distillation process of the gases emitted during Carbonization/pyrolysis. Four wood species namely Phyllanthus discoideus, Diallum guinesis, Mangefera indica and Gmelina aborea were used in the carbonization/pyrolysis and results compared in terms of their charcoal and wood tar production yields. The study found out that 500kg of wood sun-dried for 144hrs produced approximately 5 to 13litres of diluted tar and 1 to 5 litres of dehydrated tar depending on the type of wood species.

The tar trapped during condensation is an indication of the harmful heavy metals extracted from the smoke by the technology. Hence reducing carbon emission causing greenhouse effect, climate change and health issues to rural charcoal producers in Sierra Leone.

Keywords: Carbon emission, pyrolysis, carbonization, chimney, Tumulus kiln, fractional distillation, greenhouse effect, climate change, wood tar, charcoal, Phyllanthus discoideus, Diallum guinesis, Mangefera indica and Gmelina aborea

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1.0 INTRODUCTION

Charcoal is the primary source of energy for cooking and heating-related activities like blacksmithing, fish drying and other small scale industrial uses in Sierra Leone. The use of charcoal is prominent in urban households and is preferred to firewood due to its high calorific value per unit of weight, ease of transportation, and comparatively less smoke (van Beukering et al., 2007), and its production continues to rise due to preferences and demands of increasing urban populations in many sub-Saharan African countries (IEA, 2014). Furthermore, charcoal production and marketing sector in Sierra Leone, like other developing economies, is a primary source of income generation and employment creation for most rural communities. Hence, making the charcoal industry one of the most significant semiformal economic sectors in Sierra Leone.

Charcoal has several benefits including provision of clean energy for domestic cooking, waste water treatment, and soil application of biochar improves soil quality and crop yields (Xiu et al., 2021) It is estimated to contribute US$650 million per annum to the Tanzanian economy, approximately six times the combined value of coffee and tea (World Bank, 2009). In Malawi it is estimated to contribute 3.5% of the gross domestic product (Zulu, 2010).

Sierra Leonean urban household energy consumption has changed considerably over the last two decades; in 2004 urban energy use was; wood 88%, charcoal 8% and kerosene 4%; in rural household wood accounted for 97% of energy use (GoSL 2007). By 2013, charcoal had increased to 73%, wood had declined to 26% and kerosene to 0.6%; LPG and electricity had entered the market but accounted for only 0.2% of energy use (Paul et al 2017). The 2014 Household Energy Consumption Survey (HECS) in Sierra Leone revealed that high income earners prefers charcoal to fire wood (SLIHS 2018).

It seems likely that production and consumption of charcoal will continue well into the future (Fayia et al. 2018), even in Ghana or Nigeria where 60-70% of households are electrified they still rely on charcoal or firewood for cooking and high-income earners rarely replace charcoal with other source of energy.

The continued reliance on the consumption of charcoal has a very serious effect on the environment that captures the concern of the Sierra Leone Government. Some Governments and development partners have concluded that charcoal production is responsible for deforestation (Post & Snel 2003).

World leaders have affirmed the urgency of climate-change mitigation in the 2015 Paris Agreement, and many new commitments to reduce GHG emissions – expressed in nationally determined contributions (NDCs) – refer to forestry and land-use measures. Opportunities for emission reductions in the charcoal sector are not well reflected in NDCs, however, and the potential role of the charcoal value chain in mitigating climate change – and how to realize this potential – is poorly understood ((FAO: The Charcoal Transition. Greening the charcoal value chain to mitigate climate change and improve local livelihoods).

Charcoal making involves burning wood or carbonization of wood in a kiln whilst controlling the amount of oxygen present. Carbonization is a form of pyrolysis which is the process of breakdown of complex substances into simpler ones by heating. When the wood is dry and heated to around 280°C, it begins to spontaneously break down to produce charcoal plus water vapour, methanol, acetic acid and more complex chemicals, chiefly in the form of tars and non-condensable gas consisting mainly of hydrogen, carbon monoxide and carbon dioxide. During carbonization, if this smoke (containing these dangerous gases) emitted is inhaled by charcoal producers will lead to compounding health issues.

This study provides knowledge on simple technology that could help in the reduction of Green House Gases (GHG) emissions in the existing traditional charcoal production thereby contribute to climate change mitigation and improved health status and livelihoods of rural charcoal producers and their communities as a whole.

1.1 Problem Analysis

The smoke and fumes given off during carbonization of wood can be a health hazard although the advent of "improved cook stoves" (ICS) reduces this (Paul et al 2017). The burning of wood during the charcoal production process releases greenhouse gases (GHGs), such as carbon mono-oxide (CO), methane (CH_4), and nitrous oxide (N_2O), into the atmosphere. These gases trap heat in the Earth's atmosphere, contributing to the greenhouse effect and leading to global warming and climate change.

An estimated 1–2.4 GT CO_2 of greenhouse gases are emitted annually in the production and use of fuelwood and charcoal, which is 2–7 percent of global anthropogenic emissions. These emissions are due largely to unsustainable forest management and inefficient charcoal manufacture and woodfuel combustion (FAO 2017). The Charcoal Transition. Greening the charcoal value chain to mitigate climate change and improve local livelihoods). Charcoal production using traditional kilns is associated with high consumption of wood since efficiency is only between 8 and 15 %.

Furthermore, apart from charcoal production being one of the leading causes of deforestation and environmental degradation in Sierra Leone, it is also a prime contributor to the huge loss of biodiversity and disturbance of local ecosystems. Studies have shown that charcoal briquettes contain heavy metals that are harmful to both human health and the environment.

Something must be done to help mitigate the emission of these dangerous gases in the environment in order to protect both charcoal producers and their communities as while as fauna and flora.

1.2 Aim and Objectives of the Study

The aim of this study is to contribute to the reduction of the greenhouse effect leading to global warming and climate change as well as improving the health status of charcoal producers and their communities.

The objectives of the study include (a) To provide a simple technology that could be used by charcoal producers to reduce the release of greenhouse gases (GHGs), such as carbon mono-oxide (CO), methane (CH_4), and nitrous oxide (N_2O), mostly in the form of wood tar into the atmosphere. (b) To provide recommendations on the efficient use of the technology to charcoal producers.

2.0 REVIEW OF LITERATURE

Rural charcoal production involves huge emission of greenhouse gases (GHG) which contribute to climate change. In order to mitigate this GHG effect, the use of technologies such as pyrolysis, gasification and liquefaction can convert biomass into valuable products for various applications to make up for the shortage of fossil fuels and mitigate climate change [Haiqing Sui et al, 2022].

Slow pyrolysis can process biomass to produce the bio-char, while it is inevitable to produce a large number of the wood tar as a by-product which contains many high value-added chemicals [Rego *et al 2022*.].

The wood tar consists of more than 400 organic chemicals with a wide range of molecular weights (60–300 g/mol) and oxygenated volatile and nonvolatile components involving organic acids, alcohols, aldehydes, ketones, phenols, furanes, benzenes, sugars, bitumen, and their derivatives [Haiqing Sui et al, 2022].

As a result of its chemical composition, wood tar as long been recognized for its medicinal property, especially for the treatment of dermatologic disorders. Although coal tar is utilized more frequently in modern dermatology, wood tars have also been widely employed. Tar is used mainly in the treatment of chronic stable plaque psoriasis, scalp psoriasis, atopic dermatitis, and seborrhei dermatitis, either alone or in combination therapy with other medications, phototherapy, or both (Kapila et al 2009).

Despite the medicinal advantages of wood tar, which is a by-product of pyrolysis, rural charcoal producers in Sierra Leone lack the technology to extract the wood tar from the smoke released during carbonization or pyrolysis. Hence the polluted smoke (GHG) is freely emitted into the atmosphere causing both health problems to producers and environmental effect such as climate change.

These include short-term effects such as eye irritation, coughing, and headache**s** (Orozco-Levi et al., 2006; UNEP, 2019), as well as more serious long-term health problems such as respiratory illnesses, cardiovascular diseases, and the heightened risk of developing carcinogenic conditions (Lachowicz et al., 2022).

A study carried out by Ndinomholo et al in July 2016 on "Respiratory health effects of occupational exposure to charcoal dust in Namibia" revealed that exposure to respirable charcoal dust levels was above occupational exposure limits in most sectors, with packing and weighing having the highest dust exposure levels (median 27.7 mg/m^3, range: 0.2–33.0 for the 8-h time-weighted average). Their study also confirm that the high cumulative dust exposure category was significantly associated with usual cough (OR: 2.1; 95% CI: 1.1–4.0), usual phlegm (OR: 2.1; 95% CI: 1.1–4.1), episodes of phlegm and cough (OR: 2.8; 95% CI: 1.1–6.1), and shortness of breath.

This brief literature review justified the need for conducting this research work, which is a simple and appropriate technology that could help to reduce GHG emissions from charcoal production in Sierra Leone thereby helping to improve the health status and livelihoods of rural communities.

3.0 EXPERIMENTAL PROCEDURES

Field experiments were conducted at the Department of Industrial Technology, Njala University in Sierra Leone using Tumulus kiln in the carbonation of wood to charcoal. The tumulus Kiln is a type of earth-kiln introduced into Guyana over a century ago, and this method is practically used by all charcoal producers in Sierra Leone.

Four wood species (S1, S2, S3, and S4) were carbonized using a tumulus kiln. Before carbonization, the weights (kg) and moisture contents (%) of both the wet and dry wood ready for stalking inside the kiln were determined as presented in Table 1. During the process of carbonization/pyrolysis smoke was allowed to pass through a chimney with fractionating columns. As the hot smoke was force to pass through these columns, fractional distillation occurred leading to the condensation of tarry liquids containing heavy metals which dripped into a cup. This eventually resulted to clean air emission free from heavy metals that could be very harmful to humans and the environment.

3.1 Raw Material

Simple and easy to find materials were used so that rural charcoal producers would have access to this technology. The technology has three components (a) wood seasoning (b) Construction of a chimney with fractionating columns (c) Construction of the Tumulus kiln

3.1.1 Wood seasoning

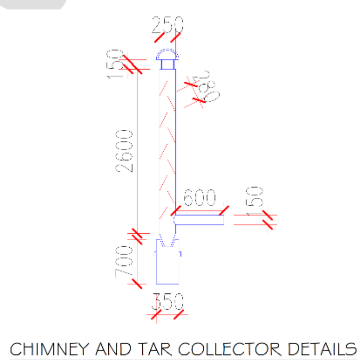
The materials used were four wood species commonly used by charcoal producers in Sierra Leone. The wood were cut to 1m length with varying diameters. Table 2 shows both the local in Mende and botanical names of these wood species.

Table 1: Wood species used in the study

Sample No.	Local name	Botanical name
S1	Tinjui	Phyllanthus discoideus
S2	Mambui	Diallum guinesis
S3	Mangoi	Mangefera indica
S4	Yamani	Gmelina aborea

3.1.2 Construction of the chimney

This is a cylindrical pipe with diameter of 300m and length of 1800mm. Figure 1 presents pictures of the chimney with technical specifications.



(a) Chimney (b) Welded blades/fractionating columns (c) Chimney specifications

Figure 1: Pictorial sections of the chimney

The blades which formed the fractionating columns are made from 1mm steel plates cut into smaller sizes with dimension 50mm by 280mm. Each of these steel pieces was welded on to the cylindrical pipe as shown in Figure 1b.

3.1.3 Construction of the Tumulus Kiln

A 2m circumference flat floor was cleared for the construction of the kiln. This floor was filled with a series of short logs, cut down to around one metre in length. These logs are set out in the shape of bicycle spokes, aligning with the vents and forming a central 'fire space'. The chimney pipe was place on this logs followed by addition of logs around the spokes to form a well-ventilated base. More wood was carefully added to form a pyramid like structure covered with grass/rice straws layer followed by clayey soil layer as demonstrated in Figure 2.

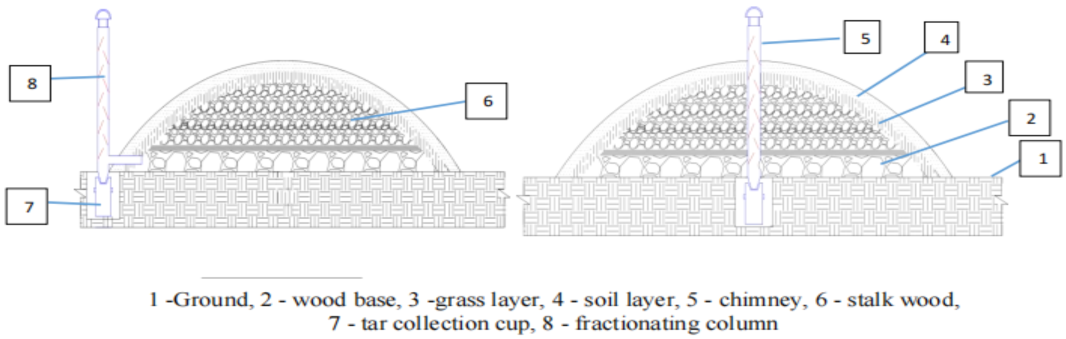


Figure2: Sketch of Tumulus kiln showing chimney position

Figure 3: Photos illustrating wood staking and carbonization process

3.2 Testing Methods

3.2.1: Determination of moisture content of wet wood

Typically, moisture content is determined via a thermo-gravimetric approach, i.e., by loss on drying, in which the sample is heated and the weight loss due to evaporation of moisture is recorded. The wood sample being tested was sun dried and its weight taken every 48hrs for up to 144hrs. This weight difference is then used to calculate the wood's original moisture content as presented in Table1.

$$\text{Moisture content (\%)} = \frac{(\text{Wt. of wet wood} - \text{Wt. of dry wood})}{\text{Wt of dry wood}} \times 100$$

Figure 4. Moisture content of wood samples determination

Table2: Determination of moisture content of wet wood

Sample No.	Local name	Botanical name	Initial wt. (kg)	Wt. after every 48hrs (kg)			Moisture content (%)		
				48hrs	96hrs	144hrs	48hrs	96hrs	144hrs
S1	Tinjui	Phyllanthus discoideus	500	474.5	462.5	449.1	5.4	2.6	2.2
S2	Mambui	Diallum guinesis	500	492.9	488.3	485.3	1.4	0.9	0.6
S3	Mangoi	Mangefera indica	500	481.0	474.0	470.0	4.0	1.5	0.9
S4	Yamani	Gmelina aborea	500	485.7	474.1	465.1	2.9	2.5	1.9

Table3: Weight of wood before and after carbonization

Sample No.	Local name	Botanical name	Wt. before carbonization (kg)	Wt. of uncarbonized wood (kg)	Total wood carbonzized (kg)
S1	Tinjui	Phyllathus discoideus	449.1	32.6	416.5
S2	Mambul	Dialium guinesis	485.3	56.4	428.9
S3	Mangoi	Mangifera indica	470.0	27.3	442.7
S4	Yemani	Gmelina aborea	465.1	15.03	450.07

3.2.2 Pyrolysis/Carbonization Process

The field experiments were done on the four wood species,namely S1, S2, S3 and S4 to determine the wood tar production efficiency of these wood species which gives a fear idea on species with high air pollutant during carbonization or phyrolysis. Figure 3 presents (a) the process of pyrolysis or carbonization (b) condensation of the wood tar which dripped into a collection pan (c) measuring the quantity of wood tar collected from each wood species' tumulus kiln. Table 3 presents results of the quantities of tar solutions obtained during the carbonization process.

1. Pyrolysis in progress (b) Condensation of tar from chimney (c) Measuring tar collected

Figure 5: Fractional distillation of wood tar during pyrolysis/carbonization

Table 3: Quantities of wood tar collected from carbonization/pyrolysis of wood samples

Sample	Local name	Botanical name	Diluted tar collected (litres)	Dehydrated tar collected (litres)
S1	Tinjui	Phyllathus discoideus	12	4
S2	Mambul	Dialium guinesis	5	1.5
S3	Mangoi	Mangifera indica	13	5
S4	Yemani	Gmelina aborea	11	3.5

4.0 DISCUSSION OF RESULTS

4.1 Pyrolysis process

Pyrolysis is defined as the process of chemically decomposing organic materials (wood) at elevated temperatures in the absence of oxygen. Since no oxygen is present, the organic material does not combust. Instead, the chemical compounds that make up the material decompose into combustible gases and charcoal. In Sierra Leone, the rural charcoal producers freely release these combustible gases into the atmosphere thereby causing compounding problems of health on charcoal producers and negative environmental impact on the ozone layer, which eventually result to climate change.

This study determined the weight loss (kg) of the wood samples during drying as presented in Figure 6. The weight loss of the wood samples investigated varied with drying time; Diallum guinesis had the lowest weight loss at the drying ranges from 48hrs to 144hrs followed by Mangefera indica, Gmelina aborea and lastly phyllanthus discoideus. This could be attributed to the water holding capacity or moisture retention of the wood fibre.

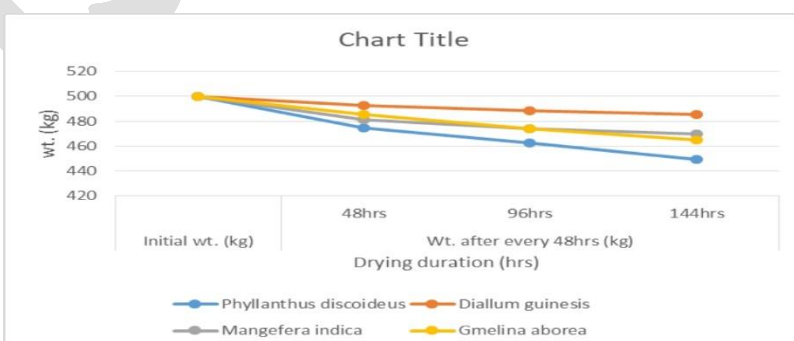


Figure 6: Weight loss (kg) of wood samples at various drying times

Moisture content has be found to be one of the primary factors that affects the pyrolysis and ignition behaviors of wood (Blasi (2008), Yan et al (2003), Izabellaet al (July 2017)). Moisture content retards rise in solid by vaporization of free water and delays the ignition of volatiles in gas by dilution. Figure 7 presents results of the moisture contents of the wood samples at different drying periods.

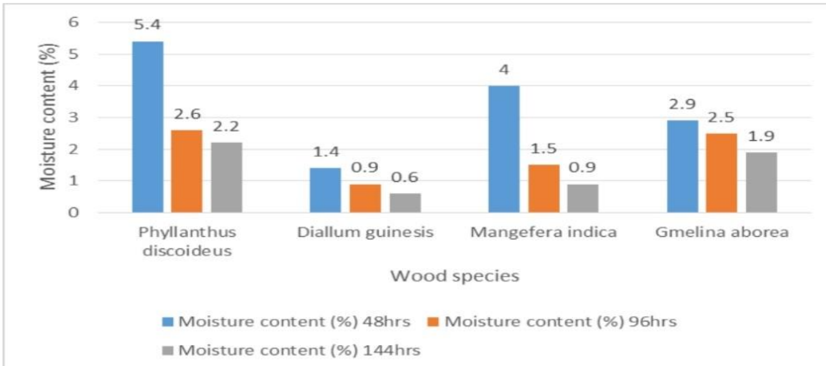


Figure 7: Moisture contents of wood samples at various drying times

An inverse relationship was found between the moisture content and weight loss at different drying times. The Phylanthus discoideus wood which had the highest weight loss (from 500 to 449.1kg) exhibited the highest moisture content of 2.2% at 114hrs drying time. While the Dialium guinesis which had the lowest weight loss showed the lowest moisture content of 1.4%.

Furthermore, the charcoal production efficiency of the wood samples was investigated as shown in Figure 8.

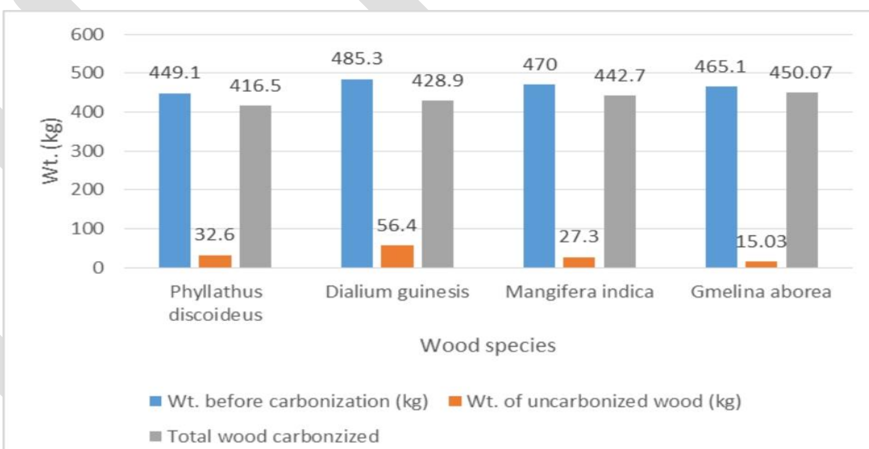


Figure 8: Charcoal production yield of the wood samples

The quantity of charcoal produce under field condition showed Gmelina aborea as having the high yield per kg (450.1kg), followed by mangifera indica (442.7kg), Dialium guinesis (428.9kg) and lastly phylantlus discoideus (416.5kg).

An assessment of the quantities of both diluted and dehydrated tar solutions obtained from the four wood samples during the fractional distillation process were measured in litres and results presented in Figure 9. Mangifera indica, which had 13litres of diluted tar and

5litres of dehydrated tar, produced the highest tar yield followed by the Phylantlus discoideus with 12 litres of diluted tar and 4 litres of hydrated tar.

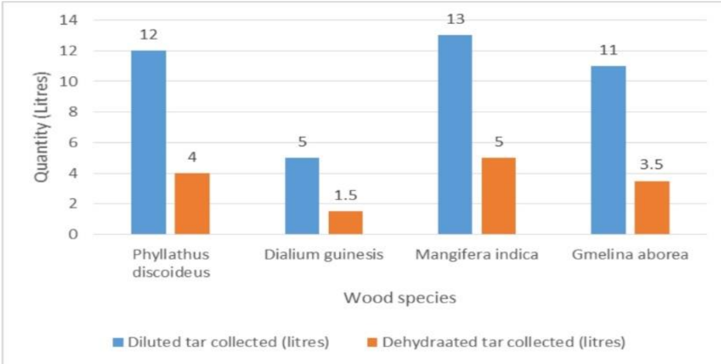


Figure 9: Wood ter production yield of wood samples

From the results of weight loss (kg), moisture content (%) and charcoal yield (kg) , a general conclusion could be made that moisture content is a key determinant of both charcoal and wood ter yield during carbonization or pyrolysis of wood.

5.0 CONCLUSION

Charcoal is the primary source of energy for cooking and heating-related activities like blacksmithing, fish drying and other small scale industrial uses in Sierra Leone. The use of charcoal is prominent in urban households and is preferred to firewood due to its high calorific value per unit of weight, ease of transportation, and comparatively less smoke. Charcoal has several benefits including provision of clean energy for domestic cooking, waste water treatment, and soil application of biochar improves soil quality and crop yields **.**

The continued reliance on the consumption of charcoal has a very serious effect on the environment that captures the concern of the Sierra Leone Government. Some Governments and development partners have concluded that charcoal production is responsible for deforestation

Sierra Leonean urban household energy consumption has changed considerably over the last two decades; in 2004 urban energy use was; wood 88%, charcoal 8% and kerosene 4%; By 2013, charcoal had increased to 73%, wood had declined to 26% and kerosene to 0.6%; LPG and electricity had entered the market but accounted for only 0.2% of energy use (Bess and Koroma 2014).

The burning of wood during the charcoal production process releases greenhouse gases (GHGs), such as carbon mono-oxide (CO), methane (CH_4), and nitrous oxide (N_2O), into the atmosphere. These gases trap heat in the Earth's atmosphere, contributing to the greenhouse effect and leading to global warming and climate change. Furthermore, if this smoke, containing these dangerous gases emitted, is inhaled by charcoal producers will lead to compounding health issues.

Therefore, to mitigate the health hazards and greenhouse effect that leads to global warming and climate change, the adoption of this simple appropriate technology by rural charcoal producers could contribute to the fight against climate change and improve community health.

6.0 RECOMMENDATIONS

Based on this study, three key recommendations could be made: (1) The rural charcoal producers should be sensitized and encouraged to use the technology. (2) Local Tinsmiths are trained at community level on the production of the chimneys using probably scrap materials. (3) Local Authorities (chiefs, village headmen, youth leaders, ward counselors etc) should reinforced the use of the technology in order to save life.

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