

UNIVERSITY OF CAPE COAST

AN ASSESSMENT OF THE CONTRIBUTION OF TRADITIONAL FISH
SMOKING TO GREENHOUSE GAS EMISSIONS IN SELECTED
COMMUNITIES OF COASTAL GHANA.

GEORGE RAYMOND ESHUN



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BY

GEORGE RAYMOND ESHUN

Thesis submitted to the Department of Fisheries and Aquatic Sciences of the
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University of Cape Coast, in partial fulfilment of the requirements for the
award of a Master of Philosophy (M.Phil.) degree in Integrated Coastal Zone
Management

SEPTEMBER 2023

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: Date:

Name: George Raymond Eshun

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Signature.....Date.....

Name: Dr. Precious Agbeko D. Mattah (Principal Supervisor)

Signature.....Date.....

Name: Dr. Noble Kwame Asare (Co-Supervisor)

ABSTRACT

The concentrations of greenhouse gases (GHGs) in the atmosphere were relatively stable during the pre-industrial era by keeping the Earth's temperature steady until the dawn of the industrial revolution when the concentrations of these gases started increasing. Major sources of GHGs include the combustion of fossilised fuels and the burning of biomass fuels. Throughout the world, fuelwood is used for heating and cooking. The fish smoking process is no exception. The study examined GHG emissions from traditional fish smoking along the coast of the Western and Central Regions of Ghana, investigating fuelwood consumption across different fishing seasons and preferences for specific fuelwood types. An explorative sequential method was employed as the study design, involving focus groups discussions and interviews with fish smokers and fuelwood suppliers. A cross-sectional survey was conducted from May to October 2022, sampling 506 respondents. The estimation of CO₂, CH₄ and N₂O emissions was done using the IPCC tier 1 methodology for stationary combustion, supplemented by air quality sensor measurement. Results show that the total quantity of fuelwood used by the communities in the study was 18,349 MT per annum. The cumulative annual of emissions resulting from the practice of fish smoking amounts to 33,871.88 MT of CO₂e. The study found that fish smoking comparatively emits lower GHGs compared to other sources with fuelwood preferences influenced by factors such as aesthetics, burning duration, and local availability. It was therefore recommended that measuring GHG emissions from other fuelwood-dependent activities in Ghana would enhance emission calculations and accuracy.

KEY WORDS

Carbon dioxide equivalent

Climate Change

Combustion

Energy

Fish Processing

Fuelwood



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DEDICATION

To the Eshun Family



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LIST OF ACRONYMS


AFOLU	Agriculture, Forestry and Other Land Use
CH ₄	Methane
CLA	Consumer Lifestyle Approach
CO ₂	Carbon Dioxide
CO ₂ e	Carbon dioxide equivalent
FAO	Food and Agriculture Organisation
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GFNG GIR	Ghana's Fourth National Greenhouse Gas Inventory Report
GHG	Greenhouse Gas
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
MT	Metric Tonnes
Mtoe	Mega Tonnes of Oil Equivalent
N ₂ O	Nitrous Oxide
NCV	Net Calorific Value
NIR	National Inventory Report
PAHs	Polycyclic Aromatic Hydrocarbons
PFCs	Perfluorocarbons
SF ₆	Sulphur Hexafluoride
SFMP	Sustainable Fisheries Management Project
Tg	Teragram

TMOs

Traditional Mud Ovens

UNFCC

United Nations Convention on Climate Change

USAID

United Nations States Agency for International
Development

Wt

Weight



CHAPTER ONE

INTRODUCTION

Climate change is an issue that is widely discussed in both scientific and political circles. Changes in the concentrations of greenhouse gas (GHG) such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and other halocarbons, could be attributed to climate change. (Ahmed,2020). Despite the fact that there are countries with high GHG emissions around the world, climate change is a global phenomenon and as a result, collaborative action is necessary to solve this common problem. The concentration of anthropogenically-related carbon dioxide in the atmosphere has been on the rise in recent times resulting in an increase in global temperature.

A GHG is a gas that absorbs light in the infrared portion of the electromagnetic spectrum. Until the industrial revolution, GHGs kept the Earth at a steady temperature and their concentrations remained relatively stable over extended periods of time. The accumulation of greenhouse gases in the atmosphere, caused by changes in their concentrations, has led to a secondary greenhouse effect resulting in the current rise in temperatures (Tuckett, 2019). This increase in Earth's surface temperature, known as the greenhouse effect, is causing permanent consequences such as global warming and climate change (Huang, Kuo, & Chou 2016).

The major sources of GHGs include fossil fuel combustion for power generation and transportation, burning of vegetative covers in forests and savannah and cooking with biomass fuels. The ultimate by-products of these processes are the release of CO₂, CH₄ and N₂O which can react with other gaseous species in the atmosphere to form secondary GHGs (Ramanathan &

Feng, 2009). Although anthropogenic CO₂ emissions account for the majority of GHG-induced warming, other gases such as CH₄, nitrous oxide, ozone depleting chemicals, and other gases have long-term effects on climate (Montzka, Dlugokencky, & Butler, 2011).

Differentiating between human-made and natural greenhouse effects is crucial when addressing the greenhouse effect (Fakana, 2020). The anthropogenic greenhouse effect is caused by human activities through the burning of fossil fuels, burning of biomass, deforestation, and industrial processes. The natural greenhouse effect is critical to Earth's survival. Without the natural greenhouse effect, the average global temperature would be less than 0 °C. The natural greenhouse effect makes life possible on Earth by trapping heat within the atmosphere (Alley et al., 2007). According to Tahir, Rafique and Alaamer (2010), when fuelwood is burnt, carbon dioxide is released, but it is anticipated that replaced trees will reabsorb this carbon dioxide during the subsequent growing season. Hence, fuelwood is generally regarded as carbon neutral in relation to GHG emissions. Nevertheless, if the harvesting of fuelwood exceeds the natural regeneration of forest covers or the pace of reforestation, there can be a cumulative release of GHGs from the combustion of fuelwood.

Background of the Study

In Ghana, fuelwood accounts for over 76% of total energy use, particularly in rural areas (Mensah & Adu, 2015). For half of the world's population, the use of fuelwood, charcoal, and non-woody biofuels is a daily occurrence. The majority of biomass combustion occurs in developing countries, primarily due to economic reasons (Ludwig, Marufu,

Huber, Andreae, & Helas, 2003). The utilisation of wood fuels for energy production has an influence on the overall carbon balance, leading to substantial net emissions of carbon dioxide, particularly over an extended duration. Although the use of fuelwood does contribute to increased net carbon dioxide emissions, the impact is modest in the long term. However, carbon dioxide emissions can become significant in the medium term. Consequently, it is crucial to include the net emissions resulting from wood fuels in the statistics of international GHG emission (Wibe, 2012). All carbon dioxide emissions whether from burning fossil fuels or biomass have an impact on the carbon cycle and, consequently, the Earth's radiative balance. This influence leads to a climatic shift that requires thorough evaluation. Regardless of the source, all CO₂ emissions have the potential to affect the climate and must be carefully assessed (Cherubini, Peters, Bernsten, Strømman, & Hertwich, 2011).

In most African countries, the household sector plays a prominent role in energy usage. Typically, energy is sourced from solid fuels burned in basic stoves that have inadequate combustion characteristics. Additionally, compared to industrialized nations, countries heavily reliant on fuelwood have lower GHG emissions. However, the adverse effects of net GHG emissions resulting from fuelwood combustion can lead to local environmental degradation. Analysing household consumption behaviour is therefore crucial in examining alternative climate policies and predicting future emission patterns, given its significant influence on GHG emissions (Girod & De Haan, 2010).

Coastal communities and nearby areas in Ghana depend on fish processing as their primary source of income. The processing and preservation of fish for sale constitute the main economic activity for these households (Aworh, 2008). Fuelwood is the primary energy source utilised by fish processors for their operations especially in commercial fish smoking. Fuelwood is particularly crucial for the fishing industry, especially in commercial fish smoking. Therefore, ensuring the supply and proper management of fuelwood is vital for the sustainability of the fishing industry (Kwarteng, Nsiah, & Aziebor, 2016).

In Ghana, fish post-harvest processing involves four primary techniques: smoking, salting, drying, and frying. Among these techniques, smoking is the most prevalent and widely practiced, often operated as a commercialised business. The smoked fish industry holds immense significance in Ghana as it contributes to job creation, revenue generation, food security, and foreign exchange earnings, thereby contributing to the long-term sustainability of food nutrition and the economy. The smoking process in Ghana varies between wet-hot smoking and dry-hot smoking, depending on the fish type, intended use, and desired storage duration. Artisanal fish smoking is predominantly carried out by women in coastal towns and villages.

Fish smoking represents a gendered small-scale socioeconomic activity which is deeply ingrained in the cultural fabric of many coastal communities in Africa (Akintola & Fakoya, 2017; Deb, Haque, & Thompson, 2015). In several communities in Ghana, fish smoking activities primarily take place within households, where families collaborate in groups while operating from their own homes (Sakyi, Jia, Ampofo-Yeboah, & Aglago, 2019). Many

Ghanaians cherish smoked fish because the smoke imparts a pleasant flavour. When compared to other perishable protein foods such as fresh meat, eggs, and milk, smoked fish offers a price advantage (Pemberton-Pigott, Robinson, Kwarteng, & Boateng, 2016).

The traditional practice of fish smoking heavily relies on use of firewood as a fuel source. This method generates a substantial amount of smoke, which carries harmful pollutants and gases, including carbon monoxide, particulate matter, and polycyclic aromatic hydrocarbons (Mushi, Mrindoko, Mbise, & Omary, 2018). In many developing countries, traditional and simple stove designs are commonly used, including those specifically employed for fish smoking. These stoves come in various forms, sizes, and materials, with significant local variations. In Ghana, for instance, fish smoking ovens encompass a range of options such as cylindrical metal ovens, mud ovens, Chorkor ovens, Morrison ovens, and others. Each of these ovens possesses its unique architectural design and combustion efficiencies, catering to precise requirements of fish smoking in Ghana and other parts of Africa (Adeyeye & Oyewole, 2016; Mushi, 2018). Traditional stoves exhibit several drawbacks, including low efficiency, leading to the inefficient use of fuel, significant emission of GHGs, and indoor air pollution. The inefficient combustion of biomass in traditional cookstoves results in the release of byproducts from incomplete combustion. These emissions have garnered significant attention in recent literature due to their impact on regional and global climate. The emissions generated from biomass burning have been recognised as a significant contributor to climate change, highlighting the need to address the environmental consequences associated with traditional

stove usage. Improving stove efficiency and reducing emissions can play a crucial role in mitigating the adverse climate effects caused by biomass burning (Jagger & Shively, 2014).

The manual harvesting of fuelwood involves the use of tools such as machetes, chainsaws, or cutlasses. To transport the fuelwood to marketplaces or fish processing centers, smaller diameter stems are bundled or carried as head loads, with the quantity varying depending on the tree species. Larger log pieces are further processed using an axe or chainsaw, and then packaged and shipped in chunks to clients. This process highlights the various steps involved in fuelwood harvesting, preparation, and transportation, with different tools and techniques are employed to ensure efficient use and distribution of this essential energy source (Ali, Saadun, Alias, & Norizah, 2019; Kwarteng, 2015).

According to a report by Torell, Owusu and Okyere Nyako (2015), the demand for fuelwood is much higher during the peak fishing season, which runs from June/July to September/October each year. The Central and Western Regions of Ghana have a higher rate of fuelwood production. It is unclear what causes the discrepancy in harvesting intensity between locations. However, as fish availability determines fuelwood demand, it could be because the Western Region smokes more fish, particularly frozen fish, during the lean season compared to the rest of the coastal regions in Ghana. Some notable fuelwood types which are mostly used for fish smoking includes: Ananta (*Cynometra ananta*), Ohia/Esa (*Celtis mildbraedii*), Ohaa (*Sterculia oblongata*), Ofram (*Terminalia superba*), Bediwonua (*Canarium schweinfurthii*), Danta (*Nesogogordonia papaverifera*), Kaku (*Lophira alata*),

Wawa (*Triplochiton scleroxylon*), Emeri (*Terminalia ivorensis*), Dahoma (*Piptadeniastrum africanum*), Neem (*Azadirachta indica*), Okoro (*Albizia zygia*), Okonkroma (*Morinda lucida*), Sese (*Holarrhena floribunda*) and Yaya (*Amphimas pterocarpoide*). In other communities along the coast of Ghana, several species of mangroves particularly *Rhizophora racemosa* are used for fish smoking.

Problem Statement

In Ghana, there have been little research on GHG emissions associated with traditional fish smoking. Studies on fish smoking are primarily concerned with the potential health effects of burning biomass during fish smoking. Emissions from various types of fish smoking ovens were not taken into account. The focus of emissions has been on air pollutants such as carbon monoxide and particulate matter. Studies suggest that a disproportionate quantity of GHGs from household sources emanate from biomass cookstoves (Dickinson et al., 2015; Flintwood–Brace, 2016).

Consequently, there is limited understanding on the amount of GHG emitted in the fish smoking activities. Empirical studies that measure the concentrations of GHG emissions from fish smoking in Ghana are absent in the literature. Given that the efficiencies of fish smoking ovens vary by type, optimising ovens to minimise GHG emissions fundamentally requires in-depth understanding of the amount of GHG emissions from each type of oven. The preferences for different fuelwood by fish smokers should also be taken into consideration. Despite the plethora of evidence that the composition and concentrations of emissions from fish smoking differ by type of biomass fuel burnt, little is known about the amount of GHGs emitted from the burning of

different fuelwood types used in fish smoking. Greenhouse gases are the primary contributors to human-induced climate change, and if left unchecked, there will be an increasing, mostly negative, direct and indirect health impact. Climate change will exacerbate health issues, livelihood vulnerabilities, and coastal floods in low-lying areas. Societies with higher sensitivity and low adaptive capacity are most likely to be affected by these issues due to their high vulnerabilities. The majority of developing countries with low lying coastal areas may be severely impacted (McMichael & Lindgren, 2011).

Purpose of the Study

The overall aim of the study is to examine the contribution of traditional fish smoking ovens to GHG emissions along the coast of Ghana. Specifically, the study seeks to assess GHG emissions from traditional fish smoking ovens in selected coastal communities, focusing on the inefficiencies in fuelwood use that contribute to these emissions. In addition, the study seeks to address the gap in understanding GHG emissions from traditional fish smoking, as previous studies have mainly focused on air pollutants.

Research Objectives

The research objectives of the study were:

1. Evaluate the preferences of fish smokers for fish smoking ovens and fuelwood types.
2. Determine the amounts of greenhouse gases generated from traditional fish smoking.
3. Assess the emission of greenhouse gases from different types of fish smoking ovens used in the coastal communities.

4. Evaluate greenhouse gas emissions from different fuelwood types used in fish smoking.

Significance of the Study

Ghana signed the United Nations Convention on Climate Change (UNFCCC) in 1992 in Rio and subsequently ratified the Convention to become a party to the Convention. This mandates Ghana to regularly communicate to the international community, its internal climate actions including the development and updates of national emissions inventory reports (NIR). The NIR publishes net GHG emissions estimates of the main economic sectors for specific reporting period (UNFCCC, 2019). It is unclear how much developing countries contribute to GHG emissions as well as the release of GHGs from the combustion of fuelwood used in the fish smoking enterprise. The findings of this research will provide detailed understanding of GHG emissions in traditional smokehouses and potential directions for future research. The findings will also likely add to the existing body of knowledge by identifying the patterns of carbon emissions in Ghanaian fish smoking industry which will be a valuable reference for policymakers and climate change activist. Furthermore, the study offers the benefit of addressing climate and health issues by utilising field data, which is typically lacking in economic activities of GHG emissions in Ghana. Finally, this study will make an important contribution to the body of knowledge on GHG emissions in one of the major economic activities in the coastal areas of Ghana. Emission factors from wood fuels as commonly used in developing countries are not well characterised. Quantification of GHG emissions from fish smoking will provide baseline information for understanding the potential for reduction in

GHG emissions and provide rationale for improving the efficiency of fish smoking techniques. This will also contribute to the knowledge generation and adoption of improved and environmentally friendly fish processing technologies.

Limitations of the Study

This study assessed GHG emissions (CO_2 , CH_4 , N_2O) from fish smoking but was limited by the unavailability of N_2O sensors. Despite efforts, N_2O data could not be collected, potentially overlooking significant nitrous oxide contributions.

Delimitations of the Study

The study was specifically delimited to traditional fish smoking activities in selected coastal communities of Ghana, focusing exclusively on the use of fuelwood as the sole energy source for fish smoking. The assessment of GHG emissions was restricted to carbon dioxide, methane, and nitrous oxide. The scope of the study did not extend to other potential energy sources or pollutants beyond the specified GHGs. Additionally, the geographical focus of the study was confined to some selected coastal communities within the Central and Western Region of Ghana.

Definition of Terms

Biomass: is a term used to describe renewable organic material that comes from plants and animals used as fuel.

Biomass energy: is the renewable energy generated from organic material that comes from plants and animals.

Fuelwood: is wood that is harvested from forestlands or local farmlands and burned directly for energy in residential or commercial sectors.

Wood fuel: is wood-based fuel in form ready to use directly for generating energy; examples include fuelwood, pellets and bio-liquids.

Emissions: is the term used to describe the gases and particles which are discharged out by various sources.

Concentration: describes the amount of material per unit volume of air.

Smoking oven: is a structure that operates by burning fuel for cooking or smoking of fish.

Organisation of Study

The study is made up of six chapters. The first chapter provides the general overview of the study which includes the background, problem statement, research objectives, purpose of the study, significance of the study and scope and limitations of the study. Chapter two focuses on the review of relevant literature on composition of fuelwood, global consumption and quantification of fuelwood, GHG emissions from biomass fuels and the fish smoking process. Chapter three deals with the materials and methods used for the study which highlights the description of the study areas and population, sampling strategies used, sample size, data collection instrument, data collection procedures and data processing and the analyses. Chapter four presents the findings of the study. Chapter five follows with a detailed discussion of how the results relates, confirms or disagree with other findings in literature. Finally, chapter six provides a summary of the study and concludes the study based on the set objectives. The study ends by providing recommendations that could be used by stakeholders, policy makers and other decision-making bodies.

CHAPTER TWO

LITERATURE REVIEW

This chapter synthesizes from literature, the composition of fuelwood, previous studies on global consumption and quantification of fuelwood, household energy consumption in developing countries, and greenhouse gas emissions from biomass fuels. The chapter also highlights the fuelwood value chain in Ghana and the processes of fish smoking in Ghana.

Combustion of Fuelwoods

Wood is a complex fuel that changes dramatically when burned. At about 300 °C, the majority of wood types begin to burn. The gases cause the wood to heat up to around 600 °C. Charcoal and ashes remain after the wood has expelled all of its gases. Temperatures of over 1,100 °C are required for charcoal to burn (Abur, Ahiaba, Bawa, Haruna & Bawa, 2020). The direct burning of solid matter is known as primary combustion. In wood combustion, this is the burning of the charcoal, referred to as hot coals or embers. The burning of the gases created by pyrolysis is referred to as secondary combustion. Only carbon dioxide (CO₂) and water vapour are produced during complete combustion; neither smoke nor creosote are produced. Carbon monoxide (CO) and a range of hydrocarbons are produced in considerable amounts by incomplete combustion. Unburnt components indicate loss of heating value, pollution emissions, and the possibility of creosote development (Li, Wang, Duan, Hao & Nie, 2009; Shen et al., 2012).

Combustion is a phenomenon that involves the simultaneous coupling of heat and mass transfer with chemical reaction and fluid flow. Its prediction for the purposes of design and control requires knowledge of fuel properties

and the manner in which these properties influence the outcome of the combustion process. Carbon is oxidised to CO_2 , and hydrogen is converted to water, in biomass combustion. Incomplete combustion and the development of several incomplete combustion products result from lack of oxygen. The system is cooled by the excess air. The amount of air required is determined by the chemical and physical properties of the fuel. The heating value, moisture content, particle size, bulk density, and temperature of wood fuels are all elements that enable efficient combustion in fuelwoods (Demirbas, 2007).

The Combustion Process of Fuelwood

Biomass combustion is a complex process that involves simultaneous liquid, solid, and gas phase processes. During the combustion process, over 200 gas compounds are produced. The combustion process is influenced by a variety of factors, including fuel composition, wood knots, and growth rings. Wood combustion can be divided into four stages: fuel drying, pyrolysis, combustion, and surface oxidation (Bailis et al., 2004; Williams, Jones, Ma, & Pourkashanian, 2012).

Drying is an endothermic process that absorbs energy from biomass combustion. As a result, the flame temperature in the combustion region is reduced, as are the combustion reaction rates. The presence of water within a piece of wood limits its maximum temperature, as it can only reach the boiling point of water until all the water within it evaporates. The quantity of moisture in the wood determines how long it takes for a segment of wood to progress to the next stage of combustion (Per & Orange, 2009).

Pyrolysis is the heating of a substance to the point that it begins to breakdown chemically. The bonds inside wood begin to vibrate as it heats up. The strength of the vibrations increases as the temperature rises, until the bonds break and volatile gases are released (Jenkins, Baxter, Koppejan, 2019; L'Orange, 2009). The pyrolysis process is influenced by the structure and composition of the fuel wood. Wood is composed of long bundles of tubular fibres forming the grain of the wood. The varied characteristics of wood species are caused by variations in the arrangement and content of these fibres (He & Behrendt, 2011). During pyrolysis, gases are produced which mix with the surrounding air as they move away from the wood surface. If these gases have enough time to mix before leaving the reaction zone, combustion will occur. However, if the gases lack sufficient energy and oxygen, they will exit the flame region and form incomplete combustion of particles or condense into smoke. The rate at which volatile gases mix with oxygen is usually the limiting factor in the combustion process. It is worth noting that the combustion of gases contributes to about two-thirds of the energy released during wood burning (Koppejan & Van Loo, 2012).

After pyrolysis, the remaining charcoal holds a significant amount of energy that can be utilised. When oxygen in the air reacts with the carbon surface of the charcoal, it generates CO and CO₂, releasing energy into the surroundings. The rate at which oxygenated molecules reach the charcoal surface determines the speed of charcoal oxidation. As carbon is extracted, an ash layer composed mainly of silicon dioxide and calcium oxide is formed, acting as insulation, and slowing down the oxidation process by reducing heat transfer. However, if the surface temperature of the charcoal exceeds 1026.9

°C, the production of CO takes precedence over CO₂, resulting in the release of large quantities of toxic gases (Price-Allison et al., 2021).

Global Overview of Fuelwood Consumption

Biomass fuels, including fuelwood and charcoal are crucial sources of domestic energy for approximately half of the global population, particularly in developing countries. They serve as primary fuels for cooking, heating, and lighting purposes (Akani, Dienye & Okokon, 2011). Biomass is renewable and can be locally sourced, making it an accessible energy option. Wood fuel alone accounts for over 14% of the world's primary energy, with biomass contributing to 33% of total energy in developing nations and even up to 80% in some African countries. Forest products like charcoal and fuelwood do not only provide income opportunities for rural communities but also contribute to household food security by creating employment. In developing countries, the proportion of energy derived from fuelwood ranges from 13.5% in Latin America, 19% in Asia to 26.2% in Africa (Raunika, Buongiorno, Turner, & Zhu, 2010).

In 2015, global fuelwood production amounted to about 2.8 billion metric tonnes. Fuelwood consumption exhibits significant variations based on economic development levels. The developing world accounts for 85% of all wood burning for fuel, with Africa comprising 35% and Asia 40%, while the United States and Europe use 20% (Dam, 2017). Additionally, around 45 million tonnes of wood charcoal were produced globally, with Africa leading at 55% of total output, followed by Latin America at 27% (29% for all of the Americas) and Asia at 15% (Köhl et al., 2015).

Compared to developing countries, fuelwood plays a much smaller role in meeting overall energy demand in developed countries. Its use in developed countries is mainly limited to rural areas, where it may hold recreational, cultural, or lifestyle value (Balat & Ayar, 2005).

Status and Trends of Fuelwood Consumption in Developing Countries

Fuelwood remains the predominant biomass energy source and continues to be highly sought after, particularly in households of developing countries. In Africa, per capita fuelwood consumption is projected to surpass that of Asian countries, and with the growing global population, fuelwood consumption is expected to increase further in the coming years (Arnold & Persson, 2003).

The current state and future evolution of traditional fuelwood consumption are intertwined with a number of critical challenges to long-term development (Burrett et al., 2009). Fuelwood demand is divided into two categories: subsistence and commercial. Subsistence demand is concentrated in rural areas, where individuals collect their own fuelwood using simple non-motorized modes of transportation. Commercial demand is often met by motorized transportation over much greater distances to cities and certain densely populated rural areas (Schure et al., 2012).

According to the International Energy Agency, Africa's total energy supply in 2015 reached 787.62 million tonnes of oil equivalent (Mtoe), an increase from 495.59 Mtoe in 2000. This accounted for 5.8% of the global total. Biomass, particularly fuelwood, dominated the energy mix in 2015, representing over 48% of the total energy supply (International Energy Agency, 2015). In Sub-Saharan Africa, the use of wood fuel is significant and

growing, and without affordable and accessible alternative fuels, the demand for fuelwood is projected to continue increasing in the coming decades. The situation in Ghana reflects the broader trend observed in developing countries (Sander, Haider, & Hyseni, 2011). Typically, Wiafe and Kwakwa (2013) reported on Ghana's strong reliance on solid fuels for residential and small-scale economic business activities. Ghana, like many other developing countries, faces a significant energy supply-demand gap, with limited access to modern and clean energy services such as Liquefied Petroleum Gas (LPG) and hydro/solar-based electricity. A substantial portion of Ghana's population, nearly half, lacks access to clean fuels, leading to heavy reliance on biomass, specifically fuelwood, as the primary energy source for the majority of households (Kemausuor, Obeng, Brew-Hammond & Duker, 2011). Most of the time, fuel wood stoves (both traditional and modern) have been used. High quantities of fine combustion-generated particulates and other pollutants are produced by these fuel-stove combinations (McCracken, Smith, Diaz, Mittleman & Schwartz, 2007). Unlike other regions where wood fuel production and use are declining, Sub-Saharan Africa continues to rely heavily on wood as an energy source, posing potential threats to the environment and economies in the region (Sulaiman & Abdul-Rahim, 2020). This shows that the potential contribution of wood to energy supply varies by country. There are also significant regional disparities in forest accessibility. As a result, biomass fuel usage differs greatly between areas (Parikka, 2004).

Hoffmann, Bruntrup and Dewes (2016), indicate that, with the current population growth trends in Sub-Saharan Africa, the use of wood energy is projected to increase in the future. Even with optimistic projections for

renewable energy production, it is estimated that wood-based energy will still constitute two-thirds of its current levels by 2030. Rural areas predominantly rely on biomass, particularly fuelwood, for energy, whereas urban populations tend to favour contemporary fuels due to their accessibility and affordability. The widespread use of fuelwood in rural areas can be attributed to factors such as easy availability, traditional customs, and the perception of lower consumer costs that do not account for labour and time expenses. The current patterns of fuelwood use, although considered unsustainable, are driven by high demand, the relatively low opportunity cost of fuelwood, and its relative availability in rural areas (Schlag & Zuzarte, 2008).

Some fuelwoods are used as firewood directly, while others are turned to charcoal in inefficient kilns (Zulu & Richardson, 2013). Before use, they are neither treated nor seasoned. In Ghana, fuelwood for smoking fish is sourced from both reserved and non-reserved forest areas, which are managed by different entities. The Forestry Commission is responsible for administering reserved forests, while traditional land-owning authorities and private landowners maintain forests in non-reserved regions. The four primary land use systems where fuelwood for smoking fish is obtained include plantations, natural forests, farmland, and natural mangrove strands (Adu-Bonnah, 2020; Gyamfi, Diawuo, Kumi, Sika & Modjinou, 2018).

Ghana's transition and savannah zones, including regions like Kintampo, Nkoranza, Wenchi, Afram Plains, and Damongo, play a significant role in supplying dense wood for wood fuels. In 2000, the annual wood production in Ghana was estimated to have exceeded 30 million tonnes, with approximately 18 million tonnes accessible for wood fuels. Given that about

80% of Ghanaian households rely on wood fuels for cooking, heating water, and various other purposes, there has been a recent increase in the demand for wood fuel. If this current consumption trends persist, it was projected that Ghana's annual fuel wood consumption will surpass 25 million tonnes by 2020 (Adusei, Seidu & Dunyah, 2017).

Fuelwood Quantification in Developing Countries

Quantifying fuelwood usage in developing countries poses challenges due to the diverse nature of fuelwood sources, ranging from split logs to small wood. Official data on fuelwood consumption focuses on industrial needs while neglecting domestic needs. Estimating domestic fuelwood consumption in these nations is inherently speculative due to limited official records of the amounts collected, transported, and burned. Typically, estimates rely on household surveys or personal interviews, often involving direct weighing of consumed fuelwood, as official channels provide little accurate documentation (Zidago & Wang, 2016). Understanding the fuelwood situation has always been hampered by lack of reliable information. Only a very small fraction of fuelwood production is recorded. The greater part of consumption is by poor households and so is seldomly reported (Arnold & Persson, 2003). Therefore, assessment of the magnitude of fuelwood used in developing countries like Ghana and in fish smoking poses quite a challenge. Up-to-date wood fuel consumption data is essential for determining the influence of wood fuel consumption on the production site's ecology, economic implications, and environmental impact (Brouwer & Falcão, 2004).

A study conducted by Specht, Pinto, Albuquerque, Tabarelli and Melo (2015) in the Atlantic Forest of Northeastern Brazil employed a strategy to

evaluate fuelwood usage. The per capita income was used to determine the average consumption for each economic class. The economic classes with a higher likelihood of consuming more fuelwood had their average consumption rate multiplied by the overall average consumption recorded in the most recent official national census.

Fuelwood Value Chain for Fish Smoking in Ghana

The fuelwood value chain for coastal fish smoking in Ghana, as described by Torell et al. (2015) involves various actors and their activities. Fuelwood supplies for fish smoking communities along the coastal zone are sourced from natural sources such as farmlands and forest reserves, as well as plantations in specific regions. Commercial fuelwood supplies are obtained from individual or community-owned farmlands, although some producers or suppliers may own the farmland themselves. The fuelwood supply chain typically involves three categories of traders: roadside vendors in producing areas, transporter middlemen, and traders in consumption areas. Fuelwood is collected and sold at harvest points or brought to the roadside for sale to transporters/middlemen. The transporters may then deliver the fuelwood to traders in fishing towns for wholesale or directly to fish smokers and other clients such as food processors or households.

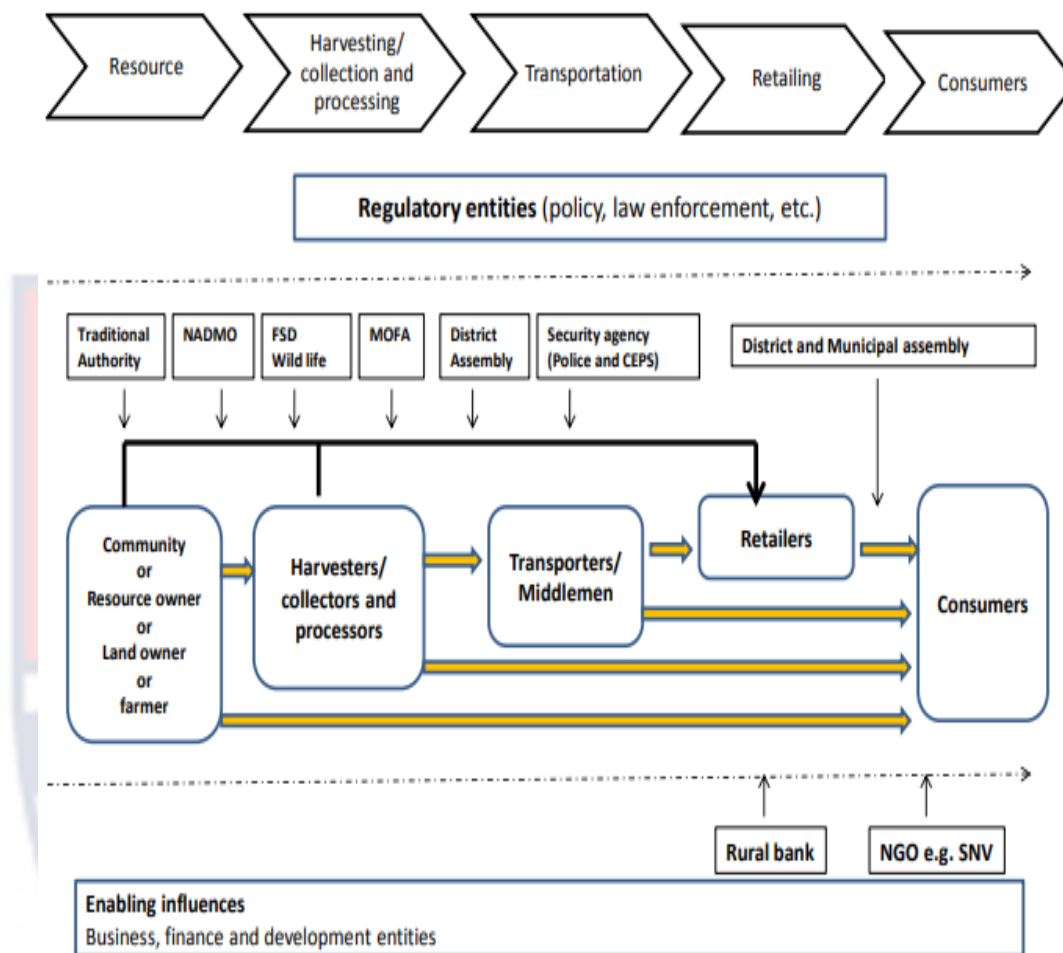


Figure 1: Fuelwood value chain for fish smoking in Ghana.

Source: (Torell et al., 2015).

Climate Implication from Fuelwood Combustion

The Intergovernmental Panel on Climate Change (IPCC) analysis indicates that Africa has experienced a warming trend over the past 50 to 100 years, with significant consequences for the continent's ecosystems. Climate change is already affecting Africa, leading to increased water scarcity and potential impacts on countries heavily reliant on biomass energy. The issue of GHG emissions, particularly CO₂ emissions, has become a central topic in the climate change debate, emphasising the important role that developing nations' play in reducing emissions in collaboration with industrialised

countries (Khan, Khan, Zaman & Naz, 2014). Radiative forcing, the balance between solar irradiance and thermal infrared energy leaving the Earth, is crucial for assessing the impact of human-caused emissions on the planet's energy budget. Household biomass combustion is a significant contributor to radiative forcing as it releases carbon dioxide, methane, carbon monoxide, nitrogen oxides, sulphur dioxide, and black carbon into the atmosphere, all of which affect the energy balance of the Earth (John & Mitchell, 2017). In 2009, unsustainable harvesting and incomplete combustion of traditional fuelwoods resulted in well-mixed GHG emissions of 1.0 to 1.2 gigatonnes of CO₂ equivalent (CO₂e), accounting for 1.9 to 2.3% of worldwide emissions and 3.5 to 4.3% of emissions in the pan-tropical region. In terms of traditional wood fuel usage and overall emissions, India and China have the highest numbers due to their large populations (Bailis, Drigo, Ghilardi, & Masera, 2015). However, their per capita emissions are relatively modest. Within the East African hotspot, Kenya, Ethiopia, and Uganda stand out as top emitters in terms of both absolute and per capita emissions (Sun et al., 2022).

Understanding the local and global environmental and health consequences of household and small-scale economic activity energy consumption has become more important as the links between household energy technologies, indoor air pollution, and GHG emissions have become more important. According to the study, biomass-based GHG emissions may be considerably greater than fossil-based GHG emissions in many developing countries (Bailis, Ezzati & Kammen, 2003; Gioda, 2019). According to reports, the burning of fuelwood accounts for about 17% of worldwide GHG emissions (Van der Werf et al., 2009). Fuelwood accounts for 77-78% of all

biomass energy sources used for household consumption in Ethiopia (Yigezu & Jawo, 2021). Traditional fuels, such as firewood, provide for 54% of total household energy. CO₂ emissions in Ethiopia increased from 5.10 million tonnes in 2005 to 6.50 million tonnes in 2010 due to the country's reliance on fuelwood for cooking (Urkato & Shin, 2015). Again, a study on the impact of wood-burning stove efficiency on the environment, health, and CO₂ emissions in Ethiopia indicates that well-adapted efficient wood-burning cooking stoves are a cost-effective and feasible alternative for mitigating climate change while also saving forests (Biratu, 2016). A similar study suggests that, the final impact on carbon savings, is dependent on the amount to which fuelwood sources are renewable, that is, whether or not the fuelwood taken is replanted (Dresen, DeVries, Herold, Verchot & Müller, 2014).

Grant and Clarke (2010), postulates that utilising wood for energy can worsen climate change until 2100. Burning wood releases CO₂, the primary GHG responsible for global warming. The climate impact of wood depends on burning efficiency and the carbon sequestration potential of regrowth, which is uncertain and time dependent.

A study by Ram and Bahadur (2020) found that in rural Nepalese households, reliance on fuelwood for daily energy needs leads to significant CO₂ emissions. Per Capita and household consumption rates were 1.8 kg and 12 kg per day resulting in daily CO₂ emissions of 14.26 kg CO₂e. In a similar study conducted by Dhanai, Negi, Singh and Parmar (2015) on fuelwood consumption by villagers in the Garhwal Himalaya region of India, the burning of fuelwood led to emissions of various GHGs, including CO₂, CH₄, and N₂O. The communities utilised an annual quantity of fuelwood totaling

3320.05 t/dm, resulting in emissions of 5478.09 t CO₂, 23.90 t CH₄, 0.16 t N₂O, and 3.87 t NO.

When comparing GHG emissions from different types of wood energy, such as fuelwood, sawdust, and wood bark, it is evident that each type has its own distinct characteristics. Life cycle assessments reveal that one cubic meter of fuelwood emits 61 to 73 kg CO₂ equivalents, whereas one cubic meter of sawdust and bark releases 25 kg and 21 kg CO₂ equivalents respectively. These findings highlight that fuelwood in comparison to other wood substitutes, has significantly higher GHG emissions (Raymer, 2006).

Alam and Starr (2009) found that the Sudanese brick making industry's GHG emissions from fuelwood consumption are higher for large-scale enterprises compared to small-scale enterprises. Carbon dioxide accounted for the majority of estimated emissions, totaling 378,028 tonnes per year.

Kyriakopoulos et al. (2015), suggest that replacing fossil fuels with renewable energy, including fuelwood, can significantly reduce GHG emissions. Comparing fuelwood and fossil fuels, auxiliary energy consumption produces relatively small emissions, particularly for fuelwood. While efforts to reduce auxiliary energy use have limited impact on overall GHG balance, the benefits of transitioning to fuelwood depend on conversion efficiency and sustainable forest management. Fuelwood is seen as an inefficient fuel which would benefit from improved technology, and initiatives such as improved cook-stove programs are necessary for fuel savings and user convenience.

Panwar, Kurchania and Rathore (2009) also asserts that GHG mitigation is quite possible through installation of improved cookstoves with higher combustion efficiencies. Improved fuelwood cookstoves can be suitable to reduced fuel demand, reduce human exposure to health damaging pollutants and a reduced emission of GHGs that are thought to increase the probability of global climate change. According to Hagemann, Gawel, Purkus, Pannicke, and Hauck (2016), substitution effects by replacing emission-intensive materials with increasing production of wood products and fuel wood offer a possible strategy to reduce GHG emissions. The potential of wood products and fuels to replace fossil fuels has been widely discussed (Gustavsson, Haus, Ortiz, Sathre & Le Truong, 2015; Myllyviita, Soimakallio, Judl & Seppälä, 2021). It is important to note the overall impact of wood products on climate change mitigation, including factors such as changes in carbon storage in forests, GHG emissions from forest management, and carbon stock changes in harvested wood products when replacing fossil fuels (Geng, Yang, Chen & Hong, 2017).

Factors that Influence the Preference for Fuelwood Types

Desta and Ambaye (2020a) conducted a study in the tropical highlands of southeast Ethiopia to examine the energy characteristics of fuelwood from different tree species. They collected data through field measurements and laboratory analysis and found that the density of the biomass material greatly influences its fuel value. Wood with higher density has more heat per unit volume and longer burning duration. The study also revealed that moisture content, chemical composition, elemental composition, and wood density are important physical qualities that affect fuelwood performance. Household

fuelwood preferences were primarily based on energy properties such as flammability, rather than individual fuelwood characteristic.

A related study by Teklay, Gebrassie and Mehari (2014) was conducted in Ethiopia to assess the fuelwood tree species utilised by households. The study employed purposive stratified sampling for interviews and questionnaire distribution, along with field observations and interviews with key informants. The study indicated that individuals' fuelwood preferences are influenced by burning speed, calorific value, smoke production, and ease of ignition. Notably, the study found that collectors prioritise the woody or stem parts of their preferred species.

In India, a fuelwood assessment was conducted to determine community preferences and the attributes of fuelwood species. Data was collected from 4210 households in 25 villages using a pre-structured questionnaire. The study identified the top 30 preferred indigenous fuelwood species through a sample of 10% of households in each village. Community preferences for different fuelwood species were assessed using the Participatory Rural Appraisal pairwise ranking tool. The results indicate that households primarily consider ease of burning and burning durability when selecting fuelwood (Sahoo, Lalremruata, & Lalramnghinglova, 2014).

The fuelwood preferences in a Brazilian community emphasise the importance of combustion characteristics, such as the ability to generate hot, long-lasting flames and produce powerful coals. The research finds that the number of qualities attributed to a fuelwood species determines its preference. In addition, the frequency of a species' use correlates strongly with the number of times it is identified as preferred, rather than its availability in the nearby

forest fragment. Ultimately, the preference of the fuelwood harvester serves as the primary criterion for selecting the fuelwood actually use (Ramos, de Medeiros, Almeida, Feliciano & Albuquerque, 2008).

Again, a study by Cardoso, Ladio, Dutrus and Lozada (2015) was conducted to assess traditional knowledge regarding fuelwood species, examining the connection between species preferences and wood characteristics for combustion. The research focused on 21 common fuelwood species in three villages located in northwest Patagonia. Through semi-structured interviews, free listing, and participant observation, the study investigated the usage patterns and preferences of local households regarding fuelwood biomass. The findings revealed that households in the three communities exhibited different perceptions and preferences for preferred fuelwood species, influenced by cultural factors. Additionally, changes in the availability of certain fuelwood species over time led to the adoption of alternative species. This highlights the complex interplay between biophysical and sociocultural factors shaping the selection of fuelwood species, which has been passed down through generations.

Moreover, Kuunibe, Issahaku and Nkegbe (2013) in the Upper West region of Ghana, employed logit model to examine the factors influencing households' decisions regarding the use of wood-based biomass fuel for cooking. The findings revealed a negative association between household size, wood price, level of education, and income with fuel choice. This study is relevant for understanding the preferences of fish smokers towards specific fuelwood species, as it aimed to identify the characteristics that influence fuelwood preferences in households.

Greenhouse Gases (GHGs)

Greenhouse gases are gases that absorb thermal radiation, leading to the retention of heat on the surface of the Earth and the creation of the greenhouse effect. The presence of gases in the atmosphere influences the temperature of our planet. CO₂ and other GHGs gases play a vital role in trapping heat, ensuring habitability of the Earth. The greenhouse effect is primarily caused by the absorption and emission of heat radiation by these gases in the atmosphere. Solar energy, in the form of solar radiation comprising ultraviolet, visible, and near-infrared light, reaches Earth and passes through the atmosphere (Kvalevåg, Samset, & Myhre, 2013; Kweku et al., 2018; Zhong & Haigh, 2013).

When reporting GHG emissions, there are six gases that are considered: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). These six GHGs were recognised by the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC). They are referred to as long-lived GHGs because they are stable and can persist in the atmosphere for many centuries (Casper, 2010). Based on Ghana's Fourth National Greenhouse Gas Inventory Report (GFNG GIR), carbon dioxide remained the dominant GHG in the country, representing approximately 64.7% (Mt CO₂) of the total emissions in 2016. Nitrous oxide accounted for 18.3% of the emissions, followed by methane at 15.4% (UNFCCC, 2019).

Greenhouse Gas Measurement

To facilitate comparison, gases are typically measured in parts per million (ppm), parts per billion (ppb), or parts per trillion (ppt) independently

(Blasing & Smith, 2016). The unit commonly used for GHGs is carbon dioxide equivalent (CO₂e), which takes into account the global warming potential (GWP) of each gas. The GWP is a metric that compares the heat-trapping potential of each GHG relative to another gas, typically carbon dioxide, over a specific timeframe, often a 100-year period. This allows for comparisons of how much energy a given amount of a gas will absorb compared to an equivalent amount of carbon dioxide (Vallero, 2019).

Carbon dioxide emissions lead to long-lasting increases in atmospheric concentrations. Methane has a shorter residence time of about ten years but has a higher ability to absorb energy than CO₂, resulting in a varying global warming potential (GWP) of 28 to 36. The GWP considers indirect impacts, such as methane's contribution to ozone formation. Nitrous oxide has a GWP of 265-298 times that of CO₂ with residence duration of about 100 years. High-GWP gases like CFCs, HFCs, HCFCs, PFCs, and SF₆ have GWPs in the tens of thousands, capable of holding significantly more heat than CO₂ for the same mass (Brander, 2012).

Table 1: Global Warming Potential for various GHGs

Common Name	Chemical Formula	GWP ₁₀₀
Carbon dioxide	CO ₂	1
Methane	CH ₄	25
Nitrous oxide	N ₂ O	298

Source: (Blasing & Smith, 2016)

Carbon Dioxide (CO₂)

CO₂ is a gas produced by the respiration of plants and animals. Human activities, including the burning of fossil fuels, deforestation, and industrial processes, contribute to its release. As a greenhouse gas, CO₂ has the ability to

trap heat in the atmosphere (Olivier, Peters, & Janssens-Maenhout, 2012). In terms of its life cycle, carbon dioxide is also unique among greenhouse gases. CO₂ in the atmosphere can be converted into carbon compounds in the biosphere via biological plant photosynthetic pathways, or into the ocean via surface layer exchange followed by a gradual process bringing carbon down into the deep ocean until the ocean and atmosphere reach balance (Sarofim, 2007).

It is the most major anthropogenic GHG, with human activities emitting approximately 38 gigatonnes into the atmosphere each year (Solomon et al., 2007). CO₂ concentrations in the atmosphere have skyrocketed during the last century, compared to pre-industrial levels of around 280 ppm, according to climate scientists. Carbon dioxide levels were nearly 40% higher in 2016 (403 ppm) than they were in the mid-1800s, with an average annual increase of 2 ppm during the last ten years (Jackson et al., 2017).

According to Tanaka (2010) household primary fuel use contributed around 18% of CO₂ emissions globally. The total national emissions of Ghana from 1990 to 2016 were made up of 64.7% CO₂ emissions, which accounted for the majority. The research shows that throughout this time CO₂ emissions increased on average year by 1.9%. In particular, there was an average 6.1% increase in CO₂ emissions between 2012 and 2016. This increase was mostly caused by increased emissions from the transportation sector, the energy sector, and changes in land use (UNFCCC, 2019).

Methane (CH₄)

Methane (CH₄) concentrations in the atmosphere are currently at 1800 parts per billion (ppb), which is higher than pre-industrial levels of about 680–715 ppb. Anthropogenic emissions make up approximately 50-60% of the global methane budget, which is around 526-569 Tg CH₄ yr⁻¹ (Bogner et al., 2008).

Biomass burning contributes approximately 40 Tg/year to global methane emissions, making it the third-largest source of methane. Methane has a shorter lifespan compared to carbon dioxide, which is influenced by the atmospheric oxidative capacity and the carbon cycle, respectively. The lifetime of methane gas can vary depending on the presence of other high-emitting compounds, including methane itself. Increased methane emissions can lead to a positive feedback loop, causing higher concentrations and an extended lifespan of the gas. Additionally, elevated methane emissions contribute to increased ozone concentrations, which have both health impacts and additional forcing effects. While fossil fuel burning is responsible for the majority of carbon emissions, it accounts for only around 10% of methane emissions, primarily due to leakage during exploration, production, transportation, and utilization (Turner, Frankenberg, & Kort, 2019).

Methane is a by-product of the combustion of carbon and hydrogen from fuel to carbon dioxide and water. Methane emissions are an indicator of too low combustion temperatures or a deficiency of adequate oxygen in wood-burning stoves (Koppejan & Van Loo, 2012). In flue gas wood stoves, CH₄ concentrations as high as 30 ppm have been recorded (Olsson & Kjällstrand, 2006), and emission factors of up to 15 g kg⁻¹ have been observed (Jacobson

et al., 2013). The most recent global estimate for biomass and biofuel burning's contribution to methane emissions is 32 to 39 Tg (CH₄) yr⁻¹, with 14 to 17 Tg (CH₄) yr⁻¹ from traditional biofuel combustion (Kirschke et al., 2013).

In Ghana, methane is the third most abundant GHG, showing a yearly growth rate of 1.8% over the past 26 years. Between 2012 and 2016, methane levels increased by 12.8%, rising from 5.57 MtCO₂e to 6.51 MtCO₂e (UNFCCC, 2019).

Methane emissions are difficult to quantify because they do not only come from point sources and there are significant natural emissions that can skew estimations. The large geographic and temporal variations in methane emissions come from regions with limited inventory capabilities. The problem is that most methane emissions emanate from area sources rather than point sources, making them difficult to assess (Sarofim, 2007).

Branson, Jones and Berman (2021), identified two main approaches for estimating methane emission rates. The first approach involves attaching a flow meter to the emission source to directly measure the gas flow rate, providing a highly accurate estimation when the methane proportion is known. The second approach involves measuring methane concentrations at multiple locations downwind of the source, reconstructing the plume's geometry based on these measurements, and using a theoretical model to calculate the emission rate.

Another approach to measure methane involves using sensors within and around a methane plume. Various types of sensors, such as optical, calorimetric, pyroelectric, semiconducting metal oxide, and electrochemical

sensors, are utilised for this purpose. Most methane measurement techniques focus on determining the difference in methane concentrations between upwind and downwind locations. The sensor's position determines where methane concentrations are detected, influencing the data used to calculate emission flow rates. Measurements can be taken using handheld devices, stationary equipment, and mobile devices on the surface, drones or aircraft, and even from different space orbits (Aldhafeeri, Tran, Vrolyk, Pope, & Fowler, 2020).

Nitrous Oxide

Nitrous oxide is a potent GHG released during biomass fuel combustion. It contributes significantly to climate change, having a global warming potential 310 times higher than carbon dioxide (Feng et al., 2019; Parker & Behringer, 2009). Additionally, N_2O plays a role in stratospheric ozone depletion, further exacerbating climate change. The reaction of N_2O with atomic oxygen leads to the formation of nitric oxide (NO), which harms the stratospheric layer and intensifies climate change (Syakila & Kroeze, 2011).

Nitrous oxide is the most abundant nitrogen molecule derived from molecular nitrogen, despite being present in small amounts in the atmosphere. Its concentration is rising by approximately 0.26% annually, currently reaching around 320 parts per billion (ppb). This rapid increase is attributed to the introduction of nitrogen compounds into the atmosphere at a higher rate than their removal. The primary anthropogenic sources of N_2O are agriculture, particularly the use of synthetic nitrogen fertilizers, as well as biomass and fossil fuel combustion (Colorado, McDonell, & Samuelsen, 2017).

With a lifespan of about 114 years, nitrous oxide (N_2O) remains in the atmosphere for an extended period. Its primary removal occurs in the stratosphere. However, due to its long lifespan, measuring changes in N_2O levels can be challenging as they are minimal (Nisbet et al., 2021; Rapson & Dacres, 2014). Nitrous oxide emissions, the second most significant GHG in Ghana, rose by an average of 2.6% per year between 1990 and 2016. In 2016, N_2O emissions increased by 11.8% compared to 2012 levels. The main contributors to N_2O emissions in Ghana are nitrogen accumulation in soils from various sources such as synthetic fertilizers, crop residues, organic fertilizer, and changes in land use and management (UNFCCC, 2019).

Characteristics of Fuelwood Emissions

Emissions from fuel burning are influenced by various factors such as stove type, fuel density, moisture content, appliance design, and user. The characteristics of the stove and its operation have a significant impact on emissions. Well-designed and modern stoves are more efficient and produce fewer pollutants when compared to older models. The emission factors are typically expressed in terms of pollutant release per kilogram of fuel consumed or per unit of energy used (Chandrasekaran, Hopke, Newton, & Hurlbut 2013; Maxwell, Gudka, Jones, & Williams, 2020; Williams et al., 2012). The temperature, calorific value, and particle density all determine CO_2 , CH_4 , and other organic gas emissions from fuelwood (Bhatt, Moanaro, & Sarkar, 2017).

Impacts of Moisture Content on Fuelwood Emissions

The moisture content of wood is a crucial factor that affects particle production and emissions. It impacts the heating value of the fuel and influences the rate of pyrolysis. Additionally, moisture influences flame

cooling, combustion chamber oxygen inhibition, and interactions with particle production in fuel gases. These factors contribute to increased emissions concentration (Price-Allison et al., 2021). At different phases of combustion and with varying quality of wood fuel, the variation and variability of each of these elements produces different compositions, morphologies, and quantities of emissions (Torvela et al., 2014).

The moisture content of wood reaches an equilibrium state over time and is influenced by temperature and humidity. Equilibrium moisture content can range from 1% to 25% under normal conditions. Moisture affects the net calorific value of wood and the energy required for pyrolysis and combustion. While high moisture reduces available energy for cooking, it can extend pyrolysis reactions and residence time in the combustion zone, potentially enhancing emission (Hill, 2007; Walker, 2006). A freshly cut tree holds between 40% and 60% moisture, depending on the species and season of the year (Desta & Ambaye, 2020b). The quality of fuelwood depends on factors such as tree species, moisture content, and particle size. For household use, it is recommended that fuelwood has a moisture content ranging from 25% to 30% (Krajnc, 2015).

Density of Wood Species

Wood density plays a crucial role in the combustion process. Higher wood density leads to prolonged burning and the formation of long-lasting coals, making it more desirable. Wood density can also indicate the softness or hardness of different wood species. Denser fuelwood species contain more heat per unit volume and tend to burn for a longer duration (Díez & Pérez, 2017).

Calorific Value

Calorific value can be explained as the amount of energy released per unit mass or volume released on complete combustion. Calorific value is highly influenced by the moisture content in the fuelwood. The moisture content of wood decreases the calorific value. Most of the energy released during the combustion process is used in evaporation thereby decreasing the amount of heat produced. The net calorific value of different fuelwood species differs within a small range (Krajnc, 2015).

Methodologies in Estimating Greenhouse Gases

As the use of biomass fuels grows, it is necessary to develop assessment methods for GHG emissions from biomass burning. It is important to consider both local and global contexts when examining atmospheric composition of GHGs. Objective procedures that can be regularly updated and works at different scales are needed to generate global estimations. Local estimates help understand emission mechanisms at a micro-scale, while regional and global modelling is necessary to evaluate the overall impact of emissions on the atmosphere and global climate change.

In the context of biomass burning emissions and impacts, direct measurement and experimentation can be carried out in natural settings or in laboratory trials. Several large-scale experiments have also been conducted at the global and regional levels at representative sites across the world in order to collect adequate information regarding emission processes and the impacts of smoke on the radiative balance of Earth and global climate. Thus, a range of experimental briquettes were evaluated in an experimental investigation by Roy and Corscadden (2012) of biomass briquette combustion and

emissions in a domestic wood stove, which included proximate and ultimate analyses as well as the measurement of the gross calorific value of wood fuels. Using a Unigas 3000⁺ flue gas analyser, GHG emissions were quantified directly at the source.

For direct GHG emission measurements from biomass burning, remote sensing approaches have also been applied. The physical basis is based on the differential scattering and absorption properties of the numerous substances in the fire plumes, which are analysed using optical bands in both digital and photographic sensors. The optical thickness of the smoke plume, which is the ratio of light scattering to light extinction, is used to calculate particle concentrations (Palacios-Orueta, Chuvieco, Parra, Carmona-Moreno, 2005).

Several studies (Alam & Starr, 2009; Beyene et al., 2015; Dhanai et al., 2015; Gioda, 2019) have used the IPCC methodology to estimate GHG emissions from biomass combustion. In a study by Maraseni and Zeng (2015), household CO₂ emissions were categorised from energy use into direct and indirect CO₂ emissions. The input-output analysis approach was used to estimate the indirect CO₂ emission whereas the IPCC reference approach was used to estimate the direct CO₂ emission.

The IPCC guidelines outline the general systematic methods and reasons for identifying emission sources in the energy sector, as well as the selection of analytical techniques, activity data, variables, and the consistent formulation of underlying assumptions. Importantly, the IPCC Guidelines provide guidance on calculating GHG emissions based on the intensity or frequency of a certain operation at a given rate, which results in GHG emissions at various stages of production and utilization. It is worth noting

that the IPCC default emission factors used in GHG inventories are usually country-specific factors that better reflect the emissions where they occurred. As a result, utilising it in diverse settings and locations comes with its own set of uncertainties. Nonetheless, the methodology provides the best available data and supports future efforts to develop country-specific criteria.

Processes of Fish Smoking in Ghana

Fish smoking is a preservation technique where fish is exposed to smoke generated by burning biomass. This process involves salting, drying, heating, and smoking the fish in a designated chamber. The smoke does not only impart desirable sensory characteristics like flavour, taste, and colour to the fish but also acts as a natural preservative. The quality and quantity of the smoke depend on the availability of air and the type of fuelwood used (Adeyeye & Oyewole, 2016).

The fish smoking process begins with washing and sorting the fish. Thereafter, the fish is placed on smoking racks and left to dry in an open area for a minimum of 15 minutes, taking into account the fish type and size. Subsequently, the fish is smoked using a specialized oven, utilising temperatures exceeding 80 °C (Asamoah, 2017). In Ghana, fish smoking methods vary depending on the fish type, intended use, and desired shelf life. Wet-hot smoking and dry-hot smoking are two common techniques used. Both involve cooking the fish at high temperatures. Wet-hot smoking typically take 1 to 2 hours, resulting in a moist product with 40% to 55% moisture content and a shelf life of 1 to 3 days. Dry-hot smoking, often done after wet hot smoking, takes 10 to 18 hours or longer. Fish smoked using this

method can be stored for 6 to 9 months when appropriately stored (Pemberton-Pigott et al., 2016).

Small pelagic fishes like sardines and anchovies are commonly smoked in this manner and are readily available in many Ghanaian markets throughout the year (Alhassan, Boateng, & Ndaigo, 2012). Different types of fish smoking ovens are used for fish smoking in Ghana. The Chorkor oven, however, is the most popular oven used in most coastal communities.

Fish Smoking Ovens

Traditional fish smoking ovens in coastal communities in Ghana and other Sub-Saharan African countries have undergone modifications to improve their performance. The common mud or clay ovens used in these communities lack air control and suffer from energy loss. "Improved" ovens aim to manage combustion and enhance heat transfer, reducing fuel usage and emissions. The decision to adopt better ovens is influenced by location, usage, and the desire to save fuelwood and improve fish quality. In the past, traditional ovens had low capacity, inefficient smoking processes, and resulted in post-harvest losses. These ovens, including cylindrical mud and metal ovens, had poor combustion and fuel efficiency (Avega & Tibu, 2017).

The Traditional Mud Oven

The traditional mud oven (TMO) depicted in Figure 2, commonly found in Ghana is a cylindrical structure made of mud, often reinforced with concrete plaster on the exterior. It has a grill installed about one-third of the way up from the bottom, with a stoke hole for fuel insertion. The oven's typical dimensions are approximately 383 cm in circumference, 124 cm in diameter, 85 cm in height, and 10 cm in thickness, with an average volume of

397,874 cm³. It has a lifespan of around 3 years but can be as short as one month without proper reinforcement and protection from rain. Although widely used in coastal communities and fish processing facilities, this oven has drawbacks such as handling difficulties, heat and smoke loss through the large combustion chamber, leading to inefficient fuelwood consumption, and the need for frequent handling of fish during smoking (Adeyeye & Oyewole, 2016).



Figure 2: The traditional mud oven.

The Chorkor Oven

The Chorkor oven (Figure 3), developed in the 1970s by the Ghana Food Research Institute in collaboration with the women of Chorkor community, was an improvement over traditional oven. It features a rectangular combustion chamber and a smoking unit with stacked trays. Compared to other traditional ovens like cylindrical metal and rectangular mud ovens, the Chorkor oven offers greater energy efficiency, improved combustion capacity, reduced health risks from smoke exposure, and higher quality smoked products (Adeyeye & Oyewole, 2016).



Figure 3: The Chorkor oven.

The Ahotor Oven

The Ahotor oven (Figure 4), introduced in Ghana in 2016 under the Sustainable Fisheries Management Project (SFMP) funded by USAID, is a modified version of the Chorkor oven. It consists of a sand and cement exterior, a burnt-brick combustion chamber, galvanized iron components, a fat collector, and metal grates and wire trays for smoking. The Ahotor oven offers enhanced fuel efficiency and convenience for fish smokers, as it consumes less fuelwood and emits less heat during the smoking process. It was first made accessible to fish processors in Ghana in August 2017 (Owusu, 2019).

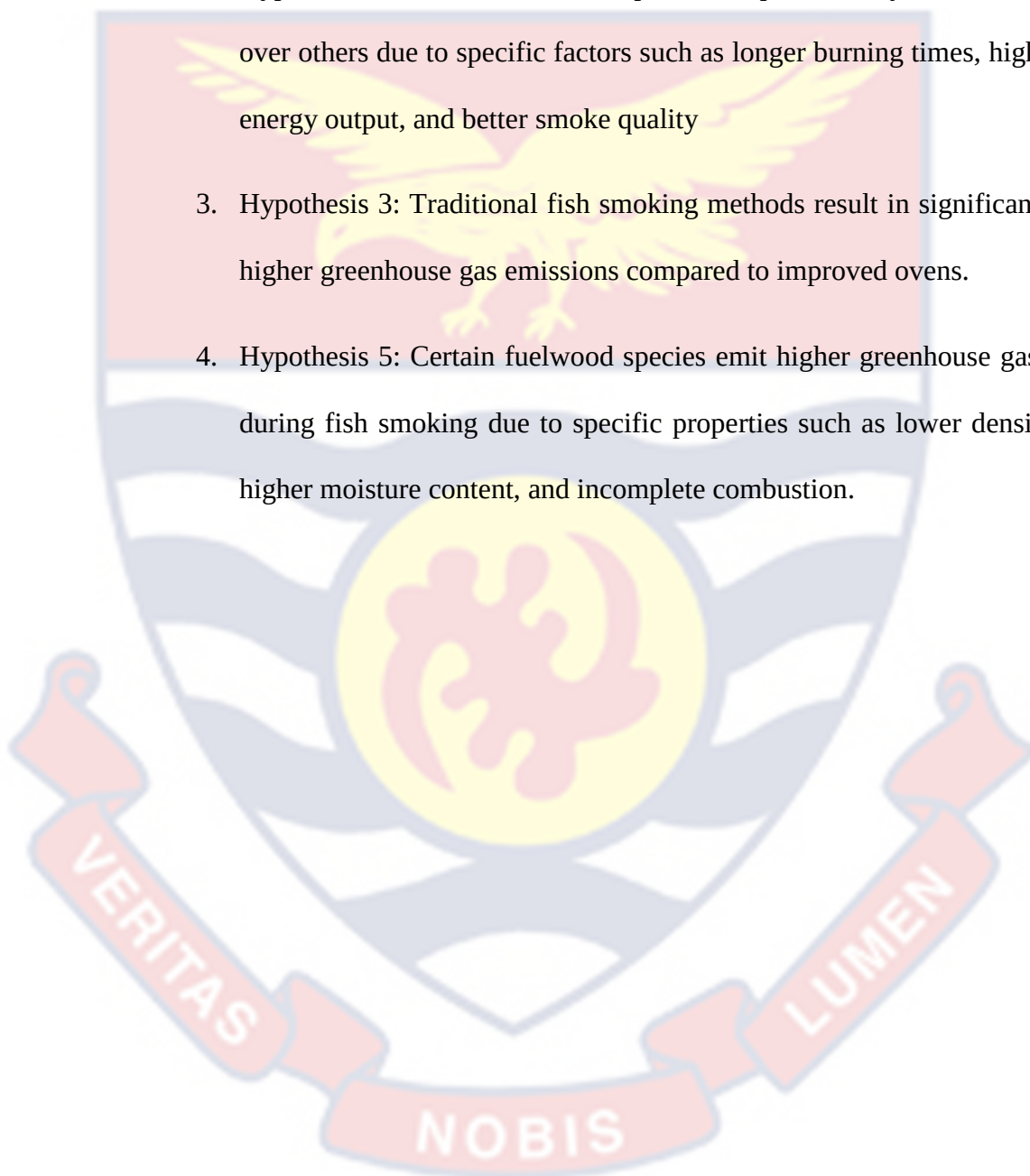


Figure 4: The Ahotor oven

Hypothesis Development

Based on the reviewed literature, several significant observations emerge regarding fish smoking practices and their environmental impact in coastal Ghana. Studies by Adeyeye and Oyewole (2016) and Owusu (2019) indicate that improved ovens like the Chorkor and Ahotor have higher efficiency and reduced fuel consumption compared to traditional mud ovens. Additionally, research by Desta and Ambaye (2020) indicates a preference among users for certain fuelwood species due to their higher calorific values and longer burning times. However, there is a noticeable gap in empirical data quantifying the specific amounts of greenhouse gases (GHGs) emitted from different oven types and fuelwood species used in traditional fish smoking. Most existing studies focus on air pollutants rather than GHG emissions, and there is limited information on how the choice of oven and fuelwood affects these emissions (Bailis et al., 2015; Gioda, 2019). To address the identified gaps in the literature, the following hypotheses have been formulated:

1. Hypothesis 1: Fish smokers in the selected coastal communities in Ghana prefer improved ovens over traditional ovens due to its higher efficiency and lower fuel consumption.
2. Hypothesis 2: Certain fuelwood species are preferred by fish smokers over others due to specific factors such as longer burning times, higher energy output, and better smoke quality
3. Hypothesis 3: Traditional fish smoking methods result in significantly higher greenhouse gas emissions compared to improved ovens.
4. Hypothesis 5: Certain fuelwood species emit higher greenhouse gases during fish smoking due to specific properties such as lower density, higher moisture content, and incomplete combustion.



CHAPTER THREE

MATERIALS AND METHODS

This chapter outlines the study locations as well as the data collected. It describes the study's design, sampling, and the methods used to collect, process, and data analyses. Finally, ethical consideration and the limitation of the study are also described.

Study Area

The study was conducted in three districts in the Central and Western Regions of Ghana, namely, Effutu Municipality, Gomaa West District and Shama District. Seven (7) coastal communities under these districts were selected for the study (Figure 5). The communities included Winneba, Woara Beba in the Effutu municipality, Apam and Mumford in Gomaa West District and Abuesi, Kesewokan and Shama Apo in the Shama District.

The communities were selected on the bases of huge commercial marine fish smoking that are undertaken. Moreover, they have a number of fish landing beaches as well as a huge number of canoes that land fish almost every day for processing. The relative average production of fish in these areas are high and there is also a notable presence of individuals engaged in fish smoking, along with a wide variety of fish smoking ovens.

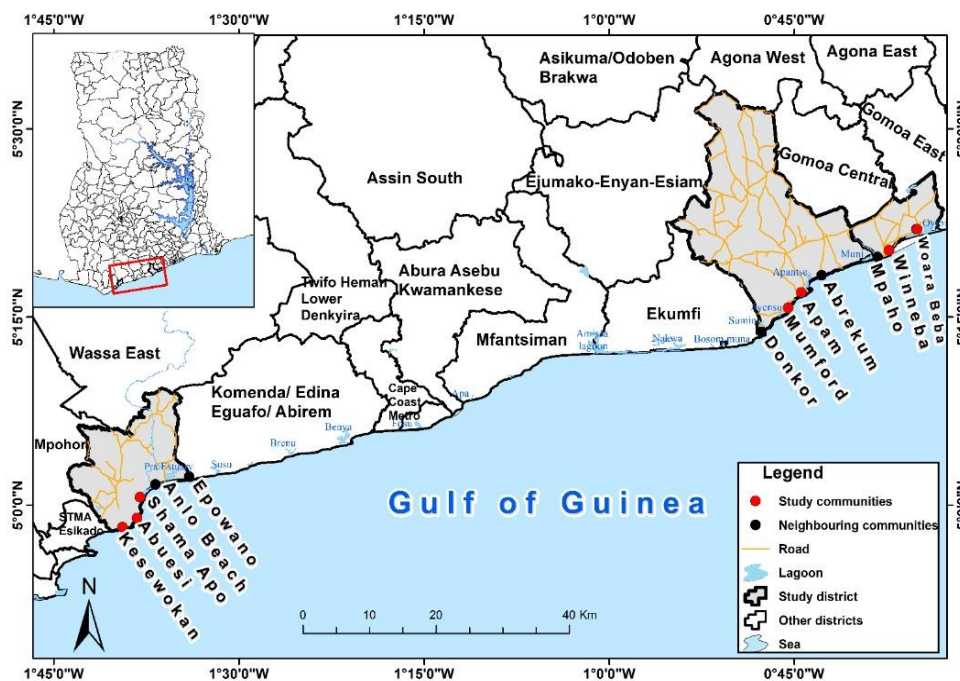


Figure 5: Map of the study locations (Kesewokan, Abuesi, Shama Apo, Mumford, Apam, Winneba, Woara Beba)

Demographic Characteristics of Study Locations

Effutu Municipality

Effutu Municipality covers a total land area of 95 square kilometres. It is sandwiched by Gomoa East District Assembly on its western, northern and eastern flanks. The area is situated with the following coordinates defining its boundaries: starting from the northernmost point at 5° 26' 20.9086" N, 0° 33' 50.8460" W. Progressing southward, it extends 5° 19' 31.5768" N, 0° 38' 15.7737" W. To the western boundary, it reaches 5° 21' 46.3406" N, 0° 40' 23.7194" W. Finally on the eastern side, it culminates at 5° 23' 44.6519" N, 0° 33' 09.4508" W. The administration capital is Winneba. The population of Effutu Municipality, according to the 2021 Population and Housing Census, is 107,798, with 54,723 males and 53,075 females. Males represent 51% and females represent 49% of the total population (Ghana Statistical Service, 2021).

In terms of occupation of the population, majority (31 %) are engaged in craft and related trades, followed by service and sales (25 %). About 27% of the male population are into agriculture, with a higher percentage of females (37%) in service and sales than males (9.0%). Manufacturing is the predominant industry (21.6%) in the municipality, followed by retail services (19.9%) and agriculture, forestry and fishing (16.1%). A higher percentage of females (28.2%) are engaged in manufacturing than males (13.0%). The fishing industry is very prominent in the coastal communities of Winneba, Akosua Village and Woara Beba within the municipality. Fishing and fish mongering are the predominant occupation of locals, being practiced by 54% and 46% of the population respectively. The municipality is generally low lying with granite rocks and isolated hills dominated around Winneba. The municipality lies within the dry-equatorial climatic zone characterised by low rainfall and long dry season of five months. The annual rainfall ranges from 400 mm to 500 mm. Mean temperatures range from 22°C to 28 °C (Ghana Statistical Service, 2013). Fish smokers in Winneba work in their homes. They smoke most of the fishes landed by the fishermen. The women use chorkor stoves made of clay and these stoves are mostly not under shed. The women use various kinds of wood from smoking, these are delivered to them by trucks from as far as the Eastern region (Akutse & Samey, 2015).

Enumeration by Akutse and Samey (2015), identified different types of stoves available, their locations and numbers. There were 504 round mud ovens, and 478 chorkor ovens. The total fish smoking ovens were 982. These were collated from Oyibi, Worabeba and Akosua Village. Woara Beba

community has a long stretch of mangrove landscape with large patches of degraded areas.

Gomoa West District

Gomoa West District covers a total land area of 458.5 square kilometres. Apam is the district capital. The area is situated with the following coordinated defining its boundaries: starting from the northernmost point at 5° 32' 42.9593" N, 0° 51' 01.9715" W. Progressing southward, it extends 5° 13' 22.6016" N, 0° 47' 33.6928" W. To the western boundary, it reaches 5° 21' 02.5037" N, 0° 53' 34.0649" W. Finally on the eastern side, it culminates at 5° 24' 41.7688" N, 0° 45' 29.2815" W. The district population was 129,512 according to the 2021 Population and Housing Census, with 45.9% being males and 54.1% females. The main occupation of the people is farming and fishing since the area lies in a forest and coastal belt respectively. Fishing constitutes the main economic activity for the communities. It employs about 5000 fishermen and 2500 women. Fishing communities include Mumford, Apam, Mankoadze, Abrekum and Dago. The fish smoking sites are more of household based, where families work together in groups but within their homes (Ghana Statistical Service, 2021).

The district lies within the semi-wet equatorial region with mean annual rainfall between 1500 mm and 2000 mm. It also experiences two rainy seasons: the major one from April to June and the minor one from September to October. July and August are very cold and dry with occasional minor showers. The district on the average experiences an annual temperature of 29 °C. The two main vegetation zones are the coastal savannah and the moist semi-deciduous forest occupying the northern territory. Pockets of semblance

of tropical rain forest exist at the extreme north and the eastern part around Eshiem and Dawurampong. The moist semideciduous forest is characterised by tall trees inter-spersed with grass cover, shrubs, and soft wood species. The topography of the district is partially low-lying with land terrain principally being undulating. It has gentle sloping land from south to the north. There are few hills in the forest areas especially in the northern part of the district and low land at the coastal plains in the south. Most of the hills are capped with rich rocks, and Kaolin (Ghana Statistical Service, 2013).

Shama District

The Shama District is bordered to the west by the Sekondi Takoradi Metropolitan Area to the east by the Komenda – Edina – Eguafo – Abrem Municipal, to the north by the Wassa East and Mpohor Districts and to the south by the Gulf of Guinea. The geographical limits of the area are established using the following coordinates: starting from the northernmost point at 5° 08' 59.9796" N, 1° 36' 25.5607" W. Progressing southward, it extends 4° 57' 53.6806" N, 1° 40' 12.7651" W. To the western boundary, it reaches 5° 01' 04.6050" N, 1° 42' 14.2175" W. Finally on the eastern side, it culminates at 5° 05' 11.5693" N, 1° 34' 52.3384" W. The district covers an area of 198 square kilometres. According to the 2021 population and housing census, the district's population was 117, 224 comprising 48.8% males and 51.2% females (Ghana Statistical Service, 2021).

Among the working population, approximately 31.7% work as skilled labourers in agriculture, forestry, and fisheries, 18.3% are in service and sales occupations, 28.4 % are involved in craft and related trades, while 5.8% serve as managers, professionals, and technicians. Shama has a long history of

fishing pre-dating the colonial era. Fishing is carried out along the coastal stretch of the district whilst farming is done inland towards the northern parts of the district. The major fishing communities in the district include Abuesi, Shama, Aboadze and Anlo Beach. These communities occupy a total of 7 km out of the 10 km stretch coastline of the district. There are ten (10) landing beaches in the district: Shama Apo, Shama Bentsir, Amina Ano, Abuesi Aboadze Compound, Abuesi Samanadze, Kesewokan, Aboadze Broni-Bema, Aboadze Ekuro Bam. Smoking and salting are the means of processing and preservation of fish in the district. Shama district is within the low-lying areas of Ghana with elevation in most parts less than 80 metres above sea level. The landscape is undulating generally, with average height of about 70 metres. Highest elevation ranges between 150 and 200 metres, even though few areas (mainly the valleys of the main river Pra) are below 150 metres above sea level. Vegetation is mainly made up of coastal thickets, and thin to dense shrubs. The Northern part of the district is made of thick bushes with other small size trees. In the coastal area, the thicket is intertwined with tall grass species including mangrove swamps and raffia groves at the estuary of Pra River (Ghana Statistical Service, 2013).

Research Design

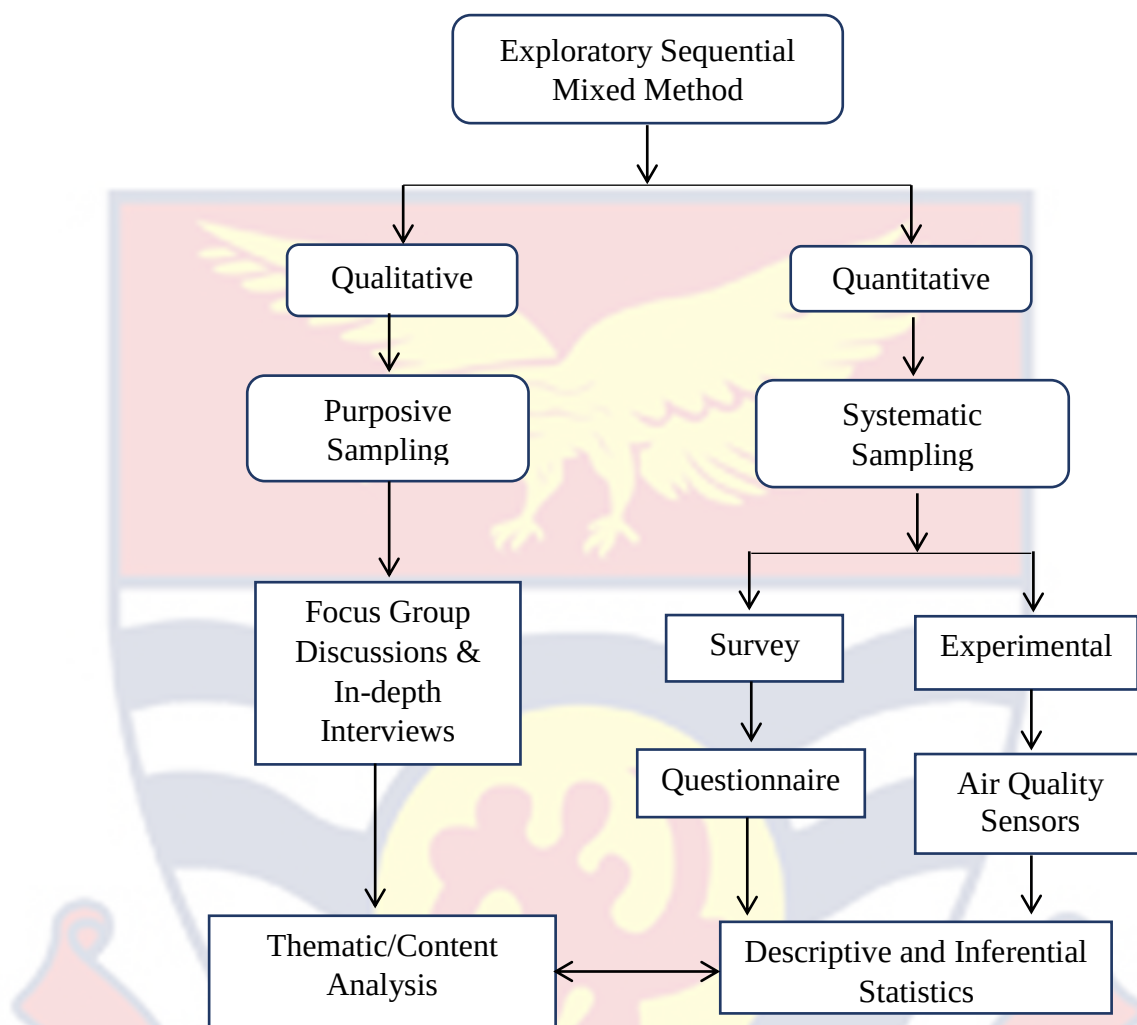


Figure 6: Conceptual diagram of the study.

Following the methodological sketch in Figure 6, an exploratory sequential mixed method was employed for the study. The approach involved first, employing qualitative techniques to collect and analyse data which is then fed into the development of instruments (structured interviews) for the quantitative data collection and analyses. The two datasets (Quantitative and Qualitative) are then triangulated during analysis to provide a comprehensive interpretation of the datasets.

The qualitative method in the form of focus group discussion (FGD) and in-depth interviews was used to evaluate the preference of fish smokers for particular fuelwood species and also to assess the performance and efficiencies of the different types of fish smoking ovens.

The quantitative survey on the other hand was done through the administration of pre-design and pre-tested structured interviews to randomly selected households in the study communities. This quantitative data was used to quantify annual fuelwood consumption to determine the amount of GHGs generated using IPCC tier 1 methodology. Lastly, there was an experimental procedure during which various gas measuring apparatus in the form of air quality sensors were installed around selected ovens and fish smoking points to measure the concentrations of GHGs released from the various types of ovens.

Sampling Procedures

Participants in all qualitative data collection processes such as in-depth interviews and focus group discussions were purposely selected. They were selected either because they are community leaders and/or occupy responsible position relating to fish processing of fish smokers' associations and for that matter could have an in-depth knowledge to share on issues pertaining to fuelwood usage for fish smoking. Focus group discussion participants were mainly selected because they were involved in fish smoking and that they used different types of fuelwood and ovens for fish smoking and for that matter could discuss their experiences relating to the use of the different types of ovens and fuelwoods to support the study. Random sampling techniques were employed in selecting the households for the quantitative data collection.

Sampling in each community was dependent on the population of the community.

$$SS = \frac{Z^2 \times (P) \times (1 - P)}{C^2} \quad (1)$$

where:

Z = z value (e.g., 1.96 for 95% confidence level),

P = percentage picking a choice expressed as a decimal (0.5 used for sample size needed),

C is confidence interval expressed as a decimal (e.g., $0.05 = \pm 5$)

The Cochran formular in equation 1 was used to calculate for the sample size (Cochran, 1977). Cochran formula is suitable in case the population size or the population proportion is unknown. This allows the researcher to calculate an ideal sample size given a desired level of precision, desired confidence level and an estimated proportion of the attribute present in the population (Chaokromthong & Sintao, 2021). To collect the necessary data for the quantitative phase, a questionnaire was designed and employed. The number of sample household selected for the questionnaire was determined using the Cochran formula. For the selection of specific households, the systematic sampling technique was used in selecting household structures. Moving from the west to the east of each community and in a zig zag format every 5th house was selected until the total number of households for that particular community was exhausted. In the selected housing structure, the first household encountered was engaged for the structured interview if an adult of age 18 and above was met and has consented/accepted to participate in the study. Where an adult of the first

household was not available or refused to participate, the next household available in the housing structure was interviewed when they consented.

Data Collection Instruments

Qualitative

The qualitative instruments were focused on understanding why certain fuelwood species and oven types were preferred to others. They were also to explore the perspectives of the respondents on implications of the use of the fuelwood species. The guides for the focus group discussions and in-depth interviews were developed and validated before being used for data collection. The guides focused on notable changes in the fish smoking activity with respect to the ovens and fuelwood species over the years, performance of the ovens under study, common and preferred fuelwood species used in the study communities and the efficiencies of the oven types under study. Figures 7 and 8 shows the focus group discussions conducted in Mumford and Winneba respectively.



Figure 7: Focus group discussion with fish smokers at Mumford.



Figure 8: Focus group discussion with fish smokers at Winneba.

Quantitative

For the quantitative phase, a questionnaire was developed and pre-tested before they were deployed in the field. The quantitative instrument was pre-tested in Elmina, a fishing community that share similar characteristics with those selected for the main study. The pre-test was to check whether the questions on the instrument were understood by the respondents. A few corrections were made after the pre-test before the instrument was sent to the field. The instrument included questionnaire on general household socio economic and demographic data, the efficiencies of the different fish smoking ovens, sources of fuelwood for fish smoking, average quantity of fish smoked in a day/week, the average number of times fish is smoked within the week and the quantity of fuelwood used in households in a day/week among others. The format was semi-structured with both close and open-ended questions. The

questionnaire was loaded onto Kobo Tool-box software for administration on the field. Figures 9 and 10 show the measurement of fuelwood during the quantitative phase at Mumford and Winneba respectively.



*Figure 9: Measurement of household fuelwood using the weighing
Scale at Mumford*



*Figure 10: Measurement of household fuelwood using the weighing
scale at Winneba*

Estimation of Greenhouse Gases using IPCC Tier 1 Methodology

Greenhouse gas emissions were calculated using the IPCC methodology for stationary combustion with a default emission factor for CO₂, CH₄ and N₂O emission and net calorific value (NCV). The emission estimates were derived based on the stated average weekly firewood consumption in a typical inefficient traditional woodstove. Level of GHG emission was estimated as the product of appropriate emission factor for each gas and the weekly, monthly and annual fuelwood consumption.

The estimation was based on the assumption that all biomass/fuelwood utilised for fish smoking was consumed. During the bumper and lean seasons, the GHG estimation was done in a segmented data set.

The calculation steps are provided below:

The emission of total carbon was estimated by applying the basic methodology. This was done by multiplying the quantity of biomass burnt (t dm) by the fraction of biomass oxidised and the biomass content (t C/t dm). The default value of 0.9 is used for the fraction of biomass oxidized. Whereas, for woody biomass a conversion factor of 0.5t C/t dm is used. This may be given by the following relation.

$$C_t = M_t \times M_f \quad (2)$$

where C_t is the total biomass burnt, measured in t dm, M_t is the fraction of biomass oxidised, which is equal to 0.9 and M_f is the carbon content of woody biomass, measured in t C.

The emission of CO₂ from fuel wood burning can be estimated by conversion of total carbon content (t C) to carbon dioxide (t CO₂) using the

conversion ratio of 44 t CO₂/12 t C. This is explained from the following equation.

$$\text{CO}_2 = M_t \times M_f \times M_c \times \frac{44}{12} \quad (3)$$

where M_t is the total biomass burnt (t dm), M_f is the fraction of biomass oxidized (0.9) and M_c is the biomass carbon content (0.5 t C/t dm)

CO_2 = total CO₂ (t CO₂) release from the fuel wood burning

To account for non-CO₂ emissions, specifically CH₄ and N₂O resulting from the combustion of biomass (fuelwood), the following equations will be used.

$$\text{CH}_4 = t \text{ C} \times \text{Emission ratio (0.012)} \times \frac{16}{12} \quad (4)$$

$$\text{N}_2\text{O} = t \text{ C} \times \text{Emission ratio (0.007)} \times \frac{N}{C} \text{ ratio} \times \frac{44}{28} \quad (5)$$

where, $t \text{ C}$ is the carbon released and $\frac{N}{C}$ is the net calorific value.

Estimation of Annual Fuelwood Consumption

The methods proposed by Dainou, Vermeulen and Doucet (2008) were modified to estimate annual fuelwood consumption and annual wood consumption per capita. The annual wood consumption (C_a) was calculated using the formula based on the volume of wood consumed per day in m³ (V_b), the number of days used per week (f), and the number of weeks in a year (52):

$$C_a = V_b \times f \times 52 \quad (6)$$

Measurement of Greenhouse Gases

The air quality was measured at selected household after household heads were taken through the nature of the experiment and their consent sought. An air quality sensor was built at the Laboratory, University of Cape Coast, Ghana using low-cost air components (MG-811 and MQ4 gas sensors).

Figure 11 shows the assembled sensors. These sensors were used to measure CO₂ and CH₄ respectively. Data analysis utilised Python programming with the aid of the Pandas library. The sensors were placed about 10 meters away from the sources of smoke in the smoke house and programmed to take CO₂ and CH₄ measurements every 5 seconds between 8 to 12 hours depending on the fish smoking period. The air quality sensor measures CO₂ ranging from 0 and 10,000 ppm, whilst methane can be detected from 300 ppm to 10,000 ppm



Figure 11: Assembled low-cost air quality sensor.

Measurement of Fuelwood Moisture Content

A wood moisture meter was used to measure the moisture content of wood before each experiment. The electronic meter allows the measurement of the moisture content in the wood in the size of 120 x 60 x 26 mm and the weight of 150 g. Figure 12 shows the measurement of fuelwood moisture content. The method of measurement is based on a balance system, which measures the dielectric value of the moisture. The instrument was calibrated by the Ghana Standard Authority and was up to date.



Figure 12: Measurement of fuelwood moisture content.

Data Collection Procedures

Focus group discussions were involving only fish smokers were conducted in all the seven (7) communities under study between May and October 2022. The number of participants in the groups ranged from eight (8) and twelve (12). In-depth interviews on the other hand involved the engagement of the leaders of fish smokers and leaders of fuelwood suppliers in the various communities. The household survey was administered using a team of four enumerators and the principal investigator. Enumerators were trained prior to the data collection exercise to understand and familiarise themselves with the questionnaire and objectives of the study. The survey tool was written in English but translated into the local Fante dialect during the data collection. Under the direction of the principal investigator, the enumerators proceeded systematically from one household to the next among selected respondents.

Data Processing and Analysis

Data collected was examined daily to ensure questions were clearly understood to help evaluate the findings and contextualise some responses. Data collected was keyed, cleaned and managed using Microsoft Excel. The data was then imported into Statistical Package for Social Sciences (SPSS version 24) for processing and analysis. The results were presented using descriptive statistics in the form of mean, percentages, crosstabs etc. Charts and graphs were also used to summarise the data. Inferential statistics were used to determine the relationships between the emissions from different fuelwood species and different fish smoking ovens.

Ethical Considerations

Ethical clearance to carry out the study was obtained from the Institutional Review Board (IRB) of the University of Cape Coast. Through the leaders of fish smokers and other community contact persons, various households were informed of about the study prior to the household survey. Each household was informed that their participation in the exercise was voluntary and that the purpose of the study was solely academic.

CHAPTER FOUR

RESULTS

This Chapter presents the findings of the study dealing specifically with fuelwood consumption by types among fish smokers in the seven (7) communities, types of ovens being used as well as the concentrations of GHG emissions by the fish smoking ovens and fuelwood used. The chapter presents the results of the study using various descriptive and inferential statistics through tables, graphs and other images. It interspersed qualitative findings with the quantitative findings to provide clear understanding and appreciation on why certain fuelwood species and oven types were preferred to others. The chapter presents the perspectives of the respondents on notable changes in the fish smoking activity with respect to fuelwood and oven use among other pertinent issues relating to the objectives of the study.

Socio-demographic Characteristics of the Study Population

All the communities in the study area had a predominantly female population of fish smokers with a percentage of 97% to 100%. Majority of respondents (31%) were between the age group of 50 to 59, followed by age group of 40 to 49 (24.7%). Kesewokan in the Western Region had relatively larger proportion of young respondents between the ages of 20 to 29 with a percentage of 16%. In fact, about 78% of all who were engaged in the household survey fell within the economically active age group of 20 to 59, while 22% fell within the retiring age of above sixty (60) years. In terms of marital status, Apam and Winneba located in the Central Region had a higher percentage of married individuals with 69% and 68% respectively, while Kesewokan and Abuesi in the Western Region had higher percentages of

singles with 12% and 11% respectively. Woara Beba and Apam in the Central Region had majority of respondents being divorced with percentages of 19% and 17% respectively.

Regarding educational attainment, majority of respondents in all the communities had no formal education with Woara Beba having the highest of 72%. Abuesi and Woara Beba had relatively higher proportion of respondents attaining primary and junior high school education with percentages of 39% and 28% respectively. Majority of respondents in the survey in all the communities were predominantly affiliated with Christianity with percentages between 89% and 100%. Winneba had a higher percentage (7.8%) of respondents without any religion. The communities engaged were not diverse in terms of ethnicity, most of the communities engaged in the survey were mainly from the Fante ethnic group of Ghana. Winneba however, had 87% of its respondents being Effutu while Woara Beba had equal percentages of respondents being Ewe and Effutu. Ga, Ahanta and Nzema ethnic groups were in the minority as far as the respondents were concerned.

The households in the study areas were predominantly large, with membership of between 6 and 10 people, accounting for 45% to 60% of the households. However, a small proportion, approximately 1%, of households engaged had as many as between 16 to 20 members. With respect to the scale of fish smoking, 85% of the respondents engaged in full-time fish smoking while a minority of 15% smoked fish as a part-time venture.

Table 2 summarises the proportion of respondents engaged in the household survey by gender, age, marital status, household size, educational attainments, ethnicity, religion and scale of fish smoking.

Table 2: Summary Characteristics of Respondents According to the

Study Communities							
Variable	Study Communities N = 506						
	Winneba N = 102 %	Woara Beba N = 18 %	Apam N = 78 %	Mumford N = 99 %	Kesewokan N = 86 %	Abuesi N = 74 %	Shama Apo N = 49 %
Gender							
Male	2.00	0.00	3.00	0.00	0.00	0.00	0.00
Female	98.0	100.0	97.0	100.0	100.0	100.0	100.0
Age groups							
20-29	4.00	0.00	5.00	1.00	16.0	10.0	2.00
30-39	17.0	6.00	18.0	22.0	13.0	19.0	10.0
40-49	28.0	28.0	26.0	18.0	27.0	19.0	35.0
50-59	31.0	44.0	32.0	32.0	22.0	31.0	37.0
60-69	16.0	22.0	16.0	20.0	17.0	18.0	16.0
Above 70	4.00	0.00	3.00	7.00	5.00	3.00	0.00
Marital Status							
Single	4.00	6.00	5.00	4.00	12.0	10.0	6.00
Married	69.0	56.0	69.0	67.0	57.0	57.0	51.0
Divorced	10.0	17.0	19.0	6.00	16.0	23.0	29.0
Widow/ widower	18.0	22.0	6.00	23.0	15.0	10.0	14.0
Education							
No formal education	70.0	72.0	47.0	67.0	45.0	43.0	55.0
Primary education	20.0	28.0	27.0	19.0	19.0	39.0	37.0
Junior high/ middle school	8.00	0.00	20.0	12.0	30.0	18.0	8.00
Secondary school	2.00	0.00	6.00	2.00	6.00	0.00	0.00
Ethnicity							
Fante	13.0	39.0	85.0	100	97.0	91.0	98.0
Ewe	0.00	22.0	1.00	0.00	2.00	4.00	0.00
Ga	0.00	0.00	13.0	0.00	0.00	0.00	0.00
Effutu	87.0	39.0	0.00	0.00	0.00	0.00	0.00
Ahanta	0.00	0.00	1.00	0.00	0.00	4.00	2.00
Nzema	0.00	0.00	0.00	0.00	1.00	1.00	0.00
Religion							
Christianity	89.0	100.0	99.0	98.0	94.0	97.0	100.0
Islam	1.00	0.00	0.00	0.00	5.00	3.00	0.00
Traditional	2.00	0.00	0.00	0.00	1.00	0.00	0.00
No religion	8.00	0.00	1.00	2.00	0.00	0.00	0.00
Household size							
1-5	34.0	56.0	44.0	33.0	37.0	47.0	41.0
6-10	60.0	44.0	51.0	63.0	56.0	47.0	53.0
11-15	6.00	0.00	5.00	3.00	6.00	6.00	6.00
16-20	0.00	0.00	0.00	1.00	1.00	0.00	0.00

Scale of fish smoking

Full-time	90.0	56.0	83.0	87.0	84.0	82.0	94.0
Part-time	10.0	44.0	17.0	13.0	16.0	18.0	6.00

Acquisition of Fish Smoking Knowledge and Skill

In all the communities under study, the majority of respondents, between 92 to 99% grew up in households where fish smoking was a major economic activity (Table 3). A minority of respondents, about 2%, underwent apprenticeship with someone else or were self-taught. There was very little disparity when comparing educational attainment of respondents and their knowledge of fish smoking. With respect to ethnicity, 90% or more of respondents in various ethnic groups having grown up in a household where smoking fish was a major economic activity.



Table 3: Acquisition of Fish Smoking Knowledge According to Study Communities, Educational Attainment, and Ethnicity.

	Grew up in a household where fish smoking was a major economic activity %	Underwent an apprenticeship with someone else. %	Self-taught %
Community			
Winneba	97.0	2.00	1.00
Woara Beba	94.0	0.00	6.00
Apam	92.0	4.00	4.00
Mumford	97.0	0.00	3.00
Kesewokan	93.0	5.00	2.00
Abuesi	99.0	1.00	0.00
Shama Apo	96.0	2.00	2.00
Educational Attainment			
No formal education	96.0	2.00	2.00
Primary Education	98.0	1.00	1.00
Junior high/middle school	94.0	3.00	3.00
Senior high school	86.0	0.00	14.0
Ethnicity			
Fante	96.0	2.00	2.00
Ewe	90.0	0.00	10.0
Ga	91.0	0.00	10.0
Effutu	96.0	2.00	2.00
Ahanta	100.0	0.00	0.00
Nzema	96.0	2.00	2.00

Notable Changes in Fish Smoking Occupation among Selected Communities

From the qualitative data, notable changes stated by the respondents were relating to the evolvement of different oven types for smoking, fuelwood types for

smoking, reduced fish catch compared to the past, increased cost of fish, reduced size of fishes as well as increased illegal fishing practices among others.

Respondents noted that four types of fish smoking ovens have evolved over the years. The first of the ovens is the traditional mud oven (TMO). This oven is cylindrical in shape and huge in size comparable to the other two types. It is made up mainly mud or clay and most often require regular maintenance. They are not durable and require yearly reconstruction as they are often destroyed during rainy seasons. According to the respondents the TMOs have huge and widely opened combustion chamber and for that matter consume huge amount of fuelwood. They also produce huge volume of smoke and their use is characterised by intense labour especially in arranging and manually turning of fish being smoked. Respondents reported of eye problems while using the TMO. It is suitable for smoking large fishes which do not require to be smoked dry.

The Chorkor oven on the other hand, is known to be more fuel efficient compared with the TMO, smaller in size and could smoke larger volume of fish than the TMO, given that the fish can be stacked severally on the oven. It is suitable for removing all moisture from fish and for that matter is not convenient for wet smoking especially leaving a considerable amount of moisture in the fish like done to big fishes. Chorkor oven according to the respondents is durable and does not require regular maintenance until about five to six years of use. Respondents averred that the Chorkor oven is fast at preparing the fish for the market as compared to the other types of ovens. The Chorkor oven can store fish

for up to five months without spoilage. It therefore has storage and preservation capabilities.

The third oven mentioned by the respondents was the Morrison oven, which shares similar characteristics of the Chorkor oven. According to the respondents, the Morrison oven was designed to minimise the fish fats dripping onto the fire and producing excess smoke which contaminate the fish. However, when fish smoked using the Morrison oven were analysed, no discernible distinction was found when compared to fish smoked using the Chorkor oven. The Morrison oven was only mentioned by the respondents from Winneba.

The last type of oven mentioned by the respondents is the Ahotor oven, which is the newest innovation in the types of ovens developed for fish smoking. Smoking with the Ahotor oven is less stressful and it can be used by anybody. It uses less fuelwood and generates very less smoke as it has a small combustion chamber. It is also the most hygienic of the ovens. Respondents claimed it is used to process fish to the standard of the international market. In other words, fish smoked with Ahotor oven could readily be exported. A respondent from Winneba summed it up as follows:

“.... when we started fish smoking at first, we were using the round traditional mud oven which was very laborious and stressful to use as you ought to put the fish on it one after the other. The oven was quite large with a significant height, so we needed to stand on a stool. From there, we had the Chorkor oven which we also realized that it consumed a lot of

fuelwoods. From there we got introduced to the Morrison oven, this is because the fats draining from the fish into the fire could cause cancer as a result and also, we could not export our smoked fish. The Morrison oven conserved some significant amount of fuelwood, but they said the laboratory test was the same as the Chorkor oven. From there, we got the Ahotor oven.....in summary, there have been changes in this occupation in relation to the introduction of different types of ovens, but all has its advantages and disadvantages....”

Regarding changes in the types of fuelwoods used for smoking, respondents noted that the changes begun to show with over exploitation of mangroves for fuelwood as well as the intense education to drive home the need to conserve the mangrove forests. This made most of the fish smokers to look for fuelwood elsewhere away from their communities. The change is therefore characterized by a shift from total focus on mangroves to different tree species including “*Klainedoxa gabonensis*, *Celtis mildbraedii*, *Cistanthera papaverifera*, *Terminalia ivorensis*, and *Blighia sapida*” among others, with specific characteristic features that enhance the quality of the smoked fish. Increasing cost and scarcity of these fuelwoods has forced fish smokers to resort to the use of commonly available wood species such as the neem tree (*Azadirachta indica*). A respondent from Apam commented:

“... We tended to use Theobroma cacao (cocoa), Klainedoxa gabonensis (Begye Woba), Terminalia ivorensis (Emire) and

Celtis mildbraedii (Esa). Nowadays, these fuelwoods are very scarce, and the prices are quite expensive. Now we use more of neem tree to smoke our fish.....”

Another respondent puts it this way:

“... There have been changes to some species of fuelwood that we used to get in this community. We used to get some of the best fuelwood for our fish smoking business in our surrounding towns but now we can only get the it at far distances. This had made the price of fuelwood to increase and subsequently making expenses on the smoked fish to also increase. We used to purchase a truck of fuelwood for GHC 1000 OR GHC 1500 but now it is GHC 2500 and GHC 3000. The only way to purchase these fuelwoods now is to buy as a group or team and share it accordingly.....”

Respondents observed that the quantities of fish landed have drastically reduced over the years. Fish catch from the ocean in the present day as compared to the past is very low. This according to the respondents is due mainly to illegal fishing activities among artisanal fisherfolks. Important among illegal fishing activities mentioned included the use of light for fishing, and chemicals for fishing among others. Increased illegal fishing practices from the perspectives of the respondents, therefore, is the main cause of reduced fish catch in Ghana's coastal waters. Related to the reduced fish catch is the reduction in the size of fishes in recent times.

Other observations from the respondents indicated that the cost of fish, just like the cost of other goods in the country, have gone up resulting in the inability of fish smokers to purchase fish for processing. Again, respondents mentioned that COVID-19 has brought some changes to their occupation though they felt short of mentioning specific changes wrought by the infectious disease. A respondent in Kesewokan summed it up as follows:

“... I started smoking fish at a tender age. I have about 50 years of experience in this occupation. Things have changed compared to old times. We used to get more fish to smoke. We currently do not get the fish we desire to smoke because the fishermen do not get enough catch. The Covid-19 also brought some significant changes to our business.....”

Ownership and means of acquisition of fish smoking ovens among respondents

Table 4 shows the distribution of fish smoking ovens in the study communities. The enumeration of TMO for fish smoking varied across communities. Shama Apo had the highest percentage of TMO at 44%, followed by Woara Beba and Winneba with percentages of 33% and 26% respectively whilst Apam had no reported TMO, Kesewokan recorded the lowest, with percentage of less than 1. Other communities showed moderate distribution of TMO, with percentages ranging from 12% in Mumford to 15% in Abuesi.

The distribution of the Chorkor oven was highest in all the study communities. Percentage of distribution ranged from 60% to 99%. The highest

was recorded in Apam and Kesewokan (99% and 98%) respectively and the lowest in Shama Apo and Woara Beba (56% and 60%) respectively. The total number of Ahotor ovens enumerated in the study communities was low, with percentages of less than 7%. Communities such as Abuesi and Shama Apo had no Ahotor ovens. In effect, the Chorkor oven was the most widely distributed fish smoking oven, followed by the TMO. These variations in oven types and their usage reflect the diversity in fish smoking practices within the study communities.

Table 4: Distribution of Fish Smoking Oven in the Study Communities

	N = 111	N = 502	N = 8
	Traditional Mud Oven	Chorkor Oven	Ahotor Oven
	%	%	%
Community			
Winneba	26.0	73.0	1.00
Woara Beba	33.0	60.0	7.00
Apam	0.00	99.0	1.00
Mumford	12.0	86.0	2.00
Kesewokan	1.00	98.0	1.00
Abuesi	15.0	85.0	0.00
Shama Apo	44.0	56.0	0.00

Table 5 shows the percentage distribution of acquisition of fish smoking ovens by different means across the study communities. In Winneba, 52.9% of households acquired their ovens by purchasing it outright, 4.9% purchased on credit, 40.2% had their ovens constructed by their households, and 2.0% received them as gifts from NGOs. Similarly, in Apam, Mumford, Kesewokan, Abuesi and Shama Apo, majority of respondents acquired their ovens by purchasing it outright. In Woara Beba, on the other hand, a significant proportion of

respondents (39%) had their fish smoking oven being constructed by their households. A minority of respondents had their fish smoking ovens being gifted to them by NGOs.

Table 5: Acquisition of Fish Smoking Ovens According to the Study

Communities

	Purchased Outright %	Purchased on Credit %	Constructed by Household %	Gifted by NGO %
Community				
Winneba	53.0	5.00	40.0	2.00
Woara Beba	33.0	17.0	39.0	11.0
Apam	92.0	1.00	6.00	1.00
Mumford	70.0	2.00	28.0	0.00
Kesewokan	88.0	0.00	11.0	1.00
Abuesi	45.0	26.0	30.0	0.00
Shama Apo	92.0	2.00	6.00	0.00

Frequently Used and Preferred Oven Type

Table 6 shows the percentages of usage and preference of the different fish smoking ovens across the communities under study. The data shows that the Chorkor oven was the most frequently used oven in the study communities, ranging from 51% to 100%. The highest was recorded in Mumford and Apam and the least recorded in Shama Apo. However, the usage of the Ahotor oven was limited to only two communities, namely, Woara Beba and Kesewokan. In some communities like Mumford and Abuesi, only the Chorkor oven was used.

Comparably, the data reveals that the Chorkor oven was the most preferred type of oven in all the communities studied, with preferences ranging from 51% to 99%. In Shama Apo, however, the difference in preferences for TMO and Chorkor oven was relatively small, with approximately 49% of respondents preferring the TMO.

Table 6: Frequently Used and Preferred Oven Type by the Communities

Community	Oven Often Used N = 506			Preferred oven N = 506		
	Traditional Mud Oven	Chorkor Oven	Ahotor Oven	Traditional Mud Oven	Chorkor Oven	Ahotor Oven
	%	%	%	%	%	%
Winneba	6.00	94.0	0.00	6.00	93.0	1.00
Woara Beba	0.00	94.0	6.00	0.00	89.0	11.0
Apam	1.00	99.0	0.00	0.00	100.0	0.00
Mumford	0.00	100.0	0.00	0.00	100.0	0.00
Kesewokan	0.00	98.0	2.00	1.00	99.0	0.00
Abuesi	0.00	100.0	0.00	1.00	99.0	0.00
Shama Apo	49.0	51.0	0.00	45.0	55.0	0.00

Table 7 presents the reasons accounting for the preference of specific fish smoking ovens in the different communities. The respondents rated different factors that influenced their preference and choice of ovens. These factors included efficiency (fuel usage/time), convenience, and aesthetics of the fish after smoking, longevity of the oven, and cost of construction. The top two reasons for the preference in most communities were efficiency and convenience. Over 41% of respondents from Shama Apo and 72% from Mumford mentioned efficiency as the main reason for their choice of ovens. Also, 46% and 43% of respondents

from Abuesi and Kesewokan respectively indicated convenience as a reason for their choice of ovens. This indicates that the respondents valued ovens that were fuel-efficient and easier to use. The aesthetics of the fish after smoking was also considered important in some communities, with 6% and 5% of the respondents from Winneba and Woara Beba respectively attesting to the fact that the visual appeal of the smoked fish was what determined their choice of oven. A small proportion of the respondents, about 1% from Winneba and Apam also considered longevity of the oven as important reason for their choice of the oven.

Table 7: Bases for Preference for the Different Fish Smoking Ovens

	Efficiency (Fuel usage/time)	Convenience	Aesthetic of the fish after smoking	Longevity of the oven	Cost of Construction
	%	%	%	%	%
Community					
Winneba	64.0	28.0	6.0	1.00	1.00
Woara Beba	61.0	33.0	6.00	0.00	0.00
Apam	71.0	26.0	3.00	1.00	0.00
Mumford	72.0	25.0	2.00	1.00	0.00
Kesewokan	57.0	43.0	0.00	0.00	0.00
Abuesi	51.0	46.0	1.00	1.00	0.00
Shama Apo	41.0	18.0	4.00	37.0	0.00

Table 8 shows the percentage distribution of the respondents' socio-demographic variables and types of ovens owned. Majority of respondents across all levels of educational attainment preferred Chorkor ovens. Respondents who attained primary education constituted the highest proportion of those who owned and used the traditional mud ovens. None of the household's Head who attained

senior high school education used the TMOs. For households using Chorkor ovens, the distribution of educational attainment was more balanced. The data revealed that respondents with no formal education (1%) preferred Ahotor oven.

Regarding household membership, only 6% of households with 1 to 5 individuals used the Traditional Mud oven while 94% of them used Chorkor oven and 0.5% used Ahotor. Households with 6 to 10 individuals had 6%, 93% and 1% using Traditional Mud oven, Chorkor oven, and Ahotor oven respectively. Again, households with 11 to 15 members recorded 8%, 88% and 4% use of the Traditional Mud oven, Chorkor oven, and Ahotor oven respectively. All (100%) households with 16 to 20 individuals used the Chorkor oven only. The data showed that household with larger members were likely to prefer the Chorkor oven than Traditional mud oven and Ahotor oven. The data on ethnic groups revealed that 20% of the respondents from the Ahanta ethnic group used the Traditional Mud oven as against 6% apiece of those from Fante and Effutu origins. All the respondents who had Ga, Ewe and Nzema origins used only Chorkor oven for smoking. Apparently, 94% and 92% of those who smoked fish on full-time and part-time bases respectively used Chorkor oven while 6% and 5% of them also used the TMO respectively. The data also revealed that respondents used the Chorkor oven for smoking only frozen fish.

Table 8: Preferred Fish Smoking Oven According to Educational Attainment, Household Size, Ethnicity, Scale of Fish Smoking and Forms of Fish Smoked

	TMO %	Chorkor Oven %	Ahotor Oven %
Educational Attainment			
No formal education	6.00	93.0	1.00
Primary education	9.00	91.0	0.00
Junior high school/middle school	4.00	96.0	0.00
Senior high school	0.00	100.0	0.00
Household Size			
1-5	5.00	94.0	1.00
6-10	6.00	93.0	1.00
11-15	8.00	88.0	4.00
16-20	0.00	100.0	0.00
Ethnicity			
Fante	6.00	93.0	1.00
Effutu	6.00	94.0	0.00
Ahanta	20.0	80.0	0.00
Nzema	0.00	100.0	0.00
Ewe	0.00	100.0	0.00
Ga	0.00	100.0	0.00
Scale of Fish Smoking			
Full-time	6.00	94.0	0.00
Part-time	5.00	92.0	3.00
Forms of Fish Smoked			
Fresh fish	2.00	97.0	1.00
Frozen fish	0.00	100.0	0.00
Both (fresh & frozen)	10.0	90.0	0.00

Complementary Usage of Fish Smoking Ovens

Table 9 shows the complementary use of the different types of fish smoking ovens that were considered for the study. There was variation in perception of the complementary use of the different fish smoking ovens across the study communities. In the community of Apam, the vast majority (98%) of

respondents responded "No" to the question, indicating that there is little or no complementary use of different fish smoking ovens in that community. Similarly, in Kesewokan, Abuesi and Winneba majority (98%, 82% and 68% respectively) responded "No" to the question, indicating that there is little or no complementary use of fish smoking ovens in those communities as well. On the other hand, in Shama Apo and Woara Beba, a significant proportion of respondents (78% and 61% respectively) responded "Yes" to the question, indicating that there was a considerable complementary use of different fish smoking ovens in those communities. The majority of respondents, regardless of their level of education, concurred that there was little to no complementary use of different types of ovens. However, with percentages of 87% and 86%, respectively, respondents who had completed junior high and senior high school made up most of the respondents in the study.

Table 9: Complementary Use of the Different Fish Smoking Ovens
According to the Study Communities, and Educational Attainment

	Complementary Use of Oven	
	No %	Yes %
Community		
Winneba	68.0	32.0
Woara Beba	39.0	61.0
Apam	99.0	1.00
Mumford	85.0	15.0
Kesewokan	98.0	2.00
Abuesi	82.0	18.0
Shama Apo	22.0	78.0
Educational Attainment		
No formal education	77.0	23.0
Primary education	73.0	27.0
Junior high school/middle school	87.0	13.0
Senior high school	86.0	14.0

Fuelwood Accessibility, Usage and Preferences

The data shows that transporters were the main source of fuelwood for most of the communities, with percentages ranging from 58% to 83%. Woara Beba and Shama Apo however, had wholesalers as their major source of fuelwood, with percentages of 61% and 55%, respectively. Harvesters and producers contributed a very small percentage in most communities, with only Woara Beba and Apam having a percentage above 7%.

In terms of availability of preferred fuelwood in the study communities, the data showed that the percentage of communities with preferred fuelwood availability varied across the different communities. Overall, the majority of communities, ranging from 55% to 97%, had access to preferred fuelwood. However, the difference was not that high in Kesewokan, Abuesi and Woara Beba with percentages of 8%, 10% and 11% respectively. In contrast, the majority of respondents in Shama Apo and Apam stated that they did not have access to their preferred fuelwood, with percentages of 67% and 54%, respectively. Regarding mixing of different fuelwood species, the majority (92%) of the respondents from all the study communities indicated that they mixed different species of fuelwood. Concerning the availability of fuelwood in the past 5 years, the majority (94%) of the respondents from all study communities indicated that the availability of fuelwood had decreased considerably over the years.

With regards to certain fuelwoods becoming extinct in the study communities, the data revealed that a significant proportion of individuals in the study communities had contemplated the potential species extinction of fuelwood

in their areas. The range of such individuals spans from 63% in Apam to 78% in Kesewokan, with Shama Apo having the lowest percentage at 63%. Notably, the community of Abuesi stands out with a higher percentage (58%) of individuals who have not considered fuelwood species extinction compared to the other communities. The findings indicate that the majority of individuals in these communities were concerned about the possibility of fuelwood depletion. The variations in responses between communities could be attributed to varying levels of awareness and firsthand experience with fuelwood scarcity and alternative energy sources.



Table 10: Major Source of Fuelwood, Availability of Preferred Fuelwood, Mixing of Different Fuelwood Species, Availability of Fuelwood in the Past Five Years and the Perception of Fuelwood becoming Extinct in the Study Communities

	Study Communities						
	Winneba	Woara Beba	Apam	Mumford	Kesewokan	Abuesi	Shama Apo
	%	%	%	%	%	%	%
Major source of fuelwood							
Wholesalers	41.0	61.0	32.0	17.0	28.0	26.0	55.0
Transporters	58.0	22.0	60.0	83.0	72.0	74.0	45.0
Harvesters/Producers	1.00	1.00	8.00	0.00	0.00	0.00	0.00
Availability of preferred fuelwood							
No	3.00	44.0	54.0	18.0	46.0	45.0	67.0
Yes	97.0	56.0	46.0	82.0	54.0	55.0	33.0
Mixing of different fuelwood species							
No	11.0	17.0	13.0	2.00	1.00	0.00	4.00
Yes	89.0	83.0	87.0	98.0	99.0	100.0	96.0
Availability of fuelwood as compared to the past 5 years							
Increasing	2.00	0.00	4.00	5.00	2.00	0.00	2.00
Decreasing	93.0	100	92.0	93.0	93.0	99.0	88.0
Constant	5.00	0.00	4.00	2.00	5.00	1.00	10.0
Ever thought of fuelwood becoming extinct in your area							
No	23.0	22.0	37.0	34.0	22.0	58.0	37.0
Yes	77.0	78.0	63.0	66.0	73.0	42.0	63.0

Fuelwood Species Used for Fish Smoking

From Figure 13, majority (25%) of users prefer *Klainedoxa gabonensis* as the main fuelwood species for fish smoking. *Celtis mildbraedii* was the second most used species at 24%, while *Tectona grandis* came third at 11%. Other species which were considerably used included *Piptadeniastrum africanum* (8%), *Azadirachta indica* (8%), *Avicennia germinans* (5%), and *Blighia sapida* (3%). Some species however, were used less frequently for fuelwood. These include *Alstonia boonei*, *Hevea brasiliensis* and *Magnifera indica* accounting for less than 1%. These latter groups of fuelwood species could be described as emerging fuelwood options due to less availability of the existing species over time.

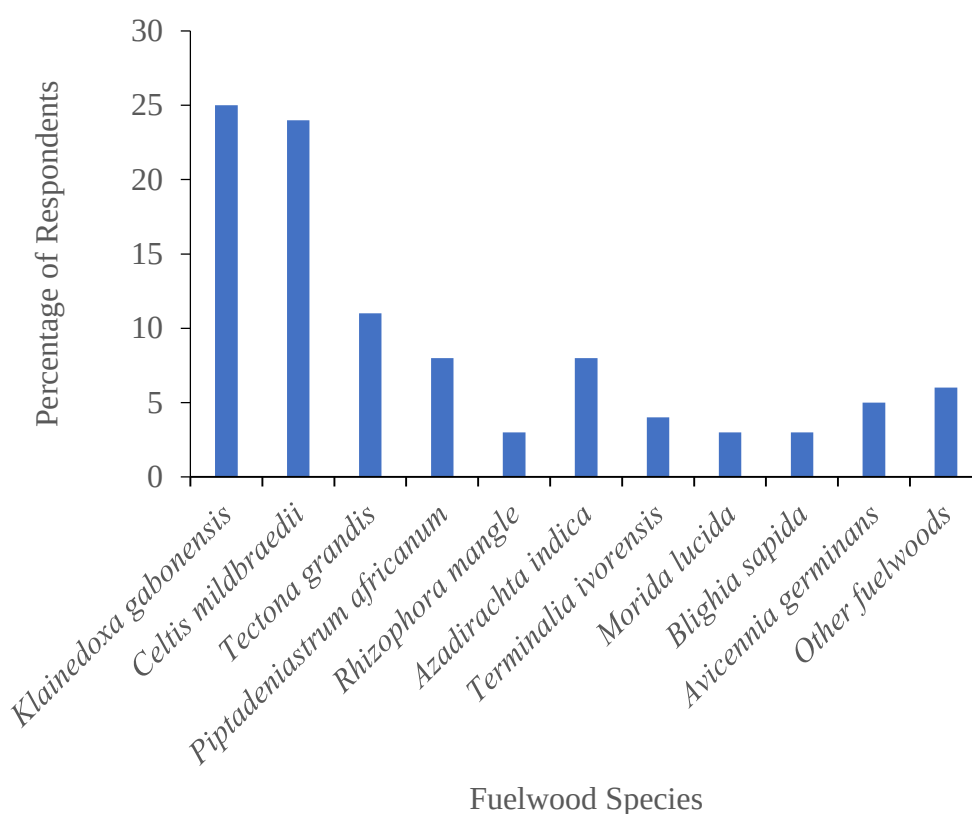


Figure 13: Mostly used fuelwood species for fish smoking.

Preferred Fuelwood Species for Fish Smoking

Figure 14 shows that the most preferred species for fish smoking was *Celtis mildbraedii*. This was used mostly by 38% of respondents interviewed. *Klainedoxa gabonensis* and *Tectona grandis* were also preferred by 36% and 6% of the respondents respectively. The other species with significant preferences for fish smoking included *Rhizophora mangle* at 6%, *Amphimas pterocarpoide* at 4%, and *Azadirachta indica* at 3%.

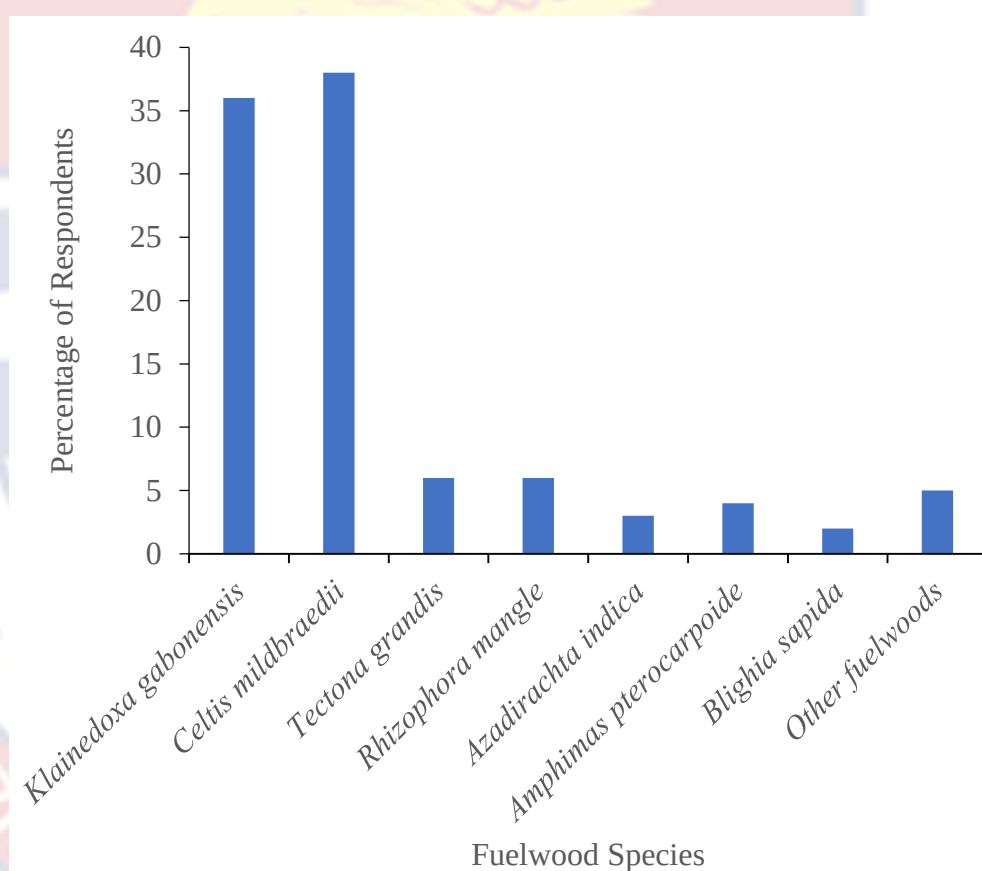


Figure 14: Preferred fuelwood species for fish smoking.

Table 11 shows the variation in mostly used and preferred fuelwood species in the study communities. For Winneba, Mumford, Woara Beba and Apam, the mostly used fuelwood species were *Klainedoxa gabonensis*, *Celtis mildbraedii* and *Azadirachta indica*. For Kesewokan and Abuesi the mostly

used fuelwood species was *Tectona grandis*. In Shama Apo, the mostly used fuelwood species was *Avicennia germinans*. In terms of the preferred fuelwood species, the result indicates that *Klainedoxa gabonensis* was the preferred fuelwood in Winneba, Apam and Mumford with percentages of 67%, 39% and 74% respectively. *Celtis mildbraedii* was preferred in Woara Beba, Kesewokan and Abuesi with percentages of 50%, 58% and 54% respectively. In Shama, the preferred fuelwood species was different from the other communities. *Rhizophora mangle* was the preferred fuelwood species with a percentage of 50%. In summary, the result indicates that *Klainedoxa gabonensis* and *Celtis mildbraedii* are the most used and preferred fuelwood types across the different communities. Nevertheless, the communities exhibit differences in their choices and preferences for fuelwood types, which could be influenced by factors like the local availability, accessibility, and traditions.

Table 11: Mostly Used and Preferred Fuelwood Species According to Study Communities

		Communities under Study N = 506						
		Winneba N = 102	Woara Beba N = 18.0	Apam N = 78.0	Mumford N = 99.0	Kesewokan N = 86.0	Abuesi N = 74.0	Shama Apo N = 49.0
Mostly Used Fuelwood								
1st	<i>Klainedoxa gabonensis</i>		<i>Celtis mildbraedii</i>	<i>Celtis mildbraedii</i>	<i>Klainedoxa gabonensis</i>	<i>Tectona grandis</i>	<i>Tectona grandis</i>	<i>Avicennia germinans</i>
Percentage (%)	63.0		44.0	36.0	42.0	35.0	35.0	53.0
2nd	<i>Celtis mildbraedii</i>		<i>Azadirachta indica</i>	<i>Klainedoxa gabonensis</i>	<i>Celtis mildbraedii</i>	<i>Celtis mildbraedii</i>	<i>Piptadeniastrum africanum</i>	<i>Rhizophora mangle</i>
Percentage (%)	29.0		44.0	22.0	17.0	22.0	24.0	27.0
Preferred Fuelwood								
1st	<i>Klainedoxa gabonensis</i>		<i>Celtis mildbraedii</i>	<i>Klainedoxa gabonensis</i>	<i>Klainedoxa gabonensis</i>	<i>Celtis mildbraedii</i>	<i>Celtis mildbraedii</i>	<i>Rhizophora mangle</i>
Percentage (%)	67.0		50.0	39.0	74.0	58.0	54.0	47.0
2nd	<i>Celtis mildbraedii</i>		<i>Klainedoxa gabonensis</i>	<i>Celtis mildbraedii</i>	<i>Celtis mildbraedii</i>	<i>Tectona grandis</i>	<i>Amphimas pterocarpoide</i>	<i>Celtis mildbraedii</i>
Percentage (%)	28.0		44.0	39.0	19.0	23.0	15.0	31.0

Factors Influencing the Preference for Fuelwood Species

Regarding the preference and choice of fuelwood for smoking of fish, respondents in the focus group discussion mentioned certain factors that influenced their choice of fuelwood. These factors included whether the wood was a hardwood or softwood. The preference was for hardwoods like *Klainedoxa gabonensis*, *Celtis Mildbraedii*, *Cistanthera papaverifera*, *Terminalia ivorensis*, and *Blighia sapida* as they burn slowly and lasted for longer hours in fire. The second factor was the Government of Ghana's prohibition from using mangroves for fish smoking and the subsequent education on the need to conserve mangroves for improved fishing. This factor actually pushed fish smokers to explore the use of other fuelwood from forest area. Hitherto, they mainly sought fuelwood from surrounding mangrove forests along the coast. Special qualities of specific fuelwoods also determine the extent of preference. According to the respondents a wood such as "*Vitellaria paradoxa*" has the ability of giving the smoked fish a glossy appearance and hence made the fish very attractive to consumers. There were some other woods like "*Celtis mildbraedii*" that had the ability of rapidly draining moisture from the fish. Aside the aesthetics quality of certain wood species, others like "*Morida lucida*" and "*Cola acuminata*" had some preservative qualities and thus prevented the fish from going bad early and others had the quality of emitting less smoke. Also, the colour of the fish after it was smoked mattered. Fuelwood species like "*Rhizophora mangle*" was preferred because, it made the fish very reddish and rendered it attractive. From Winneba, a respondent stated that:

“... not long ago, we were using mangroves to smoke our fish, but we got education that mangrove systems provide spawning grounds for fish therefore we should stop cutting them. Then we started using fuelwoods from forest and farms....”

In Apam, a respondent indicated various types of fuelwoods and reasons for their preference.

“.... we used to get Klainedoxa gabonensis, Celtis Mildbraedii, Cistanthera papaverifera, Terminalia ivorensis, and Blighia sapida. These are hardwood and can remove the moisture content from the fish. The softwoods usually do not last long in fire and the fish will not be cooked properly whilst the fuelwood is already consumed. Therefore, when using the hardwoods like Blighia sapida, you only need small quantity to smoke your fish....”

Another respondent from Abuesi stated that:

“... I sometimes prefer Sarcocephalus diderrichi or Amphimas pterocarpoide. These fuelwoods burn more thoroughly and don't emit a lot of smoke. Additionally, because of how dry and hot this fuelwood is, fish can easily dry out....”

At Woara Beba, respondents confirmed that one change they observed was the decrease rate of consumption of fuelwood because of the change in the oven type:

“... The changes in fuelwood types also have to do with consumption rate of fuelwood. The improved oven which has been developed consumes considerably less quantity of fuelwood. For instance, the Ahotor consumes less quantity of fuelwood as compared to the other oven types. The fuelwood types that we use have changed. We no longer use mangroves for smoking but use other fuelwood species within the community and also source some from outside the community....”

Table 12 displayed the list of notable fuelwood species used for fish smoking in the study communities and their respective scientific names.

Table 12: Notable Fuelwood Species Used for Fish Smoking in the Study Communities with their Respective Scientific Names

Common Name	Scientific Name
Esa	<i>Celtis mildbraedii</i>
Begye Woba	<i>Klainedoxa gabonensis</i>
Emire	<i>Terminalia ivorensis</i>
Cocoa	<i>Theobroma cacao</i>
Odanta	<i>Cistanthera papaverifera</i>
Light pole/Teak	<i>Tectona grandis</i>
Dahoma	<i>Piptadeniastrum africanum</i>
Rubber	<i>Hevea brasiliensis</i>
Ankyi	<i>Blighia sapida</i>
Koogyabena	<i>Rhizophora mangle</i>

Opepe	<i>Sarcocephalus diderrichii</i>
Yaya	<i>Amphimas pterocarpoide</i>
Okonkroma	<i>Morida lucida</i>
Neem	<i>Azadirachta indica</i>
Mango	<i>Magnifera indica</i>
Besedua	<i>Cola acuminates</i>
Nkudua	<i>Vitellaria paradoxa</i>
Nyamedua	<i>Alstonia boonei</i>
Duankor	<i>Avicennia germinans</i>
Funtum	<i>Funtumia elastica</i>
Onyina	<i>Ceiba pentandra</i>

Participants in focus group discussions were probed to name their preferred fuelwood species for fish smoking and the rationale for their preference. Table 13 summarises the responses of fish smokers in the study locations.

Table 13: Summary of Fuelwood Species for Fish Smoking and Reasons for Preference

Fuelwood Species	Reason for Preference	Notable Study Communities Using the Fuelwood
<i>Celtis mildbraedii</i>	Last longer in fire Ability to take the moisture out of the fish with ease. Produces less smoke. Perceived to have some	Winneba, Woara Beba, Apam, Abuesi Mumford,

	preservative functions against moulds, fungi, and other microbes	
<i>Klainedoxa gabonensis</i>	Gives the fish a reddish colour after smoking.	Winneba and Woara Beba
	Last longer in fire Produces hot flames. Fast smoking time or period Can generate charcoal for household use	
<i>Morida lucida</i>	Makes the fish very reddish.	Winneba, Apam, Mumford
	Retains the moisture in the fish	
<i>Terminalia ivorensis</i>	Makes the fish very dried. Preferred for smoking smaller fish types. Gives the fish a bright colour	Fairly used in all communities under study
<i>Azadirachta indica</i>	Gives a preservative function against moulds, fungi, and other microbes. Price is relatively cheaper. Readily Available throughout the year	Used by all communities under study
<i>Blighia sapida</i>	Can generates charcoal for household use. Last longer in fire	Winneba Mumford Apam Kesewokan
<i>Tectona grandis</i>	Hardwood and has some considerable weight.	Abuesi Kesewokan

	Last longer in fire	Shama Apo
	Readily available	
<i>Sarcocephalus diderrichii</i>	Last longer in fire	Fairly used in all
	Produces less smoke.	communities under
	Makes the smoke fish very shiny	study
<i>Rhizophora mangle</i>	Reddish in colour and makes the fish very reddish and attractive.	Shama Apo
	Preserves the fish against spoilage which extends the shelf life	
<i>Avicennia germinans</i>	Maintains the moisture in the fish.	Shama Apo
	Readily available in the community	Abuesi
	Price is relatively cheaper.	
	Preferred for smoking Tuna and other large pelagic.	

Table 14 show the results in the study communities regarding their preferences for different types of fuelwoods based on various criteria. For each community, the percentage of respondents who preferred a particular type of fuelwood was displayed based on the criteria listed in the first row of the table. For instance, in Winneba, 10% of respondents preferred fuelwood that lasted longer in fire, 1% preferred fuelwood that produced less smoke, 77% preferred fuelwood that enhanced the aesthetic value of smoked fish, 1% preferred fuelwood that was easy to ignite, and 1% preferred fuelwood that was readily available. In addition, 2% of respondents preferred fuelwood that produced hot flames, 8% preferred fuelwood that dried fish quickly. Similarly, for each of the other communities, the table showed the percentages of respondents who preferred each type of fuelwood based on the criteria listed. The table provided an overview of the different factors that influenced the respondent's preferences for different type of fuelwood species in different communities.

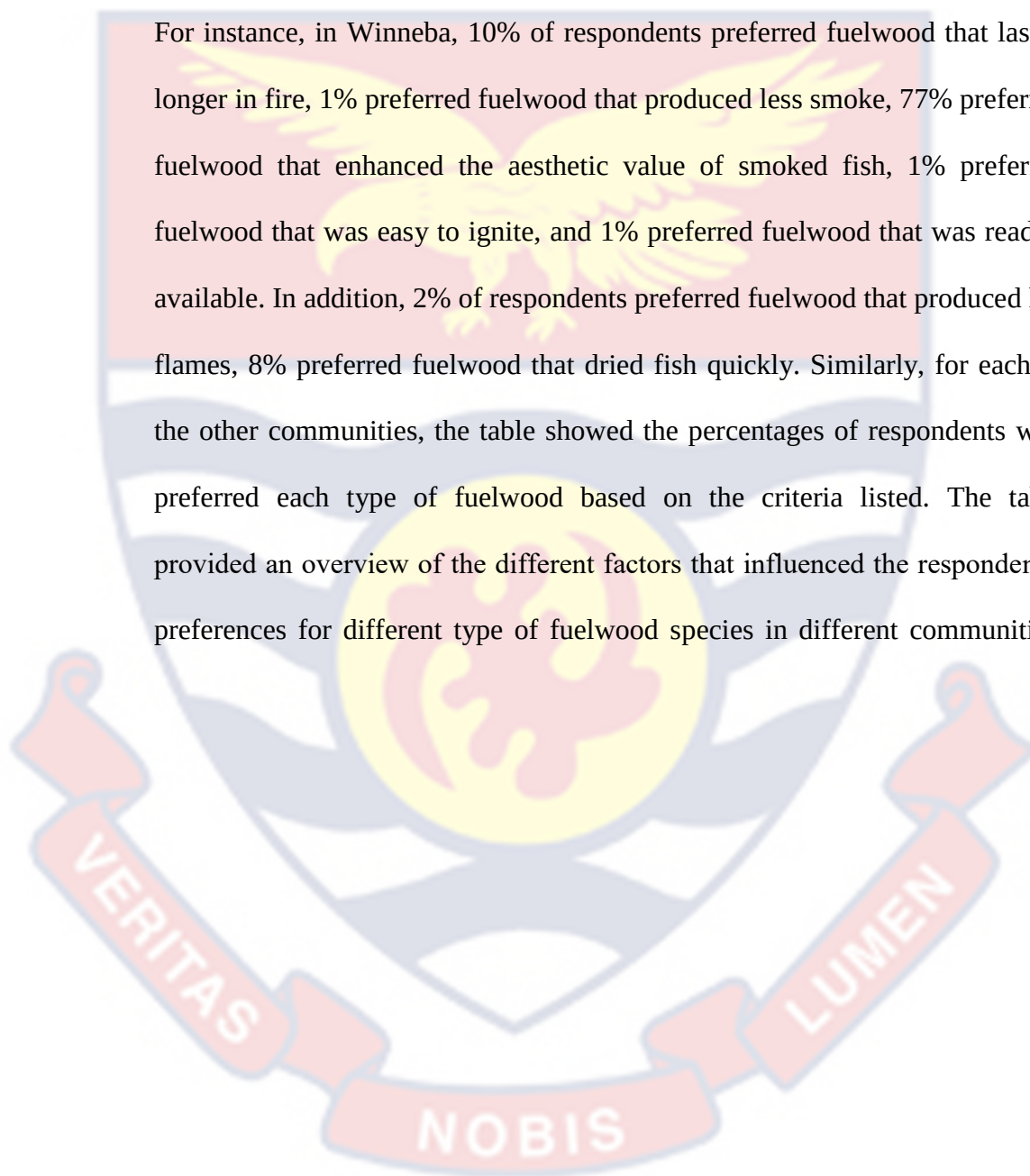


Table 14: Reasons for Fuelwood Preference in the study Communities

Study Communities							
N = 506							
	Winneba %	Woara Beba %	Apam %	Mumford %	Kesewokan %	Abuesi %	Shama Apo %
Fuelwood							
Characteristic							
Last Longer in Fire	10.0	17.0	6.00	13.0	30.0	26.0	12.0
Produces Less Smoke	1.00	0.00	3.00	0.00	5.00	4.00	0.00
Aesthetic of the Smoked Fish	77.0	44.0	60.0	69.0	41.0	47.0	45.0
Easiness of Flammability	1.00	6.00	1.00	0.00	0.00	0.00	0.00
Availability	1.00	6.00	4.00	0.00	4.00	0.00	2.00
Hot Flames	2.00	0.00	1.00	1.00	6.00	7.00	8.00
Fast Drying of Fish	8.00	29.0	22.0	17.0	14.0	16.0	33.0
Affordability	0.00	0.00	3.00	0.00	1.00	0.00	0.00

Reasons for Mixing Different Fuelwood Species for Fish Smoking

The study revealed that some respondents mixed fuelwood products during the process of smoking. According to 55% of the respondents (Figure 15), the main reason for doing this is to achieve easier and higher flammability. The second most common reason is the unavailability of preferred fuelwood, (24%). Combining different fuelwood characteristics is the third most common reason for mixing fuelwood, indicated by 9% of the respondents. Finally, 8% of respondents indicated that they mixed different types of fuelwood species to achieve a better appearance of fish.

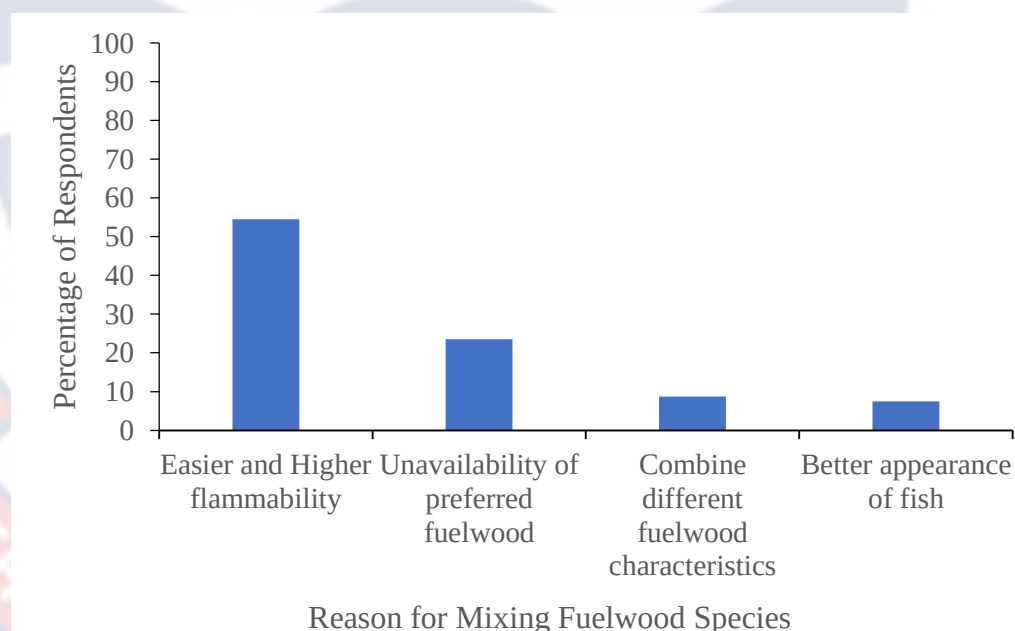


Figure 15: Reasons for mixing different fuelwood species for fish smoking.

Fuelwood Consumption by the Different Fish Smoking Ovens

Table 15 depicts the quantity of fuelwood required by the three fish smoking ovens under study. The mean quantity of fuelwood required by TMO to smoke 100 kg of fish was (mean = 58.6, std = 8.15, $n = 134$). The average

quantities of fuelwood required by the Chorkor and Ahotor Ovens to smoke 100 kg of fish were (mean = 62.5, std = 5.75, $n = 506$) and (mean = 33.8, std = 3.92, $n = 6$) respectively.

Table 15: Summary of Quantity of Fuelwood Used by the Different Oven

Quantity of fuelwood used by different oven types to smoke 100 kg of fish	N	Minimum Statistic	Maximum Statistic	Sum Statistic	Mean Statistic	Std. Error	Std. Deviation
Traditional Oven	134	45.0	78.0	7863	58.6	0.704	8.15
Chorkor Oven	506	50.0	80.0	31629	62.5	0.256	5.75
Ahotor Oven	6.00	28.0	38.0	203	33.8	1.60	3.92

Fuelwood Consumption Required by the Various Fish Smoking Ovens by Study Communities

Table 16 shows the data on the quantity of fuelwood required by the different types of fish smoking ovens to smoke 100 kg of fish across the study communities. The table includes the total number of respondents who had access to the ovens (N) and the Standard deviations. For Winneba, the mean quantity of fuelwood required to smoke 100 kg using the TMO and chorkor oven were (mean = 54.3, std = 5.65, $n = 41.0$) and (mean = 60.7, std = 6.00, $n = 102$). Respondents engaged in Winneba were not in possession of the Ahotor oven. For Woara Beba, the mean quantity of fuelwood required to smoke 100 kg of fish using TMO,

chorkor and Ahotor ovens were (mean = 66.8, std = 5.39, $n = 13.0$), (mean = 63.6, std = 6.43, $n = 18.0$), and (mean = 34.0, std = 5.66, $n = 2.00$). For Apam, the mean quantity of fuelwood required to smoke 100 kg of fish using the TMO, Chorkor and Ahotor ovens were (mean = 60.0, std 0.00, $n = 5.00$), (mean = 63.6, std = 5.09, $n = 78.0$) and (mean = 36.0, std = 0.00, $n = 1.00$) respectively. Similarly for Mumford, the mean quantity of fuelwood required to smoke 100 kg of fish using the TMO, Chorkor and Ahotor ovens were (mean = 60.4, std = 8.30, $n = 14.0$), (mean = 62.9, std = 5.68, $n = 99.0$) and (mean = 31.5, std = 4.95, $n = 2.00$) respectively. For Kesewokan, the mean quantity of fuelwood required to smoke 100 kg of fish using the three different ovens were (mean = 70.0 std = 0.00, $n = 1.00$) for TMO, (mean = 63.7, std = 6.45, $n = 86.0$) for Chorkor oven and (mean = 36.0, std = 0.00, $n = 1$) for Ahotor oven. For Abuesi the mean quantity of fuelwood required to smoke 100 kg of fish using the TMO and Chorkor ovens were (mean = 54.7, std = 7.72, $n = 13.0$) and (mean = 63.7, std = 6.45, $n = 86.0$). For Shama Apo community the mean quantity of fuelwood required to smoke 100 kg of fish using the TMO were (mean = 60.5, std = 8.61, $n = 47.0$) and (mean = 62.5, std = 5.58, $n = 49.0$). Respondents engaged for the survey in Abuesi and Shama Apo were not in possession of the Ahotor oven.

Table 16: Fuelwood Consumption Required by the Different Fish Smoking Ovens According to Study Communities

Community	Quantity of fuelwood required to smoke 100 kg of fish			
		TMO	Chorkor oven	Ahotor oven
Winneba	N	41.0	102	*
	Mean $\pm$ SD	54.3 $\pm$ 5.65	60.7 $\pm$ 6.00	-
Woara Beba	N	13.0	18.0	2.00
	Mean $\pm$ SD	66.8 $\pm$ 5.39	63.6 $\pm$ 6.43	34.0 $\pm$ 5.66
Apam	N	5.00	78.0	1.00
	Mean $\pm$ SD	60.0 $\pm$ 0.00	63.6 $\pm$ 5.09	36.0 $\pm$ 0.00
Mumford	N	14.0	99.0	2.00
	Mean $\pm$ SD	60.4 $\pm$ 8.30	62.9 $\pm$ 5.68	31.5 $\pm$ 4.95
Kesewokan	N	1.00	86.0	1
	Mean $\pm$ SD	70.0 $\pm$ 0.00	63.7 $\pm$ 6.45	36.0 $\pm$ 0.00
Abuesi	N	13.0	74.0	*
	Mean $\pm$ SD	54.7 $\pm$ 7.72	61.6 $\pm$ 4.60	-
Shama Apo	N	47.0	49.0	*
	Mean $\pm$ SD	60.5 $\pm$ 8.61	62.5 $\pm$ 5.58	-

Table 17 shows the output of the ANOVA used to test the significant difference between the quantities of fuelwood used by the three different oven types across the three districts. The test results show that there was no statistical difference in the quantity of fuelwood required to smoke 100 kg of fish using the Ahotor oven, ($F = 0.240$, $P = 0.864$). However, there was a statistical difference in the quantity of fuelwood used with respect to the TMO and Chorkor oven ($F = 6.975$, $P = 0.000$) and ($F = 3.289$, $P = 0.003$) respectively.

**Table 17: ANOVA Test for Quantity of Fuelwood Required by the
Different Oven Types by Study Communities**

			Sum of Squares	Df	Mean Square	F	Sig.
Fuelwood required to smoke 100 kg of fish (TMO)	Between Groups	Combined	2190	6.00	365	6.98	0.00
	Within Groups		6640	127	52.3		
	Total		8830	133			
Fuelwood required to smoke 100 kg of fish (Chorkor)	Between Groups	Combined	636	6.00	106	3.29	0.003
	Within Groups		16100	499	32.2		
	Total		16700	505			
Fuelwood required to smoke 100 kg of fish (Ahotor)	Between Groups	Combined	20.3	3.00	6.78	0.240	0.864
	Within Groups		56.5	2.00	28.3		
	Total		76.8	5.00			

Quantity of Fuelwood Required to Smoke Different Fish Types

Table 18 shows the different quantities of fuelwood necessary to smoke various species of fish. The data revealed that smoking a specific type of fish necessitates the use of the appropriate fuelwood. The average quantity of fuelwood required to smoke 100 kg of large pelagic fish such as tuna was (mean = 57.3, std = 8.04, $n = 506$) and the quantity of fuelwood required to smoke 100 kg of fish such as anchovies was (mean = 62.4, std = 5.92, $n = 506$).

Table 18: Summary of Quantity of Fuelwood Used to Smoke Different Type of Fish

	N	Minimum	Maximum	Sum	Mean	SE	SD
Quantity of fuelwood used to smoke 100 kg of large pelagic fishes.	506	40.0	78.0	28986	57.3	0.36	8.04
Quantity of fuelwood used to smoke 100 kg of small pelagic fishes.	506	50.0	80.0	31597	62.4	0.26	5.92

Table 19 shows the output of the ANOVA analysis to test whether there was a significant difference between the means of the quantities of fuelwood required to smoke different fish species across the communities under study. The findings of the study revealed that there were significant differences in the quantities of fuelwood required to smoke large pelagic fish and small pelagic fish ($F = 10.3$, $p < 0.05$) and ($F = 6.69$, $p < 0.05$), respectively.

Table 19: ANOVA Test for Quantity of Fuelwood Required to Smoke**Different Fish Types by Study Communities**

			Sum of Squares	Df	Mean Square	F	Sig
Quantity of fuelwood required to smoke large pelagic fish * communities	Between Groups	(Combined)	1280	2.00	641	10.3	0.00
	Within Groups		31300	503	62.3		
	Total		32600	505			
Quantity of fuelwood required to smoke small pelagic fish * communities	Between Groups	(Combined)	459	2.00	229	6.69	0.00
	Within Groups		17200	503	34.3		
	Total		17700	505			

Fuelwood Consumption during the Major and Minor Fishing Seasons

Table 20 shows the summary of the average number of days fish smokers smoked fish in a week during the major and minor fishing seasons, the quantities of fish smoked during the minor and major seasons and the average quantities of fuelwood used during the major and minor fishing seasons. The study discovered that the mean observation of times fish is smoked in the week during the minor season was (mean = 2.42, std = 0.97, $n = 506$) and the major season (mean = 5.03, std = 1.17, $n = 506$). During the minor and major fishing seasons, the mean quantities of fish smoked in a week were (mean = 753, std = 1101, $n = 506$) and (mean = 2300, std = 3130, $n = 506$) respectively. Similarly, the mean quantities of fuelwood used during the minor and major fishing seasons were (mean = 473, std = 711, $n = 506$) and (mean = 1444, std = 1990, $n = 506$) respectively.

Table 20: Summary of Average Fish Smoking Times, Quantity of Fish Smoked, and Quantity of Fuelwood Used During the Major and Minor Seasons

	N	Minimum	Maximum	Sum	Mean	SE	SD
Number of times you smoke fish in a Week during the minor Season	506	1.00	6.00	1225	2.42	0.43	0.97
Number of times you smoke fish in a Week during the major Season	506	1.00	7.00	2546	5.03	0.52	1.17
Quantity of fish (kg) smoked in a week during the minor season	506	100	15000	381100	753	49.2	1101
Quantity of fish (kg) smoked in a week during the major season	506	100	36000	1161700	2300	139	3130
Quantity of fuelwood (kg) used during the minor season	506	50.0	9750	239287	473	31.6	711
Quantity of fuelwood (kg) used during the major season	506	70.0	22680	730499	1444	88.6	1990

Annual Fuelwood Consumption in the Study Locations

The annual fuelwood consumption for fish smoking in the study areas are shown in Table 21. The estimated annual fuelwood usage was 183,880,020 kg (183,880 MT). The estimation was made using values from August, September, November, and December as the major fishing seasons, and January, February, March, October, April, May, and June as the minor seasons. July was excluded from the calculations because it is the period for the closed season and hence no fishing activity was observed.

Table 21: Annual Fuelwood Consumption in the Study Locations

Fishing Seasons	Weekly Fuelwood Consumption (kg)	Mean Weekly Fuelwood Consumption (kg)	Number of Weeks in a Fishing Season	Total Fuelwood Used (kg)
Minor	239287	473	28.0	11687984
Major	730499	1440	16.0	6700036
Total				18,388,020

Amount of Greenhouse Gases Generated from Fish Smoking

Table 22 shows the amount of GHGs measured in metric tonnes (MT) from smoking in this study. The survey indicated that about 18, 880 Metric tonnes (MT) of fuelwood is used for fish smoking annually. The recorded emission from the combustion of fuelwood were 8,260 MT of Carbon, 30, 300 MT of CO₂, 132 MT of CH₄ and 0.910 MT of N₂O.

Table 22: Amount of CO₂, CH₄ and N₂O Measured (MT) from Annual Fish Smoking in the Study Communities

Parameter	Value (Metric Tonnes)
Fuelwood consumption per year (MT)	18,880
Greenhouse gas emissions	
Carbon content in biomass (MT Ct)	9,170
Carbon dioxide released (MT C)	8,260
Carbon dioxide emissions from burning (MT CO ₂)	30,300
Non-Carbon dioxide emissions	
CH ₄ emissions (MT CH ₄)	132
N ₂ O emissions (MT N ₂ O)	0.91

Concentrations of Greenhouse Gases Emitted by the Different Fish Smoking Ovens and Specific Fuelwood Species

Tables 23 and 24 show the summary of the mean concentrations (ppm), and standard deviation of CO₂ and CH₄ emissions, temperature (°C), and percentage moisture content (%) during the combustion of fuelwood use for TMO and Chorkor oven with the most preferred and frequently used fuelwood species. Each observation is labelled with a code (e.g., TC1, CK1) to identify the specific combinations of oven type and fuelwood species. For CO₂ emissions, the mean concentration was highest in TK1, which used *Klainedoxa gabonensis* in a TMO (mean = 1799 ppm, std = 143, *n* = 714), and lowest in CC2, which used *Celtis mildbraedii* in a Chorkor oven (mean = 139 ppm, std 7.32, *n* = 3250). For CH₄, the mean concentration of emissions varied significantly across each observation. The highest mean concentration of

methane was recorded by TK1 (mean = 4037 ppm, std = 156, $n = 714$), while the lowest was recorded in CC3 (mean = 2922 ppm, std = 703, $n = 4856$). The temperature and moisture content conditions varied across the observations, potentially contributing to the differences in emission of CO_2 and CH_4 concentrations.



**Table 23: Mean, Standard Deviation of Carbon Dioxide (ppm),
Temperature (°C), and Percentage Moisture Content (%) in
Fuelwood Species**

No of Observations (Codes)	Oven Type/Fuelwood Species	Count (N)	Mean Conc. (ppm)	Std. Deviation	Temperature (°C)	Moisture Content in Fuelwood (%)
TC1	TMO/ <i>Celtis mildbraedii</i>	4035	231	9.65	36.8	27.0
TC2	TMO/ <i>Celtis mildbraedii</i>	2684	539	37.5	34.3	22.0
TC3	TMO/ <i>Celtis mildbraedii</i>	3233	372	15.8	35.4	18.0
TK1	TMO/ <i>Klainedoxa gabonensis</i>	714	1799	143	36.5	24.0
TK2	TMO/ <i>Klainedoxa gabonensis</i>	2927	992	170	36.0	27.0
CC1	Chorkor/ <i>Celtis mildbraedii</i>	4455	468	209	34.4	25.0
CC2	Chorkor/ <i>Celtis mildbraedii</i>	3250	139	7.32	37.4	22.0
CC3	Chorkor/ <i>Celtis mildbraedii</i>	4856	373	10.7	35.9	19.0
CK1	Chorkor/ <i>Klainedoxa gabonensis</i>	3997	311	14.5	36.1	20.0
CK2	Chorkor/ <i>Klainedoxa gabonensis</i>	1837	679	48.8	36.3	22.0
CK3	Chorkor/ <i>Klainedoxa gabonensis</i>	3472	868	78.3	34.8	18.0
CK4	Chorkor/ <i>Klainedoxa gabonensis</i>	3477	467	26.9	33.5	24.0

**Table 24: Mean, Standard Deviation Concentration of Methane (ppm),
Temperature (°C), and Moisture Content (%) in Fuelwood
Species.**

No of Observations (Codes)	Oven Type/Fuelwood Species	Count (N)	Mean Conc. (ppm)	Std. Deviation	Temperature (°C)	Moisture Content in Fuelwood (%)
TC1	TMO/ <i>Celtis mildbraedii</i>	4035	3875	382	36.8	27.0
TC2	TMO/ <i>Celtis mildbraedii</i>	2684	3868	315	34.3	22.0
TC3	TMO/ <i>Celtis mildbraedii</i>	3233	4044	168	35.4	18.0
TK1	TMO/ <i>Klainedoxa gabonensis</i>	714	4037	156	36.5	24.0
TK2	TMO/ <i>Klainedoxa gabonensis</i>	2927	3671	351	36.0	27.0
CC1	Chorkor/ <i>Celtis mildbraedii</i>	4455	3016	434	34.4	25.0
CC2	Chorkor/ <i>Celtis mildbraedii</i>	3250	3687	548	37.4	22.0
CC3	Chorkor/ <i>Celtis mildbraedii</i>	4856	2922	703	35.9	19.0
CK1	Chorkor/ <i>Klainedoxa gabonensis</i>	3997	3723	272	36.1	20.0
CK2	Chorkor/ <i>Klainedoxa gabonensis</i>	1837	2946	430	36.3	22.0
CK3	Chorkor/ <i>Klainedoxa gabonensis</i>	3472	3558	412	34.8	18.0
CK4	Chorkor/ <i>Klainedoxa gabonensis</i>	3477	3648	605	33.5	24.0

Figure 16 shows the mean concentrations and standard deviations of CO₂ measured for different oven types and fuelwood species. The mean concentration (ppm) of CO₂ for TMO/ *Celtis mildbraedii* (231 ± 9.65 , $n = 4035$); TMO/*Klainedoxa gabonensis* (1799 ± 143 , $n = 714$); Chorkor/*Celtis mildbraedii* (468 ± 209 , $n = 4455$), Chorkor/*Klainedoxa gabonensis* (311 ± 14.5 , $n = 3997$), Chorkor/*Klainedoxa gabonensis* (868 ± 78.3 , $n = 3472$) were recorded as shown in Table 23. A comparison of the mean concentrations of oven/fuelwood indicates that TMO/*Klainedoxa gabonensis* had the highest concentration (1396 ± 655) ppm and the combination of Chorkor/*Celtis mildbraedii* had the lowest concentration with 327 ± 150 ppm. Figure 17 shows a visual comparison of the mean concentrations and standard deviations across different oven types (TMO and Chorkor) and fuelwood species (*Celtis mildbraedii* and *Klainedoxa gabonensis*). These findings highlight the significant influence that the choice of oven type and fuelwood species can have on the resulting concentration.

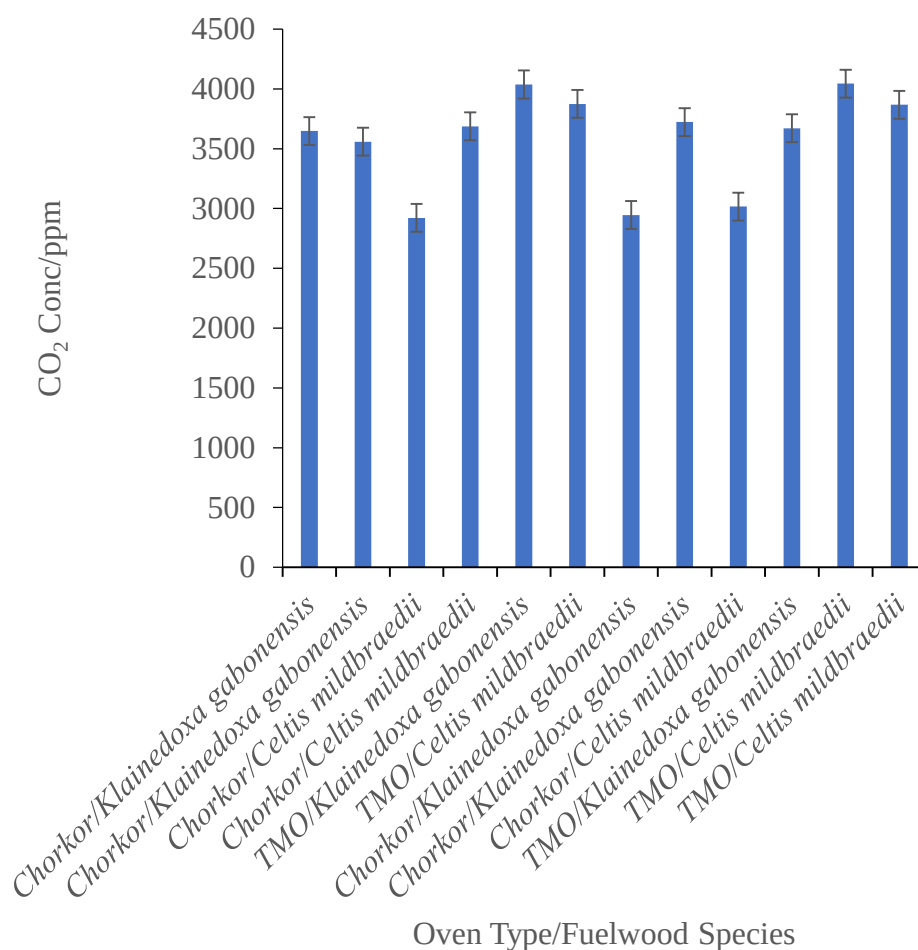


Figure 16: Mean and standard deviation concentrations of CO₂ of different oven type and fuelwood species.

Figure 17 shows the mean concentrations of CH₄ using different oven types and fuelwood species. The mean concentrations (ppm) of CH₄ for TMO/*Celtis mildbraedii* (3868 ± 168 , $n = 2684$) and (3875 ± 382 , $n = 4035$). In the case of TMO/*Klainedoxa gabonensis* the recorded mean concentrations were (3671 ± 351 , $n = 2927$) and (4037 ± 156 , $n = 714$). For Chorkor/*Celtis mildbraedii* the values were (2922 ± 703 , $n = 4856$) and (3687 ± 548 , $n = 3250$) were recorded. Similarly, for Chorkor/*Klainedoxa gabonensis* the mean concentrations (3558 ± 412 , $n = 3472$) and (3648 ± 605 , $n = 3477$) were measured. The analysis of mean concentrations for the different combinations of oven/fuelwood revealed that TMO/*Celtis mildbraedii* had the highest

concentration with a mean concentration of 3929 ± 109 ppm. On the other hand, the combination of Chorkor/ *Celtis mildbraedii* had the lowest concentration with a mean concentration of 3208 ± 152 ppm.

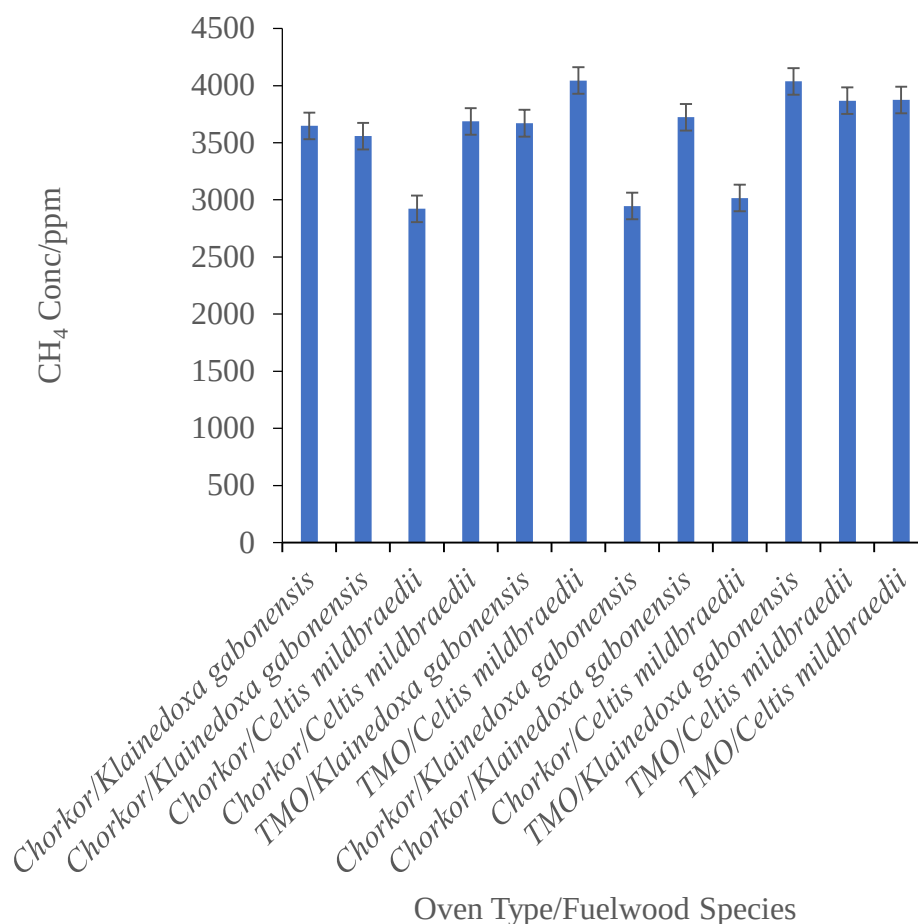


Figure 17: Mean and standard deviation concentrations of CH₄ of different oven type and fuelwood species

CHAPTER FIVE

DISCUSSION

This chapter discusses the findings of the study with reference to existing literature. It explains the characteristics of the respondents in the study locations. The chapter also discusses the efficiencies of the three fish smoking ovens under study, the preference of specific fuelwood species and the amounts of GHGs released from fish smoking.

Characteristics of Respondents in Fish Smoking in the Study Locations

A total of five hundred and six fish smokers from Winneba, Woara Beba, Apam, Mumford, Abuesi, Kesewokan and Shama Apo were drawn to participate in this study. The study shows that females are the predominant group, constituting 99% of the participants. In Ghana, fish smoking is a gender centered occupation carried out mainly by women in coastal communities as an important avenue for employment, revenue generation and food security (Asiedu, Failler & Beygens, 2018; Odotei, 2002). This result is consistent with the fact that women in many coastal areas in Africa are often involved in fish processing activities including smoking, drying, frying, salting etc. activities as part of their livelihoods. Studies by Adegoye (2022) in Nigeria found that women constituted the majority of fish processors and traders in coastal communities. Also, according to a recent report, it is estimated that women comprise approximately 50% of the total workforce engaged in both primary and secondary sectors of the fisheries industry worldwide. This finding highlights the significant contribution of women to the fisheries sector and

underscores their role in various aspects of fishing activities and related enterprises (Monfort, 2015).

With the majority of respondents spanning the age range of 40 to 59 years across most of the communities. The finding suggests that middle-aged individuals are more likely to be involved in fish smoking activities. This is consistent with studies that have shown that fish processing and marketing are often dominated by middle-aged women in many African countries (Adegoye, 2022). Economically active women are therefore involved in fish processing in the study areas and by extension, the entire country.

Since the findings indicated that between 43% and 72% of participants had no formal education. It implies that fish smoking activities in Ghana may be the preserve of women with little or no formal education. However, it is important to note that education could potentially affect the standard of fish smoking practices, particularly in terms of hygiene and safety, which can affect the marketability of the smoked fish. Literacy rates in coastal communities in Ghana and in the sub-region are often low, and this remains a severe concern (Amadu, Armah & Aheto, 2021).

Most participants had households between 1 and 5 and 6 and 10 members, on average, across all communities. This result raises the possibility that family-based businesses are widespread in the fish smoking industry, with family members frequently engaged in various stages of fish processing, including smoking, and marketing. Comparing the relationship between household size and scale of fish smoking, the trend observed indicate that as household size increases, the percentage of households engaged in full-time fish smoking activities increases, while the percentage of households engaged

in part-time fish smoking activities decreases. This relationship may be explained by the economies of scale that come with larger households, where the fixed costs associated with setting up and maintaining a fish smoking operation can be spread out among more people, making full-time smoking a more viable alternative. Additionally, larger households may have greater access to the necessary resources, such as space and equipment, needed to undertake fish smoking activities. However, it is important to note that the data only shows a correlation between household size and scale of fish smoking and does not necessarily imply causation. Further research is needed to explore the causal mechanisms behind this relationship.

In terms of marital status, most participants were married, and these ranges from 51% to 69%. The findings from Nti, Plahar and Larweh (2002) support the current result by indicating that a significant majority of fish processors in Ghana are married. Several studies have confirmed that marriage holds significant importance for women involved in fish processing. Being married provides these women with a reliable connection to fishermen or fishing communities, ensuring a consistent supply of fish for their processing activities (Ameyaw, Breckwoldt, Reuter & Aheto 2020; Britwum, 2009).

The insight gained from this correlation sheds light on the social dynamics within the fish processing industry in Ghana. It may imply that the occupation of fish processing is not only influenced by economic factors but also by cultural and social aspects such as marriage and family obligations. Understanding this aspect is crucial for developing targeted interventions and policies that support the needs and well-being of married fish processors and their families. Additionally, the correlation with marital status provides

insights into gender roles and responsibilities within the fish processing industry. It reinforces the significance of women's involvement as fish processors and their dual roles as both income earners and caretakers within their households. This reiterates the need for gender-responsive approaches that empower women in the industry, addressing their specific challenges and promoting gender equality and social inclusion.

Regarding ethnicity, the majority of participants across all communities were from the Fante ethnic group, which is a dominant ethnic group in the western and central coastal areas in Ghana. For religion, most participants across all communities were Christians. This finding is consistent with the fact that Christianity is the dominant religion in many coastal areas in Ghana.

Finally, the data shows that most participants (82% to 94%) across the study communities were involved in fish smoking activities on a full-time basis. The aforementioned finding aligns with the research conducted by Alabi et al. (2020) who observed that the majority of individuals involved in fish processing regarded it as their main occupation and relied on it as their primary source of income. This observation highlights the significant role played by fish processing with regards to livelihoods and emphasises its pivotal role within the occupation choices of those involved in the industry.

In effect, the demographic characteristics of individuals in the different study communities in Ghana may provide insights into the factors that could influence fish smoking practices, particularly in coastal areas of Ghana and Africa. The findings suggest that gender, age, marital status, household size, and participation in fish smoking activities on a full-time basis may be

important factors in determining participation in fish smoking activities, while education, and religion may not be significant factors.

Preference to Fish Smoking Oven Types

It can be observed that the chorkor oven is the most preferred oven, with the highest percentage of usage among the respondents. According to Nunoo, Tornyeviadzi, Asamoah and Addo (2019), it has been firmly established that the Chorkor oven stands as the predominant traditional fish smoking oven employed in Ghana for the smoking of fish. This finding not only highlights the prevalence of the Chorkor oven but also underscores its status as the preferred choice among traditional fish smoking techniques in the country. Such insight sheds light on the cultural significance and practical advantages associated with the utilisation of the Chorkor oven within the Ghanaian context. This suggests that the majority of fish processors in Ghana still prefer and use traditional methods for fish smoking. However, it is important to note that other types of ovens such as the TMO and Ahotor ovens have some level of preference in some communities.

Report from Forkour, Peprah and Alhassan (2018) indicate that, fish processors expressed their dissatisfaction with the TMO due to the labour-intensive process involved in using clean broom sticks to stack the fish in distinct layers within the oven. Consequently, they predominantly opted for the Chorkor oven as an alternative. The main reasons for this shift was the cumbersome nature of the TMO, which required additional effort and time for layering the fish.

In the Western Region of Ghana, fish processors who use the Chorkor oven express a clear preference for it over the TMO. Their primary reason for

preferring the Chorkor oven is its ability to produce a more uniformly smoked product (Gordon, Pulis, & Owusu-Adjei, 2011).

The distribution of ovens across the communities is also notable. In 2015, an enumeration of traditional fish smoking ovens in Ghana revealed that there are around 120,000 Chorkor and traditional smoking ovens in operation (Okyere-Nyarko, Aziebor, & Robinson, 2015). In this study, the community of Winneba had the highest number of Chorkor ovens and TMO. Shama Apo community, on the other hand, had the lowest number of ovens overall, with only Chorkor ovens and no Ahotor ovens. It is worthy of note that some communities, such as Apam and Abuesi, do not use TMO, which suggests that Chorkor ovens have largely replaced the TMO in these communities. In all the locations studied, the prevalence of traditional ovens significantly overshadowed the number of improved ovens. The adoption of improved ovens was relatively low compared to their traditional counterparts. This observation highlights the persistent dominance of traditional ovens in fish processing in Ghana. Despite the purported advantages and efforts to promote improved ovens, their acceptance and widespread use have remained limited.

In the study conducted by Etsra and Avega (2018) it was found that the widespread adoption and usage of improved ovens, such as the Ahotor oven, have faced significant challenges despite their perceived benefits. These challenges primarily stem from weaknesses in the upstream segment of the value chain, which encompass various aspects such as business models, access to financing, market intelligence, consumer awareness, and regulatory frameworks. The research emphasises that in order to achieve the desired scale of adoption, there is the need for deliberate and transformative shift in the

approach taken. Specifically, it is suggested that moving away from a socially oriented strategy, which often involves the free distribution of stoves and subsidizing their costs, towards a commercially viable approach is crucial.

This highlights the need for a comprehensive and sustainable solution that takes into account the various factors influencing the adoption and usage of improved ovens. Merely providing free or subsidised stoves does not address the underlying challenges and may not lead to long-term behavioural change or market development. Instead, a commercially viable approach recognises the importance of creating a viable business model that ensures the financial sustainability of improved oven initiatives.

The preference for fish smoking ovens in the majority of communities appears to be heavily influenced by efficiency, as assessed by fuel consumption and time. Mumford and Apam, for instance, have the highest ratings in this aspect, indicating that the bases for preferring specific oven types are highly dependent on its efficiency. On the other hand, Shama Apo has a low rating in terms of efficiency, meaning that respondents base their reason of preference on other factors.

Literature indicates that traditional cookstoves exhibit low efficiency levels, characterised by high fuelwood consumption and slower cooking times. In contrast, improved cookstoves are recognised for their high efficiency, resulting in reduced fuel consumption. This observation underscores the importance of transitioning from traditional to improved cookstoves as a means to enhance energy efficiency and address fuel-related challenges (Coffey et al., 2017; Commeh et al., 2017; Didier et al., 2017; Kucerova, Banout, Lojka, & Polesny, 2016).

The findings of the study indicate that traditional ovens consume a higher amount of fuelwood compared to improved ovens. However, an observation was made regarding the traditional oven's relatively faster cooking time, which contributed to its preference among fish processors. Additionally, it was noted that a portion of fish processors lacked firsthand experience with improved ovens and relied solely on hearsay information. Consequently, they were unable to fully comprehend the efficiencies and benefits offered by the improved ovens. These findings shed light on the complex dynamics influencing the adoption of improved ovens within the fish processing industry. While improved ovens are recognised for their fuel efficiency, the allure of faster cooking times associated with traditional ovens cannot be underestimated. Therefore, it is imperative not to consider only the quantitative aspects, such as fuel consumption, but also the qualitative factors that impact user preferences and satisfaction.

Traditional stoves were deemed less desirable compared to alternative stove options. Households prioritised cooking efficiency, emphasising features such as large cooking capacity and rapid heat generation, which are inherent characteristics of traditional open-fire stoves. However, the reduction of smoke emissions was highly valued, surpassing other factors like fuel cost and availability. This strong preference to minimize exposure to smoke may contribute significantly to the dissatisfaction expressed towards the stove they used most frequently (Hooper et al., 2018).

The preference for fish smoking ovens is influenced by other key factors, including convenience, aesthetic appeal, longevity, and cost considerations. These factors collectively shape the decision-making process

and highlight the multifaceted nature of choosing an appropriate oven for fish smoking. Convenience emerges as a crucial aspect in the preference for fish smoking ovens. Users highly value ovens that offer ease of use and require minimal effort to smoke fish. The emphasis on convenience reflects the practicality and user-friendliness of an oven, enabling fish processors to streamline their smoking operations and enhance overall productivity. In addition to convenience, the aesthetic of the smoked fish holds significant sway over oven preference. The visual appeal of the final product plays a pivotal role in consumer satisfaction. Ovens that consistently produce visually appealing smoked fish tend to garner higher preference ratings, indicating the significance of the sensory experience and presentation of the end result.

According to a study conducted by Bomfeh (2021), the preference of the Chorkor oven is evident, as it offers various benefits such as its ease of use, user-friendliness, and time-saving features. This results in a notable reduction in labour demands by about 30% and a corresponding decrease in the consumption of firewood. The study further highlights the significant impact of the Chorkor oven on the production of smoked fish, as it boasts a remarkable capacity to smoke approximately 200 kg of fresh fish at a go, which is roughly ten times the capacity of traditional mud oven and the Ahotor oven. These findings emphasise the transformative potential of the Chorkor oven in improving efficiency and enhancing the quality of smoked fish production.

In a similar research conducted to evaluate the preferences for cookstoves in Madagascar, it was found that traditional cookstoves were predominantly used and widely present in households. When considering

cookstove preference, factors such as cooking time, fuel efficiency, and the amount of smoke produced were frequently cited by respondents as major considerations (Blanco et al., 2019).

Bolorunduro, Adesehinwa and Ayanda (2005) states that the technical complexity and operational difficulties of improved ovens is another challenge that affects their adoption. Users may find it difficult to understand and operate the advanced features and functionalities of these ovens. This lack of technical knowledge and skills can discourage potential users from embracing the improved technologies, as they may prefer to stick with familiar and easier-to-use traditional ovens.

Moreover, the longevity and cost of the oven strongly influence preference. Fish processors value ovens that exhibit durability and withstand long-term use. Ovens with extended lifespans ensure reliability and cost-effectiveness by minimizing the need for frequent repairs or replacements.

In a research study aimed at evaluating the cost-effectiveness of different fish smoking ovens in Ghana, it was found that the traditional oven had an approximate cost of GHS 200 (US\$ 39), whereas the Chorkor and Ahotor ovens were priced at around GHS 400 (US\$ 77) and GHS 1768 (US\$ 340), respectively (Owusu, 2019). Another study focusing on the comparison of fish smoking oven costs in Ghana reported an estimated price of GHS 1200 (US\$ 315) for the Chorkor oven (Entee, 2015). These findings highlight the varying cost ranges associated with different types of fish smoking ovens, emphasising the significant disparity between the traditional and improved oven options in terms of financial investment. Such insights contribute to the understanding of

the economic considerations and affordability factors that influence the choice of fish processors when selecting an appropriate smoking oven.

When examining the influence of educational attainment on oven preference, it is evident that individuals with little or no formal education lean towards the Chorkor oven. Conversely, those with junior high school/middle school and senior high school education tend to favor the traditional mud oven and Ahotor oven. However, the disparity in oven preference based on educational attainment is not particularly significant. This suggests that factors beyond education play a more substantial role in shaping oven preferences among fish processors.

In terms of household size, the preference for the Chorkor oven remains consistent across all household sizes. This indicates that the convenience and efficiency offered by the Chorkor oven are universally appreciated, regardless of the number of individuals in the household. The consistent preference for the Chorkor oven suggests its versatility and adaptability to meet the needs of different-sized households.

Considering the scale of fish smoking, those engaged in full-time fish smoking activities tend to gravitate towards the Chorkor oven. On the other hand, individuals who smoke fish part-time lean towards the traditional mud oven. This indicates that the Chorkor oven's efficiency and capacity are particularly advantageous for those involved in continuous and extensive fish smoking operations. Meanwhile, the traditional mud oven may suffice for occasional or smaller-scale fish smoking activities. Lastly, the type of fish being smoked also affect oven preference. Those who primarily smoke fresh fish show a preference for the Chorkor oven, which aligns with the oven's

ability to handle larger quantities of fresh fish efficiently. In contrast, individuals who smoke both fresh and frozen fish tend to prefer the traditional mud oven. This distinction suggests that different ovens may be better suited for specific fish preservation methods, emphasising the importance of considering the desired outcome and characteristics of the fish being smoked.

Acquisition and Complementary Usage of Fish Smoking Ovens

The data shows that most fish smoking ovens in these communities were acquired through direct purchase or construction by households, with a smaller proportion acquired through credit or gifts by NGOs. The acquisition method varied somewhat between communities, with some communities having a higher proportion of ovens purchased outright and others having a higher proportion constructed by households or acquired on credit. Specific literature solely focusing on how fish smokers acquire their ovens to operate their businesses in Ghana is quite limited. According to Nolan (2019), many fish processors in Ghana acquire their ovens through informal channels and entrepreneurial networks. The study further emphasised some support given to fish processors to acquire ovens with improved combustion efficiency through NGOs and financial institutions on credit-based arrangements.

Based on a study by Lazar et al. (2018) the acquisition of smoking ovens in Ghana is often hindered by limited access to credit and technical expertise, as well as the high cost of purchasing or constructing them. The study recommends that interventions to improve access to credit and technical assistance could help to promote the acquisition of smoking ovens and support the local fishing industry.

The complementary use of fish smoking ovens varies across different communities and educational attainment levels. In general, there is a significant proportion of respondents who do not use complementary ovens (ranging from 22% to 98%), indicating that they rely solely on a single type of fish smoking oven. The reason for this is because for some fish smokers the type of oven required depends on the type of fish being smoked. Different types of fish smoking ovens are also employed, depending on the required moisture content of the smoked fish. However, there are also communities where a majority of respondents reported using complementary ovens, such as Woara Beba and Kesewokan. This implies that some fish processors recognize the benefits of using different types of ovens for smoking fish, such as faster processing times or better preservation of fish quality.

Research investigating the complementary utilisation of traditional and improved ovens reveals that traditional stoves are specifically tailored to accommodate distinct cooking methods, fuel types, and available resources for maintenance and renovation. Households have expressed their perspective that the improved cookstoves currently available to them do not align with their needs and preferences. The finding reveals that a universal stove design for household use would be inadequate in meeting the diverse cooking requirements and resource constraints of different households (Rhodes et al., 2014).

Forms of Fish Smoked in the Study Locations

The fish species that fish processors typically smoke come from artisanal fishing within their respective communities. The fish species commonly smoked include Sardinella, Cassava fish, Chub mackerel, tuna, red

snapper and others. The fish species can be classified into pelagic or coastal or demersal or deep-sea fish species (Michael et al., 2019).

Fish smokers typically purchase fresh fish caught by small-scale canoes and, to a lesser extent, authorised in-shore vessels. During lean fishing seasons, fish smokers would sometimes purchase imported fish, such as frozen sardinella, to smoke (Asiedu et al., 2018). This is no longer the case, since fish smokers increasingly smoke imported frozen fish even during major fishing seasons in Ghana owing to a decline in fish capture in Ghana's marine waters and consumer demand for fish. According to the 2019 Sustainable Fisheries Management Project report, despite increased fishing effort by the artisanal fishing fleet in Ghana's seas, small pelagic fish capture, which is the main fish smoked in Ghana, has decreased by more than 85% (Lazar et al., 2018). According to this study, only 44% of respondents smoke exclusively fresh fish capture, while 54 % smoke both fresh fish catch and imported frozen fish. Only about 1% of respondents exclusively smoke frozen seafood. The type of fish smoked, and the use of any types are influenced by the locality and accessibility of the fish smoking site.

Fuelwood Accessibility and Usage

The study communities rely heavily on wholesalers and transporters as the primary sources of fuelwood, suggesting a well-established fuelwood distribution supply chain. However, there is a notable distinction between these two groups, with transporters reporting greater access to fuelwood compared to wholesalers. This discrepancy can be attributed to the mobility of transporters, enabling them to access fuelwood from distant locations, while wholesalers, being more stationary, depend on local fuelwood sources. This

finding is consistent with previous reports on fuelwood value chains by Kwarteng (2015) further confirming the role of wholesalers and transporters in the fuelwood supply network. It highlights the importance of understanding the dynamics within the supply chain, particularly the different capabilities and access levels of wholesalers and transporters. Efforts to sustainably manage and distribute fuelwood should consider the specific needs and challenges faced by each group, aiming to optimize the availability and accessibility of fuelwood resources.

The finding suggests that there is a high demand for preferred species of fuelwood, with most respondents reporting that they have access to their preferred type of fuelwood. However, this could also contribute to the depletion of certain species of wood, and the need for sustainable harvesting practices. The mixing of different species of fuelwood is also common in most of the studied communities, which can help to reduce the pressure on specific species. The availability and accessibility of fuelwood for fish smoking is a major concern in many developing countries, including Ghana. Unsustainable harvesting practices, population growth, and the expansion of agriculture and urbanisation are some of the factors contributing to the depletion of forest resources. To address this issue, there is a need for sustainable forest management practices, such as reforestation, afforestation, and agroforestry. In addition, alternative sources of fuel for fish smoking, such as gas and electricity, could be explored, which could help to reduce the demand for fuelwood. However, these alternatives may not be feasible for some communities, due to cost and infrastructure limitations.

In Ghana, a number of tree species are cultivated by farmers specifically for fuelwood purposes. These species include *Albizia lebbbeck*, *Azadiracta indica*, *Butyrospermum parkii*, *Parkia biglobosa*, *Moringa oleifera*, *Diospyros mespilliformis*, and *Mangifera indica*. However, it is worth noting that the adoption of these agroforestry practices remains relatively limited, with only a smaller proportion of farmers engaging in them (Abukari, 2019).

According to a study by Atinga, Bannor and Sarfo (2023) the market for fuelwood harvesting and trade in Ghana exhibits relatively low concentration, as indicated by the Gini coefficients of 0.22 for both the fuelwood harvesters' market and the fuelwood intermediaries' market (wholesalers and retailers). These coefficients suggest a relatively equal distribution of market share among the participants. The study also found that the price of fuelwood varied depending on the type of market outlet. When fuelwood was sold through retailers and wholesalers, the prices tend to be comparatively lower. However, when sold directly to end-users, the prices tend to be comparatively higher. This suggests that intermediaries play a role in lowering the price by aggregating and distributing the fuelwood to end-users. The price of fuelwood was also influenced by the characteristics of the wood itself. Fuelwood species that produced less smoke commanded higher prices in the market, while those that were easy to ignite were sold at lower prices.

Preference for Specific Fuelwood Species Used for Fish Smoking

The selection of fuelwood for fish smoking in coastal communities in Ghana is influenced by a range of factors. These factors exhibit variation

among different communities and can have a significant impact on the choice of fuelwood for the smoking process. The specific factors influencing fuelwood preference may differ from one coastal community to another. These factors can encompass a variety of considerations such as local availability of fuelwood species, accessibility to specific types of wood, cultural practices, traditional knowledge, and even personal preferences within the community. This finding is in agreement with that of Koroma, Mansaray and Sesay (2021) indicating that fuelwood preference is influenced by several factors, including seasonal availability, accessibility, cooking time, and affordability. This convergence of outcomes underscores the importance of these factors in shaping the choices made regarding fuelwood selection.

A study conducted by Osei, Etuah, Aidoo, Fialor and Adams (2023) reveals significant differences in fuelwood availability and the types of fuelwood species used between the semi-deciduous and coastal savannah ecological zones of Ghana. These disparities can be categorized into three main aspects. Firstly, over the past two decades, there has been a 12% increase in the number of tree species utilized for fuelwood by households in the semi-deciduous zone and a slightly higher increase of 16% in the coastal savannah zone. This indicates a growing diversity of tree species used as fuelwood resources in both regions.

Within the scope of the study, various fuelwood types were employed for fish smoking purposes. Among these, *Klainedoxa gabonensis*, *Celtis mildbraedii*, *Tectona grandis*, and *Rhizophora mangle* emerged as popular choices. The selection of these particular fuelwoods can be attributed to their specific characteristics and advantages in the fish smoking process.

Klainedoxa gabonensis, *Tectona grandis*, and *Celtis mildbraedii* are preferred due to their high flammability rate and their ability to last longer in fire, which are crucial for effectively smoking fish. These fuelwoods possess properties that facilitate the desired heat levels necessary for the smoking process. Consequently, they are widely preferred in many coastal communities for smoking fish, as they contribute to achieving the desired flavours, aesthetics, and preservation of the fish. Additionally, according to the study conducted in the fish smoking communities, a considerable number of fish processors showed a preference for utilising *Azadirachta indica* (Neem) in the fish smoking process due to its perceived preservative capabilities. Neem is believed to possess pesticidal and medicinal properties that effectively deter insects and prevent the growth of mould (Bhattacharyya, Chutia, & Sarma, 2007).

The findings of the study conducted by Allou (2012) confirm that different fuelwood species exhibit varying burn rates during fish smoking. For instance, fuelwoods like *Tectona grandis* (teak) and coconut trunk were completely consumed within 10 hours, while others like *Azadirachta indica* (neem) and *Mangifera indica* (mango) took 24 hours to burn completely. Furthermore, the study observed a correlation between the aesthetics of the smoked fish and the choice of fuelwood. Preferred fuelwood species produced smoked fish with golden brown and dark brown colours, indicating a visually appealing appearance. On the other hand, fuelwood species that performed poorly resulted in smoked fish with light brown colours, which were generally disliked by consumers.

In practice, fish smoking is done using a mixture of fuelwood, which is crucial for achieving optimal results. Certain types of fuelwoods cannot be used alone and serve as supplementary wood species to facilitate combustion and maintain a steady burn. Additional fuelwood varieties, such as coconut husk, dry sugarcane peel, and similar materials, are incorporated towards the end of the fish smoking process. Their inclusion serves multiple purposes, such as imparting preservative properties to the fish or enhancing its visual appeal (Bomfeh, Jacxsens, Meulenaer, Amoa-Awua & Afoakwa 2019; Obodai, Muhammad, Obodai & Opoku, 2009; Odote, 2009).

The utilisation of mangrove species like *Rhizophora mangle* and *Avicennia germinans*, despite its importance to fish smoking, has faced criticism due to its negative environmental consequences. The practice of using mangrove wood for fish smoking has been linked to adverse effects such as deforestation and habitat destruction. The excessive exploitation of mangrove wood, not only for fish smoking but also for other purposes, has resulted in a decline in mangrove tree populations in Ghana and other regions of West Africa. Recognising the need to address this issue, various initiatives have been undertaken to encourage the adoption of alternative sources of wood for fish smoking. These alternatives offer greater sustainability and have a reduced environmental impact compared to mangrove wood. By promoting the use of alternative fuelwood sources, the pressure on mangrove forests can be alleviated, helping to preserve these vital ecosystems and protect their associated biodiversity. Furthermore, efforts have been made to promote the sustainable management of mangrove forests in Ghana. Sustainable management practices aim to balance the utilization of mangrove resources

with the need for their conservation. These initiatives often involve community engagement, capacity building, and the implementation of regulations to ensure the responsible use of mangrove wood (Allou & Cohort, 2012; Dongmo Keumo Jiazet, 2019; Feka & Ajonina, 2011; Okyere-Nyarko et al., 2015).

Fuelwood Consumption by the Different Fish Smoking Ovens

The quantity of fuelwood required for fish smoking varies depending on the type of oven used. To estimate the fuelwood consumption for different oven types, participants were surveyed regarding the amount of fuelwood needed to smoke 100 kg of fish. In local fish processing communities in Ghana, the marine fish catch is commonly traded at landing beaches, where it is typically sold to fishmongers and fish processors in pans or basins (Gordon et al., 2011). A pan of fish is equivalent to approximately 100 kg in weight. However, in specific areas like Mumford, fish quantities are measured in boxes or cases, where two cases are equivalent to one pan (100 kg). By employing these specific containers as a means of quantifying fish, it showcases the local knowledge and traditions that have evolved over time to facilitate efficient trade and exchange at the landing beaches. Some cold storage facilities also use pans or labelled boxes with specified weights as units of measurement.

The study data reveals that, on average, the Ahotor oven has the lowest fuelwood consumption, followed by the TMO oven. In contrast, the Chorkor oven was found to have the highest fuelwood consumption. However, there are exceptions to this pattern. In Woara Beba, the Chorkor oven requires less fuelwood than the Traditional oven. Similarly, in Abuesi and Shama Apo, the

fuelwood consumption between the TMO and Chorkor ovens is relatively equal. As Chorkor and TMO are traditional oven types and Ahotor is an improved oven, it is evident that the fuelwood consumption of these types of ovens differs significantly. In comparison to the Ahotor oven, which benefits from enhanced design and efficiency, both the Chorkor oven and the TMO tend to consume larger quantities of fuelwood due to their traditional design. The Ahotor oven, on the other hand, incorporates advancements in design and efficiency, resulting in significant fuelwood savings. This distinction highlights the importance of transitioning from traditional ovens to improved ones to achieve significant fuelwood savings. The ANOVA analysis results indicate that there are significant differences in fuelwood consumption across the study communities for the Traditional and Chorkor ovens, but not for the Ahotor oven.

According to the report by Dongmo Keumo Jiazet (2019), the average capacity of a traditional oven for fish smoking is approximately 528.5 kg of fish. In order to smoke this quantity of fish, the oven consumes an average of 1,204.5 kg of fuelwood, requiring a smoking time of approximately 53 hours. These findings shed light on the resource-intensive nature of traditional fish smoking methods, both in terms of the large quantity of fuelwood consumed and the extended smoking time required.

The results of the study reveal a significant advantage of the Ahotor oven over both the Chorkor oven and the TMO in terms of fuelwood efficiency. Specifically, the Ahotor oven demonstrates 59% and 54% reduction in fuelwood consumption over the Chorkor oven and the TMO respectively. This highlights the Ahotor oven's potential as an environmentally

friendly and sustainable cooking solution, as it significantly reduces the demand for fuelwood while still providing efficient cooking capabilities. These results emphasise the importance of promoting and implementing technologies like the Ahotor oven to mitigate the environmental impact caused by traditional cooking methods, while also offering tangible benefits in terms of fuelwood savings. In support of these findings, Pemberton-Pigott et al. (2016) conducted a comparative study on the efficiency of the Chorkor and Ahotor ovens. The results revealed that the Ahotor oven has the potential to save 32% more fuel than the Chorkor oven.

Moreover, Kwarteng et al. (2016) conducted energy assessment studies on fish smoking ovens in Ghana, which agree with the aforementioned results. The study emphasizes that the Ahotor oven demonstrates higher fuel efficiency compared to the Chorkor oven. In an experiment to assess the performance of the Chorkor oven, it was estimated that smoking 60 kg of fish requires 30 kg of fuelwood to be used (Asamoah, 2019).

In a study conducted by Malla Thakuri (2009) the fuelwood consumption of traditional and improved stoves was examined. The findings indicate that improved stoves consume approximately 42% less fuelwood compared to traditional stoves when cooking the same quantity of food. Biratu (2016) similarly reported that improved stoves have the potential to achieve significant fuelwood savings, with an estimated range of up to 48.8%. Furthermore, Manaye et al. (2022) conducted a study comparing fuelwood consumption in rural households in Ethiopia between improved cooking stoves (ICS) and traditional stoves. The results revealed significant differences in fuelwood consumption between the two types of stoves. The Per capita,

fuelwood consumption for improved stove users was estimated to be around 242 ± 169 kg per year, while traditional stove users consumed approximately 307 ± 120 kg per year. These studies collectively highlight the substantial potential for fuelwood savings through the adoption of improved stoves, which can contribute to sustainable energy practices and reduce the environmental impact associated with traditional ovens.

In this study, there were variations in the amount of fuelwood required to smoke different fish type. The variation was found to be attributed to the distinction between wet soft or dry smoking. Pemberton-Pigott et al. (2016) ascertains this results that fish is either wet hot smoked or dry smoked depending on the size of the fish, consumer choice, and the desired shelf life. Wet hot smoking is typically preferred by fish smokers for fish such as Tuna. This is to ensure that the moisture content in the fish is retained and subsequently retaining the size of the fish which will have a higher value in the market. In contrast, for small pelagic fishes like Sardinella, fish smokers typically use dry hot smoking to ensure the fish is sufficiently dried to extend its shelf life. These fish are stored and sold during the lean season, when fish catch is relatively low. The findings on the quantity of fuelwood required to smoke different types of fish species indicate that small pelagic fish require more fuelwood than large pelagic fish. Conversely, other fish smokers also testify that large pelagic fish requires more fuelwood than small pelagic fish. This is because larger fish have higher moisture content and a thicker skin, which makes them harder to smoke compared to smaller fish species. This conflicting finding underscores the importance of implementing suitable

smoking technology that can effectively conserve fuelwood, regardless of the specific method used for smoking fish.

Annual Fuelwood Consumption Used for Fish Smoking

Accurately determining fuelwood consumption and quantifying it in Ghana presents a formidable challenge. This arises from the absence of records maintained by both producers and consumers regarding the amount of fuelwood utilised (Abakah, 1990; Amissah-Arthur & Amonoo, 2004). This lack of data poses significant obstacles to understanding the extent of fuelwood usage and its impact on the environment and sustainable resource management in the country.

Recent estimates indicate that a significant majority, approximately 70%, of the Ghanaian population residing in rural areas relies heavily on wood fuel for their cooking and heating needs. This high dependence on wood fuel underscores its crucial role in meeting the energy demands of these communities. Presently, it is approximated that each individual consumes approximately 640 kg of wood fuel annually (Aabeyir, Quaye-Ballard, Van Leeuwen, & Oduro, 2011; Abdul-Wakeel Karakara & Dasmani, 2019; Simon, Bumpus, & Mann, 2012).

This study finding reveal significant variations in the average amount of fuelwood consumed for fish smoking between the minor and major fishing seasons. Specifically, the research indicates that the average quantity of fuelwood utilised during the minor fishing season was 472.90 kg, while increasing substantially 1443.67 kg during the major fishing season. The quantities of fuelwood used for fish smoking during both the minor and major fishing seasons are notably higher compared to the annual fuelwood

consumption by households. This disparity in fuelwood usage sheds light on the substantial impact of the fish smoking industry on Ghana's overall wood fuel consumption. The quantity of fuelwood consumed daily for fish smoking in each household is influenced by multiple factors, including the fish catch, financial capabilities of the fish smoker, and the prevailing fishing season. This dynamic interplay of variables reiterates the complex nature of fuelwood consumption within the fish smoking industry. The amount of fuelwood required can fluctuate based on the availability and size of the fish catch, as well as the financial resources of the fish smoker, which determine their ability to acquire an adequate supply of fuelwood. Additionally, the fishing season can have a direct impact on fuelwood usage, as different seasons may yield varying fish catches, thereby affecting the fuelwood demands for smoking.

According to literature, it has been suggested that the annual fuelwood consumption attributed to fish smoking during the major fishing season surpasses that of the minor season (Kwarteng et al., 2016). Contrary to what one might expect, it was observed that the total quantity of fuelwood consumed for fish smoking during the minor fishing season is comparatively higher than the major fishing season. Several factors contribute to this phenomenon, adding depth to our understanding of fuelwood usage in the fish smoking industry. Firstly, the minor fishing period extends over a longer duration than the major fishing period, resulting in an increased overall demand for fuelwood. According to Tall and Failler (2012), seasonal upwelling affects marine fisheries in Ghana. The major upwelling or bumper season lasts around three months per year. It starts around the end of June or

early July and ends in late September or early October. The minor upwelling or lean season lasts around three weeks in January or February, and rarely in December or March. However, at the beginning of 2018, the government of Ghana imposed a temporary one-month restriction on marine fishing in either July or August with the aim of revitalising depleting marine fish stocks (Owusu & Andriesse, 2020). Additionally, there has been a notable shift in the practices of fish smokers, as they now tend to smoke imported frozen fish rather than relying solely on fresh catches. This finding is consistent with Antwi (2021) study, which indicates that fish processors engage in specific practices during the lean season. They either purchase fish that has been stored in cold storage or they travel to alternative landing sites where fish is more readily available for purchase. This change reduces their reliance on the fishing season for sourcing fish, leading to a sustained demand for fuelwood throughout the year. Furthermore, the recent prohibition of fishing during the upwelling season has further impacted fuelwood consumption patterns, as fish smokers adapt their processes to align with the regulatory measures.

The findings indicate that the communities included in the study collectively consumed 18,349 metric tonnes (MT) of fuelwood annually. This data highlights the significant amount of fuelwood utilised by these communities and emphasises the importance of sustainable management practices to ensure the availability of this vital resource in the long term. Additionally, it reinforces the potential environmental impact of fuelwood consumption and the need for alternative energy sources to mitigate deforestation and related ecological consequences.

Emission of Greenhouse Gases from Traditional Fish Smoking

Data from the field indicated that, the cumulative annual GHG emissions were quantified at 30,300 MT of CO₂, 132 MT of CH₄, and 0.910 MT of N₂O (Table 22). The climate change impacts of these greenhouse gas emissions (GHGs) were assessed and compared using the global warming potential concept, which was also utilised by Tahir et al. (2010). The analysis revealed that Carbon dioxide possesses a GWP of 30,300 MT of CO₂e (carbon dioxide equivalent), methane possesses a GWP of 3,300.75 MT of (CO₂e), while nitrous oxide has a GWP of 298 MT of CO₂e. The cumulative annual of emissions resulting from the practice of fish smoking amounts to 33,871.88 MT of CO₂e.

To validate these results, they were cross-referenced with similar studies conducted in both Africa and other regions across the world. For instance, a study conducted in Senegal focused on the annual CO₂ emissions generated by traditional stoves. The findings of this study revealed that emissions from these traditional stoves amounted to 1727.5 MT of CO₂e. The percentage difference in emissions between the annual CO₂ emissions generated by traditional stoves in Senegal are roughly 95% lower than annual CO₂e emissions from fish smoking (de la Sota et al., 2019).

In a parallel study conducted in Bangladesh, examining traditional fuelwood-dependent cookstoves, an annual emission of more than 30 million MT of CO₂e was observed (Mondal, 2017). When contrasting these emission findings with those from this study, it becomes evident that fish smoking contributes merely 0.1% to the total emissions. This substantial disparity, however, can be attributed to the scale of the studies, where the Bangladesh

study encompassed the entire nation, this was confined to selected communities with a specific focus on fish smoking practices.

In the context of brick-making enterprises in Sudan, annual emissions were examined across three key regions: 319,346 MT CO₂e in Khartoum, 38,690 MT CO₂e in Kassala, and 97,632 MT CO₂e for the rest of Sudan (Alam & Starr, 2009). When juxtaposed with the emissions from fish smoking, significant disparities emerge, revealing distinct patterns in emissions contributions. Specifically, Khartoum's brick-making emissions exhibited an 89.4% difference from fish smoking, Kassala displayed a 12.4% contrast, and the rest of Sudan demonstrated a 65.3% variation. Specifically, Khartoum's brick-making emissions differed by 89.4% compared to fish smoking.

Again, when assessing these emissions alongside those originating from thermal power plants in Ghana due to stationary combustion in 2022, a contrast emerges. The annual emissions from these thermal plants amount to 12,019,452.73 MT CO₂e, overshadowing the comparatively modest emissions from fish smoking (Nyasapoh, Debrah, Anku, & Yamoah, 2022). The percentage difference between thermal plants and fish smoking emissions stands at 98.3%, highlighting the magnitude of emissions produced by the former. Conversely, fish smoking accounts for 1.68% of the emissions when juxtaposed with the emissions from thermal power plants.

With respect to the greenhouse gas emissions from Ghana's large-scale gold mining sector in 2016, 95,800.98 MT CO₂e was attributed to electricity usage and an additional 6,150.46 MT CO₂e from stationary combustion (Amoako, Gordon, Sakyi, & Gyimah, 2018). The gold mining industry

significantly surpasses the comparatively moderate emissions associated with fish smoking. The percentage difference in emissions between the two sectors is substantial, with the gold mining industry surpassing fish smoking emissions by approximately 66.8%.

Fuelwood consumption in Ghana resulted in emission total of 23,006,439.52 MT CO₂e in 2016 (UNFCCC, 2019). In comparison, the emissions attributed to fish smoking in this study represent only 0.147% of the overall CO₂e emissions generated by fuelwood consumption in Ghana. These findings underscore that while fish smoking does contribute notably to local emissions, its impact is relatively small in the broader context of fuelwood usage. Consequently, it suggests that sectors like commercial and residential use have a more significant role in driving emissions in Ghana.

With reference to greenhouse gas emission (GHG) for Ghana in the year 2020, a noticeable gap emerges when considering the emissions from fish smoking practices. Ghana's total GHG emissions during that year amounted to 39,070,290 MT of CO₂e, reflecting the combined emissions from various sectors (The World Bank, 2023). In contrast, the emissions produced from fish smoking practices, as revealed in this study, represent infinitesimal fraction, contributing only 0.087% to the overall emissions.

On a global scale for the year 2019, the combined greenhouse gas emissions stemming from household fuelwood combustion amounted to 799,220,500 MT of CO₂e (Flammini, Adzmir, Karl, & Tubiello, 2023). In light of this, the findings of this study highlight a stark contrast, fish smoking, in the context of the study area, contributes a mere 0.0042% to this global total. This discrepancy reinforces that the emissions associated with fish

smoking, while significant at a local level, hold relatively limited sway over the overarching global greenhouse gas emissions landscape.

Greenhouse Gas Emissions from Different Fuelwood Types and Fish

Smoking Ovens

Cookstoves or ovens that predominantly use biomass fuel have an impact on the environment by emitting climate-changing compounds. Considering the fact that biomass fuels have the potential to provide near-zero-carbon energy, many cookstove designs are inefficient (Meng et al., 2021; Pandey, Pervez, & Chakrabarty, 2018). The climate impact of cookstoves is determined by how the fuelwood is harvested and the amount of pollution generated. According to experts, increasing the combustion efficiency of biomass ovens or stoves potentially decrease the global warming effect of cookstoves in half. The climate consequences of biomass cookstoves are determined by elements such as the concentration of emissions produced, the local geography, and the type of fuel utilised (Sharma & Jain, 2019; Sidhu, Ravindra, Mor, & John, 2017).

Literature specifically addressing emissions from particular fuelwood and traditional fish smoking ovens is currently lacking. However, comparisons can be made with studies focusing on emissions from traditional fuelwood-dependent cookstoves that utilise similar combustion technology. Most studies examining GHG concentrations emitted by traditional ovens or cookstoves primarily rely on laboratory experiments (Arora, Das, Jain, & Kishore, 2014; MacCarty, Still, & Ogle, 2010; Roden et al., 2009).

Field investigations, on the other hand, involve studying cookstove emissions in their actual operating environments, such as households or

community settings. These investigations offer the advantage of providing a more accurate representation of the emissions generated during daily cooking practices. Field studies can account for factors like fuel type, cooking methods, stove design, and user behavior, which significantly influence GHG emissions.

The study utilised air quality sensors to measure the concentrations of GHG emissions from various types of fish smoking ovens. The emergence of sensor-based measurements for biomass cookstoves has provided a means to objectively quantify GHG emissions. Researchers suggest that integrating sensor-based measurements with other data sources, such as demographics, fuel consumption, emissions, user perceptions, health information, and indoor air pollution data, can lead to a more holistic understanding of stove use and adoption dynamics (Grupp et al., 2009).

The study revealed that *Klainedoxa gabonensis* produced the highest mean CO₂ concentrations (1799 ± 143 , $n = 714$) in a TMO, while *Celtis mildbraedii* in a Chorkor oven resulted in the lowest concentrations (468 ± 209 , $n = 4455$). Comparing these findings to traditional cookstoves used in the Northern Region of Ghana, both the Ace stove and Jumbo stove showed mean CO₂ concentrations of 808.44 ppm and 836.49 ppm, respectively (Moro, 2020). These results indicate significant variations in CO₂ emissions compared to *Klainedoxa gabonensis* and TMO. The Ace stove and Jumbo stove showed percentage differences in emissions of 55.07% and 53.50%, respectively, when compared to *Klainedoxa gabonensis* and TMO. The chorkor oven with *Celtis mildbraedii* exhibited lower CO₂ concentrations compared to both the

Ace stove and Jumbo stove, with percentage differences of approximately 72.79% and 78.81%, respectively.

Roden et al. (2009) reported on laboratory studies measuring the mean concentration of carbon dioxide emissions from traditional cookstoves. The study reported concentration levels of CO₂ as high as 3000 ppm and as low as 100 ppm. In field tests, the CO₂ concentrations ranged from 100 ppm to 400 ppm. The study suggests that in order to gain a more comprehensive understanding of real-world emissions, field testing should focus on identifying the key conditions and variables that govern emissions, while laboratory testing should aim to replicate these conditions. This approach would enable a more accurate assessment of the environmental impact of traditional cookstoves and facilitate the development of effective mitigation strategies. Furthermore, Ram and Bahadur (2020) conducted a study on the emissions resulting from fuelwood combustion in households. The research revealed that the average concentrations of CO₂ were between 400 ppm and 420 ppm. However, the study recorded a maximum concentration of 900 ppm. Comparing emissions between TMO and Chorkor ovens using *Klainedoxa gabonensis* and *Celtis mildbraedii* indicates significant differences. The mean emission concentration varied by 76.7% for *Klainedoxa gabonensis* in TMO and by 10.26% for *Celtis mildbraedii* in Chorkor. The highest recorded emission showed a 50% difference.

In a similar study examining the concentrations of CO₂ emitted by traditional stoves, the researchers assessed a range of mean CO₂ concentrations from 100 ppm to 6000 ppm. The study investigated the variation in emission levels among different types of cookstoves, namely;

Gyapa charcoal stove, coal pot charcoal stove and wood burning cookstove. The annual assessment of the environmental impact of emissions reveals significant differences among the three stoves. The wood-burning cookstove was found to have an estimated global warming impact potential of 4 tonnes of CO₂e, indicating a relatively high level of emissions. In comparison, the coal pot charcoal stove exhibited a lower impact potential of 2 tonnes CO₂e, suggesting a slightly better environmental performance. However, the Gyapa Charcoal stove stands out with the lowest impact potential, estimated at only 1 tonne CO₂e, indicating its superior sustainability and reduced contribution to global warming (Obeng, Mensah, Ashiagbor, Boahen, & Sweeney, 2017).

Moreover, a study by Lea-Langton et al. (2019) focused on assessing emissions from African open fire cookstoves, particularly evaluating methane emissions resulting from fuelwood combustion. The mean concentration of methane (CH₄) recorded in the study was 161 ppm. However, when comparing methane emissions from different scenarios within the study, significant variations were observed. The highest mean concentration recorded was 4037 ppm, which occurred when using *Klainedoxa gabonensis* in TMO. In contrast, the lowest mean concentration was 2922 ppm, observed when using *Klainedoxa gabonensis* in Chorkor.

Several factors impact the emissions of traditional cookstoves. These factors encompass the type of fuel used, the efficiency of combustion, the design of the stove, the quality of fuel, and cooking practices (Shen et al., 2015).

In relation to fuel type and quality, a study by Wasilewski, Zajac and Szyszlak-Barglowicz (2022) evaluated the combustion of wood pellets and

straws. The study found that methane CH_4 concentrations were notably higher than carbon dioxide (CO_2) concentrations. The lower CO_2 levels were explained by higher moisture content in the biomass materials, which affects the net calorific value of the fuelwood. The findings from the study are consistent with the observed trend, as methane concentrations were found to be considerably higher than carbon dioxide concentrations. This disparity can be attributed to the higher moisture levels in the fuelwoods utilised, which exceeded the ideal moisture content for efficient combustion. The moisture levels of the fuelwood types in this investigation were found to be higher compared to the moisture content of ideal fuelwood, which is typically less than 10% (Morin, Allen, Martin, Rector, & Ahmadi, 2022; van Zyl et al., 2019; Yuntewi, MacCarthy, Still, & Ertel, 2008).

The exclusion of nitrous oxide from the field measurement of GHGs in the study can be attributed to two primary factors. Firstly, most wood fuels have relatively low nitrogen content, resulting in minimal release of nitrogenous species from the fuel itself. Consequently, the emission of N_2O , which has a high GWP, is not considered a significant factor. Furthermore, domestic biomass stoves typically operate at moderate combustion temperatures that restrict substantial interactions with atmospheric nitrogen. As a result, the formation and release of N_2O from nitrogen present in the combustion process are limited. This characteristic of biomass stoves helps to explain the omission of N_2O measurement in the study (Bailis, Ezzati & Kammen, 2003).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter briefly discusses the findings and their implications. It also summarises the entire study and offers recommendations to enhance current research and expand future understanding.

Summary

Globally, fuelwood is an important source of energy. In the developing world, fuelwood is widely considered as a renewable energy source, accounting for a large share of energy for both rural and urban areas. Fish smoking is one of the economic activities in Ghana and other part of Africa that rely on fuelwood energy. Fish smoking is a major livelihood activity for women in coastal communities who had little or no education. Typically, fish smokers do not have any supplementary livelihood activity aside fish smoking. Majority of fish smokers learn the trade from their household where fish smoking was a major economic activity. Fish smokers are usually initiated into the occupation often by their mothers who are fish mongers or fish smokers themselves.

According to the study's findings, the amount of fuelwood necessary to smoke a certain quantity of fish depends on the type of oven utilised. The Chorkor oven and the Traditional oven use significantly more fuelwood than the Ahotor oven. The reasons for preferring a specific type of fish smoking oven have to do with its efficiency, convenience, the appearance of the fish after smoking, and the oven's longevity. Although improved ovens for fish smoking have emerged, these ovens have not been embraced by fish smokers. There are numerous fuelwood species used for fish smoking, and some are

preferred over the others. The reason for preference of specific fuelwood species includes the aesthetic of the fish after smoking, ability of the fuelwood to last longer in fire, ability of the fuelwood to dry the fish with ease, the easiness of flammability, the cost of the fuelwood, the availability of the fuelwood in the locality and other equally important reasons contribute to the preference of specific fuelwood species.

The IPCC Tier 1 methodology was used to determine the amount of GHGs emitted through the fish smoking activity. Results show that the total quantity of fuelwood used by the communities under study was 18,349 MT per annum. The cumulative annual of emissions resulting from the practice of fish smoking amounts to 33,871.88 MT of CO₂e. The concentrations of GHGs emitted from the different fish smoking ovens and specific fuelwood species were also measured using air quality sensors. Fish smoking in Ghana, despite using substantial amounts of fuelwood, contributes only 0.087% of total greenhouse gas emissions.

Conclusions

This study assessed the contribution of traditional fish smoking to greenhouse gas (GHG) emissions in selected coastal communities of Ghana, with a focus on the preferences for smoking ovens and fuelwood types, and their impact on emissions. The conclusions drawn from the study are as follows:

1. The study found that fish smokers' preferences for specific ovens and fuelwood species are heavily influenced by factors such as efficiency, convenience, fish appearance after smoking, and the longevity of the ovens. Despite the availability of improved ovens, traditional mud

ovens (TMO) and Chorkor ovens remain the dominant choices due to their cost-effectiveness and capacity to handle larger quantities of fish. In terms of fuelwood, species like *Celtis mildbraedii*, *Klainedoxa gabonensis*, and *Rhizophora mangle* are preferred for their qualities that enhance the smoking process, though their continued use poses environmental sustainability concerns.

2. The study quantified the greenhouse gases generated from traditional fish smoking practices, revealing that while these activities contribute to GHG emissions, their impact is relatively modest on a national scale. However, the reliance on traditional ovens and less efficient fuelwood types, which consume more wood, results in higher localised emissions, which reinforces the significant environmental impact of these practices.
3. The study revealed that traditional fish smoking ovens, particularly the TMO and Chorkor ovens, produce higher levels of GHG emissions compared to the more efficient Ahotor ovens. This difference highlights the potential for reducing emissions by promoting the adoption of improved oven technologies, which not only use less fuelwood but also produce less smoke and emissions, thereby offering both environmental and health benefits.
4. The study further assessed the GHG emissions from the preferred fuelwood types used in fish smoking and found that the type of fuelwood significantly affects the volume and type of emissions. The findings indicate that certain commonly preferred fuelwood species, such as *Klainedoxa gabonensis*, contribute disproportionately to higher

GHG emissions. Specifically, burning *Klainedoxa gabonensis* in a traditional mud oven resulted in the highest mean CO₂ concentration at 1799 ± 143 ppm, and the highest CH₄ concentration at 4037 ± 156 ppm. In contrast, *Celtis mildbraedii*, when used in a Chorkor oven, produced the lowest CO₂ concentration at 139 ± 7.32 ppm and the lowest CH₄ concentration at 2922 ± 703 ppm. The results revealed that CO₂ and CH₄ concentrations from the different fuelwood types exceeded typical household emission levels commonly associated with traditional cookstoves.

Recommendations

Based on the findings and conclusions discussed, the study proposed some recommendations. The following recommendations are hereby proffered:

1. Strong collaboration between fish smokers and the developers of the fish smoking ovens is recommended to improve the acceptability of improved ovens that conserve fuelwood.
2. All organisations including NGOs and institutions that are engaged in the promotion of efficient and improved fish smoking ovens should include behavioural models toward fuelwood utilisation.
3. Farmers, Forestry Commission, researchers and interested private organisations should collaborate to cultivate preferred fuelwood species to optimise efficient fish smoking to offset GHG emissions.

Suggestion for Further Research

This study recommends to researchers in Ghana to conduct studies on field measurement of GHG emissions from various economic activities that relies on fuelwood combustion to augment the gap in GHG emissions in

Ghana and to improve the accuracy of emission factors used to calculate emissions from different sources.



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APPENDICES

Appendix A: Normality graphs for quantity of fuelwood required to smoke 100 kg of fish using the Traditional, Chorkor and Ahotor ovens.

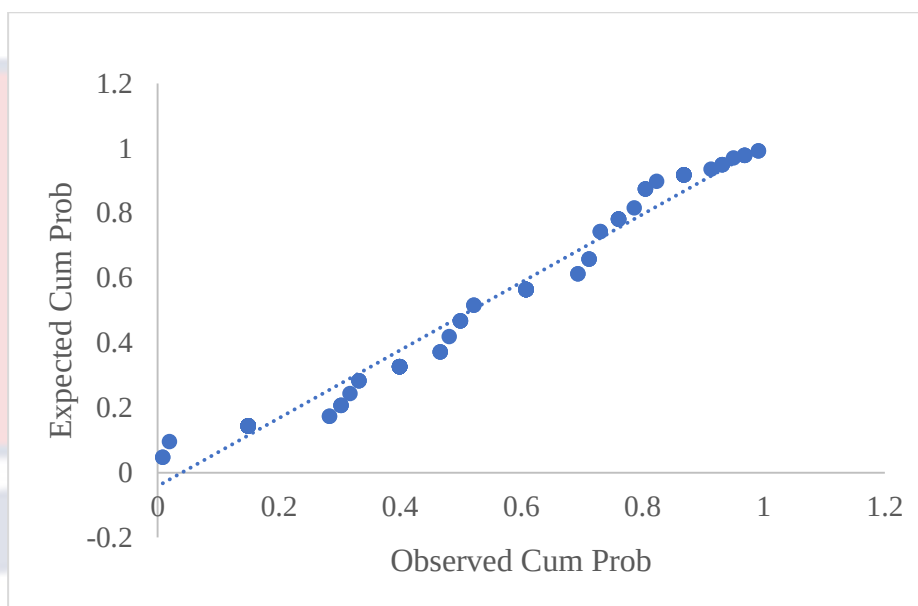


Figure 18: Normal P-P Plot of quantity of fuelwood Traditional oven take to smoke 100 kg of fish.

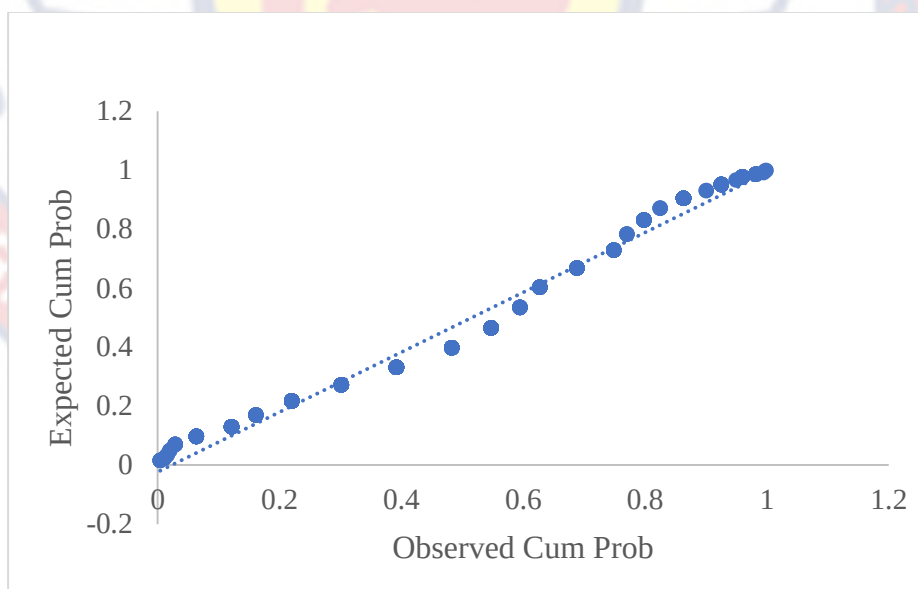


Figure 19: Normal P-P Plot of quantity of fuelwood Chorkor oven take to smoke 100 kg of fish.

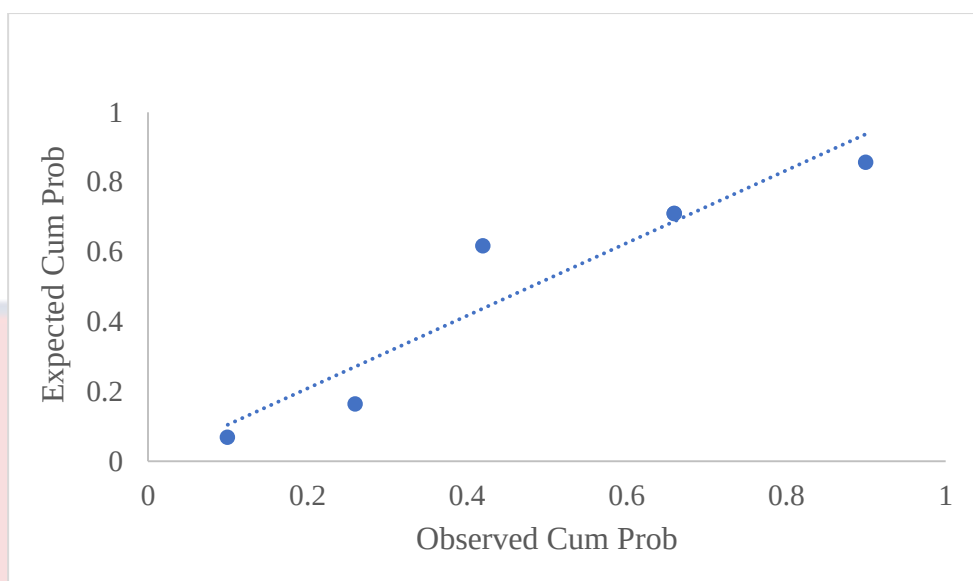


Figure 20: Normal P-P Plot of quantity of fuelwood Ahotor oven take to smoke 100 kg of fish.

Appendix B: Normality graphs for quantity of fuelwood required to smoke 100 kg of large and small pelagic fishes.

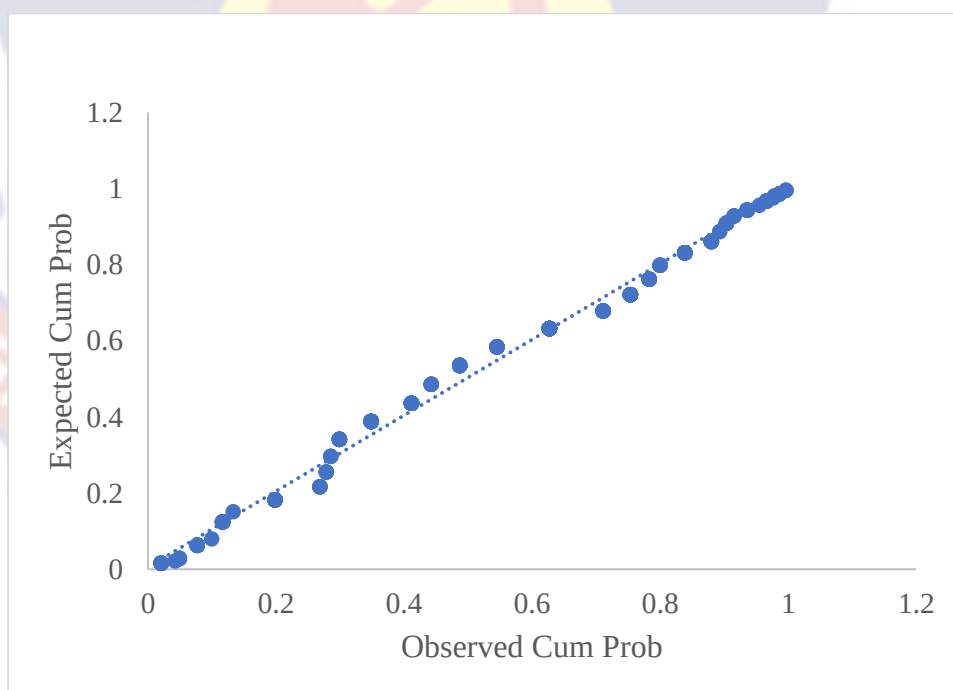


Figure 21: Normal P-P Plot of quantity of Fuelwood to smoke 100 kg of large pelagic fishes.

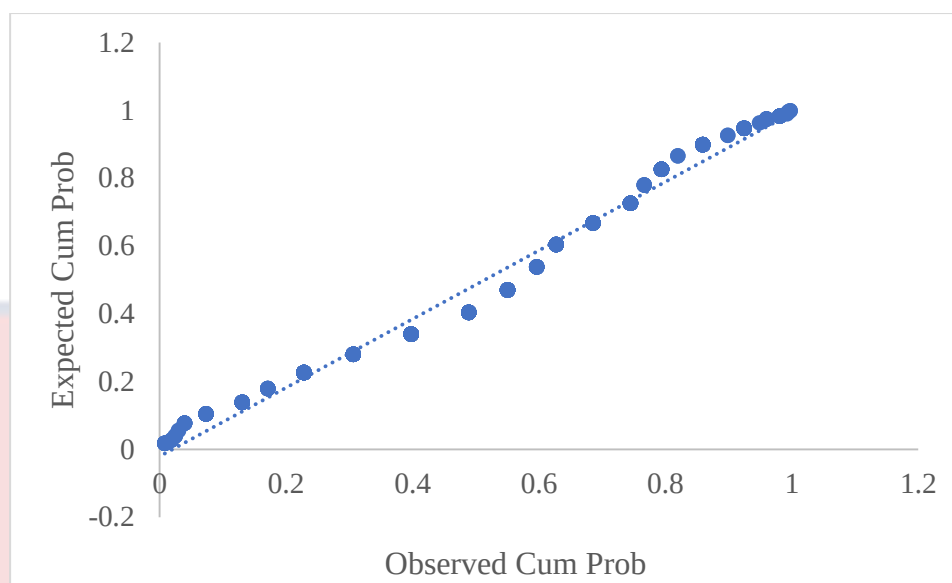
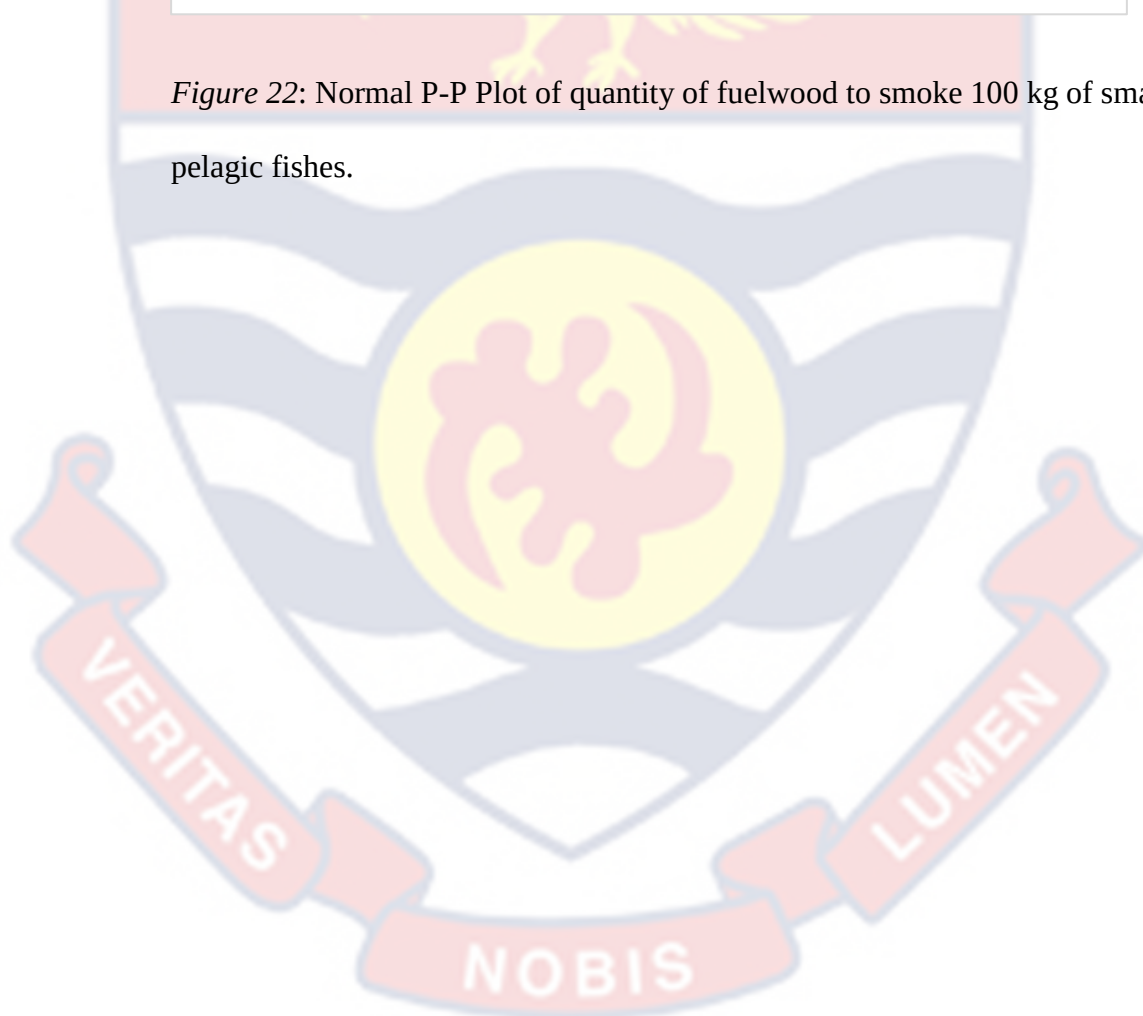


Figure 22: Normal P-P Plot of quantity of fuelwood to smoke 100 kg of small pelagic fishes.



APPENDIX C: QUESTIONNAIRE INSTRUMENT USED FOR SURVEY

UNIVERSITY OF CAPE COAST

SCHOOL OF BIOLOGICAL SCIENCES

DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES



QUESTIONNAIRE

**ASSESSING THE CONTRIBUTION OF TRADITIONAL FISH
SMOKING TO GREENHOUSE GAS EMISSIONS AMONG SOME
SELECTED COMMUNITIES ALONG THE COAST OF GHANA**

INTERVIEWER:

Your participation in the study is completely voluntary. We would also want to assure you that all information collected in the course of the study will be completely confidential. Thanks a lot for your participation. In case you have any questions please let us know. Please also ask when you have a problem understanding the meaning of any of the questions.

Community:..... Date:.....

Name:

Contact:

SECTION A: SOCIO-DEMOGRAPHIC PROFILE OF RESPONDENT

1. How old are you? (In complete years)
2. Gender 1. Male [] 2. Female []
3. Marital status? 1. Single [] 2. Married [] 3. Divorced [] 4. Widow/Widower []
4. Educational attainment. 1. No formal education [] 2. Primary education [] 3. Junior High School/Middle school [] 4. Senior High School/Vocational training [] 5. Tertiary []
5. Ethnicity? 1. Fante [] 2. Ewe [] 3. Ga. [] 4. Other [] (specify)
6. Religious affiliation? 1. Christianity 2. Islam [] 3. Traditional [] 5. Other (specify).....
7. Number of people in your household?.....
8. Do you engage in full time fish smoking? 1. Yes [] 2. No []
9. If No, what form of additional livelihood activity do you engage in?
10. 1. Fishing [] 2. Farming [] 3. Artisanry (dressmaking, hairdressing, carpentry etc. []. 4. Public servant [] 5. Other (specify).....
11. Weekly income (GHS)?.....

SECTION B: FISH SMOKING ACTIVITY

12. How long have you been into fish smoking? (In complete years)
13. How did you learn how to smoke fish? 1. Grew up in a household where fish smoking was a major economic activity? [] 2. Underwent an

apprenticeship with someone else [] 3. Self-taught [] 4. Other (specify).....

14. Do you own a fish smoking stove? 1. Yes [] 2. No []

15. How many fish smoking ovens do you own?.....

16. What type of fish smoking ovens do you own? 1. Traditional mud oven [] 2. Chorkor oven [] 3. Ahotor oven [] 4. Morrison oven [] 5. Other (specify).....

17. How long have you been using the ovens.....?

18. Which of these stoves do you often use to smoke fish? 1. Traditional mud oven []

2. Chorkor oven [] 3. Ahotor oven [] 4. Morrison oven [] 5. Other (specify).....

19. In addition to the ones you normally use, which of the following ovens have you used in the past? 1. Traditional mud oven [] 2. Chorkor oven [] 3. Ahotor oven [] 4. Morrison oven [] 5. Other (specify).....

20. How did you acquire the stoves you use? 1. Purchased outright [] 2. Purchased on credit [] 3. Constructed by household [] 4. Gifted by NGO [] 5. Gifted by government agency [] 6. Other (specify).....

21. In your opinion, which of the fish smoking ovens is the most efficient (fuel consumption, individual input and time) in fish processing?

1. Traditional mud oven [] 2. Chorkor oven [] 3. Ahotor oven []

4. Morrison oven [] 5. Other (specify).....

22. Which oven do you prefer if you own more?

1. Traditional mud oven [] 2. Chorkor oven [] 3. Ahotor oven [] 4. Morrison oven 5. Other (specify).....

23. Why do you prefer this oven type? 1. Efficiency (fuel/time) [] 2. Convenience [] 3. Nice appearance of the fish [] 4. Longevity [] 5. Lower cost in construction [] 6. Cultural reasons [] 7. Other (specify).....

24. Do you switch between fish smoking oven types 1. Yes [] 2. No []

25. Why do you switch between oven types?.....

26. What form of fish do you mostly smoke? 1. Fresh catch from the sea [] 2. Frozen fish [] 3. Both []

27. What quantity (kg) of fish do you smoke in a day?.....

28. Average number of times you smoke fish within the week?.....

29. On average what quantity (kg) of fish do you smoke per week?.....

30. Have you smoked fish using the Traditional, Chorkor and Ahotor oven? 1. Yes [] 2. No []

31. How many hours does it take to smoke 1 pan (100kg) of fish using the traditional mud oven?.....(skip logic)

32. How many hours does it take to smoke 1 pan (100kg) of fish using the chorkor oven?..... (skip logic)

33. How many hours does it take to smoke 1 pan (100kg) of fish using the Ahotor oven?.....(skip logic)

34. What are the problems you face in the fish smoking activity? 1. Lack of dry storage space [] 2. Lack of cold storage space [] 3. Product quality

and consistency [] 4. Access to fresh fish [] 5. Access to fuelwood []

6. Health effects of smoke [] 7. Other (specify).....

35. Do you belong to any fish smoker's association? 1. Yes [] 2. No []

36. What is the name of the association?.....

37. How was the association formed?

1. Internal effort [] 2. External effort [] 3. Both []

38. What is the purpose of the association? 1. Technical knowledge of training

[] 2. Voice in decision making [] 3. Social support [] 4. Market

Access [] 5. Credit/loans [] 6. Facilities or Workspace [] 7. Women

empowerment []

8. Other (specify).....

39. What form of support do you need from government or non-governmental

organization? 1. Access to credit [] 2. Fish smoking inputs [] 3. Training

[] 4. Education [] 5. Mechanization of stoves []

SECTION C: FUELWOOD INFORMATION AND PREFERENCES

40. What is your major source of fuelwood?

1. Wholesaler [] 2. Transporters [] 3. Harvester/producers [] 4.

Personal forested land [] 5. Other

(specify).....

41. How much do you spend on fuelwood for smoking fish per day?.....

42. How much do you spend on fuelwood for fish smoking per week?.....

43. Which species of fuelwood have you used within the past week?

1. Esa [] 2. Begye Woba [] 3. Okonkroma [] 4. Odanta []

5. Ankyin [] 6. Opepe [] 7. Neem [] 8. Koodjabena [] 9. Nyamedua [] 10. Emire [] 11. Odum [] 12. Akutu Gya 13. Mango [] 14. Rubber [] 15. Cocoa [] 16. Dahoma [] 17. Esudur [] 18. Other (specify).....

44. Which species of fuelwood do you mostly use?

1. Esa [] 2. Begye Woba [] 3. Okonkroma [] 4. Odanta []
 5. Ankyin [] 6. Opepe [] 7. Neem [] 8. Koodjabena []
 9. Nyamedua [] 10. Emire [] 11. Odum [] 12. Akutu Gya 13. Mango [] 14. Rubber []
 15. Cocoa [] 16. Dahoma [] 17. Esudur [] 18. Other (specify).....

45. Which fuelwood species do you prefer to use? Add the fuelwood options)

46. Reason for preference? 1. Last longer in fire [] 2. Produces less smoke [] 3. Gives the smoked fish a nice appearance [] 4. Easiness of flammability [] 5. Availability [] 6. Hot flame [] 7. Fast Drying [] 8. Hot flame [] 9. Ability to produce ember [] 10. Produces less smoke [] 11. Easiness of flammability [] 12. Other (specify).....

47. Is your preferred fuelwood readily available in your community?

1. Yes [] 2. No []

48. Which characteristic do you look for when purchasing or selecting fuelwood for fish smoking? 1. Last longer in fire [] 2. Produces less smoke [] 3. Gives the smoked fish a nice appearance [] 4. Easiness of flammability [] 5. Availability [] 6. Hot flame [] 7. Fast Drying [] 8. Hot flame [] 9. Ability to produce ember [] 10. Produces less

smoke [] 11. Easiness of flammability [] 12. Other
(specify).....

49. Is the most preferred fuelwood available throughout the year? 1. Yes [] 2.

No [].

50. Do you use mix different fuelwood species when smoking fish? 1. Yes []

2. No []

51. Why?.....

52. How has the availability of fuelwood been in the past 5 years? 1.

Increasing []

2. Decreasing [] 3. Constant []

SECTION D: FUELWOOD CONSUMPTION

53. What quantity of fuelwood does the traditional oven take to smoke 1 pan
(100 kg) of fish on average?.....

54. What quantity of fuelwood does the chorkor oven take to smoke 1 pan
(100 kg) of fish on average?.....

55. What quantity of fuelwood does the Ahotor oven take to smoke 1 pan (100
kg) of fish on average?

56. Does the quantity of fuelwood use depend on the type of fish being
smoked?

1. Yes [] 2. No []

57. If yes, what quantity of fuelwood does it take to smoke 1 pan (100 kg) of
large pelagic fishes e.g. Tuna?.....

58. If yes, what quantity of fuelwood does it take smoke 1 pan (100 kg) of
small pelagic fishes e.g. Mackerels, Anchovies?.....

59. Average number of times you smoke fish in a week during the major season?.....

60. Average number of times you smoke fish in a week during the minor season?.....

61. Average quantity of fish smoked per day during the major season?.....

62. Average quantity of fish smoked per day during the minor season?.....

63. Average quantity of fish smoked per week during the major season?.....

64. Average quantity of fish smoked per week during the minor season?.....

65. What quantity of fuelwood do you use per week during the major season?.....

66. What quantity of fuelwood do you use per week during the minor season?.....

67. Are you worried on the future availability of fuelwood in your community?

1. Yes [] 2. No []

68. Have you ever thought of the fuelwood in your area becoming extinct? 1. Yes [] 2. No []