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Emission quantification associated with firewood usage: A case study of Mangondi village in Limpopo Province, South Africa.

By

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Declaration

I, MUDAU PHUMUDZO, hereby declare that this dissertation, submitted for Masters in Earth Sciences, at the University of Venda, is my own work and has not been previously submitted for a degree at this or any other institution and this work is mine from conceptualization to execution; all references and sources used have been fully acknowledged.

Signature:  Date: 26 July 2023

Abstract

For a long time, firewood has been used as an affordable source of energy, available for cooking, lighting, and heating. Firewood combusted using informal stoves which are not properly designed are characterized by not having regulatory control facilities to achieve complete combustion, hence, resulting in increased smoke and gaseous emissions since the firewood is not fully combusted. A large quantity of criteria pollutants and greenhouse gas (GHG) are released to the atmosphere from such combustion which potentially contributes to global warming and climate change. The aim of this study was to quantify the emissions resulting from the use of firewood in Mangondi village, a rural village in the Limpopo Province, South Africa. This study employed structured questionnaires and face-to-face interview to gather required information, to identify preferred tree species used as firewood in Mangondi village. The questionnaires were administered to forty households that were selected randomly in the village. Additionally, a crane scale was used to quantify the firewood mass burnt daily by the 40 households during the winter and summer seasons of 2021.

The study used the data generated as a baseline for estimating the GHG, and criteria pollutants' emissions released from burning firewood in winter and summer by the participating households in Mangondi village. The results obtained from the questionnaires and interviews, revealed that the preferred tree species used as firewood in the households were *Dichrostachys cinerei*, *Euclea divinorum* Hiern and *Combretum imberbe*. Firewood was the main source of energy used by the households of Mangondi village for preparing meals and space heating. The results from this study illustrate that several factors, such as, socio-economic conditions, accessibility and availability were reasons for the utilization of firewood as a preferred choice of energy for households in Mangondi village.

The average wood mass burnt in 2021, in the morning sessions (2-5 hours) was 4.04 kg/day and 2.94 kg/day in the evening (1-1h30) and amounted to an average of 2545.30kg per household, per year. More firewood was used in winter than summer mostly due to space-heating needs. The emission rate per household for GHG, CO_2 (1771.12 g/day) was higher in winter than in summer (1014.86 g/day). Results for the criteria pollutants estimated, show that PM2.5, PM10, CO, SO_2 and NOx was 169.24 g/day; 60.23 g/day; 68.09 g/day; 0.79 g/day; 5.12 g/day in winter and 1014.86 g/day; 96.98 g/day; 3.38 g/day; 34.51 g/day; 39.02 g/day;0.45 g/day; 2.93 g/day in summer. This study shows that households in rural areas still choose to use firewood to meet

their daily energy needs because it is easily accessible and cheap. This study illustrated that burning firewood leads to GHG and criteria pollutants being emitted, therefore, intensive awareness and pollution control programs are suggested to improve indoor air quality and health condition of the rural population.

Keywords: Firewood, emission rates, green house gases, air pollution, human health

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Dedication

I dedicate my dissertation to God Almighty, my source of life and my provider with whom everything is possible and a special dedication to my family, for showing love and appreciation of my efforts.

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LIST OF ABBREVIATIONS

BC- Biofuel Consumption rate

CH_4- Methane

CO_2 - Carbon Dioxide

CO - Carbon Monoxide

DEA - Department of Environmental Affairs

DWC - Domestic Wood Combustion

EF- Emission Factor

FAO - Food and Agriculture Organization

GHG - Greenhouse Gases

GPS - Global Positioning Systems

GW - Gigawatts

GWEC - Global Wind Energy Council

He - Helium

H_2S - Hydrogen Sulphide

IEA - International Energy Agency

IPCC - Intergovernmental Panel on Climate Change

LPG - Liquified Petroleum Gas

NAAQS - National Ambient Air Quality Standards

N_2 - Nitrogen

N_2O - Nitrous Oxide

NO_2 - Nitrogen Dioxide

NOx - Nitrogen Oxide

O_3 - Ozone

Pb - Lead

PM - Particulate Matter

SO_2 - Sulphur dioxide

SPSS - Statistical Package for Social Sciences

USEPA - United States of America Environmental Protection Agency

VOC - Volatile Organic Compounds

WHO - World Health Organization

WWEA - World Wind Energy Association

Scholarly Outputs from this study

TOPIC	RESEARCH OUTPUT	STATUS
Emissions quantification associated with firewood usage: a case study of Mangondi village in Limpopo Province, South Africa.	Conference 3MT PowerPoint Presentation. Poster presentationon Air Quality Monitoring and Management. P Mudau, and J Edokpayi, 2022.	Completed - Presented at the annual National Association for Clean Air (NACA) National Conference held in Johannesburg, South Africa from the 5th - 7th October 2022.
Emissions quantification associated with firewood usage: a case study for Mangondi village in Limpopo Province, South Africa.	**Poster presentation** Theme: Air Quality Management P Mudau and J Edokpayi. 2022.	Completed - Presented at Research Day of the Faculty of Science, Engineering and Agriculture at the University of Venda (July 2022).
Evaluation of the factors that influence the selection of wood species as domestic fuel: A Case study of Mangondi village, Limpopo Province, South Africa.	Article	Submitted, under review in Journal of Energy in Southern Africa.
Fuelwood usage in South African households in rural settings: A case study for Mangondi village in Limpopo province.	Article	In draft, to be published with Environmental Science Journal.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Firewood has been used as a source of energy. Domestic wood combustion (DWC) is practiced by a lot of people, all over the world as an affordable source of energy for cooking, lighting, and heating (Gioda, 2019). The World Health Organization (WHO) (2016a) reported that about 2.8 billion of the world's population relies on firewood, which can be used in fireplaces, ancient stoves, and outdoor open fires for cooking and heating. About 40% of people in the United Kingdom use firewood for space heating in winter (Neill, 2020); about 80% of the population in rural settings in Nepal depend on firewood as a source of energy to meet their daily needs (Chaudhary and Rimal., 2016). Koffi et al. (2016) reported that firewood is the main source of energy for cooking and space heating by households residing in low-income settings in the sub-Saharan Africa. In Uganda, firewood is used by over 50% of households in rural areas to meet their daily domestic needs (Maininno et al., 2022). Shackleton et al. (2022) reported that over 96% of households in rural areas of South Africa depend on DWC for cooking and space heating. About 91% firewood is burnt for cooking and space heating by households in rural settlements in Johannesburg, South Africa (Makonese et al., 2016).

The burning of firewood in rural areas in a low-income setting is done mostly using informal stoves which is a regular and continuous process of incomplete combustion; hence, this results in the emissions of air pollutants (WHO, 2016a). During the combustion of firewood, the combustion reaction generates heat and emits a mixture of gases, such as benzene, Polycyclic Aromatic Hydrocarbons, CH_4, NOx, SO_2, CO, CO_2, PM2.5 and PM10 (USEPA, 2022). Due to their persistent and undesirable effects, greenhouse gases (GHG) and criteria pollutants are undesirable in the environment as they have negative environmental impacts and adverse human-health effects (Saxena and Sonwami., 2019). Ujih et al., (2016) reported that deforestation and other environmental problems were observed in Nasarawa Local Government Area of Nigeria where DWC was predominantly used. Inhalation of fumes from the burning of firewood causes irritation to lungs of humans, inflammation, lung infections and other respiratory diseases (Feyisa et al., 2017).

In South Africa, there is a variety of tree species that are commonly used for cooking and space heating, such as *Dichrostachys cinerea* (sekelbos), *Vachellia erioloba* (kameeldoring), *Senegalia mellifera* (swarthaak), *Colophospermum mopane* (mopani), *Myrtus communis*

(myrtle), *Acacia mearnsii* (black wattle) and *Eucalyptus globulus* (blue gum) as they are hard wood, easily accessible and burn steadily for a long period (Urban Lumberjack., 2020).

1.2 Problem statement

In some countries of the world, mostly in the Asia and African continents, the government is unable to supply clean energy to several communities, therefore, they often resort to the use of firewood to meet their basic energy needs (Kihombo et al., 2021). Burning firewood, however, has some disadvantages as it contributes to deforestation and to air pollution which leads to adverse health effects (Li et al., 2016).

The burning of firewood contributes to the release of GHG and criteria pollutants which are toxic and persistent in the environment, thereby, they have the potential to increase the global burden of air pollutant emissions (USEPA, 2021). WHO (2022) reported that approximately 3.2 million mortalities globally were caused by air pollutant emissions released from indoor DWC. Inhalation of indoor air pollutants was identified as one of the major causes of respiratory diseases, such as lung cancer, persistent coughing and heart diseases in households in rural settings, using firewood as a source of energy. In Sub-Saharan African countries, particulate matter (PM) was estimated to have caused health risks, such as bronchitis, lung infection and shortness of breath; inhalation of wood smoke has led to high rates of deaths in children below the age of 5 according to Sulaiman et al., (2017).

Households burning firewood experience a lot of challenges. Studies have shown that people who are directly exposed, (for instance, people responsible for preparing meals), to burning firewood to meet their daily needs suffer more from respiratory illnesses, such as pulmonary cardiovascular disease, breathing problems, eye aches and headaches, as compared to people less exposed to indoor air pollution (Das et al., 2017). Health concerns caused by the inhalation of indoor air pollutants released from wood smoke, have been established, however, not much research, on the emissions of air pollutants, has been conducted in rural settings in Limpopo Province.

Mangondi village is a small rural setting in the Vhembe District, in the Limpopo Province of South Africa. Evidence from available literatures reveal that firewood burning is causing health challenges to the people in that village as most households use firewood for cooking and space heating, daily. In South Africa, the government has invested in sustainable development,

however, households in rural settings receive little to no financial support for their energy requirements, forcing them to rely on firewood (Shackleton et al., 2022).

This study, therefore, will serve as a pioneer to generate information on issues such as, the type of tree species preferred as firewood in rural settings in the Vhembe District in Limpopo Province; the firewood burning consumption rate and air pollutant emissions released from DWC in the study area. The data generated in this study will also help in the monitoring of air pollutants released from firewood burning and in mitigating the environmental and health risks associated with air pollutants emissions in households, in rural settings, that rely on firewood as a source of energy.

1.3 Motivation

The global contribution of air pollutant emissions released from DWC from African countries is about 30-50% and firewood are the most utilized source of energy to meet the domestic needs of about 753 million Sub-Saharan African people; this represents about 80% of the overall population. DWC, however, has undesirable consequences, such as being one of the contributors to air pollution as the emissions released contain criteria pollutants and greenhouse gases, which when inhaled, causes respiratory diseases such as shortness of breath, bronchitis, asthma, lung cancer and death (Badamassi et al., 2017).

A study conducted in China found that DWC may have influenced early fatalities among an estimated 250000 people which accounts for about 5-10% of deaths that were recorded annually (Yadav et al., 2018). Health risks have been a legacy of air pollution from DWC over centuries with about 1.3 million individuals reported annually to have died due to exposure to DWC; these were mainly women and children, since they are usually responsible for the cooking and domestic chores in rural households (International Energy Agency, 2021).

Little work, however, has been done to appraise these associated problems and quantify DWC in South Africa, particularly, in Limpopo Province, which could serve to prioritise and motivate the implementation of mitigation efforts. The objectives of this research are to quantify the firewood burnt by households in low-income settings in Mangondi village in the Vhembe District in Limpopo Province, South Africa and to estimate the emissions of criteria pollutants and greenhouse gases released from DWC.

1.4 Objectives

1.4.1. Main objective

The primary objective of this study is to quantify the amount of wood combusted for domestic purposes as well as calculate the seasonal emission rates of criteria pollutants and GHGs.

Specific objectives

i. To identify the most preferred wood type used as a source of energy in Mangondi village in Vhembe District.
ii. To quantify the amount of firewood usage in Mangondi village in Vhembe District.
iii. To estimate the emission rate of greenhouse gases (CO_2) and criteria pollutants (SO_2 NO_X, CO, PM2.5 & PM 10) from firewood usage in winter and summer seasons in Mangondi.

1.5 Research questions

i. What are the preferred tree species for firewood in Mangondi village?
ii. What is the amount of firewood usage in Mangondi village?
iii. What is the estimation of the greenhouse gases and criteria pollutants emitted from firewood usage in Mangondi village?

1.6 Study area

This study was conducted in Mangondi village, a low-income setting which can be categorized as a rural area, located in the Thulamela Municipality, in the Vhembe District, Limpopo Province of South Africa. This community has a high unemployment rate and low literacy level with few school and proper functioning health facilities. The Limpopo Province is the northern part of South Africa; its northern region shares a border with Zimbabwe; in the eastern side is Mozambique, while Botswana is on the western side.

It occupies a total area of 125 754 km^2 and is ranked the 5^{th} largest province in South Africa. The province comprises of Tshivenda, Xitsonga and Sepedi-speaking people (Britannica, 2020). Mangondi village was selected to represent a rural setting in the Thulamela Local Municipality, within the Vhembe District in Limpopo Province; it is located 22°56 '21"S and 30°37'24"E.

Mangondi village (Figure 1.1) has a population of about 6444 and the major ethnic groups in the village are the Vhavenda and Xitsonga people occupying an area of 3.46 km (Thulamela local Municipality, 2022). Mangondi village lies in a region which receives precipitation in summer, and the climate can be described as wet and warm, whereas winter days are cold and dry, with January as the hottest month and July the coldest.

This region receives approximately 609 mm rainfall annually, with most rainfall experienced from November - January and the least in June (Weather SA, 2022). The region is characterised by savanna, grassland, and forest biomes (Department of Forestry, Fisheries, and the Environment, 2022). Tree species such as *Euclea divinorum* Hiern, *Combretum imberbe*, *Dichrostachys cinerea*, *Ziziphus mucronate* and *Diospyros mespiliformis* are predominate within the village.

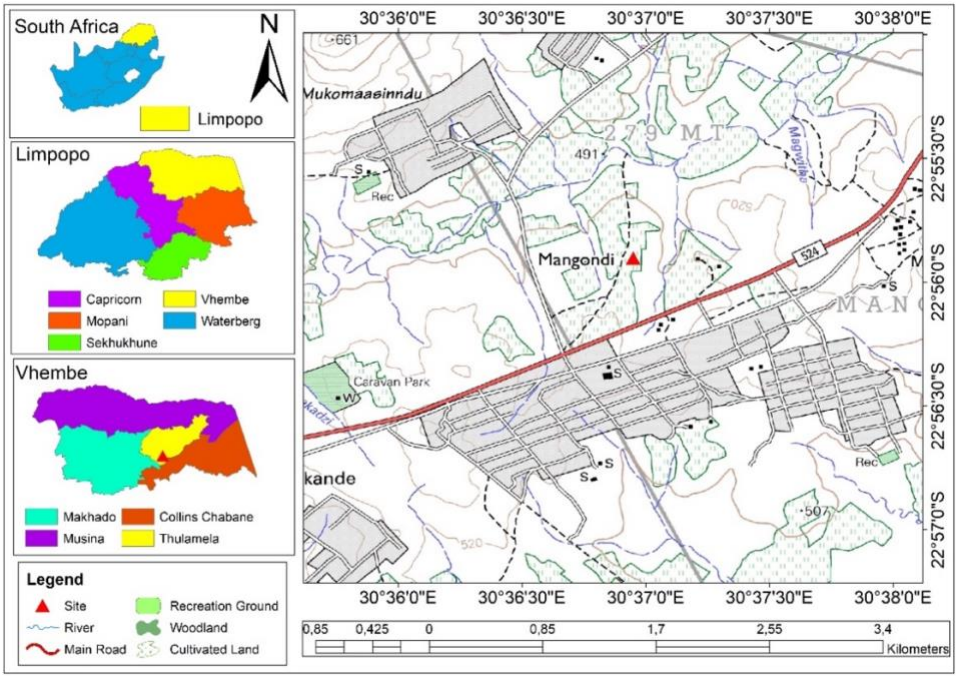

Figure 1.1: Map of the study area.

CHAPTER TWO: LITERATURE REVIEW

Preamble: This chapter provides a detailed description of the types of fuels that are used as sources of energy to meet domestic needs; various tree species that are utilised as firewood will be identified and outlined. The legislation and regulations related to air quality will be highlighted as well as the standards and guidelines of different air pollutants required to ensure compliance. This chapter also discusses the environmental and health impacts of air pollutants and provide remedial actions which could be implemented to prevent and regulate emissions associated with firewood combustion.

2.1. Introduction

The demand for energy has increased very rapidly over the years, thus, creating a global energy crisis for developed and developing countries (Iddrisu and Bhattacharyya, 2015, Pietrosemoli and Rodríguez-Monroy, 2019). Each country requires energy to sustain its economic growth (Bouzguenda et al., 2019, Jefferson, 2006), thus, other sustainable energy sources need to be explored to replace the use of fossil fuels, since their extensive use pollutes the environment and causes global warming (Ahmad et al., 2020).

2.2 Factors affecting the choice of energy sources

The choice of energy sources in the countries depends on specific households' needs. Factors, such as - supply and demand, total reserves, political and socio-economic issues, cultural influences, number of inhabitants per household as well as affordability - influence the choice of energy source used (Chen et al., 2016). A similar study by Makonese et al. (2018) concurred that factors like - lack of connection to the electricity grid, number of people residing in a household, literacy, and financial status - affect the type of energy source chosen by communities to meet daily needs.

According to Sidhu et al., (2017), households in low-income settings have been unable to meet their essential energy supply to satisfy their daily domestic needs for decades. In rural areas, the factors affecting the choice of fuel source can be explained using the "energy ladder theory", which illustrates that when households' income increases, they tend to steer away from using

energy sources, such as firewood, cow dung, crop residue and opt for modern technologies such as gas and electricity, as shown in Figure 2.1. The energy ladder theory has 3 stages to illustrate the transition to different energy sources, as the income of households increases. In the **first stage**, crop residue, cow dung and firewood are the types of fuel source households use; as the income status increases households transition to using coal and kerosene in the **second stage** and they opt to use cleaner energy, such as electricity and gas in the **third stage** due to improvements in income (Heltberg, 2003).

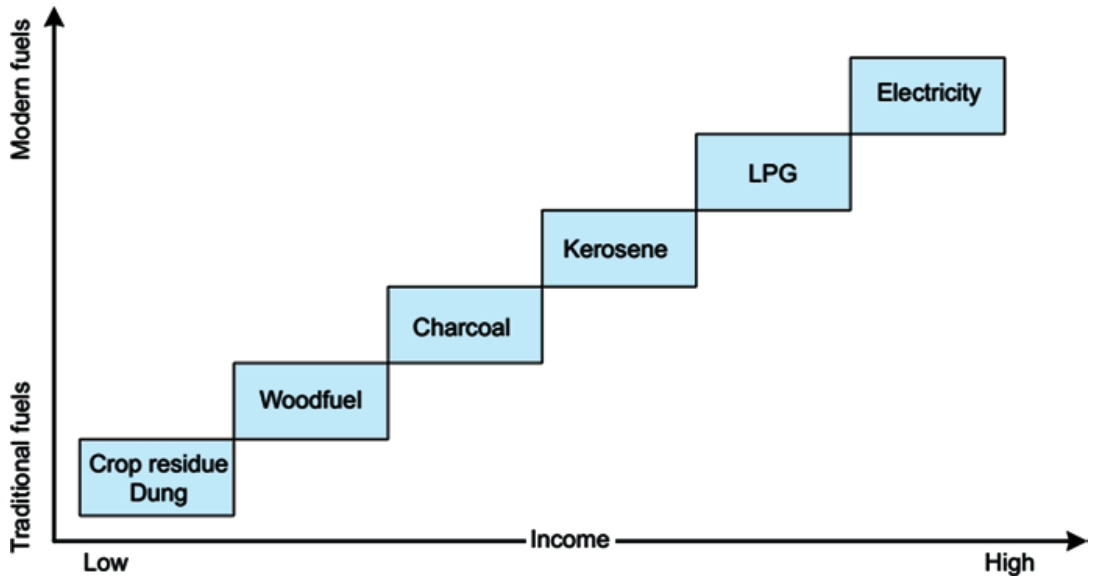

Figure 2.1: The energy ladder theory (Tucho, 2020)

Electric power generation and distribution in South Africa

Approximately 1.5 billion people in the world are not connected to their national electricity grids (Hanna and Olivia., 2015). Energy is supplied by power plants using nuclear energy, fossil fuels, hydropower, biogas, and wind power. In South Africa, 59 % is generated from coal which is abundant in regions such as Mpumalanga. These plants powered by coal supply electricity to the national grid which is then distributed to the country (Ratshomo and Nembahe., 2018).

In South Africa, the state entity responsible for the supply of electricity is ESKOM. The entity has experienced a decline in the electricity reserve margin recently which has resulted in the shutting down some of its generating plants and this has had a huge impact on its ability to meet the electricity demands of South African communities (Aikins, 2016).

Elements such as the price of electricity, climatic conditions, increased population, improved technological systems and economic expansion may sway the pressure of electricity provision to people (Platchkov and Pollitt., 2020). Many households residing in rural areas do not have access to electricity from the national grid due to their remote location and inability to pay for electricity (Motjoadi et al., 2020). Households in low-income settings, usually face plenty of challenges due to their social and economic status, hence, many of them do not have access to electricity, therefore, electrified households are few as compared to those in developed areas (Longe et al., 2019).

Availability and accessibility

The choice of energy source used in rural household is influenced by the price of fuel. The main reason most households in rural areas still continuously use firewood is due to it being available in the environment, its free to access and some cultural preference. Some communities believe the food tastes better cooked by firewood in terms of the smell and taste, as compared to other fuel sources, in addition to the process of using firewood not requiring any complicated and expensive equipment (Toole, 2015; Khan et al., 2017). Moeen et al., (2016), note that households in rural areas in Pakistan still choose to use firewood as a source of energy because it is affordable and accessible. According to Hou et al., (2017) factors, such as transport difficulties and remote locations influenced the choice of fuel used in rural areas in China, hence they continue use firewood.

Due to lack of accessibility to electricity and gas, households in Bangladesh have continued to use firewood and crop residue in impoverished areas (Aziz et al., 2022). A similar study reported that social and cultural influences steer households to ongoing use of affordable and accessible fuel sources, such as firewood (Yadav et al., 2021). Traditional practices affect the choice of fuel used and since women mostly run households, they prefer firewood to prepare meals because duration in preparing these meals is shorter than using electricity or gas (Treiber, 2015). A study conducted in South Africa reported that the number of women in Limpopo Province was the highest when it comes to using firewood as a source of energy for cooking due to their socio-economic status and traditional practices (Longe et al., 2021).

Education and Income

Musango (2014) suggested that education plays a role in choosing energy sources as it is assumed that more education acquired means a higher income is earned, hence, such households are more likely to choose to use cleaner fuel. Giri and Goswami., (2018) narrate that the concept of energy ladder applied in a case study conducted in Nepal, showed that the level of education and economic status of households in rural areas influenced the choice of energy sources. Households led by educated women who earned above-average income opted to use electricity and gas as compared to households run by elderly and illiterate women who live under disadvantageous circumstances use firewood and cow dung as energy sources.

Several studies have found that higher education level influences households' option to use cleaner energy source (Keller et al., 2022); similarly, Dias et al., (2021) reported that higher educational levels (and the associated higher economic status) allow households to utilise cleaner energy technologies as they are more informed about the negative impacts of using crop residue, fuelwood, and coal as fuel sources. Being more educated and knowledgeable on various energy sources, therefore, contributes to choosing cleaner energy technologies and aids in preserving energy (Fang et al., 2021; Martins et al., 2020; Blasch et al., 2017 and Ozcicek, 2017).

Age

A study conducted in the United States of America revealed that age is one of the contributing factors as to which type of energy is required and preferred by households (Estiri and Cagheni., 2019). Researchers in Nigeria reported that age does affect the choice of energy source as it was observed that households led by older people tend to steer towards using firewood as compared to gas or electricity (Baiyegunhi and Hassan., 2014). In Thailand, it was reported that the age and literacy levels of people influenced their choice of fuel, with people in their mid-40 to 50s being amenable to using cleaner energy technologies (Wall et al., 2021). Masekela and Semenya (2021) made a similar point that age influences the type of energy source used as their study reported that middle aged people in the Ga-Malahlela village in the Limpopo province, preferred to use firewood over any other source of energy; Semenya and Machete and (2019) narrated that age of the people running households in the Senwabarwana village in Limpopo Province (South Africa) had an influence on them choosing fuelwood as a source of energy.

2.3 Firewood usage as a source of energy

The Food and Agriculture Organization (FAO) in 2022 published the fact that about 2 billion households globally rely on firewood for cooking and space heating. A case study in Maroua (far north region), Garoua (northern region) and Ngaoundere (Adamawa region) in Cameroon, found that 86% of the inhabitants depend on firewood as the source of energy for cooking and space heating (Atyi et al., 2016). Research conducted in Jimma Town, about 335 km southwest of Addis Ababa in Ethiopia with about 17,078 households showed that firewood was the source of energy mostly used in rural settings as well as urban areas (Abebaw, (2021).

Firewood was reported as the main source of energy, hence, provided about 90% of the energy required for cooking, boiling water, space heating and other domestic chores in Wassorola village in Mali (West Africa) (Konare et al., 2013). Several studies have reported that over 700 million of the Sub-Saharan African population utilize firewood as a source of energy, to satisfy their domestic needs (Lambe et al., 2015; Mortimer et al., 2016a, Ozturk and Bilgili, 2015; World Bank, 2012). Lambe et al., (2015) and Dilaver et al., (2014) assert that firewood accounts for about 85% of the energy used in rural settings in Sub-Saharan Africa compared to Asia (37%) and 25% in Latin America. Similarly, firewood is the most widely used energy source for cooking and space heating in Sub- Saharan Africa (Swemmer et al., 2019); and is a crucial source of energy in South African households, where it is used to meet daily domestic needs, such as, meal preparation, heating, and a source of income in low-income settings (Guild et al., 2018).

Approximately about 2.5 billion households use firewood to satisfy their daily needs and about 90% of households use fuelwood as the main source of energy to cook and for space heating in Sub Saharan African countries, according to Sogbon et al, (2018). In Kenya, firewood is still the leading source of energy used for cooking and heating households (Kariuki., 2021). A similar finding, that firewood is the most used source of energy and has advantages for households as they can use different parts of trees, such as the branches, bark, stems while they prepare their meals and warm their homes (Mononen et al., 2016).

In Cameroon, about 2.2 million m^3/tones of firewood are consumed by households in rural areas and the firewood is also sold and this serves as an economic contribution to the gross domestic product by about 1.3% which accounts for approximately about 304 million US dollars (Atyi et al., 2016). Wollen et al. (2016) states that low-income households in rural areas mainly

used firewood to meet their daily needs, which was corroborated by Win et al., (2018) in their research conducted in the Yeshede Township in Myanmar where high consumption rates of firewood were observed in rural areas because it was the only source of energy available.

2.4 Common types of Locally fabricated direct-fired stoves.

Households in rural areas use items like, mud, dung, crop branches and leaves to construct traditional stoves (Hollada et al., 2017). The high dependency on traditional stoves and open fires leads to a high amount of firewood consumption, substantial loss of energy with low combustion efficiency, indoor air pollution and high emission of greenhouse gases and criteria pollutants. These types of stoves are cheap and simple with poor designs, such as the three iron-legged stove, clay stove and stones positioned and aligned to pots as illustrated in Figure 2.2 (Adenaiya, 2016).

Figure 2.2: Traditional clay stove (*left)* and stones placed in triangular shape (*right*) used to prepare meals in rural areas (Earthbuddies, 2022 & Mbedza, 2022).

In Chile (South America), (Guerrero et al., (2021) reported that traditional stoves used in rural areas contributed to the overall PM2.5 and PM 10 emissions released from firewood combustion. Households in rural areas in Ethiopia use traditional stoves such as the *mirt* constructed from cement and clay and a traditonal stove known as the *Gonzie*; the combustion efficiency of open fires and these tradition equipment is low during the preparation of food leading to undesirable air pollutant emissions (Kedir et al., 2019; Berrueta et al., 2017).

Okello et al. (2018) reported that women in rural households in Uganda use traditional stoves to prepare meals, however, combustion is incomplete during firewood burning, generating smoke which leads to respiratory dieseases. Approximately 730 million households in Sub-Saharan Africa, however, continue to use tradional stoves (IEA, 2014).

The - 5 star, rocket, *isitofu,* charcoal mbaula, the Kenyan *jiko, chitetezo* mbaula (Figure 2.5), 3RL, *peko pe* and mud stoves - were the traditional stoves identified in a study conducted in South Africa, Malawi, Mozambique and Zambia. The findings were that the households preferred to use these type of stoves because they are affordable, durable, versatile, use less firewood, and require less time when preparing meals, (Paliman et al., 2018).

Figure 2.5: Mbaula stove (left) used to meet domestic needs in rural households (Fuchs, 2022) & *chitetezo mbaula, right* (Kalima, 2020).

2.5. Impact of selected indigenous tree species used for firewood in South Africa

Understanding the characteristics of the various tree species is crucial when it comes to selecting the best firewood to use for domestic purposes. Factors such as - location, availability, affordability, burning properties, heat generation capacity, durability, and the ease in lighting - must be considered when choosing the wood that will suit a required need (Poynton, 2010). Hardwoods are dense, usually dark in colour, generate more heat, ignite for long periods and are great for cooking and space heating. In South Africa these include: Dichrostachys *cinerea (Sekelbos), Vachellia erioloba* (*Kameeldoring), Senegalia mellifera* (*swarthaak), Combretum imberbe, Colophospermum mopane* (*mopani tree), Ziziphus mucronate* (*buffulothorn), Acacia mearnsii* (*black wattle) and Eucalyptus globulus (blue gum*) **(**Firewood for life, 2021).

Several studies have reported the multiple functions of some wood species, for fuel and for medicinal purposes (such as remedy for, snake bites, scorpion stings, toothaches, and stomach aches). Some trees are also used to manufacture household tools, fence posts because the wood is hard and impenetrable by termites; some are suitable for decorative purposes, such as bonsai trees (www.feedipedia.org, 2021; Gardening in South Africa, 2022; Naturalist, 2022; Ghasham et al., 2017; Ads et al., 2017; Eslami et al., 2016; Aisha et al., 2015; Sameera et al., 2015; Najafi, 2013; Huan et al., 2017; Afzal et al., 2017 and Cabi, 2022). Studies have reported that some tree species are great for cooking and space heating because they are high-quality wood that is very heavy, durable and burns steadily, generating intense and prolonged heat (Gutierez et al., 2018; Pedroso et al., 2012; Bainbridge, 2022 and Mokgolodi et al., 2015). Residents in rural households still burn some trees for firewood despite their medicinal properties and availability of alternative fuel sources. This is because of these trees' extreme availability and accessibility. This practice, however, will exert pressure on the remaining wood resource in the upcoming years.

2.6 Environmental and health impacts of fuelwood usage as a source of energy

2.6.1. Environmental impacts of fuelwood usage

Some of the environmental and health impacts of firewood burning as a source of energy is described in this section.

2.6.1.1 Deforestation

Natural forests can be identified as crucial drivers of ecosystems, (Mori et al. 2017). Deforestation is the large removal of trees and plants over a wide area through anthropogenic activities such as timber collection, farming, fuelwood harvesting, as well as natural causes such as veld fires and flooding (Mba, 2018). This process causes undesirable effects, such as irregular rainfall patterns (floods and droughts) (Leite-filho et al., 2020) and loss of biodiversity (Morales et al., 2017) as shown in Figure 2.6. The loss of biodiversity affects, for example, the use of indigenous plants as traditional medication (The Human League, 2022). The harvesting of firewood wood is usally associated with a decrease in wood species and loss of biodiversity. The loss of indegenious trees can give rise to alien vegetation encroachments as well as other

related environmental hazards, such as soil erosion and flooding during rain events (Leite-filho et al., 2020).

A study was conducted in two rural villages in Caatinga (Brazil) to identify how the seasonal variations of the savanna climatic conditions would affect the criterion of harvesting firewood by the indigenous residents. The study employed interviews to outline the type of species used as firewood. The results of the findings showed that higher amounts of fuelwood were collected in winter for space heating due to the cold weather as compared to summer season; these impacts negatively on the biodiversity as it elevates the demand for those tree species (Ramos et al., 2012).

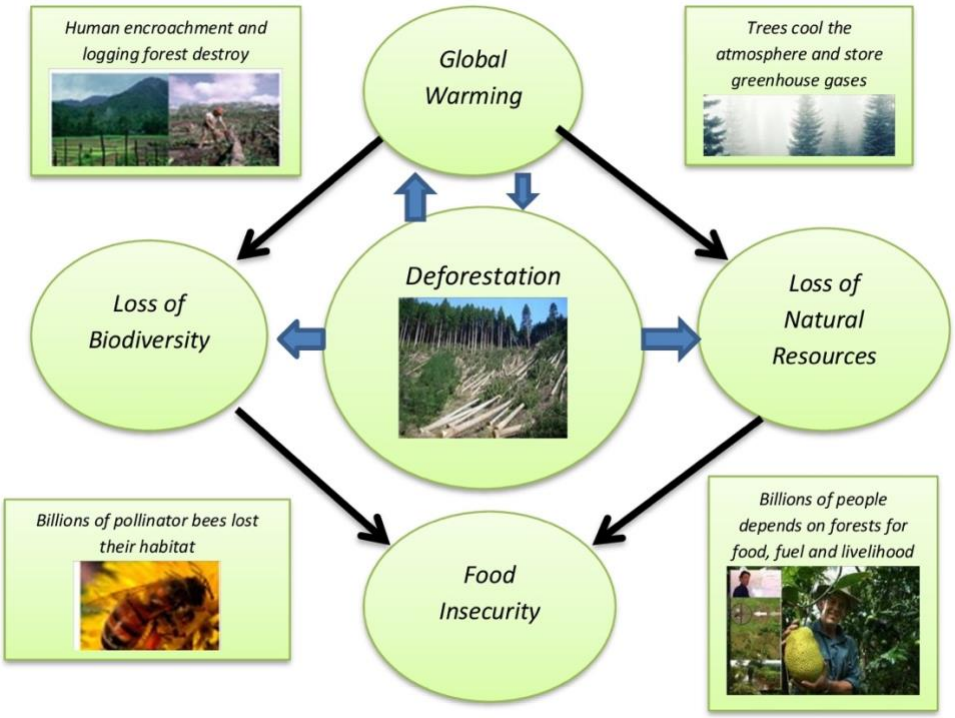

Figure 2.6: Impacts of deforestation on people and environment (World Bank, 2022).

Magrin et al., (2014) maintain that the increase of global warming can be linked to land degradation caused by deforestation. In another study, the researchers attest that

deforestation, caused by firewood harvesting in the Lower Himalayan community forests, in India, had a negative impact on soil properties such as - deterioration of soil fertility, environmental imbalances, destruction of roads, water pollution due to deposition of sediments and alteration of atmospheric composition (Hayat et al., 2021). Veldkamp et al. (2020) note that deforestation results in the decrease in soil quality in tropical forests, causing the soils to be unable to sustain plant growth and to alteration of substrata as well.

A study conducted in the basin of the Amazon of South America revealed that the hydrological cycle around the basin had been affected over the past years due to increasing deforestation rates (Ruis-Vasquez et al., 2020). Kong et al. (2022) predict that by 2035 there will be a spike in the reservoir eutrophication caused by deforestation in the eastern Harz Mountains, located in central Germany. Environmentalists in Southern Amazonia observed that the rainfall pattern has changed due to deforestation, resulting in long dry spells and rainfalls being delayed by 0.12 - 0.17 days, as the rate of deforestation got higher (Leite-fihlo et al., 2019).

Deforestation leads to climate change due to the burning of fuelwood which releases GHG and has adverse effects on the atmosphere, leading to global warming (Bennert, 2017). Mitchard (2018) assert that because of deforestation and firewood burning, tropical forests have become responsible for increased air pollutant emissions. In Malawi, researchers note that the acceleration of the deforestation rate among the Sub-Saharan African countries, due to the removal of trees harvested as firewood, has caused an increase in water yields leading to floods (Mapulanga et al., 2019). Several studies have reported that afforestation is a great initiative, however just for the grassy biomes with shrubs and tall trees such as pines which easily catch fire as compared to wood lands (Dass et al., 2018). About 70% of the global veld fires are reported in the African continent (Retallack et al., 2013). In South Africa, there is legislation prohibiting and regulating afforestation programs to control alien species invasion as well as preserve water resources as it decreases flow of water in rivers and this a serious problem in most communities (Bond et a., 2019).

2.6.1.2 Impact of air pollutant emitted from firewood burning.

The presence of oxygen and high temperatures are the main factors that influence the combustion efficiency of firewood. During the burning of firewood, heat is released through convection, radiation and conduction and result in the emission of - carbon monoxide, volatile

organic compounds, trace pollutants such as polycyclic aromatic hydrocarbons, benzene, toluene, ethylbenzene, xylenes, trimethylbenzene, phenols, aldehydes and ketones Phenol and methoxy-phenols as syringol and guaiacol; PM2.5 and PM10; nitrogen oxide (NOx); CH_4) and CO_2 (Figure 2.7). Some of these create some concerns as they contribute significantly to air quality pollution which has adverse effects on human health and the environment (Li et al., 2016; Bloemsa et al., 2016).

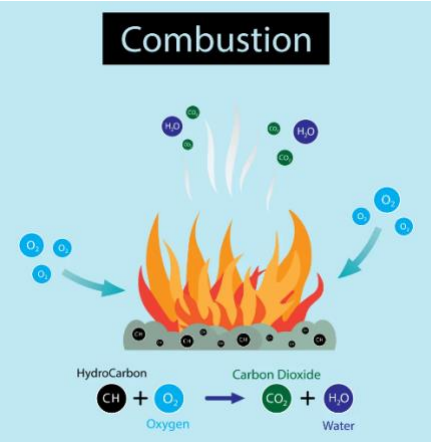

Figure 2.7: Firewood combustion process (ScienceABC, 2022).

Table 2.1: Case studies of air pollutants reported from firewood combustion.

Region	Case Study reported	Reference
In Nepal	CO_2 emissions of 14.26 kg CO_2 e/ (households per day) from firewood burnt.	Ram et al., 2020.
In Hawella Tula, of Hawassa city in Ethiopia	carbon dioxide emissions were 0.93 kg CO_2e/ kg from firewood combustion by households.	Yigezu et al., 2021.
In Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti State in south-western Nigeria	Average emission rates for SO_2 ranged from 13-330 mg/ m^3 and NOx 0-23.67 mg/ m^3 from firewood combustion used for	Fakinle et al., 2020.

	cooking and space heating in households.	
In Ethiopia and in Uganda	In a case study the PM 2.5 concentrations emitted from cooking in kitchens in the Kumbursa village and Kikati village were 205 µg/m^3 and 177 µg/m^3 respectively.	Okello et al., 2019.
in Gazi Bay, Southern Kenya	Households burnt firewood for domestic purposes and an average CO (5.9 ppm) and PM2.5 (10 mg/m^3) concentrations were emitted.	Jung et al., 2019.
In Sub-Saharan Africa.	Reported concentrations of PM2.5 (1574 µg/m^3) and carbon monoxide (0.64 ppm) from firewood combustion.	Bede-Ojimadu and Onsankwe 2020.
In Brong-Ahafo region of Ghana.	A study conducted on pregnant women revealed that CO concentrations of 1.04 ppm were released from firewood burning during cooking and this may cause negative health impacts such as damage to the baby's brain and other organs in unborn babies.	Quinn et al., 2016.

In two villages in the Nyando Division of Nyanza Province in rural western Kenya.	A study conducted reported CO (4.99 ppm) and PM2.5 (588 µg/m^3) emissions from firewood burnt in kitchens preparing meals .	Yin et al., 2017.

2.6.2. Health effects of firewood combustion

When wood is combusted, it releases smoke which comprise of various gases, such as criteria pollutants and greenhouse gases which have health implications on human beings. The most harmful of these organic compounds is the fine particulate matter (PM2.5) which causes most damage to the human respiratory system (Bruce et al., 2000; Naeher et al., 2007).

Indoor and outdoor air quality can be polluted by the smoke coming from burning firewood and causes irritation of the nasal cavity and eyes; this induces - coughing, makes breathing painful, causes asthma, deteriorates the functioning of the lungs, brings on chronic bronchitis and cardiovascular problems - because these gases and the fine particles enter the respiratory system and get absorbed into the bloodstream, as illustrated in Figure 2.9 (Weidong et al., 2017).

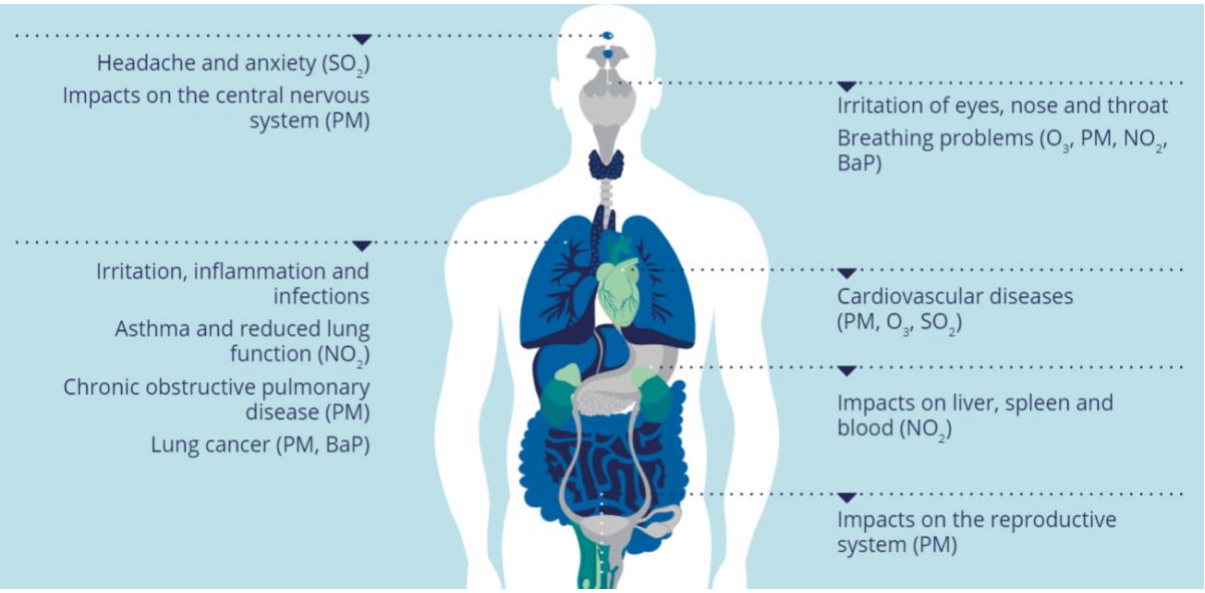

Figure 2.9: Health effects of exposure to smoke inhalation (European Environmental Agency, 2019).

In European cities, it was reported that the particulate matter (PM) was one of the pollutants emitted from wood combustion (Cincinelli et al., 2019). Health effects such as cardiovascular and respiratory diseases, high blood pressure and a shutdown in the functioning of the lungs can be related to inhalation of PM from firewood emissions (Vicente et al., 2018). Germany was recorded as exhibiting over 45% of PM 2.5 emissions from residential wood combustion devices using firewood (Clean Heat- Environmental Action., 2016).

PM emissions from domestic combustion result in health implications such as lung failure because they are nanoparticles (Trojanowski et al., 2019). Total Suspended Particles, $PM_{2.5}$,carbon monoxide, nitrous oxides were released from domestic firewood combustion from research by Schmidt et al., (2018). Pollutant concentration emitted from Sub-Saharan African households burning of firewood, according to Bede-Ojimadu et al., (2020), ranged from 26.3 - 1574 µg/m^3 for $PM_{2.5}$ and from 0.64 - 22 ppm for carbon monoxide; these can cause severe health impacts when inhaled by human beings.

Research in north-east India, revealed PM2.5 concentrations emitted from firewood burning affected the bloodstream and caused oxidative stress to women exposed to the inhalation of firewood fumes, in households, in rural areas (Rhaba et al., 2018). It was observed that about 24.6% of the residents responsible for preparing meals in rural households in Malawi was more likely to have respiratory diseases from their exposure to firewood burning (Das et al., 2017).

Several studies have illustrated that a combination of particles and gases from open air pollution yields a toxic mixture with ozone; this is linked to various acute and chronic health implications, as well as mortality from cardiovascular, respiratory, and other diseases (Nuvolone et al., 2018; WHO, 2016; Global Burden Disease Study, 2015; Landrigan et al, 2018). Human health and wellbeing are dependent on clean air, however, globally it has been observed that air pollution creates risks which adversely affect the human health. WHO (2014) asserts that households burning firewood in traditional stoves are more susceptible to toxic emissions, resulting in many deaths recorded every year.

Children and female are the groups more likely to be affected by health risks associated with firewood combustion, such as respiratory diseases and early mortality as they are more exposed to fumes from firewood burning (Gioda et al., 2019). Indonesian households using fuelwood for cooking, reported that individuals responsible for preparing meals were affected negatively by being exposed to smoke from wood burning and a decrease of about 9.4% of the lung's ability to perform its respiratory functions (Silwal et al., 2015). Similar findings indicated that exposure to smoke from firewood combustion led to approximately 1.6 billion mortalities, annually, in Mexico (Stabridis et al., 2018).

Pallegedara et al., (2020) assert that the potential of inhabitants being diagnosed with asthma in Sri Lankan households using firewood as a source of energy, has increased by 10.9%. Using firewood as a source of energy increases the chances of getting diagnosed with health issues such as persistent coughing, shortness of breath and asthma from inhaling smoke during firewood burning (Mohapatra et al., 2018). Piabuo et al. (2019) added that about 70% of people exposed to burning firewood would be affected negatively from inhalation of smoke in Sub-Saharan African countries.

The World Health Organization (WHO), the Department of Environmental Affairs (DEA in South Africa) and the South African National Ambient Air Quality Standards (NAAQS) have developed a response to this global problem by setting air-quality standards which contaminants need to comply with over a period, usually, hourly, and annually. These guidelines serve as restrictions and assist in the management of pollutants and their exposure to humans. These pollutants include - nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$), benzene (C_6H_6), carbon monoxide (CO) and lead (Pb). The air quality standards are listed below in Table 2.1 (DEA, 2009). It is, therefore, essential to constantly monitor these pollutants and ensure the emissions fall within these guidelines set.

Table 2.2: South African National Air Quality Standards NAAQs (USEPA, 2023).

Pollutant [links to historical tables of NAAQS reviews]		**Primary/ Secondary**	**Averaging Time**	**Level**	**Form**
Carbon Monoxide (CO)		primary	8 hours	9 ppm	Not to be exceeded more than once per year
			1 hour	35 ppm	
Lead (Pb)		primary and secondary	Rolling 3 month average	0.15 µg/m^3 (1)	Not to be exceeded
Nitrogen Dioxide (NO_2)		primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		primary and secondary	1 year	53 ppb (2)	Annual Mean
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm (3)	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 µg/m^3	annual mean, averaged over 3 years
		secondary	1 year	15.0 µg/m^3	annual mean, averaged over 3 years

Pollutant [links to historical tables of NAAQS reviews]		Primary/ Secondary	Averaging Time	Level	Form
		primary and secondary	24 hours	35 µg/m^3	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 µg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb (4)	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

CHAPTER THREE: METHODOLOGY

Preamble: This chapter provides a detailed description of the processes, equipment and methods employed to conduct this study.

3.1 Research design

A quantitative and qualitative research methods were used in this study. Primary data were obtained with the means of questionnaires and interviews, as well as the measurement of firewood from households. Figure 3.1 shows the schematic design of the research process.

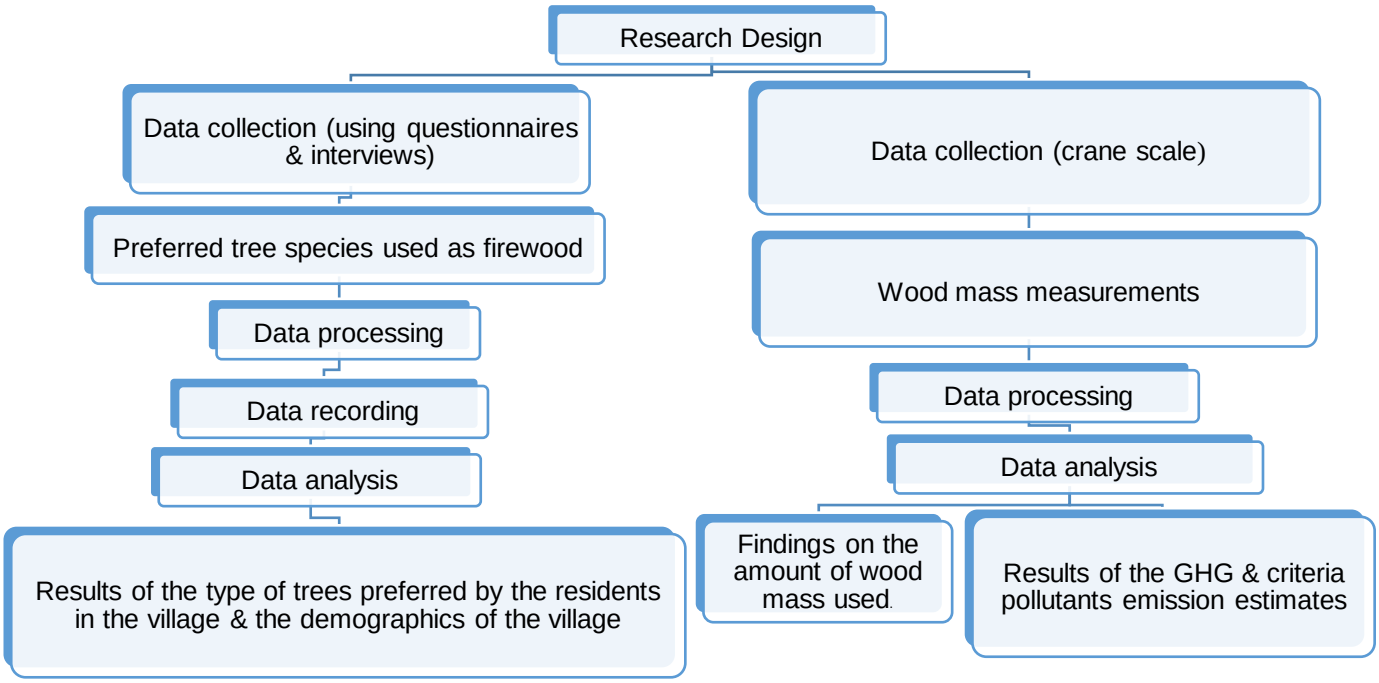

Figure 3.1: Schematic design of the research design.

3.2. Pilot Study

Commencement of the research was preceded by a pilot study for the researcher to become familiar with the study area and to correct any shortcomings such as analysis challenges like survey fatigue, reluctance towards certain questions, incorrect interpretation of the questions, incomplete entries and skipping questions prior to conducting the main survey. A consent form approved by the Research Ethic Committee of the University of Venda (see Appendix A) was

distributed to the participants describing what the study entailed and reassuring the participants of confidentiality in relation to any information obtained during the study.

A questionnaire was drafted (Appendix B) and was administered to 10 subjects randomly selected at Mangondi village. The questionnaire probed for information about - firewood combustion in various seasons, the tree species located within the study area, the burning activities practiced, the cost of firewood purchased from commercial outlets and the frequency of harvesting firewood. For the quantification of firewood used daily to meet their domestic needs, 10 households were selected to partake in the pilot study. The amount of wood used was weighed for 1 week and measurements were obtained both in the morning and evening. The aim of this pilot study was to determine, the burning pattern of the households, the amount of firewood burnt, and what remained after the burning sessions.

3.3 Data collection

3.3.1 Sampling and data collection

Using the probability sampling method as outlined by Leedy & Ormrod (2015), a random sample was selected to represent the overall population. This selection criterion ensured that each person in the population had an equal chance to participate in the survey.

Using equation 1 the sample population was calculated.

$n = \frac{N}{1+Ne2}$ .....equation 1

Where

n = sample size,

N = population size,

e = level of precision (At 95% level of precision p = 0.05)

$n = \frac{N}{1+Ne2}$

n= 400/1+400(0.05)^2

=200 households

The number of households in the Mangondi village is about 400 and a total of 195 questionnaires were distributed to the households that agreed to participate in this survey, adopting the sampling method of Leedy & Ormrod (2015). Information obtained from the participants was used to achieve objective 1, which was to identify the preferred tree species used as domestic firewood in the study area.

Proper COVID health protocols were adhered to during the study, such as ensuring the use of hand sanitizers, wearing of masks, and maintaining a 2 m social distance. The questionnaires were distributed using a purposive sampling technique, therefore, the participants targeted were the individuals who were responsible for the daily domestic chores in each household. Questions requesting demographic data, fuel wood uses, types of trees used and preferred were on crucial aspects of the study. The questionnaire consisted of 31 questions, with 18 forming part of the interview section (Appendix A, section B). The households were chosen based on them showing an interest to partake in the study and them using fuelwood for cooking and space heating was mandatory for selection.

3.3.2 Measurement of Firewood used in households of the study area

Firewood measurements was done in forty households (Figure 3.2) in both winter (June-August) and summer (November- January) seasons. The measurement was done daily for a period of six weeks in both seasons. Firewood used daily for cooking, boiling water and space heating were quantified with a crane scale of capacity 300 kg (Figure 3.3).

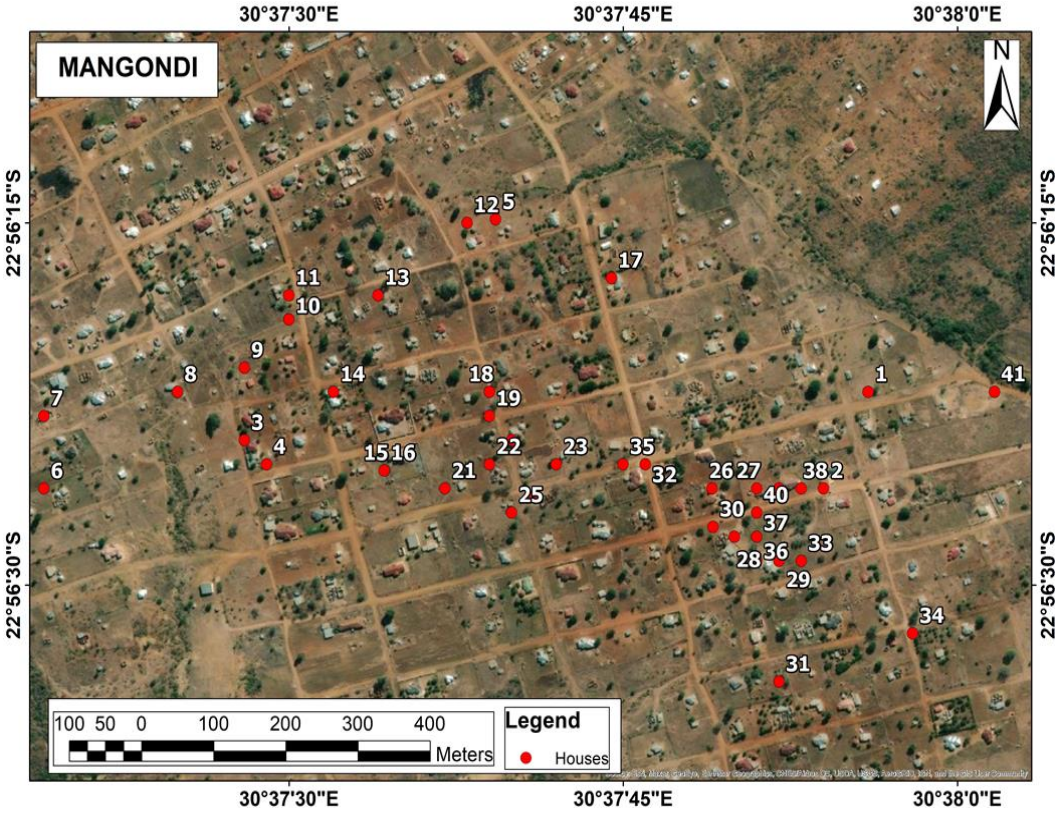

Figure 3.2: Location of selected households for the study.

Figure 3.3: Crane scale used to measure firewood.

Firewood consumption rate of each household was determined using firewood consumed per household per hour. The determination of the daily firewood consumption rates, the amount of firewood (kg) used was recorded daily and coded on an Excel sheet.

The collected data showed average firewood consumed weekly and monthly from each of the 40 households during winter and summer seasons (2021) in Mangondi village in tabular format. This data was used to determine the fuelwood consumption rate per capita/ day using the following formula:

Daily consumption rate (kg. person^{-1}day^{-1}) = total amount of firewood used per day (kg) / total number of people in the household (Ram et al., 2020). The daily consumption rate per capita was calculated from two burning sessions, in the morning and evening.

The emission factor is a value that can be used to describe the amount of a pollutant emitted in the atmosphere as a result of an activity. The emission factors listed in the AP-42 as per the guidelines drafted by the Emission Factor and Inventory Group (EFIG) is a crucial and universal tool that can be utilized for managing pollutants by government organizations as well as independent companies (USEPA, 2023).

Estimation of greenhouse gases (CO_2) and criteria pollutants (SO_2, NO_X, CO, $PM_{2.5}$ & PM_{10}) emissions from firewood combustion in each of the households in winter & summer seasons (2021) in Mangondi village was determined using Equation 3.1, described by Ludwig et al., (2003), where the emission rates were estimated by multiplying firewood consumed by the emission factors.

Emission (g C. kg^{-1}) = BC x EF……. Equation (3.1)
Where:

BC- is the biofuel consumption rate.

EF- is the Emission Factor for the gas.

Activity rate is the consumption of wood per household per hour and the emission factors for firewood combustion are presented in Table 3.1.

Table 3.1: Emission factors used to calculate emission estimates.

Source	Units	CO_2 [a]	CO [a]	NO_x [b]	PM2.5 [b]	PM10[b]	SO_2[b]
wood	g/kg	450	43	1.3	15.3	17.3	0.2

(a: Ludwig et al, 2003; b: USEPA, AP-42, 2022).

3.4 Statistical analysis

The data collected from the questionnaires was evaluated using statistical procedures (analysed for mean, Anova, regression, frequency analysis) of the Statistical package for Social Sciences (SPSS 21.0) and the amount of firewood recorded was calculated using Microsoft Excel (Excel 2010).

3.5 Ethical Considerations

This study was approved by the University of Venda Research Ethics Committee (FSEA/22/GES/07/2306) (Appendix B). Permission to conduct the study was also obtained from the tribal authority of Mangondi village.

CHAPTER FOUR: RESULTS AND DISCUSSION

Preamble: This section presents the results obtained from this study and analysis discussion of the domestic energy use, questionnaire distribution, preferred tree species, scale measurement of wood mass and estimation of emissions from air pollutants released from firewood usage pattern. Finally, through these five analyses, the objectives of this study can be achieved.

4.1 Domestic Energy Use

The questions asked during the pilot study aided the researcher to observe whether the participants of the households of Mangondi village understood the aim of the study and they were improved and updated for the main study.

This study employed semi-structured questionnaires and interviews where the information recorded was inclusive of - the age, education level, occupation, monthly income needed to meet domestic needs per household, number of inhabitants residing in the household, fuel type used as a source of energy in the house and the preferred tree species used as firewood. The criteria for distinguishing and outlining the "preferred tree species " in this study were that the species was recognised as the main types of trees used as by the participants.

After this phase was completed, preferred tree species used as firewood in Mangondi village was identified. The participants in this study all utilised firewood for cooking and space heating, hence, the questionnaire and interview questions were designed to establish the rationale behind the continuous use of firewood as a source of energy while they have electrified homes; information was also sought on participants' appropriate time for firewood harvesting and collection, the frequency of harvesting firewood per week, daily burning activities, the mode of transport used for collection and the family members responsible for the firewood harvesting and collection.

Results on the preferred tree species and the quantity of wood mass used in Mangondi village were obtained from questionnaires and using scale measurements. There were only two types of energy sources used in Mangondi village - wood and electricity. The harvested firewood is usually put into a 3-legged iron stove by all the households (Figure 4.1). The harvesting locations of fuelwood were along the riverbed, forest and the hilltop and firewood were used twice daily, in the morning and evening burning sessions.

Figure 4.1: Three-legged iron stove used to cook and boil water by the households.

4.2. Questionnaire distribution

The availability of the type of tree species determined which tree species would be harvested, collected, and burned during winter and summer. One representative from each household was chosen for the completion of the questionnaire and taking part in the interview process. During the study, it was observed that the number of people residing in various households ranged from 1 - 11 people, who were - a mother, father, children, and grandparents - with an overall average of 4 or 5 people residing in each household (Figure 4.2). Household size is a factor that may sway the choice of energy in rural areas, especially, when the unemployment rate is high. One participant responded by saying: “My family consists of 9 people and only depends on my grandmother’s pension every month to meet our domestic needs, therefore, it is cheaper to use firewood instead of electricity for cooking”. Another mentioned that: “My household has 5 people and rely on my 3 children’s social grant money; I prefer using fuelwood because it is available

and “free”. I enjoy the taste of food cooked with firewood as compared to when it is cooked using electricity”.

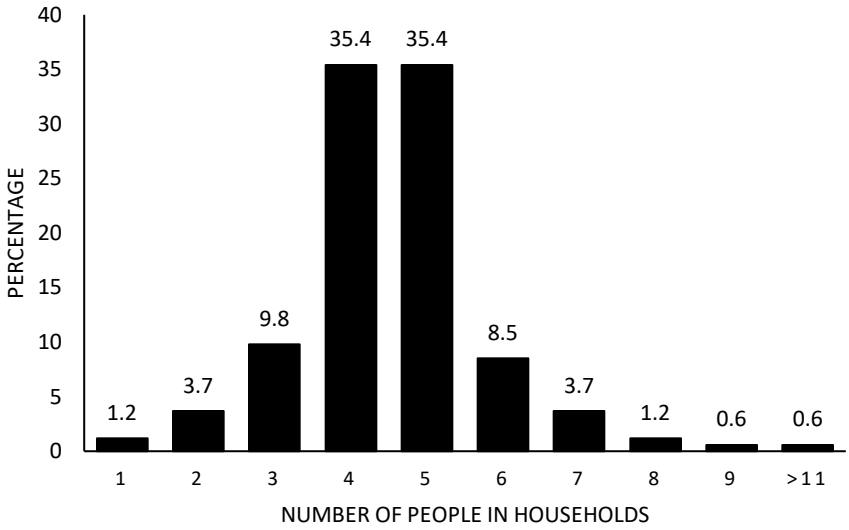

Figure 4.2: Number of people residing in each household.

The responses provided by the participants from the questionnaires accentuated that the main sources of energy used to meet domestic needs in Mangondi village, were firewood and electricity. This reveals that not all rural settings can be assumed to be using coal, paraffin, and gas as sources of energy since households social and economic status can influence the choice of fuel used (Uhunamure et al., 2017).

Sfez et al. (2017) reported that cow dung is used for combustion in households, to cook, in rural settings in India. Studies have reported that over a million households in the rural Sub-Saharan Africa use coal as a main source of cooking (IEA, 2009). A case study evaluating the implementation of LPG in one of South Africa’s townships (Atteridgeville, Pretoria) was initiated by the Department of Energy in 2006 and the outcomes provided substantial evidence that the residents of Atteridgeville considered LPG as an effective alternative source of energy for cooking and heating (Kimemia et al., 2016).

The participants explained that electricity was only used to illuminate their homes and charge small gadgets such as their radios and phones and would only be used for cooking when it is raining, since most of the households do not have a properly designated and covered area for

outdoor cooking. It was also observed that climatic conditions such as temperature play a major role in the consumption rate of fuelwood since more wood is used in the dry season as compared to the wet season. The number of people residing in each household affects the amount of firewood-burning rate as this equates to the burning activities conducted daily to meet the domestic needs of the households. Availability, durability, and accessibility influenced the type of tree species preferred as a source of energy as stated by the respondents.

4.2.1. Demography of the participants in *Mangondi village*

The participants in this study are characterised as being 100% African race with 75.6% females, and 24.4 % males. More female participants headed the households as compared to the males since many males are in other parts of the country in search of job opportunities to provide for their families. Majority of the households are run by people older than 45 years (52.4 %) as illustrated in Figure 4.3 and they still opt to use firewood for cooking because the food prepared in that manner tasted better than meals prepared by other energy sources.

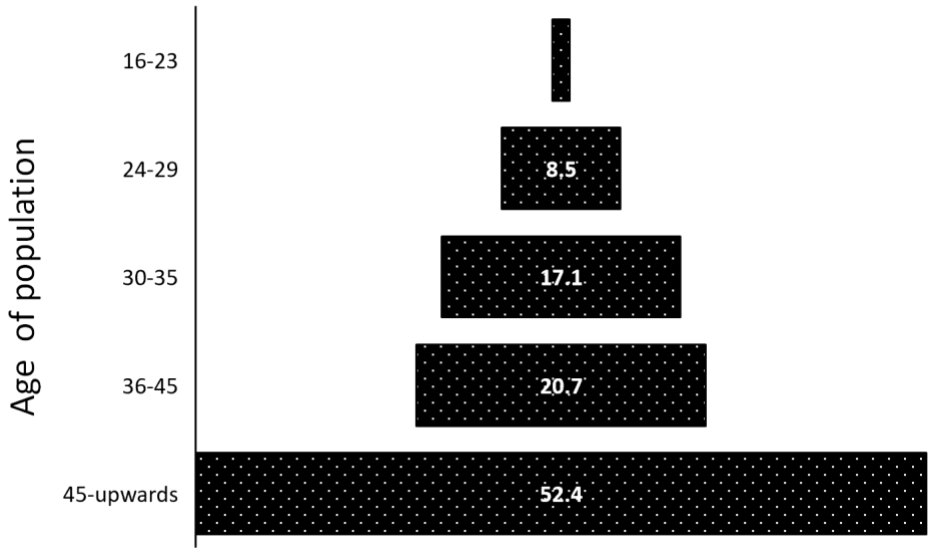

Figure 4.3: Age variation of the residents

The female members of these homes are responsible for chores like - harvesting and collecting wood, collecting water from the local drawing point, cooking, cleaning, and doing the laundry. The study sought to determine if age influences who is responsible for firewood harvesting in the

household. The possible correlation between age and who is responsible for firewood harvesting in the household variables was determined by using the linear regression analysis (Table 4.1). There was no statistically significant association between age and who is responsible for firewood harvesting in the household [(F (1,89) =0.003, p = 0.954), as the p-value is more than the significance level p > 0.05 as shown in Table 4.2. A low inverse correlation (R=-0.11) was observed in this study, as the population age group increases the people harvesting firewood decreases.

Table 4.1: Model summary

Model	R	Adjusted R Square	Std. Error of the Estimate
1	0.006[a]	-0.011	0.56615

a. Predictors: (Constant), Age

Table 4.2: Anova [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.001	1	0.001	0.003	0.954b
	Residual	28.526	89	0.321		
	Total	28.527	90			

a. Dependent Variable: the one responsible for fuelwood harvesting in the household

b. Predictors: (Constant), Age

To check the linear regression – the person responsible for firewood harvesting in the household - was used as the dependent and gender as the independent variable. This indicates that the dependent and independent variables were included in the test. Pearson's correlation (R^2 = 0.91) between the person responsible for firewood harvesting in the household and gender was given;

there is a perfect positive interrelation between the two variables, which implies that only 91% of the population responsible for harvesting firewood is explained by the gender of the person.

The ANOVA table shows the “usefulness” of the linear regression model with P < 0.05. This provides the quantification of the relationship between the person responsible for firewood harvesting in the household and gender. Firewood is mostly harvested and collected by women (90.2%, n=176) and there is a statistically significant association between gender and the person responsible for firewood harvesting in the household [(F (1,89) =8.962, p = 0.04), as the p-value is less than the significance level p > 0.05 (Table 4.4).

Table 4.3: Model summary

Model	R		Adjusted R Square	Std. Error of the Estimate
1	0.302[a]	0.91	0.81	0.53964

a. Predictors: (Constant), Gender

Table 4.4: Anova [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.610	1	2.610	8.962	0.004b
	Residual	25.918	89	0.291		
	Total	28.527	90			

a. Dependent Variable: the person responsible for fuelwood harvesting in the household

b. Predictors: (Constant), Gender

4.2.2 Socio-economic status of Mangondi Village

The economic status of the households in this study area showed that 59.8% (n=115) of residents in Mangondi village are unemployed, 21.3% (n=49) are pensioners, 16.5% (n=27) are self-employed and 2.4% (n=4) are employed, as illustrated in Table 4.5.

Table 4.5: Employment status of households in Mangondi village.

Employment status	Percentage (%)	n
Unemployed	59.8	115
Employed	2.4	4
Self-employed	16.5	27
Pensioners	21.3	49

A high percentage of household heads (60.4%, n-130) have completed secondary schools and only (1%, n=2) had tertiary education as shown in Table 4.6.

Table 4.6: Educational status of household heads in Mangondi village.

Educational status	Percentage	n
Primary	13.4	22
Secondary	60.4	130
Tertiary	1.2	2
None	25.0	41

The study revealed that the households were family-oriented with a percentage of (54.3, n=99) consisting of married couples (Table 4.7) and this could help support the observation made in the field that different chores are designated to different members of the household.

Table 4.7: Marital status of households in Mangondi village.

Marital status	Percentage (%)	n
Single	31.7	62
Married	54.3	99
Divorced	0.6	2
Widow	12.8	30
Widower	0.6	2

Majority of the respondents (40.9%, n =83) fall under the monthly income range of R1001-R1500 and they usually depend on government grants for their livelihood (Table 4.8).

Table 4.8: Monthly income of households in Mangondi village.

Monthly income (Rands)	Percentage (%)	N
0-500	0.6	1
501-1000	31.1	61
1001-1500	40.9	83
1501-3500	24.4	40
>3500	3.0	10

A study conducted by Zaku et al., (2015) reported that it is relevant to know the factors that may influence which type of energy source will be used by households. A study by Uhunamure et al. (2017) on households of Altein, Botsoleni, Makhovha and Thenzheni villages revealed that majority of these residents receive a monthly income of <R1500. Also, majority of the respondents of that study were unemployed, hence, the financial status of the people may be one of the factors influencing the choice of firewood as their major energy source for cooking and space heating. Karakara et al., (2019) reported that households will opt for better and more convenient energy sources, as their socio-economic status upgraded.

4.3 Preferred tree species

In Mangondi village, firewood is collected from three locations - the hills near the Luvubu river, the forest (flood plain) and the riverside. The Floodplain is the most preferred for harvesting firewood represented by (64.4%, n=117) of the participants, followed by the hills (23.3%, n=55) and then along the riverbanks (12.3%, n=23). The residents mentioned that the forest was the most preferred location to collect fuelwood as it provides easy access to the preferred tree species. Majority of the households stated that the choice in the type of tree harvested, therefore, depended on availability, accessibility, and the rate of combustion.

Firewood is mostly harvested and collected by women (90.2%, n=176). Majority of the respondents (44.5%,n=19) usually harvest firewood more than twice weekly (Figure 4:4). The number of people in the households determines the amount of wood harvested as well as the frequency of harvesting. This is because, naturally, larger household would require more firewood for cooking and space heating.

The harvesting of firewood wood is usally associated with a decrease in wood species and loss of biodiversity (Hayat et al., 2021). The loss of indigenious trees can give rise to alien vegetation encroachments as well as other related environmental harzards, such as soil erosion and flooding during rain events (Leitefilho et al., 2020). Some trees are also used for medicinal purposes and their loss could affect the health of the people who depends on them (Arshad et al. , 2022).

A study that was conducted in two rural villages in Caatinga (Brazil) to identify how the seasonal variations of the savanna climatic conditions would affect the criterion of harvesting firelwood by the indigenous residents. The study employed interviews to outline the type of species used as firewood. Findings were that higher amounts of firewood were collected in winter for space heating due to the cold weather as compared to summer season; this impacts negatively on the biodiversity as it elevates the demand for those tree species (Ramos et al., 2012).

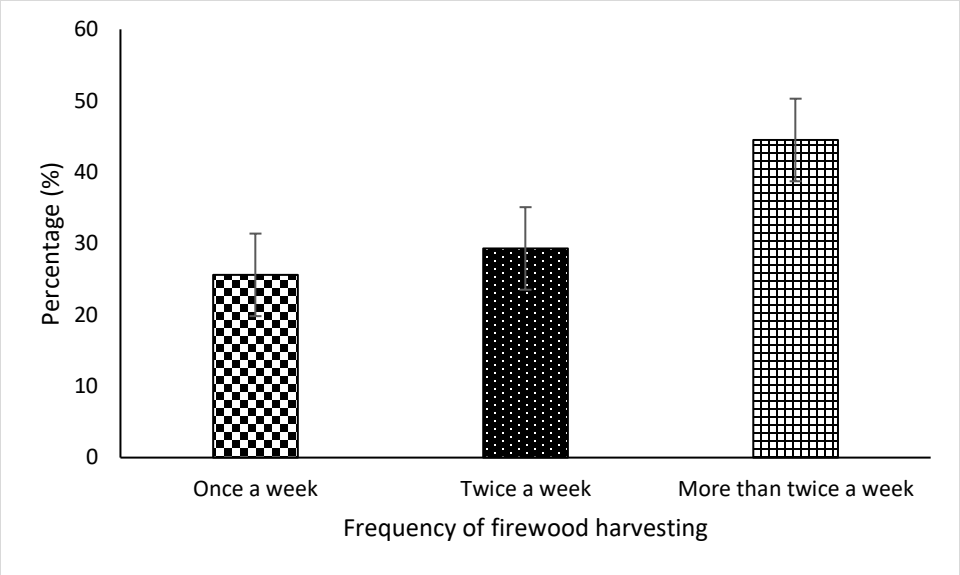

Figure 4.4: Frequency rate of firewood harvesting weekly.

The respondents usually covered varied distance and spend varied amount of time to harvest firewood from the various locations. They usually walk about 500 m to 2 km to collect firewood from the hilltop (2h30 - 4 hours), along the riverbed (2- 3 hours), from the forest (1h30 hour) and an hour – 4 hours collecting firewood around the village (Table 4.9). The forest was, hence, the most preferred location to harvest firewood because the distance travelled was the shortest; this increased the overall amount of wood collected due to multiple trips possible.

The respondents stated that they start collecting firewood from 6:00 -10:00 am in summer season since its hot and there is sufficient light when they head to the forest; this also provides a safety measure as they proceed deep into the forest and surrounding areas. They start around 10:00 – 11:00 am in winter because its colder and darker in the early hours of the morning, therefore, they spend most of their early morning ensuring that the domestic chores such as cooking, preparing water for bathing are completed prior to heading to the locations for harvesting firewood. The households mentioned that collecting firewood is a strenuous activity since it requires a lot of energy to harvest and the distance travelled from their homes to the hills makes it tiring to make several trips, back and forth, with the harvested wood. Mangondi village has various plant species, trees, shrubs, and grasses. The description and uses of the preferred trees species in the village is outlined in Table 4.10.

Table 4.9: Preferred tree species harvested for firewood.

Time spent (hours) during firewood harvesting	**Location of firewood harvesting**	**Distance travelled (km)**	**Type of trees**
2 – 3	Along riverside (Luvubu)	1 – 2	Euclea divinorum Hiern (Mutangule), Dichrostachys cinerei (Murenzhe)
2:30- 4.00	Hilltop (mountain)	1 - 3	Euclea divinorum Hiern (Mutangule), Combretum imberbe (Mudzwiri)and Dichrostachys cinerei (Murenzhe)
1:30	Forest (flood plain)	0.5- 1	Euclea divinorum Hiern (Mutangule), Dichrostachys cinerei (Murenzhe)

The residents of Mangondi village preferred three types of tree species. From the *Fabaceae family* are Dichrostachys cinerei (Murenzhe); Combretum imberbe (Mudzwiri) and *Ebenaceae family* is Euclea divinorum Hiern (Mutangule) as shown in Figure 4.6. These tree species were preferred because they are high-quality wood, very durable, and burn steadily, generating intense heat. The Dichrostachys cinerei (Murenzhe) was the most preferred tree type because its an incroaching species and is readily available and also for its burning properties as it generates intense heating and burns even when wet. Several studies conducted in - Mantheding Community; Duthuni; Tshidzivhe, Vuvha, Lwamondo, Mashau and Tshiendeulu - in Limpopo Province in South Africa reported that the most preferred tree species used as firewood for cooking and space heating are from the Fabaceae family (Semenya. 2020; Rankoana. 2016 and Constant et al., 2018).

Table 4.10: Preferred firewood species used by households in Mangondi village

Botanical name	**Local name**	**Family**	**Description**
Dichrostachys cinerei	Murenzhe	Fabaceae family	Dichrostachys cinerei - is a tiny shrub that grows 7 metres high with a dense crown about 3 metres in width having a spiny leafy appearance (El-Sharawy et al., 2017). It is mixed with traditional herbs to also treat stomach aches and sexual illnessess (Kimani et al., 2018).
Combretum imberbe	Mudzwiri	Fabaceae family	Combretum imberbe- is the tallest when compared to the other South African combretums; it grows up to 20m high (The Namibian, 2015). It has medicinal purposes such as being remedies for coughs, colds, diarrhoea, chest pains, stomach pains and bilharzia. It can also be used as toothpaste, for tanning leather, furniture and sculptures; in Namibia it is used during cultural practices as it is referred to 'white magic'' (Mtsweni, 2016).
Euclea divinorum Hiern	Mutangule	*Ebenaceae family*	Euclea divinorum Hiern- grows up to 9 m tall, characterised by densely-branched canopy and looks like a shrub. It is used to make traditional remedies for stomach illness, sexually-transmitted diseases, water purification in South-Western Ethiopia. East Africa, Northern Namibia, and the Yemen Island (Ngari et al., 2013 and Al-Fatima, 2019).

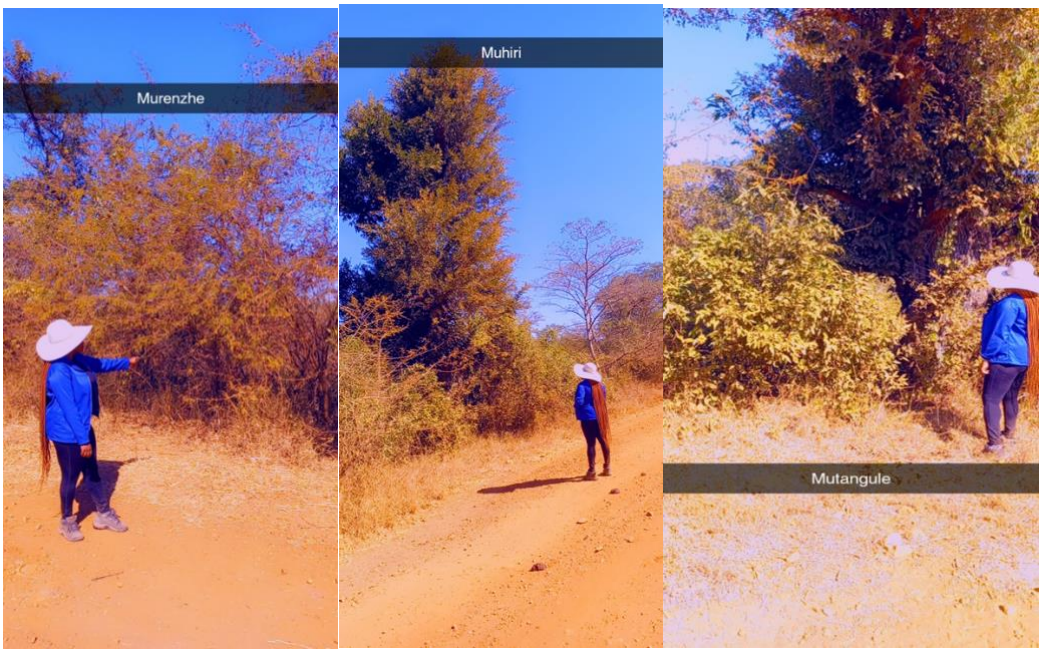

Figure 4.6: Most preferred tree species: Dichrostachys cinerei (Murenzhe) (left), Combretum imberbe (Mudzwiri) (middle) and Euclea divinorum Hiern (Mutangule) (right).

Madubansi et al., (2007) reported in a study conducted in Bushbuckridge (Mpumalanga Province) that Dichrostachys cinerei and Combretum imberbe were the tree species preferred as firewood because they produce fire that burns intensely and lasts longer. In the Mochudi village (Eastern Botswana) the most preferred tree species were Combretum imberbe and Dichrostachys cinerei as they burn steadily; some tree species were not consumed as firewood because of traditional beliefs, such as their association with curses and evil spirits and their generation of irritating fumes (Tamboeti – Spirostachis Africana)(Mphinyane et al., 2018).

There were four modes of transportation of firewood from the harvesting spots back to the households - carrying wood on the head, using a bakkie or truck, using a wheel burrow and using a donkey cart. The respondents highlighted that their mostly used methods for transporting the wood were using a wheelbarrow (66.3%, n=129), using a bakkie/truck (20.2%, n=39), carrying fuelwood on the head (12.9%, n=25) and the least being the use of a donkey cart which accounted for (0.6%, n=2), (Figure 4.10). The wheelbarrow, therefore, was the most favoured mode of transportation due it is simple, affordable, and easily accessible to the community members. In Gaatinga rural village, modes of transport used by households in transporting firewood were - horse/donkey (41%), head (45.5%) and human-powered carts (13%) (Ramos et al. (2012)

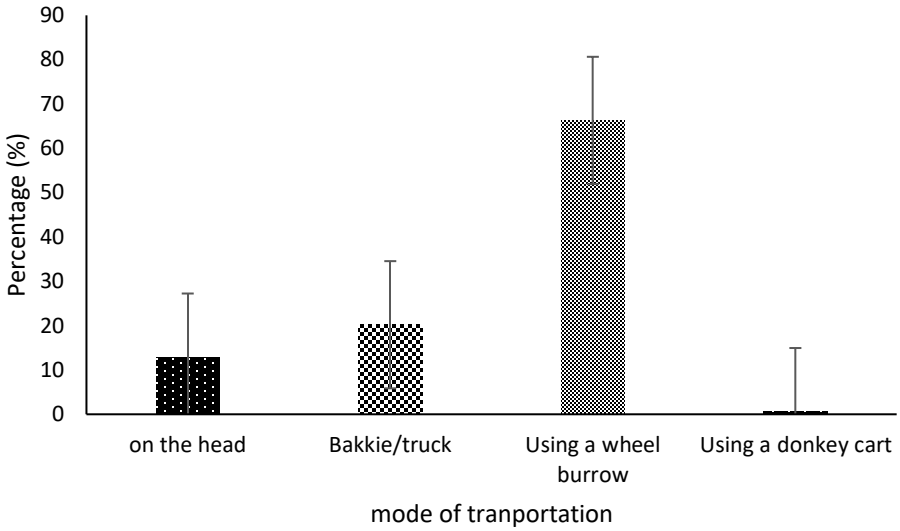

Figure 4.10: Modes of transportation of firewood.

4.4. Scale measurement of wood mass.

To have a clear understanding of the firewood used at Mangondi village, the average daily consumption of firewood in the households was quantified; an average was then calculated for both morning and evening burning periods, for winter and summer seasons. A total of 40 households were used in this study to measure the firewood usage during the winter (June-August 2021) and summer seasons (November-January).

There are 2 activities which require burning firewood, per day in the village. The households burn firewood in the morning and evening, although, households burn more firewood in the morning than in the evening. It was observed that substantial amounts of wood were combusted during the winter season in comparison to summer season.

There is a difference in the duration of combustion between the morning and evening burning sessions, as most domestic chores are done in the morning. The residents stated that they spend about 2-5 hours to cook pap and meat/vegetables which will be eaten the whole day as well as boil water for tea, bathing and washing dishes in the morning, however, burning sessions last for 1-1h30 hours in the evenings, as then the predominant activity is boiling water for bathing and space heating and seldom for preparing meals as these have already been prepared in the morning, in large quantities.

Space heating usually occurred outside the households in the yards as most households do not have a designated kitchen used for cooking. There is a 5–6 hours' time lap before the households starts burning wood between the morning and evening burning events. The weekly mean firewood mass burnt in the summer season ranged from 77.15 -169.31 kg in the morning session and 34.45- 58.14 kg in the evening, with the highest wood mass (1214.16 kg) was consumed during the first week when less rain was observed during the summer (Table 4.11).

Table 4.11: Average quantity of wood used in the mornings and evenings by 40 households in Mangondi village in the summer season.

Description	Summer season			
	Morning		Evening	
	Mean kg/week	(Sum) kg/week	Mean kg/day	(Sum) kg/week
Week 1	169.31± 27.9	1214.16	47.86 ± 13.25	380.07
Week 2	102.89 ± 50.53	702.32	39.44 ± 14.53	246.10
Week 3	80.14 ± 10.4	546.1	34.45 ± 11.75	275.53
Week 4	82.5 ± 27.69	633.03	50.16 ± 6.42	362.41
Week 5	77.15 ± 9.64	580.29	58.14 ± 8.55	440.7
Week 6	88.47 ± 24.71	638.48	55.4 ± 13.88	409.8

The weekly mean mass burnt in winter season during week 1-6 ranged from 152.08 -226.25 kg in the morning and 126.94-170.95 kg in the evening. The highest wood mass was recorded as 1627.88 kg in the morning and 1308.61 kg in the evening and this was consumed during the fourth week, the coldest time in winter, as illustrated in Table 4.12.

Table 4.12: Average quantities of wood used in the mornings and evenings by 40 households in Mangondi village in the winter season.

Description	Winter season			
	Morning		Evening	
	Mean kg/day	(Sum) kg/week	Mean kg/day	(Sum) kg/week
Week 1	152.08± 24.21	1151.68	148.38 ± 11.20	1031.07
Week 2	204.65 ± 8.30	1412.91	170.95 ± 2.87	1192.2
Week 3	163.93 ± 13.40	1095.35	126.94± 11.37	933.37
Week 4	226.25 ± 19.28	1627.88	188 ± 8.14	1308.61
Week 5	208.34 ± 21.20	1412.72	166.32 ± 17.23	1155.46
Week 6	212.03 ± 26.96	1404.84	164.83 ± 11.83	1111.27

The total wood mass used by the 40 households in winter (June-August) was 14837.19 kg and in the summer season (November-January) it was 6428.99 kg, showing a higher quantity of firewood burnt in the winter season (Figure 4.8). The respondents stated that they opt to use electricity for cooking during summer season because of high rainfall and lack of designated cooking areas, hence, they use less quantity of firewood during that period.

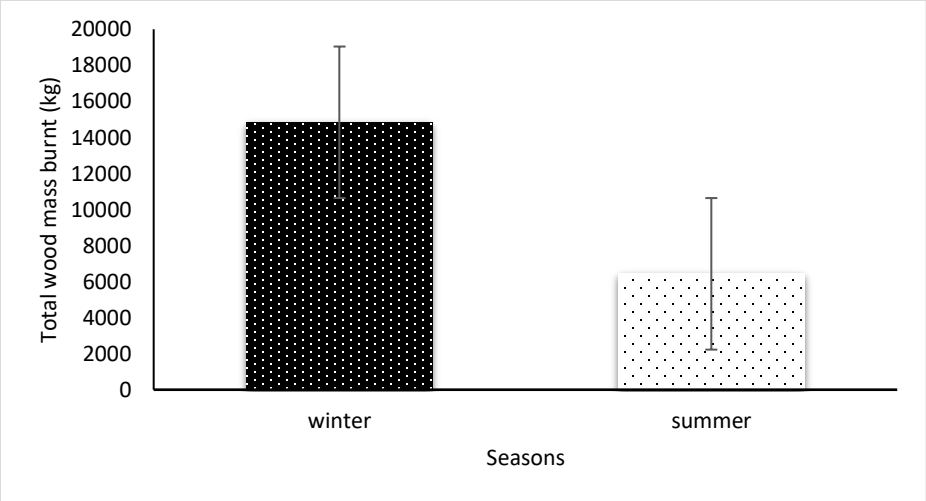

Figure 4.8: Total wood burnt by the 40 households in Mangondi village in winter and summer.

The maximum and minimum values of firewood burnt by the 40 households, in each season are presented in Table 4.4. The minimum amounts of firewood were 1.15 kg in summer season, and this was because during this period, the households did not prepare meals using firewood as it was raining and they lacked a designated area for cooking, hence, they opted to use electricity. The maximum mass of firewood used in winter, during the first week was 14.85 kg and 14.1 kg in summer season, as illustrated in Table 4.13.

Table 4.13: Maximum and minimum values of wood used by the 40 households in Mangondi village in summer and winter seasons.

Week	Summer season		Winter season	
	Max kg/week	Min kg/week	Max kg/week	Min kg/week
1	14.1±1.32	2.87±0.56	14.85±0.79	4.3±1.32
2	10.2±0.69	2.35±1.07	13.75±1.58	3.61±1.03
3	10.4±1.58	1.85±1.46	13.01±0.49	3.1±1.44
4	10.2±0.81	2.22±0.63	12.46±4.49	3.36±3.17
5	11.9±0.42	1.15±1.79	12.15±0.81	5.1±0.41
6	9.3±1.03	2.64±0.58	12.14±1.46	4.45±0.47

There was an increase in the amount of wood consumed in winter, particularly during the fourth week, which was the peak of cold weather conditions in July. After peaking in winter, the average and total consumption of firewood during the weekly burning session started to decline progressively from November to January in summer as it started raining more and the use of firewood wood became less; during this period, residents opt to use electricity to prepare meals.

During both winter and summer season, more firewood was consumed in the morning as compared to the evening as shown in Figures 4.9 and 4.10. Furthermore, there is a statistically significant difference between firewood used in the morning and in the evening during winter ($p=0.02$) and summer ($p = 0.015$), as the p-value is less than the significance level ($p > 0.05$). This validates, the fact that there is a difference between the amount of firewood burnt in the morning and in the evening. The average firewood combusted in winter (week 1-6) was 5.45

kg/day in the morning and 4.59 kg/day in the evening, with a total of 10.04 kg/day firewood used daily. More wood was used in the morning because more domestic chores are done in the earlier hours of the day. The residents stated that firewood is a great source of heat, also cheap ‘free”; space heating using firewood lasts longer as residents can continuously add more wood if needed and at the same time allow the fire to die out when they are ready to sleep.

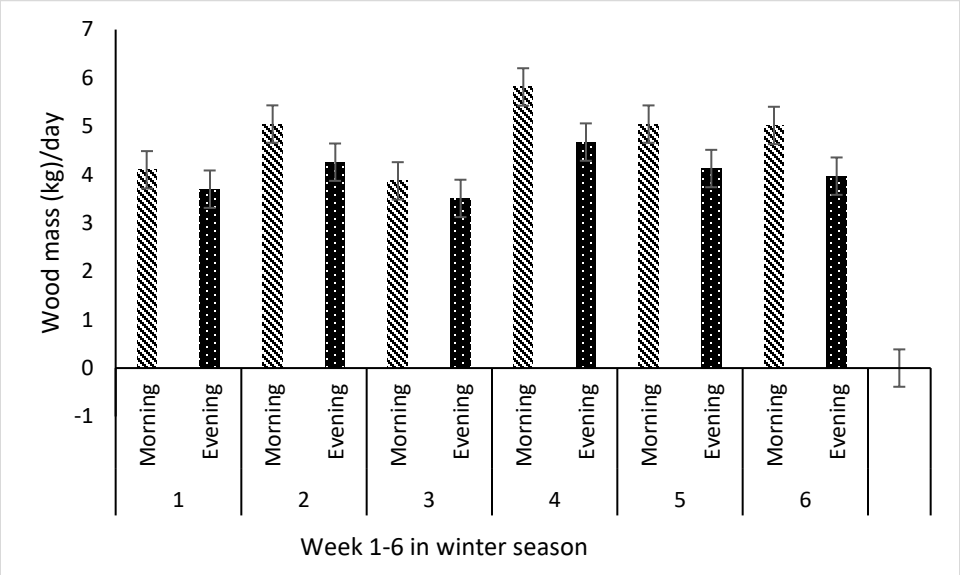

Figure 4.9: Average wood mass used in Mangondi village, from week 1-6 in winter.

During summer, the average firewood burnt was 2.63 kg/day in the morning and 1.28 kg/day in the evening, therefore, residents used a total of 3.91 kg/day as shown in Figure 4.10.

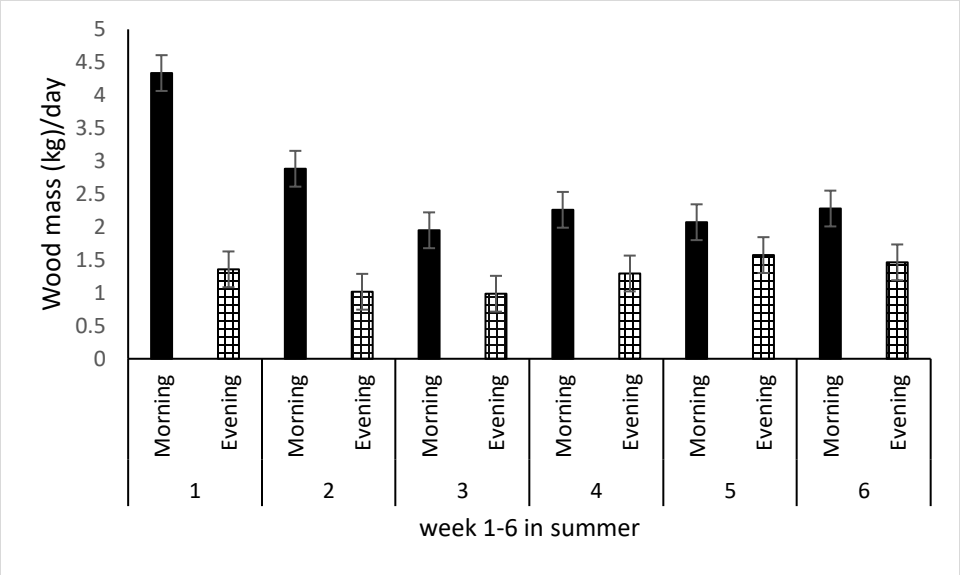

Figure 4.10: Average wood mass used in Mangondi village from week 1-6 in summer.

The respondents explained that during the summer season (wet) meeting their daily domestic firewood needs is strenuous since they lack a better designated area for cooking. The average wood mass burnt in 2021 in the morning sessions was 4.04 kg/day and 2.94 kg/day in the evening. The average wood consumption in Mangondi village was 2545.27 kg/day, per household, per year. Findings from case studies conducted in Limpopo Province where fuelwood was also used by electrified households was 1833 kg/year in Bela-Bela, 5100 kg/year in a township in Tzaneen and 2200 kg/year in a low-income setting in Tzaneen (VTAPA, 2017). In the Teknaf Peninsula of Bangladesh about 1168 kg of fuelwood were combusted each year for space heating, cooking and boiling water (Asik et al., 2017).

In most countries, the average per-household firewood consumed was within reasonable range in comparison to the information available from similar studies in Limpopo Province. The firewood combusted in Mangondi village was 10.04 ± 2.9 kg (wood) person^{-1}.day^{-1} in winter and 6.8 ± 0.9 kg (wood) person^{-1}.day^{-1} in summer, as illustrated in Table 4.14. These findings showed that the winter and summer monthly per-capita wood consumed in the households was 3.86 ±0.37 kg (wood) and 2.04±0.85 kg (wood), respectively. The firewood burnt annually per-capita was 46.37 ±0.93 kg in winter and 24.46 ±0.67 kg in summer.

Table 4.14: Average wood consumption per capita in Mangondi village.

Description	Winter wood mass (kg)	Summer wood mass (kg)
Morning	5.45 ± 1.30	4.51± 0.90
Evening	4.59 ± 1.24	2.55 ± 0.23
Sum/ day	10.04 ± 0.60	6.8 ± 0.94
Average number of inhabitants per household	5 ± 1.72	5 ± 1.72
Consumption of wood person^{-1}. day^{-1}	0.91±0.35	0.51±0.33
Consumption of wood person^{-1}. month^{-1}	3.86±0.37	2.04±0.85
Consumption of wood person^{-1}. year^{-1}	46.37±0.93	24.46±0.67

The firewood consumption per-capita for Mangondi village was lower than the values recorded in other studies. A study conducted by Koffi et al., (2018) in Burkina Faso, reported that the estimated firewood burnt per-capita from two villages was 1.8 kg person ^{1}.day ^{1} and 1.5 kg person ^{1}.day ^{1}. The difference might have been caused by the socio-economic status of the people, the availability of sources of fuels and the family size. In electrified households in rural areas, firewood is still the most common and preferred source of energy, particularly for cooking and space heating, however, variations in seasons do have an impact on the quantity of wood used.

4.5 Estimation of emissions from domestic fuel use by households in Mangondi village.

The data on the wood mass measured and recorded using the crane scale was converted into emission estimates. The standard emission factors used in calculating the emission estimates of firewood burnt were 15.3 g/kg for $PM_{2.5}$, 17.3 g/kg for PM_{10}, 0.2 g/kg for SO_2; 43 g/kg for CO; 1.3 g/kg for NOx and 450 g/kg for CO_2 (USEPA, AP-42, 2022) these emission estimates were calculated using the sum of hours recorded during the daily burning sessions. A total of 5 hours was used daily for burning firewood to meet the domestic needs of the residents at Mangondi village. Figures 4.11 - 4.14. Illustrate the average emission rates of the greenhouse gases and criteria pollutants calculated from the collective 40 households in Mangondi village for both summer and winter season.

Figure 4.11 shows that the emission rate of carbon dioxide from the 40 households was 1771.12 g/day in winter, and 1014.86 g/day in summer, from the burning sessions. These findings show

that more carbon dioxide was emitted during winter, and this was because more firewood was burnt for space heating.

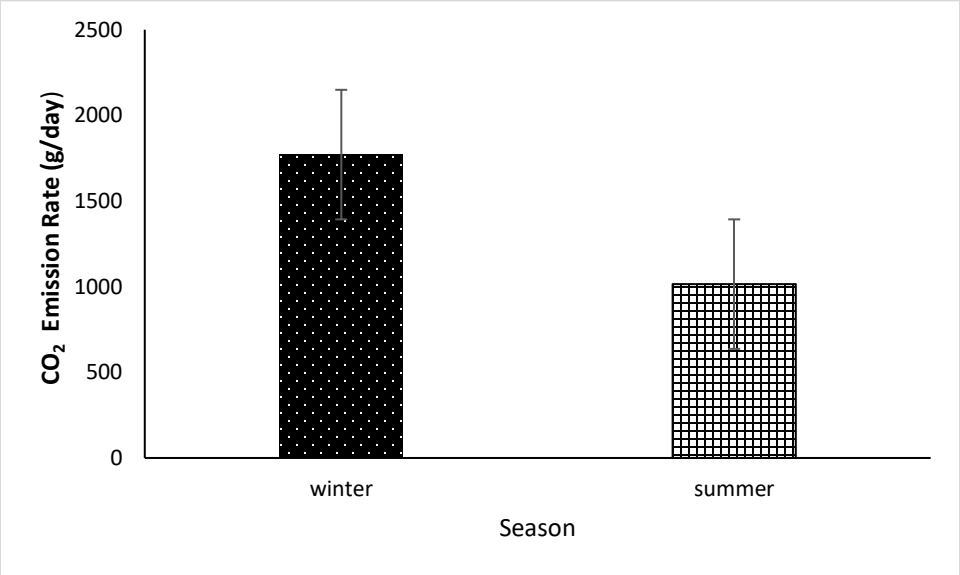

Figure 4.11: Carbon dioxide emissions from the 40 households in Mangondi village in summer and winter.

The emission rate of CO was 169.24 g/day in winter and 96.98 g/day, in summer, from the burning sessions of firewood, as illustrated in Figure 4.12. It was already observed in the study that more firewood was burnt in winter as compared to summer based on the cold temperatures exposed to the residents during the dry season.

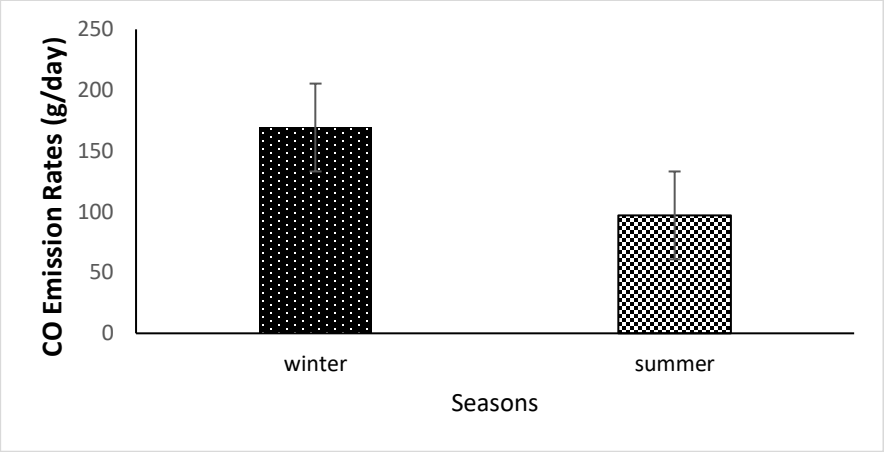

Figure 4.12: CO emissions from the 40 households in Mangondi village in winter and summer.

The average emission rates for PM2.5 and PM10 were 60.23 g/day; 68.09 g/day in winter and 34.51 g/day; 39.02 g/day in summer (Figure 4.13) with PM10 having higher emission rates from combustion of wood, when compared to PM2.5.

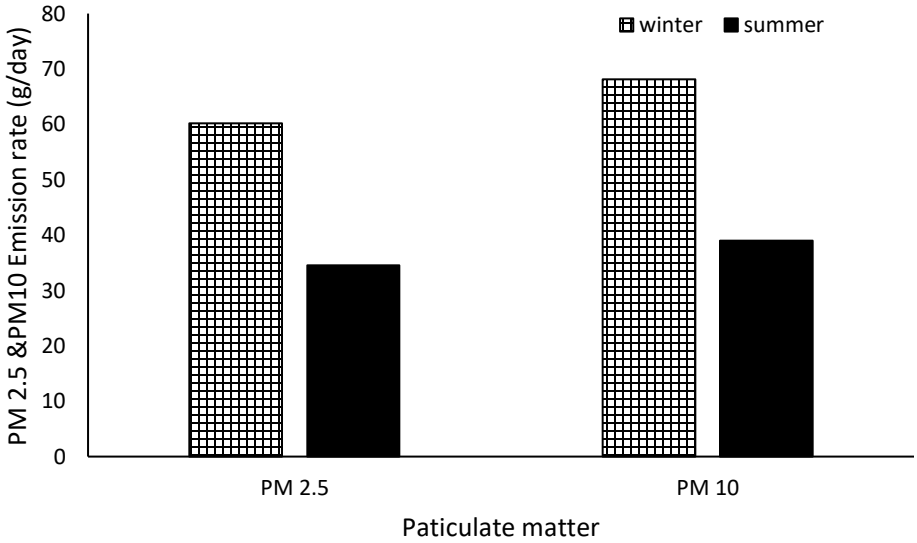

Figure 4:13: $PM_{2.5}$ and PM_{10} emissions from the 40 households in Mangondi village in winter and summer.

The average emission rates for SO_2 and NOx are presented in Figure 4.14. The average emission rates for SO_2 and NOx were 0.79 g/day; 5.12 g/day in winter and 0.45 g/day; 2.93 g/day in summer.

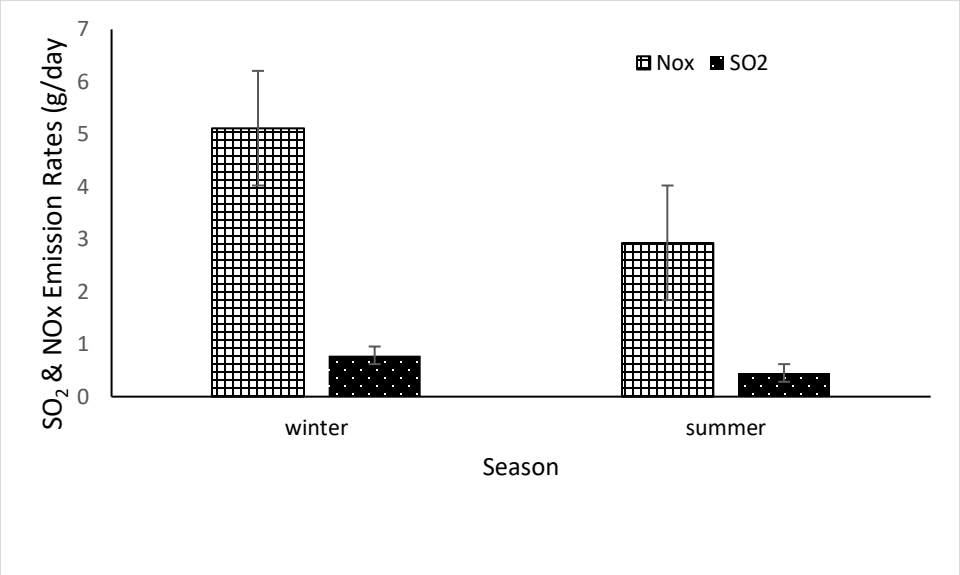

Figure 4.14: Emissions from the SO_2 and NOx emissions from the 40 households in Mangondi village in winter and summer.

The CO_2 and CO emissions from firewood burning in this study were observed to be higher than what was reported in other studies. A study conducted in Zenzele (Johannesburg) in South Africa reported CO_2 emissions of 78.11 g/day and CO emissions of 5.79 g/day (Naidoo et al, 2014).

Overall, the emission rates of criteria pollutants and greenhouse gases from firewood burning were established and seasonal variations linked to fuelwood combustion have been outlined. In general, the emission rates of pollutants are higher during the winter season. Lower emissions observed from the 40 households in Mangondi village were assumed to be associated with a lower amount of firewood used per household daily.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Firewood is the source of energy used by many households for cooking and space heating in Mangondi village because it is accessible, affordable and generates high energy. The preferred tree species used as firewood were identified as Euclea divinorum Hiern (Mutangule), Combretum imberbe (Mudzwiri) and Dichrostachys cinereal (Murenzhe) due to their durability and steady generating of intense heat. Major drivers of 195 households' firewood use are - gender, age, household income, educational status, household sizes, affordability, and accessibility. The study highlighted that there are two burning sessions per day, in the morning and evening in both winter and summer seasons. Findings revealed that more firewood was burnt in winter compared to summer, partly due to space heating needs, especially, in the evening. The amount of firewood consumed by each of the 40 households per burning event was different, with an average burning rate of 5.45 in the morning and 4.59 kg/day in the evening during winter, while the average fuelwood burnt in summer was 2.63 kg/day in the morning and 1.28 kg/day in the evening. The annual average wood burnt per household was 2545.27 kg/day. The households in Mangondi village burn fuelwood in open spaces, using a three-legged stove, therefore, the risk from air pollutants emitted is high. This study reported that some of the preferred tree species have medicinal purposes, however, the households in Mangondi village still chose to harvest and burn fuelwood as source of energy. Factors such as seasonal variation, accessibility, affordability, household demographics and cultural influences have a significant impact on the households' burning habits.

5.2 RECOMMENDATIONS

The study recommends the following for further studies:

i. Real time measurement of criteria pollutants and greenhouse gas concentrations from the households in Mangondi village to validate the results obtained in this study,
ii. A detailed health and environmental risk assessment on criteria pollutants and greenhouse gas emissions on the residents residing in the households of Mangondi village.

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APPENDIX A: PARTICIPANTS' QUESTIONNAIRE

Randomly selected people will be interviewed using questionnaires (Appendix B), participation will be on voluntary basis and will ensure obtaining of consent, confidentiality, and anonymity.

I _____ hereby confirm that I understand the contents of this documents and the nature of the study, and I agree to participate in the research project.

Participant signature Date

_____ _____

Researcher signature Date

_____ _____

SECTION A: Demographic information

1. AGE:

11-15	
16-23	
24 – 29	
30-35	
36-45	
45-upwards	
Race	
African	
Indian	
Coloured	
Asian	
White	

2. GENDER:

Female	
Male	
Contact Details	
Telephone number	
Email address	

3. MARITAL STATUS:

Single	
Married	
Divorced	
Widow	
Widower	

4. OCCUPATION:

5. HIGHEST LEVEL OF EDUCATION:

6. What is your monthly income?

R0-500	1	
R501-1000	2	
R1001-1500	3	
R1501-3500	4	
R3500+	5	

7. How many dependants do you have?.....

8. How many times do you harvest firewood in your household?

Once a week	1	
Twice a week	2	
More than twice a week	3	

9. Who is responsible for firewood harvesting in your household?

Children	1	
Female	2	
Men	3	
Everyone	4	

10. Which method do you use to harvest firewood?

Cut live trees	1	
Picking deadwood	2	

11. What kind of trees do you target the most when harvesting firewood?

12. Why are these type of trees targeted?

Easily available	1	
Energy content	2	

13. How difficult is it to find these trees?

Easy to locate	Moderately difficult to locate	Very difficult to locate
1	2	3

14. How is the wood transported?

Using Head load	1	
Using a Donkey cart	2	
Using a Wheelbarrow	3	
Using Truck/Bakkie	4	

15. What is the distance from your household to where you harvest firewood?

<50M	1	
50-<100M	2	
100-<500M	3	
500-<1KM	4	
1KM-<2KM	5	
>2KM	6	

16. Where do you prefer to harvest firewood?

Flood plain	1	
Mountain	2	
Along riverbanks	3	

17. Why do you prefer these locations?

18. Do you have electricity in your household? **Yes**……, **No**……..

19. Why do you use firewood in your household?

Electricity is expensive	1	
Firewood is abundant	**2**	
Cheaper option to use Firewood	3	
Makes a difference in the taste of food	4	

20. How much electricity do you use per month?

21. Which type of energy sources do you prefer using for cooking in your household?

Electricity	1	
Firewood	2	
Combination of electricity & fuel wood	3	

22. What energy source do you use in heating your household?

Electricity	1	
Firewood	2	

Combination of electricity & firewood	3	

23. How many times do you use firewood in your household?

Daily meal preparation	1	
Two meals a day	2	
One meal a day	3	
Others (specify)	4	

24. What do you think is the advantage and disadvantage of using wood as a source of energy?

25. Do you burn the wood in a stove?

Yes	1	
No	2	

26. Which type of stove do you use?

Improved stove	**1**	
Mud	**2**	
Clay	**3**	
Open fire	**4**	
Others	**5**	

27. Do you buy firewood?

28. Where do you buy the firewood?

Informal Market	**1**	

Supermarket/Retailer	**2**	

29. How far is your household from where you buy firewood?

<50M	1	
50-<100M	2	
100-<500M	3	
500-<1KM	4	
1KM-<2KM	5	
>2KM	6	

30. How long have you been using firewood as a source of energy?

>month-a year		
>a year-5 years		
>5 years-10 years		
More than 10 years		

31. Any additional information?

SECTION B: Interview Questions

1. Do you know what a domestic firewood use is?
2. How would you describe your current health status?
3. Do you know that domestic firewood combustion releases toxic gases into the environment?
4. What type of wood do you use for domestic purposes, that is, for cooking, boiling, heating?
5. Which type of tree do you prefer to use as firewood?
6. Why do you prefer that tree type over the others?
7. How much do you buy the wood for? A. >R100-350, B. R350-500, C. R500-1000, D. More than R1000.
8. Is the firewood collected around the vicinity where you stay in or do you have to travel from your village to get it?
9. Which time during the day do you use more firewood? A. Morning….., B. Evening….
10. What other source of energy beside firewood do you use? Gas……., Electricity…….., Coal……,Solar……
11. Which season would you say more firewood is used? A. Winter……, B. Summer…….
12. What are the challenges that you have encountered while using firewood?
13. What are the changes you have noticed about the environment (climate changes)?
14. Do you think there is any health and environmental risks associated with firewood combustion?
15. If yes, what do you think are the possible health and environmental risks?
16. What do you think the Municipality can do to reduce/prevent these health and environmental issues around your community?

APPENDIX B: ETHICAL CLEARANCE CERTIFICATE

ETHICS APPROVAL CERTIFICATE RESEARCH AND INNOVATION

OFFICE OF THE DIRECTOR

NAME OF RESEARCHER/INVESTIGATOR: Ms P Mudau

STUDENT NO:

11575133

PROJECT TITLE: Emissions quantification associated with firewood usage: a case study for Mangondi village in Limpopo Province,

South Africa.

ETHICAL CLEARENCE NO: FSEA/22/GES/07/2306

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Dr JN Edokpayi	UNIVEN, Earth Sciences	Supervisor
Ms P Mudau	University of Venda	Investigator — Student

Type: Masters Research

Risk: Minimal risk to humans, animals, or environment (Category 2)

Approval Period: June 2022 — June 2024

The Animal, Environmental and Biosafety Research Ethics Committee (AEBREC) hereby approves your project as indicated above.
